2009 Progress Report

GOAPP

Global Ocean-Atmosphere Prediction and Predictability (GOAPP) Network

Submitted to:

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

350 Sparks Street, Suite 901
Ottawa ON K1R 7S8

Submitted by:

Global Ocean-Atmosphere Prediction and
Predictability (GOAPP) Network
Network Manager
Department of Oceanography
Room 5660A LSC
Dalhousie University
1355 Oxford Street
Halifax, NS B3H 4J1

Tel: (902) 494-5035
Fax: (902) 494-2885
Email: swoodbury@dal.ca

Date of Submission: 25 June 2009
Approved by the GOAPP Board of Directors: 25 June 2009

2009 Progress Report

Global Ocean-Atmosphere Prediction and Predictability (GOAPP) Network

This third progress report of the Global Ocean-Atmosphere Prediction and Predictability (GOAPP) Network covers the period from July 1, 2008 to June 30, 2009.

In accordance with instructions from the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS), 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 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. Please note that two projects (I.2.3 and II.1.1) were removed from the network at contract award and two new projects (I.1.6 and II.3.4) were added, supported by funds released by the departure of R. Greatbatch.

Dr. Y. Lu, an adjunct professor at Dalhousie University and an experienced GOAPP Collaborator, has been appointed as a new GOAPP Co-Investigator.

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), the 2009 Annual GOAPP Workshop Agenda and CMOS Presentations (Appendix C) and the GOAPP Science Day Agenda (Appendix D).

1 PROGRESS (1 JULY, 2008 TO 30 JUNE, 2009)

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 overall 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 Halifax in late May 2009. The goals of the meeting were to review progress, identify problems and opportunities for new research, encourage collaboration, discuss information management and review network structure. (Appendix C gives the agenda and a list of participants.) Co-Investigators discussed links between themes, i.e., spectral nudging, coupled data assimilation and model development. In addition they were briefed on CONCEPTS, Data Management processes and the GOAPP Supplement. The meeting was well attended and successful. We are particularly pleased to note the participation of Dr Magdalena Balamaseda, a research scientist from ECMWF, who gave an interesting and relevant presentation on coupled ocean-atmosphere prediction work at ECMWF. The reason for holding the annual workshop in Halifax 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 3 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. Balmaseda also gave the invited lead-off presentation in these CMOS Congress sessions.

Another important event during this reporting period was the GOAPP Science Day held in Victoria, British Columbia. This was an opportunity to brief the GOAPP Board of Directors, and a wider audience, on the science being tackled by the network researchers. Close to 30 people from GOAPP Themes I and II, the Board of Directors (including Dr E. Dombrowsky who travelled from France and Dr. Ben Kirtman from Miami), Environment Canada, Fisheries and Oceans Canada and the Department of National Defence attended the all day meeting. The agenda can be found in Appendix D. The Science Day focused primarily on research undertaken by Theme II.

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 data assimilation and prediction on 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 is being well trained to meet future challenges.

Theme I: Days to Seasons

Theme I research strives to develop better predictive models of the variability of the atmosphere and ocean, 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 third 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 of the assimilation schemes developed in Theme I is presently being implemented in a pre-operational model of the North Atlantic, one-way coupled to an atmospheric forecast model, in order to assess its effectiveness in an operational setting.

One reason for the rapid progress this year is the decision to focus almost all of the 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 between Theme I and II researchers. One example is the transfer of spectral nudging (a method for suppressing the ubiquitous drift and bias in ocean models) from Theme I to Theme II in order to help initialize coupled models for seasonal forecasting. Preliminary results are encouraging (bias reduced with minimal effect on El Nino and similar modes of variability) and this holds promise as a way of increasing the skill of seasonal forecasts.

Theme I investigators have continued their Discussion Group at Dalhousie University in order to encourage collaboration. Local investigators and visitors have been invited to talk about their work in an informal and constructive environment. All presentations are made available to all GOAPP investigators on the GOAPP webpage and comments and discussion are invited. This informal meeting has made significant contributions to the cohesiveness of Theme I.

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.

<u>*Schedule and Milestones*</u>*:*

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.

This project was expected to be largely completed in the second year and it was. However, it has continued at a reduced level to continue development and support other projects.

We note first an interesting study by Entcho Demirov in which he has used an eddy admitting model of the North Atlantic Ocean to study model drift, focusing on water transport and water mass characteristics. The error associated with model drift was quantified in terms of errors in the water transport and the characteristics of the energetics of the model solutions. The model simulations were repeated with spectral nudging applied to suppress the drift which resulted in significant improvement. However, restrictions are identified that must be satisfied to use spectral nudging without unwanted contamination of the model dynamics and interannual variability. The effects on the model solution are studied. An article is in preparation which is planned to be submitted before the end of June.

Dr. F. Dupont (GOAPP Research Associate) has taken the lead in assisting Dr. W. Merryfield to implement spectral nudging in the CCCMa model for project II.3.1 (Coupled Model Initialization -- led by Flato and Merryfield). Recent results indicate that this has been accomplished. They show a clear bias reduction in the mean state with variability about the mean developing as expected. The next goal will be to include nudging of very low frequencies while permitting decadal and higher frequency variability to evolve according to the model dynamics.

The use of spectral nudging to consider low frequency variability is an area where we have very little experience and will require experimentation to determine whether or not it can be used successfully for such a problem. One of the issues will be to retain the nudging on the mean while allowing decadal variability to develop according to the model dynamics. In view of the work by Entcho Demirov mentioned above, this is a concern since long model simulations will be undertaken at CCCMa and it is in such long simulations that Dr. Demirov has seen a problem that appears to be associated with resonant interaction between the nudges and the model dynamics. Similar symptoms have also been observed by Dr. Y. Liu (GOAPP Research Associate) while working on coastal ocean simulations. A slightly modified form of spectral nudging has been developed by Dr. Liu to eliminate this unwanted interaction. He has successfully used the modified approach in the POM model for the coastal application and has recently implemented it in the NEMO model to be used in 1/6 degree model simulations of North Atlantic variability. Results are presently being evaluated as part of the development of a pre-operational system.

The use of spectral nudging in a global model also introduces concerns associated with nudging in the vicinity of the equator where problems had been seen in the past. These were associated with errors in the climatology that become far more obvious as the Coriolis parameter tends to zero. One way to deal with this problem is to increase the amount of spatial smoothing of the nudges, but this has been a computationally expensive task in the past. Recently, an iterative approach has been developed that permits strong spatial smoothing with minimal CPU cost. The approach results in the lowest frequency variability being strongly smoothed while higher frequencies are smoothed less. Thus, the nudges applied to the model are smoothed without wasting time smoothing nudges that are filtered out by the time filter. The iterative approach also has the advantage of automatically allowing for complex topography (as in the area of the

Indonesian Archipelago) by slowly (iteratively) extending its footprint around the topography without crossing land boundaries. Local tests have shown the iterative smoother to perform well with the capability of including strong smoothing with approximately the same cost as used for our standard approach to spatial smoothing. An initial test of the iterative filter in the implementation in the CCCMa model used excessive amounts of CPU suggesting that there is an error in the implementation that needs to be corrected. This will be investigated during the next year.

Spectral nudging is also being used at the University of Alberta by Paul Myers' group. In an ongoing effort to reduce the need for this approach, considerable effort has gone into understanding the cause of model drift in the sub-polar gyre, leading to the following conclusions so far:

- Initial Labrador Sea drift is the same in both regional (NATL4) and global configurations (ORCA025)
- Initial Labrador Sea drift is the same whether perpetual year or interannually varying forcing is used – the behaviour is the same through the first 14-15 years, and only after the initial drift has 'finished' does the inter-annual forcing take over
- The inclusion of a sea-ice component does not seem to play a significant role in curtailing the drift in the Labrador Sea
- A detailed freshwater budget for the Labrador Sea suggests competing roles for the freshwater supplied by the boundary currents and the provision of salty mode water from the Irminger Current
- The freshwater supply in the East Greenland Current, and its evolution along its path, is very dependent on the strength of the SSS restoring, the field being restored to (i.e., Is there a fresh EGC core in the restoring field) as well as the strength of the eddy activity

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.

A paper on the mean sea surface topography (MSST) of the North Atlantic, and its validation in the vicinity of the Gulf Stream and the Labrador Shelf and break, is in press with the Journal of Geophysical Research. This study uses a new map of North Atlantic MSST, based on satellite and terrestrial gravity data, to evaluate our deep ocean models. (This non-oceanographic MSST map was calculated by colleagues at NRCAN.) This paper shows conclusively that such satellite-based MSST, enhanced with terrestrial gravity data, are surprisingly realistic. Over the last year we have extended our analysis of the Gulf Stream region to include the Labrador shelf, slope and adjacent deep ocean and found the new MSST to be in excellent agreement with independent oceanographic observations and expectations. Although the work was carried out primarily with funding from the GEOIDE NCE, the results are proving useful in evaluating GOAPP models of the North Atlantic (along with spatial maps of sea level variance and skewness) by groups at Dalhousie and BIO.

The comparison of the new satellite based MSST with results from our ocean models has pointed to unrealistic, high wavenumber variability in the temperature and salinity climatology to which the ocean model was spectrally nudged. For this reason a new method has been developed for generating seasonal climatologies of ocean temperature and salinity. The idea is to "de-eddy" the observed temperature and salinity profiles using (i) information on sea surface height (from altimeters), and (ii) a dynamical relationship between changes in interface displacement and dynamic height. Most of the work has been carried out by Simon Higginson, a graduate student (initially funded by GEOIDE, now funded by GOAPP). Results for the North Atlantic are encouraging; in the main thermocline region in the vicinity of the Gulf Stream the standard error of the mean is reduced by a factor of two, equivalent to an effective fourfold increase in the number of temperature and salinity profiles. A new climatology has been developed using the above method is now being used in the pre-operational model of the North Atlantic model being supported with Supplementary funding from CFCAS (as described later in this report). A paper on the new method is just about to be submitted to Geophysical Research Letters and a presentation was made at the CMOS Annual Congress in late May 2009 by Simon Higginson.

The Northeast Pacific has also been subject to a similar comparison of ocean and satellite based MSST. Drs. Foreman, Crawford, Cherniawsky and Galbraith (2009) recently compared an ocean model-based MSST for the Northeast Pacific Ocean to an MSST based on independent satellite observations. The two MSST results agree reasonably well in the deep ocean but the agreement deteriorates on continental margins where the ocean model estimates have revealed significant seasonal variations, and have been shown to be reasonably accurate when compared with satellite altimetry and coastal tide gauge measurements. The ocean model based MSST will permit more accurate calculations of the geoid and satellite altimeter absolute height and currents.

Drs Foreman and Wakamatsu recently obtained ocean model output from 2001 to 2007 from Mercator. (The model used to generate the output was NEMO with a resolution of 1/12 of a degree, ORCA12.) The first step is to compare higher order moments of sea surface height with altimeter data. This is presently underway. Empirical relationships between the higher order moments and the background large scale circulation will be used in the variational data assimilation experiments in Project I.1.4.

Moments of satellite-observed sea level variability developed by GOAPP (mean and skewness) are now used routinely by other GOAPP Theme I co-investigators to test their ocean models, e.g., Dr D. Wright (North Atlantic: mean and skewness) and Dr M. Stacey (North Pacific: skewness). Dr Wright and his team have been successful in using such comparisons to identify model errors and this has contributed to a number of improvements to both the NEMO models and also spectral nudging.

Development of tangent linear and adjoint models for gauging the sensitivity of moments of variability, and spectral nudges, of GOAPP's ocean models to a "large number of controls" (e.g., surface forcing, lateral boundary conditions, bathymetry) has evolved over the last year. The planned development of a 4DVAR system based on the adjoint and tangent linear codes of a simplified OGCM (written by Dr. Yaremchuk, University of Hawaii) was terminated due to coding problems and inconsistencies with schemes based on more complete physics. Instead attention has now focused on a 4DVAR code based on an earlier version of NEMO (specifically the 4DVAR system developed by Dr Anthony Weaver based on OPA8.0, OPAVAR). Since OPA8.0 is based on the same numerical schemes as NEMO, we believe OPAVAR can be used to meet the goal of developing a 4DVAR system for NEMO.

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.

Progress continues to be made with the implementation of a new method for assimilating altimeter and Argo data into eddy permitting models of the North Atlantic at Dalhousie University. A paper on the subject is just about to appear in Monthly Weather Review. The technique is also being implemented in a pre-operational, 1/6 degree model of the North Atlantic under the guidance of Dr Y. Liu. Present indications, based on results from prognostic (no assimilation) runs are encouraging and suggest that the NEMO model at 1/6 degree resolution is significantly more realistic (based on comparisons with moments of variability) than the earlier 1/3 degree POP model. Results from the assimilative form of the pre-operational North Atlantic model were presented at the GOAPP annual workshop, and the CMOS Annual Congress, in Halifax in late May, 2009.

A SEEK filter was implemented and is undergoing testing and verification in a regional model of the Labrador Sea at Memorial University. Forecasting skills of the data assimilation scheme are assessed through comparison with observational data. Results from this work were presented at European Geosciences Union annual assembly in Vienna. These talks were also presented at CMOS and IAPSO conferences in 2009.

A 1 degree North Pacific configuration of NEMO/OPA9 (NPAC_ORCA1) with climatological forcing was developed and implemented on the IOS Linux cluster at IOS with the help of Y. Lu, Z. Wang and D. Wright from BIO-DFO. When the 3DVAR system becomes available, it will be tested with this model.

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.

Schedule and Milestones:

Years 1-2

- *Implementation of global and basin-scale models. The global model will have a nominal horizontal resolution of 1 degree while the basin scale models will have nominal horizontal resolution of ¼ degree.*
- *Implementation of basic spectral nudging code in the OPA model.*
- *Perform initial prognostic ocean-only simulation covering the ECMWF reanalysis period using the 1 degree global model.*
- *Comparisons of prognostic model results with previous work in the North Pacific and the North Atlantic.*
- *Development of embedded finer resolution sub-domains for the regions around Cape Hatteras and the Grand Banks of Newfoundland.*

Years 2-3

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

Years 3-4

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

The primary goals of this subproject for the present time period are to do reanalysis experiments with and without data assimilation and to analyse the results to determine strengths and weaknesses – and make improvements to reduce the latter where possible. The availability of either the Mercator or the GOAPP methods for assimilating synoptic data has been delayed so our experiments have proceeded with either prognostic or spectrally nudged ocean models. As it turns out, there has been plenty to do without including assimilation of synoptic data.

The following steps have been accomplished:

1. Initialization and Forcing Fields

- Completed the development of a global hydrographic climatology using a blend of the Levitus 2005 data set and the Polar Hydrographic Centers (PHC) climatology for the Arctic. The PHC data set was found to be substantially superior to the Levitus data in the Arctic, but investigations by Dr. Wang have revealed several regions that have unrealistic SST under the sea-ice cover. These problems have been reported to the data center and the dataset manager has agreed to update the dataset.

- Completed the development of the initial global forcing fields to be used in reanalysis runs. The forcing fields are based on the CORE and DFS4 data sets.

- Finished a report entitled "A Discussion of Atmospheric Forcing plus Preparation Routines for Ocean Hindcast Forcing Fields" (work done by Zeliang Wang funded by other projects).

2. Reanalysis work with 1 degree models

- 1 degree global reanalyses for the years 1958-2004 were completed at BIO 1) using both CORE and DFS4 forcing fields in prognostic ocean-only simulations and 2) using the CORE forcing with spectral nudging included as a preliminary sensitivity study. The run with spectral nudging included revealed problems associated with nudging in the presence of sea ice. Essentially, the nudging can act as a dominant source or sink of heat that can melt or create sea ice. A simple solution is to turn off spectral nudging in the top few layers in regions where sea ice may be present. (Further discussion of spectral nudging in the context of global modelling is covered under project I.1.1.)

- The prognostic run with CORE forcing has been analysed and results are being prepared for publication.

- Several runs have been completed intended to clarify the sensitivity of the Meridional Overturning Circulation to specific physical processes. The analysis of this set of runs is under way.

- Papers have been written on sea ice variability in the Arctic Ocean (Dupont with others) and on representing eddy stresses in a global model (Holloway and Wang).

- Other papers are at varying stages of preparation. One investigation of particular relevance is considering the possibility of monitoring transport variations based on quantities that are already routinely measured. Preliminary results are encouraging but the outcome is still uncertain. Another investigates the correlations between model simulated SSH and SST variations in the Atlantic basin, and compares results with available observations. The goals of these two papers are to improve the current understandings of observed variability in the

North Atlantic and use this improved understanding to get the most out of available observations. The analyses completed so far have shown that 1) We obtain good agreement between model results and satellite observations of the large scale variations of sea level and sea surface temperature in the North Atlantic; and 2) The correlation between the NAO index and variations of SSH and transports across several sections suggests that it may be possible to monitor gyre strength variations using a combination of the available observations of SSH and the NAO index.

3. Reanalysis work dealing with eddy admitting models

- A North Atlantic Ocean reanalysis with an eddy permitting model has been produced at MUN for the time period 1948-2005. Studies of (a) Interannual variability of water mass characteristics and water transport and (b) Interannual variability in the water mass spreading were done using the data from these simulations. Two articles are in preparation and are planned to be submitted before the end of June 2009.

- The North Pacific NEMO model, with 0.25 degree horizontal resolution and 46 vertical levels, has been run in prognostic mode, and using spectral nudging. The model temperature and salinity fields have been nudged to the Levitus climatology in two ways: (1) the model mean has been nudged to Levitus, and (2) the model mean and annual cycle have been nudged to Levitus. It is clear that spectral nudging improves the simulations significantly.

- Using spectral nudging, it has been shown that the North Pacific Current is better simulated and that the influence of Rossby waves on the Current can be documented. Rossby waves generated at the coast of North America propagate away from the coast and take 3-5 years to reach the middle of the northeast Pacific Ocean. This time lag between the generation of the waves and their arrival at Ocean Weather Station Papa, for example, suggests that there may be a degree of predictability of the ocean circulation in the northeast Pacific.

- An anomalous cold water intrusion was observed in the northeast Pacific in 2001-2002. It propagated eastward to the coast and then southwards. Its influence was detected as far south as the south coast of California. As long as spectral nudging is included, model simulations can reproduce the available observations. According to the model, anomalous wind stress caused by the constructive interference of the Victoria mode and La Nina resulted in enhanced vertical mixing in the northeast Pacific during the winter, which generated this observed cold water intrusion. According to the model, the intrusion did not continuously hug the coast as it propagated south, but rather followed a winding route that had the same pattern as the contemporaneous wind stress curl. (Curchister et al. (2005) simulated the initial progress of the cold water intrusion. Simulations at RMC generally agree with this part of their simulation except that the RMC mixed-layer depths are larger, and in closer agreement with observations. We attribute a large part of this success to spectral nudging.)

- Observations show that along line Papa the mixed layer depth decreased at a 'moderate' rate from at least 1970 until about 1999. From 1999 until about 2004 the rate of decrease became significantly larger, and then the mixed-layer depth started to increase, with the mixed-layer depth then approaching more typical values for the region. Simulations that use spectral nudging are able to reproduce these observations. They indicate that the enhanced shallowing during 1999-2004 was due to enhanced upwards Ekman pumping caused by the Victoria mode. (Note that important observations for the North Pacific region were provided by Howard Freeland (personal communication)).

- Dr. Dupont has started the analysis of a data-assimilative NEMO run provided by Greg Smith (CONCEPTS) performed on a ¼ degree global model (1987-2004). The preliminary analysis shows that the simple data assimilation technique used was sufficient to significantly reduce the mean bias present in SSH, but that some bias remains in SST. This activity shall continue into the next fiscal year.

4. <u>Ocean Modelling Developments</u>

- Dr. Dupont has made very good progress on the extension of the AGRIF (Adaptive Grid Refinement in Fortran) embedding technology for applications of interest to Canadians. In particular, AGRIF did not previously support inclusion of sea ice, a problem that greatly reduces its usefulness in mid to high latitude studies. This shortcoming has been corrected, making the method applicable to regional problems such as those considered in project I.1.6 (Assessing the Capability of a Nested-Grid Shelf Circulation Model for the Eastern Canadian Shelf led by Jinyu Sheng).

- Tests of the AGRIF technology have been performed with a ¼ degree North Atlantic subdomain imbedded in a 1 degree global model and with a 1/12 degree "Gulf Stream region" imbedded in a ¼ degree NA model. The former has been used to confirm the applicability of AGRIF with sea ice extending across the boundary between child and parent domains while the latter has been used to confirm improvements in Gulf Stream separation and eddy statistics with local improvements in the resolution.

- Dr. Dupont has also made significant improvements to the treatment of open boundary conditions (including low frequency and tidal contributions) in the NEMO code. Use of high-resolution limited-domain regional models offer an alternative to using the AGRIF embedding approach for regional studies.

4. <u>Other related work</u>

- Dr. Thompson and colleagues have worked on the validation of satellite-derived estimates of mean sea surface topography. The results compare very well with buoy data and numerical model results, so well in fact that the satellite product is now regarded as a useful benchmark with which to compare/validate numerical model results for mean sea level and currents.

- Dr. Wright and colleagues have examined the influence on model results of modified mixing slopes near topography. The essential idea is that mixing slopes will be controlled by bottom topography rather than isopycnal slopes very near the bottom. Initial results were encouraging but somewhat confusing. It now seems that the improvements are associated with reduced mixing rates near the bottom rather than the change in bottom slope. Further investigations will be undertaken during the coming year.

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.

A detailed analysis of the sea-ice representation in the coupled ice-ocean NATL4 configuration is being completed. This includes comparisons with satellite based climatology as well as Canadian Ice Service charts; this includes a detailed comparison for the years 2003 and 2005. In general, the non-assimilative version of the model is under-predicting the sea-ice concentration and thickness along the Canadian eastern sea-board.

The role of resolution in the sea-ice representation is also being considered. NEMO configurations at resolutions of 2 degree (ORCA2), 0.5 degrees (ORCA05) and 0.25 degrees (NATL4) have been run and the sea-ice fields are presently being analyzed.

Sea ice concentration fields from the Canadian Ice Service have been prepared for assimilation into the model (NATL4 configuration) for 2003 and 2005. The model code is presently being modified to allow for sea ice assimilation (initially simple nudging, although more advanced forms based on those developed by the Canadian Ice Service will be implemented) and we expect to carry out initial assimilation runs in NATL4 for 2003 and 2005 in May/June. Additionally, the SEEK filter was implemented to assimilate sea ice for the years 2005 and 2006.

We are just finishing carrying out tests of a new setup using the NATL4 configuration with the new NEMO v3.1 and the new LIM3 sea-ice model. We then plan to repeat our basic experiments with their configuration to examine the impact of using LIM3.

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.

Since this project is a 2-year student project and the report period is the first year of this project, we decided to focus on the development and calibration of a coarse-resolution (1/4 degree) northwest Atlantic Ocean model in year 3. In year 4 we will focus on the development of a high-resolution (1/12 degree) shelf circulation model for the eastern Canadian Shelf to be nested inside the coarse-resolution northwest Atlantic Ocean model. The following are the key results achieved to date:

Significant progress was made in developing a northwest Atlantic Ocean circulation model using NEMO. This model domain covers an area between 32W and 80W and between 33N and 54N, with a model horizontal resolution of 0.25 degree and 46 z-levels in the vertical. The model is forced by 6 hourly atmospheric forcing including wind stress and surface heat and freshwater fluxes.

The 5-day reanalysis data produced by the British Atmospheric Data Centre (BADC) were used in specifying variables along open boundaries of this northwest Atlantic Ocean model.

To reduce model drift in the multi-year simulations, the semi-prognostic method was implemented in the model. (The spectral nudging method was already implemented in the model code by Dan Wright and his colleagues). Preliminary model results demonstrate that the semi-prognostic method and the spectral nudging method improve the model performance significantly. Efforts were also made in using the conventional Laplacian mixing and Orlanski open boundary condition in the model code.

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 the basic coupled model. This is not yet completed.

Diagnostics of the coupled system
Atmospheric and oceanic diagnostics based on surface fluxes from the two models have been carried out and compared with data from the SURFA database. This has shown significant differences between the GEM model and SURFA. Similar diagnostics are planned to be completed with the coupled model (when available).

Work is going on at Environment Canada to evaluate the impact of different atmospheric analyses used to force the NEMO model. ECWMF analyses are used by the MERCATOR group and those have been used to validate the NEMO implementation on the Environment Canada computers. Similar experiments are to be carried out by having the GEM 4d-Var analyses used for the forcing.

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. 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 is being introduced within the GEM-4D-Var system. This has never been done before and is requiring substantial changes to the GEM-model and the assimilation component. This work is about to be completed and experiments will aim first at assessing the impact this may have on the model integration. This is done with the atmospheric model only and 4D-Var. This involves changes to parameters for the heat and moisture fluxes computations. As pointed out in Sugiura et al. (2008), this may in turn require balancing those changes with modifications in vertical diffusion, the atmospheric boundary-layer, and even the large-scale condensation scheme. Moreover, in coupled mode, adjustments in the ocean model parameterizations may also be required (e.g., isopycnal diffusion coefficient).

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.*

The first milestone listed above has been completed by Post Doctoral Fellow Faez Bakalian. RA (Redundancy Analysis) and EOF (Empirical Orthogonal Function) analyses were carried out for a coupled CCCma run (supplied by Bill Merryfield) and NCEP reanalysis data. Global time-lagged RA and EOF patterns were computed for SST and SLP (see last year's report). 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. The eigenvector analyses of the coupled system revealed several important differences between RA and EOF analysis. One of the most important findings is that for weakly coupled atmosphere-ocean models, EOF analysis 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. These results have been presented at several workshops and conferences, and prepared for submission as a journal publication (see the list in section 4.1).

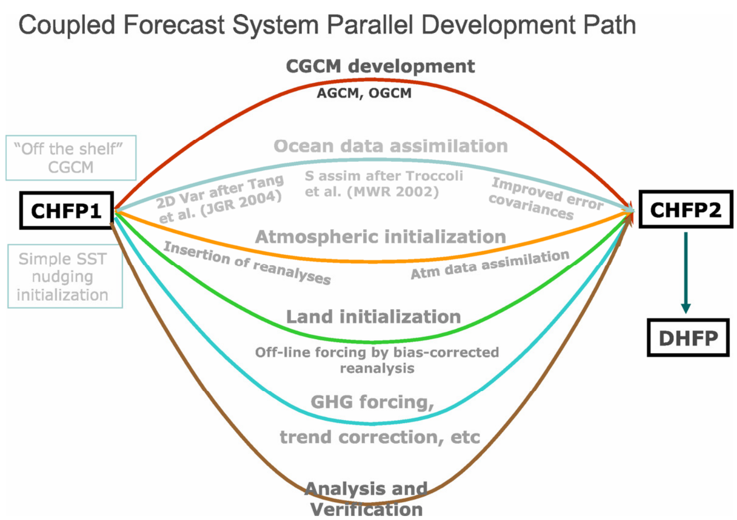
Owing to unforeseen delays in the availability of the coupled GEM-NEMO model, it was not possible to perform the control simulation of the twin experiment as outlined in the second milestone noted above. Instead, the twin experiments were run using a simplified state space model modified to include data 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 then 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. We anticipate including these results in a journal publication in the near future.

On the subject of coupled atmosphere-ocean interactions, research has also been conducted on ocean predictability associated with the Madden-Julian Oscillation. This has been carried out by PhD student Eric Oliver supervised by Keith Thompson and PhD student Xu Zhang co-supervised by Youyu Lu, Keith Thompson and Hal Ritchie. One paper on the topic has been accepted for publication in the Journal of Physical Oceanography, one is under review by the Journal of Geophysical Research, and another is about to be submitted.

Theme II: Seasons to Decades

The broad reach of Theme II research continues to be reflected in progress on a broad front and along the "end-to-end parallel track" discussed in last year's report. In particular, Theme II research extends from the analysis of coupled model behaviour pertinent to seasonal-to-decadal (s2d) prediction; to potential and prognostic predictability and the mechanisms involved; to the complex problem of initialization and ensemble generation for the coupled system; to the production of results from the first Coupled Model Historical Forecast project (CHFP1, the namesake for the CLIVAR/WGSIP Climate-system Historical Forecast Project); to the much improved CHFP2 that is the result of the experience and new knowledge gained; and to the sophisticated analysis and post-processing of s2d results, including multi-model and the CHFP results particularly.

Theme II reports indicate the considerable progress that has been made, the success attained, the new and pertinent knowledge achieved and the considerable number of published and publishable results realized. The reports also show how the parallel tracks of research are converging to form the relatively "seamless" approach to s2d prediction indicated in the Figure below.



The connections between Themes I and II have also been strengthened during the year which saw the spectral nudging approach implemented in the coupled climate model and coupled model simulation results used to investigate coupled assimilation techniques. The land surface initialization gap in GOAPP was also addressed with a new effort in that area.

The considerable connections between Theme II research and international efforts will continue and expand. The research effort will see the production of a complete suite of CHFP2 forecasts and their submission to the WMO/CLIVAR/WGSIP CHFP intercomparison project. Active steps are being taken to allow a contribution also to the US CLIVAR Hindcast Experiment for Intraseasonal Prediction and to the 2nd phase of the Global Land Atmosphere Coupling Experiment (GLACE-2). Finally, decadal predictions and our DHFP (Decadal Historical Forecasting Project) will become active in the next year and will ultimately contribute to the WMO/WGCM/WGSIP fifth Coupled Model Intercomparison Project (CMIP5) as a contribution also to the Intergovernmental Panel on Climate Change (IPCC) fifth Assessment Report (AR5).

Results on all s2d timescales will be analyzed and assessed using the sophisticated approaches developed under GOAPP.

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.

<u>*Schedule and Milestones*</u>*:*

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 first phase of this project concerns the evaluation of systematic errors in the simulation of North Pacific atmospheric and oceanic surface climatology and variability. Observational data and output from most of the World's global climate models has been assembled, and a detailed intercomparison between the models and the observations has revealed several important systematic model biases which are currently under detailed investigation. In the last 12 months the graduate student, Fabian Lienert, responsible for this project has completed his course work at the University of Victoria and has presented his preliminary research findings at the CMOS Congress in Kelowna and the GOAPP workshop in Victoria. After completing his upcoming candidacy exam it is anticipated that Fabian will submit his latest research findings for publication and then move onto the second phase of his research which involves a similar analysis of the CCCma coupled data assimilation and climate prediction 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.

Schedule and Milestones:

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

Further progress has been made on this project and, in view of the interesting results obtained; efforts have been extended beyond Years 1 and 2. In particular, the effect of climate change on the internal variability and decadal potential predictability of temperature and precipitation has been analyzed in results from the CMIP3/IPCC archive of coupled model results and the results presented at CMOS (Boer, 2008a) and now published in the Journal of Climate (Boer, 2009a). The internally generated variability about the climate change signal is analyzed and a warmer world sees a decrease in the standard deviation of annual mean temperature at extratropical latitudes and a slight increase in the tropics. The variability for precipitation increases at all latitudes. By contrast, the standard deviation of decadal means decreases in general for temperature while increasing for precipitation. Geographical patterns of the differences in annual mean standard deviations and of decadal potential predictability are obtained. One result is that decadal potential predictability of the internally generated component generally decreases in a warmer world.

In a related analysis (Boer, 2009b) the decadal potential predictability of both the externally forced (due mainly to greenhouse gasses) and internally generated (natural variability) components of temperature are analyzed in multi-model simulation results for the 21st century. On decadal timescales, the natural variability may enhance or counteract the general warming trend and the attempt here is to give some idea of the additional decadal prediction skill that might be available if the deterministic part of this natural variability component could be predicted. The results are under revision for Climate Dynamics.

A further analysis of the CMIP3/IPCC archive of coupled model results referred to above was undertaken by Merryfield and PDF Ravindran. Motivated by exploratory predictions from the Hadley Centre and researchers in Germany that the earth's climate will warm relatively slowly or perhaps even cool during the coming decade, the frequency with which cooling episodes occur in a warming climate was diagnosed from model output, considering both global and regional measures on 5- and 10-year time scales. These diagnosed frequencies were found to be in accord with predictions of a simple statistical model given knowledge of the long term trend and the amount of variability about the trend, indicating for example that cooling episodes tend to occur least frequently in the tropics where trends are relatively strong and pentadal/decadal variability is relatively weak. In relation to this work the predictability of successive *differences* of *N*-year means as opposed to the mean values themselves is being considered. In addition to Merryfield (2009a) this work will be described in a presentation at the upcoming IAMAS IAPSO IACS 2009 Joint Assembly in Montreal and in a journal article in preparation.

Potential predictability results are directly relevant to the new WCRP/IPCC effort in decadal prediction. Boer was an invitee to the Aspen Global Change Institute's Workshop "Climate Prediction to 2030" and made two presentations (Boer, 2008a.b) including an assessment of the prospects for decadal prediction. The Workshop has led to a review paper (Meehl et al, 2009) on the topic. Dr. Boer also attended the WGCM Paris Working Group Meeting, representing WGSIP and proposing a project for decadal prediction (Boer, 2008c) which was enthusiastically adopted. The resulting fifth Coupled Model Intercomparison Project (CMIP5) now includes experimentation dealing with decadal prediction along with the more usual climate change simulations. Finally, Boer is a member of a WGSIP/WGCM/CMIP5 panel charged with coordinating the decadal experimentation. The expectation is that the results will add a new and important source of information to the IPCC AR5 Working Group I Assessment. Several other presentations discussing decadal prediction and the proposed coordinated experiment were also made (Boer, 2009a,c,d,e)

CMIP5 and other MIPs are supported by the Program for Climate Model Diagnosis and Intercomparison (PCMDI) led for many years by L. Gates. Boer has been associated with Gates and PCMDI over the years and was one of a handful of US and international senior scientists invited to make presentations at the Gates Symposium and the 20th Anniversary Symposium of PCMDI (Boer, 2009f)

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.

A "coupling surgery" or "partial coupling" technique has been implemented in which the atmosphere sees specified climatological sea surface temperatures (SSTs) rather than interactive SSTs in specified regions in order to isolate the impacts of SST variability and air-sea couplings in these regions on global and regional climate variability and predictability. A series of seven coupled model runs, each 370 years long using the last 300 years for analysis, has been completed. (These runs employed a newer version of the model and supersede much shorter runs described in last year's report.) Analysis of this model output has included (i) quantification of the impact of regional SST variability on global sea level pressure, tropospheric temperatures, 500 mb height and so forth (ii) estimates of pentadal/decadal predictability based on analysis of variance of annual means as in the studies of G. Boer described above, and (iii) measures of interannual predictability based on analysis of variance of monthly means. Preliminary results were presented by Ravindran (2009) at the GOAPP Science Day, and analysis and interpretation are ongoing.

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.

For reasons detailed in Section 1.2 below, year 1-2 milestones for this project were moved to years 3-4. The primary technical reason is 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, and (ii) provides differences in initial conditions between ensemble members that reflect, in a realistic way, uncertainties in the initialization of climate system forecasts.

By contrast, previous investigations have typically initialized such ensembles by combining identical ocean states with atmospheric states drawn from different days or from the same calendar day in different years. Deficiencies in this approach include its inability to characterize the impact of atmospheric predictability on shorter timescales and the unrealistic lack of any uncertainty in ocean initial conditions.

An initialization technique being developed by the investigators overcomes these deficiencies. The technique is based on the atmospheric data assimilation method, developed by S. Polavarapu and implemented in AGCM3 by J. Scinocca, which is described under project II.3.1. The idea is that, one or more months prior to the predictability experiment initialization time, an ensemble is created by adding N random perturbations to the atmospheric state. During the period leading up to the initialization time, the atmospheric state of the "central" model run is assimilated into each ensemble member while ocean state perturbations are allowed to grow. This procedure produces a set of N initial conditions in which differences in the atmospheric and ocean initial states reflect much more realistically uncertainties in the initial conditions of practical forecasts, enabling prognostic predictability on time scales of days to years or longer to be investigated in a seamless and consistent manner.

Thus far collaborators J. Scinocca and S. Kharin have succeeded in implementing the assimilation of six-hourly atmospheric states produced by a model run, which forms the primary basis of this technique.

The study described in last year's report of extreme rainfall trends and predictability in relation to those of synoptic events by Drs. Ravindran, Merryfield and Kharin has been accepted pending revision by *Journal of Climate*.

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.

Forecasts for the CHFP1 pilot project, initialized using simple SST nudging and based on an "off the shelf" model version available at the beginning of GOAPP, has been completed, analysed and written up (Merryfield et al. 2009) in accordance with Year 2 objectives.

Progress has continued on the application of variational data assimilation methods to initialization of the 3D ocean. Following implementation of off-line assimilation of 3D temperature using the method provided by collaborator Tang, this method was extended by (i) applying as well a simple procedure for assimilation of salinity, described in papers by Troccoli and Haines, and (ii) employing alternative and likely more realistic forms for the background spatial error covariances which reflect the covariance structure of the modeled temperature variability. Implementing these techniques has required addressing several technical challenges, including development of a method for overcoming pathologies in the Troccoli-Haines procedure and importing and adapting the M1QN3 optimization package to carry out assimilation calculations using the more spatially extensive, model-based covariances.

To assess the impacts of these methods on ENSO forecast skill, sets of ensemble forecasts have been carried out by RA W.-S. Lee which incorporate each of the techniques described above, as well as (i) direct insertion of the ocean temperature analyses, which has been shown by Kirtman and Min to yield good results for the NCAR CCSM3 model, and (ii) the SST nudging procedure used for CHFP1. The results, which show ENSO forecast skill generally improves with increasing sophistication of the assimilation technique, will be described in an oral presentation by Lee at the 2009 CMOS Congress.

Progress has been made also on two aspects of atmospheric initialization. First, a technique for constructing atmospheric initial states from the NCEP reanalysis was implemented by collaborator Kharin for the two CHFP2 models using AGCM3 and AGCM4 (see report for II.3.2), and the skill improvements over atmospheric initialization from SST nudging along were assessed on timescales of days to seasons. (One noteworthy result is a statistically significant 2nd month improvement for some variables.)

The second aspect of atmospheric initialization that has been studied is a simple method of sequentially assimilating the NCEP reanalysis developed by Saroja Polavarapu and colleagues at EC Downsview and implemented by collaborator Scinocca. In addition to producing a relatively realistic atmospheric state at the beginning of the forecast, use of this technique exposes the ocean and land surface more realistic meteorological conditions during the time leading up to the forecast; such “preconditioning” could be expected to lead to more realistic initial states and subsequent forecasts. Assessments of impacts on initialization and forecast skill are being carried out.

A sea ice initialization procedure was also developed which employs strong nudging of sea ice concentration toward observations prior to the start of the forecast (also toward sea ice mass, not observed directly but constructed from concentration values via a statistical procedure). The impact of this procedure on sea ice prediction skill is currently being evaluated.

In a significant interaction with Theme I, the ocean spectral nudging technique developed under I.1.1 has been implemented in the CCCma climate model by collaborator Wright, RA DuPont and investigator Merryfield. This procedure can serve to correct ocean model biases both in the forecast initialization and the forecast itself. Performance in the model and impacts on skill are being investigated as reported under II.3.2.

Under this project Tang and coworkers at UNBC undertook the following:

i) introduced a new ensemble-based filter, called the sigma-point filter, and tested it using simple dynamics models. This work has been published in J. Atmos. Sci., (2009).

ii) built an assimilation system based on the Ensemble Kalman Filter, and used this to assimilate Argo temperature and salinity profiles into NEMO for the Pacific Ocean from 2005-2007. Validation against observed temperature and salinity data that were withheld from the assimilation showed that this assimilation system significantly improves the simulation of temperature and salinity. A manuscript to document this work is in preparation.

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.

Analysis of retrospective forecasts from the pilot project CHFP1, consisting of 12-month, 10-ensemble forecasts initialized 4 times per year from 1972 to 2001, was completed and a journal article describing these results was submitted (Merryfield et al. 2009). In addition to being a valuable development exercise, these results will serve as a baseline skill measure for assessing how model and initialization improvements affect the skill of the second-generation forecast set CHFP2.

Forecast system development leading toward CHFP2 has proceeded on several parallel tracks:

1. **Model development efforts and skill assessment of test forecasts** have led to two model versions being selected for use in CHFP2, which thus becomes a multi model ensemble, exceeding the scope of the single-model forecast set originally envisaged. The two model versions consist of (i) the recently developed ocean model version OGCM4 coupled to the AGCM3 atmospheric model used in CHFP1, and (ii) OGCM4 coupled to the new-generation

atmospheric model AGCM4. Both versions show improvement in surface climatology and ENSO variability relative to previous model versions, in addition to yielding promising skill in test seasonal forecasts.

2. **Ocean data assimilation** as detailed in the report for sub-project II.3.1.

3. **Atmospheric data insertion and assimilation** as detailed in the report for II.3.1.

4. **Land surface initialization** as detailed in the report for II.3.4

5. **Sea ice initialization** as detailed in the report for II.3.1. This procedure should impart some skill for seasonal prediction of sea ice, the extent of which is being evaluated.

6. **Implementation of climate trends** due to changing anthropogenic radiative forcing. The potential for improving seasonal forecast skill when such trends are taken into account was demonstrated in a study of the HFP2 forecasts by G. Boer (2009, *Atmos-Ocean* in press as per report for II.3.3).

7. **Ocean spectral nudging** as developed under sub-project I.1.1 has been implemented in OGCM4 and tested in CCCma climate model through the efforts of D. Wright, F. Dupont and W. Merryfield. (This, to the investigators knowledge, represents the first time ocean spectral nudging has been used in a coupled climate model.) A series of test runs has confirmed that the desired properties of spectral nudging are being realized, namely (i) ocean model biases in the mean climate and seasonal cycle are greatly reduced, and (ii) ENSO variability in the model is not suppressed, and potentially is improved by the suppression of climatological biases. Because spectral nudging uses no future information it can be applied in seasonal forecasts, where the suppression of ocean model biases could lead to improvements in forecast skill. Test forecasts will determine whether such improvement occurs.

Extensive sets of test forecasts examining the efficacy of the above methods for seasonal forecasts are being undertaken by Dr. W-S. Lee. These have determined, for example that insertion of NCEP reanalysis data into the AGCM initialization markedly improves skills in the first month of the forecasts, and for some variables provides a statistically significant second-month improvement as well. Similarly, 3D ocean temperature assimilation using techniques discussed under II.3.1 improves ENSO forecast skill as compared to SST nudging alone, whereas simple assimilation of 3D salinity as well results in further skill improvement.

Based on the status of these development efforts near the end of the reporting period, a configuration will be chosen for the CHFP2 forecasts, and production of those forecasts will begin. Any lines of development that have not been adequately proven at that point will continue to be investigated in a research context, based on whether they might contribute to future improvements in the coupled forecast system.

The CHFP2 forecasts will comprise CCCma's contribution to the WCRP/WGSIP Climate-system Historical Forecast Project (referred to in the milestones as the *COPES TFSP).*

Efforts are underway to determine also the feasibility of CCCma contributing to the two additional, sub-seasonal forecast projects: the US Clivar Hindcast Experiment for Intraseasonal Prediction (aimed mainly at assessing MJO forecast skill) and the 2nd phase of the Global Land Atmosphere Coupling Experiment (GLACE-2). In support of these efforts Dr. Ravindran has carried out a comprehensive assessment of MJO variability in the CHFP2 forecast models. Challenges at this stage appear mainly to involve whether sufficient person-power exists at CCCma to carry out these tasks rather than any technical issues.

Decadal forecasts can be carried out using a similar (perhaps identical) forecast system configuration as in CHFP2. Such forecasts have been requested as part of the CMIP5 intercomparison for the next IPCC assessment, and it is anticipated they will be carried out in the next reporting period.

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 Merryfield et al. (2009) describe the initial CHFP forecast system and also analyze results from the large suite of coupled model predictions that constitute CHFP1. See the discussion of CMIP1 under II.3.2. Boer (2009b) also presents some of these results.

The continuing development of new and more sophisticated analysis and post-processing approaches is an important part of GOAPP and SIP in general. Because forecasting on these timescale is so difficult at the mid-latitudes of Canada and elsewhere it is important to access all sources of skill that may exist. The HFP2 four-model ensemble of seasonal hindcasts provides a "test bed" for these approaches which may then be applied both to the current operational 2-tier forecast system but also directed toward the future 1-tier coupled CHFP-based forecast system. A paper documenting the performance of the HFP2 four-model ensemble of seasonal hindcasts and, in particular, investigating techniques to combine and calibrate multimodel hindcasts has been accepted for publication in Atmosphere-Ocean (Kharin et al. 2009). This paper also examines the dependence of skill of seasonal predictions on the ensemble size and the number of models in a multimodel ensemble.

Regression techniques to adjust forecasts (some of which were considered in Kharin et al. 2009) may not always work well since data samples available for training a statistical model are relatively short. A novel technique to improve the robustness of a linear regression method by taking into account seasonal and spatial dependences in model forecasts and in the observations was developed and tested on HFP2 seasonal hindcasts. The idea behind the method is to smooth regression coefficients estimated for each grid point and each forecast season both spatially and temporarily. The technique utilizes hindcasts for all 12 rolling seasons which effectively increases the training sample size. The results indicate that skill score improvements using the proposed method can be substantially larger than those obtained by a conventional linear regression technique. A paper describing the method and the results is currently in preparation by Kharin. This approach also allows one to consider more complex multivariate regression techniques to improve seasonal forecasts, in particular, of precipitation which is notoriously unskilful in the extra tropics in general, and in Canada in particular. Preliminary results indicate that skill of deterministic seasonal precipitation forecasts in Canada are modestly improved using multivariate predictors in combination with the proposed smoothed-regression method. A further development which is currently underway is to apply this approach for calibrating probabilistic seasonal forecasts, and possibly proposing it for the operational use at the CMC. All of these techniques may potentially be applied to CHFP2 results.

Related investigations by Finnis and Hsieh on both CHFP and HFP2 data sets have compared a modern nonlinear robust machine learning method, namely support vector regression (SVR), with traditional linear regression (LR) in post-processing the GCM forecasts, and found that both methods added value to the raw GCM temperature and precipitation forecasts, with SVR being able to improve significantly on LR in precipitation forecasts (especially in correlation skills). Presentations of this work were given at the CMOS Congress in Halifax in June 2009 and will be given at the MOCA conference in Montreal in July 2009. A paper will be submitted during summer 2009.

The analysis of trend in HFP2 data (Boer, 2009c) is now in press and has helped motivate the inclusion of GHG forcing in experiments with the coupled model for CHFP2 which also shows sensitivity to the presence (or lack of) this forcing in seasonal prediction skill. The Boer and Hamilton (2008) study of the influence of the QBO on extratropical predictive skill reported in the last Annual Report is being extended to the study of seasonal predictions made the NOAA coupled forecast system. This system is reputed to be able to predict (sustain) the QBO for some period and should be able to access additional QBO skill but this is yet to be determined. Although additional QBO-related skill may not be large, any increase is welcome and there are implications for future version of the CHFP.

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) which is being prepared for the Third World Climate Conference (WCC3).

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.

The first milestone for the past year was the completion of the bias - correction of the NCEP reanalysis data following the methods of Berg et al (2005). The observational data sets required for this project are air temperature, humidity, precipitation and radiation. A preliminary comparison of the global bias-corrected output with the Canadian precipitation analysis was presented at the CMOS 2008 conference. The final components of the bias-corrected meteorological data set were completed in September of 2008.

The second aspect of this milestone was the development of the offline Canadian Land Surface Scheme (CLASS) model runs to generate the initialization soil moisture and land surface fields. Due to the availability of observed datasets for the bias-correction, the CLASS model runs span the period from 1979 to the end of 2007 at a half hourly time step. The offline CLASS was run at the CCCMA T63 grid spacing resulting in almost two thousand land points of soil moisture data. Preliminary Soil moisture and land surface fields were delivered to the CCCMA in March of 2009.

As of April, 2009 we are continuing with two significant tasks. Firstly, we are examining the realism of the soil moisture fields using any available data available across the globe. For our second task it is necessary to provide any assistance or supply additional fields for the CCCMA forecast model runs as required. The first fully coupled model runs are anticipated to be run in early May, 2009.

Towards the analysis of the soil moisture fields produced by CLASS, MSc student Lisa Courtney has been investigating the factors controlling modelled and measured soil moisture using both these CLASS outputs and an extremely high quality soil moisture dataset available in southern Alberta. Furthermore, PhD student Jon Belanger is performing evaluations of the factors that control soil moisture persistence and its realism in the CLASS.

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 for the proposal 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 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 will develop pre-operational forecast systems and thus facilitate transfer of useful technology from GOAPP to its government partners. The first year of supplementary funding is 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 will cover the whole of the North Atlantic and the adjacent shelves off the east coast of Canada. This will be the first Canadian operational open ocean forecast system that can assimilate altimeter and in situ data, and also provide realistic predictions of mesoscale features such as ocean eddies and meanders in the Gulf Stream. It is important to note that the forecasts generated by the North Atlantic model will be useful in their own right and will be made available to our partners, in particular to DND who have an interest in nowcasts and forecasts of open ocean temperature fields, and also to coastal modellers in DFO who need accurate open boundary conditions for their models.

The targets stated in the proposal for Project 1 are as follows:

- *Development of a pilot forecast system for North Atlantic mesoscale variability with predictions out to 15 days. Model resolution will be ¼ degree and sea ice will be included as a prognostic variable. Prototype to be running by end of year 1.*

- *Provide prototype system to project 2 by the end of year 1 to be extended for global domain activities.*
- *Systematic assessment of forecast skill in operational setting. Comparison with baseline system being developed by CONCEPTS and other systems internationally. Completed during year 2.*
- *Selected products made publicly available through the GOAPP web page. More extensive products (e.g. forecasts of 3D fields of ocean temperature) to partners on request (DND for sound speed calculations, DFO regional modellers for specification of open boundary conditions for regional models). Initial products made available by end of year 1.*
- *Transfer of this pre-operational system to CONCEPTS during year 2.*

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

Progress from July 2008 to July 2009:

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

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

The ***research technician*** has focused on two main areas over the last reporting year: supplying observations for assimilation into the North Atlantic model, and setting up a data storage and dissemination system. Details are given below.

<u>Research Technician Contribution 1</u>: Access to Near Real Time Data. Links to the data streams of AVISO, Environment Canada and BADC have been established. 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. Downloads of twice weekly quality control reports from AVISO are attempted once a day. Any task failure is reported via email to the technician.

<u>Research Technician Contribution 2</u>: Developing a Data Management Strategy. To facilitate the implementation of aspects of the GOAPP data management policy, research was performed regarding the distribution and sharing of scientific datasets via the internet. A number of GOAPP participants provided input. The scientific community has gravitated to two, not dissimilar, solutions, specifically, OPeNDAP (Open-source Project for a Network Data Access Protocol)

and LAS (Live Access Server). Both solutions provide data access and downloading capability (supporting a variety of server and client file formats), augmented with metadata, data subsetting, and security capabilities. Both packages are compatible with a range of operating systems and are freely available open source. Many organizations support both OPeNDAP and LAS data servers. A draft report was written on the design and functionality of OPeNDAP. The specifications for the server hardware for hosting the GOAPP data have been drafted.

Research Technician Contribution 3: Building the Data Management System. Testing of the client and server components of OPeNDAP is being completed. An OPeNDAP client (Matlab OPeNDAP Ocean Toolbox) which integrates with Matlab has been tested. It provided access to OPeNDAP served data and metadata, and converted downloaded data into Matlab format. The testing of the server software was performed on a virtual host. The newest version of the OPeNDAP Hyrax server (OLFS front end, BES back end), augmented with data handlers for netCDF, ASCII, DBF and binary file formats, was installed. The OLFS Java front end server requires Java, Apache Tomcat, and optionally, Apache web server and Apache Ant. The BES C++ back end server requires an assortment of standard development tools and development-version libraries for compilation of the source. The LAS server will be installed and tested in June, 2009. A summary of the capabilities of OPeNDAP and LAS was presented at the annual GOAPP workshop at the end of May, 2009.

Research Technician Contribution 4: Software Development. Matlab routines have been developed for generating statistics such as spatial and temporal means, standard deviations, moving averages and vector to 2-D conversions. Matlab routines have also been developed for reading HDF-SDS format data into Matlab variables and for the extraction of metadata and data structure information as text (e.g., the HDF format AVHRR Pathfinder v5 SST 4km monthly time series dataset). The Matlab routines have been made more flexible by utilizing the "eval" command rather than hard-coding the names of the dataset variables that are being processed, in the routine. Bash shell scripts have been written for invoking Matlab routines that facilitate the processing of collections of files, rather than a single file.

The research scientist has focused on the development of a pre-operational, assimilative forecast model of the North Atlantic. Details are given below.

Research Scientist Contribution 1: Model Development. The NEMO model has been configured for the North Atlantic with a resolution of 1/6 degree in the horizontal and 40 levels in the vertical (to a maximal depth 5500 m). A new temperature and salinity climatology has been generated based on WOA05 and observations from Argo floats and sea level from altimeters using a newly developed de-eddying technique (Higginson, Thompson and Liu, 2009). Significant improvements in the climatology were noted in the Gulf Stream region. A modified form of spectral nudging was developed in order to suppress a nonlinear resonant interaction between the nudges and model state, and then implemented in the North Atlantic model. (The modification involves a new term that nudges the model state according to both the observation and the time history of the state.)

Research Scientist Contribution 2: One Way Coupling of the Ocean Model to an Atmospheric Forecast model. The atmospheric forcing for the ocean model are Environment Canada's mesoglobal GEM forecasts out to 15 days. A one-way coupler was developed; the fluxes from the coupler involve fluxes of heat, salt and momentum and they resolve the diurnal changes.

Research Scientist Contribution 3: Ocean Model Optimization and Evaluation. The ocean model has been spun up from 2003 to 2008, during which time the GEM atmospheric forcing data from 2007-2008 were used twice in succession in order to make the spin up run longer (6+2 years); this was required in order to obtain a stable model state. The results show that the free run of the model can reproduce the main structures of temperature, salinity, sea surface height and currents of the North Atlantic.

Research Scientist Contribution 4: Implementation of the Ocean Data Assimilation System. The assimilation method of Liu and Thompson (2009) has been implemented in the NEMO-based model of the North Atlantic; tests and evaluation of the scheme are underway. A talk on the implementation of the scheme in NEMO was given at the CMOS Annual Congress in early June 2009.

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.1.3 - Delay in the development of both 4DVAR and Green's function methods for NEMO occurred due to a change in direction. The development of a 4DVAR system was to be started by evaluating the adjoint and tangent linear codes of the simplified OGCM written by Dr. Yaremchuk of the University of Hawaii. However, we found significant differences between this simplified model and the NEMO numerical schemes and dynamics and decided to stop developing a 4DVAR system based on this code due to those incompatibilities and its lack of readability. In order to estimate the amount of effort needed to derive tangent linear and adjoint codes from the NEMO code, a pseudo code for NEMO, along with its tangent linear and adjoint codes, were developed. This system was applied to a 1-dimensional configuration of NEMO and part of this work was reported at the 42nd CMOS congress. This exercise demonstrated that the development of a 4DVAR system for the full three dimensional configuration of NEMO would require too much time. So in November 2008, we contacted Anthony Weaver of CERFCAS, France and obtained his 4DVAR system based on OPA8.0 (OPAVAR). Since OPA8.0 shares its numerical schemes with NEMO, we believe OPAVAR can be used to meet our goal of developing 4DVAR system for NEMO. The development of a Green's Function method in NEMO has been delayed because of the unexpected long period required for developing the 4DVAR system.

Project I.1.4 - Delay in transferring the ocean data assimilation methodology from Dr. Thompson's group to the researchers involved including Drs. Wright, Lu and Stacey. This delay has resulted in emphasis being shifted to analysis of results produced with prognostic and spectrally nudged results rather than with assimilation of synoptic data. Emphasis will shift to synoptic variations when the data assimilation methodology is available in the NEMO code.

Project I.1.5 - Withdrawal of PhD student after more than two years in the program: After analysis of the work which the student had carried out before withdrawing, it was decided that better progress would be made by beginning this work anew. Three new master's students (two at the University of Alberta and one at Memorial University) were recruited to work on this sub-project. They have now finished their course work and are learning the model and beginning the analysis of the output of the relevant model fields, as well as processing observational sea ice data. Additionally, to speed progress, and because the new students are masters students, rather than Ph.D. students, aspects of the code modification and running of the model tasks are being carried out by the Investigator. This has allowed for the progress described above on running the model with sea-ice, at different resolutions and with different configurations, etc. The timing is designed to allow the masters students to finish their research (and thus the associated tasks in this subproject) and defend their thesis in fall 2010, just as GOAPP is preparing to finish.

Project I.2.1- Delay in obtaining access to a coupled model: 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 into the final year of the project this is a source of serious concern. We will meet again with our colleagues at EC to express this concern and hope that a GEM-NEMO model becomes available. On our side, Dr. Skachko has devoted a lot of his time to understanding the complex data flow within the GEM model 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.

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 in the second year of research and development activity, 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 - Scheduling change: There are three main reasons why year 1-2 milestones were moved to years 3-4: (i) this has enabled the investigators to take advantage of model improvements undertaken in years 1-2, (ii) an ensemble initialization technique, described under 1.1 above, has become available which is far more suitable for this study the one initially developed, and (iii) year 3-4 milestones under project II.2.1 relating to the "coupling surgery" investigation by Dr. Merryfield and Ravindran were moved to years 2-3 as described in the report for that project.

Project II.3.1 - Challenge due to inability to find a suitable student: Work is being completed using existing staff and resources as no suitable candidate was found.
Project II.3.4 - Delay due to 3 months of parental leave: This resulted in a slight but not significant delay in the delivery of the offline product to the CCCma. During the absence of the researcher, the focus of our analysis was shifted to the evaluation of soil moisture process controls in observational data and the CLASS.

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.

Release of funds: A major deviation has been the release of $22,000 from G. Flato's budget. These funds have been reallocated to the Network Secretariat to support Data Archiving and Data Management and other initiatives.

Release of funds: $6,587 was recovered from J. Fyfe's budget to meet the expected expenditure of funds during 2010.

Reallocation of funds: K. Thompson reported that Y. Liu is now funded by GOAPP Supplementary funding. S. Higginson and E. Oliver, two PhD students under his supervision, are now funded by the money thus freed up. (The GEOIDE funding that covered Simon Higginson finished in March, 2009.)

Redirection of funds: P. Myers reported that, with the withdrawal of the original PhD student, funds that were earmarked for her at the University of Alberta were not used and thus accumulated. To ensure completion of the work by the time GOAPP ends, 2 M.Sc. students were recruited, and thus the accumulated funds will be used towards the funding of these two students over the next year. Since this accumulated funding will not be sufficient to fully fund both students, additional funding will be provided from another grant.

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

Overall the integration and coordination of the research was good. One encouraging trend is the 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.

Extensive research into the most effective methods of data management is an ongoing project being undertaken by F. Woslyng, GOAPP Technician at Dalhousie University.

The GOAPP researchers in the Halifax-Dartmouth area met on a periodic basis at Dalhousie University. Both G. Smith from Environment Canada and L. Parent from Mercator Ocean gave presentations during their visits. All talks are made available on the GOAPP webpage and are listed in Section 4.1 of this report. Activities have been effectively coordinated through email exchanges.

Investigators and collaborators at CCCma at the University of Victoria held bi-weekly meetings to discuss progress and coordinate efforts. 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.

The GOAPP Network sponsored a Science Day on 12 March, 2009 in Victoria. This was an opportunity to brief the GOAPP Board of Directors on the science being tackled by the network researchers. Close to 30 people from GOAPP Themes I and II, the Board of Directors, Environment Canada, Fisheries and Oceans Canada and the Department of National Defence attended the all day meeting. The agenda can be found in Appendix D.

The GOAPP Annual Workshop took place in Halifax on 31 May 2009. 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 (e.g., DRI) and also with fellow Canadian and international scientists.

Some individual activities are listed below:

1. K. Thompson visited the west coast in March 2009 and consulted with T. Wakamatsu at IOS regarding ocean data assimilation.

2. J. Sheng reported that his research team (PhD student J. Urrego Blanco and J. Sheng) worked very closely with F. Dupont, D. Wright and Y. Lu in setting up the northwest Atlantic Ocean model using NEMO and collaborated with K. Thompson, G. Smith, F. Woslyng, and Y. Lin in downloading and evaluating the 5-day reanalysis data produced by the BADC.

3. Dan Wright's group has actively assisted other groups with the setup and use of the NEMO model in different areas. His group has also actively exchanged information on model developments with the NEMO developers group.

4. Paul Myers has had active collaboration with Anne-Marie Treguier, Claus Boning, Arne Biastoch and other DRAKKAR scientists on understanding drift in NEMO simulations – as part of this work, he has been provided with the fields from the French G70 ORCA025 hindcast simulation and the German KAB001, KAB002 ORCA025 hindcast simulation. The results from the G70 ORCA025 hindcast were also obtained independently from G. Smith under project I.1.4.

5. P. Myers obtained Canadian Ice Service sea-ice fields through discussion with Canadian Ice Service personnel.

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. Close ties have also been maintained with DFO's new Centre for Ocean Model Development and Application (COMDA); D. Wright and M. Foreman are on the COMDA scientific steering committee as well as being involved as theme leaders and SSC members for GOAPP.

3. P. Myers reported interactions with Mark Buehner of the Data Assimilation and Satellite Meteorology Research Section of EC on assimilation plans and approach, as well as acquiring Canadian Ice Service data to use for assimilation and validation.

4. Some GOAPP researchers are partially funded by government. For example, T. Wakamatsu receives 50% of his salary from DFO and works part time at DFO-IOS and approximately 90% of Z. Wang's salary is provided by COMDA and other DFO project funds.

University: There are ten universities participating in the GOAPP project. 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: We have made the spectral nudging method known to the French-based Mercator and DRAKKAR groups and let them know that we will help them to use the method if requested (D. Wright). Collaboration has continued with Anne-Marie Treguier, Claus Boning, Arne Biastoch and other DRAKKAR scientists on understanding drift in NEMO simulations. He 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).

- The development of a northwest Atlantic Ocean model using NEMO. The model is forced by 6-hourly surface wind, heat and freshwater fluxes, with model open boundary conditions specified from 5-day reanalysis data produced by BADC. Both the spectral nudging method and semi-prognostic method were used in the model code.

- Spectral nudging has helped us to achieve significant advances in modelling the mean state and variability in ocean conditions. We have also achieved greater understanding on the physical causes of bias and drift in prognostic eddy-permitting simulations of the North Atlantic.

- The analysis of trend in HFP2 data has indicated the potential importance of external forcing mechanisms, such as greenhouse gasses, for seasonal to interannual prediction and has motivated their inclusion in CHFP2.

- The effect of climate change on the internal variability and decadal potential predictability of temperature and precipitation has been analyzed in results from the CMIP3/IPCC archive of coupled model results. A warmer world sees a decrease in the variability of annual mean temperature at extratropical latitudes and an increase in the tropics. Precipitation variability increases at all latitudes. Decadal potential predictability of the internally generated component decreases in a warmer world.

- A novel post-processing methodology has been developed to improve seasonal forecasts, in particular, of precipitation which is notoriously unskilful in the extra tropics in general, and in Canada in particular. A complementary approach applies a modern nonlinear robust machine learning method to the post-processing of forecasts and also promises an increase in skill.

- Decadal potential predictability results have helped motivate the new WCRP/IPCC effort in decadal prediction as part of the fifth Coupled Model Intercomparison Project (CMIP5) which will add a new source of information to the next IPCC AR5 Working Group I Assessment.

- With regard to sea ice, we have improved our understanding of the base sea-ice representation and dynamics of water mass spreading in the Labrador Sea in the NATL4 configuration, completed simulations of sea-ice fields in 2003 and 2005, with and without assimilation, developed a greater understanding of the causes of bias and drift in prognostic eddy-permitting simulations of the North Atlantic, developed advanced data assimilation scheme for ocean studies and a sea-ice data assimilation scheme.

- We have completed and archived a 30-year, half hourly, data set of global soil moisture conditions, snow water equivalence and other components of the land surface hydrology. These initial land surface states are being used by the CCCma to evaluate the impact of the land surface hydrological state on seasonal forecast skill. This data set and the product will be of use for evaluating the land surface hydrological cycle from the fully coupled CGCM3.

- We have now developed a set of tools for the offline calculation of soil moisture fields using CLASS. We anticipate that this software will be useful for further studies and particularly in the characterization and possible forecasting of drought in the prairies.

- A simple atmospheric data assimilation method developed for initializing seasonal forecasts is being applied to the initialization of perfect model predictability experiments that contribute to improved understanding of the factors that limit current forecast capabilities.

- The initial set CHFP1 of coupled model seasonal forecasts has been completed, analysed and results have been written up. Building from this effort, numerous lines of forecast system development have been undertaken in conjunction with a large set of test forecasts to assess impacts of system improvements. A convergence of these efforts is influencing the determination of the system configuration for CHFP2.

- Spectral nudging has been implemented in the CCCma coupled modelling system and its influence on model simulations of observed variability will be evaluated over the final year of the project.

- The first milestone on the diagnostic evaluation of atmosphere-ocean cross-correlations in a long coupled CGCM run has been achieved, and considerable progress has been made with respect to the second milestone in that twin experiments have been carried out for independent and joint assimilation using a simplified state space model representation. Similarly, the NMC method has also been carried out for the simplified state space model, which is one of the milestones for 2009-2010. These experiments will pave the way for implementation of the fully coupled GEM-NEMO system.

- A fully coupled global model is now available that includes 3-D ocean data assimilation, along with atmosphere, sea-ice and land-surface initialization. This model has been used to undertake extensive historical forecasts and will serve as a contribution to the international CHFP project and the WCRP CMIP5 coordinated experiments aimed at providing input to the next IPCC Assessment.

- Significant advances have been made in modelling the mean state and variability in ocean conditions through model improvements and data assimilation advances. We look forward to examining the effects of these advances with synoptic variability assimilated and with the ocean model coupled to Environment Canada's state-of-the-art atmospheric model.

- Better ways of assessing the performance of models have been developed and also better ocean data assimilation schemes that are being used to develop a pre-operational forecast model of the North Atlantic for a range of practical applications. The work on the MJO is also leading to insights into processes that may provide better, long term (tens of days) forecasts of the state of the coupled atmosphere-ocean system.

- Mean sea surface topography estimates for the North Pacific and its continental margins were computed using a high resolution model and shown to compare favourably with satellite altimetry and coastal tide gauge values.

- A data assimilation scheme based on SEEK Kalman Filter was developed and applied in hindcast study of the Labrador Sea.

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 a "made in Canada for Canada" system.

- **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 (most notably W. Merryfield) on the west coast and oceanographers (university and DFO) on the east coast.

The tools and data sets created in this project are currently being used to develop a method for improving Statistics Canada's Canadian Crop Assessment Program (CCAP).

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

  The initial CHFP publication by Merryfield et al. (2009) has shown that for seasons (mainly winter) where ENSO most strongly affects surface temperatures over Canada, the simple, first-attempt CHFP1 forecasts using a single, "off-the-shelf" version of the CCCma climate model outperforms on average the four-model two-tier system that forms the basis of current operational seasonal forecasts.

  Novel post-processing methodologies for seasonal forecasts have been developed and are expected to further improve skill.

  It is anticipated that the soil moisture products will be useful for improving prediction in streamflow forecasts and in crop condition.

- **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.

- **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. Eric Dombrowsky, Scientific and Technical Director, of MERCATOR OCEAN is an active member of the GOAPP Board of Directors who also participated in the Victoria Board of Directors' Meeting. He reinforced our efforts for cooperation with his organization.

  There is a considerable connection between Theme II research and international efforts in the production of a complete suite of CHFP2 forecasts in conjunction with the WMO/CLIVAR/WGSIP CHFP intercomparison project. Participation is also foreseen with the US CLIVAR Hindcast Experiment for Intraseasonal Prediction and to the 2nd phase of the Global Land Atmosphere Coupling Experiment (GLACE-2). Finally, decadal predictions and our DHFP (Decadal Historical Forecasting Project) will be undertaken in conjunction with the WMO/WGCM/WGSIP fifth Coupled Model Intercomparison Project (CMIP5) as a contribution also to the Intergovernmental Panel on Climate Change (IPCC) fifth Assessment Report (AR5).

  Dr. Ben Kirtman, a member of the GOAPP Board of Directors gave a presentation titled: "Seamless Climate Prediction from Days-to-Decades" at the GOAPP Science Day in Victoria, BC on March 12, 2009. He also participated in the Board of Directors' Meeting the next day.

- **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 will also make 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.

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. For example, CFCAS funded 90% of F. Dupont's salary, 50% of T. Wakamatsu's salary and 10% of Z. Wang's salary. The remainder of the salaries for these individuals were covered by DFO. CFCAS provides full travel and publication support for Dupont and Wakamatsu while DFO covers these costs for Wang.

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. 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.

2. T.Wakamatsu (IOS) received approximately 50% support from the DFO Centre for Ocean Model Development and Analysis (COMDA) program.

3. Dr. Berg reported that J. Belanger and L. Courtney are funded through a separate funding source.

4. 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

5. Dr. Wright reported that Dr. Wang has made significant contributions to numerous aspects of this project. He is fully supported as a DFO employee by contributions from the DFO Center for Ocean Model Development for Applications and by the Canadian Space Agency. (Total cost is approximately $70K/year.)

6. Part of the work E. Demirov's project in Memorial University is done by students who are supported from his NSERC grant and additional funding from another CFCAS project.

7. 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

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 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 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. This 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 2009: Increasing trend of synoptic activity and its relationship with extreme rain events over central India. *Journal of Climate,* accepted pending revision.

Bakalian, F., H. Ritchie, K. Thompson and W. Merryfield, 2009: Coupled principal component and redundancy analyses of global SST-SLP data fields, Journal of Climate (in preparation).

Boer, G.J., 2009a: Changes in interannual variability and decadal potential predictability under global warming. J. of Clim. doi:10.1175/2008JCLI2835.1 (early online release)

Boer, G.J., 2009b: Decadal potential predictability of 21st century climate. Under revision for Climate Dynamics.

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

Boer, G.J. and K. Hamilton, 2008: QBO influence on extratropical predictive skill. *Climate Dynamics*. doi:10.1007/s00382-008-0379-5.

Dupont, F., Lu, Y., Wang, Z., Wright, D.G., 2009: Effects of thermal and wind forcing in a model study of Arctic sea-ice changes, submitted to GRL, under major revision.

Foreman, M.G.G., W.R. Crawford, J.Y. Cherniawsky, J. Galbraith. 2008: Dynamic ocean topography for the Northeast Pacific and its continental margins. Geophysical Research Letters, 35, L22606, doi: 10.1029/2008GL035152.

Higginson, S., K. Thompson, Y. Liu, 2009: Estimating climatologies for the Argo period: Dealing with noise due to mesoscale variability. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Holloway, G. and Z. Wang, 2009: Representing eddy stresses in an Artic (global) model. Journal of Geophysical Research. In Press.

Liu, Y. and K. Thompson, 2009: Predicting Mesoscale Variability of the North Atlantic Using a Simple Method for Assimilating Argo and Altimeter Data. Monthly Weather Review. In Press.

Kharin, V., Q. Teng, F. Zwiers, G.J. Boer, J. Derome, J.-S. Fontecilla, 2009: Skill assessment of seasonal hindcasts from the Canadian Historical Forecast Project. *Atmos-Ocean* (accepted)

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)

Meehl, G., L. Goddard, J. Murphy, R. Stouffer, G.J. Boer et al., 2009: Decadal prediction: Can it be skillful? Accepted for publication, *Bull. Amer. Meteor. Soc.*

Myers, P.G., S.S.P. Rattan, A-M Treguier, S. Theetten, A. Biastoch and C. Boning ,2009: Understanding Drift in the Labrador Sea in Eddy-Permitting Numerical Models, to be submitted to Ocean Modelling, June 2009

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 (in draft).

Thompson, K., J. Huang, M. Veronneau, D. G. Wright and Y. Lu, 2009: The Mean Surface Topography of the North Atlantic: Comparison of Estimates based on Satellite, Terrestrial Gravity and Oceanographic Observations. Journal of Geophysical Research. In Press.

Wakamatsu, T., M.G.G. Foreman, P. Cummins and J.Y. Cherniawsky, 2009: On the influence of random wind stress errors on the four dimensional, mid-latitude ocean inverse problem. Monthly Weather Review, in press.

Zhang, X., Y. Lu and K. R. Thompson, 2009: Sea level variations in the tropical ocean and the MJO. Journal of Physical Oceanography, In Press.

J. Zhu, E. Demirov, 2009: Interannual variability of the Labrador Sea: Results from eddy permitting simulations. To be submitted to Geophys. Res. Lett. before the end of June 2009.

J. Zhu, E. Demirov, 2009: Water masses characteristics and flow regime in an eddy permitting model: impact of the model bias. To be submitted to Ocean Dynamics before the end of June 2009.

Oral and Poster Presentations/Conference and Workshop Proceedings

Bakalian, F., H. Ritchie, K. Thompson, and W. Merryfield, 2009: Redundancy analyses of the coupled atmosphere-ocean system and joint assimilation, 13th conference on integrated observing and assimilation systems for atmosphere, oceans, and land surface (IOAS-AOLS), (presentation 4B.3). AMS 89th annual meeting in Phoenix, Arizona, 10-16 January, 2009.

Bakalian, F., H. Ritchie, K. Thompson, and W.H. Merryfield, 2009: Redundancy analyses of the coupled atmosphere-ocean system: application to state-space models and global climate data, CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Balmaseda, M., L. Ferranti, F. Molteni, 2009: Impact of recent Artic ice anomalies on the North-Atlantic Summers, CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Balmaseda, M., 2009: Initialization of ocean models for coupled forecasting, 3rd GOAPP Workshop, Halifax, NS, 31 May, 2009.

Belanger, J, A. Berg, G. Drewitt and L. Courtney, 2009: Towards Improved Drought Understanding: Temporal Persistence of Soil Moisture Fields in Alberta, Canada. Joint Assembly of the American Geophysical Union, Canadian Geophysical Union, Geological Association of Canada, International Association of Hydrogeologists and Mineralogical Association of Canada. Toronto Ontario.

Belanger J. and A. Berg, 2009: Characterizing the temporal persistence of soil moisture fields in Alberta. Drought Research Initiative Workshop #4 Regina Saskatchewan.

Berg A. 2009: Applications of the Global Ocean-Atmosphere Prediction and Predictability results to the DRI. Invited presentation to Drought Research Initiative Workshop #4, Regina Saskatchewan.

Boer, G.J., 2008: Prospects for decadal prediction. Invited presentation at the Workshop "Climate Prediction to 2030: is it possible, what are the scientific issues and how would those predictions be used?" Aspen Global Change Institute, 22-28 June, 2008.

Boer, G.J., 2008: "Decadal potential predictability in a multi-model ensemble". Presented at the Workshop "Climate Prediction to 2030: is it possible, what are the scientific issues and how would those predictions be used?" Aspen Global Change Institute, 22-28 June, 2008.

Boer, G.J., 2008a: Changes in the decadal-scale potential predictability of the coupled system with global warming. CMOS Congress, Kelowna, BC, May 25 - 29, 2008.

Boer, G.J., 2008b: Climate trends in seasonal forecasts. CMOS Congress, Kelowna, BC, May 25 - 29, 2008.

Boer, G.J., 2008c: A project for decadal prediction. Invited presentation at the WGCM Paris Working Group Meeting, representing WGSIP and proposing that decadal prediction be part of CMIP5 and a potential contribution to the IPCC AR5. Paris, Sept 22-24, 2008.

Boer, G.J., 2009a: Prospects and Plans for Decadal Prediction. Presented at the Working Group for Seasonal to Interannual Prediction (WGSIP) WG meeting, Jan. 12-14, 2009, University of Miami Rosenstiel School of Marine and Atmospheric Science, Miami.

Boer, G.J., 2009b: Seasonal prediction at CCCma. Presented at the Working Group for Seasonal to Interannual Prediction (WGSIP) WG meeting, Jan. 12-14, 2009, University of Miami Rosenstiel School of Marine and Atmospheric Science, Miami.

Boer, G.J., 2009c: Prospects for decadal prediction. Canadian Centre for Climate Modelling and Prediction (CCCma) Seminar, 29 Jan, University of Victoria.

Boer, G.J., 2009d: What are the prospects for decadal prediction? Invited Joint International Pacific Research Institute (IPRC) and University of Hawaii Department of Meteorology Seminar, 25 February, Honolulu.

Boer, G.J. 2009e: Decadal potential predictability. Presented at the Joint IPCC-WCRP-IGBP Workshop; New Science Directions and Activities Relevant to the IPCC AR5, University of Hawaii, 3-6 March, Honolulu.

Boer, G.J., 2009f: Dreams of a final model. Special invited presentation at the Gates Symposium and the 20th Anniversary Symposium of PCMDI. April 6, Bethesda, MD.

Courtney L. and A. Berg, 2009: Evaluation of process controls on soil water content variability. American Association of Geographers Annual Meeting, Las Vegas, NV, USA.

Courtney, L. A. Berg and G. Drewitt, 2009: Assessing the use of Singular Value Decomposition for Model and Data Inter-comparisons of Hydrologic Process Controls. Joint Assembly of the American Geophysical Union, Canadian Geophysical Union, Geological Association of Canada, International Association of Hydrogeologists and Mineralogical Association of Canada. Toronto Ontario.

Demirov, E., 2009: Development of a Labrador Sea regional model and data assimilation scheme for forecasting on seasonal and interannual time scales. 3rd GOAPP Workshop, Halifax, NS, 31 May 2009.

Demirov, E., J.-M. Brankart, J. Zhu, C. Pike-Thackray, 2009: On the predictive skills of a North Atlantic eddy permitting ocean model. Presentation at the EGU assembly, Vienna, 2009

Demirov, E., J.-M. Brankart, C. Pike-Thackray, 2009: On the predictive skills of the Labrador Sea eddy permitting ocean model. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Drewitt, G., A. Berg, S. Kharin, W-S. Lee, G. Boer, W. Merryfield. 2009: The role of soil moisture initialization in seasonal forecasting. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

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

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

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

Dupont, F., Wang, Z., Wright, D. and Lu, Y.:1958-2006 Reanalysis project using AGRIF for the North Atlantic. Poster presentation at the Fall meeting of the Mercator Group in Toulouse, France. October, 2008.

Hsieh, W., 2009: Robust nonlinear machine learning methods applied to climate and weather. 3rd GOAPP Workshop, Halifax, NS, 31 May, 2009.

Katavouta, A., 2009: Ice modelling and assimilation in GOAPP, 3rd GOAPP Workshop, Halifax, NS, 31 May, 2009.

Lienert F., J.C. Fyfe, and William J. Merryfield, 2009: North Pacific Sea Surface Temperature Climatology and Variability in an Ensemble of AOGCMs. GOAPP Science Day 2009, Victoria, BC 12 March 2009

Lienert F., J.C. Fyfe, and William J. Merryfield, 2009: North Pacific Sea Surface Temperature Climatology and Variability in an Ensemble of AOGCMs. University of Victoria, SEOS Graduate Student Research Workshop 2009, Victoria, BC 20 April 2009

Lu, Y., 2009: Simulations and analyses of global NEMO models. 3rd GOAPP Workshop, Halifax, NS, 31 May, 2009.

Merryfield W., W-S. Lee, G. Boer, G. Flato, S. Kharin, J. Scinocca, Y. Tang, A. Berg and G. Drewitt. 2009: Seasonal forecast development at CCCma: Toward the second Coupled

Historical Forecasting Project (CHFP2). CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Ravindran, A., 2009: Likelihood and predictability of cooling episodes in a warming climate. 3rd GOAPP Workshop, Halifax, NS 31 May, 2009.

Oliver, E. and K. Thompson, 2009: The Madden-Julian Oscillation and Local and Remote Forcing of the Ocean (GOAPP), (session Il4). CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Ritchie, H., F. Davidson, G.M. Flato, Y. Lu, P. Pellerin, W. Renaud, M. Taillefer, K. Thompson, B. Topliss, and D. Wright: Recent developments in the Canadian Operational Network of Coupled Environmental Prediction Systems (CONCEPTS), 16th Conference on Satellite Meteorology and oceanography (poster JP6.9), AMS 89th annual meeting in Phoenix, Arizona, 10-16 January, 2009

Liu, Y., K. Thompson, S. Desjardins, S. Higginson, 2009: Forecasting Mesoscale Variability of the North Atlantic: Towards an Operational System. CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Lu, Y., Z. Wang, D. Wright and F. Dupont, 2009: 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.

Merryfield, W.J. 2009: Likelihood and predictability of cooling episodes in a warming climate. Canadian Centre for Climate Modelling and Prediction (CCCma) Seminar, 19 Feb, 2009, University of Victoria.

Merryfield, W. J., 2009: Review and Discussion of Theme II, 3rd GOAPP Workshop, Halifax, NS, 31 May 2009.

Merryfield, W. J., 2009: Theme II overview. GOAPP Science Day, Victoria, BC 12 March, 2009

Myers, P.G., 2009: Studies of the Sub-Polar Gyre, Physics Department, University of Bremen, July, 2008

Myers, P.G., 2009: C. Donnelly and M.H. Ribergaard, West Greenland Current Variability, Arctic Change Conference 2008, Quebec City, December 2008

Myers, P.G., 2009: Observations and Numerical Studies of Processes in the Sub-Polar Gyre, Department of Earth and Atmospheric Sciences, University of Alberta, January 2009

Myers, P.G., 2009: An Examination of Drift and Processes in the Sub-Polar Gyre in NATL4 and ORCA025, Annual DRAKKAR Workshop, Grenoble, February 2009

Myers, P.G., 2009: Observations and Numerical Studies of Processes in the Sub-Polar Gyre, National Oceanographic Centre, Southampton, United Kingdom, April, 2009

Myers, P.G., Observations and Numerical Studies of Processes in the Sub-Polar Gyre, Ifremer, Brest, May, 2009

Oliver, E. and K. Thompson, 2009: The Madden-Julian Oscillation and Local and Remote Forcing of the Ocean, CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Parent, L., N. Ferry and the Mercator Océan team, 2009: Global Ocean Reanalysis Simulations at Mercator Océan GLORYS1: the Argo years 2002-2008, 9 December, 2008.

Ravindran, A., 2009: Regional influences on climate variability and potential predictability. GOAPP Science Day, Victoria BC, 12 March 2009.

Roy, F., Y. Lu, J-M Bélanger, and H. Ritchie: Validation and analysis if the ¼-deg global NEMO-CONCEPTS ocean model, (session I9). CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Skachko, S., Pierre Gauthier, and J-M. Bélanger, 2009: Parameter Estimation for Data Assimilation with a Coupled Ocean-Atmosphere System. Poster presentation, CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Smith, G, 2009: Title: Development and evaluation of ice-ocean reanalyses using the S(T) assimilation system. Dalhousie Discussion Group, Halifax, NS. 24 February, 2009.

Urrego Blanco, J., R., and J. Sheng, 2009: Development of a nested-gridshelf circulation model using OPA for the eastern Canadian Shelf, Conference of Dalhousie Oceanography Graduate Students, 13 March, 2009.

Wang, Z., Wright, D., Lu, Y. and Dupont, F.: 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.

Wakamatsu, T., M.G.G. Foreman, P. Cummins and J.Y. Cherniawsky, 2008: On the influence of random wind stress errors on the four dimensional, midlatitude, ocean inverse problem, July 2008, Summer School Workshop on Stochastic and Probabilistic methods for atmosphere, ocean, and climate dynamics, Victoria BC.

Wakamatsu, T., M.G.G. Foreman, P. Cummins and J.Y. Cherniawsky, Influence of wind stress error in the 4DVAR basin scale ocean circulation analysis, GODAE Final Symposium, November 2008, Nice, France.

Wakamatsu, T. and M.G.G. Foreman, Observability of a large control vector in a 4D-Var ocean data assimilation, CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Woslyng, F., 2009: OPeNDAP and LAS for GOAPP Data Serving, CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Wright, D.G.: Some effects of mixing on Gulf Stream separation. Presented at the Millimeters to Megameters Symposium, Victoria, August, 2008.

Wright, D.G., Lu, Y., Dupont, F., Wang, Z., Prinsenberg, S. and Hannah, C.: Global and Arctic Modelling at BIO, ASOF Workshop held at BIO, Nov. 2008.

Wright, D.G., 2009: Review and Discussion of Theme I, 3rd GOAPP Workshop, Halifax, NS, 31 May 2009.

Wright, D.G., 2009: Global and North Atlantic Ocean Modelling Studies given at four research institutes in Quindao, Nanjing and Beijing during a research exchange and coordination tour of China in April, 2009.

Zhang, X., Y. Lu, K. Thompson, J. Jing and H. Ritchie, 2009: A modelling study of the responses to MJO wind forcing in the tropical Pacific Ocean (GOAPP), (session Il4). CMOS Congress, Halifax, NS, 31 May to 4 June, 2009.

Zhu, J., and E. Demirov, 2009: Model study of the Labrador Sea variability at interannual and decadal time scales. Presentation at the EGU assembly, Vienna, 2009

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.

Developing a Data Management Strategy: To facilitate the implementation of aspects of the GOAPP data management policy, research was performed regarding the distribution and sharing of scientific datasets via the internet. The scientific community has gravitated to two, not dissimilar, solutions, specifically, OPeNDAP (Open-source Project for a Network Data Access Protocol) and LAS (Live Access Server). Both solutions provide data access and downloading capability (supporting a variety of server and client file formats), augmented with metadata, data subsetting, and security capabilities. Both packages are compatible with a range of operating systems and are freely available open source. Many organizations support both OPeNDAP and LAS data servers. A draft report was written on the design and functionality of OPeNDAP. The specifications for the server hardware for hosting the GOAPP data have been drafted.

Building the Data Management System: Testing of the client and server components of OPeNDAP is being completed. An OPeNDAP client (Matlab OPeNDAP Ocean Toolbox) which integrates with Matlab has been tested. It provided access to OPeNDAP served data and metadata, and converted downloaded data into Matlab format. The testing of the server software was performed on a virtual host. The newest version of the OPeNDAP Hyrax server (OLFS front end, BES back end), augmented with data handlers for netCDF, ASCII, DBF and binary file formats, was installed. The OLFS Java front end server requires Java, Apache Tomcat, and optionally, Apache web server and Apache Ant. The BES C++ back end server requires an assortment of standard development tools and development-version libraries for compilation of the source. The LAS server was installed and tested in June, 2009. A summary of the capabilities of OPeNDAP and LAS was presented at the annual GOAPP workshop at the end of May, 2009.

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?

The GOAPP Science Day in Victoria provided us with the opportunity to publicize GOAPP in government circles, specifically to Environment Canada, Fisheries and Oceans Canada and the Department of National Defence. Furthermore, GOAPP science was highlighted at several CMOS sessions.

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 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 – Will work 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. He is working on predictability in the Labrador Sea model.

Master's Students: 8

L. Courtney (Berg) – Project II.3.4. 50% of her time (funded through other grants)
She has been examining the behaviour of soil moisture generated in CLASS and comparing this to observations in the Agricultural regions of Alberta. Her completion date is August 2009 and we expect 1 publication from her work.

S. Graham (Demirov) – Project I.1.3. She is working on the modeling of the polar and sub-polar ocean.

M. Hakobyan (Demirov) – Project I.1.4. She works on data archiving, data quality control and data management.

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

R. Roche (Demirov) – Project I.1.3. He is doing a model study of interannual variability of deep convection in the Labrador Sea.

ZY Wang (Tang) – Project II.3.1. He focuses on actual application of data assimilation, i.e., the assimilation of sea surface temperature into a realistic ocean model. Graduated in May 2009.

Y. Zang (Demirov) – Project I.1.3. He is working on coupled atmosphere – ocean modeling.

PhD Students: 7

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

S. Donohue (Stacey) Project I.1.4. This PhD candidate at RMC is running POP for the North Pacific, and although he is not directly involved in this project, he has benefited from discussions with Dr Shao, and vice versa. He is modelling the North Pacific, so there is obvious benefit to him that this project is occurring at RMC.

S. Higginson (Thompson) – Projects I.1.2 and I.1.3. He works on coupled ocean – atmospheric model data analysis and study of the Madden Julian Oscillation.

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. He works on 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. Zhang (Thompson) - Projects I.1.2 and I.1.3. (Not funded by GOAPP). He is a visiting student from Nanjing University studying the tropical response of the Pacific to the MJO.

Post Doctoral Fellows: 5

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

Finnis, Joel (Hsieh) – Project II.3.3. Started June 1, 2008. He will be developing better ways to post process global coupled model forecasts.

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

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

J. Zhu (Demirov) – Project I.1.4. He works on development of a regional model of the Labrador Sea, model hindcast and study of interannual variability and its predictability.

Research Associates: 7

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

F. Dupont (Wright) – Project I.1.4. He is an expert in oceanography and computational methods. He is heavily involved in NEMO model development. He has become the unofficial "keeper of the NEMO code".

W-S Lee (Boer) – Project II.3.2.   She is running coupled forecasts, managing and interpreting output and contributing to science. PDF Ravindran is contributing to assessment of subseasonal forecast potential for CCCma models through comprehensive diagnostics of modeled MJO variability.

Y. Shao (Stacey) – Project I.1.4. He is an expert in computational physics, and he does most of the simulations involving NEMO. He is heavily involved in model development.

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. He is working on the development of 4-D VAR method for data assimilation. (Partially funded by GOAPP)

Z. Wang (Wright) – Project I.1.4.   He prepared model forcing fields, performed several numerical hindcast experiments and assisted in the analysis of model results. (Partially funded by GOAPP)

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. 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	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
IOS	Institute of Ocean Sciences
IPCC	Intergovernmental Panel on Climate Change
LAS	Live Access Server
LIM3	Louvain-la-Neuve Ice Model, version 3
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
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

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
Y. Lu	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

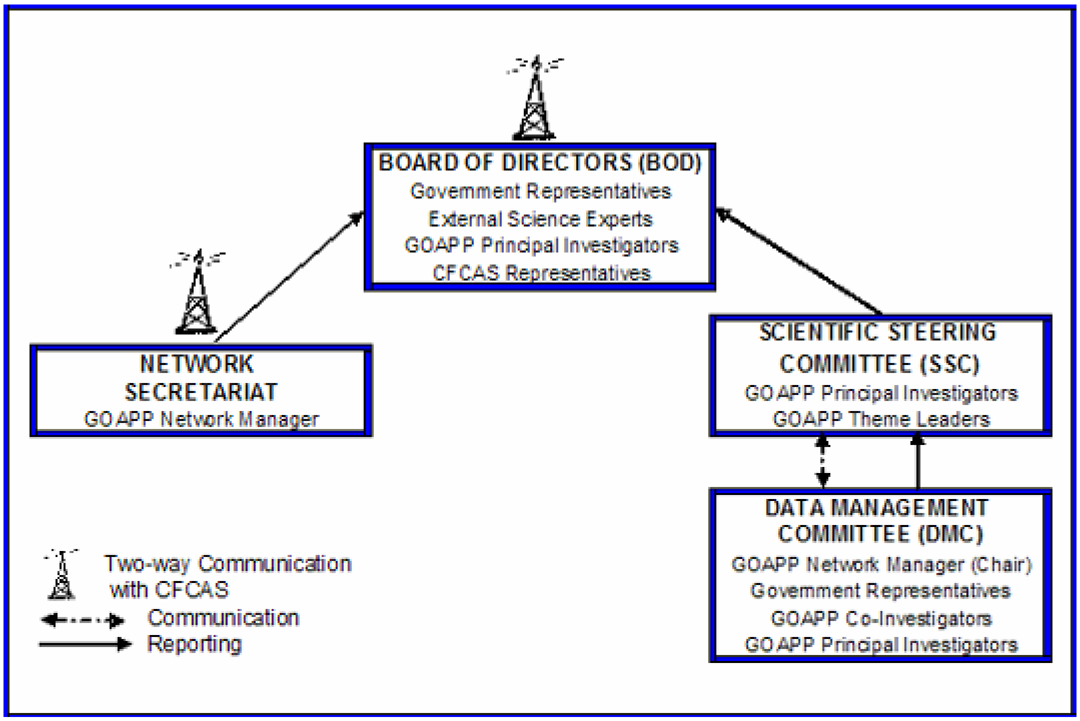
Appendix B

Board of Directors

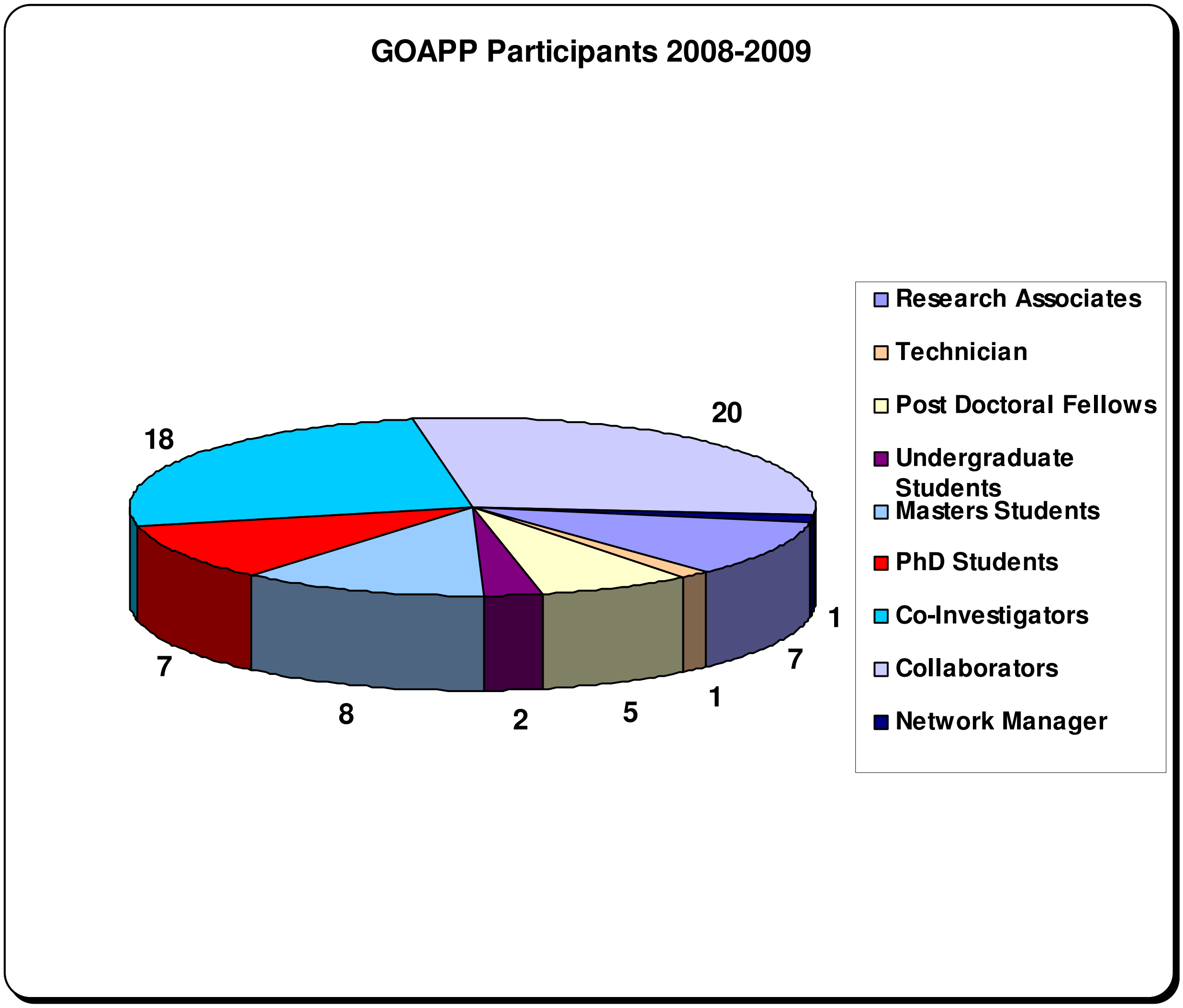
Name	Affiliation
M. Anderson	Department of National Defence
T. Aston (ex-officio)	Canadian Foundation for Climate and Atmospheric Sciences
A. Clarke	Fisheries and Oceans Canada
E. Dombrowsky	MERCATOR OCEAN
B. Kirtman	Rosenstiel School of Marine and Atmospheric Science
C. Lin	Environment Canada
S. Narayanan	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 2008-2009
20
18
1
7
7
8
2
5
1
Research Associates
Technician
Post Doctoral Fellows
Undergraduate Students
Masters Students
PhD Students
Co-Investigators
Collaborators
Network Manager

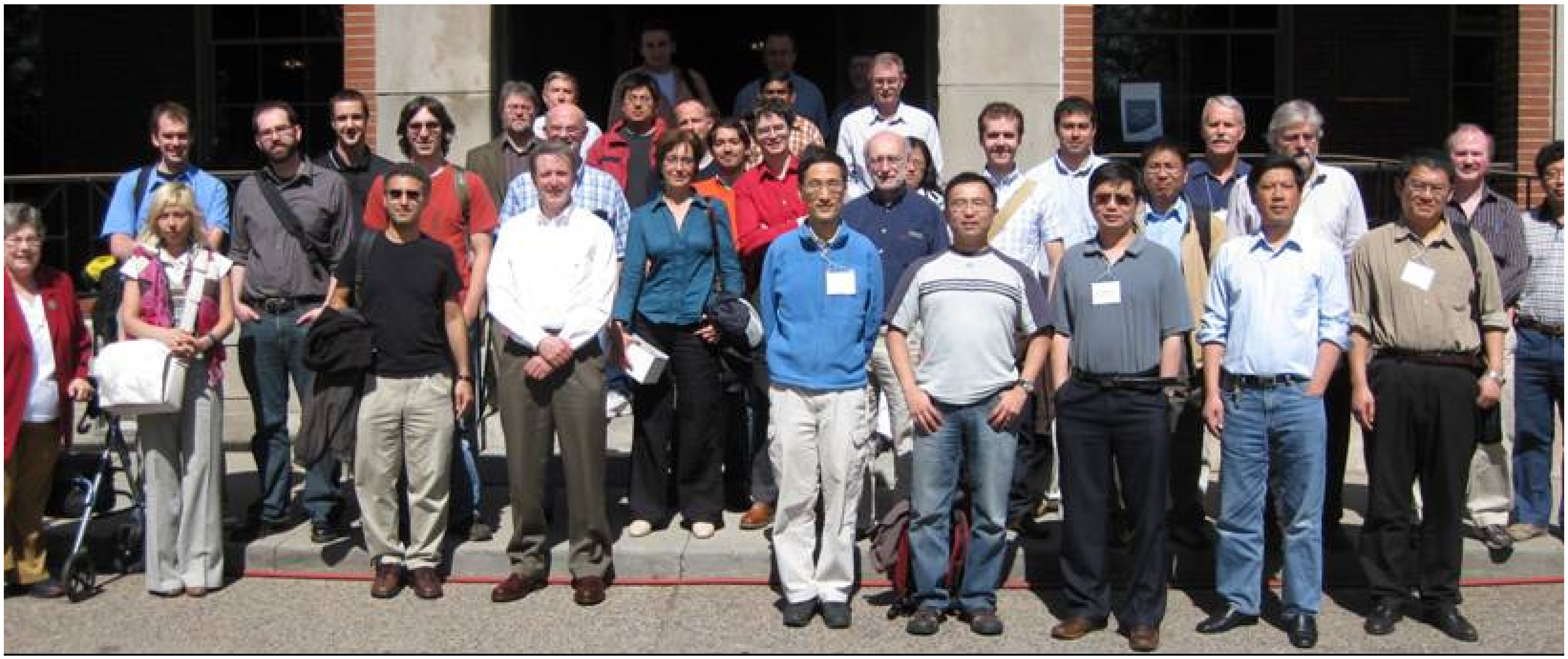
Appendix B

Highly Qualified Personnel (HQP)

Name	Position	Affiliation
Faez Bakalian	Post Doctoral Fellow	Dalhousie University
J. Belanger	PhD Student	University of Guelph
L. Courtney	Master's Student	University of Guelph
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
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
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
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)
Ying Zang	Master's Student	Memorial University
Xu Zhang	PhD Student	Dalhousie University
Jieshun Zhu	Post Doctoral Fellow	Memorial University

Appendix B

GOAPP Workshop May 31, 2009



First row (l to r): Susan Woodbury, Anna Katavouta, Faez Bakalian, William Merryfield, William Hsieh, Tsuyoshi Wakamatsu, Youmin Tang, Yimin Liu, Zeliang Wang
Second row (l to r): Gordon Drewitt, Joel Finnis, Eric Oliver, Hal Ritchie, Magdalena Balmaseda, Carlos Gaitan-Ospina, Fred Dupont, Jacques Derome, Simon Higginson, Jorge Urrego-Blanco, Hai Lin, Keith Thompson, Fred Woslyng, Youyu Lu
Third row (l to r): Colin Pike-Thackray, Pierre Gauthier, Jieshun Zhu, Fabian Lienert, Woo-Sung Lee, Mike Foreman
Fourth row (l to r): George Boer, Ajayamohan Ravindran, Tim Aston
Fifth row (in the shadows): Sergey Skachko, Entcho Demirov, Dan Wright
In attendance at the workshop but missing from the picture: Jinyu Sheng Xu Zhang, Mike Stacey, Yunfeng Shao

Appendix C

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

Lord Nelson Hotel, 1515 South Park St., Halifax, NS – **Admiral and Georgian Rooms**

Sunday, 31 May, 2009

0845	Welcome and Logistics	Hal Ritchie
0900	Review and Discussion of Theme I	Dan Wright
0920	Review and Discussion of Theme II	Bill Merryfield
0940	Development of a Labrador Sea regional model and data assimilation scheme for forecasting on seasonal and interannual time scales	Entcho Demirov
1000	Ice modelling and assimilation in GOAPP	Anna Katavouta
1015	Likelihood and predictability of cooling episodes in a warming climate	Ajayamohan Ravindran
1030	***Health Break***	
1045	Initialization of ocean models for coupled forecasting	Magdalena A. Balmaseda
1130	Simulations and analyses of global NEMO models	Youyu Lu
1155	Robust nonlinear machine learning methods applied to climate and weather	William Hsieh
1215	***Lunch Break (Provided)***	
1315	Links between Themes - Spectral nudging into CCCma's coupled models - Coupled data assimilation - Model developments, e.g., AGRIF, Ice - Travel fund opportunities	 Merryfield/Wright Gauthier/Bakalian Dupont/Wright/Lu Susan Woodbury
1415	Technology transfer - CONCEPTS - Supplementary Project - Data Management (OPeNDAP setup)	 Hal Ritchie Keith Thompson Fred Woslyng
1500	***Health Break***	
	CO-INVESTIGATORS ONLY	
1515	- Plans for final year, e.g., dedicated journal issue or review articles to reach a broader audience, 2010 workshop in Ottawa - Annual report & spending of funds in the final year - Planning for the long term legacy of the Network - Planned presentations by the Principal Investigators in Ottawa in September 2009.	All
1645	Wrap up	Hal Ritchie
1800	CMOS Ice Breaker (be sure to register with CMOS first at the WTCC)	Brewery Market

LIST OF PARTICIPANTS

Magdalena Alonso Balmaseda	ECMWF
Tim Aston	CFCAS
Faez Bakalian	GOAPP Post Doc
George Boer	GOAPP Co-Investigator
Entcho Demirov	GOAPP Co-Investigator
Jacques Derome	GOAPP Co-Investigator
Gordon Drewitt	GOAPP Research Associate
Frederic Dupont	GOAPP Research Associate
Joel Finnis	GOAPP Post Doctoral Fellow
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
Woo-Sung Lee	GOAPP Research Associate
Fabian Lienert	GOAPP PhD Student
Hai Lin	GOAPP Collaborator
Yimin Liu	GOAPP Post Doc
Youyu Lu	GOAPP Collaborator
Bill Merryfield	GOAPP Co-Investigator
Eric Oliver	GOAPP PhD Student
Colin Pike-Thackray	GOAPP Undergraduate Student
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
Youmin Tang	GOAPP Co-Investigator
Keith Thompson	GOAPP Principal Investigator
Jorge Urrego-Blanco	GOAPP Master's Student
Tsuyoshi Wakamatsu	GOAPP Post Doc
Zeliang Wang	GOAPP Research Associate
Susan Woodbury	GOAPP Network Manager
Fred Woslyng	GOAPP Technician
Dan Wright	GOAPP Co-Investigator
Xu Zhang	GOAPP PhD Student
Jieshun Zhu	GOAPP Post Doctoral Fellow

CMOS 2009 Schedule for "Global Atmosphere-Ocean Prediction and Predictability"

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

Impact of recent Artic ice anomalies on the North-Atlantic Summers
Magdalena Balmaseda, Laura Ferranti, Franco Molteni

Seasonal forecast development at CCCma: Toward the second Coupled Historical Forecasting Project
William Merryfield, Woo-Sung Lee, George Boer, Greg Flat, Slava Kharin, John Scinocca, Youmin Tang, Aaron Berg, Gordon Drewitt

The prospects for decadal prediction
George Boer

Impact of Ocean Initialization Strategies on Seasonal Forecast Skill
Woo-Sung Lee, William J. Merryfield, Youmin Tang

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

The influence of the Madden-Julian Oscillation on Canadian wintertime surface air temperature
Hai Lin, Gilbert Brunet

A modelling study of the responses to MJO wind forcing in the tropical Pacific Ocean
Xu Zhang, Youyu Lu, Keith Thompson, Jing Jiang, Hal Ritchie

The Madden-Julian Oscillation and Local and Remote Forcing of the Ocean
Eric Oliver, Keith Thompson

North Pacific Sea Surface Temperature Climatology and Variability in an Ensemble of AOGCMs
Fabian Lienert, John C. Fyfe, William J. Merryfield

Redundancy analyses of the coupled atmosphere-ocean system: application to State Space Models and global climate data
Faez Bakalian, Harold Ritchie, Harold Ritchie, Keith Thompson, William Merryfield

Bred Vector and ENSO predictability in a hybrid coupled model during the period 1881-2000
Youmin Tang

Monday June 1   16:00 - 17:30 (Part 3)

A model study of the inter-annual and decadal variations of sea surface height, temperature, and gyre circulation in the North Atlantic
Zeliang Wang, Dan Wright, Youyu Lu, Frederic Dupont

Simulation of the 2001-2002 Intrusion of Cold Water into the Gulf of Alaska
Shawn M. Donohue, Michael W. Stacey, Jennifer Shore

Simulating the North Pacific Ocean using NEMO
Yunfeng Shao, Michael W. Stacey

Assessment of predictive skills of the Labrador Sea eddy permitting circulation model
Entcho Demirov, Colin Pike-Thackray

Forecasting Mesoscale Variability of the North Atlantic: Towards an Operational System
Yimin Liu, Keith Thompson, Serge Desjardins, Simon Higginson

Development of a nested-grid shelf circulation model using OPA for the eastern Canadian shelf
Jorge R. Urrego-Blanco, Jinyu Sheng

Tuesday June 2 15:30 - 17:00 (Posters)

Nonlinear Post-Processing of Dynamical Seasonal Climate Forecasts
Joel Finnis, William Hsieh, Hai Lin, William Merryfield

Simulation of the Mixed-Layer Depth in the North East Pacific
Shawn M. Donohue, Michael W. Stacey, Jennifer Shore

Parameter estimation for data assimilation with a coupled ocean-atmosphere system
Sergey Skachko, Pierre Gauthier, Jean-Marc Bélanger

Appendix D - GOAPP Science Day

Thursday, March 12, 2009

Coast Harbourside Hotel and Marina, Fairfield Room

Victoria, British Columbia

AGENDA

0845	Welcome and Logistics	Allyn Clarke, Erica Wilson, Keith Thompson, Susan Woodbury
0900	Overview Theme I	Keith Thompson
0945	Overview Theme II	Bill Merryfield
1015	***Refreshment Break***	
1045	Theme II project II.1.2	John Fyfe
1100	Theme II projects II.2.1 and II.2.2	Bill Merryfield/Youmin Tang
1125	Theme II projects II.3.1 and II.4	Greg Flato
1140	Theme II projects II.3.2 and II.3.3	Slava Kharin
1200	Discussion	
1230	***Lunch (Provided by GOAPP)***	
1330	Seamless Climate Prediction from Days-to-Decades	Ben Kirtman
1420	Ziwang Deng (PDF)	Assimilation of Argo profiles for the Pacific Ocean
1435	Woo-Sung Lee (RA)	Ocean data assimilation for CHFP2
1445	Fabian Lienert (PhD)	North Pacific SST Climatology and Variability in an ensemble of AOGCMs
1500	Ajaymohan Ravindran (PDF)	Regional influences on climate variability and potential predictability
1510	Joel Finnis (PDF)	Nonlinear post-processing of GCM climate forecasts
1520	***Refreshment Break***	
1540	Updates on CONCEPTS and GOAPP Supplement	Keith Thompson
1600	Other business	
1630	Adjournment	