NSERC/AES INDUSTRIAL RESEARCH CHAIRS IN CLIMATOLOGY, McGILL UNIVERSITY

ANNUAL PROGRESS REPORT

Lawrence A. Mysak & Charles A. Lin

CRG Report No. 88-1
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NSERC/AES Industrial Research Chairs

in Climatology, McGill University

Incumbents - L.A. Mysak and C.A. Lin

Subject - Annual Progress Report,
(Second Report) March 1988

1. Research accomplished during 1987-88

MYSAK

1) Midlatitude Pacific atmosphere/ocean interactions (with A.J. Weaver) - A theoretical study has been completed of both the steady state and time dependent response of a two-level atmosphere to oceanic heat fluxes. The results help to explain the large-scale statistical correlations McBean and Zhao found in SLP and 700 mb height fields in the North Pacific.

2) Circulation model of the Northeast Pacific Ocean (with P.F. Cummins) - A limited-area quasi-geostrophic model with mesoscale resolution has been developed to study the circulation in the Gulf of Alaska. A long-term integration has been carried out with climatological wind stress forcing. Several statistical properties of the solution have been determined and compare very favorably with in situ and satellite observations.

3) Sea ice extent and anomalies in the Arctic Ocean (with D.K. Manak) - Ice extent and anomalies in the Arctic Ocean as well as in seven subregions (Bering Sea, Beaufort Sea, Hudson Bay, Baffin Bay and Labrador Sea, Greenland Sea, Barents Sea and East Siberian Sea) were studied using 32 years of monthly Arctic sea-ice concentration data on a 1 x 1° grid. Of particular interest is the discovery of a large positive ice anomaly in the Greenland Sea for the 1962-72 period which appears to travel southward into the Labrador Sea at a speed of about 2.7 cm s^{-1}. It is of significant interest to note that this travel speed is roughly the same as the average current speed of the subpolar gyral circulation and the advection speed of the "Great Salinity Anomaly" in the Northern North Atlantic.

4) A simple coupled steady-state Arctic ice-ocean model (with A.J. Willmott) - A thermodynamic reduced-gravity ocean model forced by the wind stress and air temperature has been used to determine the ice-edge position, ice thickness, ocean circulation and ocean temperature in a high latitude meridional channel. The model has been applied to the Greenland and Norwegian Seas, and successfully predicts the climatological position of the ice-edge boundary recently presented in the ice atlas of Manak and Mysak (1987).

5) Physical oceanography of Georgia and Johnston Straits, B.C. (with B. TerHart) - A descriptive study of the fronts and baroclinic and tidal circulation in the B.C. coastal waters has been completed and related to the return migration of the Fraser River sockeye salmon. (Note - This is part of a large DFO/NSERC Strategic grant study which I directed during 1984-87: project MOIST - Meteorological and Oceanographic Influences on Sockeye Tracks.)

6) Geostrophic adjustment and wind-driven spin-up in coarse resolution upper-ocean models (with J.Y. Cherniawsky) - Geostrophic adjustment in one- and two-layer upper-ocean primitive equation models with initially zonal pressure gradients has been examined with and without wind stress forcing. In all cases the initial response consists of inertia-gravity waves which in turn lead to the formation of cycloically propagating numerical-viscous Kelvin waves around the lateral boundaries. In higher resolution models, westward propagating Rossby waves are also generated after the Kelvin waves have been established.

LIN

1) Instability of planetary waves - A high vertical resolution model is used to examine the instability of a baroclinic zonal flow and a finite amplitude topographic wave. Unstable modes characteristic of localized cyclogenesis and of low frequency variability in the atmosphere are found; the results are interpreted in terms of an interaction between forcing and baroclinic instability to create favoured regions for eddy development.

2) The summer Southern Hemisphere wavenumber 5 circulation, and heat transport by baroclinic waves (with A. Chan and Y.B. Chen) - The linear baroclinic instability of the observed latitude/height January 1979 zonal wind of the mid-latitude Southern Hemisphere is examined. The unstable mode at zonal wavenumber 5 bears qualitative resemblance to the observed wavenumber 5 circulation; the latter frequently dominates the summer Southern Hemisphere circulation. A nonlinear version of the model is used to examine the stationary and transient heat transports of baroclinic planetary waves.

3) Diagnostic analysis of general circulation model (GCM) data (with Y. Laberge and J. Derome) - A sophisticated software diagnostic package for analyzing GCM output, first developed at the Canadian Climate Centre (CCC) of the Atmospheric Environment Service (AES), has been implemented on the McGill computing system. The package is used to analyze the potential vorticity distribution in data from the atmospheric GCM of the CCC. The results are interpreted in terms of the mean flow being a finite amplitude solution of the potential vorticity equation, as well as being maintained by eddy forcing.

4) Isopycnal diffusion in the ocean (with W. Gough) - A two-dimensional latitude/depth box diffusion model has been formulated to compare the effects of lateral and isopycnal diffusion. The results show that both the steady and transient responses to a given surface

forcing are different with the two diffusive parameterizations. This can have significant impact on simulated climate changes on time scales of tens to hundreds of years. A three-dimensional primitive equation ocean circulation model (Cox-Bryan model) is also used to examine the effects of the two diffusion formulations on active and passive tracer distributions.

5) Diagnostic analysis of CASP (Canadian Atlantic Storms Program) storm (with P. Jarrett and R.E. Stewart) - An analysis of the thermodynamic equation is carried out using CASP data. In particular, the magnitude and distribution of the diabatic forcing due to melting are compared to those of the other terms, such as horizontal and vertical advections. The results are interpreted in terms of modelling studies of melting induced mesoscale circulations.

6) Modelling of diabatically forced mesoscale circulations (with A. Robichaud) - Simple models of flow over an elevated diabatic source and a surface source are formulated. The former is identified as due to cooling by melting and the latter due to land/sea temperature differences. The results show that the strong change in static stability associated with the presence of the melting layer can lead to a resonant amplification of mesoscale perturbations. This mechanism is potentially important for precipitation enhancement due to melting effects.

LIN AND MYSAK

1) Numerical experiments with a 2-layer upper-ocean box model (with J.Y. Cherniawsky and C.W. Yuen) - A 2-layer upper-ocean circulation model with idealized North Atlantic box geometry is spun up using an idealized wind stress forcing function. The results show that characteristic gyre circulations with "fan-out" temperature structures are obtained; potential vorticity is also homogenized in parts of the basin. The deepening and cooling of the mixed layer are comparable to results of analytical models published in the literature.

2) Global 2-layer upper-ocean circulation model forced at the surface (with C.W. Yuen and J.Y. Cherniawsky) - A global 2-layer upper-ocean primitive equation model with realistic continental geometry is formulated. The model is forced at the surface by seasonally varying observed wind stress and heat fluxes as defined by an atmospheric equilibrium temperature. The results show that the mixed layer temperature and depth are well simulated. The currents are too weak, due probably to the coarse horizontal resolution.

Both of the above studies are the first phase of the research aimed at providing, for the first time, an ocean circulation model for coupling to the atmospheric general circulation model of the Canadian Climate Centre for climate studies. A thorough understanding of the ocean model in the uncoupled mode, will be obtained upon completion of this phase of the research.

2. Research team and manpower training (research associates, postdoctoral fellows, and graduate students)

1) Research Associates

MYSAK

Dr. A.J. Willmott, Lecturer, University of Exeter, visitor for summer 1987.

LIN and MYSAK

Dr. J. Cherniawsky
Dr. C.W. Yuen

2) Postdoctoral Fellow

MYSAK

Dr. Rose G. Wood (arrived January 1988), Ph.D. 1987, University of Exeter

3) Ph.D. students

MYSAK	LIN
P.F. Cummins	W. Gough
B. TerHart	A. Robichaud
A.J. Weaver (Ph.D. completed, Oct. 1987)	

4) M.Sc. students

MYSAK	LIN
D.K. Manak	A. Chan
	Y.B. Chen
	P. Jarrett
	Y. Laberge

5) Diploma student

MYSAK

A.M. Allingham

3. Interaction with sponsor (AES) and other organizations

1) Lin (PI) and Mysak continue to work with G. Boer (AES, Canadian Climate Centre (CCC)) under the sponsorship of an NSERC Strategic grant to develop an ocean circulation model for coupling to the AES atmospheric circulation model. (Further details are given above in item 1., LIN and MYSAK.)

2) In October 1987, the Climate Research Group (CRG) hosted a meeting of the Canadian Climate Program Research Committee, which is chaired by Mr. J.A.W. McCulloch, Director General of the CCC, AES. Drs. Mysak and Lin gave presentations at this meeting which described the climate related studies being carried out at McGill.

3) Mysak appointed as 1987-88 tour speaker for the Canadian Meteorological and Oceanographic Society (CMOS) and will give lectures on large-scale atmosphere-ice-ocean interactions to 8 local chapters of CMOS. This will bring him into direct contact with many researchers and managers from AES, DND, DFO, and several universities.

4) Mysak completed his assignment as convenor of IAPSO Symposium on "Pacific Ocean Studies" at 19th General Assembly at IUGG, Vancouver, August 1987.

5) Mysak completed his term as a member of NSERC Task Force on Supercomputing.

6) Mysak appointed a member of NSESC Earth Sciences Grant Selection Committee.

7) Mysak continues to serve as Associate Editor of J. of Phys. Oceanogr. and Editorial Board Member of Geophys. & Astrophys. Fluid Dynamics.

8) Mysak invited to serve as Associate Editor of Atmosphere-Ocean, a CMOS publication.

9) Mysak serves as Rapporteur of Interdisciplinary Section of Academy III (Science), Royal Society of Canada (RSC).

10) Mysak co-chairman of RSC Working Group on Marine and Atmospheric Interactions for the Global Change Program (IGBP).

11) Mysak a member of CNC/SCOR subcommittee on WOCE (World Ocean Circulation Experiment).

12) Mysak and Lin members of AES/DFO Working Group on large-scale atmosphere/ocean models.

13) Mysak, Lin and others from the Dept. of Meteorology, McGill, awarded an NSERC major equipment grant of $198,000 for a super-minicomputer and network system. In September 1987, a PRIME 9755 computing system with 8 MB core memory, 773 MB disk storage, monitors, was installed in the Department.

14) Lin a member of the Local Organizing Committee of the Third CASP Analyses Workshop, held in Montreal, 1987.

15) Lin a member of the CMOS Committee on Education in Meteorology.

16) Lin, and research associates Cherniawsky and Yuen, visited the numerical modelling group of the Canadian Climate Centre, AES, in December 1987. Research progress and future plans in the development of the ocean circulation model for climate studies were reviewed. Cherniawsky and Yuen gave informal presentations.

17) Lin and colleague J. Derome implemented a software diagnostic package, first developed at the CCC of AES, on the McGill computing facility. The package is designed to analyze and display GCM output data.

18) Lin contributes an extended abstract, "A review on general ocean circulation models" to the Report on the Technical Meeting on the Modelling of the Global Biogeochemical Cycle of Carbon, published by the AES, 1987.

19) Lin a participant in the Arctic Regional Modelling Workshop, AES, May 1987. He gave a presentation, "Ocean and sea-ice modelling at McGill".

4. Departmental and university interactions

1) The Climate Research Group at McGill (with Mysak as Director and Lin as charter member) continues to serve as an excellent focus for climate research, and is now attracting many visitors, graduate students, research associates and other senior investigators from North America and abroad. Besides Mysak, Lin and their PDFs, other participants in the activities of CRG include Drs. Davies, Derome, Dunbar, Ingram, Lewis and Orvig. A list of their research interests is given in Appendix 1.

2) The CRG Newsletter, which is issued quarterly, has become a collector's item, and now reaches over 300 readers on an ever-increasing mailing list. Dr. Lin has taken over the editorship of this publication and has just compiled the fifth issue, dated January, 1988. Those wishing to receive future issues of the Newsletter should contact Ann Cossette, assistant to the CRG.

3) A total of eleven CRG reports have now been printed. Included are a number of frequently requested atlases and data reports, as well as preprints of articles submitted to refereed journals. As these reports appear, they are listed in the CRG Newsletter.

4) Mysak gave McGill seminars on air-sea-ice interactions (Meteorol. Dept.) and Large scale air-ice-ocean interaction models and observations (Physics Dept.).

5) Mysak, Lin and Davies jointly offered a course on climatology and climate modelling.

6) Mysak served on faculty search committee in Meteorology Dept.

7) Mysak served on curriculum committee in Meteorology Dept.

8) Mysak served as internal examiner for Ph.D. thesis in Meteorology.

9) Mysak elected for a three-year term as a Faculty of Science Representative on McGill's Senate.

10) Mysak served as a member of Burnside Hall Library and Space Project Group.

11) Mysak gave lectures at St. John's (June, CMOS annual meeting), Vancouver (August, IUGG General Assembly), Stony Brook, S.U.N.Y. (June), UQAR (Oct.), Univ. of Maine (Oct.), Ottawa (Feb., local CMOS chapter).

12) Lin is Chairman of the Departmental Computing Committee. He is also appointed as the Faculty of Science representative to the Subcommittee on Faculty Computing, of the Senate Committee on Computing of McGill University.

13) Lin presented a seminar, "An introduction to chaos" in the Department.

14) Lin presented papers at St. John's (June, CMOS Annual Congress), Vancouver (August, AMS Mesoscale Meteorology Conference), Edmonton (Department of Mathematics, University of Alberta); he is also an invited participant at the NATO Advanced Research Workshop on Ocean-Climate Interactions, to be held at Oxford University in September, 1988.

5. Publications

MYSAK

Journal publications

1987 1. Weaver, A.J., L.A. Mysak, and A.F. Bennett, The steady state response of the atmosphere to midlatitude heating with various zonal structures. Geophys. & Astrophys. Fluid Dyn., in press.

2. Reason, C.J., L.A. Mysak and P.F. Cummins, Generation of annual period Rossby waves in the South Atlantic ocean by the wind stress curl. J. Phys. Oceanogr., 17: 2030-2042.

3. Mysak, L.A., McGill's Climate Research Group. Can. Appl. Math. Soc. Newsletter, No. 23, pp. 1-2; Climatol. Bull., 21(2): 26-27; EOS, 68(22), p.554.

1988 4. Bermejo, B., and L.A. Mysak, A finite element model of the quasi-geostrophic ocean circulation: preliminary results. Atmosphere-Ocean, submitted.

5. Weaver, A.J., and L.A. Mysak, A time dependent model of the atmospheric response to midlatitude heating with various zonal structures. J. Meteorol. Soc. Japan, in press.

6. Cummins, P.F., and L.A. Mysak, A quasi-geostrophic circulation model of the northeast Pacific. Part I: A preliminary numerical experiment. J. Phys. Oceanogr., in press.

7. Willmott, A.J., and L.A. Mysak, A simple coupled steady-state Arctic ice-ocean model. J. Phys. Oceanogr., submitted.

Technical Reports

1987

1. Weaver, A.J., L.A. Mysak and A.F. Bennett, The steady state response of the atmosphere to midlatitude heating with various zonal structures. Climate Research Group Report No. 87-1, Dept. of Meteorology, McGill Univ., 58 pp.

2. Allingham, A.M., K. Hamilton and L.A. Mysak, Climatic Atlas of the North Atlantic - Seasonal sea level pressures and sea surface temperature anomalies, 1919-1979. Climate Research Group Report No. 87-4, Dept. of Meteorology, McGill Univ., 248 pp.

3. Weaver, A.J., and L.A. Mysak, A time dependent model of the atmospheric response to midlatitude heating with various zonal structures. Climate Research Group Report No. 87-7, Dept. of Meteorology, McGill Univ., 41 pp.

4. Manak, D.K., and L.A. Mysak, Climatic Atlas of Arctic Sea Ice Extent and Anomalies, 1953-1984. Climate Research Group Report No. 87-8, Dept. of Meteorology, McGill Univ.

Ph.D. thesis supervised

1987

1. Weaver, A.J., Numerical and analytical modelling of oceanic/atmospheric processes. (U.B.C.).

LIN
Journal publications

1987

1. Lin, C.A., A simple model of baroclinic adjustment and parameterization of eddy heat transport. Meteorol. Atmos. Phys., 37, 72-81.

2. Lin, C.A. and J.N. Koshyk, A nonlinear stochastic low-order and energy balance climate model. Climate Dynamics, 2, 101-116.

3. Gough, W.A. and C.A. Lin, Distribution of blocks in data from the Canadian Climate Centre general circulation model. Climatolog. Bull., 21, 3-15.

4. Lin, C.A., Instability of planetary waves in a high vertical resolution model. Geophys. Astrophys. Fluid Dyn., 39, 227-259.

5. Lin, C.A., A mechanistic model of isopycnal diffusion in the ocean. Climate Dynamics (in press).

1988 6. Szeto, K.K., C.A. Lin and R.E. Stewart, Mesoscale circulations forced by the melting of snow in the atmosphere. Part I: Basic simulations and dynamics. J. Atmos. Sci. (in press).

7. Szeto, K.K., R.E. Stewart and C.A. Lin, Mesoscale circulations forced by melting snow. Part II: Application to meteorological features. J. Atmos. Sci. (in press).

8. Robichaud, A. and C.A. Lin, Simple models of diabatically forced circulations and the role of resonance. J. Geophys. Res. (submitted).

Technical Reports

1987 1. Lin, C.A. and J.N. Koshyk, A nonlinear, stochastic, low-order energy balance climate model. Climate Research Group Report No. 87-3, Dept. of Meteorology, McGill University.

2. Lin, C.A., Ocean models for carbon cycle studies. Report prepared for the AES carbon cycle group.

MYSAK and LIN
Technical Reports

1987 1. Cherniawsky, J.Y., L.A. Mysak, C.A. Lin and C.W. Yuen, Numerical Experiments with a Two-Layer Upper-Ocean Box Model: I. Initialization and Wind-Driven Deepening of the Mixed Layer. Climate Research Group Report No. 87-9, Dept. of Meteorology, McGill Univ.

2. Yuen, C.W., C.A. Lin, L.A. Mysak and J.Y. Cherniawsky, Preliminary Results of a Two-Layer Upper-Ocean General Circulation Model Forced at the Surface. Climate Research Group Report No. 87-10, Dept. of Meteorology, McGill Univ.

6. Research planned for coming year

1) Ocean circulation modelling (Lin, Mysak, Cherniawsky and Yuen). The first phase of the research to formulate and analyze a global ocean circulation model for climate studies is nearing completion: the diagnostic heat budget analysis of a 40-year control run spun up from rest, resolution experiments and salinity effects in the box version of the model, and the sensitivity of the model results to variations in the surface heat flux forcing. The second phase is the initiation of coupling efforts of the ocean model to the CCC atmospheric general circulation model. This is expected to take place sometime in 1988.

2) Arctic sea ice fluctuations and relation to atmospheric and oceanic parameters (Mysak and Manak). The sea ice extent anomalies for the period 1953-84 presented in Manak and Mysak (1987) will be analyzed for longshore advection in Canadian waters and for in-phase or out-of-phase behaviour with variations in high-latitude air temperature, precipitation and river discharge.

3) Coupled ice-ocean modelling (Mysak and Wood). The simple steady-state model of Willmott and Mysak will be extended to include salinity variations and a representation of the buoyancy driven East Greenland Current. Also, the model response to time-dependent forcing (an annual cycle) will be investigated.

4) Modelling of the NE Pacific Ocean circulation (Mysak and Cummins). The model of Cummins and Mysak (1988) will be subjected to a sensitivity test, which is to include variations in topography, horizontal resolution, and forcing.

5) Modelling of 100 y time scale variations in the atmosphere-ocean-cryosphere climate system (Mysak and Stocker, a PDF who will be coming from Zurich in Sept., 1988). A dynamic systems approach will be used to model the small but important climatic fluctuations of this time scale that have been observed during the Holocene.

6) Two-dimensional latitude/depth advection-diffusion ocean model with isopycnal diffusion (Lin). The time dependent advection-diffusion equation is to be solved in a latitude/depth box geometry with lateral and isopycnal diffusion. The latter is modelled using the rotated eddy diffusivity tensor. The evolution of an initial surface tracer distribution will be examined with both diffusive parameterizations. Homogenization properties will be of particular interest.

7) Three-dimensional Cox-Bryan ocean model studies of lateral and isopycnal diffusion (Lin and Gough). The three-dimensional primitive equation Cox-Bryan ocean model with an idealized North Atlantic box geometry is being formulated with lateral and isopycnal diffusion. A diagnostic analysis of the different terms in the tracer equation will be performed, with both types of diffusion. The tracer uptake into the thermocline region will also be examined.

8) Three-dimensional mesoscale model studies of diabatically forced circulations (Lin, Robichaud and Stewart). The Clark model, a state-of-the-art mesoscale model, will be used to examine the three-dimension effects of melting induced circulations, and the feedback between the circulation and the precipitation. This is an important extension of the two-dimensional results on melting induced circulations obtained by Szeto, Lin and Stewart in 1987.

9) Nonlinear spherical quasi-geostrophic model for planetary wave studies (Lin). The linear β-plane model results obtained by Lin and Chan suggest that nonlinearity and spherical effects are important for the proper simulation of the Southern Hemisphere zonal wavenumber 5 circulation. The improved spherical geometry is expected to yield a better latitudinal eddy structure, while the nonlinear effects should improve the vertical eddy structure.

7. Financial statement for the NSERC contribution

This statement is given in Appendix 2 (Statement of Expenditures) and also includes expenditures of AES funds.

8. Account of sponsor's contribution

See 7. above, but also note that the funds are a combination of NSERC and AES monies. The exception is that the typist's salary is not paid by the NSERC portion of the grant.

Appendix 1

DIRECTORY

CLIMATE RESEARCH GROUP
DEPARTMENT OF METEOROLOGY
McGILL UNIVERSITY

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Montreal, Quebec H3A 2K6
(514) 398-3759

Director:	Lawrence A. Mysak
Assistant:	Ann Cossette
Newsletter Editor:	Charles A. Lin

FACULTY MEMBERS

Roger Davies, Ph.D. (Wisconsin-Madison)	Radiation, clouds & climate theory
Jacques Derome, Ph.D. (Michigan)	Dynamic meteorology & climatology
Max J. Dunbar, Ph.D. (McGill), D.Sc. (Memorial), F.R.S.C.	Marine biology & Arctic climatology
R. Grant Ingram, Ph.D. (M.I.T.)	Physical oceanography
John E. Lewis, Ph.D. (Illinois)	Urban climatology & remote sensing
Charles A. Lin, Ph.D. (M.I.T.)	Atmospheric, oceanic dynamics & climate
Lawrence A. Mysak, Ph.D. (Harvard), F.R.S.C.	Ocean & climate dynamics
Svenn Orvig, Ph.D. (McGill), F.R.S.C.	Arctic climatology

RESEARCH ASSOCIATES

J.Y. Cherniawsky, Ph.D. (U.B.C.)	Physical oceanography
C.W. Yuen, Ph.D. (Wisconsin-Madison)	Boundary layer meteorology & physical oceanography

POSTDOCTORAL FELLOW

R.G. Wood, Ph.D. (Exeter)	Ocean & climate dynamics