2010 Progress Report

Global Ocean-Atmosphere Prediction and Predictability (GOAPP) Network

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Global Ocean-Atmosphere Prediction and Predictability (GOAPP) Network

This is the fourth progress report of the Global Ocean-Atmosphere Prediction and Predictability (GOAPP) Network and covers the period from July 1, 2009 to June 30, 2010. This report answers a series of questions posed under the general headings of Progress, Impact, Level of Support, Dissemination, Training and Other. As requested by Canadian Foundation for Climate and Atmospheric (CFCAS), the report is a non-technical description of progress.

For each GOAPP project we have presented the specific objectives and milestones and the progress achieved to date. We have also included in this report appendices containing Acronyms and Abbreviations (Appendix A), lists of personnel involved in the Network (Co-Investigators, Researchers, Scientific Steering Committee Members, Board of Directors, and Collaborators, Appendix B), and the 2010 Annual GOAPP Workshop Agenda and CMOS Presentations (Appendix C).

1 PROGRESS (1 JULY, 2009 TO 30 JUNE, 2010)

1.1 DESCRIBE PROGRESS TOWARDS MEETING THE PROJECT OBJECTIVES. HOW ARE THE ORIGINAL MILESTONES BEING MET? LIST THE KEY OBJECTIVES AND RESULTS ACHIEVED TO DATE AS WELL AS ANY RELEVANT APPLICATION(S) OF THE RESULTS.

The Network has been functioning since October 2006 and the progress overall has been excellent. All of the research personnel (graduate students, post doctoral fellows, and research associates) are in place and the Network Secretariat continues to provide outstanding service. The Scientific Steering Committee has functioned well in terms of providing scientific guidance to the Principal Investigators and Board of Directors, and also reflecting the opinions of the wide range of co-investigators from across Canada.

One of the highlights of this reporting period was the GOAPP annual workshop held in Ottawa in late May 2010. The meeting was well attended and successful. We are particularly pleased to note the participation of Dr. F. Doblas-Reyes, a research scientist from the Catalan Institute for Climate Sciences (IC3) in Spain, who gave an interesting and relevant presentation on techniques to represent model uncertainties and generate ensembles for dynamical seasonal and interannual forecasting. The reason for holding the annual workshop in Ottawa at this time was to link the Workshop to the Annual Congress of the Canadian Meteorological and Oceanographic Society (CMOS). GOAPP co-investigators chaired three session blocks during CMOS that primarily covered the research of GOAPP researchers. In total 17 talks and 4 posters were presented by GOAPP scientists. (See Appendix C) This provided excellent exposure of GOAPP research to the Canadian scientific community, and the opportunity for GOAPP researchers to inform each other of their recent progress. Dr. Doblas-Reyes also gave the invited lead-off presentation in these CMOS Congress sessions. GOAPP was also one of only four networks invited to make a key-note presentation during a special session at the CMOS Congress entitled "CFCAS Achievements - The First Decade". This provided further exposure of the GOAPP network to not only researchers but also managers and policy makers.

As in previous years, individual projects have generally made excellent progress with some of them exceeding their milestones. The remainder of this section describes the progress achieved by individual projects, grouped by Theme. The milestones for each project are given in italics. It will become clear when reading these descriptions that many of the co-investigators and their research personnel are working on more than one project and thus the research is both collaborative and integrated.

GOAPP research and development on improved ocean-atmosphere modelling, data assimilation and prediction on the time scales relevant to Theme I and II is progressing well. Interactions among GOAPP investigators and government partners are effective, benefits are being realized and technology transfer mechanisms are in place. An excellent group of highly qualified personnel is being well trained to meet future challenges.

Theme I: Days to Seasons

Theme I strives to develop better predictive models of the variability of the atmosphere and ocean occurring on time scales of days to seasons, and also to better understand the physical processes that provide, and limit, predictability. As detailed below, progress over the fourth year has been excellent and has led to the development of new assimilation schemes, improved model codes, increased collaborations amongst researchers, and the publishing and presentation of results.

One reason for the rapid progress this year was the decision to focus almost all of the Theme I modelling on common codes: NEMO and GEM for the ocean and atmosphere respectively. This has greatly aided collaboration, and the sharing of code and experience, thereby making the best use of available computer resources and personnel.

One of the encouraging developments this year has been an increase in collaboration amongst Theme I co-investigators from across the country (e.g., Foreman and Wakamatsu collaborating with Wright and Stacey) and also disciplines (e.g., Ritchie and Gauthier collaborating with Thompson and Lu). A new development has been the creation of a research activity focussed on intraseasonal variability of the coupled atmosphere ocean system. Y. Lu and K. Thompson have supervised three PhD students over the last year who have worked on the influence of the Madden-Julian Oscillation on the predictability of surface air temperature, surface winds, sea surface temperature and sea level.

Sub-Theme I.1 Ocean Modelling and Data Assimilation

Project I.1.1 Suppression of Bias and Drift in Ocean Model Components
Co-Investigators: D. Wright, K. Thompson

Specific Objectives: (i) Implement and test the spectral nudging technique in the basin-scale and global ocean models developed in Theme I, (ii) 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.

As expected this project was largely completed by the second year. It has however continued at a reduced level in order to complete publications and continue the development and support of other projects. Details are given below.

A manuscript was submitted to Ocean Dynamics on the impact of model bias on the characteristics of the sub-polar ocean in a regional model of the North Atlantic. The first reviews were favourable for publication and asked for minor revisions. The paper was revised and recently resubmitted to the journal. The main results of the study are:

- The dominant patterns of the model bias in the surface layer in the western part of the sub-polar North Atlantic show a good correlation with the uncertainty in the simulated sea-ice in the Labrador Sea. The bias in the eastern part of the sub-polar gyre shows a relation to the spurious intensification of the sub-polar circulation due to the model bias.

- At intermediate depth the bias is towards saltier and warmer water masses and shows a good correlation with the uncertainties in the surface heat and water fluxes and sea-ice.

- The bias in the deep layers is mainly driven by the error in the characteristics of the overflow through the Greenland-Scotland ridge.

A manuscript on issues of Labrador Sea salinity drift in NEMO was submitted this past fall to Ocean Modelling. The reviews were favourable and a revised version was recently returned to the journal. The main conclusions of this study were:

- The rapidity of the drift: As shown in the paper, the drift was split into two periods, beginning with an initial 3 year period, associated with the adjustment of the model from its initial conditions that was almost identical in all simulations. Basically by the end of this initial 2 to 3 year period, all simulations had significantly diverged from the observations. This suggests that further research must be carried out to test whether different strategies of model initialisation could limit this initial drift.

- The initial drift does not depend on whether the configuration is global or regional, restricted to the North Atlantic Ocean. This demonstrates that the representation of the freshwater flux through the Canadian archipelago using a global model does not improve significantly the freshwater balance of the Labrador Sea over a time scale of a decade. However, as shown with the later changes in freshwater content, approaching year 2000, the presence (and representation) of the Arctic Ocean and its fluxes becomes important.

- The inclusion of an explicit sea-ice component did not have a significant impact on the model drift in the central Labrador Sea. Representing the sea-ice may be important for ocean or climatic studies but the effect on the interior of the Labrador Sea is small.

- The forcing details during the first stage of the drift are irrelevant. The simulations examined used different air-sea fluxes as well as significantly different sea surface salinity restoring strategies and yet the behaviour in the Labrador Sea was the same in each case.

- Similar behaviour during both drift phases was seen in both inter-annual and perpetual year experiments. Again, the forcing details are not significant in controlling the initial model drift. Clear evidence is seen that the drift has an advective origin.

- The advective drift is related to *two* sources, the freshwater pathways around Greenland and the transport of warm salty water by the Irminger Current.

- The details of the advective pathways are very dependent on the details of the specific model factors and parameterization. An example of this is the spurious influence in the East Greenland Current of restoring to smoothed (and thus wrong) salinity climatologies on the shelf.

- Research is ongoing on the first stage of the model drift. We believe we have identified the cause of this drift in NEMO through a detailed analysis of 5 daily outputs during the first 2 years of each run. This analysis included a highly detailed budget study of salinity transport in the Labrador Sea as well as the use of a Lagrangian particle tracking tool to trace back the origin of the salinity anomalies.

An outstanding issue that we would like to address is the inclusion of spectral nudging in the climate change/variability simulations being done at CCCma. Unfortunately, Bill Merryfield has been too busy to follow up on this work this past year, but it is still an area of great interest. We are presently doing a ¼ degree NA run with spectral nudging with the bandwidth of the temporal filter reduced to 1/(20 years) and the spatial filtering increased by using the recursive spatial filter. The results are very interesting since even with these substantial reductions in the control placed on the model's climatological conditions, the Gulf Stream still separates at Cape Hatteras and the broad comparisons with observations are very reasonable. This contrasts with earlier results using a different form of spatial smoothing on the nudges that required much more CPU time and was not guaranteed to be conservative. We have now determined an analytical estimate of the filter gain using this new smoother and we are in the process of writing a paper on the merits of improved dynamics, improved filters and improved climatologies when using spectral nudging. These results should assist applications to climate change simulations when time permits.

Project I.1.2 Statistics of Observed Variability for Model Testing and Improvement
Co-Investigators: K. Thompson, M. Foreman and E. Demirov

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.

<u>Schedule and Milestones</u>:

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.

Good progress continues to be made on the development and evaluation of new mean sea surface topographies (MSST) that are based on a combination of gravity measured by the recent GRACE satellite mission and terrestrial observation campaigns carried out using land, air and ship-borne instruments. Thompson, Huang, Véronneau, Wright and Lu (2009) compared independent estimates of MSST of the northwest Atlantic based on satellite, terrestrial gravity, and oceanographic observations. They showed that, overall, the agreement amongst the various estimates of surface topography and circulation is excellent. There were, however, some interesting differences that were attributed to problems with the MSST and also the ocean model (in particular the ocean climatology to which it was nudged) as explained in the following paragraphs.

Comparison of the Thompson et al. (2009) MSST with predictions from a spectrally nudged model (project I.1.1) indicated unrealistic, high wave number variability in the mean position of the Gulf Stream. This led to a new method for generating seasonal climatologies of ocean temperature and salinity based on "de-eddying" Argo temperature and salinity profiles using co-located sea level measured by altimeters. A paper on the de-eddying method, and a description of encouraging results for the North Atlantic, has been published recently by Higginson et al., 2009. (Simon Higginson is a GOAPP funded Ph.D. student; his initial work on this topic was funded by the GEOIDE research network.) Over the last year S. Higginson has demonstrated that spectrally nudged models of the North Atlantic using this new seasonal climatology agree better with the geodetic and surface drifter based estimates of MSST in the Gulf Stream region. The new climatology has been transferred to project I.1.1 where it has led to further improvements in the spectrally-nudged model predictions of MSST and surface circulation (see annual report of this project for details).

The MSST of Thompson et al. (2009) also showed some unrealistic high wave number variability in the sub polar gyre of the North Atlantic. This was explained by Thompson et al. (2009) in terms of the poor quality terrestrial gravity data. Over this reporting year a new MSST has been constructed that incorporates terrestrial gravity data that were subject to more stringent quality control procedures. (The geoid on which this new MSST was based was calculated by M. Véronneau and J. Huang from the Geodetic Survey Division of Natural Resources Canada.) Comparisons of the new MSST with model predictions and surface circulation inferred from surface drifters from the subpolar gyre are encouraging, particularly for the boundary currents flowing along the east and west coast of Greenland which had been poorly sampled by oceanographic measurements in the past. The root mean square difference in current speed between the drifters and the new MSST estimate is reduced by a factor of 2 in these regions, with little change in the Gulf Stream and Labrador Current regions. The MSST estimates highlight some areas, particularly on the shelf around Greenland, where ocean model estimates of MSST and the surface circulation can be improved. A manuscript on the evaluation of the new MSST will be submitted to Journal of Geophysical Research in the summer of 2010.

M. Foreman and T. Wakamatsu obtained output from the 1/12 degree global NEMO model (ORCA12) for the period from 2001 to 2007 from Mercator-Ocean for the Northeast Pacific. The mean and higher statistical moments of the model output were compared to associated observations, including AVISO altimeter data and temperature/salinity data from Argo floats and Line-P hydrographic cruises. It was found that the mean vertical structure of temperature and salinity in the ORCA12 output had significant biases relative to the observational data. Analyses of temporal variations and their statistical moments are continuing.

In order to study the impact of horizontal grid resolution on eastern boundary currents in the Alaskan Gyre, numerical experiments were performed using a two layer quasi-geostrophic model. The statistical character of baroclinic instabilities and associated eddy fluxes were calculated from an ensemble experiment. It was found that the development of instabilities in the boundary currents was not sensitive to changing the model resolution from 1/2 to 1/12 degree because the former was sufficient to resolve the baroclinic instability wavelength. However, the subsequent offshore transport of coastal water due to the propagation of eddies that are generated from these instabilities was highly sensitive to the resolution change because the coarser model could not adequately resolve individual eddies.

Project I.1.3 Multivariate Assimilation of Altimeter and Argo Data for Ocean Forecasting
Co-Investigators: E. Demirov, K. Thompson and M. Foreman

Specific Objectives: (i) Determine means and error covariance structure of the altimeter and Argo data to be assimilated into the global and basin models using 3DVar (ii) 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.

A computationally efficient scheme for assimilating sea level measured by altimeters and vertical profiles of temperature and salinity measured by Argo floats was published in Monthly Weather

Review during the reporting year (Liu and Thompson, 2009). The scheme is based on a transformation of temperature, salinity, and sea level into a set of physically meaningful variables for which it is easier to specify spatial covariance functions. The scheme also allows for sequential correction of temperature and salinity biases and online estimation of background error covariance parameters. Two North Atlantic applications, both focused on predicting mesoscale variability, were used to assess the effectiveness of the scheme. In the first application the background was a monthly temperature and salinity climatology and skill was assessed by how well the scheme recovered Argo profiles that were not assimilated. In the second application the time-varying backgrounds were short-term forecasts made by an eddy-permitting model of the North Atlantic. Skill was assessed by the quality of forecasts with lead times of 1–60 days. Both applications show that the scheme has useful skill.

More recently work has begun on the development of a new data assimilation scheme based on a form of ensemble based multivariate optimal interpolation. The scheme is based on the Bluelink Ocean Data Assimilation System of Oke et al. (2007, Ocean Modelling, doi:10.1016/j.ocemod.2007.11.002). An initial implementation using an operational shelf circulation model is very encouraging and work is underway to implement the scheme in NEMO. It is anticipated that this new scheme will be used by project I.1.4 in place of the Liu and Thompson (2009) scheme. One of the advantages of the new scheme is that is can be used to assimilate a wide range of data (not just Argo profiles and altimeter observations) and can be implemented in both deep ocean and coastal models.

E. Demirov decided to change the approach he had proposed initially to develop a data assimilative model of the Northwest Atlantic and Labrador Sea. Instead of using a traditional SEEK implementation as an Extended Kalman Filter, work has begun on the development of an ensemble based version of the SEEK filter. Preliminary results suggest that, although the computational cost is increased, this change in methodology improves significantly the quality of data assimilation and, in particular, the representation of the error covariance matrix. (This work is co-funded by ACEnet.) Presently work is underway on the validation of the new scheme. First practical applications of the new data assimilation approach are planned to be completed by the end of summer of 2010.

M. Foreman and T. Wakamatsu have focused on the development of a Green's function method to perform ocean re-analysis and forecasting studies. Theoretical aspects of the multivariate assimilation (4D-Var) were studied in order to develop an algorithm to calculate useful information like the observable modes. The method was implemented for the NEMO ocean model and tested using the GYRE configuration included in the tools downloaded from the NEMO website. The original formulation was found to be unstable due to insensitivities associated with a model control parameter. A refined formula was derived and is presently being tested with the 1 degree North Pacific model using satellite altimeter data and Argo temperature/salinity profiles. Foreman and Wakamatsu also developed an algorithm for the calculation of the observable modes in a 4D-Var analysis and tested it using a wind-driven, single layer quasi-geostrophic model. This algorithm can be applied to any variational system with tangent linear and adjoint codes. Foreman and Wakamatsu have obtained the variational system of the NEMO ocean model, OPAVAR, from Dr. Anthony Weaver at CERFACS, and hope to test the algorithm on the NEMO configuration before the termination of the GOAPP project.

Project I.1.4 Ocean Reanalysis and Forecasting
Co-Investigators: D. Wright, E. Demirov, M. Foreman, M. Stacey

Specific Objectives: (i) Test the ability to hindcast and forecast variability in ocean conditions using the NEMO model with various forms of data assimilation, including those developed in I.1.1-3, (ii) Use embedded finer resolution sub-domains in a North Atlantic basin model to investigate the possibility of improving specific aspects of model results through improved resolution in critical regions, (iii) Investigate the causes of variability where good agreement with observations is found, (iv) 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.

<u>Schedule and Milestones</u>:

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.*

At this point in this project, we had planned to be using the Liu and Thompson data assimilation method for reanalysis work in the North Atlantic and North Pacific. This has not been possible due to Dr. Liu's sudden departure without preparation of appropriate documentation. This development has most affected Drs. Wright and Stacey and their Research Associates. They have nevertheless continued as outlined below.

<u>Bedford Institute of Oceanography (D. Wright and F. Dupont)</u>

Dr. Dupont continued working on the implementation of AGRIF (automatic grid refinement in FORTRAN) until he left to work for Environment Canada in September 2009. One application has been related to the Gulf Stream-subpolar gyre dynamics (1/12 degree zoom over the Gulf Stream and parts of the subpolar gyre embedded into a 1/4 degree North Atlantic model). This application aims at improving our understanding of the water exchange between the 2 current systems.

A second application uses a global one degree model with a ¼ degree AGRIF zoom over the North Atlantic. It produces a very realistic current system in the zoom region thanks to the use of the spectral nudging technique and despite being forced by a coarser resolution model.

Drs. Dupont and Wang are developing tidal modelling capabilities for the ocean model NEMO applied to the Northwest Atlantic. Dr. Dupont has introduced tides in a simulation using the AGRIF nesting technique and shown that with some careful treatment of the bathymetry, tides are correctly propagating in and out of the nested region.

Dr. Wang has completed a ¼ degree North Atlantic model simulation driven by CORE forcing covering the period from 1958 to 2004. The preliminary analysis has shown that the model gives an excellent Gulf Stream separation and a strong deep western boundary current including flow around the tip of the Grand Bank. However, the response to NAO variations is smaller than expected from observations and from numerical experiments without spectral nudging. We are currently redoing this simulation with the spectral bandwidth used in the time filter reduced from 1/(10 yr) to 1/(20 yr) and with the scale of the spatial smoothing increased by roughly a factor of 3. The goal is to continue to maintain the very low frequency, large scale background fields while permitting quasi-decadal variability associated with the NAO to develop more realistically.

Dr. Wang and colleagues have completed a study of the sensitivity to the parameterization of open water in the ice model LIM2. They found substantial sensitivity to the choice of an uncertain parameter that is used to mimic the effect of leads in ice-infested regions. A paper has been written up on this work and submitted to the journal Operational Oceanography.

The ORCA1 global ocean model has been used to study the forcing mechanisms of the intra-seasonal variations in the tropical Pacific Ocean. A paper written by Drs. Lu, Thompson and Ritchie in collaboration with visiting PhD student Xu Zhang has been accepted for publication in JGR.

The NEMO-based ocean and sea-ice modelling and embedding technologies have helped the development of the new high-resolution ocean and sea-ice models for the Arctic Ocean. This development involves the leadership and collaborations among Drs. Lu, Dupont, Hannah and Myers. The model has been tested with the climatological forcings of CORE and OMIP. We are now in the process of studying the freshwater budget in Canada Basin and the model sensitivity to surface forcing. A conference proceeding paper by Lu et al has been accepted for publication.

A collaborative proposal entitled "Seasonal ocean forecasting for ecosystem and fisheries management applications", by Drs. Lu, Lin, Thompson, Hannah and Ritchie has been accepted as a CFCAS "Knowledge Synthesis Grant". This project is primarily based on the achievements in the area of model development and applications within GOAPP. The ORCA1 model and the embedding capacity will be used for the ocean component. The objective is to contribute to the development of useful forecasts for ecosystem and fisheries management applications.

Royal Military College (M. Stacey and Y. Shao)

It has been shown unequivocally that spectral nudging greatly improves the simulation of the circulation in the North Pacific Ocean, given the spatial resolution that we are using. Simulations that degrade quickly when spectral nudging is not used, because of numerical diffusion, give realistic simulations when spectral nudging is used. Because of this, we have been able to concentrate, during this final year, on one important milestone, 'Examine dynamics of events well represented by the model'. Within this milestone, three aspects of the circulation in the northeast Pacific have been concentrated on: (1) the meridional location and intensity of the North Pacific Current (Freeland, personal communication), (2) the 2001-2002 cold water intrusion in the northeast Pacific (e.g. Crawford et al, 2005), and (3) the variability of the mixed layer depth (MLD) in the northeast Pacific Ocean (Freeland et al, 1997; Li et al., 2005).

The results of Li et al. (2005), who analyzed observations along line Papa to calculate MLD variability, are reproduced by the simulations as are the long term trends calculated by Freeland et al. (1997). Some of this work was done during the previous year, but most of the comparisons to the results of Li et al. were done during this year. The observations and the model simulation show a long term trend of shoaling of the MLD in most of the northeast Pacific. Also, however, according to the simulation there is considerable variability in the rate of shoaling over the northeast Pacific and there are even locations where the MLD may be deepening. Regarding the variability in the MLD, according to the simulation the variability is influenced more by the North Pacific Gyre Oscillation than either the Pacific Decadal Oscillation or ENSO.

Regarding the variability of the North Pacific Current simulated by the model, coastally generated disturbances (Rossby-like waves influenced by two-dimensional turbulence) that take 2-3 years to propagate into the region of the North Pacific Current may have a noticeable influence on the current. This suggests that aspects of the current's circulation may be predictable.

Regarding the cold water intrusion in the northeast Pacific, its influence is detected over two years later off the coast of southern California. This again suggests a degree of predictability.

References

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Memorial University (E. Demirov, J. Zhu, A. Polomska, M. Cooke and students)

Ocean hindcast simulations were conducted with the NEMO model using three model configurations:

(a) A North Atlantic Ocean ¼ degree ocean model from 1948 to 2005;
(b) A High-resolution regional simulation (1/16 degrees) of the Labrador Sea; and
(c) Simulations of the Arctic Ocean from 1960 to 2005.

The results from these simulations are described in three submitted articles and two articles in preparation. The main results are:

- Improved understanding of the impact of forcing variations during the 1990s associated with the North Atlantic Oscillation on mass variability in the sub-polar gyre;
- A detailed analysis of the processes and time scales involved in the spreading of the Labrador Sea Water mass;
- Development and application of a high resolution regional atmospheric model for the sub-polar ocean. The hindcast simulations showed that the high resolution patterns in the spatial variability of the surface forcing have an important impact on the quality of simulated water mass properties and circulation;
- A 50 year hindcast of the interannual variability of the Arctic Ocean and its interaction with the North Atlantic.

Institute of Ocean Sciences (M. Foreman and T. Wakamatsu)

As described in the report for project I.1.3, a Green's function data assimilation method was developed for the NEMO ocean model and tested with the GYRE configuration included in the tools downloaded from the NEMO website. The original formulation was found to be unstable due to insensitivities associated with a model control parameter. A refined formula was derived and is presently being tested with the 1 degree North Pacific model using satellite altimeter data and Argo temperature/salinity profiles.

Project I.1.5 Modelling and Assimilation of Sea Ice
Co-Investigators: P. Myers, E. Demirov

Specific Objectives: (i) Develop a version of the NEMO coupled sea-ice ocean model for the North Atlantic incorporating data assimilation (both on the ocean and sea ice components), (ii) Validate the data-assimilative coupled ice-ocean model against observed sea-ice measurements and existing models used operationally, (iii) 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.

Significant progress has been made in the modelling and assimilation of sea-ice as detailed below:

- Further analysis has been carried out on the sea ice fields in the Labrador Sea in NATL4 and how they interact with underlying oceanic fields such as temperature and salinity. This includes examining inter-annual variability in the forcing over 2002 to 2005.

- Assimilation experiments involving the nudging of sea ice fields to Canadian Ice Service products have been carried out for the Canadian East Coast in NATL4, for the years 2002 to 2005. These experiments show that the Canadian Ice Service fields are appropriate for model assimilation; even if the domain covered by the Canadian Ice Service fields varied throughout the year, the model was able to handle this, with no serious discontinuities at the edges of the analyzed regions. However, by only assimilating concentration, we found that improving this field led to increased errors developing in other fields, especially sea ice thickness.

- Atmospheric forcing data from the Common Ocean Reference Experiment (CORE) were taken and perturbed by noise (based on a random sum of the first 50 EOFs for each field – temperature, humidity, winds, etc.) to produce a 10 member ensemble for model forcing (i.e. a Monte Carlo type approach).

- An ensemble of 10 NATL4 runs was carried out for January 2002 based on the perturbed forcing. From this ensemble, the 10 runs were used to determine the error covariances between the sea ice concentration and three other fields (sea ice thickness, upper ocean temperature and upper ocean salinity).

- NATL4 was then used for another assimilation experiment, where the sea ice was nudged to the Canadian Ice Service fields, and the sea ice thickness, as well as upper ocean temperatures and salinities were updated based on the previously computed error covariances. This has led to an improved representation of all model fields compared to observations.

- Further testing of the LIM2 sea ice model in NATL4 has been carried out, which led to a switch to the newer EVP version.

- We attempted to implement the newer LIM3 model but this has not yet been a success due to technical issues.

- Further work on the role of model resolution is ongoing (2 degree to ¼ degree simulations). However, this analysis is presently focussing on the oceanic fields as the results in this area seem more interesting and encouraging.

- Configurations of NEMO for the Arctic Ocean and the Canadian Arctic Ocean have also been run and validated. Although these studies are focussing on high latitude issues, they have allowed us a greater understanding of the LIM2 sea ice model that we can apply in the North Atlantic.

Project I.1.6 Assessing the Capability of a Nested-Grid Shelf Circulation Model for the Eastern Canadian Shelf
Co-Investigator: Jinyu Sheng

Specific Objectives: (i) to develop a high-resolution 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, and (ii) to quantify the change in skill of the shelf model that results from nesting shelf model within the deep ocean model. Most of the original milestones during the report period were made.

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.

We have continued to focus on the development of a coarse-resolution (1/4 degree) regional ocean circulation model for the northwest Atlantic Ocean using NEMO due to the fact that this project is a student project with a limited budget. During the present reporting period, we have continued to refine this coarse-resolution shelf circulation model by using a combination of the spectral nudging method and the semi-prognostic method, both with weaker-than-normal nudging coefficients. The preliminary model results demonstrate that the combination of these two approaches is capable of simulating the seasonal and interannual variability of circulation over the Canadian shelf region.

We have also carried out several additional numerical experiments by forcing the model with different combinations of model external forcing (such as wind, surface heat/freshwater fluxes, flows specified along model lateral open boundaries). Comparison of model results in these experiments will be used to identify, and quantify the contribution of, the major physical processes responsible for interannual variability of circulation over the Slope Water region off the Scotian Shelf.

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

Project I.2.1 Independent Assimilation into Coupled Models
Co-Investigators: P. Gauthier, H. Ritchie

Specific Objectives: (i) 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 behaviour), (ii) To further improve atmosphere and ocean forecasts when the component models are coupled together during assimilation cycles, but not within the analysis step, (iii) 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.*

Development of the coupled model: Meetings have been held with colleagues at Environment Canada in Dorval to coordinate the development effort towards having a coupled atmosphere-ocean global system. The immediate objective is to speed up the development of the coupled GEM-NEMO atmosphere-ocean model. This task is highly technical and EC has the responsibility to deliver this. This is still not yet completed. While waiting for this development to be completed, our work concentrated on introducing the parameter estimation within the framework of the 4D-Var data assimilation system to be able to test the parameter estimation within the atmospheric component alone. The development of the coupled model is making sure that it could be inserted within the assimilation system to be able to run full-fledged assimilation cycles.

Parameter estimation for coupled ocean-atmosphere models: Recent studies (e.g., Sugiura et al., 2008) indicate that the assimilation with coupled models needs to include the estimation of parameters involved in the calculation of surface fluxes to prevent the development of the drift. The quality of the results is then significantly improved if the assimilation addresses both the characterization of the initial conditions and the estimation of parameters used in the parameterization.

A variational parameter estimation scheme has been introduced within the GEM-4D-Var system. This has never been done before and has required substantial changes to the GEM model and the assimilation component. This work is now completed and experimentation with 4D-Var assimilation cycles have just begun to assess the impact of parameter estimation on the adjustment to observations. Preliminary results with parameter estimation will be presented at the 2010 CMOS conference (Skachko et al., 2010).

Project I.2.2 Exploratory Studies on Joint Assimilation into Coupled Models
Co-Investigators: H. Ritchie, P. Gauthier

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.*

As reported last year, the first milestone listed above has been completed by Post Doctoral Fellow Faez Bakalian. RA (Redundancy Analysis) and PCA (Principal Component Analysis) analyses were carried out for a coupled CCCma run (supplied by Bill Merryfield) and NCEP reanalysis data. Global time-lagged RA and Empirical Orthogonal Functions patterns were computed for SST and SLP. As a continuation of this work, a simplified state space model was developed consisting of a toroidal atmosphere and ocean counterpart, with advection, diffusion and coupling for both media. The experimental design was set up such that the forcing terms could be turned "on" or "off" for either medium. Eigenvector analyses of the coupled system revealed several important differences between RA and PCA. One of the most important findings is that for weakly coupled atmosphere-ocean models, PCA tends to pick up the dominant mode in only one medium whereas RA is insensitive to the strength of the coupling. This could prove important for future work with joint assimilation into coupled models. During the past year these results have been submitted as a journal publication which has been revised and returned for further review (see the list in section 4.1).

Also as reported last year, owing to unforeseen delays in the availability of the coupled GEM-NEMO models, it was not possible to perform the control simulation of the twin experiment as outlined above in the second milestone and to use it for the third milestone noted above. Instead, the twin experiments were run using a simplified state space model modified to include data assimilation and Kalman filtering. Initially, the model was run without any data assimilation; this run was treated as observation data. The model parameters were then varied and several experiments were run with either ocean data or atmosphere data only assimilated into the system. In addition, this data was either assimilated independently, i.e. assimilated into the respective medium only, or jointly, i.e. both media were influenced simultaneously. The output generated was compared to the "observation" data and the error variances were computed for independent and joint assimilation. In each case study, considerable improvements in the error variances were observed for joint assimilation. The NMC method was also employed to determine the overall improvement in the background error variances when producing forecasts of the climate system. Considerable improvement in forecasting ability is observed for both ocean and atmosphere states when assimilating data jointly as compared to independent assimilation. During the past year, a novel iterative hybrid data assimilative approach has been developed and tested in this simplified framework in an attempt to reduce computation time while retaining the advantages of joint assimilation. The hybrid method is an iterative data assimilation scheme, in which data is assimilated independently and alternately in the ocean and atmosphere until convergence is reached.

During the past year these results have been presented at the 5th WMO international symposium on Data Assimilation in Melbourne, Australia (October 5 to 9, 2009): the poster presentation was titled "Towards Joint Data Assimilation for a coupled atmosphere-ocean system" and highlighted many of the findings of our simplified state space model with data assimilation and Kalman filtering. The feedback and response from other scientists was highly encouraging, reflecting the importance and relevance of this work for future joint assimilation studies involving fully coupled models. This work has also been accepted for presentation at the upcoming CMOS Congress in June in Ottawa. The research results will be submitted shortly for journal publication (see the list in section 4.1).

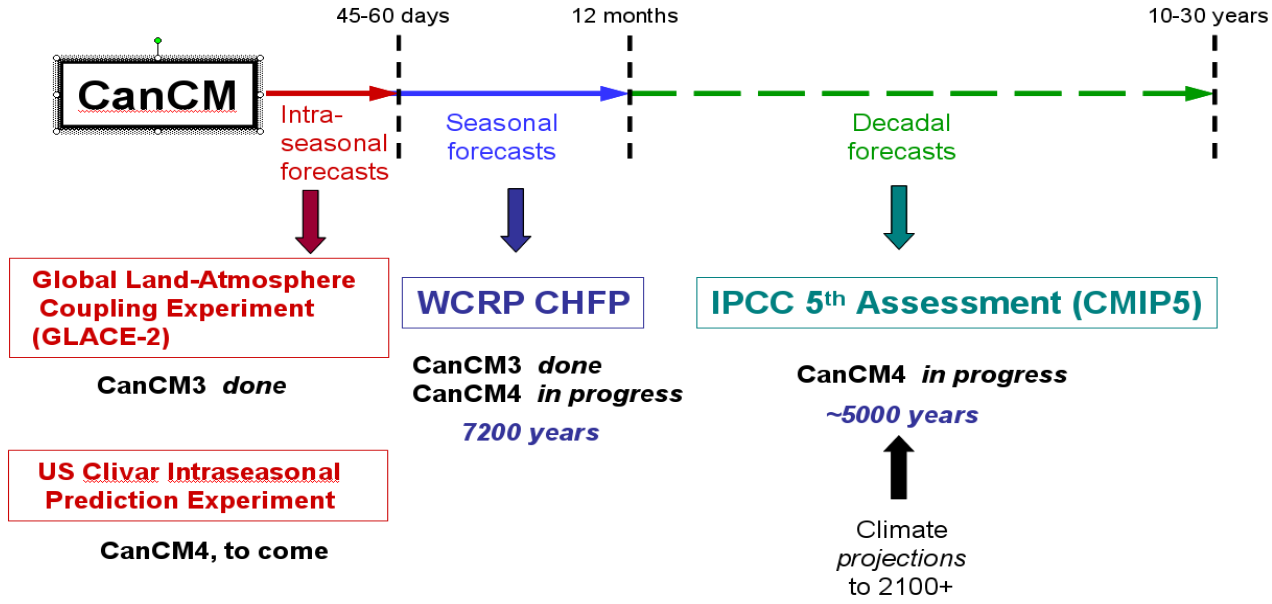
Progress is being made in the coupling of the GEM and NEMO models, and in anticipation of using the coupled system in the coming year. Faez Bakalian participated in a training session on the use of GEM-LAM in Montreal (January 19-20, 2010). The sessions covered many of the basic operational tasks associated with running these codes such as setting up directories, executable files, running jobs in batch mode and submitting jobs on multiprocessors. Faez Bakalian also discussed the coupling progress with GOAPP and Environment Canada colleagues, Pierre Gauthier, Jean-Marc Belanger, and Sergey Skachko in Montreal (January 22, 2010). The discussions mainly focused on steps taken to couple the GEM and NEMO models and how the data assimilation component would be combined with these models; anticipated time lines for these different research components was also discussed.

Faez Bakalian collaborated with Bill Merryfield and acquired data output from coupled atmosphere-ocean runs of CanCM3. These data fields were compared to those of an atmosphere-only model, AGCM. Faez Bakalian is planning to run a series of different statistical analyses on these data sets, such as Principal Component, Redundancy, Canonical Correlation, and Single Value Decomposition. One of the objectives is to better understand how the exchange of latent and sensible heat fluxes and energy/momentum transfer at the ocean-atmosphere boundary influences regional to global patterns of variability in the atmosphere. Analysing the differences between the coupled and non-coupled fields should lend insight into how error is propagated across both media and highlight some of the fundamental differences between joint and independent assimilation.

Theme II: Seasons to Decades

The past year marked several important milestones for Theme II, as development of a coupled model-based climate forecasting system came to fruition, forecast production began in earnest, and contributions to several international forecasting studies became a reality. Such rapid progress was enabled by the convergence of several streams of development leading from a prototype system, based on the first phase of the Coupled Model Historical Forecast project (CHFP1), to a much improved, operation-ready system based on the second phase of this project, CHFP2. As described in last year's report these development streams included model development, ocean data assimilation, atmospheric and land initialization, incorporation of greenhouse gas and other time-dependent radiative forcings, and improved post-processing.

Model development efforts have yielded two new climate model versions, CanCM3 and CanCM4, based on a common (improved) ocean model and versions 3 and 4 of CCCma's AGCM. Using both models to produce forecasts takes advantage of the generally higher skill (for a given ensemble size) of multimodel versus single model forecasts. CanCM4 further includes detailed treatments of time-dependent anthropogenic (greenhouse gas and aerosol) and natural (volcanic and solar) climate forcings, making it particularly effective for decadal and longer-range forecasting.



The "seamless" initialization and forecasting methodologies developed under Theme II have enabled the CHFP2 forecasting system to be applied across a broad range of time scales, ranging from sub-seasonal to a decade and longer. This in turn is enabling CCCma to contribute to several coordinated international forecasting projects, each focusing on particular time scales and processes, as illustrated schematically above. These include the 2nd phase of the Global Land Atmosphere Coupling Experiment (GLACE-2), results from which have already been published (land initial states produced under II.3.4 were instrumental to CCCma's participation in this project). The large set of multiseasonal forecasts comprising CCCma's contribution to the WCRP/WGSIP CHFP intercomparison project are intended to serve as the basis for a coupled model-based operational climate prediction system. Analyses conducted so far indicate that its performance will be quite competitive with that of other such systems worldwide. Finally, decadal predictions are being carried out that are contributing to the WMO/WGCM/WGSIP fifth Coupled Model Intercomparison Project (CMIP5) in association with the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). Participation in the US Clivar Intraseasonal Prediction Project is envisaged to begin once CHFP and CMIP5 forecasts have been completed.

Connections between Theme I and Theme II have been strengthened further by consideration of subseasonal forecast timescales (days to a season), particularly in connection with the MJO as discussed under II.2.2. Forecast interpretation and processing continues to be enhanced by the analysis (II.1), predictability (II.2) and verification (II.3.3) components of Theme II, and groundwork for future forecast system enhancements is being laid through ongoing research on data assimilation and bias suppression.

Sub-Theme II.1 Analysis and Mechanisms

Project II.1.2 Pacific Decadal Oscillation and Northern Annular Mode
Co-Investigator: J. Fyfe, J. Derome, Wm. Merryfield

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 behaviour 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 behaviour 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.*

The research for this project has been successfully completed. Fabian Lienert successfully completed his candidacy exam and submitted a paper to Geophysical Research Letters entitled "Do models capture the tropical influences on North Pacific temperature variability" by Lienert, Fyfe and Merryfield. He is presently writing a second paper on North American surface temperature and precipitation variability, and beginning his work with the CCCma global coupled data assimilation system.

Sub-Theme II.2 Predictability of the Coupled System

Project II.2.1 Potential Predictability of Current and Future Climates
Co-Investigators: G. Boer, W. Merryfield

Specific Objectives: (i) 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, (ii) Extend the diagnostic study of potential predictability to include effect of climate change, (iii) 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.

<u>Schedule and Milestones</u>:

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.

Progress continues to be made on this project and, in view of the results obtained, efforts have continued into the current period and overlap with the Years 3 and 4 Milestones. In addition, the publication process has been completed for a number of papers reporting the completion of efforts begun in past years. Publication has been completed of a paper reporting the effect of climate change on the internal variability and decadal potential predictability of temperature and precipitation in results from the CMIP3/IPCC archive of coupled model results (Boer, 2009). The analysis of decadal potential predictability is extended to both the internally generated and externally forced components in a paper finally published in Climate Dynamics (Boer 2010). The paper presents comparative results for potential predictability as a consequence of external forcing such as that due to increasing greenhouse gasses as well as that available from predicting the long timescale internal variability of the system. These results apply regionally and, in a nutshell, the internally generated component provides predictability mainly over the extratropical oceans while the forced component implies additional predictability over various land areas. The results suggest that decadal prediction for middle to high latitude land areas, i.e. at the latitude of Canada, will be a challenge however. This is counter-intuitive in the sense that the strongest global warming occurs over land (e.g. Boer, 2010) and should provide a predictable signal. However, unpredictable (on decadal timescales) "noise" variability is large for these areas and this lessens the predictability.

As reported last year, these potential predictability results are directly relevant to the new WCRP/IPCC effort in decadal prediction. The survey paper (Meehl et al, 2009) which is an outgrowth of the Aspen Global Change Institute's Workshop "Climate Prediction to 2030", held last year, has now been published in BAMS. A presentation surveying the prospects for decadal prediction was given at CMOS2009 (Boer, 2009). Dr. Boer remains on the WGSIP/WGCM/CMIP5 panel charged with coordinating the decadal experimentation component of the fifth Coupled Model Intercomparison Project (CMIP5) which will provide an important source of new information to the upcoming IPCC AR5. He has recently been invited to become an ex-officio member of the US CLIVAR Decadal Predictability Working Group.

That we are in a position to participate in and contribute to these international decadal prediction efforts is a tribute to GOAPP's prescience in including this topic in the original proposal. Invited presentations were given on decadal predictability at the Workshop on Earth-system Initialization for Decadal Prediction held at KNMI, deBilt, the Netherlands (Boer, 2009) and at the Workshop on Predicting the Climate of the Coming Decades held at the Rosenstiel School of Marine and Atmospheric Sciences, University of Miami (Boer, 2010). The EU sponsored ENSEMBLES Final Workshop in Exeter, UK which dealt with decadal prediction among other topics, was also attended.

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.

Analysis of climate variability and potential predictability in approximately 2000 years of coupled climate simulations using "coupling surgery" to mask air-sea interactions in various specific regions has concluded, and a paper on these results by Merryfield and PDF Ravindran is under preparation. A value-added aspect of these model results is that a subset has been provided to PDF Bakalian and investigator Ritchie to aid their investigation of atmosphere-ocean covariability under I.2.2.

In a related analysis, Yu et al. (2009) investigate the relationship between SST and surface heat fluxes over the oceans in results from the CMIP3 data set and from reanalyses. While not a direct predictability study, these fluxes are what drive the current 2-tier HFP first season forecast and their behaviour in the coupled model is critical for the seasonal predictions in the CHFP prediction effort.

Project II.2.2. Prognostic predictability from ensembles of coupled model simulations
Co-Investigators: W. Merryfield and G.J. Boer

Specific Objectives: (i) Obtain measures of prognostic predictability through "perfect model" predictability experiments based on large ensembles of coupled model integrations, (ii) Investigate influence of initial climate regime on seasonal-to-decadal predictability

<u>Schedule and Milestones</u>:

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.

As detailed in last year's report, year 1-2 milestones for this project were moved to years 3-4. The primary technical reason was the investigators' desire to develop an initialization technique for "perfect model" experiments that (i) enables a seamless assessment of prognostic predictability on timescales of days to decades, (ii) provides differences in initial conditions between ensemble members that reflect in a realistic way uncertainties in the initialization of climate system forecasts, and (iii) enables the creation of arbitrarily many statistically equivalent ensemble members.

Such a technique has been developed based on the IRU atmospheric assimilation method discussed under II.3.1. Using this method arbitrarily many ensemble members equally consistent with the data can be generated by beginning the assimilation process from different initial conditions. Through extensive experimentation a combination of parameters was obtained such that the random differences between atmospheric initial conditions associated with different ensemble members are comparable to observational uncertainties as reflected by differences between reanalysis datasets. Ensemble spread is imparted to the ocean as well, particularly for phenomena sensitive to surface forcing such as the Atlantic meridional overturning, and these differences between ensemble members have been diagnosed and quantified.

Originally it was proposed that general and regime-dependent prognostic predictability would be examined through perfect model ensemble forecast experiments, i.e. where a particular model run is considered truth and the ability of the forecast ensemble to reproduce the future behaviour of this run is examined. This has become feasible due to the above assimilation method, which provides a means for initializing such ensembles in a way that improves upon past studies of this type, e.g. by accounting for uncertainties in the ocean initialization. However, because of the demand placed on computational and investigator resources by the far greater than proposed scope of subprojects II.3.1 and II.3.2, running large (~100-member) perfect model ensembles as originally proposed has not been feasible in the current reporting period. Instead, these runs will be carried out when retrospective forecast production is complete.

Regime-dependent prognostic predictability is alternatively being examined in available CHFP forecasts. The initial focus has been dependence of wintertime sub-seasonal predictability on the state of the Madden-Julian Oscillation, or MJO. To facilitate this investigation PDF Ravindran has classified MJO states according to a complex EOF analysis, binned the forecasts accordingly, assembled verification datasets, removed interannual variability from the forecast and verification datasets, and computed actual and potential predictive skills vs MJO regime. These results are currently being analyzed, with initial findings being presented by Dr. Ravindran at the 2010 GOAPP Workshop.

A paper on trends and predictability of extreme rainfall events in relation to synoptic activity that was submitted by Drs. Ravindran, Merryfield and Kharin during the previous reporting period has appeared in *Journal of Climate*. Two additional publications are being drafted based on Dr. Ravindran's work under II.2.1.

Sub-Theme II.3 Prediction

Project II.3.1 Coupled Model Initialization
Co-Investigators: G. Flato and W. Merryfield

Specific Objectives: (i) Investigate and implement several relatively simple ocean initialization schemes in a global coupled model, (ii) 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, (iii) 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 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.

Development of the coupled model initialization scheme for CHFP2 concluded in late 2009, and production of retrospective ensemble forecasts began at that time as described under sub-project II.3.2.

One important improvement to CHFP2 initialization during the current reporting period involved the type of sea surface temperature data used to constrain model SSTs during the assimilation period preceding each forecast. Previously, in CHFP1 for example, these SST values were interpolated between monthly means valid at mid-month. For CHFP2, the SSTs that are assimilated instead consist of daily values interpolated from NCEP's weekly OISST analysis. In addition to providing greater time resolution, this approach more closely parallels the use of CMC's daily SST analyses as will occur under operational use (CMC's product is only available for recent years and hence could not be used for CHFP2 retrospective forecasts which begin in 1979).

A second important improvement to CHFP2 initialization methodology was the further development the atmospheric data assimilation method first proposed to us by S. Polavarapu of EC Downsview. The method, known in its initial form as Incremental Reanalysis Update or IRU and implemented in CCCma models by J. Scinocca, constrains AGCM variables (temperature, winds, specific humidity) to remain near their 6-hourly reanalysis values, but without the fictitious dissipation that accompanies simple nudging. Through extensive experimentation, it was determined that (i) use of ERA rather than NCEP analyses led to better ocean properties (mean currents, equatorial Pacific thermocline, etc.), and (ii) inserting ¼ of the analysis increment rather than the full increment enabled the assimilating AGCM to better reproduce observed time series for precipitation without degrading other fields. Because such a procedure no longer strictly constitutes IRU, it has subsequently been referred to as Constant Incremental Nudging or CIN.

A further consideration was the spread between CIN analyses begun from different AGCM initial conditions, which provide a convenient means for ensemble generation. Through further experiments it was found that smoothing the assimilated fields via a spectral truncation (in addition to inserting only ¼ of the analysis increment) led to ensemble spreads that were comparable to the rms differences between different reanalyses. This was considered optimal in terms of sampling of observational uncertainty by the analysis ensemble, as discussed further under II.2.2.

The initialization methods described here, plus those previously established for sea ice, 3D ocean temperature and salinity, were employed in initializing the project-oriented subseasonal, seasonal and decadal forecasts described under II.3.2.

Although this CHFP2 initialization methodology is providing encouragingly skilful forecasts and is targeted for operational use, several areas have been identified where further improvement potentially could be realized in future forecast system versions. These include (i) bias removal through spectral nudging in the OGCM (implemented in collaboration with D. Wright) and comparable procedures in the AGCM; (ii) improved land surface initialization through an off-line procedure similar to that developed by Berg and co-workers under II.3.4, but realizable in an operational environment, and (iii) more sophisticated ocean data assimilation methods.

With regard to the latter, there has been ongoing communication between CCCma and Y. Tang's group at UNBC, which is conducting research on ocean data assimilation methods. Relating to this, in the current reporting period Tang and coworkers

i) after introducing a new ensemble-based filter, called sigma-point filter, into the earth sciences using a 3-component Lorenz model (J. Atmos. Sci., 2009), started to apply this method to a realistic oceanic model for Argo assimilation. Especially, some significant issues relevant to the application have been studied. This work led to a manuscript submitted already.

ii) because an important issue in data assimilation is to consider the model bias, concentrated on bias correction and have been working on this issue. Some significant progress has been made, and a manuscript that documents our efforts in developing bias correction methods is being drafted and will be submitted soon.

Project II.3.2 The Coupled Model Historical Forecasting Project
Co-Investigators: W. Merryfield, G. Boer, J. Derome and G. Flato

Specific Objectives: (i) 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, (ii) Investigate methods of generating ensembles of initial conditions and of forecasts, possibly including multi-analysis and multi-model approaches, (iii) Obtain basic skill measures of multi-seasonal forecasts produced in this way and some insight into the possible utility of predictions at longer times, (iv) Analyse 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.

Summary. In the previous reporting period, the seasonal forecast pilot project CHFP1 was completed and initial groundwork laid for the second-generation system CHFP2. The current reporting period saw completion of CHFP2 development, leading to intensive production of subseasonal, seasonal and decadal forecasts as well as archiving and assessment/verification of the forecast data; these results are contributing to several international projects as detailed below. Overall, the scope of this sub-project has far exceeded that originally proposed.

Forecast model configuration. As reported last year, the CHFP2 seasonal forecast system is comprised of two models, CanCM3 (OGCM4 coupled to AGCM3) and CanCM4 (OGCM4 coupled to AGCM4). In addition to being distinguished by differing physical parameterizations and hence model uncertainties, the two model versions complement each other in that CanCM3 exhibits ENSO variability that is slightly weaker than observed, whereas CanCM4's ENSO is slightly too strong. Unlike CanCM3, CanCM4 includes realistic representations of all major radiative forcings, including volcanic aerosols (in seasonal forecasts volcanic forcing decays from initial values with a 12-month e-folding time so that no future volcanic eruptions are predicted). CHFP2 development and testing proceeded in parallel with ongoing development of AGCM4, leading in late 2009 to the version that is being employed in IPCC AR5 climate simulations as well as CHFP2.

Forecast model initialization. Initialization strategies for ocean, sea ice and land were finalized in the previous reporting period, whereas development of the atmospheric initialization method continued into 2009-2010. The method chosen is based on the simple Incremental Reanalysis Update technique and was implemented as the result of a collaboration with S. Polavarapu of Environment Canada, with some modifications as detailed in the report for sub-project II.3.1. In addition to imparting realistic atmospheric initial conditions for the forecast, this method provides a means for generating an arbitrarily large ensemble of statistically equivalent initial conditions without the use of lagged (and hence less accurate) atmospheric states as in the current operational system.

Subseasonal forecasts. The impact of land surface initial conditions on subseasonal forecast skill was examined in an extensive set of CanCM3-based forecasts for the international Global Land Atmosphere Coupling Experiment (GLACE-2). The core GLACE-2 objective was for each participating group to produce two sets of 60-day forecasts: Series 1, with land surface initial conditions obtained by forcing the model land surface scheme off-line with observation-based data, and Series 2 in which these same initial states were randomized with respect to the start dates of the forecasts. (The land initial conditions used were those produced by A. Berg and G. Drewitt under sub-project II.3.4, rescaled to the climatology of the forecast model.) Initial analysis showed Series 1 forecasts of surface temperature to be consistently more skillful throughout the forecast period. These forecasts have contributed to two papers describing to GLACE-2 results, and to studies by investigators Berg and Drewitt under II.3.4.

If resources permit, a further set of CanCM4-based forecasts will be undertaken for the US Clivar Hindcast Experiment for Intraseasonal Prediction

Seasonal forecasts. A complete set of 12-month seasonal forecasts, initialized at the beginning of each calendar month from 1979-2008, was completed for CHFP2a (based on CanCM3). A comparable set of forecasts for CHFP2b (based on CanCM4) was begun and is expected to conclude in the summer of 2010. (Forecasts initialized through 2009 are also planned.) Together these efforts, comprising over 7200 years of model integration, will provide a basis for calibration and skill assessment of an operational system, as well as a rich database for ongoing methodological investigations. These will represent CCCma's contribution to the World Climate Research Program's Climate-system Historical Forecast Project (referred to in the milestones as the *COPES TFSP).*

Decadal forecasts. Decadal forecasting, though still in its infancy, will be a key component of the IPCC Fifth Assessment (AR5). Because of its sophisticated representation of natural and anthropogenic forcings, CanCM4 is providing the basis for CCCma's decadal forecasts. The relative effectiveness of different initialization strategies is still an active area of research and so different techniques are being attempted. So far, one set of decadal forecasts has been completed, with completion of least one more set expected by the end of the reporting period. For these first forecasts the model was spun up for several hundred years while assimilating a repeating decadal cycle of atmospheric, SST and sea ice data spanning the 1960s. The observed time series from 1958 to 2008 were than assimilated, and forecasts launched from these states. In the first set of forecasts, no further ocean data assimilation was undertaken; whereas the second set uses the subsurface ocean data assimilation methods employed in CHFP2. Initial assessments of the first set show apparent skill in predicting global-mean surface air temperature as well as the strength of the Atlantic meridional overturning circulation (verified against the assimilating model).

Post-processing and data sharing. Processing, analysing and sharing results from many thousands of years of forecast data is a formidable undertaking, but good progress has been made largely thanks to supplemental funding from GOAPP which supported acquisition of an OPeNDAP-based web server and a dedicated data analyst, Dr. Badal Pal. Such efforts have included (i) producing requested daily data for the subseasonal GLACE-2 forecasts, and sharing with other GLACE-2 investigators as well as subproject II.3.4 investigators Berg and Drewitt via ftp; (ii) producing requested daily and monthly data for the WCRP CHFP project and making these publically available via the OPeNDAP server (the CanCM3-based contribution is complete, with CanCM4 to follow); (iii) processing of the initial round of decadal forecasts.

Transition to operational use. Because the CHFP2 forecast system is intended for operational use, care has been taken to make its design compatible with data availability and timelines in an operational environment. Because products such as the ERA reanalyses, HadISST sea ice and NCEP SST data which were used to initialize the 1979-2008 CHFP2 forecasts are not available in real time, 6-hourly analyses of these fields produced by the CMC in support of weather forecasts have been automatically acquired, regridded and archived as of late 2009. In addition, daily 3D ocean temperature and salinity analyses are being acquired in near-real time through an agreement with NCEP. These products will enable CHFP2-based forecasts to be produced within operational constraints, while having such archives covering a significant time span will enable verification of operational against retrospective forecasts.

Ongoing research and development. Some forecasting methodologies investigated under CHFP2, while promising to improve forecast quality, turned out not to be compatible with timely development of an operation-ready system and completion of associated retrospective forecasts. These will nonetheless continue to be investigated for possible application to a next-generation system, and include (i) ocean bias suppression via spectral nudging, which has been implemented and demonstrated in the CCCma model through a collaboration with Theme I investigators D. Wright, F. Dupont, and for which certain technical issues remain to be worked out, (ii) atmospheric bias suppression through a procedure developed by Theme II collaborator V. Kharin; (iii) land surface initialization through an off-line forcing procedure that is realizable in real-time, to be pursued with Theme II investigator A. Berg.

Project II.3.3 Forecast Combination, Calibration and Verification
Co-Investigators: Jacques Derome, G. Boer and W. Hsieh

Specific Objectives: (i) 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, (ii) 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, (iii) Assessment of potential economic value in a cost-lost decision framework.

Schedule and Milestones:

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.

Skill analyses are an important and continuing part of CHFP and the Merryfield et al. (2009) paper has now been accepted for publication in Atmosphere-Ocean. The paper describes the initial CHFP forecast system and also analyzes results from the large suite of coupled model predictions that constitute CHFP1. Of course, vigorous analyses of the results of the new CHFP2 forecast system is underway as described in Section II.3.2. The analysis of trend in HFP2 data (Boer, 2009) has now been published and has given an indication of the importance of the inclusion of GHG and other forcing in CHFP2.

New and more sophisticated analysis and post-processing approaches are continuing to be developed. All sources of skill that may exist must be accessed in the difficult area of seasonal to interannual prediction especially as it applies at Canadian latitudes. The paper (Kharin et al., 2009) assessing the performance of the HFP2 four-model ensemble seasonal prediction scheme in hindcast mode has now been published. This document provides the research and development background for the current operational CMC first-season forecast.

A more detailed analysis of skill of monthly and seasonal HFP2 hindcasts derived from daily model output is performed for Canada in general and West Canada in particular. An emphasis is made on quantities that are thought to be related to energy demand and production. The results of this study are summarized in a PCIC report (Kharin and Fyfe, 2010). One of the main conclusion of this study that monthly and seasonal temperature forecasts are found to be a good predictors for quantities that are derived from daily model output, such as heating and cooling degree days, mean warm spell durations, and various other indices that characterize intra-seasonal temperature variability.

In cooperation with Dr. J. Scinocca, a method to reduce climatological model biases in an atmospheric general circulation model (AGCM) was developed. The bias reduction is realized by deriving a fixed annual cycle of spatially varying tendencies, which are applied to the right-hand-side of the model's prognostic equations at run time. The seasonally varying bias corrections are constructed from previous multi-year adaptation runs of the AGCM in which its prognostic variables are relaxed towards observational data. The bias correction methodology is used to perform a number of AMIP-type simulations to estimate the effect of bias-correcting tendencies on various aspects of model performance, including climatological annual cycle, intra-annual variability, and monthly-to-seasonal predictability. Preliminary results indicate that inter-annual covariability and seasonal predictability is improved by applying such run-time bias corrections (Kharin and Scinocca, 2010)

Investigations into a methodology, referred to in the last Report, to improve the robustness of a linear regression method of statistically improving forecasts by taking into account seasonal and spatial dependences in model forecasts have been completed and show an improvement in skill over Canada for deterministic forecasts.

Similar methods are applied for calibrating probabilistic forecasts and both are described in Kharin, (2010). Forecast calibration is particularly important since seasonal forecasting is essentially probabilistic and some indication of uncertainty should accompany a seasonal forecast. This is implicit in probabilistic forecasts which, however, need to be calibrated to properly represent this uncertainty. It has been agreed at the CMC Seasonal Forecast Forum that seasonal forecasts calibrated with this method should replace the current operational deterministic and the 3-panel probability forecasts with a single panel calibrated probability forecast. Coloured regions represent probabilities in the three standard categories which are greater than 40% and so give a very economical presentation of the information. In uncoloured regions no category has a probability greater than 40% and so the forecast is uncertain. This approach avoids one of the pitfalls of deterministic forecasts which can predict a certain category even if the probability is barely above chance.

Methods of explicitly presenting uncertainty in the seasonal forecasts at the local level in Canada have also been developed based in the calibrated forecast procedure. In particular, an interactive web application has been developed which presents, for the chosen location, an actual probability distribution based on the forecast for that location. More sophisticated users will be able to calculate explicit probabilities, rather than simply the probability of the three categories. The approach is also described in (Kharin, 2010).

The Forum for Seasonal Forecasting is composed of members of CMC, RPN and CCCma who jointly oversee changes and improvements to the operational seasonal forecasts. The results of Project II.3.3. have been and are of particular importance to the actual operational production of seasonal forecasts. Essentially all of the proposed changes to the seasonal forecast production and presentation are heavily influenced by the work done under this Project.

Finally, the growing interest and importance of seasonal to interannual prediction has led to the preparation of a White Paper entitled "Understanding and predicting seasonal to interannual climate variability "(Stockdale et al., 2009), co-authored by a GOAPP investigator, which served as the basis for a presentation at the Third World Climate Conference (WCC3). Both the White Paper and the presentation are available from the WCC3 website http://www.wcc3.org/sessions.php?session_list=WS-3.

Project II.3.4 Sensitivity of Seasonal Climate Forecasts in the CCCma GCM to Initialization of Land Surface Hydrological States
Co-Investigator: A. Berg

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.

<u>Schedule and Milestones</u>:

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.*

During the summer and fall of 2009 we were in regular contact with collaborators at the CCCMA regarding the CLASS-derived land surface data we delivered in the spring of 2009. The discussions were generally regarding technical issues on integrating the land surface data into the CCCMA seasonal forecast model. During the fall of 2009 our collaborators at the CCCMA was invited to participate in the GLACE-2 (Global Land-Atmosphere Coupling Experiment) project which is an AGCM intercomparison study led by Dr. Randy Koster at NASA. The full CCCMA model forecast experiment, using our land surface initial conditions, ran in the late fall 2009 with the final results delivered in January 2010. An overview paper of this experiment was published in Geophysical Research Letters. From January to the present we have been developing the tools to examine the increase in forecast skill due to improved initialization. As of March 2010 we have also been investigating methods to examine forecast skill, land surface initialization and the relationship to soil moisture extremes (drought and wet conditions). The results of these investigations are still at a preliminary stage but will be presented at the 2010 CMOS/CGU conference in Ottawa and the Drought Research Initiative (DRI) conference in Winnipeg (May 12, 2010). Our results show a small but significant increase in forecast skill of the CCCMA model when initialized with realistic land surface conditions. This work leads directly to achieving the milestones in our original proposal of completing the forecasting experiment and examining a case study of drought. It is anticipated that a publication resulting from this work will be ready for submission in the fall of 2010.

In August 2009 a graduate student (Lisa Courtney) successfully defended her master's thesis on a comparison of the process controls of soil moisture in the CLASS model and an observational network. A manuscript from these results is currently in preparation for submission to the Journal of Geophysical Research. This work is directly relevant to improving our understanding of the CLASS model which can have application to generating in near real time the surface fields for forecast initialization.

In September of 2009 a post-doctoral Fellow (Nasim Alavi) began working part time on examining the role of land surface initialization in the HFP (Historical Forecasting Project) dataset. This work aims to determine if soil moisture initial conditions leaves a detectable signal in the forecast results. This work will be presented at the CMOS 2010 conference and is being prepared for submission to Atmosphere-Ocean.

GOAPP Supplementary Project: Transitioning GOAPP Research to Operations: Real-time Data Assimilation and Forecast Systems

Co Investigators: K. Thompson, H. Ritchie, D. Wright and P. Gauthier
Collaborators: Y. Lu

Background: In early 2008 a proposal was submitted to CFCAS for supplementary funding for the network. The motivation was that GOAPP had made rapid progress in the development of modeling and assimilation techniques and this had led to an opportunity to transfer research developments to the Canadian Operational Network of Coupled Environmental PredicTion Systems (CONCEPTS) for operational use. The proposal argued that the transfer would be carried out most effectively through the development of pre-operational forecast systems (an activity not budgeted for in the original GOAPP proposal). In July 2008 we were informed by CFCAS that the proposal was fully funded ($196,000) for two years.

The supplementary proposal is organized as a single theme with two related projects: 1) Real-Time System for Forecasting Mesoscale Variability of the North Atlantic; and 2) Real-Time Global Coupled Atmosphere-Ocean System. Both projects were designed to develop pre-operational forecast systems and thus facilitate transfer of useful technology from GOAPP to its government partners. The first year of supplementary funding was mainly to support research on Project 1 and this is the focus of the present annual report.

The goal of Project 1 (Real-Time System for Forecasting Mesoscale Variability of the North Atlantic) is to set up and validate a pre-operational modeling and data assimilation system for forecasting mesoscale variability of the North Atlantic on space scales of 10 to 5000 km and lead times up to 15 days. The domain covers the whole of the North Atlantic and the adjacent shelves off the east coast of Canada. The goals of Project 2 (Real-Time Global Coupled Atmosphere-Ocean System) are to set up and evaluate a pre-operational global coupled atmosphere-ocean data assimilation and forecasting system incorporating improvements resulting from GOAPP research on models and methods, in preparation for transfer CONCEPTS.

The bulk of the supplementary funding covers the salary of a research technician and a Research Associate. The technician's responsibilities include data management, establishing and maintaining data feeds (e.g. altimeter, Argo and XBT data, atmospheric forcing), routine running of the models, making selected results publicly available through the GOAPP website, making available more extensive datasets to partners as requested and assisting in the transfer of model and assimilation codes to CONCEPTS. The Research Associate is responsible for optimizing the data assimilation parameters and model code for operational use, and working with CMC and DFO to facilitate technology transfer.

Following an extensive search in 2008, the two new positions were filled as follows:

Position	Person	Start Date
Research Technician	Fred Woslyng	October, 2008
Research Associate	Dr. Yimin Liu	November, 2008

Progress from July 2009 to July 2010:

Unfortunately Dr. Yimin Liu left GOAPP in October of 2009 with relatively little notice and this did not leave much time to complete existing activities and also prepare documentation. On the positive side, Dr. Liu left GOAPP to work with Dr. Fraser Davidson of DFO's Northwest Atlantic Fisheries Centre in St. John's, Newfoundland. He was hired to help with operational ocean modeling and so much of the technology developed by GOAPP was successfully transferred to DFO.

Following Dr. Liu's departure an international search commenced for a replacement and promising candidates have been identified. (Update: An excellent applicant has accepted our offer of a position and will join the project in September, 2010.) There have also been unexpected delays in the availability of the global coupled baseline atmosphere-ocean system from CONCEPTS which will serve as the host for the GOAPP advancements and the basis for intercomparison of the systems. Consequently we have requested and received CFCAS approval to extend this activity until March 31 2011 using the existing funding for this project. We are confident that with the hiring of the new postdoctoral fellow, and the extension of the end date of the project, we will be able to recover the ground lost due to Dr. Liu's departure.

The research technician has focused on two main areas over the last reporting year: data management tasks and supplying data to researchers. Details are given below.

A) Data Management

Theme I Legacy Data and DFO: Talks between the GOAPP DMC and DFO / C-NOOFS regarding data serving and visualization established a number of common objectives and similar technical approaches. A subsequent teleconference in February between the DMC, DFO ISDM and DFO C-NOOFS representatives produced positive feedback regarding having DFO serve Theme I legacy data. A face-to-face meeting in St. Johns produced a list of proposed hardware and software for the Theme I server, which was forwarded to DFO ISDM for consideration.

Server Hardware Delivery and Configuration: The purchase and delivery of the server for Theme I data was completed in May, 2010. A server similar to those at DFO / C-NOOFS was selected in order to facilitate the transfer of the hardware to DFO after the termination of the GOAPP Network. The server has 23 TB of usable disk space, with data redundancy (RAID 6), and 8 hyper-threaded Intel Xeon processor cores. Configuration of the server is ongoing.

Attend and present at Data Managers Workshop: CFCAS organized a Data Mangers workshop, held in November, 2009, in Winnipeg, to identify and discuss issues and courses of action, related to data management. In attendance were representations of CFCAS, GOAPP, CANDAC, STAR and DRI, and via teleconference, IP3 / WCN2, C-SPARC, CPP and CAFC. Critical issues common to several research networks include hosting of legacy data, metadata standards and data validation. The GOAPP presentations focused on the difficulty in finding a partner to host its legacy data, and data serving (OPeNDAP) and visualization solutions.

Technical support and guidance: Significant support and guidance has been provided to the Data Management Committee over the reporting year.

B) Data Access

Access to Data Streams: Maintained and monitored links to data streams from Environment Canada and AVISO. Downloads have been automated and launched by the cron utility. The tasks are shell scripts which utilize wget to download new or updated data files only. The Environment Canada data server is accessed twice a day (in case the first access fails), to download the daily data files. Any task failure is reported via email to the technician. Transferred NEMO output datasets from ACEnet. Provided technical support to a researcher using the loaddap interface to DAP servers, to access data from an OPeNDAP server on the internet, within Matlab.

1.2 EXPLAIN ANY SIGNIFICANT DELAYS OR DEPARTURES FROM THE RESEARCH PLAN, OR THE RESCHEDULING OF ACTIVITIES, AND HOW THEY WERE ADDRESSED.

Overall the research is on track. The following delays and departures have been reported by Co-Investigators of the following projects:

Project I.1.4 – Delays created by departures of personnel

Research Associate, Y. Liu, who was working with K. Thompson, left the GOAPP project without providing useful documentation on, and support for, the FORTRAN code related to the data assimilation method of Liu and Thompson. This resulted in the reanalysis projects not being able to make use of the Liu and Thompson data assimilation scheme as planned. In response researchers at BIO and RMC have focused efforts on reanalyses that include spectral nudging, and at IOS effort has focused on the development of alternative data assimilation methods. In all cases, useful work has been achieved, but there has been a delay in meeting deliverables involving the assimilation of observed synoptic ocean variability. The hiring of replacement personnel (see above), and the no cost extension of GOAPP, should allow us to recover.

Research Associate F. Dupont accepted a position with Environment Canada in September, 2009 and was replaced by Dr. Vasily Korabel starting at the end of May, 2010. The loss of Dr. Dupont has slowed progress on the North Atlantic component of this project but it has also freed up funds to support a new hire to complete our goal to perform reanalyses using a data assimilative model that includes synoptic variability.

Project I.1.3 Change of Approach - E. Demirov decided to change the approach he had proposed initially to develop a data assimilative model of the Northwest Atlantic and Labrador Sea. Instead of using a traditional SEEK implementation as an Extended Kalman Filter, work has begun on the development of an ensemble based version of the SEEK filter.

Project I.1.4 Focus of research - Focus has shifted to the development of a Green's Function method to perform ocean re-analysis and forecasting studies. Theoretical aspects of the multivariate assimilation (4D-Var) were also studied in order to develop an algorithm to calculate useful information related to observable modes.

Project I.1.6 Focus of Research – Effort has focused on (i) the development and validation of a coarse-resolution shelf circulation model for the northwest Atlantic Ocean using a combination of spectral nudging and smoothed semi-prognostic method, and (ii) a process study of interannual variability of hydrography and circulation over the slope water region off the Scotian Shelf. A finer resolution shelf circulation model of the eastern Canadian shelf, nested inside the northwest Atlantic Ocean model, will be developed in 2010-2011.

Project I.2.1 Coupled GEM-NEMO model not available - The development of a data assimilation scheme requires that we have a coupled model suitable for data assimilation. The plan is to couple the GEM-4D-Var analysis with a NEMO-VAR analysis. The first step requires only the coupled GEM-NEMO model which is not yet available. As we are moving in the last year of the project this is still a source of serious concern as the coupled GEM-NEMO model is still not available. On our side, Dr. Skachko has devoted a lot of his time to understanding the complex data flow within the GEM model and the assimilation system to be able to 1/ perform parameter estimation as described in the previous section, 2/ have the necessary "channels" to transfer information from analyses to the coupled model. This has now been completed and first experimentations with the uncoupled system are now being done.

Project 1.2.2 Due to the long delay in the coupling of the GEM and NEMO models, it was not possible to carry out the coupled twin experiment using these 3-D numerical codes. Very good progress has been made however, as reported above, in applying the general principles of joint data assimilation to a simplified state space model representation of the coupled atmosphere-ocean system. The research carried out this past year should serve as a solid foundation for future efforts on the joint assimilation of data into the coupled GEM-NEMO system.

Project II.2.2 Demands placed on computer and investigator resources by the larger than proposed scope of the CHFP have dictated that the large perfect model ensembles originally proposed as a pert of this sun-project be carried out in the next reporting period, after CHFP forecasts have concluded. Regime-dependent prognostic predictability is being examined as proposed, but in the CHFP rather than perfect model forecasts.

Project II.3.1 Exceeded expectations - The scope of this project, with attention to atmospheric data assimilation and the initialization of ocean salinity and sea ice, as well as potential application of these techniques in an operational environment, has exceeded that originally envisioned.

1.3 EXPLAIN SIGNIFICANT DEVIATIONS FROM THE BUDGET. (NOTE: CHANGES OF 20% OR MORE FROM BUDGET CATEGORIES REQUIRE ADVANCE APPROVAL FROM THE CFCAS SECRETARIAT).

The SSC and the Board of Directors approved the following budget deviations.

Transfer of funds: $1775.22 was moved from Jacques Derome's budget to the Network Secretariat. $4637.70 was transferred from K. Thompson's account to the Network Secretariat.

1.4 DESCRIBE HOW THE WORK OF CO-INVESTIGATORS WAS INTEGRATED OR COORDINATED.

Overall the integration and coordination of the research was good. There is continued strengthening of collaborations between themes, and across disciplines. This bodes well for the success of the network and the training of the next generation of coupled modellers. Details of the integration and coordination are given below.

At the Network level, six Co-Investigators are members of the Scientific Steering Committee (SSC). The SSC acts as an important integrating mechanism among projects and between the two Themes. Principal Investigators, Hal Ritchie and Keith Thompson hold formal meetings with Network Manager, Susan Woodbury, on a weekly basis.

The extensive research into the most effective methods of data management by F. Woslyng, GOAPP Technician at Dalhousie University has resulted in the purchase of a data management server (see above for details).

The GOAPP researchers in the Halifax-Dartmouth area met on a periodic basis at Dalhousie University. Investigators and collaborators at CCCma at the University of Victoria held bi-weekly meetings to discuss progress and coordinate efforts.

The GOAPP Annual Workshop took place in Ottawa on 31 May 2010. The attendance exceeded fifty researchers, students and invited guests. The workshop and the subsequent CMOS Annual congress provided an excellent opportunity for GOAPP researchers to review progress and encourage collaboration internally, with other networks and also with fellow Canadian and international scientists.

Some individual activities are listed below:

1. Researchers using the ACEnet facilities have also participated in video conferences on the use of the NEMO model. The conferences were supported by ACEnet staff to help resolve technical issues. (ACEnet is a pan-Atlantic network of world-class, high performance computing clusters that is available to qualified researchers in the region.)

2. Experience on various aspects of NEMO modeling was exchanged through the GOAPP web site with the help of Susan Woodbury. Matlab scripts for working with NEMO have been distributed through this site and extensions of the Green's Function method will also be distributed through this web site.

3. CCCma investigators are in regular email and phone contact with Guelph investigators Berg and Drewitt in order to integrate their work under II.3.4 into the CHFP and provide forecast results. Work between Dr. Alavi and Dr. Drewitt has required a degree of collaboration and sharing of data that is generally accomplished with weekly meetings.

4. Paul Myers (University of Alberta) visited Memorial University, Dalhousie University and the Bedford Institute to facilitate information exchanges. He also interacted with Canadian Ice Service at the Canadian Sea Ice Workshop in Ottawa. He interacted with European collaborators by spending 2 months at Institut français de recherche pour l'exploitation de la mer (Ifremer)Ifremer as part of his sabbatical (plus also involvement at the DRAKKAR workshop in Grenoble).

5. Entcho Demirov visited Dalhousie University and the Bedford Institute to discuss work on GOAPP projects.

6. The research team comprised of graduate student J. Urrego Blanco, and J. Sheng worked very closely with F. Dupont, D. Wright and Y. Lu in refining the northwest Atlantic Ocean model using NEMO and collaborated with K. Thompson in determining the main physical processes responsible for interannual variability of hydrography over the slope water region off the Scotian Shelf.

7. The NEMO global ocean model has been used to study the forcing mechanisms of the intra-seasonal variations in the tropical Pacific Ocean by Drs. Youyu Lu, Keith Thompson and Harold Ritchie in collaboration with a visiting PhD student, Xu Zhang, and Professor Jing Jiang from Nanjing University (China).

8. Dr. Faez Bakalian visited UQAM to discuss GOAPP data assimilation projects.

9. Close collaboration is pursued with the group at EC in Dorval working on CONCEPTS, particularly Dr. G. Smith and with Dr. F. Davidson (DFO) in St. .John's, Newfoundland. Dr. Skachko visited St. John's.

10. Dr. Merryfield visited Dr. Tang's group at UNBC in April 2010 to share and discuss research results.

11. Collaborator Scinocca is principal contact with the Downsview atmospheric data assimilation group and is facilitating technical aspects of this collaboration. Investigators at CCCma and UNBC communicate their respective groups' research progress through visits and seminar presentations.

1.5 DESCRIBE THE PARTICIPATION OF GOVERNMENT (FEDERAL, PROVINCIAL OR MUNICIPAL), UNIVERSITY, INDUSTRY, FOREIGN OR PRIVATE SECTOR RESEARCHERS (AND/OR OTHER STAFF) INVOLVED IN THE PROJECT.

Government (Federal, Provincial, Municipal): The participation of government researchers in the project continues to be excellent. Seven of the Co-Investigators are adjunct professors and are fully engaged in research and development. Seventeen government collaborators are involved in a variety of capacities. (See Appendix B) In addition, the following activities were reported:

1. Since four of our co-investigators (Hal Ritchie (EC), Dan Wright (DFO-BIO), Mike Foreman (DFO- IOS) and Keith Thompson (Dalhousie)) are involved in the inter-agency initiative to develop a Canadian Operational Network of Coupled Environmental PredicTion Systems (CONCEPTS), we have quite naturally coordinated our work with researchers within DFO and EC. Work on ocean model developments is closely coordinated between GOAPP investigators and related federal government activities. As EC moves into the use of coupled

Ocean-Atmosphere modelling, we anticipate that this coordination will be further strengthened in order to meet the challenges ahead.

2. Interaction has continued with Mark Buehner at the Canadian Ice Service on assimilation plans and approach, as well as acquiring CIS data to use for assimilation and validation. P. Myers had interactions with Entcho Demirov at MUN on Labrador Sea modelling and sea-ice assimilation.

University: There are ten universities participating in the GOAPP Network. Each university provides office space and computing facilities for GOAPP researchers.
The NEMO ocean model has also been implemented at HPCVL (http://www.hpcvl.org) and on ACEnet machines (http://www.ace-net.ca/). HPCVL and ACEnet are university-based consortiums that provide high performance computing resources. Each group has received support from the Canadian Foundation for Innovation and other organizations.

Industry, Foreign or Private Sector: Collaboration has continued with Anne-Marie Treguier, Claus Boning, Arne Biastoch and other DRAKKAR scientists on understanding drift in NEMO simulations. P. Myers has been provided with the fields from the French G70 ORCA025 hindcast simulation and the German KAB001, KAB002 ORCA025 hindcast simulation.

2 IMPACT

2.1 WHAT SHORT AND MEDIUM TERM OBJECTIVES HAVE BEEN ACHIEVED, OR ARE ANTICIPATED;

GOAPP research and development on improved ocean-atmosphere data assimilation and prediction on both Theme I and II time and space scales is progressing well. Interactions among GOAPP investigators and government partners are effective, benefits are being realized and technology transfer mechanisms are in place. An excellent group of highly qualified personnel are being well trained to meet future challenges.

The major advances made by GOAPP over the reporting year are listed below (order unimportant).

- We have continued to advance our abilities to model the mean state and variability of the North Atlantic, North Pacific, Arctic and global oceans.
    - A clear demonstration of the ability to use the AGRIF imbedding technology to include the NA ¼ degree subdomain within the 1 degree global domain and recover results similar to those obtained when the ¼ degree NA is run in isolation with specified open boundary conditions. Since Dr. Dupont also has the AGRIF technology working with sea ice, we are now able to perform global 1 degree simulations over decadal time scales with an imbedded ¼ degree NA region.
    - A clear demonstration of our ability to reproduce and diagnose the causes of major observed ocean variations. This has involved the development and validation of new mean sea surface topographies of the North Atlantic.

  - o Demonstration of potential low frequency predictability associated with Rossby waves in the North Pacific.
  - o Better understanding of the role of the Madden Julian Oscillation in controlling extratropical variability in both the atmosphere and ocean.
  - o The development of a Green's function parameter optimization method for NEMO and the development of an algorithm for calculating observable modes in 4D-VAR analyses.
  - o The identification of systematic biases in the global 1/12 degree OPA global model that is run at Mercator-Ocean.
  - o An improved model for the sub-polar gyre and better understanding of its interannual variability.
  - o Development of a regional atmospheric model for downscaling of atmospheric forcing.
  - o A better understanding of the sea-ice variability and assessment of the sea-ice model error statistics.
  - o Improved SEEK data assimilation scheme for the sub-polar ocean.
  - o Improved understanding of the causes of model drift.

- Development of a coarse-resolution (1/4 degree) model of the northwest Atlantic Ocean based on NEMO. The model is forced by 6-hourly surface wind, sea surface net heat and freshwater fluxes, with model open boundary conditions specified from 5-day reanalysis data produced by BADC. This northwest Atlantic circulation model will be used in the development of a dynamically downscaling shelf circulation model for the eastern Canadian shelf.

- A simple atmospheric data assimilation method developed for initializing seasonal forecasts has been optimized for the initialization of perfect model predictability experiments.

- The surface initial condition fields for integration into the CCCMA model have been finalized. The forecast experiment has now been performed and we are in the process of analyzing the data for effects of soil moisture on drought forecasting.

- A long-term subsurface heat content reanalysis dataset was produced for climate study. This dataset has been put in the website to public with free charge. An assimilation system with bias-correction has been built for the assimilation of Argo profiles for the Pacific Ocean.

- Sets of retrospective subseasonal, seasonal and decadal forecasts contributing to various international projects (GLACE-2, WCRP CHFP, IPCC AR5) have either completed or are nearing completion.

- The diagnostic evaluation of atmosphere-ocean cross-correlations in a long coupled CGCM run has been achieved Twin experiments have been carried out for independent and joint assimilation using a simplified state space model representation. Similarly, the NMC method was tried using the simplified state space model. These experiments will pave the way for implementation of the fully coupled GEM-NEMO system

2.2 DESCRIBE THE SIGNIFICANCE / IMPACT OF THE RESULTS ACHIEVED TO DATE AND HOW THIS NEW KNOWLEDGE HAS INFLUENCED RESEARCH POLICY, ENHANCED RESEARCH COLLABORATION OR COMPETITIVENESS, OR HELPED ATTRACT OR TRAIN SKILLED PERSONNEL.

Address the following items, as appropriate:

- **The impact of the project on government policy development (federal, provincial or municipal);**

The GOAPP network complements an interagency initiative to develop an operational ocean modelling capability in Canada (CONCEPTS). The research done by this group and others is seen as a critical contribution to the R&D stream of the CONCEPTS initiative and was a factor in the coordinated development of marine environmental prediction systems. The transfer of technology to this initiative through funding of the supplementary project was strongly supported by EC and DFO as contributions to the development of the CONCEPTS system.

The CHFP2 forecast system is intended for operational application, and several presentations have been made to colleagues at CMC and senior Environment Canada management to highlight its coming availability and potential benefits as an ENSO prediction and seasonal forecast system for Canada; a White Paper on the Development of a Multi-timescale Coupled Climate Forecasting System at Environment Canada, co-authored by Merryfield and Boer, was distributed within EC.

- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation;**

Links with DFO and EC research scientists have continued to strengthen over the last year due to GOAPP. There have also been encouraging interactions between research scientists from CCCma on the west coast and oceanographers (university and DFO) on the east coast.

Integration of subproject II.3.2 and II.3.4 has led to extensive and ongoing collaboration between CCCma personnel and A. Berg's hydro-climate group at the University of Guelph.

The preliminary and encouraging results of the forecast experiment are of interest to the operational seasonal forecast group at the CCCMA. We are now in discussion with this group about methods to simplify the land surface condition generation through a combination of modeling and data assimilation.

- **Whether and how it has improved the reliability of predictive methods;**

This work has led to a measureable, significant improvement in seasonal forecast skill during the boreal summer period. This is accomplished by initializing the model with realistic land surface conditions rather than default or "climatological" values.

Initial assessments of CHFP2 skill against forecasts by EC's current operational system and the NCEP CFS (USA) have been positive. Operational use of CHFP2 would provide Canada with dynamical ENSO forecast capability that it currently lacks.

- **The impact of the project on your own institution;**

The Network has increased the number of highly qualified personnel in all of the partner institutions. At Dalhousie University, the home of the Network Secretariat, the GOAPP initiative continues to be positively received by the senior administration and they anticipate that it will raise the profile of ocean and atmospheric research at Dalhousie and in Canada. At the University of Alberta access to computer time on the WestGrid system has improved because of participation in GOAPP. At Memorial University the project facilitated the extension of the research group working on modeling and data assimilation. The experience and knowledge on modeling and data assimilation, and the data archive from hindcast studies provide a strong base to develop student research projects.   The Department of Geography at the University of Guelph has benefited from this project by the presence of postdoctoral fellows (Alavi and Drewitt). They have assisted graduate students with many aspects of their research.

- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships;**

  With GOAPP involvement in the development and improvement of the NEMO model, the interactions of Myers' group with other NEMO groups associated with the European DRAKKAR consortium has led to two further links/funding partnerships:
  - To support a partnership with Anne-Marie Treguier at Ifremer, Brest, France, Myers has a received a France-Canada Research Grant to support exchange between the two groups, related to NEMO ocean/sea-ice modelling and the subpolar North Atlantic.
  - To support interactions (and visit to IFM-GEOMAR, Kiel), he received a Visiting Professor Scholarship from the German DAAD.

- **Any current (or potential) commercial or social applications, which the results may have;**

  Not applicable.

- **Links with international initiatives and the potential impact of these;**

Coordination of activities with the Mercator operational center in Toulouse, France and the European DRAKKAR Research and Development group has continued.

Dr. Berg's project has benefited with links to the GLACE 2 project based at the NASA Goddard Space Flight Center.

CCCma is contributing forecast data to several international projects (GLACE-2, WCRP CHFP, IPCC AR5 decadal forecasts) as detailed above, helping to maintain its status as a major climate modelling centre.

We invited Dr. F. Doblas-Reyes from the Catalan Institute for Climate Sciences (IC3) in Spain to be an invited speaker at the GOAPP Workshop and CMOS Congress in Ottawa.

- **Anticipated benefits of the work for Canadians.**

Ultimately GOAPP will lead to better predictive models of the marine environment. The main potential for benefit to Canadians is through improved prediction skill being transferred to the inter-agency CONCEPTS initiative. Improved knowledge of the state of the atmosphere and ocean from global coupled models and data assimilation systems is a critical need for science and for several government departments (including EC, DFO and DND). Improved predictions on time-scales from days to decades can have both immediate and long-term societal benefits, despite the difficulty in their production and, in some cases, modest skill. The Network is also making important contributions to the development of research capacity and the training of personnel in coupled atmosphere-ocean forecasting. This is essential if Canada is to remain internationally competitive in this field and also have the capability of making the best possible forecasts in response to national needs.

The expectation is that the coupled climate prediction system developed here will become an operational system, providing quantitative climate forecasts for Canadians. The collaborative research has allowed higher visibility participation of CCCma in international climate prediction activities such as CHFP and to have a greater presence in the upcoming IPCC Fifth Assessment (via the decadal climate prediction results we are producing as a direct offshoot of the research).

Improved seasonal forecasting is anticipated to provide benefits for Canadians in such sectors as Agriculture, Tourism and any other industry that is sensitive to weather.

3 LEVEL OF SUPPORT

3.1 WHAT PROPORTION OF THE TOTAL BUDGET WAS PROVIDED BY CFCAS?

In most cases, CFCAS has provided full support for students, Post Doctoral Fellows and Research Associates. However, in a few cases there have been significant contributions from other sources.

All host universities and government departments provide funds for desktop computers, office space, computing and telephone services and supplies. Salaries of the co-investigators were supplied by their home institutions.

3.2 ANY ADDITIONAL OR 'MATCHING' RESOURCES THAT WERE SECURED OR COMMITTED TO THE PROJECT: SOURCES AND AMOUNTS, AND WHETHER THEY WERE FURNISHED AS AGREED (ON SCHEDULE AND IN THE AMOUNTS AGREED).

The following additional or matching resources were reported:

1. Dr. Foreman reported that T. Wakamatsu received approximately 50% support from the DFO Centre for Ocean Model Development and Analysis (COMDA) program.

2. The COMDA program also provided approximately 40% support for Zeliang Wang.

3. The Atlantic Computational Excellence Network (ACEnet) provided 50% of the support for a postdoctoral fellow to work at MUN on development of ensemble SEEK filter.

4. Three graduate students and one research assistant at MUN were supported by another CFCAS project (GR-631) to work on ocean modeling of the sub-polar and polar oceans and atmospheric dynamic downscaling.

5. Computer facilities purchased as a part of a grant funded by Canadian Foundation of Innovation are used in the present project.

6. Dr. Berg reported that J. Belanger and L. Courtney are funded through NSERC and CFCAS and that Nasim Alavi is partially supported through CFCAS grant "Role of soil moisture initialization on seasonal forecasts in Canada."

7. For the two M.Sc. students now working at the University of Alberta, P. Myers is using his NSERC Discovery Grant to supplement the funding they are receiving from GOAPP

8. P. Myers said that he received $10,000 from the French Embassy in Canada to support links with Anne-Marie Treguier and the Ifremer laboratory in Brest, France

9. PhD student J. Urrego-Blanco was also partially supported by J. Sheng's NSERC Discovery funding and POKM (Platform for Ocean Knowledge Management) funded by CANARIE

3.3 DESCRIBE IN-KIND CONTRIBUTIONS RECEIVED FROM COLLABORATORS OR SPONSORS AND, IF POSSIBLE, THEIR ESTIMATED VALUE (E.G. EXPERTISE OF FEDERAL OR OTHER SCIENTISTS, FACILITIES, TECHNICAL SUPPORT, ETC.).

Secretariat: DFO and Dalhousie University have continued to contribute to the running of the Network Secretariat (e.g., phone charges, furniture).

Computer Resources: A major contribution in-kind has been computer resources provided by government partners. Without these resources it would be impossible to undertake the Network's research. Equally important have been the computer resources made available to us by the ACEnet, HPCVL and WestGrid high performance computing consortiums. The annual fee ($5000.00) for access to HPCVL is provided by another research grant obtained through Royal

Military College. All institutes are providing basic facilities, including personal computers, for both co-investigators and support personnel at no extra cost. The soil moisture networks we are using for model validation are co-managed by Environment Canada's National Hydrology Research Centre in Saskatoon Saskatchewan. Additional data sets of soil moisture (validation data sets) were provided by Alberta Agriculture.

Model Development: Much of the Theme II research is based on the most recent version of CCCma's CGCM3 coupled climate model (T63, no flux adjustment, new ocean physics). The time of numerous CCCma researchers contributing to the development and the computing resources in Victoria and Dorval are paid for by Environment Canada.

Similarly, much of the Theme I research is based on a recent version of the NEMO model made available by the NEMO developers group and a significant part of the NEMO model implementation has been carried out by DFO researchers (under COMDA). GOAPP received limited technical support from Sebastien Theetten and Jean-Marc Molines – France, DRAKKAR consortium for new model developments, as well as diagnostic code.

Support by Government Researchers: Both Environment Canada and Fisheries and Oceans Canada have allowed some of their most experienced and effective researchers to contribute directly to GOAPP research. DFO personnel (D. Wright, Z. Wang and M. Foreman) and Environment Canada personnel (H. Ritchie, P. Pellerin, S. Bélair, G. Boer, Y. Lu, W. Merryfield, J. Fyfe, S. Kharin, G. Flato, P. Gauthier, S. Polavarapu and J. Scinocca) have been extensively involved in the GOAPP Network.

3.4 DESCRIBE TRANSFER OF FUNDS TO CO-INVESTIGATORS: TO WHOM AND WHERE? HOW DID THE CO-INVESTIGATOR(S) REPORT ON THE FUNDS USED; AND WERE INTER-INSTITUTIONAL AGREEMENTS USED.

Funds were transferred from Dalhousie University to the Co-Investigators on a quarterly basis. Dalhousie required each participating university to sign a letter of agreement prior to releasing the funds to the institution. The amount of funds transferred was in accordance with the request of the Co-Investigator for the specific time period.

The list of Co-Investigators and their affiliation can be found in Appendix B.

3.5 INDICATE ANY OUTSIDE FACILITIES USED DURING THE PROJECT (E.G. METEOROLOGICAL INSTRUMENTS, RESEARCH LABORATORIES, SHIP TIME, ETC.) AND DESCRIBE THE ARRANGEMENT.

The GOAPP Network relies on the use of outside computing resources such as ACEnet high performance computing resources, HPCVL, IOS, BIO, MUN, EC, CCCma, UVic and Dalhousie computers. The user fee for HPCVL is paid by RMC. Computer facilities are available through internet connections. To help understand some model results, we have received output from a global ¼ ORCA025 simulation run at Grenoble as well as data from Mercator runs. These simulations were experiment was run on super-computing facilities in France.

Evaluation of soil moisture simulation and realism in CLASS are being assessed using instrumentation and meteorological instruments operated by Alberta Environment and instruments purchased by Dr. Berg through a Canadian Foundation for Innovation and Ontario Research Fund grants and maintained with an NSERC discovery and strategic grants to Dr. Berg.

4 DISSEMINATION

4.1 PROVIDE INFORMATION ON DISSEMINATION OF THE RESEARCH RESULTS (PUBLICATIONS, INCLUDING JOURNAL NAMES AND WHETHER REFEREED), CONFERENCE CONTRIBUTIONS, SEMINARS, WORKSHOPS OR VIDEOS, WEBSITES OR OTHER METHODS OF TRANSFERRING THE RESULTS.

GOAPP Publications

Ajayamohan, R. S., W. J. Merryfield and V. V. Kharin 2010: Increasing trend of synoptic activity and its relationship with extreme rain events over central India. *Journal of Climate,* 23, 1004-1013

Alavi, N., A. Berg, J.S. Warland, G. Parkin, D. Verseghy and P. Bartlett, 2010: Assimilating soil moisture variability into the CLASS to improve latent heat flux estimation. Canadian Water Resources Journal. In press.

Ambadan, T. J., and Y. Tang, 2009: Sigma-point Kalman Filters for the assimilation of strongly nonlinear systems. J. Atmos. Sci., 66(2), 261-285.

Bakalian, F., H. Ritchie, K. Thompson and W. Merryfield, 2010: Exploring Atmosphere-Ocean Coupling Using Principal Component and Redundancy Analysis, Journal of Climate, under revision.

Bakalian, F, H. Ritchie and K. Thompson, 2010: Towards Joint Data Assimilation for a Coupled Atmosphere-Ocean System, Geophysical Research Letters, to be submitted.

Boer, G.J., 2009: Climate trends in seasonal forecasts. *Atmos-Ocean*, **47**, 123-138.

Boer, G.J., 2010: Decadal potential predictability of 21st century climate. *Climate Dynamics*. DOI: 10.1007/s00382-010-0747-9**.**

Cooke, M., E. Demirov and J. Zhu, A model study of the mechanisms of interannual sea-ice variability in the Labrador Sea, J. Geophys. Res, (under review)

Courtney L.J 2009: Evaluation the controls of soil moisture variability within the Canadian Land Surface Scheme (CLASS). Unpublished Master's Thesis. Department of Geography. University of Guelph. 103 pgs.

Deng, Z and Y. Tang, 2010: A scheme for bias-correction in EnKF (In preparation)

Dumedah G. 2010. Multi-objective calibration of hydrological models and data assimilation using genetic algorithms. Unpublished PhD Dissertation. Department of Geography. University of Guelph. 304 pgs.

Higginson, S., K. R. Thompson, and Y. Liu, 2009. Estimating ocean climatologies for short periods: A simple technique for removing the effect of eddies from temperature and salinity profiles. Geophys. Res. Lett., 36, L19602, doi:10.1029/2009GL039647.

Higginson, S., K. R. Thompson, M. Véronneau, D. G. Wright and J. Huang, 2010. The mean surface circulation of the North Atlantic subpolar gyre: A comparison of estimates derived from new gravity and oceanographic measurements. To be submitted to J. Geophys. Res., Summer 2010.

Kharin, V. V., Q. Teng, F.W. Zwiers, G.J. Boer, J. Derome, J.-S. Fontecilla, 2009: Skill assessment of seasonal hindcasts from the Canadian Historical Forecast Project. Atmosphere-Ocean, 47, 204–223.

Kharin, V., 2010: Statistical forecast adjustment with seasonally and spatially smoothed statistics. To be submitted to J.Climate.

Kharin, V, and M. Fyfe, 2010: Skill analysis of monthly and seasonal hindcasts over Canada derived from daily model output. PCIC report. (submitted)

Koster, R.D., S.P.P. Mahanama, T. J. Yamada, G. Balsamo, A.A. Berg, M. Boisserie, P.A. Dirmeyer, F.J. Doblas-Reyes, G. Drewitt, C.T. Gordon, Z. Guo, J.-H. Jeong, D.M. Lawrence, W.-S. Lee, Z. Li, L. Luo, S. Malyshev, W.J. Merryfield, S.I. Seneviratne, T. Stanelle, B.J.J.M. van den Hurk, F. Vitart, and E.F. Wood. 2010. Contribution of land surface initialization to subseasonal forecast skill: First results from a multi-model experiment, *Geophys. Res. Lett*., 37, L02402, doi:10.1029/2009GL041677

Lienert, F, J. Fyfe, W.J. Merryfield, 2010: Do models capture the tropical influences on North Pacific temperature variability. Submitted a paper to Geophysical Research Letters.

Liu Y. and K.R. Thompson, 2009: Predicting Mesoscale Variability of the North Atlantic Using a Physically Motivated Scheme for Assimilating Altimeter and Argo Observations, Monthly Weather Review, 137, Issue 7, pp. 2223-2237.

Lu, Y., S. Nudds, F. Dupont, M. Dunphy, C. Hannah, and S. Prinsenberg, 2010: High resolution modelling of ocean and sea-ice conditions in the Canadian Arctic coastal waters. ISOPE 2010, Beijing, China.

Lu, Y., D.G. Wright, F. Dupont, Z. Wang, M. Dunphy, C. Hannah and B. Topliss, 2010: Large-scale ocean modelling for operational and climate applications. Submitted for publication in the 2010 BIO Annual Review.

Lundrigan, L. and E. Demirov. On the mechanism of variability of the Atlantic Water mass in Arctic during the recent 30 years. (In preparation)

Meehl, G.A. L. Goddard, J. Murphy, R.J. Stouffer, G. Boer, G. Danabasoglu, K. Dixon, M.A. Giorgetta, A. Greene, E. Hawkins, G. Hegerl, D. Karoly, N. Keenlyside, M. Kimoto, B. Kirtman, A. Navarra, R. Pulwarty, D. Smith, D. Stammer, and T. Stockdale, 2009: Decadal prediction: Can it be skillful? *Bull. Amer. Meteorol. Soc*., **90**, 1467-1485.

Merryfield, W. J., W.-S. Lee, G. J. Boer, V. V. Kharin, B. Pal, J. F. Scinocca and G. M. Flato, 2009: The first Coupled Historical Forecasting Project (CHFP1). *Atmosphere-Ocean* (submitted).

Myers, P.G., S.S.P. Rattan, A-M Treguier, S. Theetten, A. Biastoch and C. Boning 2010: Towards an Understanding of Labrador Sea Salinity Drift in Eddy-Permitting Numerical Models, Ocean Modelling (Under review)

Myers, P.G. and N. Kulan, 2010: Variability of Labrador Sea Water Formation and Export from a High-Resolution Reanalysis. To be submitted to the Journal of Physical Oceanography, summer 2010

Stockdale, T., O. Alves, G.J. Boer, et al., 2009: Understanding and predicting seasonal to interannual climate variability. Third World Climate Conference (WCC3) White Paper World Climate Conference-3 (WCC3), White Paper, Published in the open-access online Conference Proceedings.

Tang, Y and J. Ambadan, 2009: Reply to comment on "Sigma-point Kalman Filters for the assimilation of strongly nonlinear systems". J. Atmos. Sci., Vol 66(11), 3501-3503

Tang, Y. and Deng, Z., 2010: Tropical Pacific upper ocean heat content variations and ENSO predictability during the period from 1881-2000. Advance in Geosciences (Ocean Science), Vol 18, 87-108

Tang, Y and J. Ambadan, 2009: Reply to comment on "Sigma-point Kalman Filters for the assimilation of strongly nonlinear systems". J. Atmos. Sci., Vol 66(11), 3501-3503

Thompson, K.R., J. Huang, M. Véronneau, D. G. Wright, and Y. Lu, 2009. Mean surface topography of the northwest Atlantic: Comparison of estimates based on satellite, terrestrial gravity, and oceanographic observations. J. Geophys. Res., 114, C07015, doi:10.1029/2008JC004859

Wakamatsu, T. and M. G. G. Foreman, 2010a, "Overview of four-dimensional variational data assimilation systems", submitted to Proceedings of the Institute of Statistical Mathematics (peer reviewed journal).

Wakamatsu and M. G. G. Foreman, 2010b, "Optimization of control parameters in ocean circulation model using a refined Green's function method", in preparation.

T. Wakamatsu, J. Galbraith and M. G. G. Foreman, 2010, "Evaluating the ORCA12 eddy resolving model over the Northeast Pacific Ocean", in preparation.

Wakamatsu, T. and M. G. G. Foreman, 2010b, "Optimization of control parameters in ocean circulation model using a refined Green's function method", in preparation.

Wakamatsu, T., J. Galbraith and M. G. G. Foreman, 2010: "Evaluating the ORCA12 eddy resolving model over the Northeast Pacific Ocean", in preparation.

Wright and F. Dupont, 2010: Sea Ice Sensitivity to the Parameterization of Open Water Area. Submitted to Operational Oceanography.

Wright, D. G., S. Higginson, Y. Liu, K. Thompson and Z. Wang, 2010: Improved simulations of the North Atlantic using a modified mixing scheme, modified spectral nudging and a new climatology. (In preparation)

Xiaoqing, Y., and Y. Tang, 2010: An analysis of multi-mode ensemble for seasonal climate predictions (In preparation)

Yu, B., G.J. Boer, F. Zwiers, W. Merryfield, 2009: Covariability of SST and surface heat fluxes in reanalyses and CMIP3 climate models. *Climate Dynamics*. DOI 10.1007/s00382-009-0669-6

Zhang, X., Y. Lu, K.R. Thompson, J. Jiang and H. Ritchie: The tropical Pacific Ocean and the Madden-Julian Oscillation: Role of wind and buoyancy forcing. Journal of Geophysical Research, in press.

Zhang, Y., J. Zhu and E. Demirov, Model simulation of sub-polar ocean driven by high resolution atmospheric forcing (In preparation)

Zhu, J., E. Demirov, F. Dupont and D. Wright, Eddy-permitting simulations of the Sub-polar North Atlantic: Impact of the model bias on water mass properties and circulation, Ocean Dynamics (under review)

Zhu, J. and E. Demirov: On the mechanism of interannual variability of the Irminger Water in the Labrador Sea, J. Geophys. Res, (under review)

Zhu, J., E. Demirov and I. Yahsayaev, Model Study of the Spreading Pathways and Transit Times of the Labrador Sea Water Produced in Different Convection Regimes. J. Geophys. Res (under revision)

Oral and Poster Presentations/Conference and Workshop Proceedings

Alavi, N, A. Berg, G. Drewitt, and B. Merryfield, 2010: Relationship of seasonal climate forecast error to uncertainty in soil moisture initializations. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Ajayamohan, R. S. and W. J. Merryfield, 2010: MJO dependence of subseasonal forecast skill. Oral presentation at the 4th GOAPP Workshop, Ottawa, 31 May.

Bakalian, F., H. Ritchie and K. Thompson, 2010: Towards joint data assimilation for a coupled atmosphere-ocean system. 14th conference on integrated observing and assimilation systems for atmosphere, oceans, and land surface, 90th American Meteorological Society Annual Meeting, Atlanta GA.

Belanger, J., A. A. Berg; G. Drewitt; L. J. Courtney. 2009: Characterization of Red Noise Processes in Soil Moisture from in situ Data, Satellite Data, and their Representation in a Land Surface Model. Prairie Hydrology Workshop. Saskatoon SK.

Berg A., G. Drewitt, N. Alavi, B. Merryfield. 2010. The role of soil moisture initialization in drought prediction. Invited presentation to Drought Research Initiative Workshop #5. Winnipeg Manitoba.

Berg A, J. Belanger, C. Champagne, and G. Dumedah 2009: Soil moisture monitoring networks for satellite and model validation: Design and applications. First Workshop on Canadian SMAP Applications and Cal-Val. Montreal, Quebec.

Boer, G.J., 2010: What are the prospects for decadal prediction? 12th Meeting of the Working Group on Seasonal to Interannual Prediction, 12-14 January 2010, Miami

Boer, G.J., 2010: Characterizing the long timescale variability of the climate system. Invited presentation. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Boer, G.J., 2010: Decadal potential predictability of forced and internally generated variability in the 21st century. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Boer, G.J., 2010: Multi-model estimates of forced and internally generated potential predictability for the 21st century. Invited presentation at the Workshop, "Predicting the climate of the coming decades". Rosenstiel School of Marine and Atmospheric Sciences, Miami, January 11-15.

Boer, G.J., 2009: Overview of decadal potential predictability. Invited presentation at the Workshop on Earth-system Initialization for Decadal Prediction. KNMI, deBilt, Netherlands, 4-6 Nov.

Boer, G.J. 2009: The prospects for decadal prediction. CMOS Congress, Halifax NS, 31 May to 4 June, 2009.

Cheng, Y, Y. Tang and P. Jackson, 2009: Further study of ENSO predictability in Lamont Model, Asia Oceania Geosciences Society's 6th Annual General meeting, Singapore, August 14, 2009.

Cooke, M. and E. Demirov, A model study of the mechanisms of interannual sea-ice variability in the Labrador Sea, AGU Ocean Science meeting, Portland, 2010.

Davidson, F., 2010: Present and longer term development of ocean forecasting and it's applications in DFO. Where GOAPP research fit's in. 4th GOAPP Workshop, Ottawa, 31 May.

Demirov, E., J. Zhu, I. Yashayaev, S. Lundrigan, Y. Zhang, M. Cooke and C. Pike-Thackray, 2010, Model study of atmospheric and ocean interannual variability in the sub-polar North Atlantic Ocean, AGU Ocean Science meeting, Portland, 2010.

Demirov, E., J.-M. Brankart and C. Pike-Thackray, 2009: Assessment of the model error in Labrador Sea eddy permitting ocean simulations. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Demirov, E., J.-M. Brankart, C. Pike-Thackray and J. Zhu, 2009: Data assimilation into an eddy-permitting model of the North Atlantic. MOCA – 2009 Conference, Montreal.

Doblas-Reyes, F., 2010: Three techniques to represent model uncertainties and generate ensembles for dynamical seasonal and interannual forecasting. 4th GOAPP Workshop, 31 May.

Doblas-Reyes, F., 2010: Impact of model uncertainty on seasonal forecast quality: the ENSEMBLES project. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Donohue, S., M. Stacey and J. Shore, 2009: Simulation of the Mixed-Layer Depth in the North East Pacific. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Donohue, S., M. Stacey and J. Shore, 2009: Simulation of the 2001-2002 Intrusion of Cold Water into the Gulf of Alaska. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Drewitt, G., 2010: Exploring the sensitivity of seasonal climate forecasts to soil moisture initialization. 4th GOAPP Workshop, Ottawa, 31 May.

Drewitt, G. and A. Berg, 2010: A high spatial/temporal resolution soil moisture data set for the Canadian Prairies. Drought Research Initiative Workshop #5 Winnipeg Manitoba.

Drewitt, G., A. Berg, B. Merryfield, and W-S. Lee 2010. The role of soil moisture initialization in forecasting drought occurrence. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Dupont, F., Z., Wang, Y. Lu and D. Wright, 2009: Arctic modelling at BIO using OPA/NEMO, ORCA1 and ORCA025. Presented during the 11th AOMIP workshop at WHOI, January 2009

Dupont, F., Z. Wang and D. Wright, 2009: Local refinement in the NEMO2.3 ocean model. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Dupont, F., Y. Lu, D. Wright and Z. Wang, 2009: Heat and wind effects on Arctic sea-ice. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Dumedah, G., A. Berg and M. Wineberg, 2009: A joint assimilation framework for improving soil moisture estimates. Prairie Hydrology Workshop. Saskatoon SK.

Dumedah, G. A. Berg and M. Wineberg, 2010: A two step assimilation procedure to improve soil moisture estimates. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Flato, G., V. Kharin 2010: Sea-ice in a coupled climate prediction system. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Flato, G.M. 2009/10: several presentations during the reporting period to senior management, staff at the Canadian Ice Service, visitors from the Finnish Meteorological Institute, and the Joint Scientific Committee of the World Climate Research Programme.

Gauthier, P., 2010: Difficulties associated with data assimilation for a coupled ocean-atmosphere model. 4th GOAPP Workshop, Ottawa, 31 May.

Katavouta, A., P.G. Myers and E. Collier, 2009: Sea Ice Modelling and Data Assimilation along the east coast of Canada using NEMO. Canadian Sea Ice Workshop, Ottawa.

Katavouta, A. and P.G. Myers, 2010: Sea Ice Data Assimilation for the Canadian East Coast. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Kharin, V. 2009: Statistical forecast adjustment with seasonally and spatially smoothed statistics. Presentation at the Canadian Seasonal Forum, CMC, Dorval.

Kharin, V., 2010: Calibrated probabilistic forecasts and their presentation on a website. 4th GOAPP Workshop, Ottawa, 31 May.

Kharin, V, 2010: Statistical forecast adjustment with seasonally and spatially filtered statistics. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Kharin, V., J. Scinocca, 2010: Real-time bias correction of an atmospheric general circulation model. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Kulan, N. and P.G. Myers, 2010: Labrador Sea Water Formation and Export from a High Resolution Reanalysis, 1949-1999, Ocean Sciences Meeting, Portland, February 2010

Lago, V. and P.G. Myers, 2010: The role of resolution on the impacts of Greenland melt on the sub-polar North Atlantic. Atlas Symposium, Department of Earth and Atmospheric Sciences, University of Alberta, April, 2010

Lago, V. and P.G. Myers, 2010: The role of resolution on the impacts of Greenland melt on the sub-polar North Atlantic. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Lago, V. and P.G. Myers, 2010: The role of resolution on the impacts of Greenland melt on the sub-polar North Atlantic. Northern Research Symposium, University of Alberta, April, 2010

Lago, V. and P.G. Myers, A. Biastoch, E. Behrens and C. Boening, 2010: The role of resolution on the impacts of Greenland melt on the sub-polar North Atlantic, Annual DRAKKAR Workshop, Grenoble, Feb 2010

Lee, W.-S., W. J. Merryfield, 2010: The second Coupled Historical Forecasting Project (CHFP2). CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Lu, Y., 2010: A high-resolution ocean-ice model of the Arctic: sensitivity to surface forcing. 4th GOAPP Workshop, Ottawa, 31 May.

Lu, Y., Z. Wang, D. Wright and F. Dupont. Inter-annual and decadal sea level variations: a CONCEPTS study based on a coarse-resolution global ocean model. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Lu, Y., D. Wright, Z. Wang, and F Dupont. Heat and wind forced variations in a global ocean model (1958-2006). MOCA'09, July 2009, Montreal, QC.

Lu, Y., M. Dunphy, F. Dupont, P. Myers, G. Holloway, C. Hannah, and S. Prinsenberg. A high-resolution ice-ocean model of the Arctic Ocean based on NEMO. ArcticNet Annual Science Meeting, December 8-11, 2009, Victoria, BC.

Lu, Y. and D.G. Wright, 2010: Modelling Study of North-West Atlantic Ocean Climate Dynamics. National Weather Association, Ocean Climate Change Meeting.

Lundrigan, S., E. Demirov, 2010: Hindcast simulations of the Arctic Ocean, CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Lundrigan, S. and E. Demirov, 2010: Model Study of Variability of the North Atlantic Water in the Arctic Ocean, AGU Ocean Science meeting, Portland, 2010.

Lundrigan, S. and E. Demirov, 2009: Regional model projections of IPCC climate scenarios in the Arctic Ocean MOCA – 2009 Conference, Montreal.

Lundrigan, S., E. Demirov. Model study of interannual variability of the North Atlantic Water mass in the Arctic Ocean. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Merryfield, W. J., 2010a: Climate Forecasting at CCCma. UNBC NRES Seminar, 29 April 2010.

Merryfield, W. J., 2010b: Climate Forecasting at CCCma. CCCma Seminar, 17 May 2010.

Merryfield, W. J., 2010: Theme II overview. Oral presentation at the 4th GOAPP Workshop, Ottawa, 31 May.

Merryfield, W. J. and Ajayamohan R. S. 2009: Likelihood and predictability of cooling episodes in a warming climate. IAMAS, IAPSO and IACS Joint Assembly, MOCA-09, July 20-24, Montréal.

Merryfield, W. J., W.-S. Lee, G. J. Boer, V. V. Kharin, J. F. Scinocca ,G. M. Flato 2009: CCCma decadal prediction for CMIP5, poster presentation at CLIVAR Workshop on Earth-System Initialization for Decadal Prediction, 12-14 November 2009.

Merryfield, W. J., W.-S. Lee, G. J. Boer, G. M. Flato, V. V. Kharin, J. F. Scinocca, B. Pal, Y. Tang, A. Berg, G. Drewitt, S. Polavarapu 2010: The CCCma sub-seasonal to decadal forecasting system, Oral presentation at the CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Myers, P.G., 2009: Update on Ocean Activities at the University of Alberta, Seminar, Bedford Institute of Oceanography, Dartmouth.

Myers, P.G., 2009: Variability and Change from the Canadian Arctic Archipelago to the Labrador Sea. Seminar, Centre for Earth Observation Science, University of Manitoba, Winnipeg

Myers, P.G., 2009: Variability and Change from the Canadian Arctic Archipelago to the Labrador Sea. Seminar, Institut national de la recherche scientifique, Université du Quebec, Quebec City.

Myers, P.G., 2010: Planned Development in 2010 at the University of Alberta Using the NEMO model. Annual Drakkar Workshop, Grenoble.

Myers, P.G., 2010: Modelling and analysis of the Labrador Sea as part of GOAPP. 4th GOAPP Workshop, Ottawa, 31 May.

Myers, P.G., C. Donnelly and M. Ribergaard, 2009: Freshwater Issues in the sub-polar North Atlantic Ocean, 17th Northern Research Basins Workshop, at sea between Iqaluit and Kuujjuaq, August, 2009

Myers, P.G. and N. Kulan, 2010: Labrador Sea Water Formation, Variability and Export. Department of Oceanography, Dalhousie University, October 2009

Myers, P.G. and N. Kulan, 2010: Labrador Sea Water Formation, Variability and Export. Department of Physics and Physical Oceanography, Memorial University of Newfoundland, October 2009

Myers, P.G. and N. Kulan, 2010: Labrador Sea Water Formation, Variability and Export. Mechanical Engineering, University of Alberta, March 2010

Myers, P.G. and N. Kulan, 2010: Links Between the Deep Western Boundary Current, Labrador Sea Water Formation and Export, and the Meridional Overturning Circulation. EGU General Assembly 2010, Vienna, May 2010

Myers, P.G. and N. Kulan, 2010: Links Between the Deep Western Boundary Current, Labrador Sea Water Formation and Export, and the Meridional Overturning Circulation, CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Ravindran R. S. 2009: Likelihood and predictability of cooling episodes in a warming climate. Institute of Tropical Meteorology seminar, July 8.

Ritchie, H., F. Bakalian, K. Thompson and J.M. Bélanger, 2009: Towards Joint Data Assimilation of a coupled atmosphere-ocean system. 5th WMO International Symposium on Data Assimilation, Melbourne, Australia.

Ritchie, H., 2010: Status of GEM/NEMO. 4th GOAPP Workshop, Ottawa, 31 May.

Ritchie, H., F. Davidson, E. Dombrowsky, G.M. Flato, Y. Lu, P. Pellerin, M. Taillefer, K. Thompson, B. Topliss, D. Williams and D. Wright, 2010: "Progress in the Canadian Operational Network of Coupled Environmental PredicTion Systems (CONCEPTS)", presentation 5B.2, 14th Conference on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface, 90th American Meteorological Society Annual Meeting, Atlanta GA, 17-21 January 2010, program p. 94.

Shao, Y. and M. Stacey. Simulating the North Pacific Ocean using NEMO. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Sheng, J., 2010: Dynamic Downscaling of Ocean Circulation over the Eastern Canadian Shelf using NEMO. 4th GOAPP Workshop, Ottawa, 31 May.

Skachko, S., P. Gauthier, M. Tanguay, J-M. Bélanger, and L. Spacek, 2010: Improved surface fluxes for a coupled ocean-atmosphere model. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Tang, Y., Potential predictability in ensemble climate prediction, Asia Oceania Geosciences Society's 6th Annual General meeting, Singapore, August 12, 2009.

Tang, Y. Argo data assimilation for the Pacific Ocean – Progress of a Sina-Canada joint Project, The second Institute of Oceanography of China, Hanzhou, China, August 3, 2009.

Tang, Y, Z. Deng and G. Wang, Argo data assimilation, Asia Oceania Geosciences Society's 6th Annual General meeting, Singapore, August 13, 2009.

Terwisscha van Scheltinga, A.D., X. Hu, J. Wang and P.G. Myers, 2009: Modelling the Arctic and the Canadian Arctic Archipelago using NEMO and FESOM. Canadian Sea Ice Workshop, Ottawa.

Thompson, K. and H. Ritchie, 2010: Review and discussion of Theme I. 4th GOAPP Workshop, Ottawa, 31 May.

Thompson, K., H. Ritchie, W. Merryfield, and D.G. Wright, 2009: Progress and Plans, Issues and Opportunities. Presentations to senior managers at DFO and EC as well as the CMOS Ottawa Centre.

Thompson, K, 2010: Overview of GOAPP's Ocean Modelling and Data Assimilation.. Invited presentation made on behalf of GOAPP researchers to a special session at the 2010 CMOS Congress entitled "CFCAS Achievements - The First Decade".

Thompson, K, 2010. Relating Ocean Physics and Data Assimilation. Ocean Sciences Meeting, Portland, Oregon, Invited.

Thompson, K. 2009: Forecasting Mesoscale Variability of the North Atlantic Using a Physically-Based Scheme for Assimilating Altimeter and Argo Observations, 5th WMO International Symposium on Data Assimilation, Melbourne, Australia.

Urrego-Blanco, J., and J. Sheng, 2009: Developing a nested-grid circulation model for the eastern Canadian Shelf. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Urrego-Blanco, J., and J. Sheng, 2010: Assessing the performance of a Northwest Atlantic Ocean circulation model using the spectral nudging and the semi-prognostic methods, Conference of Dalhousie Oceanography Graduate Students.

Wakamatsu, T., Michael G. and G. Foreman, P. F. Cummins, J. Y. Cherniawsky, 2009: On the influence of random wind stress errors on the four-dimensional, mid-latitude ocean inverse problem, MOCA-09, Montreal, QC, July 2009.

Wakamatsu, T., 2009: Statistics of eddy flux from an eastern boundary current, MOCA-09, Montreal, QC, July 2009.

Wakamatsu, T., 2010: Multiple approaches in correcting errors of OGCM. 4th GOAPP Workshop, Ottawa, 31 May.

Wakamatsu, T., Michael G. and G. Foreman, 2009: Observability of a large control vector in a 4D-Var ocean data assimilation, 5th WMO International Symposium on data assimilation, Melbourne, Australia, October 2009.

Wakamatsu, T., Michael G. and G. Foreman, 2009: On the influence of random wind stress errors on the four-dimensional, mid-latitude ocean inverse problem, 5th WMO International Symposium on data assimilation, Melbourne, Australia, October 2009.

Wakamatsu, T., Michael G. and G. Foreman, 2009: Refinement of Green's function method for parameter tuning, CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Wakamatsu, T., Michael G. G. Foreman,2009: Inter-connections among three vector spaces in 4D-Var system. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Wang, Z., D. Wright, Y. Lu and F. Dupont. A model study of North Atlantic SSH and SST variability with indications of variations in the strength of the subpolar and subtropical gyres. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Wang, Z., G. Holloway, Y. Lu and D.G. Wright. Representing Eddy Stress in the Arctic. AOMIP Meeting, WHOI. October, 2009.

Wang, Z., Y. Lu, D.G. Wright, F. Dupont, C. Hannah. The Link Between Variations in Sea Level and Circulation in the North Atlantic. BIO Coffee Talk. October, 2009.

Woslyng, F, 2010: Data Management Status Report and discussion. 4th Annual GOAPP Workshop, Ottawa, 31 May.

Wright, D.G. plus GOAPP and CONCEPTS colleagues: A talk entitled "Global and North Atlantic Ocean Modelling Studies", based on work under the GOAPP, CONCEPTS and COMDA projects was given at four research institutes in Quindao, Nanjing and Beijing during a research exchange and coordination tour of China in April, 2009. The importance of coordinated contributions from GOAPP and government researchers was an important theme of the presentation.

Yu, B., W. Merryfield, G.J. Boer, F. Zwiers, 2009: Covariability of SST and Surface Heat Fluxes in Reanalyses and CMIP3 Climate Models. IAMAS, IAPSO and IACS Joint Assembly, MOCA-09, July 20-24, Montréal.

Zhang, X., Y. Lu, K. Thompson, J. Jiang, and H. Ritchie. Response of the tropical Pacific Ocean to MJO forcing. MOCA09, July 2009, Montreal, QC.

Zhang, Y., E. Demirov, 2010: Impact of atmospheric forcing on model simulations of the Northwest Atlantic Ocean, CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Zhang, Y. and E. Demirov, 2009. Regional climate atmospheric model for the Labrador Sea, MOCA – 2009 Conference, Montreal.

Zhu, J. and E. Demirov. Mesoscale variability in the Labrador Sea – a model study. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Zhu, J. and E. Demirov, 2010: Assessment of the hindcast of the Labrador Sea. CMOS-CGU Congress, Ottawa, ON, 31 May to 4 June, 2010.

Zhu, J. and E. Demirov, 2009: Model study of interannual and decadal variability of the Labrador Sea from 1950 to 2005. MOCA – 2009 Conference, Montreal.

Zhu, J. and E. Demirov, 2009: Model study of the Labrador Sea Water formation and spreading CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

4.2 DESCRIBE DATA MANAGEMENT/SHARING ACTIVITIES INCLUDING ORGANIZATION OF THE METADATA. ALSO IS THE DATA BEING ARCHIVED, AND HOW WILL IT BE MADE AVAILABLE TO OTHER RESEARCHERS?

GOAPP's data management technician, F. Woslyng, who was hired as part of the GOAPP Supplement project, has reported on data management progress in the Supplement project section of this report. For completeness, much of his report is reproduced below.

Theme I Legacy Data and DFO: Talks between the GOAPP DMC and DFO / C-NOOFS regarding data serving and visualization established a number of common objectives and similar technical approaches. A subsequent teleconference in February between the DMC, DFO ISDM and DFO C-NOOFS representatives produced positive feedback regarding having DFO serve Theme I legacy data. A face-to-face meeting in St. Johns produced a list of proposed hardware and software for the Theme I server, which was forwarded to DFO ISDM for consideration.

Server Hardware Delivery and Configuration: The purchase and delivery of the server for Theme I data was completed in May, 2010. A server similar to those at DFO / C-NOOFS was selected in order to facilitate the transfer of the hardware to DFO after the termination of the GOAPP Network. The server has 23 TB of usable disk space, with data redundancy (RAID 6), and 8 hyper-threaded Intel Xeon processor cores. Configuration of the server is ongoing.

Attend and present at Data Managers Workshop. CFCAS organized a Data Mangers workshop, held in November, 2009, in Winnipeg, to identify and discuss issues and courses of action, related to data management. In attendance were representations of CFCAS, GOAPP, CANDAC, STAR and DRI, and via teleconference, IP3 / WCN2, C-SPARC, CPP and CAFC. Critical issues common to several research networks include hosting of legacy data, metadata standards and data validation. The GOAPP presentations focused on the difficulty in finding a partner to host its legacy data, and data serving (OPeNDAP) and visualization solutions.

G. Boer reported that data production and sharing for CHFP2 is being coordinated with CCCma's contribution to the CMIP5 model intercomparison for the next IPCC assessment. Data will be formatted as CF-compliant netCDF and served via CCCma's OPeNDAP web server.

G. Flato stated that data is stored at CCCma and at the EC supercomputing facility in Dorval. It is available to collaborators and will be made more broadly available when appropriate.

A. Berg reported that they are currently archiving the global land surface hydrology data set at the University of Guelph. The entire data set has also been delivered to the CCCma.

According to P. Myers, all model simulations from the University of Alberta are being archived on WestGrid's gridstore data server at Simon Fraser University. Model results are being shared with DRAKKAR consortium members in Europe. Model simulations carried out at Memorial are being archived on ACEnet.

The GOAPP Data Management Committee (DMC) consists of: J. Chaffey (DFO), W. Merryfield (GOAPP Co-Investigator), M. Ouellet (DFO), H. Ritchie (GOAPP Principal Investigator), K. Thompson (GOAPP Principal Investigator), Lt. (N) D. Williams (DND) and S. Woodbury (GOAPP Network Manager)

4.3 COMMENT ON ANY OUTREACH OR PUBLIC INFORMATION ACTIVITIES, INCLUDING PRESS INTERVIEWS OR OTHER MEDIA INTEREST OR REPORTS. HAS THE PROJECT HELPED TO POPULARIZE SCIENCE OR INCREASE PUBLIC AWARENESS?

Drs. Thompson, Ritchie and Merryfield gave overview presentations titled "Progress and Plans, Issues and Opportunities" in Ottawa to senior personnel at DFO and EC. While there, they gave the same presentation at the Ottawa CMOS Centre meeting. GOAPP science was highlighted at several CMOS sessions at the annual congress in June.

GOAPP hired a science writer to write a couple of articles for use by CFCAS. This activity had not been completed as of 30 June.

4.4 HOW HAVE YOU ACKNOWLEDGED SUPPORT FROM CFCAS?

Most GOAPP presentations and publications and journal articles formally acknowledge CFCAS as the primary funding agency. The CFCAS logo is often displayed on the first pages of power point presentations, on posters and in other appropriate locations. The CFCAS logo is also prominently displayed on the GOAPP website at www.goapp.ca and interested people can follow a link to the CFCAS website.

4.5 ATTACH COPIES OF ANY PAPERS PUBLISHED OR ACCEPTED FOR PUBLICATION.

No papers are attached.

5 TRAINING

5.1 QUANTIFY STUDENT AND POSTDOCTORAL INVOLVEMENT IN THE PROJECT, INDICATING THE NUMBER OF: UNDERGRADUATE, MASTERS, DOCTORAL OR PDFS. ALSO SUMMARIZE THEIR ROLES IN THE PROJECT.

Research Assistants: 2

M. Cooke (Demirov) – Project 1.1.4 – Analysis of the sea-ice variability in the hindcast ocean simulations of the Labrador Sea.

J. Lei (Wright) – Project I.1.4 - Assistance assembling data sets for NA model validation

Research Technician: 1

F. Woslyng (Thompson) Supplement. He works on the development of the operational system for ocean forecasting.

Undergraduate Student: 2

E. Collier (Myers) – Project I.1.5 – Worked during the summer of 2009 (May-August) as part of an NSERC USRA on GOAPP related issues of sea ice modelling in the sub-polar North Atlantic

C. Pike-Thackray (Demirov) – Project I.1.3. Worked as summer student in 2009 on model data inter-comparison for the Labrador Sea.

Master's Students: 7

L. Courtney (Berg) – Project II.3.4. 50% of her time (funded through other grants) Evaluation of the realism of soil hydrologic processes in the Canadian Land Surface Scheme (CLASS).

M. Hakobyan (Demirov) – Project I.1.4. Observational data archiving, data quality control and data base.

A. Katavouta (Myers) – Project I.1.5 – She is analyzing the impact of sea ice data assimilation on NATL4 simulations.

V. Lago (Myers) – Project I.1.5 – Analyzing impact of resolution on sea-ice in NATL4, as well as the impact of enhanced Greenland melt

S. Lundrigan (Demirov) – Project I 1.4 – Model experiments with Arctic Ocean model

R. Roche (Demirov) – Project I.1.3. Hindcast study of the fresh water balance in the eastern Labrador Sea.

Y. Zang (Demirov) – Project I.1.3 – Development of regional atmospheric model of the Labrador Sea

PhD Students: 10

J. Belanger (Berg) Project II.3.4 - 20% of his time (funded through other grants). Evaluation soil moisture persistence and memory controls

Yanjie Cheng (Tang) Project II.3.1 His duties included coding, analyses of results and preparation of scientific manuscripts.

S. Donohue (Stacey) Project I.1.4 – Research involves modeling the circulation of the North Pacific Ocean.

G. Dumedah (Berg) Project II.3.4 – 10% of his time (funded through other grants). Evaluation of methods for assimilation of soil moisture information into land surface models.

Dan Godlovitch (Flato) Project II.3.1 is exploring spatial statistics of sea-ice thickness which will inform the development of more sophisticated sea-ice data assimilation schemes.

S. Higginson (Thompson) – Projects I.1.2 and I.1.3. Development of improved climatologies for the North Atlantic used in regional model of the North Atlantic. Validation of results against observations.

F. Lienert (Fyfe) – Project II.1.2. He has assembled observational data and output from most of the World's global climate models and has completed a detailed intercomparison.

E. Oliver (Thompson) – Projects I.1.2 and I.1.3. Coupled ocean – atmospheric model data analysis and study of the Madden Julian Oscillation.

J. Urrego Blanco (Sheng) – Project I.1.6. Development and calibration of a coarse-resolution (1/4 degree) northwest Atlantic Ocean model

X. Yan (Tang) – Project II.3.1 His duties included coding, analyses of results and preparation of scientific manuscripts

Post Doctoral Fellows: 9

N. Alavi (Berg) – Project II.3.4. Evaluation of seasonal climate forecast errors due to land surface initialization error and methods of assimilation of soil moisture into land surface models. 25% of time (funded through other grants)

F. Bakalian (Ritchie) – Project I.2.2. He is working in close cooperation with the co-investigators and collaborators.

Z. Deng (Tang) Project II.3.1 is working on data assimilation.

Y. Liu (Thompson) – Supplement. Development and operational implementation of a data assimilation method for altimeter and ARGO observations.

M. Mambia (Tang) Project II.3.1 is working on data assimilation.

A. Polomska (Demirov) – Project I 1.4 – Development of ensemble SEEK filter for data assimilation.

A. Ravindran (Merryfield) – Project II.2.2. He is integrally involved in the II.2.2 investigations as well as the decadal predictability and partial coupling investigations reported under II.2.1.

Y. Shu (Tang) Project II.3.1 is working on data assimilation.

J. Zhu (Demirov) – Project I.1.4. Development of regional model for the sub-polar North Atlantic, ocean hindcast.

Research Associates: 6

G. Drewitt (Berg) Project II.3.4. He is the main programmer for this study.

F. Dupont (Wright) – Project I.1.4.

- Major contributions to model development, particularly the development of the ability to use the AGRIF imbedding technology to provide improved resolution in critical regions.
- Has developed the ability to obtain realistic Gulf Stream simulations *without* data assimilation. This is a first for our project.
- Significant contributions to Arctic model developments.
- Significant contributions to the development of functional open boundary conditions that are required for regional modelling studies, including both low frequency and tidal forcing.
- Performs related model simulations and analysis of model results.
- Contributes to manuscript preparation and presentation of results.

W-S Lee (Boer) – Project II.3.2. She is running coupled forecasts, managing and interpreting output and contributing to science.

B. Pal (Merryfield) – Project II.3.2. He is working on analysis of model output and preparation for dissemination via the web.

Y. Shao (Stacey) – Project I.1.4. Responsible for running NEMO.

S. Skachko (Gauthier) – Project I.2.1. Dr. Skachko is working on the development of the coupled atmosphere-ocean data assimilation, in close collaboration with colleagues from Environment Canada and from other GOAPP projects under Theme I.

T. Wakamatsu (Foreman) – Projects I.1.2, I.1.3, I.1.4.

- Design of the data assimilation system.
- Data and model acquisitions.
- Validation of the model outputs with data.
- Documentation and presentation of the project results

Physical Scientist at BIO: 1

Z. Wang (Wright) – Project I.1.4.

- Substantial contributions through the preparation of model inputs (initial conditions, forcing fields, climatological T and S fields)
- Performs related model simulations and analysis of model results. Contributes to manuscript preparation and presentation of results.
- Has been a critically important access point for people outside of the group at BIO requesting assistance from that group.

See Appendix B for a diagram that shows the distribution of GOAPP participants.

6 OTHER

6.1 HOW COULD CFCAS ENHANCE ITS SUPPORT FOR UNIVERSITY-BASED RESEARCH IN CLIMATE AND ATMOSPHERIC SCIENCES, OR OTHERWISE ASSIST THE COMMUNITY? PROVIDE ANY REMARKS OR ADDITIONAL SUGGESTIONS FOR CFCAS.

Network participants are pleased with CFCAS support of university-based research in climate and atmospheric sciences. There is great concern among scientists about the lack of government commitment to continuing this funding source given its importance to the development of Highly Qualified Personnel in Canada.

Appendix A
Acronyms and Abbreviations

Acronym/Abbreviation	Explanation
ACEnet	Atlantic Computational Excellence Network. ACEnet is Atlantic Canada's entry into this national fabric of high-performance computing facilities.
AGCM	Atmospheric General Circulation Model
AGRIF	Adaptive Grid Refinement In Fortran
AVHRR	Advanced Very High Resolution Radiometer
AVISO	Archiving, Validation and Interpretation of Satellite Oceanographic data
BADC	British Atmospheric Data Centre
BES	Back End Server
BIO	Bedford Institute of Oceanography
CCAP	Canadian Crop Assessment Program
CCCma	Canadian Centre for Climate Modelling and Analysis
CGCM3 and CGCM4	Coupled Global Climate Model
CHFP	Coupled Historical Forecast Project (1, 2 and so forth)
CLASS	Canadian Land Surface Scheme
CLIVAR	An international research programme investigating climate variability and predictability
CMIP5	Fifth Coupled Model Intercomparison Project
cron	UNIX Scheduler
COMDA	Center of Ocean Model Development and Analysis
CONCEPTS	Canadian Operational Network of Coupled Environmental PredicTion Systems
DBF	dBase or generic database file extension
DFO	Fisheries and Oceans Canada
DRAKKAR	Multi-scale Ocean Modelling Project http://www.ifremer.fr/lpo/drakkar/index.htm
EC	Environment Canada
DRI	Drought Research Initiative
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño-Southern Oscillation
EOF	Empirical Orthogonal Functions
GEM	Global Environmental Multiscale Model
GEOIDE	GEOIDE's mission is to consolidate and strengthen the domestic geomatics industry, while making optimum use of Canada's Research and Development resources and to create a sustainable networking structure integrating all sectors of the Canadian geomatics community.
GHG	Greenhouse Gas

GOAPP	Global Ocean-Atmosphere Prediction and Predictability
HFP2	Historical Forecast Project 2
HPCVL	High Performance Computing Virtual Laboratory
Ifremer	Institut français de recherche pour l'exploitation de la mer
IOS	Institute of Ocean Sciences
IPCC	Intergovernmental Panel on Climate Change
LAS	Live Access Server
LIM3	Louvain-la-Neuve Ice Model, version 3
MLD	Mixed Layer Depth
MSST	Mean Sea Surface Topography
MUN	Memorial University
NAO	North Atlantic Oscillation
NCEP	National Centers for Environmental Prediction
NEMO	Nucleus for European Modelling of the Ocean http://www.lodyc.jussieu.fr/NEMO/
netCDF	Network Common Data Form (from unidata/UCAR)
NSERC	Natural Science and Engineering Research Council of Canada
OPeNDAP	Open-source Project for a Network Data Access Protocol
OGCM	Oceanic General Circulation Model
OLFS	OPeNDAP Lightweight Front End Servlet
OPA	Another name for the NEMO model
QBO	Quasi-Biennial Oscillation
PCA	Principal Component Analysis
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PDF	Post Doctoral Fellow
POP	Parallel Ocean Program
RA	Redundancy Analysis
RMC	Royal Military College
SEEK filter	Singular Evolutive Extended Kalman filter
SLP	Sea Level Pressure
SSH	Sea Surface Height
SST	Sea Surface Temperature
UVic	University of Victoria
WCC3	Third World Climate Conference
WestGrid	Collaborative project providing high-performance computing and multimedia/visualization resources to researchers and educators across Western Canada.
wget	Non-interactive network downloader
WGCM	Working Group on Coupled Modelling
WCRP	World Climate Research Programme
WGSIP	Working Group on Seasonal to Interannual Prediction
WMO	World Meteorological Organization

Appendix B – Lists and Diagrams

Co-Investigators

Name	Affiliation
A. Berg	University of Guelph
G. Boer	University of Victoria
E. Demirov	Memorial University
J. Derome	McGill University
G. Flato	University of Victoria
J. Fyfe	University of Victoria
P. Gauthier	Université du Québec à Montréal
Y. Lu	Dalhousie University
W. Merryfield	University of Victoria
P. Meyers	University of Alberta
M. Foreman	University of Victoria
H. Ritchie	Dalhousie University
J. Sheng	Dalhousie University
M. Stacey	Royal Military College
Y. Tang	University of Northern British Columbia
K. Thompson	Dalhousie University
W. Hsieh	University of British Columbia
D. Wright	Dalhousie University

Scientific Steering Committee

Co-Investigators	Affiliation
G. Boer	University of Victoria
J. Derome	McGill University
M. Foreman	University of Victoria
W. Merryfield	University of Victoria
H. Ritchie	Dalhousie University
K. Thompson	Dalhousie University
S. Woodbury (ex-officio)	Dalhousie University

Appendix B

GOAPP Collaborators

Name	Affiliation
B. Archambault	Environment Canada
V. Arora	Environment Canada
S. Bélair	Environment Canada
J.M. Bélanger	Environment Canada
M. Buehner	Environment Canada
G. Brunet	Environment Canada
T. Carrieres	Environment Canada
S. Kharin	Environment Canada
H. Lin	Environment Canada
S. Laroche	Environment Canada
A. Monahan	University of Victoria
T. Murdock	Pacific Climate Impact Consortium, University of Victoria
P. Pellerin	Environment Canada
J. Scinocca	Environment Canada
A. Shabbar	Environment Canada
M. Tanguay	Environment Canada
A-M Treguier	Laboratoire de Physique des Océans, Brest, France
M-F Turcotte	Environment Canada
I. Yashayaev	Fisheries and Oceans Canada
B. Yu	Environment Canada

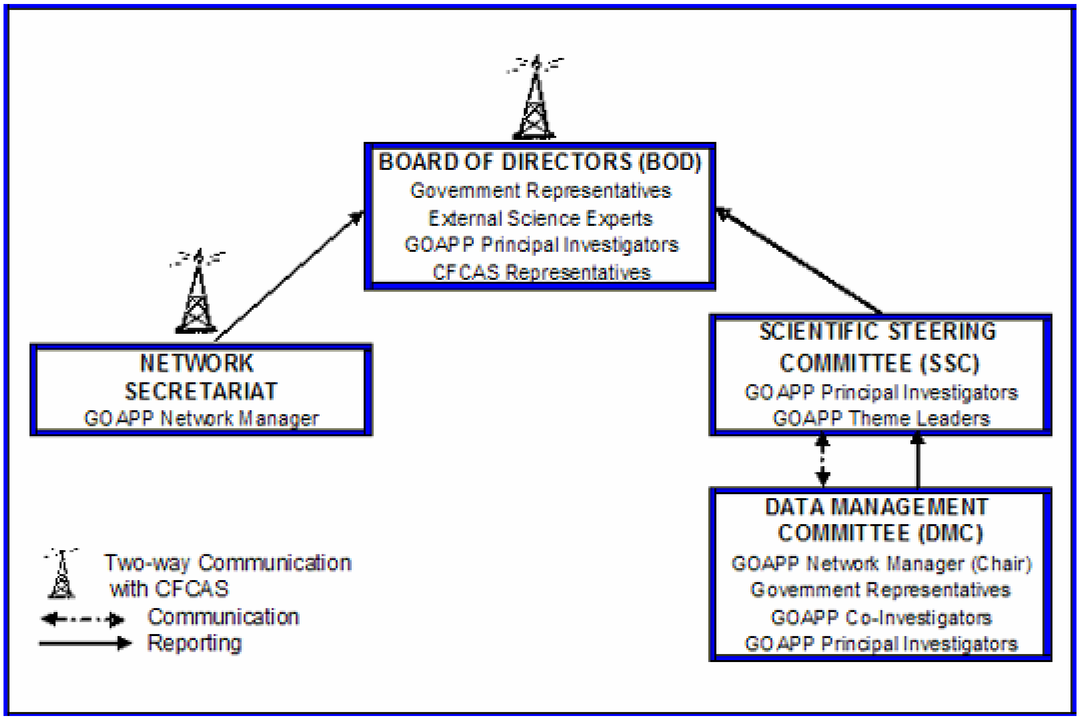
Appendix B

Board of Directors

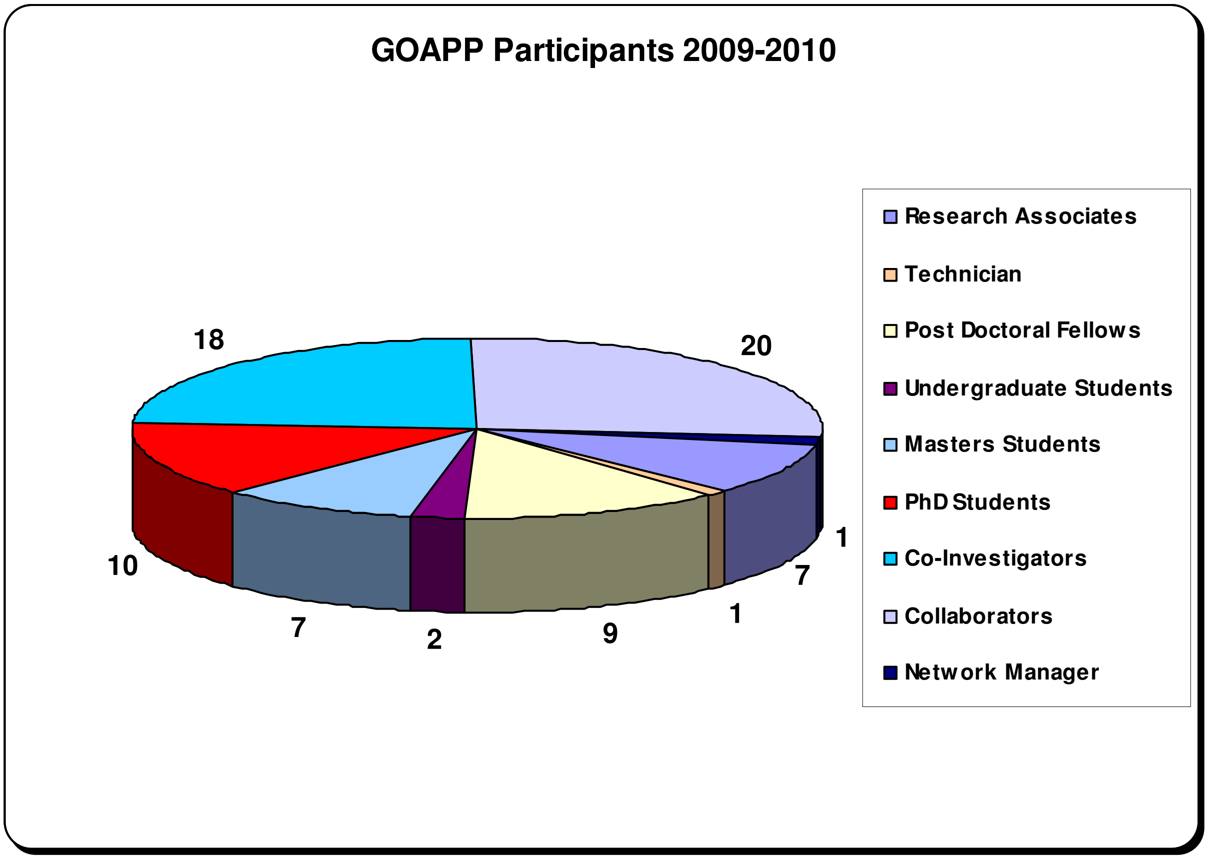
Name	Affiliation
M. Anderson	Department of National Defence
T. Aston (ex-officio)	Canadian Foundation for Climate and Atmospheric Sciences
A. Clarke	Fisheries and Oceans Canada
E. Dombrowsky	MERCATOR OCEAN
B. Kirtman	Rosenstiel School of Marine and Atmospheric Science
C. Lin	Environment Canada
S. Narayanan	Fisheries and Oceans Canada
H. Ritchie	Dalhousie University
K. Thompson	Dalhousie University
E. Wilson (ex-officio)	Canadian Foundation for Climate and Atmospheric Sciences
S. Woodbury (ex-officio)	Dalhousie University

APPENDIX B

GOAPP Management Structure



Appendix B



GOAPP Participants 2009-2010
18
20
1
7
1
9
2
7
10
Research Associates
Technician
Post Doctoral Fellows
Undergraduate Students
Masters Students
PhD Students
Co-Investigators
Collaborators
Network Manager

Appendix B

Highly Qualified Personnel (HQP)

Name	Position	Affiliation
Nasim Alavi	Post Doctoral Fellow	University of Guelph
Faez Bakalian	Post Doctoral Fellow	Dalhousie University
J. Belanger	PhD Student	University of Guelph
Yanjie Cheng	PhD Student	University of Northern British Columbia
L. Courtney	Master's Student	University of Guelph
Ziwang Deng	Post Doctoral Fellow	University of Northern British Columbia
Shawn Donohue	PhD Student	Royal Military College
Frederic Dupont	Research Associate	Dalhousie University
Gordon Drewitt	Research Associate	University of Guelph
Joel Finnis	Post Doctoral Fellow	University of British Columbia
Dan Godlovitch	PhD Student	University of Victoria
Madlena Hakobyan	Master's Student	Memorial University
Simon Higginson	PhD Student	Dalhousie University
Anna Katavouta	Master's Student	University of Alberta
Veronique Lago	Master's Student	University of Alberta
Woo-Sung Lee	Research Associate	University of Victoria
Fabian Lienert	PhD Student	University of Victoria
Yimin Liu	Post Doctoral Fellow	Dalhousie University
Sarah Lundrigan	Master's Student	Memorial University
Manoj Mambia	Post Doctoral Fellow	University of Northern British Columbia
Badal Pal	Research Associate	University of Victoria
Eric Oliver	PhD Student	Dalhousie University
A. Ravindran	Post Doctoral Fellow	University of Victoria
Ray Roche	Master's Student	Memorial University
Yunfeng Shao	Research Associate	Royal Military College
Yeqing Shu	Post Doctoral Fellow	University of Northern British Columbia
Sergey Skachko	Research Associate	Université du Québec à Montréal
Jorge Urrego Blanco	PhD Student	Dalhousie University
Tsuyoshi Wakamatsu	Research Associate	University of Victoria and DFO
ZhiYu Wang	Master's Student	University of Northern British Columbia

Zeliang Wang	Research Associate	DFO (BIO)
Xioqin Yan	PhD Student	University of Northern British Columbia
Ying Zang	Master’s Student	Memorial University
Xu Zhang	PhD Student	Dalhousie University
Jieshun Zhu	Post Doctoral Fellow	Memorial University

Appendix C

Fourth Workshop on the CFCAS-funded Research Network
Global Ocean Atmosphere Prediction and Predictability (GOAPP)

Crowne Plaza Ottawa Hotel, 101 Lyon Street, Ballroom C, Ottawa, Ontario

Monday, 31 May, 2009

0845	Welcome and Logistics	Hal Ritchie
0900	Review and discussion of Theme I	Keith Thompson / Hal Ritchie
0925	Review and discussion of Theme II	Bill Merryfield
0950	Questions and discussion	
1000	Modelling and analysis of the Labrador Sea as part of GOAPP	Paul Myers
1015	Difficulties associated with data assimilation for a coupled ocean-atmosphere model	Pierre Gauthier
1030	***Health Break***	
1045	Three techniques to represent model uncertainties and generate ensembles for dynamical seasonal and interannual forecasting	Francisco Doblas-Reyes (Invited Speaker)
1130	Exploring the sensitivity of seasonal climate forecasts to soil moisture initialization	Gordon Drewitt
1145	A high-resolution ocean-ice model of the Arctic: sensitivity to surface forcing	Youyu Lu
1200	***Lunch Break (Provided)***	
1300	Status of GEM/NEMO	Hal Ritchie
1315	MJO dependence of subseasonal forecast skill	Ajayamohan Ravindran
1330	Multiple approaches in correcting errors of OGCM	Tsuyoshi Wakamatsu
1345	Dynamic Downscaling of Ocean Circulation over the Eastern Canadian Shelf using NEMO	Jinyu Sheng
1400	Calibrated probabilistic forecasts and their presentation on a website	Slava Kharin
1415	Present and longer term development of ocean forecasting and it's applications in DFO. Where GOAPP research fit's in.	Fraser Davidson
1430	Data Management Status Report and discussion	Fred Woslyng
1500	***Health Break***	
	CO-INVESTIGATORS ONLY	
1530	Plans for final year, e.g., discussion of network wrap-up, annual and final reports, spending of funds in the final year, and review articles to reach a broader audience	CFCAS Rep / Susan Woodbury
1615	Wrap-up	Hal Ritchie

LIST OF PARTICIPANTS

Alavi Nasim	GOAPP Post Doctoral Fellow
Tim Aston	CFCAS
Faez Bakalian	GOAPP Post Doc
George Boer	GOAPP Co-Investigator
Dawn Conway	CFCAS
Melanie Cooke	DFO
Fraser Davidson	DFO
Francisco Doblas-Reyes	Spain – Invited Speaker
Shawn Donohue	GOAPP PhD Student
Gordon Drewitt	GOAPP Research Associate
Frederic Dupont	GOAPP Research Associate
Joel Finnis	GOAPP Post Doctoral Fellow
Greg Flato	GOAPP Co-Investigator
Mike Foreman	GOAPP Co-Investigator
Carlos Gaitan-Ospina	GOAPP Post Doctoral Fellow
Pierre Gauthier	GOAPP Co-Investigator
Simon Higginson	GOAPP PhD Student
William Hsieh	GOAPP Co-Investigator
Anna Katavouta	GOAPP Master's Student
Slava Kharin	GOAPP Collaborator
Veronique Lago	GOAPP Master's Student
Fabian Lienert	GOAPP PhD Student
Hai Lin	GOAPP Collaborator
Youyu Lu	GOAPP Collaborator
Sarah Lundrigan	GOAPP Master's Student
Bill Merryfield	GOAPP Co-Investigator
Paul Myers`	GOAPP Co-Investigator
Eric Oliver	GOAPP PhD Student
Mathieu Ouellet	GOAPP Data Management Committee
Andry Ratsimandresy	DFO
Ajayamohan Ravindran	GOAPP Post Doc
Hal Ritchie	GOAPP Principal Investigator
Yunfeng Shao	GOAPP Research Associate
Jinyu Sheng	GOAPP Co-Investigator
Sergey Skachko	GOAPP Post Doctoral Fellow
Mike Stacey	GOAPP Co-Investigator
Keith Thompson	GOAPP Principal Investigator
Jorge Urrego-Blanco	GOAPP Master's Student
Tsuyoshi Wakamatsu	GOAPP Post Doc
Jennifer Wells	DFO
Susan Woodbury	GOAPP Network Manager
Fred Woslyng	GOAPP Technician
Dan Wright	GOAPP Co-Investigator
Ying Zhang	GOAPP PhD Student
Jieshun Zhu	GOAPP Post Doctoral Fellow

APPENDIX C

CMOS 2010 Schedule for "Coupled Atmosphere-Ocean Prediction and Predictability"

Tuesday June 1   11:00 - 12:30 (Part 1)

Impact of model uncertainty on seasonal forecast quality: the ENSEMBLES project
Doblas-Reyes, Francisco

The CCCma sub-seasonal to decadal forecasting system
Merryfield, William

Decadal potential predictability of forced and internally generated variability in the 21st century
Boer, George

The second Coupled Historical Forecasting Project (CHFP2)
Lee, Woo-Sung (Presented by William Merryfield)

Measuring Prediction Utility of Seasonal Predictions of Asian Summer Monsoon in a Coupled Model
Yang, Dejian

Tuesday June 1   14:00 - 15:30 (Part 2)

Relationship of seasonal climate forecast error to uncertainty in soil moisture initializations
Alavi, Nasim

The role of soil moisture initialization in forecasting drought occurrence
Drewitt, Gordon

Assessing the performance of a Northwest Atlantic ocean circulation model using the spectral nudging and the semi-prognostic methods
Urrego-Blanco, Jorge R.

New Developments in Spectral Nudging
Wright, Dan

Simulation of the Mixed-Layer Depth in the North East Pacific implementing Spectral Nudging
Donohue, Shawn M

Meridional heat transport simulated with a high-resolution North Atlantic model
Lu, Youyu

Tuesday June 1   16:00 – 18:00 POSTERS

Inter-connections among three vector spaces in a 4D-Var system
Wakamatsu, Tsuyoshi

Hindcast simulations of the Arctic Ocean
Lundrigan, Sarah

Simulation of the Mixed Layer Depth in the North Pacific Ocean using NEMO with Spectral Nudging
Shao, Yunfeng

Assessment of the hindcast of the Labrador Sea
Zhu, Jieshun

Wednesday June 2 10:30 - 12:00 (Part 3)

Mesoscale variability in the Labrador Sea – a model study
Zhu, Jieshun

The mean surface circulation of the western North Atlantic subpolar gyre: Model validation using drifter observations and a new geodetically-determined mean sea surface topography
Higginson, Simon

Estimating Model Errors in an Ensemble Kalman Filter Assimilation System of Argo profiles for the Pacific Ocean
Deng, Ziwang

Improved surface fluxes for a coupled ocean-atmosphere model
Skachko, Sergey

An Exploratory Study into the Joint Assimilation of Atmosphere and Ocean Data
Bakalian, Faez

Refinement of Green's function method for parameter tuning
Wakamatsu, Tsuyoshi