CCAF Science Evaluation Team Report on Climate System Processes and Modelling Themes

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Introduction

In the second phase of the Climate Change Action Fund (CCAF) which extended from April 2001 through March 2004, the Science sub-component focused its research support on three themes: climate system processes, climate modelling, and climate scenarios. Nine projects were funded on the theme of climate system processes. These projects were developed in response to a Call for Proposals issued in early 2002. Proponents commenced their investigations in the spring or summer of 2002 with a target for completion of March 2004. In addition, CCAF Science funds were provided to the Canadian Centre for Climate Modelling and Analysis (CCCma) to enhance its modelling capacity in the atmospheric and oceanic components, and modelling infrastructure. This funding ran from late in the 2001/02 fiscal year through to March 2005.

The results of the climate processes and modeling projects supported by CCAF Phase 2 funding were the subject of a February 24-25, 2005 workshop in Victoria, B.C. This document presents an evaluation of those projects. The evaluation team based its assessment of the CCAF projects on presentations and discussion at the workshop, as well as project reports that were available at the time of the workshop. A similar assessment was undertaken of the Phase 1 “Climate Model Improvements” projects, the final report of which is published on the CCAF Science Web site at http://www.ec.gc.ca/climate/CCAF-FACC/Science/reports_e.htm .

Day 1 of the workshop covered Climate System Processes projects, S02-13-02 to S02-13-09, while on Day 2 there was a brief discussion of S02-13-01 followed by presentations related to Modelling work undertaken within S01-14-01

Climate System Processes

Nine projects were funded. While there were some links between them, this report focuses on the performance of individual projects, as viewed by the evaluation team.

Project S02-13-01: The Effect of Arctic Ocean Processes on Global Climate Change

The material available for evaluation consisted of reprints of four published papers and a Final Project Evaluation Report prepared by the proponent. The proponent did not attend the evaluation meeting and there was no presentation. No explanation was provided beforehand.

The initial objectives of this project were to investigate the impact of various components of the climate system on the simulated climate. The components to be studied were air-sea heat and fresh water fluxes, flux adjustments, sea-ice representation, fresh water flow through the Canadian Arctic Archipelago and deep density-driven flow over steep ocean-bottom topography. The published results document several findings, including the importance of the position of the sea-ice edge for North Atlantic deep water formation, the attenuating effect of sea-ice dynamics on climate-warming induced sea-level rise, and a rather surprising linkage between processes determining deep water formation in the Northern and Southern Hemispheres. Although the project reports indicate that the proponent claims to have met the objective regarding the sensitivity to flow through the Canadian Arctic Archipelago and flow over North Atlantic bottom topography, no evidence for these claims was presented. However the other objectives seem to have been met and some unanticipated new results described.

The experiments performed were appropriate to the objectives; the results are well described in the published papers. One could criticise the University of Victoria Earth System Climate Model for employing an over-simplified atmospheric component and wonder how important this might be for the results.

The results contribute to our understanding of the dependence of climate system sensitivity on a number of aspects. They suggest that the North Atlantic thermohaline circulation is reasonably stable to even extreme anomalies in the input of fresh water to the region of deep-water formation.

There appears to be good interaction with the modelling work at CCCma, especially with respect to sea-ice modelling. All of the papers acknowledge the primary importance of CCAF funding and mention other sources of funding that contributed to the work.

Project S02-13-02: Simulating Aerosol-Cloud Interactions and Cloud Radiative Forcing over Hudson Bay

The proposal correctly states the important role of clouds in climate and the importance of aerosols and aerosol chemistry, plus cloud microphysics, in determining cloud properties and stability. The Northern Aerosol Regional Climate Model (NARCM) is an appropriate model to use, and the National Centers for Environmental Prediction (NCEP) reanalysis and Atmospheric Model Intercomparison Project (AMIP) are appropriate sources of input data. Although the proposal (p5) indicated the use of a prognostic aerosol model including anthropogenic emissions, it appears that a rather generic treatment of aerosol and ice nuclei concentrations has been used so far. This seems less satisfactory since air parcel trajectories would affect the critical SO4 concentrations within the model domain.

The proposal focuses on the “dehydration-greenhouse feedback” whereby changes in aerosol properties associated with SO4 concentrations lead to the formation of fewer, but larger ice crystals which precipitate more readily, reducing cloud amount and hence downward long wave radiation, and thereby causing cooling at the surface. Girard and Blanchet had earlier drawn attention to this process and the project aimed to further investigate it using SHEBA data before exploring the effects on the Hudson Bay region. The latter were highlighted as the main focus of the proposal. One puzzling aspect (p4) was a proposal to compare simulations with observations from Resolute. Why not stations on the shores of Hudson Bay?

The final report, dated 1 April 2004, a 6 page technical report and the PowerPoint presentation materials, plus the oral presentation were available for evaluation. Overall the results to date have not achieved the expectations raised in the proposal. This appears to be recognised by the PI and additional work is in hand to more fully address the issues related to Hudson Bay (see Final Report, section 5).

Most results obtained to date, and presented in the talk, are for an Arctic domain centred at 70N, 0E with Hudson Bay excluded, and for February 1990. For the purposes of this project, it would have seemed logical to centre the larger domain at a more westerly location and to include Hudson Bay within it. The larger domain results confirm the findings of Girard and Blanchet, obtained with 1D models. No comparisons of the 3D NARCM model with Resolute data, or with SHEBA data, as indicated in the original work plan (p5, 7), were reported.

The work on the Hudson Bay area seems to be at a relatively early stage, with the written report and oral presentation showing apparently different results from 5-member ensemble runs, both for January 1990 only. Results for this particular month show increased cloudiness along the eastern shore area of Hudson Bay, associated with synoptic scale weather features and the location of the polar front. Other years and other months may be different. Plots in the PowerPoint presentation appear smoother than in the technical report.

Overall we considered that this project had fallen slightly short of our expectations in terms of the quantity and quality of the results obtained. We recognise that further work is in hand (see reports) and hope that this will lead to clearer and better-supported conclusions.

Project S02-13-03: Test and Improvement of Cloud and Radiation Parameterizations in CCCma GCM using SHEBA Data.

Radiation processes and clouds are key items in a climate model, and the improvement of their parameterization is an important task within the GCM (Global Circulation Model) community. The proposal, to make use of SHEBA (Surface Heat Budget of the Arctic Ocean) data to investigate parameterization improvements appropriate to Arctic conditions, was cogently argued and offered as exceptional value for CCAF support.

It is clear from the final report that considerable progress was made. In particular the researchers established a problem with the ECMWF cloud parameterization scheme when applied under Arctic conditions, and established new methods for partitioning condensate between ice crystals and super-cooled water droplets.

The workshop presentation, by Norman McFarlane, provided additional details of the theory involved in the new scheme, and presented results from its implementation in a Single Column Model. The next step appears to be implementation in the full AGCM (Atmospheric Global Circulation Model). This project was excellent value, for it extended MSC-University collaboration and helped train two graduate students. Its implementation appears capable of improving GCM performance with minor changes to the current parameterizations.

Project S02-13-04: Variability Analysis of Aircraft Cloud *In-situ* Observations and Cloud Microphysical Parameterizations for Climate Studies.

The material available for evaluation consisted of reprints of eight published papers and a Final Project Evaluation Report prepared by the proponents. The proponents did not attend the evaluation meeting but there was a visual slide presentation and voice commentary by a telephone link that allowed limited interaction.

The broad objectives of the project were to exploit previously collected aircraft-based, in-situ data on clouds to develop new parameterisations for use in GCMs and to compare them with older schemes. Actual testing in a GCM was supposed to be funded from sources other than the CCAF. Cloud droplet number concentration probability density functions were developed for different cloud types using several different statistical distribution functions. These results show a strong dependence on temperature that is not currently taken into account in the Canadian GCM. Cloud liquid fraction for mixed ice and water phase clouds was parameterised in terms of temperature and total water content.

The aircraft observations obtained by the authors under a range of conditions constitute a valuable resource for understanding how best to deal with the enormous range of variability found in nature for micro-scale cloud variables. The authors have attempted to capture some of the dependence of this variability on the sort of bulk parameters that are available in GCMs. This is a lofty goal and the authors have made a substantial contribution.

New parameterizations have been developed. One would wish for more information on how difficult they are to implement in a GCM, how sensitive the GCM-calculated climate is to them and how much more development work might be required. The proper representation of clouds in GCMs has been identified as one of the most urgent issues facing climate modellers and is highly relevant to refining projections of future climate.

It is clear that the proponents would like large-scale modellers to pay more attention to their results. It is not so clear that they have put a lot of effort into understanding the nature of the scale transfer issues faced by those modellers and working with them to resolve them. There seems to have been a stronger interaction with mesoscale modellers.

It is difficult to determine how this work has levered funding from other sources. Not all of the papers provided acknowledge the CCAF funding and some appear to even pre-date the start of the CCAF funding. Earlier papers certainly produced data for analysis during this project The CFCAS-funded project on modelling of clouds for climate presumably results at least partly from work initiated through this CCAF project.

Project S02-13-05: The Physics and Scaling of Snowcover Processes in Cold Regions: Improving Our Understanding of Key Climate System Processes.

The material available for the review team was one published paper, a very detailed Project Summary Report that lists five other papers either submitted for publication or in draft and the Final Project Evaluation Report prepared by the proponents (PIs).

The objectives of the project were to enhance understanding of the factors affecting the energy and water balances over snow-covered surfaces using detailed data sets and to develop methods of upscaling the representation of these processes for use in numerical models. New snowpack parameterisations were developed for implementation in CLASS based on detailed field measurements. The algorithms were investigated in CLASS and improvements were made in the simulations of snowpack density, snow water equivalent and sensible and latent heat fluxes. Tests were also conducted with WATCLASS, the version that incorporates horizontal hydrology.

The data collected in the BERMS and Trail Valley Creek field measurement programmes will be very useful for validating land surface and hydrologic models. Snow processes over several land cover types were investigated and understanding of the importance of various factors was substantially advanced.

Improvement to the representation of land surfaces, land cover and surface hydrology are all very relevant to the science goal to reduce the sources of uncertainty in climate model predictions of climate change. The interaction with the developers of CLASS and the contribution of this project to CLASS improvement is strong and important. Strong research ties were developed between the MSC and the NWRI as well as with the Mackenzie GEWEX study (MAGS), CRYSYS and BERMS. CCAF, as one of the few funding sources open to government scientists, appears to be the main source of outside funding for this project. Substantial government support in kind was also available.

Project S02-13-06: Climate Research and Monitoring of the Canadian Arctic Archipelago Ocean and Ice Conditions

The project aimed to examine data and develop a numerical model to quantify variability in oceanographic properties such as sea ice conditions and mass and fresh water fluxes in the Canadian Archipelago. Data collected from moorings under the joint PERD/DFO Strategic Science Fund (SSF) project were to be processed, published and compared with a similar data set taken in the 1980s. CCAF funding was also used to speed the development of a finite element numerical code to be used in modelling studies of the Archipelago.

Certainly, it makes sense that Canada should monitor and model the Archipelago. Not only is it a region where global change signals are likely to be large, but fresh water fluxes passing through it are relevant to the global thermohaline circulation, and monitoring sea ice conditions is relevant to a possible future opening of the area to navigation. This study made a small, but potentially useful contribution.

There were three principal objectives

1) To analyse and publish mooring data from the PERD/SSF projects

Most of the data have been processed and published. Mass and fresh water fluxes were estimated for Lancaster Sound. The mass flux was estimated to have both large seasonal and large inter-annual variability. Maximum fluxes were around 1.3 Sverdrups and minima were near zero. It was less clear how one might establish error bars on these measurements, or how the Lancaster Sound flux correlated with the flux into the Arctic through the Bering Strait. Some evidence was presented of a "seesaw" effect, in which flux out of the Arctic through the Sound was anticorrelated with mass flux through Fram Strait. (This anti-correlation was discussed in the presentation, but did not appear in the written final report.)

The data were incorporated into the numerical model, which showed the Lancaster Sound flux to account for about 40% of the mass flux through the Archipelago. Few details of this experiment were given.

Estimates of fresh water fluxes were also made. These proved somewhat problematic since the upper part of the moorings had to be deep enough so as to be safe from ice ridges. This complicates monitoring fresh water fluxes since these are often linked to low salinity, near-surface currents. Moreover, using the model to extrapolate total Archipelago fresh water fluxes from Lancaster Sound fluxes was apparently more difficult than was the case with the mass fluxes.

2) To compare this with 1980s data

This was done, but did not seem to produce results that were particularly interesting or surprising. Specifically, the 1980s (apparently from 1981-83) data showed qualitative differences with data collected between 1998 and 2001, but was more similar to data from 2002. Nonetheless, comparison of the data sets was needed and the result at least serves as a caution against interpreting changes between 2001-2002 as “climate change” rather than as ”variability”.

3) To accelerate development of a numerical code for modelling the Archipelago

It was reported that this goal was met at the 75% level but few details were given (in either the written report or oral presentation). Apparently, the model is at least functional, as it was used (see above) to infer Archipelago fluxes, given measurements of Lancaster Sound fluxes. Our point of view is that developing this sort of model is a difficult task and it is not surprising that results are as yet incomplete. Nonetheless, this sort of model development should clearly be supported. It is not apparent that there is currently any Canadian modelling effort to do high-resolution simulations of the Arctic Ocean. The effort here is hence worthy. Unfortunately, details on the modelling part of the project were sketchy.

Project S02-13-07: Surface Albedo Simulation and Validation for Climate Modelling: Improvements through Rremote Sensing Products

A key parameter in the surface energy budget is the albedo (the ratio of reflected to incoming irradiance on the surface). Although to first order this parameter can be estimated based on land use, vegetation type, snow cover etc. it does vary considerably, for example with the state of health of the vegetation, or the dryness of the soil. Monitoring from space offers the potential of time dependent surface albedo maps and corresponding improvements in our ability to represent this in weather prediction and climate models. The project objectives of developing a land surface albedo model utilising data from satellite-based radiometers, validated against in situ measurements, and then using that model to establish an albedo map for Canada were well worthy of CCAF support.

The PIs produced an excellent, detailed final report on this project, clearly demonstrating that the objectives had been met and exceeded. The report includes details of a new canopy model including effects of reflection beneath the canopy. Comparisons of observed versus previously modelled albedo for the Mackenzie basin showed the strong dependence on snow cover. Albedo maps were produced, and a study made of the impacts of climate change on albedo. An innovative step is to infer biophysical parameters from the radiation measurements as a part of the albedo study.

The presentation was very well constructed, and many of the products of this work are available through the geogratis web site (http://geogratis.cgdi.gc.ca/)**.** The project was run primarily out of CCRS. Two postdoctoral fellows were involved, and there was collaboration with the Universities of Saskatchewan and Alaska.

Project S02-13-08: Multiple Tracer Studies on Sources and Transport of Freshwater through the Canadian Arctic Archipelago and the Hudson Bay Region

The main objective of this proposal was to use a variety of chemical tracers, together with hydrographic data to characterise the sources and variability of fresh water fluxes through the Canadian Arctic Archipelago. The region connects the Arctic to the Labrador Sea and fresh water fluxes from the former to the latter are thought to influence deep ocean convection, which feeds the thermohaline circulation. The results are “sold”, in part, as being important for “calibrating” models. Our perspective is that this would be the case if a more substantial effort in realistic modelling of the Arctic Ocean were underway. Even without a significant link to models, however, the results were interesting and useful: Canadian science should be characterising exchanges through the Archipelago as a first step in monitoring variability and changes in these fluxes.

One interesting result was that the majority of fresh water exiting the Arctic through the Archipelago was of Pacific and runoff origin, with sea ice playing a relatively minor role. This seemed consistent with results from S02-13-06, which also showed sea ice fluxes to be small and with S02-13-09, which showed Pacific waters to be draining from the Beaufort Gyre region.

Another interesting result used total alkalinity measurements to suggest that more/fresher Arctic water with a high river runoff component has been incorporated into the North Atlantic Deep water in recent years.

Overall the main objectives of the project seem to have been met. Much of the data is not “stand alone”, however, and public archiving awaits final processing of related hydrographic data (by other researchers). One area in which expectations were not met had to do with a delay in the processing of Oxygen-18 data. This should have been done as an in-kind contribution from GEOTOP, but instrumentation problems have led to delays. (Oxygen-18 is useful in determining relative contributions of seawater, sea-ice melt water and runoff (plus rain, snow, etc.) to fresh water.) There were also problems, due mainly to funding and logistical limitations, that prevented the determination of water mass residence times in Hudson Bay.

The project seemed to deliver value for money. Much of the funding was used to bring a new, highly competent, research scientist (Kumiko Azetsu-Scott) to Canadian Arctic research. Her research is continuing with funding from other sources.

S01-13-09: Rate Control Processes of Freshwater Withdrawal from the Arctic Ocean through the Arctic Archipelago: Evidence from Physical Properties and Tracer Fields

The main objective of this project was to use tracers and other data (e.g., ice cover) to study processes controlling the rate at which fresh water was withdrawn from the Arctic.

Data from both the Canadian Basin of the Arctic Ocean and from different channels in the Canadian Arctic Archipelago were synthesised and examined.

Some of the most interesting results from the project seemed to come from the Canadian Basin data. The Beaufort Gyre was shown to have decreased in size and shifted eastward in position in the last five years or so. It was also found that nutrient-rich, near-surface Pacific waters are declining in the Beaufort Gyre. The Pacific water mass is being replaced by an Atlantic origin water mass that enters through Fram Strait. Because the Atlantic water has a higher salinity, this means that the Arctic is now storing less fresh water than was previously the case.

It was also noted that, although sea ice cover appears to be in decline overall, regionally, this need not be the case. For example, no evidence was seen for a decline of ice cover in the Beaufort Sea. In a Geophysical Research Letters paper, it was suggested that Arctic warming is likely to lead to an increase of ice in northern Canadian waters. The reason for this has to do with the pathway by which thick, multi-year ice moves through the Northwest Passage. Much of the ice enters through Sverdrup Basin, where it is landfast during much of the year. Movement of ice out of the basin is intermittent. It occurs in conjunction with the breaking up of landfast ice bridges. Warmer conditions are likely to make these bridges form later and break up earlier, thus allowing for a less constricted flow of ice into regions where shipping may be affected. The main implications of these changes seem to relate more to shipping than to the supply of fresh water to the Labrador Sea affecting the thermohaline circulation.

In the Archipelago, the tracer data were organised around three main pathways for flow exiting the Arctic (Southern, Central and North-eastern). Much of this work seems to be ongoing. Clear characterisations of the distinctions between the three pathways remain to be elucidated. Part of the problem here was related to ship scheduling problems relating to sea ice conditions. Nonetheless, most of the objectives were at least partially met and a book chapter on the oceanography of the Northwest Passage was produced.

In addition to the book chapter mentioned above, two journal articles (dealing with the changing hydrography of the Arctic and the relative roles of Atlantic and Pacific origin waters) came out of the project. All in all, the project seems to have been worthy of support.

CCCma Modelling Project

Project S01-14-01: Enhanced Modelling Capacity at the Canadian Centre for Climate Modelling and Analysis

This is an ongoing project (with some of its original CCAF funding re-profiled into 2004/05), closely integrated with the core activities of CCCma. It is estimated that the CCAF support currently represents about 25% of the research support, and has been used to hire several new researchers. The activities supported include improvements to the atmospheric and coupled models, and support of carbon cycle research.

Written reports provided in advance of the workshop were rather minimal, largely because the CCAF funding had not yet ended, but the presentations on day 2 of the workshop were excellent, and the slides used in those presentations give a good account of progress to date.

Overview / Model Infrastructure

Greg Flato gave an excellent overview of the extensive work being undertaken at CCCma in preparation for the upcoming IPCC Fourth Assessment Report. In addition to model development tasks, the group has had to expend considerable time and effort on coping with the change of processor, from a NEC vector machine, to the multiprocessor IBM. While clearly time consuming, there have been some benefits in that the code has had a thorough overhaul, and is now portable to either MPI or vector machines. The CCCma AGCM (Atmospheric Global Circulation Model) and CGCM (Coupled Atmospheric-Ocean Global Circulation Model) models are among the world leaders in this field, which is somewhat amazing given the limited number of researchers involved. The CCCma clearly benefits from having a well-directed, highly competent, and highly dedicated team working on model development and on the analysis and interpretation of the model output. Recent model developments clearly demonstrated the steady improvements being made, despite the time that the group has had to invest in producing output for IPCC assessment reports and other uses.

Atmospheric Modelling Component

John Scinocca, a key member of the team, gave a presentation focussing on some of the technical details of the model, including changes needed for the transition from Vector to MPI processors and the model structure needed to efficiently use the new IBM P690 machine. He also presented material on the numerical treatment of advection, and issues related to radiation. Advection, because it is non-linear in the horizontal domain must be done on a higher resolution grid than that required for physical processes that involve only a single column at each time step. This means that a double spectral transform to and from physical space must be done each time step, once for advection at high resolution and once for columnar physical processes that are calculated on a lower resolution grid. In spite of the overhead for double transforms, doing the radiation and other columnar processes at lower resolution saves wall-clock time.

Knut von Salzen discussed issues pertaining to aerosols and atmospheric chemistry and Jiangnan Li presented details of improvements to the radiation scheme within the AGCM4 model and validation of the schemes currently in use in AGCM3 and CGCM3.

Vivek Arora made a well-illustrated presentation on the land surface components of the carbon cycle. This is essentially an add-on to CLASS, the land-surface scheme integrated with the GCM. CLASS has fixed land surface types and vegetation classes. With the added carbon cycle components there is a representation of dynamic vegetation that responds to the availability of light and moisture to store carbon in leaves and stems of the canopy, roots in the ground and litter that falls to the ground. Plant respiration and decay that releases carbon to the atmosphere is represented as well.

Ocean Modelling Component

Although it was not clear from the written report (which was sketchy), it became clear from the oral presentations that the ocean-modelling portion of this project was entirely worthy of support. Funding allowed CCCma to hire Bill Merryfield to help with the ocean component of their climate model. Arguably, this component of the CCCma climate model has been under-supported in the past. This project helped to correct that.

The main achievements were to improve the model tropical variability and the El Niño-Southern Oscillation and to introduce improved physics schemes that led to improvements in model representation of mixed layer depths, particularly in summertime.

Parts of the improvement were related to increased vertical and horizontal resolution. While seemingly mundane, altering resolution in these models can involve a fair amount of work in that parameters must be re-tuned to minimise model drift. The approach taken here differs slightly from what had been done previously. Previously, the ocean grid was such that four ocean grid cells fit into one atmospheric cell. The current approach uses a 3-to-1 ratio for the relative meridional resolutions and a 2-to-1 ratio in the zonal. This makes sense in light of pole problems relating to the convergence of meridians.

Ocean general circulation models require schemes to represent turbulent mixing in the surface boundary layer. The previous KPP scheme (which accounts for turbulent kinetic energy and shear inducing mixing events) has been updated. This led to significant improvements in summertime mixed layer depths in the Southern Ocean. Wintertime mixed layer depths did not show significant improvements, however. This may present a problem in that the wintertime mixed layers may have a stronger influence on ocean uptake of carbon.

Another change was to account for strong differences that have recently been observed in diapycnal mixing. Mixing is strong over rough topography and weak over smooth topography. This is associated with tidal forcing (and subsequent breaking) of internal waves. It is now common to account for this effect in modern ocean general circulation models; however, the prognostic approach here seemed like a particularly important step forward. Adding the effect has allowed for much improved model results with respect to the basic stratification of the Pacific.

An additional modification was to allow for an anisotropic viscosity, with across-stream momentum mixing being considerably weaker than along-stream mixing. This led to improvement in the Equatorial Undercurrent. It was not clear, however, how this scheme related to other schemes (e.g., the popular Smagorinsky scheme) or whether the across-stream viscosities could be lowered to the point where the linear Munk layer was not resolved at western boundaries.

Based on the presentations one must conclude that CCCma is doing an excellent job and proving excellent value for the CCAF investment. It is crucial that this additional support be maintained at the present level, or higher and that the vital work of this Centre be fully recognized as making a major contribution to Canada's, and the world's climate research.

Concluding Discussion

There was only time for a brief discussion of areas where further work is particularly needed. These areas would include more development and testing of cloud parameterization, further development of the carbon and sulphur cycles, improvement of the linkage between ocean, land and atmosphere components, better representation of the Arctic Ocean Basin geometry and the flow through the Canadian Arctic Archipelago, and studies of freshwater processes and the supply of fresh water to the Arctic and North Atlantic Oceans.