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Title: Modeling Clouds and Climate, Project #LOI-029

Co-investigators:
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Progress report:

MOC2 is focused on improving the representation of clouds in Canadian global and regional models in five different areas:

1) radiation: The development of a new treatment of long and short wave radiative transfer that accounts for sub-grid scale fluctuations in cloud properties.

2) variability: The use of cloud resolving models and aircraft and satellite observations to characterize the cloud vertical and horizontal variability for a broad range of climatically important cloud types, and the development of new methods of representing fractional cloudiness within the GCM grid cell.

3) boundary layer: The development of a new parameterization for turbulent transport within the lowest part of the atmosphere.

4) microphysics: The development of parameterizations which predict representative cloud particle sizes and number and mass concentrations for cloud ice and liquid water, using new microphysical data for cold clouds.

5) dynamics: The development of a new parameterization to represent the sub-grid scale transport of momentum, energy and moisture due to dynamical processes active in extra-tropical cyclones and Arctic weather systems.

Below we compare progress in each of the 5 categories against MOC2 milestones for CFCAS year 2 (which includes the end of NSERC year 2 and the start of year 3).

Radiation: As we reported in FY 1, MOC2-sponsored work has resulted in the development of a new stochastic radiative transfer algorithm (the Monte Carlo Independent Column Approximation or McICA) for use in both single-column and large-scale models (Pincus et al., 2003). Work is now focused on the implementation of a stochastic subgrid-scale cloud generator that was developed and tested during FY 2 by Räisänen et al., (2003). This generator has been installed in the new version of the CCCma-GCM single-column model (SCM15). The generator is also being used as a tool for assessing cloud-radiative sensitivities (Barker and Räisänen, 2003). Testing with McICA and the generator is underway; the new parameterization approach provides an efficient and flexible way to couple radiative fluxes to cloud variability, which is a primary FY 2 milestone. We have also tested McICA in the cloud system-resolving model (CSRM) of Marat Khairoutdinov (CSU) (Ph.D. thesis work of J. Cole). Currently, the McICA method is being tested in the 'super-parametrized' Community Atmospheric Model (CAM) which is being developed at CSU by Randall et al. Cole, Raisanen, and Barker are in the process of performing climate sensitivity experiments with the regular CAM making use of McICA and its generator; we plan similar sensitivity experiments with the CCCma-GCM in NSERC FY 4. A parallel study at ECMWF (Barker, Pincus, and Morcrette) is being conducted, but it is restricted to plane-parallel, homogeneous clouds arranged in maximum-random overlap fashion. The intention is to deduce McICA's impact on short- and medium-range weather forecasts.

A new algorithm for computing absorption of radiation by gases has been developed at CCCma (Li and Barker 2003). This method has been shown to be accurate, efficient, and ideally suited to use with McICA. It is used currently in the newest version of the CCCma-GCM.

Variability/boundary layer/convection: Another year 2 milestone involves the ongoing use of cloud-resolving model studies for parameterization design and testing. As reported in FY 1, we have modified Khairoutdinov's model to include passive tracers, and during FY 2 have employed it to study energy and moisture transport in the trade-cumulus boundary layer (Zhao and Austin, 2003b; Zhao and Austin, 2003c). These LES results will be used to test and improve both the transient cumulus parameterizations of von Salzen and McFarlane (2002) and a buoyancy sorting cumulus parameterization (Zhao and Austin, 2003a). Preliminary tests of the transient cumulus parameterization in the CCCma-GCM have been completed. These model runs highlight the impact of shallow convection in the GCM on both stratiform cloud amount and on the distribution of precipitation between stratiform and convective clouds. (von Salzen, McFarlane and Lazare, manuscript in preparation).

MOC2 cloud simulations have included both continental and tropical convection. The tropical case uses TOGA (Tropical Ocean Global Atmosphere) data; a focus of this work is the role played by large-scale ascent, convective available potential energy and surface potential temperature differences in triggering convection (Nagarajan et al., 2003). Continental convection has been simulated using the CSRM as part of the McICA work of Cole, Räisänen and Barker.

As noted in the proposal milestones, implementing and testing a statistical cloud scheme is an ongoing MOC2 activity. Our focus is on the accurate representation of cold/mixed phase clouds in climate models. For this purpose, the performance of five cloud cover schemes (three statistical and two explicit) and two mixed phase cloud parameterizations have been examined in simulations of Arctic spring-time cloud properties using CCCma SCM13 (Zhang and Lohmann, 2003). Results in this study show that the statistical cloud schemes are generally superior to explicit schemes. However, some shortcomings remain in the commonly used statistical cloud schemes. To find a cloud cover parameterization that overcomes these shortcomings, Junhua Zhang has conducted an initial study on the feasibility of diagnosing Probability Density Functions (PDFs) using model predicted thermodynamic fields. Y. Cheng is currently working to link the statistically based coalescence scheme (Zhang and Lohmann, 2002) with the McICA stochastic cloud generator in the single column model.

Observational work continues using radar and aircraft data. Radar work is focussed on observations made at Ft. Simpson, NWT. Comparisons are being made between these observations and Global Environmental Model (GEM) output. The comparison shows that the observed and modeled cloud amount agrees well in the spring and autumn but that model cloud amount is much too high in the winter. GEM also produces too much cloud in the upper troposphere and too little in the lower troposphere and more cloud layering than observed. Canadian Regional Climate Model runs runs using the Canadian Land Surface Scheme (CLASS) are currently underway and will lead to detailed comparisons with this surface model (Stewart, manuscript in preparation).

Microphysics: During FY2 the UQAM warm cloud resolving model, which uses the MC2 dynamical kernel, has been extended to include a light precipitation ("drizzle") mode. Simulated cloud fields generated by the model have been used to estimate the sensitivity of surface-based retrievals of cloud optical depth to the scattering phase function, surface albedo, instrument noise and the presence of aerosols (Beaulne et al., 2003). Work is also underway on a modified version of the nested Regional Climate Model which incorporates two ice crystal categories, focusing on the use of the model to constrain satellite retrievals of cloud microphysical properties (C. Stefanof, Ph.D. thesis)

Aircraft measurements of cloud droplet number concentration, condensed water content and relative humidity are being used to test GCM cloud cover/microphysics parameterizations (Isaac and Gultepe, manuscript in preparation), and to develop parameterizations for ice and mixed phase (ice/liquid) clouds. The ice phase parameterization schemes have been tested in the CCCma GCM and are now being used by U.S. groups (F. Boudala, Ph.D. thesis). In addition, microphysical variability in nocturnal marine boundary layer clouds has been measured using a new retrieval technique on satellite imagery (Austin and Zhong, manuscript in preparation). Coincident, in-situ aircraft observations are being analyzed as part of the Dynamics and Chemistry of Marine Stratocumulus (DYCOMS) field program.

We are also focusing on studies of aerosol-cloud interaction in both cold and warm clouds. Single column model simulations of the clouds observed during the Arctic FIRE-ACE/SHEBA experiment have been used to estimate the effect of changes in aerosol concentration and ice crystal shape on the snowfall rate in a cold climate (Lohmann et al., 2003). Yanjie Cheng is working on the aerosol effect on rainfall in southern China using decade-long time series of observed aerosol optical depth, visibility and low-cloud amount (Cheng and Lohmann, manuscript in preparation).

Dynamics: Postdoctoral fellows Badrinath Nagarajan and Yongsheng Chen, with the help of Richard Harvey of CCCma, have implemented a slant-wise convective parameterization in GCM13. Preliminary tests have shown that slant-wise convection acts to decrease the strength of the zonal jet and the transport of heat and momentum by transient eddies in mid-latitudes, bringing the results in better agreement with observations. Further testing is underway to arrive at an optimal set of parameters to improve the simulation of the present climate.

Summary: During CFCAS year 2 MOC2 has made significant progress in each of its 5 focus areas. One highlight not mentioned in the topic summaries was the successful port (by Q. Geng) of the newest version of the CCCma single column model (SCM15) to the Linux operating system. This has made possible the collaborative work on McICA and the statistical coalescence scheme mentioned above, and will continue to be an important integration tool as we begin to test the radiation, microphysics, turbulence, shallow and deep convection schemes together in the GCM. As anticipated, not all candidate parameterizations will be selected for combined testing. At the close of FY 2, Roland Stull has decided to focus entirely on his ensemble forecasting research, and no longer needs support for the work on the cumulus potential and transilient turbulence parameterizations. Ming Zhao, who will receive his Ph.D. in September, 2003, will begin a PDF at CCCma which will focus in part on implementing a boundary layer turbulence parameterization in the GCM.

As listed below, during year 2 the project supported 4 PDFs, 8 graduate students, 6 research associates and 4 undergraduate coop students. Eighteen peer-reviewed journal articles (with acknowledgements of CFCAS support) have either appeared or been submitted, and MOC2 provided travel support for 16 conference presentations, as well as a successful December, 2002 workshop which brought together the co-investigators, associates, and several scientists from the international community.

Budget:

CFCAS Fiscal Year[1]	Amount($) awarded by CFCAS	Total CFCAS($) Expenditure to date	Total Cash ($) Contribution Provided by all Partners[2]	Total In-kind Contribution Provided by all Partners
Year 1	34,000	27,032	461,500[4]	
Year 2	179,500	185,982[3]	335,500[5]	
Year 3	189,500		245,500[6]	
Year 4	0		240,000[7]	
Year 5	0		240,000[8]	

[1]NSERC year 1: 2000/12 - 2001/11/30, MSC Year 1: 2000/12/1 - 2001/3/31, CFCAS year 1: 2001/4/1 - 2002/3/31

[2]Partners are Meteorological Service of Canada (MSC) and Natural Sciences and Engineering Research Council (NSERC)

[3]As of March 31, 2003 (expenses include advances of $40,000 to York University and $60,000 to Dalhousie University)

[4]Includes MSC year 1: 118,000, MSC Year 2: 100,000, NSERC year 1: 243,500

[5]Includes MSC year 3: 90,000, NSERC year 2: 245,500

[6]Includes NSERC year 3: 245,500

[7]Includes NSERC year 4: 240,000
[8]Includes NSERC year 5: 240,000

Training of Research Personnel (supported during CFCAS FY 2):[9]

	position	funding	role	dates
Y. Chen (Ph.D.)	PDF	NSERC	slant-wise convection (Yau)	2003/3 - present
B. Nagarajan (Ph.D.)	PDF	NSERC	slant-wise convection (Yau)	2001/4 - 2003/2
P. Räisänen (Ph.D.)	PDF	CFCAS	cloud variability (Barker/Isaac)	2001/9 - present
J. Zhang (Ph.D.)	PDF	NSERC	statistical cloud scheme (Lohmann)	2001/4 - present
L. Berg (M.Sc.)	Ph.D.	NSERC	shallow cumulus parameterization (Stull)	2001/9 - 2002/7
F. Boudala (M.Sc.)	Ph.D.	CFCAS	ice parameterizations (Isaac)	2003/2 - present
Y. Cheng (B.Sc.)	M.Sc.	MSC	cloud microphysics (Lohmann)	2002/9/1 - present
J. Cole	Ph.D	CFCAS	radiation (Barker)	2002/9 - present[10]
P. Lehr (B.Sc.)	M.Sc.	MSC	cloud microphysics (Lohmann)	2002/9/1 - present
C. Stefanof (M.Sc.)	Ph.D.	NSERC	model constraints on satellite retrievals (Blanchet)	2002/12 - present
M. Zhao (M.Sc.)	Ph.D.	NSERC	shallow cumulus parameterization (Austin)	2000/12 - present
J. Zhong (B.Sc.)	M.Sc.	CFCAS	cloud statistics (Austin)	2002/7/1 - present
J. Burford (M.Sc.)	RA	CFCAS	mid-latitude cloud obs/models (Stewart)	2001/4 - present
V. Cochin (M.Sc.)	RA	NSERC	satellite cloud variability (Austin)	2002/4 - 2002/9
H. Modzelewski (M.Sc.)	RA	NSERC	Beowulf cluster/cloud models (Austin/Stull)	2001/1 - 2002/12
Q. Geng (Ph.D.)	RA	MSC	single-column model development (Austin)	2002/7 - present
W. Szyrmer (Ph.D.)	RA	NSERC	high resolution cloud modeling (Blanchet)	2000/12/1 - 2002/12
N. Tukacov (B.Sc.)	RA	MSC	single column model (McFarlane)	2001/7 - 2002/7
C. Seymour	coop	CFCAS	Single column model (Austin)	2002/1 - 2002/9
G. Naoumov	coop	CFCAS	Aircraft data (Isaac)	2003/1 - present

[9]see `http://www.eos.ubc.ca/research/moc2/personnel.html` for a complete list of MOC2 personnel
[10]travel support only

continued	position	funding	role	dates
C. Leung	coop	CFCAS	Single column model (Austin)	2002/9 - present
J. Charbonneau	coop	NSERC	single column model (Stull)	2002/5 - 2002/9

Journal Publications[11]

Barker, H. W., R. Kenji-Goldstein and D. E. Stevens, 2003, Monte Carlo simulations of solar reflectances for cloudy atmospheres, *J. Atmos. Sci.*, 60, 1881-1894.[12].

Barker, H. W. and P. Räisänen, 2003: Neglect by GCMs of subgrid-scale horizontal variations in cloud droplet effective radius: a diagnostic radiative analysis. *Submitted to Q. J. R. Meteorol. Soc.*

Beaulne, A., H. W. Barker and J.-P. Blanchet, 2003: Estimating cloud optical depth from surface radiometric observations: Sensitivity to droplet phase function, surface albedo, instrument noise and aerosols. *submitted to J. Geophys. Res.*

Jeffery, C. A. and P. H. Austin, 2003: Unified treatment of thermodynamic and optical variability of unresolved low clouds, *J. Atmos. Sci.*, 60, 1621-1631.[12]

Lewis, G. A. and P. H. Austin, 2003: Spatial statistics of marine stratocumulus clouds, *submitted to J. Geophys. Res.*[12]

Li, J. and H. W. Barker, 2003: A radiation algorithm with correlated K-distribution. Part I: local thermal equilibrium. *submitted to J. Atmos. Sci.*

Lohmann, U., J. Zhang and J. Pi, 2003: Sensitivity studies of the effect of increased aerosol concentrations and snow crystal shape on the snowfall rate in the Arctic, *J. Geophys. Res.*, 108, doi: 10.1029/2003JD003377

Nagarajan, B., M. K. Yau, and D.-L. Zhang, 2003: Numerical study of the 15 December 1992 TOGA-COARE Mesoscale Convective System: Part II. *submitted to Mon. Wea. Rev.*.

Pincus, R., H. W. Barker and J-J. Morcrette, 2003: A fast, flexible, approximate technique for computing radiative transfer in inhomogeneous cloud fields. *submitted to J. Geophys. Res.*

Räisänen, P., G. A. Isaac, H. W. Barker and I. Gultepe, 2002: Solar radiative transfer for stratiform clouds with horizontal variations in droplet effective radius, *Q. J. R. Meteorol. Soc.*, 129, 2135-2149, Part A.[12]

Räisänen, P. , H. W. Barker, M. Khairoutdinov, and D. A. Randall, 2003: Stochastic generation of subgrid-scale cloudy columns for large-scale models. *submitted to Q. J. R. Meteorol. Soc.*

Stewart, R.E. and J. E. Burford, 2002: On the features of clouds occurring over the Mackenzie River basin. *J. Geophs. Res.* , 107: D23: AAC 18-1-18-13.[12]

Vaillancourt, P. A., M. K. Yau, P. Bartello, and W. W. Grabowski, 2002: Microscopic approach to cloud droplet growth by condensation. Part II: Turbulence, clustering and condensational growth. *J. Atmos. Sci.*, 59, 3421-3435.[12]

Zhang, J. and U. Lohmann, 2003: Sensitivity of SCM simulations of Arctic spring time clouds to cloud cover parameterizations and large scale forcing, *J. Geophys. Res.*, 108, doi: 10.1029/2002JD003136.

Zhang, J., U. Lohmann and B. Lin, 2002: A new statistically based autoconversion rate parameterization for use in large-scale models. *J. Geophys. Res.* , 107(D24), 4750, doi:10.1029/2001JD001484.[12]

[11]see `http://www.eos.ubc.ca/research/moc2/papers.html` for a complete publication list

[12]Also appears (as submitted/in press) in FY 1 progress report

Zhao, M. and P. H. Austin, 2003a: Episodic mixing and buoyancy-sorting representations of cumulus convection, *J. Atmos. Sci.* , 60, 892-912.[12]

Zhao, M. and P. H. Austin, 2003b: Life cycle of numerically simulated shallow cumulus clouds. Part I: Transport, *submitted to J. Atmos. Sci.*

Zhao, M. and P. H. Austin, 2003c: Life cycle of numerically simulated shallow cumulus clouds. Part II: Mixing Dynamics, *submitted to J. Atmos. Sci.*

Conference presentations (MOC2 funded travel, CFCAS Year 2):

MOC2 Workshop, December 12-13, 2002[13]:

H. W. Barker (MSC), J.-J. Morcrette (ECMWF), R. Pincus (NOAA), P. Räisänen (Dalhousie), G. Stephens (CSU): Uncertainty and error in parameterization of subgrid-scale radiative and cloud processes.

Wayne Evans (Trent): The Absorption of NIR Solar Radiation by Precipitation from Clouds.

David Hudak (MSC) and Ron Stewart (McGill): Ground-based radar studies of cloud properties.

George Isaac, Ismail Gultepe, Faisal Boudala (MSC): Cloud microphysics and climate.

Steven Krueger (Utah): GEWEX Cloud System Study (GCSS).

Jiangnan Li (CCCma): Correlated-k parameterization at the CCCma.

Jocelyn Mailhot and Stéphane Bélair (RPN): Treatment of cloud-related processes in GEM.

Badrinath Nagarajan and Peter Yau: Slant-wise convective parameterization and TOGA COARE convection.

Petri Räisänen (Dalhousie) and Howard Barker (MSC): Stochastic cloud generator for McICA radiation calculations.

Graeme Stephens (CSU): Cloudsat and possible contributions to the cloud parameterization problem.

Wanda Szyrmer, Jean-Pierre Blanchet, Alain Beaulne (UQAM): Ice Cloud Cirrus model for the EarthCARE simulator.

Wanda Szyrmer, Jean-Pierre Blanchet, Alain Beaulne (UQAM): Realistic detailed model generated cloud scenes for EarthCARE.

Knut von Salzen and Norm McFarlane (CCCma): Effects of parameterized shallow convection in simulations with an experimental version of AGCM4.

Junhua Zhang and Ulrike Lohmann (Dalhousie): Sensitivity of SCM simulations of Arctic spring time clouds to cloud cover parameterizations and large scale forcing.

Ming Zhao and Philip Austin (UBC): Life cycle of numerically simulated shallow cumulus clouds.

Other presentations in CFCAS FY 2[14]:

Austin, P. H. and G. Lewis, 2002: Spatial variability in boundary layer clouds, GCSS-ARM Workshop on the Representation of Cloud Systems in Large-Scale Models, 20-24 May 2002, Kananaskis, Alberta, Canada.[15]

Barker, H. W.and D. Stevens, 2002: Assessing the integrity of 3D cloud-resolving models using simulated and observed radiances, GCSS-ARM Workshop on the Representation of Cloud Systems

[13]see http://www.eos.ubc.ca/research/moc2/workshop_2002.html for pdf versions of these talks

[14]See http://www.eos.ubc.ca/research/moc2/conference.html for a complete list of presentations

[15]Also appears in FY 1 progress report

in Large-Scale Models, 20-24 May 2002, Kananaskis, Alberta, Canada[15]

Boudala, F. S., G. A. Isaac, S. G. Cober, Q. Fu, A. V. Korolev, 2002: Parameterization of liquid fraction in terms of temperature and cloud water content in stratiform mixed-phase clouds, 11th AMS Conference on Cloud Physics, Ogden, Utah, 3-7 June 2002.[15]

Cole, J., M. Khairoutdinov; H. W. Barker; D. Randall; E. Clothiaux, 2002: Effect of horizontal resolution of radiative transfer calculations on a simulation of continental convection, GCSS-ARM Workshop on the Representation of Cloud Systems in Large-Scale Models, 20-24 May 2002, Kananaskis, Alberta, Canada.[15]

Isaac, G. A., I. Gultepe, S. G. Cober, A. V. Korolev, H. Guan, P. Räisänen, F. Boudala and A. Tremblay,2002: Using in-situ observations of cloud properties to develop and verify parameterizations for large-scale models, GCSS-ARM Workshop on the Representation of Cloud Systems in Large-Scale Models, 20-24 May 2002, Kananaskis, Alberta, Canada.[15]

Lewis, G. M. and P. H. Austin, 2002: An iterative method for generating scaling log-normal simulations, 11th AMS Conference on Atmospheric Radiation, Ogden, Utah, 3-7 June 2002.[15]

Lohmann, U.and B. Kaercher,2002: First interactive simulations of cirrus clouds formed by homogeneous freezing in the ECHAM GCM, GCSS-ARM Workshop on the Representation of Cloud Systems in Large-Scale Models, 20-24 May 2002, Kananaskis, Alberta, Canada.[15]

Lohmann, U. and B. Kaercher, 2002: First interactive simulations of cirrus clouds formed by homogeneous freezing in the ECHAM GCM., 11th AMS Conference on Cloud Physics, Ogden, Utah, 3-7 June 2002.[15]

Lohmann, U.and G. Lessins, 2002: Stronger Constraints on the Anthropogenic Indirect Aerosol Effect by Combining Climate Models and Satellite Observations, Fall Meeting, American Geophysical Union, Eos Trans. AGU, 83(47), Fall Meet. Suppl., Abstract A22E-09.

Perez, J. C. and P. H. Austin, 2002a: A method for the determination of cloud parameters using nighttime MODIS images, 11th AMS Conference on Atmospheric Radiation, Ogden, Utah, 3-7 June 2002.[15]

Perez, J. C. and P. H. Austin, 2002b: Retrieval of boundary layer cloud properties using infrared satellite data during the Dycoms-II field experiment, 15th AMS Symposium on boundary layers and turbulence, , July 15-19, 2002, Wageningen, the Netherlands.[15]

Räisänen, P., H. Barker, G. Isaac, I. Gultepe, 2002: Effects on solar radiative transfer for stratiform clouds due to horizontal variations in cloud liquid water and droplet effective radius, GCSS-ARM Workshop on the Representation of Cloud Systems in Large-Scale Models, 20-24 May 2002, Kananaskis, Alberta, Canada.[15]

von Salzen, K. and N. McFarlane, 2002: Effects of shallow convection on cloud amounts and radiative fluxes in the CCCma AGCM, GCSS-ARM Workshop on the Representation of Cloud Systems in Large-Scale Models, 20-24 May 2002, Kananaskis, Alberta, Canada.[15]

Zhang, J. and U. Lohmann, 2002: Simulation of Arctic cloud properties during the spring season of the SHEBA/FIRE-ACE experiment using a statistical cloud scheme in the CCCma single-column model., 11th AMS Conference on Cloud Physics, Ogden, Utah, 3-7 June 2002[15]

Zhang, J. and U. Lohmann, 2002: Evaluation of cloud parameterizations in Canadian SCM using ARM SGP March 2000 IOP data (case 4), ARM Cloud Parameterization and Modeling Working Group Meeting, Reston, Virginia, November 6-8, 2002.

Zhao, M. and P. H. Austin, 2002: A diagnostic study of buoyancy-sorting parameterizations of shallow cumulus convection, GCSS-ARM Workshop on the Representation of Cloud Systems in Large-Scale Models, 20-24 May 2002, Kananaskis, Alberta, Canada.[15]