nadian Meteorological and Oceanographic Society
ciété canadienne de météorologie et d'océanographie

34th Congress / 34e Congrès
Victoria 2000
29 May mai - 2 June juin

eme: The Role of the Pacific in Climate and Weather
ème: L'influence de l'océan Pacifique sur le climat et le temps

www.cccma.bc.ec.gc.ca/cmos2000

Program and abstracts
Programme et résumés

UNIVERSITY OF VICTORIA

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CO-EDITORS/CO-ÉDITEURS: Dr. George Boer
Dr. Howard Freeland

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A WORD FROM THE PRESIDENT OF CMOS

On behalf of the CMOS Council and Executive, it is a pleasure for me to welcome you to the 34th Annual Congress of the Canadian Meteorological and Oceanographic Society in beautiful Victoria, British Columbia. The University of Victoria, where we are meeting, is the centre of burgeoning activity in the oceanic and atmospheric sciences. The UVic School of Earth and Ocean Sciences is the home of a powerful group in oceanography and ocean modelling. The Canadian Centre for Climate Modelling and Analysis of the Meteorological Service of Canada, which has been located here since 1994, is the heart of Canada's very important contributions to global climate modelling. The institution for which I work, the Canadian Institute for Climate Studies is also on this campus. It channels funding from Environment Canada to university climate researchers across the country through the Climate Research Network. Within a few miles of UVic are the Institute of Ocean Sciences, the heart of Canada's West Coast oceanographic activity and Royal Roads University with its new and very active program in environmental studies. Victoria is also the home of numerous private sector firms in both oceanography and meteorology.

As always, CMOS Congresses are organised by local volunteers. This practice has the advantage that every Congress is a bit different from its predecessors with the happy result that each is memorable because of its unique local flavour. This year, Centre Chair Greg Flato, aided and abetted by Scientific Program Committee co-chairs George Boer and Howard Freeland, Local Arrangements Chair John Fyfe, Commercial Exhibits Chair Diane Masson and many others too numerous to mention, have put together a program of scientific and social events second to none.

Congress is not just a scientific and social event but is also an occasion for Council and the CMOS committees to meet and carry on some of the essential business of the Society. These meetings are open to all interested members and I would urge you to take part. This year your Council has new responsibilities regarding the establishment of the Canadian Foundation for Climate and Atmospheric Sciences, charged with managing an important new source of funding for our sciences.

All signs point to the beginning of a new era of expansion for Canadian science in general and for meteorology and oceanography in particular. I am very much looking forward to participating in this 34th national Congress for CMOS and at the same time celebrating the many contributions of the Vancouver Island Centre to our Society and our sciences. Congratulations to all the organisers and Welcome to all participants!

Ian Rutherford
President

UN MOT DU PRÉSIDENT DE LA SCMO

Il me fait plaisir au nom du Conseil et de l'exécutif de la SCMO, de vous souhaiter la bienvenue au 34e congrès annuel de la Société canadienne de météorologie et d'océanographie dans la belle ville de Victoria en Colombie-Britannique. L'Université de Victoria où nous nous réunissons est le centre d'une activité croissante en océanographie et météorologie. À l'École des sciences de la terre et de l'océan à UVic travaille une équipe très respectée dans les domaines de l'océanographie et de la modélisation de l'océan. Le Centre canadien pour l'analyse et la modélisation du climat, une division du Service météorologique du Canada situé à UVic depuis 1994, est au coeur de l'importante contribution canadienne à la modélisation du climat. L'Institut canadien pour les études du climat, avec qui je travaille présentement, est aussi situé sur le campus de l'Université. L'Institut est responsable de l'octroi des subventions d'Environnement Canada aux chercheurs membres du Réseau canadien de recherche sur le climat. Tout près de l'Université se trouve l'Institut des sciences de l'océan, le coeur de l'activité en océanographie de la côte ouest, et l'Université Royal Roads et son nouveau programme en études environnementales. À Victoria on retrouve aussi de nombreuses firmes du secteur privé oeuvrant dans le domaine de l'océanographie et de la météorologie.

Comme toujours, l'organisation du congrès de la SCMO est confiée à des bénévoles locaux. Cette pratique a l'avantage que chaque congrès est légèrement différent de ces antécédents, et due à la saveur locale de chacun, ils sont donc tous plus mémorables les uns que les autres. Cette année, le comité organisateur fut dirigé par le président du Centre de l'Ile de Vancouver Greg Flato, avec l'aide des coprésidents du comité scientifique George Boer et Howard Freeland, le président des arrangements locaux John Fyfe, le président des exposants commerciaux Diane Masson ainsi que plusieurs autres bénévoles que je ne peux malheureusement pas tous nommer. Les membres de ce comité ont élaboré un programme scientifique de première classe et des évènements sociaux sans pareils.

Le Congrès est non seulement un évènement scientifique et social mais aussi l'occasion pour le Conseil et les comités de la SCMO de se réunir pour discuter de divers enjeux et du futur de la Société. Toutes ces réunions sont ouvertes aux membres et je vous encourage à y participer. Cette année le Conseil s'est vu confier une nouvelle responsabilité; la mise sur pied de la Fondation canadienne pour les sciences du climat et de l'atmosphère. Cette Fondation sera chargée de la gestion d'une nouvelle source importante de fonds pour nos sciences.

Tout semble indiquer que nous sommes à l'aube d'une nouvelle ère d'expansion de la science en général, et de nos sciences en particulier. J'anticipe avec grand plaisir participer dans les activités de ce 34e congrès national de la SCMO et célébrer en même temps les nombreuses contributions du Centre de l'Ile de Vancouver à nos sciences et à notre Société. Mes félicitations aux organisateurs et encore bienvenue aux congressistes!

Ian Rutherford
Président

QUELQUES MOTS À PROPOS DE LA SOCIÉTÉ

ABOUT THE SOCIETY

Quelques mots à propos de la Société

La Société canadienne de météorologie a été formée en 1967, à partir d'un chapitre de la Royal Meteorological Society. Lorsque les océanographes s'y sont joints en 1977, le nom de la société est devenu Société canadienne de météorologie et d'océanographie. La Société fut incorporée sous ce nom en 1984.

La SCMO est une organisation nationale regroupant des individus, centres et chapitres voués à la promotion au Canada de la météorologie et de l'océanographie, ainsi que des disciplines environnementales connexes, sous tous leurs aspects. La Société offre aussi la certification d'experts conseils en météorologie et l'approbation des présentateurs Météo.

Quatorze centres locaux ou sections sont les pivots des activités locales et régionales. Les intérêts scientifiques de la Société incluent la météorologie opérationnelle, la climatologie, l'hydrologie, la pollution de l'air, la météorologie agricole et forestière, la mésométéorologie, les glaces flottantes, et l'océanographie chimique, physique et halieutique.

La Société offre des bourses de voyages a des étudiants pour assister aux congrès annuels, une bourse de voyage à un enseignant pour l'atelier "Project Atmosphere" de l'AMS/NOAA, et la bourse du troisième cycle "Weather Research House/SCMO/CRSNG".

Les principales publications de la Société sont le CMOS Bulletin SCMO bimestriel et Atmosphere Ocean (A-O), une revue scientifique trimestrielle qui présente des articles, préalablement soumis à la critique, sur les résultats de recherche originale. La SCMO a aussi une page d'accueil sur son sites web où on trouve de l'information générale sur la SCMO et ses activités, ainsi que sur la science et l'enseignement de la météorologie et de l'océanographie au Canada.

On trouvera plus d'information sur la SCMO à http://www.scmo.ca

About the Society

The Canadian Meteorological Society was formed in 1967 from a branch of the Royal Meteorological Society. In 1977 when the oceanographic community joined, the name of the Society was changed to the Canadian Meteorological and Oceanographic Society (CMOS). The Society was subsequently incorporated with this name in 1984.

CMOS is a national society, individuals, centres and chapters dedicated to advancing all aspects of atmospheric science, oceanography, and related disciplines in Canada. The Society also offers accreditation to meteorological consultants and endorsement of media weathercasters.

Fourteen Society centres and chapters across Canada serve as focal points for local and regional, activities. Scientific interests of the Society include: operational meteorology, climatology, hydrology, air pollution, agriculture/forestry meteorology, mesoscale meteorology, floating ice, physical, chemical and fisheries oceanography.

The Society offers travel bursaries for students to attend Annual Congresses, a secondary school teacher travel bursary for the AMS/NOAA Workshop "Project Atmosphere", and the "Weather Research House/CMOS/NSERC" graduate student supplementary scholarship.

The main publications of CMOS are the bimonthly "CMOS Bulletin SCMO" and Atmosphere-Ocean (A-O), a quarterly refereed journal for the publication of results of original research. The Society also, maintains an electronic web site, with information on the Society and its activities, and meteorological and oceanographic science and education across Canada.

Detailed information on CMOS can be found on this web site at http ://www.cmos.ca

LOCAL ARRANGEMENTS COMMITTEE

COMITÉ ORGANISATEUR LOCAL

Chair: John Fyfe
Canadian Centre for Climate Modelling and Analysis
Meteorological Service of Canada

Social: Greg Flato
Canadian Centre for Climate Modelling and Analysis
Meteorological Service of Canada

Treasurer: Bob Lake
Victoria, BC

Registration: Gary Reid
GEMS Registration Services
Nanaimo, BC

Sue Dunlop
Centre for Earth and Ocean Research
University of Victoria

Secretary: Wanda Lewis
School of Earth and Ocean Sciences
University of Victoria

Translation: Richard Harvey
Canadian Centre for Climate Modelling and Analysis
Meteorological Service of Canada

Exhibits: Oscar Koren
Concord, Ontario

Diane Masson
Institute of Ocean Sciences
Fisheries and Oceans Canada

Mike Berkley
Canadian Centre for Climate Modelling and Analysis
Meteorological Service of Canada

Media: Doug Bancroft
Maritime Forces Pacific

Website and Design: Vivek Arora
Canadian Centre for Climate Modelling and Analysis
Meteorological Service of Canada

SCIENTIFIC PROGRAM COMMITTEE

COMITÉ DU PROGRAMME SCIENTIFIQUE

Co-Chairs:

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Canadian Centre for Climate Modelling and Analysis
Environment Canada

H. J. Freeland
Institute of Ocean Sciences
Fisheries and Oceans Canada

P. Austin
Department of Geography
University of British Columbia

K. Denman
Institute of Ocean Sciences
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M. Foreman
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T. Oke
Department of Geography
University of British Columbia

H. Ritchie
Recherche en prévision numérique
Environnement Canada

R. Stull
Department of Geography
University of British Columbia

STUDENT TRAVEL BURSARY RECIPIENTS

BÉNÉFICIAIRES DES BOURSES DE VOYAGES POUR ÉTUDIANTS

Claude Bélanger
Institut des sciences de la mer de Rimouski

Natacha Bernier
Dalhousie University

Betty Carlin
Dalhousie University

Richard E. Danielson
McGill University

Bertrand Denis
Université du Québec à Montréal

Jian Feng
McGill University

Selma R. Maggiotto
University of Guelph

Ramzi Mirshak
University of British Columbia

Xin Qiu
York University

Christine Rigby
University of Guelph

Ayrton Zadra
McGill University

METEOROLOGICAL SERVICE OF CANADA/SERVICE MÉTÉOROLOGIQUE DU CANADA

Environment Canada recently announced that the Meteorological Service of Canada (MSC) and in French, Service météorologique du Canada (SMC), is officially the national institution with responsibility for weather forecasts and warnings, the national water survey, the ice service and science of the atmosphere, climate and air quality. As such, the work of MSC is as the principal scientific authority on the atmosphere, and related elements of the hydrosphere and cryosphere.

The goals of MSC are to apply meteorological and hydrological science to:

- Help save lives
- Help avoid health risks
- Help reduce property losses
- Contribute toward the enhancement of economic productivity
- Contribute toward the adoption of the best environmental policies

Environnement Canada a annoncé récemment que le Service météorologique du Canada (SMC)/ Meteorological Service of Canada (MSC) est l'institution nationale officielle ayant la responsabilité des prévisions et avertissements météorologiques, des relevés hydrologiques du Canada, du service des glaces, de la science de l'atmosphère et climatique, et de la qualité de l'air. En ce sens, le travail du SMC est donc celui de la principale autorité scientifique dans le domaine atmosphérique et en ce qui concerne les éléments connexes de l'hydrosphère et de la cryosphère.

Les objectifs du SMC consistent à appliquer les principes scientifiques de la météorologie et de l'hydrologie pour :

- aider à sauver des vies;
- aider à éviter des risques pour la santé;
- aider à réduire les pertes de biens;
- contribuer à améliorer la productivité économique;

contribuer à l'adoption de meilleures politiques environnementales.

PLENARY SPEAKERS

CONFÉRENCIERS DES PLÉNIÈRES

PLENARY SESSION 1 | **AM1**
Cinecenta | Monday, May 29, 0830–0950

The dominant patterns of North American climate variability
J.M. Wallace
University of Washington, Seattle, WA

PLENARY SESSION 2 | **AM1**
Cinecenta | Tuesday, May 30, 0830–0950

Teleconnections and ENSO – The tropical problem (with implications for midlatitudes)
D. Neelin
University of California, Los Angeles, CA

Next steps in ocean observing systems and climate forecasting
Ants Leetmaa
CPC/NCEP/NWS/NOAA, Washington, D.C

PLENARY SESSION 3 | **AM1**
Cinecenta | Wednesday, May 31, 0830–0950

The Atmospheric Radiation Measurement Program (ARM)
T. Ackerman
Pacific Northwest National Laboratory, Richland, WA

Advances in understanding and forecasting of the weather of the west coast of North America
Clifford F. Mass
Dept. of Atmospheric Sciences, University of Washington

PLENARY SESSION 4 | **AM1**
Cinecenta | Thursday, June 1, 0830–0950

Ocean biogeochemical cycles and climate change
K. Denman
Institute of Ocean Sciences, Sidney, BC

PICES, Pacific climate and marine ecosystems
S. McKinnell
North Pacific Marine Science Organization (PICES), Sidney, BC

SOCIAL EVENTS

ÉVENEMENTS SOCIAUX

Time	Event	Location
Sunday, May 28		
1800–2000	Ice Breaker	Michele Pujol Room, Student Union Bldg.
Tuesday, May 30		
1220–1350	Awards Luncheon	Cadboro Dining Room
1745–1900	CCRN/CCCma Reunion	Felicita's Pub, Student Union Bldg.
Wednesday, May 31		
1830–1930	Cocktails	Caddy's Lounge, Cadboro Commons Bldg.
1930–2130	Banquet	Cadboro Dining Room

COMMITTEE MEETINGS

RÉUNIONS DES COMITÉS

Time	Meeting	Location
Sunday, May 28		
0900–1200	Publications Committee	Room B 025
1230–1430	University Education Committee	Room B 025
1300–1600	SCORE/ECOR Meeting	Room B 024
1500–1700	Science Committee	Room B 025
1500–1600	CMOS Vice President and Centre Chairs Meeting	Room B 203
1600–1800	CMOS Council	Room B 028
Monday, May 29		
2000–2130	Annual General Meeting	Univ. Lounge
Tuesday, May 30		
1800–2000	School and Public Education Committee Meeting	Room B 025
1800–1930	Weathercast Endorsement Committee	Room B 024
Wednesday, May 31		
1220–1330	MAGS Working Lunch	Room B 025
1220–1330	Private Sector Committee	Room B 024
Thursday, June 1		
1330–1530	NSERC Town Hall	Cinecenta
Friday, June2		
0900–1700	Ice Modelling Workshop	TBA

Note: All rooms are located in the Student Union Building (SUB)

INSTRUCTIONS FOR INTERNET ACCESS DURING CMOS 2000

INSTRUCTIONS POUR L'ACCÈS À L'INTERNET DURANT LE CONGRÈS SCMO 2000

Congress attendees wishing internet access (e.g. to read their e-mail) can do so by going to the U.Vic student computing facilty located on the main floor of the Clearihue Building (room A112). Present your Congress identification badge to a consultant at the front counter and ask to be logged in as a visitor. You will then be logged in on your choice of a MAC or PC workstation. From there you may use the 'telnet' command to connect to your home machine (you must know its complete domain name or IP address). Please note that this service is provided as a courtesy by the University, to be used only for legitimate purposes.

Week at a Glance

Time	Clearihue Building, Wing A				Other Activities Cinecenta
	Room 207	Room 307	Room 309	Room 311	
Sunday, May 28					
1800–2000 hrs	*Ice Breaker at the Student Union Bldg.*				
Monday, May 29					
0830–0950 hrs	**Welcome, Plenary Session 1 at the Cinecenta, Student Union Bldg.**				
0950–1020 hrs	*Health Break Michele Pujol Room, Student Union Bldg.*				
1020–1220 hrs	Climate variability and change 1 ***5***	Ocean mixing ***8***	Data assimilation ***11***	Flow over inhomogeneous surfaces ***14***	EC Meteorologists' Forum
1220–1330 hrs	*Lunch*				
1330–1510 hrs	Climate variability and change 2 ***17***	Coastal oceanography 1 ***19***	Environmental prediction ***22***	Plant/atmosphere fluxes 1 ***25***	
1510–1540 hrs	*Health Break, Michele Pujol Room, Student Union Bldg.*				
1540–1720 hrs	Climate variability and change 3 ***27***	Coastal oceanography 2 ***29***	Meso-scale prediction ***32***	Plant/atmosphere fluxes 2 ***34***	
Tuesday, May 30					
0830–0950 hrs	**Plenary Session 2 at the Cinecenta, Student Union Bldg.**				
0950–1020 hrs	*Health Break, Michele Pujol Room, Student Union Bldg.*				
1020–1220 hrs	Observed climate and variability ***37***	Thermohaline circulation ***40***	Long-range forecasting ***43***	Boundary layers 1 ***46***	
1220–1340 hrs	*Awards Luncheon at the Cadboro Dining Room, Cadboro Commons Bldg.*				
1350–1510 hrs	Ocean & coupled models and processes ***49***	Ocean boundary layer ***51***	Value of weather services 1 ***53***	Boundary layer clouds ***55***	
1510–1540 hrs	*Health Break, Michele Pujol Room, Student Union Bldg.*				
1540–1720 hrs	Climate variability and change 4 ***57***	Surface waves ***60***	Value of weather services 2 ***63***	Boundary layers 2 ***64***	
Wednesday, May 31					
0830–0950 hrs	**Plenary Session 3 at the Cinecenta, Student Union Bldg.**				
0950–1020 hrs	*Health Break, Michele Pujol Room, Student Union Bldg.*				
1020–1220 hrs	Dynamics and balances ***67***	Eddies and waves ***70***	Operational meteorology ***72***	Radiation measurements ***75***	
1220–1330 hrs	*Lunch*				
1330–1510 hrs	CRCM ***77***	Canyon and channel flow ***79***	The Atlantic Storm of 21 January, 2000 ***82***	Clouds, aerosols and radiation ***85***	
1510–1540 hrs	*Health Break, Michele Pujol Room, Student Union Bldg.*				
1540–1740 hrs	Regional analysis and verification ***88***	Cryosphere ***90***	GEWEX/MAGS ***93***	Aerosols and atmospheric chemistry ***96***	
1830–1930 hrs	*Cocktails at Caddy's Lounge, Cadboro Commons Bldg.*				
1930–2130 hrs	*Banquet at Cadboro Dining Room, Cadboro Commons Bldg.*				
Thursday, June 1					
0830–0950 hrs	**Plenary Session 4 at the Cinecenta, Student Union Bldg.**				
0950–1020 hrs	*Health Break, Michele Pujol Room, Student Union Bldg.*				
1020–1220 hrs	MC2 ***99***	Bio-physical interactions ***102***	Land surface and hydrology ***104***	Surface energy balance and microclimate ***108***	
1220–1330 hrs	*Lunch*				
1330–1530 hrs					NSERC Town Hall

Note: The bold page numbers in the lower right-hand corners locate the abstracts for each session.

Sunday, May 28					
	1800–2000	*Ice Breaker at the Student Union Building*			
Monday, May 29					
AM1	0830–0950	**Plenary Session 1** *Cinecenta*	(1) ***Welcomes*** (2) The dominant patterns of North American climate variability, *J.M. Wallace*		***Chair: J. Fyfe*** ***Chair: G. Boer***
	0950–1020	*Health Break, Michele Pujol Room, Student Union Building*			
Monday, AM2	1020–1220	***Room 207*** **Climate variability and change 1** ***Chair: F. Zwiers*** ***5***	***Room 307*** **Ocean mixing** ***Chair: H. Melling*** ***8***	***Room 309*** **Data assimilation** ***Chair: D. Steenbergen*** ***11***	***Room 311*** **Flow over inhomogeneous surfaces** ***Chair: C. Wagner-Riddle*** ***14***
	10:20	1. What is the Arctic Oscillation? *Lionel Pandolfo*	1. Reynolds stresses from a vertical beam ADCP. *Steven Stringer*	1. Ozone data assimilation using the 3D-Var assimilation system of the Canadian Meteorological Center (CMC). *Sandrine Edouard*	1. A revision to the Davenport roughness classification for cities and sheltered country. *Tim Oke*
	10:40	2. The influence of the stratospheric circulation on the annular modes of climate variability in a middle atmosphere model. *John Fyfe*	2. Problems with measurements of the oceanic rate of dissipation using shear probes. *Paul Macoun*	2. The Canadian 3D-Var analysis scheme on model vertical coordinate. *Clément Chouinard*	2. Comparison between wind tunnel and field measurements of turbulent flow in forest clearings. *Michael Novak*
	11:00	3. Mid-latitude cyclones and the North Atlantic Oscillation: A natural symbiosis. *Lionel Pandolfo*	3. Estimates of dissipation in the ocean mixed layer using a quasi-horizontal microstructure profiler. *Neil S. Oakey*	3. The use of RTOVS/ATOVS data in the new CMC 3D variational analysis. *Clément Chouinard*	3. Modified microclimate behind a windbreak. *John D. Wilson*
	11:20	4. Climate change in atmospheric recurrent regimes under increased greenhouse gas forcing. *C. Juno Hsu*	4. Observations of enhanced mixing in the abyssal canyons of the Brazil Basin. *Louis St. Laurent*	4. Impact of ACARS/AMDAR data in the new CMC 3D-Var analysis system. *Réal Sarrazin*	4. Shear stresses and coherent motions downwind of variable-width shelterbelts. *J. S. Warland*
	11:40	5. A regime view of Northern Hemisphere atmospheric variability and change under global warming. *John Fyfe*	5. Mixing in San Juan Channel. *Tetjana Ross*	5. Empirical orthogonal functions for modelling 3D-Var forecast error statistics. *Mark Buehner*	5. Internal boundary layers revisited and guidelines extended. *Sergey Savelyev*
	12:00		6. Vertical mixing and tracer budgets in stratified estuaries. *R. Pawlowicz*		6. Numerical simulation of wind in plant canopies. *Jean-Paul Pinard*
	1220–1330	*Lunch*			
Monday, PM1	1130–1510	***Room 207*** **Climate variability and change 2** ***Chair: G. Brunet*** ***17***	***Room 307*** **Coastal oceanography 1** ***Chair: M. Foreman*** ***19***	***Room 309*** **Environmental prediction** ***Chair: J. Abraham*** ***22***	***Room 311*** **Plant/atmosphere fluxes 1** ***Chair: D. Spittlehouse*** ***25***
	13:30	1. Projection of enhanced greenhouse warming onto modes of climate variability. *Dáithí Stone*	1. Internal tides and waves in a complex estuary. *Rich Pawlowicz*	1. RPN coupled modelling for environmental prediction research. *Harold Ritchie*	1. The carbon budget of Canadian forests. *Werner A. Kurz*
	13:50	2. The cold ocean-warm land pattern in CCC GCM. *Jian Sheng*	2. Inertial motions in Lake Ontario from coincident current meter and drifter measurements. *Badal Pal*	2. Drift trials in the southern Gulf of St. Lawrence to improve Search-and-Rescue (SAR) planning. *Peter C. Smith*	2. Winter measurements of N_2O, NO and NO_2 fluxes using a micrometeorological method, following fall applications of various fertilizers. *Selma R. Maggiotto*

Monday, PM1	14:10	3. Middle atmosphere response to CO_2 doubling with the Canadian Middle Atmosphere Model. (CMAM). *Jean de Grandpré*	3. Monthly mean and tidal flows in Cabot Strait. *Denis Gilbert*	3. Operational forecasting of surface drifter trajectories in Cabot Strait. *Josko Bobanovic*	3. Cuvette studies of isoprene emission and NO_2 deposition associated with agricultural plants. *Christine Rigby*
	14:30	4. Perturbation and recovery of chemical species due to the Mount Pinatubo eruption as modeled by the Canadian Middle Atmospheric Model. *Darryl Chartrand*	4. Observation of a summer renewal event in the Saguenay Fjord. *Claude Bélanger*	4. Validation of an oilspill trajectory model against a shallow drifter buoys deployment when driven by more realistic surface oceanic currents instead of oceanic depth averaged climatological currents. *S. Desjardins*	4. Measurement of soil carbon dioxide efflux using soil chambers in a coastal temperate rain forest. *Gordon Drewitt*
42	14:50	5. Mineral dust and climate change. *Cathy Reader*	5. Response of an estuary to changes in river flow. *Daniel Bourgault*	5. A study of the extra-tropical re-intensification of former Hurricane Earl using Canadian Meteorological Centre regional analyses and ensemble forecasts. *Hal Ritchie*	
	1510–1540	*Health Break*			
Monday, PM2	1540–1720	***Room 207*** **Climate variability and change 3** ***Chair: T. Shepherd*** ***27***	***Room 307*** **Coastal oceanography 2** ***Chair: R. Pawlowicz*** ***29***	***Room 309*** **Meso-scale prediction** ***Chair: L. Neil*** ***32***	***Room 311*** **Plant/atmosphere fluxes 2** ***Chair: D. Spittlehouse*** ***34***
	15:40	1. Climate sensitivity and climate state. *G. J. Boer*	1. The energetics and influence of the M_2 tide on the circulation of a two-silled fjord. *Michael W. Stacey*	1. High-resolution real-time forecast research over W. Canada. *Roland Stull*	1. Environmental controls of carbon dioxide fluxes above a Pacific Northwest Douglas-fir forest. *Eva-Maria Jork*
	16:00	2. Cyclones, precipitation, and global warming. *Steven Lambert*	2. Seasonal and interannual variability of sea surface heights and slopes on the Scotian and Newfoundland Shelves. *Guoqi Han*	2. Verification of high-resolution numerical weather models for snow avalanche forecasting. *Claudia Roeger*	2. Carbon fluxes following harvesting and fire in the boreal forest. *Brian Amiro*
	16:20	3. Extreme sea-level sensitivity to changes in storminess. *Natacha Bernier*	3. Topographically induced tidal mixing. *Burkard Baschek*	3. Heavy precipitation in the Greater Vancouver Regional District: The White Rock storm of 1999. *Brad Snyder*	3. Water vapour and carbon dioxide fluxes above a boreal deciduous forest. *M. A. Arain*
	16:40	4. The effects of simulated climate change on the hydrology of major river basins. *Vivek Arora*	4. A finite-element model of the Arctic Archipelago. *David A. Greenberg*	4. Ensemble forecasting a bust. *Joshua P. Hacker*	4. Evaporation from a Canadian West Coast Douglas-fir forest: Seasonal patterns and controls. *Elyn R. Humphreys*
41	1700		5. Influence of a step-like coastline on basin scale vorticity budget, for A-B-C-grid shallow water equation models and a quasi-geostrophic model. *Frederic Dupont*	5. Models of coastally trapped disturbances: Validation from realistic simulations. *P. L. Jackson*	5. Climate change, Douglas-fir growth and carbon sequestration. *D.L. Spittlehouse*

Tuesday, May 30						
AM1	0830–0950	**Plenary Session 2** *Cinecenta*	(1) Teleconnections and ENSO – The tropical problem (with implications for midlatitudes), *D. Neelin* (2) Next steps in ocean observing systems and climate forecasting, *A. Leetmaa*			***Chair: W. Hsieh***
	0950–1020	*Health Break*				
Tuesday, AM2	1020–1220	***Room 207*** **Observed climate and variability** ***Chair: S. Lambert*** ***37***	***Room 307*** **Thermohaline circulation** ***Chair: C. Garrett*** ***40***	***Room 309*** **Long-range forecasting** ***Chair: L. Lefaivre*** ***43***	***Room 311*** **Boundary layers 1** ***Chair: I. McKendry*** ***46***	
	10:20	1. Climate Station History Metadata Project. *Anna Deptuch-Stapf*	1. On a stabilizing feedback to the ocean thermohaline circulation. *Stephen C. Newbigging*	1. Skill of seasonal hindcasts as function of the ensemble size. *Slava Kharin*	1. Wind and temperature profiles in the radix layer. *Roland Stull*	
	10:40	2. Gridded climate data for the prairie provinces. *R. F. Hopkinson*	2. Changes in Northwest Atlantic Deep Water properties in the early 1990's. *R.M. Hendry*	2. Probabilistic approach to seasonal forecasting. *Normand Gagnon*	2. Turbulent fluxes in the very stable nocturnal boundary layer. *Jennifer Salmond*	
	11:00	3. Characteristics of daily and extreme temperatures over Canada. *Barrie Bonsal*	3. Stability of the Mediterranean's thermohaline circulation under modified flux forcing. *Paul Myers*	3. Bootstrap estimation of errors in predicting Niño 3.4 SST anomalies. *Yuval*	3. Predicting joint frequency distributions in the surface layer. *Larry Berg*	
	11:20	4. Bias in the observations of precipitation amounts from AWOS. *Ewa Milewska*	4. Response of the thermohaline circulation to cold climates. *Zhaomin Wang*	4. Long-lead prediction of summer precipitation over the Canadian prairies – A Brief overview and present status. *Edmund R. Garnett*	4. Spatial and temporal variability of mixed layer depth and entrainment zone thickness. *Pascal Hägeli*	
	11:40	5. Brief intense rainfalls are becoming more frequent in Vancouver B.C. *Reg Dunkley*	5. A thermally and mechanically driven model of the ACC. *Richard Karsten*	5. Midlatitude Pacific SSTs: Equilibrium and transient atmospheric responses and implications for seasonal forecasting. *Nick Hall*	5. Numerical modelling of sub-grid scale momentum and heat fluxes over a heterogeneous surface. *Sreerama Daggupaty*	
	12:00	6. An exploration of precipitation variability in the southern Canadian Cordillera over the past four centuries. *Emma Watson*	6. Circulation within the North Water Polynya in Baffin Bay. *Humfrey Melling*		6. An airborne case study of evolving Kelvin-Helmholtz waves. *Fikrettin Celik*	
	1220–1340	*Awards Luncheon at Cadboro Dining Room*				
Tuesday, PM1	1350–1510	***Room 207*** **Ocean and coupled models and processes** ***Chair: G. Flato*** ***49***	***Room 307*** **Ocean boundary layer** ***Chair: R. Lueck*** ***51***	***Room 309*** **Value of weather services 1** ***53***	***Room 311*** **Boundary layer clouds** ***Chair: P. Austin*** ***55***	
	13:50	1. CMIP1 evaluation and intercomparison of coupled climate models. *Steven Lambert*	1. Turbulence and bubbles in the surf zone. *Roblyn Kendall*	1. Keynote address: Societal aspect of weather: Implications for research and policy. *Roger A. Pielke*	1. Satellite measurements of layer-cloud spatial variability. *Gregory Lewis*	
	14:10	2. Sensitivities of a global OGCM to variability in surface forcing. *Warren Lee*	2. Numerical modelling studies of processes on the ocean sloping bottom boundary layer. *Ming Li*	2. Value of climate and weather products. *Valerie Sexton*	2. Entrainment and mixing in buoyancy-sorting cumulus parameterizations. *Ming Zhao*	

Tuesday, PM1	14:30	3. Seasonal variability in the Northwest Atlantic. *Jinyu Sheng*	3. Calibration of an oceanic mixed layer model for coupling to CRCM. *Charles Tang*		3. The summertime cycle along the central Oregon coast. *Soline Bielli*
	14:50	4. Coupling between wind-driven currents and mid-latitude storm tracks. *Francois Primeau*	4. Sensitivity of oceanic mixed layer to surface forcing. *Serge D'Alessio*		4. Development and implications of a parameterization for transient shallow cumulus convection. *Knut von Salzen*
	1510–1540	*Health Break*			
Tuesday, PM2	1540–1720	***Room 207*** **Climate variability and change 4** ***Chair: J. Fyfe*** ***57***	***Room 307*** **Surface waves** ***Chair: D. Masson*** ***60***	***Room 309*** **Value of weather services 2** ***63***	***Room 311*** **Boundary layers 2** ***Chair: P. Taylor*** ***64***
	15:40	1. Nonlinear principal component analysis and its extensions. *William Hsieh*	1. Evaluation of the risk of erosion and flooding along coastal British Columbia. *Laurie Neil*	1. Weather prophets: The private industry perspective. *Ron Bianchi*	1. Convective transport theory for surface fluxes. *Roland Stull*
	16:00	2. Nonlinear canonical correlation analysis, and its application to studying ENSO. *William Hsieh*	2. Storm Wind Study (SWS II) – Wind and wave evaluation. *Ewa Dunlap*	2. The economic context of weather information generation and dissemination. *Kim Rollins*	2. An algebraic heat flux turbulence model for flows dominated by buoyancy effects. *Slavko Vasic*
	16:20	3. ENSO simulation and prediction using a hybrid coupled model. *Youmin Tang*	3. Storm Wind Study II (SWS-II) – The effects of swell on the wind stress. *Fred W. Dobson*	3. Panel discussion: Value of weather services. *Moderator: Richard Berry*	3. Third-order moment closure through a mass-flux approach. *Kenzu Abdella*
	16:40	4. The influence of ENSO and PDO across the Canadian prairies. *Bill Hartman*	4. Validation study of CMC ocean wave forecasting system. *Roop Lalbeharry*		4. Lagrangian simulations and eddy diffusivities for blowing snow. *Peter A. Taylor*
	17:00	5. Gauging impacts of climate change on the Pacific Northwest using the Pacific Decadal Oscillation and ENSO. *Philip Mote*			5. An object-oriented approach to micrometeorological modeling. *Brian Crenna*

Wednesday, May 31

Session	Time	Room 207	Room 307	Room 309	Room 311
AM1	0830–0950	**Plenary Session 3** *Cinecenta*	(1)The Atmospheric Radiation Measurement Program (ARM), *T. Ackerman* (2) Advances in understanding and forecasting of the weather of the west coast of North America, *Clifford F. Mass*		***Chair: P. Austin***
	0950–1020	***Health Break***			
Wednesday, AM2	1020–1220	***Room 207*** **Dynamics and balances** ***Chair: N. McFarlane*** **67**	***Room 307*** **Eddies and waves** ***Chair: H. Freeland*** **70**	***Room 309*** **Operational meteorology** ***Chair: P. Chen*** **72**	***Room 311*** **Radiation measurements** ***Chair: T. Ackerman*** **75**
	10:20	1. Shaken, or stirred? Transport and mixing in the atmosphere. *Theodore G. Shepherd*	1. Generation of eddies in winter along the northwest coast of North America. *William Crawford*	1. Improving the GEM model for medium-range forecasting and analysis. *Sylvie Gravel*	1. Determination of integrated water vapour using a GPS sensor in southern Ontario: Initial results. *Frank Seglenieks*
	10:40	2. A fine balance: Constraints on vortical/gravity-wave interactions. *Theodore G. Shepherd*	2. Parameterization of the effect of sub-grid-scale buoyancy forcing variability in an OGCM convection scheme. *Konstantin Zahariev*	2. Automated model validation of clouds, radiation and diurnal cycle using satellite data. *Louis Garand*	2. Measurements Of Pollution In The Troposphere (MOPITT) global measurements of tropospheric composition. *James R. Drummond*
	11:00	3. Empirical normal mode diagnosis of variability in dynamical core experiments. *Ayrton Zadra*	3. Could ocean eddies set the stratification of the main thermocline? *Richard Karsten*	3. An update on updateable MOS. *Pierre Bourgouin*	3. Measurements of the A-band on the AIRS/CLOUDSAT Simulator Experiment. *W.F.J. Evans*
	11:20	4. Dynamics and predictability of ensemble forecasts. *Bill Merryfield*	4. Shelf waves in the Gulf of Alaska. *Josef Cherniawsky*	4. TAF tools: Development of TAF Guidance Part I: Very-short range forecast. *Pierre Bourgouin*	4. Using scanning radars as radiometers: Why not? *Frederic Fabry*
	11:40	5. Comparison of western and eastern North Pacific cold-season cyclones in terms of kinetic energy and eddy energy conversion. *Richard Danielson*	5. Large amplitude internal wave excitation below a turbulent mixing region. *Bruce Sutherland*	5. TAF tools: Development of TAF guidance – Part II: Short range forecast. *Jacques Montpetit*	5. Polarization diversity at the remote sensing facilities of McGill University. *Isztar Zawadzki*
96	12:00	6. Are changes in temperature over the Mackenzie River Basin affected by global-scale energy fluctuations? *Werner Wintels*	6. Internal wave transmission across a reflecting level in uniform shear. *Bruce Sutherland*	6. The Cooperative Program for Operational Meteorology, Education and Training (COMET). *Patrick Dills*	
	1220–1330	***Lunch***			
Wednesday, PM1	1330–1510	***Room 207*** **CRCM** ***Chair: J. Scinocca*** **77**	***Room 307*** **Canyon and channel flow** ***Chair: P. Cummins*** **79**	***Room 309*** **The Atlantic storm of 21 January, 2000** ***Chair: H. Ritchie*** **82**	***Room 311*** **Clouds, aerosols and radiation** ***Chair: U. Lohmann*** **85**
	13:30	1. The new version of the Canadian Regional Climate Model. Part I: Model formulation and its simulation of current climate del. *Daniel Caya*	1. Dynamics of advection-driven upwelling over a submarine canyon. *Susan Allen*	1. Synoptic description of the Atlantic storm of January 21, 2000. *John MacPhee*	1. Cloud droplet size formation by ripening process: Roles of radiative processes. *Fikrettin Celik*
	13:50	2. The new version of the Canadian Regional Climate Model. Part II: Transient greenhouse gases concentration and aerosols forcing simulations. *René Laprise*	2. Approximating submarine canyon upwelling through laboratory spin-up experiments. *Ramzi Mirshak*	2. Storm-surge, sea-ice, and wave impacts of the 21-22 January 2000 storm in coastal communities of Atlantic Canada. *George Parkes*	2. The absorption of NIR solar radiation by liquid water in clouds. *W.F.J. Evans*

Wednesday, PM1	14:10	3. Various convection schemes applied on short climate simulations with the CRCM. *Dominique Paquin*	3. Observations of the flow of abyssal water through the Samoa Passage. *Howard Freeland*	3. Real-time forecasts of the January 21st storm surge in Atlantic Canada. *Josko Bobanovic*	3. Sea salt radiative forcing in CCC GCM. *Jiangnan Li*
	14:30	4. Large-scale forcing for the Canadian RCM. *Sébastien Biner*	4. Mixing and exchange in the Bosphorus. *Frank Gerdes*	4. The wave in Channel Head. *John MacPhee*	4. Simulations of aerosol optical depth using the CCCma GCM as compared to AERONET and AVHRR data. *Ulrike Lohmann*
105	14:50		5. Western Mediterranean sea-level rise: Changing exchange flow through the Strait of Gibraltar. *Tetjana Ross*	5. Dynamic fetch and the "rogue" wave event at Port-aux-Basques. *R. Bigio*	5. Cirrus horizontal inhomogeneity and solar albedo bias. *Betty Carlin*
	1510–1540	***Health Break***			
Wednesday, PM2	1540–1740	***Room 207*** **Regional analysis and verification** ***Chair: R. Laprise*** ***88***	***Room 307*** **Cryosphere** ***Chair: H. Melling*** ***90***	***Room 309*** **GEWEX/MAGS** ***Chair: R. Stewart*** ***93***	***Room 311*** **Aerosols and atmospheric chemistry** ***Chair: P. Ariya*** ***96***
	15:40	1. A spectral analysis technique suitable for limited area grids. *Bertrand Denis*	1. The warm summer of 1998 and its effect on sea ice and glacier melt in the Canadian Arctic Islands. *Tom Agnew*	1. Twin Otter flux measurements in the Mackenzie GEWEX Study (MAGS). *Ian MacPherson*	1. Are chlorine and bromine cycles involved in atmospheric S (IV) to S (VI) conversion? *P.A. Ariya*
	16:00	2. Correlation between various CRCM and CGCMII fields over western Canada under different greenhouse gases concentrations. *Hélène Côté*	2. Interannual variability of accumulated snow in the Columbia basin, British Columbia. *William Hsieh*	2. Analysis of airborne flux observations in the Mackenzie GEWEX Study (MAGS). *Peter H. Schuepp*	2. Simulations of sulphur dioxide, sulphate and aerosol concentrations with NARCM for the North Atlantic Regional Experiment (NARE). *Henry Leighton*
	16:20	3. A permutation approach to the validation of short regional climate model simulations. *Murray D. MacKay*	3. A comparison of modelled sea-ice concentration with observational data from 1958 to 1998. *Anne E. Armstrong*	3. Solar radiation budgets for the Mackenzie GEWEX study (MAGS) from ScaRaB and AVHRR measurements. *J. Feng*	3. The continuity equation for the stratospheric aerosol and its characteristic curves. *Jiangnan Li*
	16:40	4. Evaluation of the performance of a mesoscale model during FIRE.ACE. *Bernard Bilodeau*	4. Decadal variability of the Arctic sea ice thickness. *Blandine L'heveder*	4. Closing the MAGS water budget. *G.S. Strong*	4. Measurements of the accumulation size aerosols during NODEM. *Ulrike Lohmann*
	17:00		5. Sea-ice variability in the CCCma CGCM2 Coupled Model. *Gregory Flato*	5. Precipitation recycling over the Mackenzie Basin. *Kit K. Szeto*	5. Sulphur budget in Northern Aerosol Regional Climate Model (NARCM). *Lubos Spacek*
126	17:20		6. Is there a dominant timescale of natural climate variability in the Arctic? *Lawrence A. Mysak*		6. Development of a global atmospheric mercury model. *Ashu P. Dastoor*
	1830–1930	*Cocktails at Caddy's Lounge, Cadboro Commons Bldg.*			
	1930–2130	*Banquet at Cadboro Dining Room, Cadboro Commons Bldg.*			

Thursday, June 1					
AM1	0830–0950	**Plenary Session 4** *Cinecenta*	(1) Ocean biogeochemical cycles and climate change, *K. Denman* (2) PICES, Pacific climate and marine ecosystems, *S. McKinnell*		***Chair: H. Freeland***
	0950--1020	*Health Break*			
Thursday, AM2	1020–1240	***Room 207*** **MC2** ***Chair: R. Stull*** ***99***	***Room 307*** **Bio-physical interactions** ***Chair: D. Mackas*** ***102***	***Room 309*** **Land surface and hydrology** ***Chair: S. Hamilton*** ***104***	***Room 311*** **Surface energy balance and microclimate** ***Chair: T. Oke*** ***108***
	10:20	1. A renewed community for mesoscale modeling. *Stéphane Chamberland*	1. Modeling dynamical circulation and nutrient pathways on the eastern Scotian Shelf. *Guoqi Han*	1. The evaluation of land surface moisture budget in the CCCma GCM3 AMIP2 simulation. *Vivek Arora*	1. Net radiation at the BERMS sites. *Alan Barr*
	10:40	2. Canadian participation to the Mesoscale Alpine Programme (MAP). *Stéphane Chamberland*	2. Current and nutrient pathway simulations for the western continental margin of Vancouver Island. *Michael Foreman*	2. Enhancing soil moisture simulation in land surface models: testing of WatCLASS with the BOREAS data archive. *K.R. Snelgrove*	2. Needle shading and bark reflectivity to solar radiation at the surface of spruce leaders for leader temperature modelling. *Brian G. Sieben*
	11:00	3. High resolution mesoscale modeling for air quality in southern Ontario. *Xin Qiu*	3. Wind-driven circulation and lobster larvae dispersion around the Magdalen Islands, Gulf of St. Lawrence. *Denis Lefaivre*	3. Generation of streamflow with WatCLASS: Theories and impacts on the soil moisture budget. *K.R. Snelgrove*	3. Observation and modelling of heat storage fluxes in roofs. *Stephanie Meyn*
	11:20	4. The Asian dust event of April 1998: 1. Impact on the Lower Fraser Valley, B.C. *Ian McKendry*	4. The effect of diurnal zooplankton migration on acoustically-measured currents. *Michael Ott*	4. The simulation of complex land cover in regional climate studies. *Diana Verseghy*	4. An algorithmic scheme to predict hourly urban heat island magnitude. *Tim Oke*
	11:40	5. The Asian dust event of April 1998: 2. MC2 simulations of downmixing. *Josh Hacker*		5. A modeling study of soil damping effects on runoff generation during a flash flood event. *Lei Wen*	5. Tests of the performance of an algorithmic scheme of the hourly urban heat island. *Mark Barton*
	12:00	6. On the GWD parametrization scheme in MC2. *Wensong Weng*		6. The Bear Creek Hydrometeorological Project. *Robert Nissen*	6. Modelling the 3-D surface temperature of urban areas viewed by remote sensors. *Andres Soux*
151	12:20			7. Georgia Basin climate and hydrology – from time to space and the future. *Paul Whitfield*	

Note: The bold page numbers in the lower right-hand corners locate the abstracts for each session.

Monday, 29 May
0830–0950 hrs
Cinecenta

Session AM1

Plenary 1

Chair: G. Boer

1. Welcomes

2. The dominant patterns of North American climate variability

J.M. Wallace
University of Washington, Seattle, WA

Named modes of variability with their respective acronyms and enthusiasts abound in the climate literature. But if the redundant and strongly interrelated modes are grouped together appropriately there are only a few such phenomena that figure prominently in global and North American climate variability. Meteorologists have been aware of their existence for over half a century, but it is only relatively recently that they've been able to exploit them in climate diagnosis and prediction.

The El Niño / Southern Oscillation (ENSO) phenomenon impacts North American climate on time scales ranging from seasons up to a year or two. I will summarize these effects and document the time history of this phenomenon extending back over the past 140 years. ENSO-like variability is also evident on the decade-to-decade time scale, particularly over the North Pacific. For example, the shift toward more El Niño-like conditions over the North Pacific around 1976–77 has had a significant influence on wintertime temperatures and rainfall over western North America. With the benefit of hindsight, several such 'regime shifts' can be identified in the climate record but whether such shifts can be diagnosed in real time remains questionable. And whether this ENSO-like decade-to-decade variability is distinctive enough to deserve a name of its own (like 'Pacific Decadal Oscillation'), or whether it is more appropriately viewed as a low frequency component of ENSO remains to be seen.

The circulations of both hemispheres exhibit ringlike (or 'annular') modes of variability encircling the poles that fluctuate in time scales ranging from a week to decades. They are marked by opposing fluctuations in barometric pressure over the polar cap regions and midlatitudes, together with opposing variations in the strength of the westerlies at subpolar and subtropical latitudes. The Northern Hemisphere annular mode impacts winter weather over the throughout much of midlatitudes and it appears to be coupled to the wintertime stratospheric circulation in a very interesting way. For reasons that are not entirely clear at this point, this mode has exhibited a trend over the past 30 years toward lower pressure over the Arctic and stronger subpolar westerlies extending upward into the stratosphere. This trend has contributed substantially to the milder winters over North America (except Alaska and Labrador) and over most of Eurasia in recent years.

Tuesday, 30May
0830–0950 hrs
Cinecenta

Session AM1

Plenary 2

Chair: W. Hsieh

1. Teleconnections and ENSO – The tropical problem (with implications for midlatitudes)

D. Neelin
University of California, Los Angeles, CA

Teleconnections from El Niño/Southern Oscillation (ENSO) to other regions create the societally important impacts, and yet the dynamics of teleconnections remains a challenging problem even as basic mechanisms of ENSO itself have become better understood. Dynamical teleconnection mechanisms will be reviewed, and recent work on tropical teleconnections, including the effects of moist convection, will be presented. Traditional views of how tropical descent anomalies occur, and the traditional view of the midlatitude problem, which takes the tropical source as given, appear questionable. Implications for both tropical and midlatitude teleconnections will be discussed.

2. Next steps in ocean observing systems and climate forecasting

Ants Leetmaa
CPC/NCEP/NWS/NOAA, Washington, D.C.

Two classes of climate variability have been identified which may provide some predictability on seasonal to longer time scales over North America. The first class includes ENSO and the Pacific Decadal Oscillation (PDO) which are associated with changes in tropical convection, i.e. represent coupled modes. The second class is associated with changes in strength and location of atmospheric zonal flows in middle and high latitudes. In this class lies the Arctic Oscillation/North Atlantic Oscillation (AO/NAO). A basic global ocean observing system of remotely sensed and *in situ* observations exists that is of considerable use in studying these, especially in the tropical Pacific where the TAO array was implemented on an operational basis. However, the overall system needs to be expanded to allow for detailed diagnostic studies and long term continuity.

A number of multi-season forecasts are routinely produced for tropical Pacific SST variability. Arguably the most skillful of these use coupled general circulation models which utilize ocean data assimilation to initialize the forecasts. The skill in these forecasts lies in the central and eastern Pacific. Experiences indicate that forecasting of sea surface temperature anomalies in this area is just the first step in exploiting the predictability that might lie in the coupled system. Large SST and rainfall anomalies have been present in the tropical Indian Ocean, in the Indonesian region, the far eastern Pacific, and the Atlantic which modeling and diagnostic studies have shown played a role in producing significant seasonal temperature and rainfall responses in different parts of the globe.

The global ocean observing system will expand in the coming years. There will be more continuity and improvements in remotely sensed surface wind data sets and for altimetric measurements of sea level. Expansions of the TAO type moored arrays are being undertaken for the Atlantic and proposed for the Indian Ocean. The first steps are being taken to deploy global arrays of autonomous profilers that measure temperature and salinity. Surface sampling from VOS temperature, salinity, and fluxes will be enhanced.

To fully utilize these measurements for improved understanding and forecasts of the impact of climate variability over North America requires the development and implementation of ocean data assimilation systems where fields from dynamical models are corrected by the actual measurements to get the best estimate of the state of the ocean. These analyses are used for initial conditions for climate forecast systems and for analyses to document what the ocean is doing. Also by routinely comparing models and data, model shortcomings can be identified and both the models and forecasts improved. NCEP has limited experience in doing this for the ENSO problem but is expanding its efforts to the global domain and to incorporate the new data sets.

Wednesday, 31May
0830–0950 hrs
Cinecenta

Session AM1

Plenary 3

Chair: P. Austin

1. The Atmospheric Radiation Measurement Program (ARM): Ground-based remote sensing of clouds and radiation

Thomas Ackerman
Pacific Northwest National Laboratory, Richland, WA

The goal of ARM is to improve the understanding of cloud and radiation processes and the parameterization of these processes in climate models through a combined data collection, data analysis, and modeling program. The ARM program operates continuous ground-based remote sensing facilities in the Southern Great Plains (SGP; Oklahoma, USA), the Tropical Western Pacific (TWP; Manus Island, Papua New Guinea, and the Republic of Nauru), and the North Slope of Alaska (NSA; Barrow, Alaska, USA). The data collected at these facilities are being used to study, among many other problems, cloud occurrence climatologies, effects of clouds on the surface radiation budget, and cloud microphysical properties. The microphysical retrievals focus largely on the properties of stratiform clouds. Results of several studies of stratus properties are available, as well as one detailed study of cirrus properties. These studies provide new insights into cloud physics processes in the atmosphere and cloud and radiation interactions.

The two sites located in the Tropical Western Pacific are providing a unique data set on tropical radiation, water vapor, and clouds. Satellite observations have documented relationships between top of atmosphere radiation, which is obviously modulated by cloud properties, and large-scale dynamics. The quantitative impact on the surface radiation budget and solar energy deposition into the ocean, however, is understood much less well. During June-July of 1999, the ARM program, in conjunction with NOAA and the Japanese Marine Science and Technology Center (JAMSTEC), sponsored a field program at Nauru. This field program deployed two research vessels and a small aircraft at Nauru. The results of this program provide a new look at the spatial scale of radiation and cloud variability in the tropical Pacific and the impact of clouds on solar input to the ocean and atmosphere. Analysis of these data and other ARM data is in its infancy, but holds great promise to improve our understanding of cloud and radiation processes.

2. Advances in understanding and forecasting of the weather of the west coast of North America

Clifford F. Mass
Dept. of Atmospheric Sciences, University of Washington

During the past two decades there has been a dramatic increase in our knowledge of the mesoscale meteorology of the Pacific Northwest and British Columbia. The regional weather circulations of the area are dominated by the interactions between the synoptic scale flow and the substantial local terrain. These local weather features–including gap flows, downslope windstorms, windward precipitation enhancement, lee rainshadows, diurnal circulations, and convergence zones, to name only a few–have been studied using both conventional observations and special field programs using dual -Doppler aircraft. High resolution mesoscale modeling has proven capable of duplicating many of these regional weather features, and has become a potent research tool. Major aspects of this new knowledge will be reviewed in the presentation.

The research programs at the University of Washington (UW), University of British Columbia (UBC), and other regional institutions have revealed the potential for skillful mesoscale forecasting over the area using high resolution numerical weather prediction (NWP). Based on these suggestive results, mesoscale NWP down to 4-km has been run operationally for several years at the UW and UBC. This talk will review the performance of these local weather prediction efforts and their implications for forecasting over western North America and elsewhere. Finally, the presentation will review the latest regional efforts to test ensemble forecasting and the coupling of regional atmospheric, hydrology, and air quality models.

Thursday, 1 June
0830–0950 hrs
Cinecenta

Session AM1

Plenary 4

Chair: H. Freeland

1. Ocean biogeochemical cycles and climate change

K. Denman
Institute of Ocean Sciences, Sidney, BC

As we enter the new millennium, at least three global issues require research in the oceans. First, the climate appears to be changing due to the increase of CO_2 in the atmosphere because of human activity, and the oceans, as the global repository or flywheel for heat, water and mobile carbon, are integrally involved in climate change. Second, climate change combined with global overfishing are forcing the harvest of marine resources to change from a hunter-gatherer activity to aquaculture, an agrarian activity. Third, the coastal domain (200m above to 200m below sea level) occupies 18% of the surface of the globe, is home to about 60% of the global population, supplies about 90% of the world fish catch, and receives 75–90% of the suspended sediment load of rivers with its cargo of known and unknown contaminants.

Central to the scientific research required to address these issues is that they are inherently multidisciplinary and they involve coupled biogeochemical cycles. For example, the ocean's role in the global carbon cycle involves transports and transformations. Transports of carbon in the ocean are conducted by organisms and by physical oceanographic processes at all scales. Transformations of carbon are conducted by organisms (inorganic/organic, dissolved/particulate) and through geochemistry (precipation/dissolution of calcium carbonate). The cycling of carbon is fundamentally linked to the cycles of virtually every other element, especially iron, nitrogen, sulphur, oxygen, and phosphorous. I am involved in developing coupled biogeochemical/ocean circulation models to explore how North Pacific planktonic ecosystems and biogeochemical cycling will respond to changes in climate. The models produce significant responses – both in the recent past and into the future, but existing observations are inadequate for critical evaluation of model performance. Will there be better observations in the future?

2. PICES, Pacific climate and marine ecosystems

S. McKinnell
North Pacific Marine Science Organization (PICES), Sidney, BC

The North Pacific Marine Science Organization was established by an international convention in 1992 to promote and coordinate marine science in the North Pacific, especially north of 30°N. Although the governments of Canada, China, Japan, Korea, Russian and the United States constitute the current formal membership of the organisation, participation in PICES, from the executive to the working groups, is almost entirely by scientists. A major development in marine science in the North Pacific during the late 20th century was the growing awareness of the relationship between climate and marine ecosystems, particularly for commercially exploited species.

The discovery of large-scale patterns of recruitment success and failure among species, and their co-variation with North Pacific climate patterns, stimulated the first major science program in PICES – Climate Change and Carrying Capacity Program (CCCC). The goal of the program is to address how climate variability affects ecosystem structure and the productivity of key biological species at all trophic levels in the open ocean and in coastal ecosystems. PICES and the CCCC program are providing a forum to integrate North Pacific marine ecosystem science from physics to upper trophic level biota. The first phase of research was to identify the spatial and temporal patterns of variability and much of the current success has been achieved in retrospective studies using correlative approaches. This progress will be reviewed by examining key published and soon-to-be published papers on basin-scale comparisons, North Pacific climate regime shifts, and scales of ecosystem variability. The next phases of research will focus on mechanisms and will increasingly require better and more comprehensive data, and the talents of modelers and process-oriented researchers. PICES will be leading these developments by supporting projects such as the NEMURO lower trophic level model, the implementation of ARGO, the development of new and better ecosystem sensors, and by providing the forum to exchange marine ecosystem ideas in the North Pacific.

1. What is the Arctic Oscillation?

Adam Monahan[1], **Lionel Pandolfo**[1], and **John Fyfe**[2]
[1]*Dept. of Earth and Ocean Sciences, University of British Columbia*
[2]*Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada*

Recently, the Arctic Oscillation (AO) has been put forth as the principal mode of short-term climate variability in the atmosphere. The AO is usually obtained by performing a principal component analysis (PCA) on geopotential heights, a linear statistical technique that finds patterns which maximise the variance of the field.

We will present results obtained by applying a non-linear generalisation of PCA (NLPCA) to the height fields from the NCAR/NCEP Reanalyses. Our one-dimensional approximation to the height field variability, which would correspond to the first mode of PCA if the dynamics were linear, does not describe the conventional AO. Instead, the variability we capture is characterised by three quasi-stationary states. Two of them weakly resemble opposite phases of the AO. We will describe these three states and their relationship to atmospheric modes of climate variability obtained by other methods like PCA, rotated PCA, cluster analysis and maximum penalised likelihood estimator.

2. The influence of the stratospheric circulation on the annular modes of climate variability in a middle atmosphere model

John Fyfe[1] and Elisa Manzini[2]
[1]*Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada*
[2]*Max Planck Institute for Meteorology*

The aim of this study is to better understand the troposphere-stratosphere coupling in the annular modes of climate variability (also known as the Arctic and Antarctic Oscillations, or the AO and AAO). The annular modes are spatially the largest and dynamically the most fundamental modes of variability spanning the troposphere and stratosphere, yet questions remain as to their maintenance and transition. Towards addressing these questions we take a modelling approach and analyze two simulations of a middle atmosphere model where the simulations differ only in how the gravity wave spectrum is treated. In a simulation where the gravity wave spectrum is launched from the tropopause, the AO is quite realistic and is characterized in it's positive phase by 1) upward and equatorward planetary wave propagation from the troposphere into the middle atmosphere 2) upper stratospheric and lower mesospheric planetary and gravity wave zonal-wind driving and 3) polar stratospheric wind and temperature tendencies which are hypothesized to contribute to the AO phase transitions. In a simulation where the gravity wave spectrum is launched from the surface the AO stratospheric structure and dynamics are unrealistic for reasons that are discussed. Similar comparisons are made for the AAO, and inter-hemispheric differences between the observations and simulations highlighted. Finally, we explore the connection between stratospheric sudden warmings and extreme negative phase AO.

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Session AM2

CLIMATE VARIABILITY AND CHANGE 1

Chair: F. Zwiers

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Session AM2

CLIMATE VARIABILITY AND CHANGE 1

Chair: F. Zwiers

3. Mid-latitude cyclones and the North Atlantic Oscillation: A natural symbiosis

Declan Quinn[1] and **Lionel Pandolfo**[2]
[1]*Dept. of Mathematics, University of British Columbia*
[2]*Dept. of Earth and Ocean Sciences, University of British Columbia*

Cyclonic systems are a ubiquitous feature of mid-latitude weather. In the Northern Hemisphere they are most prevalent over the east coast of large continents and the adjacent ocean. For the North Atlantic region, many studies have linked the surface climatology of storm tracks with the phases of the North Atlantic Oscillation (NAO). Since the NAO represents the principal mode of atmospheric climate variability for that region, this link could potentially be used to predict storminess once the tendency of the NAO is determined. However, the physical mechanisms responsible for a storms/NAO link have not yet been clearly established.

We have analysed the fields of sea level pressure, sea surface temperature, surface air temperature, surface sensible heat flux and latent heat flux and related their patterns of variability to those characterising the intensity and frequency of surface storms over the North Atlantic. The results that we will present establish the symbiotic relationship between storminess, as measured by storm frequency and intensity, and the NAO. We will discuss the implication of these results for the predictability of storminess and the NAO.

4. Climate change in atmospheric recurrent regimes under increased greenhouse gas forcing

C. Juno Hsu and Francis Zwiers
Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada

We have identified recurrent regimes of atmospheric states in a reduced phase space by testing against the null hypothesis that the atmospheric states are normally distributed and can be described by an AR(1) process. Both the observational NCEP reanalysis data and CCCma model simulations with and without increased GHG forcing were analyzed. The reduced phase space is described by the leading northern hemisphere EOFs or by sectorial EOFs of the Atlantic region and the Pacific region. Statistical tests were developed to check whether the short time series can be used to identify significant changes in the frequency of occurrence of certain flow patterns.

For the sectorial analysis (as opposed to the global NH analysis) of the model simulation, the time series are sufficiently long to clearly show that the increased GHG forcing leads to a change in the frequencies of occurrence of the recurrent regimes. For the observational analysis, the time series is found to be too short for the changes in the recurrent regimes to be statistically significant in all cases except for the changes in the flow pattern corresponding to the COWL pattern. The changes in the COWL pattern which occurred in recent decades are found to be robust.

5. A regime view of Northern Hemisphere atmospheric variability and change under global warming

Adam Monahan[1], **John Fyfe**[2], and Greg Flato[2]
[1]*Department of Earth and Ocean Sciences, University of British Columbia*
[2]*Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada*

The leading mode of wintertime variability in Northern Hemisphere sea level pressure (SLP) is the Arctic Oscillation (AO). It is usually obtained using linear principal component analysis, which produces the optimal, although somewhat restrictive, linear approximation to the SLP data. Here we use a recently introduced nonlinear principal component analysis to find the optimal nonlinear approximation to SLP data produced by a 1001 year integration of the CCCma coupled general circulation model (CGCM1). This approximation's associated time series is strongly bimodal and partitions the data into two distinct regimes. The first and more persistent regime describes a standing oscillation whose signature in the mid-troposphere is alternating amplification and attenuation of the climatological ridge over Northern Europe, with associated decreasing and increasing daily variance over Northern Eurasia. The second and more episodic regime describes a split-flow south of Greenland with much enhanced daily variance in the Arctic. In a 500 year integration with atmospheric CO_2 stabilized at concentrations projected for year 2100, the occupation statistics of these preferred modes of variability change, such that the episodic split-flow regime occurs less frequently while the standing oscillation regime occurs more frequently.

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CLIMATE VARIABILITY AND CHANGE 1

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Session AM2

OCEAN MIXING

Chair: H. Melling

1. Reynolds stresses from a vertical beam ADCP

Steven Stringer and Richard Dewey
University of Victoria

Juan de Fuca Strait is a coastal channel with strong mean, tidal, and internal wave velocities. Since 1996 we have been studying the interactions between these flows. In the summer of 1999 we deployed three acoustic Doppler current profilers and three thermistor chains near the northern side/slope to investigate boundary – interior flow interactions. Of special interest is the calculation of the mean Reynolds stresses $\overline{u'w'}$ and $\overline{u'v'}$, representing vertical and horizontal momentum fluxes, respectively. A new ADCP with three oblique beams and one vertical beam was recently obtained and deployed in 1999. While spatial gradients affect the estimates of both u and w from a standard ADCP, this is only true of u for the new instrument. Since w' is likely to be more inhomogeneous than u', we will investigate the improvement of calculating Reynolds stress from the vertical beam ADCP.

A statistical comparison of the two estimates of w' measured independently by the vertical beam and by the three oblique beams will be presented. Of interest is the coherency as a function of both range and frequency. This comparison is repeated for the estimates of w' from a traditional ADCP moored in the same area. Finally, the Reynolds stress is calculated from both instruments to identify any bias in the Reynolds stress estimated from a standard ADCP with four oblique beams.

2. Problems with measurements of the oceanic rate of dissipation using shear probes

Paul Macoun and Rolf G. Lueck
School of Earth and Ocean Sciences, University of Victoria

The air-foil shear probe is the only tool currently available for the measurement of the rate of dissipation of kinetic energy in the ocean. The rate of dissipation is used, among other things, to estimate the vertical diffusivity of the ocean which is a major parameter controlling the over-turning circulation and the depth of the thermocline. The ability of shear probes to resolve all of the wavenumbers (or spatial scales) of velocity fluctuations is determined by their physical dimensions and by the rate of dissipation. For most oceanic work the current shear probes are adequate. However, dissipation rates are very large in boundary regions, such as the near surface layer and coastal channels. In these regions the spatial resolution is inadequate.

New shear probes with linear dimensions one-half of a conventional probe were tested in Sansum Narrows using the horizontal turbulence profiler TOMI. Side by side comparisons of the probes clearly indicate that the new probes have twice the spatial resolution of the regular one. Thus, the improvement in the resolved rate of dissipation is 16 times. However, the comparison also shows that the response originally proposed by Ninnis (1984), a response widely used to adjust oceanic measurements, is overly optimistic by nearly a factor of 2. This implies under-estimation in previous work and a more turbulent ocean. Also, the form of the response proposed by Ninnis cannot be correct and is better described by a single space-constant low-pass filter.

3. Estimates of dissipation in the ocean mixed layer using a quasi-horizontal microstructure profiler

Neil S. Oakey, Blair J.W. Greenan, and Fred W. Dobson
Bedford Institute of Oceanography

Some recent measurements of the mixed layer in oceans and lakes have indicated that the rate of the dissipation of turbulent kinetic energy, epsilon, is much higher than expected from a purely shear-driven wall layer. This enhancement has usually been attributed to wave breaking. In this study, measurements of dissipation in the open ocean mixed layer on the continental shelf off Nova Scotia are integrated with air-sea flux estimates and directional wave spectra to further study this issue. A quasi-horizontal gliding microstructure profiler provides estimates of epsilon starting within 2 m of the ocean surface as it slowly descends through the mixed layer. Results from this experiment demonstrate that the proposed scaling of the WAVES and SWADE experiments for epsilon based on wind and wave parameters holds for the case of a simple wind sea in which the swell can be easily separated. In more complex situations, epsilon remains enhanced relative to the classical wall layer, however, the proposed scaling that decays as z^{-2} does not hold.

4. Observations of enhanced mixing in the abyssal canyons of the Brazil Basin

Louis St. Laurent
School of Earth and Ocean Sciences, University of Victoria

The abyssal Brazil Basin is bounded on the west by the continent of South America, and on the north, south and east by the Mid Atlantic Ridge (MAR). The bottom waters that circulate in this basin are imported from the Argentine Basin through the Vema Channel. Though some warm classes of bottom water leave the Brazil Basin through deep passages near the equator, the coldest classes of bottom water are transformed by mixing and upwelled in the basin's interior.

Observations of turbulent dissipation indicate that mixing levels are enhanced in regions of rough topography near the MAR. In particular, mixing levels are strongest in the abyssal canyons of MAR fracture zones. Furthermore, canyons are sites of strong diapycnal advection. Estimates of diapycnal upwelling suggest that water-mass transformation in canyons plays a significant role in the basin-scale mass budget of bottom waters.

5. Mixing in San Juan Channel

Tetjana Ross and Frank Gerdes
University of Victoria

San Juan Channel – the central waterway through the San Juan Islands, Washington – is one of three major passages between the Strait of Georgia and Juan de Fuca Strait. It acts as a mixing site for the 200 km long estuary system that extends from the Fraser River to the Pacific.

We present results from a study of tidal flow in San Juan Channel, done as part of a five week summer course in Coastal and Estuarine Geophysical Fluid Dynamics at Friday Harbor Laboratories, University of Washington.

Long-channel CTD (Conductivity, Temperature, Depth) sections show that fresh Fraser water enters from the north. It extends south to a mixing region at mid-channel where it is heavily stirred and mixed with deeper, more saline water.

Cross-channel ADCP (Acoustic Doppler Current Profiler) and CTD measurements taken simultaneously at two cross-sections for an entire tidal period allowed the amount of mixing in the channel to be estimated by two methods: calculation of fluxes across diapycnal surfaces and calculation of Thorpe scales. The estimates of eddy diffusivity from these two methods were in agreement.

The Foreman tide model was applied to the channel and was used to predict tidal currents and trace particle paths. The modeled tidal excursions were compared with those estimated from ADCP and GPS-tracked surface drifter measurements.

6. Vertical mixing and tracer budgets in stratified estuaries

Rich Pawlowicz and Trish Bellchamber
University of British Columbia

Although conceptual understanding of estuarine flow dominated by surface outflow and deep inflow is straightforward, actual computation of transports is less simple, especially in cases where multiple channels exist. Tracers are sometimes useful in addressing such issues but specification of realistic flow geometries often leads to ambiguities and hence underdetermined systems. Here it shown that a theory can be developed uniquely relating changes in salinity and temperature with transport and mixing parameters in a 2 layer exchange flow. Along-channel changes in the slope of T/S correlations are virtually independent of vertical mixing, but are directly related to horizontal layer transport and the input of heat through the surface. Changes in the layer salinity can be related to various ratios of horizontal and vertical (mixing) transports. Combining these two features of the theory permits a diagnostic determination of Lagrangian transport and mixing from standard hydrographic observations of layer temperature and salinity, and an estimate of the surface heat input. The theory is successfully applied to observations made in Haro Strait, British Columbia. Extension of the theory allows the computation of budgets for other nonconservative tracers, e.g. nutrients.

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Session AM2

DATA ASSIMILATION

Chair: D. Steenbergen

1. Ozone data assimilation using the 3D-Var assimilation system of the Canadian Meteorological Center (CMC)

Sandrine Edouard, Paul-Antoine Michelangeli, Simon Pellerin, Pierre Gauthier, and Gilbert Brunet
RPN, Environnement Canada

The Canadian 3D-var assimilation system (3D-var) has been used to produce univariate ozone analyses based on total ozone measurements. During the northern hemisphere winter of 1997, TOVS data were used in a data assimilation cycle driven by the Global Environmental Multiscale model (GEM) extended up to 1 mb, treating ozone as a passive tracer. The dynamics variables were updated every 24-hr using the CMC analyses (up to 700 mb) and the UKMO analyses (above 700 mb).

The resulting analyses show the deficiencies of total ozone data to correctly retrieve ozone vertical distribution, which is in this case entirely dominated by the dynamics of the model, the background-error statistics and the lack of chemistry.

To assess the impact of the vertical information, results of ozone profiles assimilation are shown using a Lidar satellite-based instrument ORACLE, under development. The lack of chemistry in the data assimilation system is investigated and some preliminary results will be shown.

2. The Canadian 3D-Var analysis scheme on model vertical coordinate

Clément Chouinard[1], Mark Buehner[1], Cécilien Charette[1], Luc Fillion[1], Pierre Gauthier[1], Pierre Koclas[2], Josée Morneau[2], Réal Sarrazin[2], and Judy St-James[2]
[1]*Meteorological Service of Canada, ARMA, Dorval*
[2]*Meteorological Service of Canada, CMDA, Dorval*

The design and testing of the new three-dimensional variational analysis scheme (3D-Var) for the operational GEM Global Environmental Multi-scale (GEM) model with vertical h-coordinate is described. We hereinafter refer to this version as E-3D-Var. The currently operational version of 3D-Var (hereinafter referred to as O-3D-Var) uses 16 mandatory pressure levels as vertical coordinate and the observations are specified at these pressure levels. The major change considered in E-3D-Var concerns the direct analysis of increments on the model s vertical coordinate. Most Numerical Weather Prediction (NWP) centers have been using their model's vertical geometry in the analysis step for some time. In its first implementation, it was decided to evaluate the E-3D-VAR against O-3D-VAR using the same basic observational data set i.e. geopotential from radiosondes and SATEM thickness data. Results from pre-implementation suites will be presented highlighting differences to the currently operational 3D-Var.

This new version of 3D-Var is based on a completely new set background-error statistics based on ensemble prediction or short-term lagged forecasts (NCEP method) including better balance constraints. As will be shown, this new version should facilitate the use of new types of data such as TOVS, ACARS/AMDAR, SSM/I, and Scatterometer data.

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DATA ASSIMILATION

Chair: D. Steenbergen

3. The use of RTOVS/ATOVS data in the new CMC 3D variational analysis

Clément Chouinard[1] and Jacques Hallé[2]
[1]*Meteorological Service of Canada, ARMA, Dorval*
[2]*Meteorological Service of Canada, CMDA, Dorval*

The CMC is currently testing in pre-implementation suite a global 3D-var analysis system formulated on terrain-following coordinate system (E-3D-Var). If the results are as positive as they were in off-line suites, this version could be operational before June 2000. This incremental E-3D-var system will also be used for the preparation of the regional model analyses, so that both the global and regional systems will produce analysis increments on their respective vertical grid with the top level still at 10 hPa. In this version, temperature and surface pressure are used as mass variables even though geopotentials from radiosondes and SATEM geopotential thickness still represent the main source of continental and remotely sensed data. Preliminary tests to replace SATEM retrievals with RTOVS/ATOVS radiances from data assimilation experiments and 10-day forecasts will be presented. These show that significant progress can be achieved using RTOVS/ATOVS radiance data rather than SATEM retrievals, and that radiance data monitoring and quality control are key components of the analysis system.

4. Impact of ACARS/AMDAR data in the new CMC 3D-Var analysis system

Réal Sarrazin[1], Bruce Brasnett[1], Cécilien Charette[2], Clément Chouinard[2], Pierre Koclas[1], and Gilles Verner[1]
[1]*Meteorological Service of Canada, CMC, Dorval*
[2]*Meteorological Service of Canada, ARMA, Dorval*

A new global 3D-var analysis system formulated on terrain-following coordinate system (E-3D-Var) is currently being testing in pre-implementation phase at CMC. This version of the 3D-Var system could be operational by June 2000 depending on the results of this parallel testing. This incremental E-3D-var system will also be used for the preparation of the regional model analyses, so that both the global and regional systems will produce increments on their respective vertical grid with the top level still at 10 hPa. In this version, temperature and surface pressure are used as mass variables even though geopotentials from radiosondes and SATEM geopotential thickness still represent the main source of continental and remotely sensed data. Work is underway to incorporate automated aircraft observations (ACARS/AMDAR) into the E-3D-Var. The quality control of both wind and temperature aircraft data are performed with new modules (background check and variational quality control). Results obtained from data assimilation experiments and 10-day forecasts will be presented. These show that significant progress can now be achieved by incorporating new data types into the operational data assimilation system, and that data monitoring and quality control are key components of the analysis system.

5. Empirical orthogonal functions for modelling 3D-Var forecast error statistics

Mark Buehner, Pierre Gauthier, and Gilbert Brunet
Data Assimilation and Satellite Meteorology Division, Meteorological Service of Canada

The forecast error statistics of the Canadian 3D-var under development (Gauthier et al. 1999) are estimated from an ensemble of lagged forecasts (NMC method). To obtain a satisfactory result, it is common practice to impose many simplifying assumptions on the structure of the error covariances such as stationarity, homogeneity, and isotropy. Our goal is to explore the impact of using a more general formulation of the forecast error statistics. The proposed approach and preliminary results will be presented.

We use empirical orthogonal functions (EOFs) estimated directly from an ensemble that is representative of the forecast error within the assimilation cycle. The EOFs are the leading eigenvectors of the complete (non-homogeneous, non-isotropic) forecast error covariance matrix that are statistically significant. The ensemble may be derived using either the lagged-forecast method, or from a set of perturbed forecasts valid at the analysis time, or a combination of the two. Therefore the approach may be applied using both stationary and non-stationary statistics. Approaches have also been developed to use the current representation of the forecast statistics for the covariances in the null space of the EOFs and to localise the horizontal correlations.

Preliminary results demonstrate that the use of EOFs calculated from an ensemble of $O(100)$ error samples is feasible and provides qualitatively reasonable analysis increments. Some non-isotropic features in the structure functions appear to be meteorologically significant.

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DATA ASSIMILATION

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Session AM2

FLOW OVER INHOMOGENEOUS SURFACES

Chair: C. Wagner-Riddle

1. A revision to the Davenport roughness classification for cities and sheltered country

Tim Oke[1], Alan Davenport[2], Sue Grimmond[3], and Jon Wieringa[4]
[1]*University of British Columbia*
[2]*University of Western Ontario*
[3]*Indiana University*
[4]*Wageningen University*

Surface roughness knowledge is needed for most boundary layer analysis and modelling, but for applications it is seldom available from local measurements. To estimate roughness visually or from maps, Davenport (*J. Am. Soc. Civ. Eng.*, 1960) classified all the then available well-exposed profile data for a wide range of terrain. Wieringa (*Bull. Am. Met. Soc.*, 1980; *J. Wind Eng. Ind. Aer.*, 1992) validated Davenport's eight roughness classes for open and moderately rough terrain and for forests, and extended its range to smooth terrain and open water. The classification is widely used, e.g. by WMO.

Recently, more good experimental roughness data have become available for cities (Grimmond and Oke, *Bound. Layer Met.*, 1998; *J. Appl. Met.*, 1999), as well as for very heterogeneous landscapes from tethered balloon observations in Britain and in the Sahel. This made it possible to validate the high-roughness classes more fully. Some shifts in roughness class descriptions prove to be necessary in order to account for differences in turbulence generation between bluff buildings and porous vegetation.

A slightly reformulated Davenport roughness classification is presented. It gives us a field-validated working tool to estimate effective aerodynamic roughness across the full range of real world terrain for application in wind engineering and boundary layer modelling over non-complex terrain.

2. Comparison between wind tunnel and field measurements of turbulent flow in forest clearings

Michael Novak[1], Jon Warland[2], Alberto Orchansky[1], and Rick Ketler[1]
[1]*Faculty of Agricultural Sciences, University of British Columbia*
[2]*Department of Land Resource Science, University of Guelph*

Public pressure is forcing the forest industry to develop harvesting and management practice alternatives to traditional clearcutting. One option is patch cutting in which small clearings alternate with uncut forest. The optimum size and the wind and turbulence pattern within a clearing greatly affect the stability of the surrounding edge trees to windthrow and the microclimate experienced by newly established tree seedlings. The wind tunnel is an excellent tool to investigate these issues because clearing size and other related variables, such as clearing surface roughness and the density of surrounding trees, can be investigated systematically, quickly, and relatively cheaply. We made wind tunnel measurements of mean wind speed and turbulence in clearings of various sizes, orientations, and shapes using a tri-axial hot-film anemometer. We will compare some of these with field measurements made at the Sicamous Creek Silvicultural Systems Research Area in the British Columbia Interior with propellor and sonic anemometers. The operational-scale clearings at this site are square with areas of 0.1, 1, and 10 ha. Comparisons with the field measurements of Gash (1986, *BLM 36*: 227–237) near a forest-heath interface will also be reported. The effects of surface roughness, surrounding tree density, and clearing shape on within-clearing wind and turbulence will be presented.

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FLOW OVER INHOMOGENEOUS SURFACES

Chair: C. Wagner-Riddle

3. Modified microclimate behind a windbreak

John D. Wilson
Department of Earth & Atmospheric Sciences, University of Alberta

The Rao-Wyngaard-Cote (RWC) second-order closure model, popularly used to examine local advection in response to changes in surface temperature and moisture, has been implemented in such a way as to also allow for shelter-belts, often occurring along fencelines bounding altered land surfaces.

Numerical simulations are compared with existing observations of the modified mean temperature field, in the wake of a windbreak of height H standing at $x = 0$, and show the daytime warm zone over $0 \leq x/H \leq 8$, with a cool zone farther to leeward.

4. Shear stresses and coherent motions downwind of variable-width shelterbelts

J. S. Warland[1], M. D. Novak[2], A. L. Orchansky[2], and R. Ketler[2]
[1]*Dept. of Land Resource Science, University of Guelph*
[2]*Faculty of Agricultural Science, University of British Columbia*

We present results from a wind tunnel study of shelterbelts consisting of model spruce trees of uniform height placed in either 1, 2, 4 or 8 staggered rows perpendicular to the flow. Trials were run either in laminar flow or with upstream turbulence. Measurements were made of the three wind components using a tri-axial hot-film anemometer and recorded at 500 Hz. Wind and turbulence profiles were measured from the floor up to 4 times the tree height at 8 locations between 0.3 to 18 tree heights downwind of the shelterbelts. We will present an analysis of the shear stress budgets and coherent eddy motions at these measurement locations. The mixing-layer analogy will be used to quantify the effect of up-wind turbulence.

5. Internal boundary layers revisited and guidelines extended

Sergey Savelyev[1], Peter A Taylor[1], and John L. Walmsley[2]
[1]*Department of Earth and Atmospheric Science, York University*
[2]*Guest Scientist at Air Quality Research Branch, Meteorological Service of Canada*

The Guidelines for flow above a change in surface roughness developed by Walmsley et al in 1989 were limited to strong wind, neutral stratification situations in part because of intended applications to wind energy and wind engineering. Current work aimed at utilising an extension of the guidelines in calculations of evaporation and gas transfer from lakes and ponds often has to deal with lower wind speeds and non-neutral stratification. As a part of this study we are revisiting the guidelines in order to allow calculations of the internal boundary-layer depth based on upwind roughness length (rather than downwind) and to include the effect of non-neutral stratification in the upstream flow. In addition the extended guidelines will allow for step changes in surface temperature, as these often accompany flow from land to water surfaces.

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FLOW OVER INHOMOGENEOUS SURFACES

Chair: C. Wagner-Riddle

6. Numerical simulation of wind in plant canopies

Jean-Paul Pinard and John D. Wilson
Department of Earth and Atmospheric Sciences, University of Alberta

Wind flow through several different plant canopies (a coniferous forest, a maize crop, and two artificial wind tunnel crops) is computer-simulated using a simple first-order closure (eddy diffusivity K is proportional to a turbulence length scale times the root of turbulent kinetic energy). Simulations are compared against observations, and against earlier simulations (using second-order closure) described by Katul and Chang (1999). The variables of interest include the mean horizontal wind speed, the mean shear stress, and the turbulent kinetic energy, all of which vary with height z in the canopy. Results show that the mean wind speed and shear stress given by the first-order closure compare very well with the Duke Forest measurements and with the second-order models.

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Session PM1

CLIMATE VARIABILITY AND CHANGE 2

Chair: G. Brunet

1. Projection of enhanced greenhouse warming onto modes of climate variability

Dáithí Stone[1], Andrew Weaver[1], and Ronald Stouffer[2]
[1]*School of Earth and Ocean Sciences, University of Victoria*
[2]*Geophysical Fluid Dynamics Laboratory / NOAA, Princeton University*

Variations in long term atmospheric circulation often take the form of large scale patterns. A possible interpretation of climate change due to rising levels of greenhouse gases is that such a change is projected onto these natural modes of variability. Inherent in this interpretation is the assumption that these patterns remain as dominant modes of variability in climates different from today.

The present study examines the validity of this assumption and the resulting interpretation. It compares 1000 years of global annual mean sea level pressure (SLP) and surface air temperature (SAT) in the climates resulting from 1×, 2×, and 4× pre-industrial concentrations of atmospheric CO_2 simulated by the Geophysical Fluid Dynamics Laboratory R15 coupled general circulation model. Empirical Orthogonal Function analysis is used to identify the modes, using both normal and standardised versions of the data fields.

While the SLP modes of covariance (normal data) and correlation (standardised data) are dominant in all three climates, only some of the SAT modes of correlation remain important. The projection of the climate change onto these modes will be presented.

2. The cold ocean-warm land pattern in CCC GCM

Jian Sheng
Canadian Centre for Climate Modelling and Analysis

Wallace et al. (1996) identified the cold ocean-warm land (COWL) pattern as the anomalously warm cold-season months over the high-latitude continents. The COWL pattern in the CCC coupled GCM integrations have been investigated. The control run of the coupled GCM simulates the COWL reasonably well with somewhat smaller amplitudes. Results from the control, the double CO_2 and the transient runs are compared. Indications of the COWL pattern as a forced mode due to the increased CO_2 in the atmosphere are discussed.

3. Middle atmosphere response to CO_2 doubling with the Canadian Middle Atmosphere Model (CMAM)

Jean de Grandpré, Victor I. Fomichev, Stephen R. Beagley, and John C. McConnell
York University, Toronto

The middle atmosphere (MA) response to the increase of anthropogenic greenhouse gases is a complex phenomenon and a subject of concern about the future evolution of the climate system. Trend analysis of observations taken over the past few decades suggest that a significant cooling between 2–10K/decade has occurred in various areas of the MA. A major concern associated with such a cooling is the impact on the long term evolution of the ozone layer and on the processes driving ozone depletion in polar regions.

The CMAM model has been used to study the response of the MA to a 'double CO_2' scenario. The model includes an interactive photochemical module to incorporate the coupling between ozone and temperature which is an important source of uncertainties in such studies. The model has been run in both interactive and non-interactive mode to address specifically the nature of the feedback mechanisms involved. It has been run with a non-interactive ocean to produce a first estimation of the direct radiative response (cooling to space) due to the CO_2 increase which is the most significant forcing mechanism leading to the MA cooling over tropical and mid-latitude regions. The results show the presence of a negative feedback between ozone and temperature which reduce the magnitude of the cooling due to the doubled CO_2 concentration. Results also show small but significant changes in the ozone distribution throughout the MA associated with the CO_2 increase. This experiment is a first step toward a more comprehensive study that would include interactive ocean and transient sources of other greenhouse gases such as methane and nitrous oxide.

4. Perturbation and recovery of chemical species due to the Mount Pinatubo eruption as modeled by the Canadian Middle Atmospheric Model

Darryl Chartrand[1], J. Jiang[2], S. Beagley[1], J. de Grandpré[1], J-P. Blanchet[3], and J. McConnell[1]
[1] *Department of Earth and Atmospheric Science, York University*
[2] *JPL/NASA*
[3] *Université de Québec à Montréal*

The eruption of Mount Pinatubo injected about 20 Mt of SO_2 into the stratosphere which subsequently was converted to stratospheric aerosols. The enhanced stratospheric aerosol number density cools the troposphere but it also results in increased stratospheric radiative heating rates and heterogeneous chemistry rates. The Canadian Middle Atmosphere Model (CMAM) is a fully interactive 3D model which has been used to study both the short term (a few months after the eruption) and long term (a few years) effects of the eruption of Mount Pinatubo on the atmosphere. The aerosol surface areas were derived from extinction coefficients from SAGE II observations. The model also includes important mid-latitude heterogeneous chemistry reactions. Preliminary analysis shows that the total water in the stratosphere as diagnosed by the tape recorder effect was affected. The ratio of active to inactive ozone destruction catalytic species such as NOy and Cly were also impacted. Results will show the chemical effects of enhanced aerosol loading as well as the recovery of the atmosphere several years after the eruption.

5. Mineral dust and climate change

Cathy Reader[1], Norman McFarlane[2], and George Boer[2]
[1] *Centre for Earth and Ocean Research, University of Victoria*
[2] *Canadian Centre for Climate Modelling and Analysis*

An on-line passive mineral dust aerosol model has been introduced into the Canadian Centre for Climate Modelling and Analysis (CCCma) second generation atmospheric general circulation model. Fixed SST time-slice simulations are performed using sea surface temperatures from coupled atmosphere-ocean transient runs of the CCCma coupled model with carbon dioxide and sulphate aerosol effects corresponding to present day and projected future conditions. The resulting atmospheric dust distributions and deposition patterns are discussed in the context of possible future effects on radiative forcing and CO_2 draw down by trace element fertilization of the ocean.

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Session PM1

COASTAL OCEANOGRAPHY 1

Chair: M. Foreman

1. Internal tides and waves in a complex estuary

Rich Pawlowicz
University of British Columbia

A spring/neap cycle in stratification correlated with modulations in tidal forcing can be seen in many estuaries and suggests that tides must be converted into mixing turbulence through some mechanism. The interaction of tidal forcing with sills is an obvious candidate. Since this behavior is strongly linked with the tide it is presumably highly regular, re-occurring in a similar fashion not only from tide to tide but also from year to year. Here I describe the time-dependent baroclinic behavior observed between two sills in a complex estuary (Haro Strait, British Columbia). Both large-scale low-frequency and small-scale high-frequency waves are generated. A theory is developed in order to understand the spatial patterns observed in temperature and velocity and it is shown that the Victoria Sill predictably generates a first mode internal tide with peak amplitude of 1 m/s. This is large enough that non-linear evolution occurs as the wave propagates away from the sill.

2. Inertial motions in Lake Ontario from coincident current meter and drifter measurements

Badal Pal[1], Richard E. Thomson[2], Alexander B. Rabinovich[3], and Raj Murthy[4]
[1]*Canadian Inst. for Climate Studies, Univ. of Victoria*
[2]*Institute of Ocean Sciences, Sidney, B.C.*
[3]*P. P. Shirshov Institute of Oceanology, Moscow, Russia*
[4]*National Water Research Institute, Burlington, Ontario*

We describe the cross-shore structure and seasonal variations of near-inertial oscillations in Lake Ontario along a transect starting from the Darlington Power Generating Station on the north shore of the lake. The analysis is based on concurrent measurements by moored 10 m-depth current meters and 3.5 m drogued satellite-tracked drifters deployed between April and October, 1990. The results show the following. (1) Fluctuations in the velocity field were predominantly in the near-inertial (0.7–1.8 cpd) and low-frequency (0.7 cpd) bands. Near-inertial currents were intermittent, wind-driven and dominated by the clockwise rotary component of motion. The peak frequency of inertial oscillations was blue-shifted by 4.7% of the local inertial frequency (f = 1.388 cpd). (2) Near-inertial motions intensified with offshore distance whereas low-frequency motions peaked at about 4 km offshore, and then decayed with offshore distance. A sharp nearshore rise in the kinetic energy of near-inertial and low-frequency motions implies a coastal boundary layer of 5–7 km width. (3) In spring, when the lake was unstratified, near-inertial currents were weak (2–5 cm/s). With the onset of summer stratification, strong inertial currents were observed by all current meters except the mooring 1 km from shore. The rms speed of near-inertial currents reached a maximum of 15–20 cm/s from August through September in the offshore region. (4) In summer, the energy of inertial motions at 3.5 m depth was an order of magnitude greater than at 10 m depth. (5) Coherence estimates from the current meter records show that near-inertial motions remain well correlated over a cross-shore distance of 11 km.

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Session PM1

COASTAL OCEANOGRAPHY 1

Chair: M. Foreman

3. Monthly mean and tidal flows in Cabot Strait

Denis Gilbert
Institut Maurice-Lamontagne

Cabot Strait is a 104 km wide, 500 m deep strait between Cape Breton and Newfoundland, at the entrance to the Gulf of St. Lawrence. In 1996, six current-meter moorings were deployed to measure the spatial and temporal structure of the flow through the Strait. Preliminary estimates give a mean inflow of about 0.8 Sv and a mean outflow of about 0.9 Sv for the June to November period for which we had simultaneous data from all instruments. A great deal of short-term current variability is superimposed onto those mean flows. We will examine this by focussing on the tidal currents in particular.

4. Observation of a summer renewal event in the Saguenay Fjord

Claude Bélanger[1], Yves Gratton[2], and François J. Saucier[3]
[1] *Institut des sciences de la mer de Rimouski (ISMER)*
[2] *INRS-eau*
[3] *Maurice Lamontagne Institut, Dept. Fisheries and Oceans*

The Saguenay Fjord is a 3-basin shallow-silled fjord discharging in the St. Lawrence estuary a few kilometers from the inner end of the Laurentian Channel. Among multi-basin fjords, the Saguenay can be considered as a typical since most of the time the density of the deep water of its inner basin is higher than the density of the deep water of its seaward basins. In fjords, deep water inflows occur when water entering across the sill is denser than the resident deep water. Due to its greater density, it sinks to the bottom displacing the resident deep water. If sufficient volumes of dense water enter the fjord, the complete renewal of the deep water occurs. In shallow-silled fjords, deep water inflows may occur as a series of pulses of denser water. According to the literature on the Saguenay Fjord, intrusions important enough to affect the entire inner basin are expected in winter. So far only partial replacements reaching halfway up in the inner basin have been observed in summer. An observation campaign has been held between May and early November 1998. CTD profiles were regularly sampled at a set of stations covering the entire length of the fjord and data from moored CTD and current meters were also obtained. The data show that, starting from the usual inverse gradient situation, a complete renewal of the deep water of the fjord has occurred in the second half of the summer, followed by a return to the inverse gradient situation. The wind over the St.Lawrence estuary has played a major role in the timing of the observed event through its effects on the density field at the mouth of the fjord. The details of this renewal event will be presented.

5. Response of an estuary to changes in river flow

Daniel Bourgault[1], François J. Saucier[2], and Charles A. Lin[1]
[1]*McGill University*
[2]*Maurice Lamontagne Institute, Dept. of Fisheries and Oceans*

Climate warming over the St. Lawrence basin would increase evaporation and thus reduce the freshwater runoff through the St. Lawrence River, by up to 40% as suggested by some climate models in a 2 × CO_2 scenario. In order to evaluate the impact of such a change on the circulation and mixing in the St. Lawrence Estuary, a simplified laterally-averaged estuarine circulation model has been developed. The model includes tidal propagation, river flow, a realistic topography, and a turbulence closure that considers the bottom turbulence and the damping effect of stratification. The model reproduces the important physical processes that are known to occur and that control mixing, in particular the interaction of the stratified tidal flow with the topography (internal tides, high-frequency internal waves, density currents, hydraulic controls). Along with the bottom friction, these processes contribute to the mixing of the water column and buoyancy distribution that, in turn, determines the baroclinic pressure gradient driving the residual circulation of partially stratified estuaries.

Numerical results as well as available observations are used to quantitatively describe the effect of changes in river flows on the salt distribution, on the stratification, on the spatial and temporal variability of vertical mixing conditions and, on the intensity of the residual circulation.

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Session PM1

ENVIRONMENTAL PREDICTION

Chair: J. Abraham

1. RPN coupled modelling for environmental prediction research

Harold Ritchie, Pierre Pellerin, and Christiane Beaudoin
Recherche en prévision numérique

The coupled numerical modelling group at Recherche en prévision numérique (RPN) is supporting research and development for environmental prediction based on coupling a variety of numerical prediction models. Much of this is being accomplished through the Atlantic Environmental Prediction Research Initiative (AEPRI) in Halifax, Nova Scotia, in collaboration with other government, industry, and academic partners. In the past year significant progress has been made in projects particularly in collaboration with the Meteorological Service of Canada (MSC) – Atlantic and the Oceanography Department of Dalhousie University (Dal). The main ongoing coupled modelling and AEPRI sub-projects are: atmosphere-ocean coupling via the NSERC/MARTEC/AES Industrial Research Chair in Regional Ocean Modelling and Prediction in the Oceanography Department at Dal, coupling data assimilation and prediction systems for coastal applications, modelling the extratropical transition of hurricanes and typhoons, coupled atmosphere-wave models, coupled atmosphere-hydrology models, coupling with estuary models, and developing expert systems for marine applications. Numerous Environment Canada (EC) scientists have gained valuable experience and made significant progress in projects in the areas of storm surge prediction, improved oil spill trajectory modelling, wave modelling, severe weather prediction, and streamflow prediction, including preparing some new and innovative forecast products which are on the point of becoming operational. AEPRI has advanced to the point where it will soon become even more inter-disciplinary and provide an opportunity to integrate activities amongst EC's various sectors. For example, the SLICK oil spill model is being used to give support to a project to study birds oiled at sea, and the AEPRI partners are principal investigators in projects on the prediction and mitigation of coastal flooding, as well as for a coupled atmosphere / ocean / biological / chemical observing and prediction system to study pollution in coastal inlets.

This presentation gives a status report, including results from several of the sub-projects not represented elsewhere in this Congress, and outlines plans for the future.

2. Drift trials in the southern Gulf of St. Lawrence to improve search-and-rescue (SAR) planning

Peter C. Smith and Donald J. Lawrence
Ocean Sciences Division, DFO, Bedford Institute of Oceanography

A set of three drift trials were conducted in the southern Gulf of St. Lawrence during Nov.-Dec., 1999, with the goals: 1) to test operational procedures for search-and-rescue and 2) to assess the skill of the newly-developed Dalhousie University Coastal Ocean Prediction System. The observed drift rates of three different types of target drifters Accurate Surface Tracker (AST), 4-person life raft (LR), and a shallow-draft disc (LCD) and two configurations of Self-Locating Data Marker Buoys (SLDMB), used for rescue operations, will be described, along with ancillary observations including hydrographic, Doppler current, bottom pressure, and wind data. Differences in target-specific mean drift will be discussed in light of leeway factors assigned to each drifter type, and the rates of horizontal dispersion for each cluster of buoys will be quantified and intercompared for later model comparisons.

3. Operational forecasting of surface drifter trajectories in Cabot Strait

Josko Bobanovic and Keith Thompson
Dalhousie University, Oceanography Department

We report on the most recent developments of Dalhousie Coastal Ocean Prediction System. In late November and early December 1999, a joint experiment was organised by the Department of Fisheries and Oceans, Canadian Coast Guard and Dalhousie to collect surface drifter data and validate model forecasts in real time. The dynamical model used to make forecast is based on the Princeton Ocean Model. It is driven by surface winds and forced to relax back to a climatological mean density field. The open boundary conditions at zero and tidal frequencies are derived using data assimilation the synoptic variability in the open boundary conditions is determined by a large-scale storm surge model.

A series of fifteen 48-hour forecasts was performed in real-time during the experiment. Predicted drifter trajectories in general agree well with the observations. Larger errors were observed for drifters that are more affected by the wind suggesting that the forecasts are sensitive to the specification of leeway factors and quality of forecast winds. Other sources of error is the specification of the local density field and baroclinic instabilities associated with it. An optimal interpolation scheme is used to assimilate various data sets into the model including surface drift, temperature and salinity data.

4. Validation of an oilspill trajectory model against a shallow drifter buoys deployment when driven by more realistic surface oceanic currents instead of oceanic depth averaged climatological currents

Serge Desjardins[1], Hal Ritchie[1], Josko Bobanovic[2], and Keith Thompson[2]
[1]*Environment Canada*
[2]*Dalhousie University*

The MSC SLICK oil spill model has been demonstrated to be a very useful tool to predict the trajectories and the horizontal spreading of oil slicks occurring in marine environments even when driven by climatological ocean depth averaged currents.

The oil spill model includes parameterizations of various physical processes representing the movement and weathering of an oil slick. The movement of the slick is affected by wind-driven, tidal and depth averaged currents. The latter two currents are specified as external inputs and may themselves be results from models developed for those specific purposes. In the present version of SLICK, those two external inputs are based on tide tables and climatology. The purpose of the present work is to replace the climatological fields by outputs from a more realistic surface oceanic current model developed at Dalhousie University, which is already driven (one way interactive coupling) by three-hourly 10 m wind and atmospheric pressure forecast fields supplied daily by the Canadian Meteorological Centre (CMC).

At the conference we will present results based on a field study, conducted in December 1999 in Cabot Strait in collaboration with Dalhousie University/BIO and the Canadian Coast Guard. We will present results from SLICK (or another oil spill trajectory model) runs driven by climatological currents and numerical surface oceanic currents, and verify them against the corresponding observations supplied by a deployment of shallow drifter buoys.

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ENVIRONMENTAL PREDICTION

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5. A study of the extra-tropical re-intensification of former hurricane Earl using Canadian Meteorological Centre regional analyses and ensemble forecasts

Suhong Ma[1], John Gyakum[2], **Hal Ritchie**[1], Jim Abraham[1], Chris Fogarty[1], and Ron McTaggart-Cowan[2]
[1]*Meteorological Service of Canada, Environment Canada, Dartmouth NS*
[2]*Department of Atmospheric and Oceanic Sciences, McGill University, Montreal QC*

Former hurricane Earl re-intensified rapidly while travelling through Canadian waters in September 1998. Its sea level pressure decreased 36hPa over a 36 hour period, and it caused heavy rain in Cape Breton Island, Nova Scotia and over Newfoundland. A diagnostic study is conducted from a potential vorticity (PV) perspective using Canadian Meteorological Centre (CMC) regional analysis data. Former hurricane Earl's re-development was related to the interaction between a pre-existing low level PV anomaly and an upper level PV anomaly with its associated baroclinic zone. The key to the rapid intensification was the juxtaposition of the surface warm anomaly and the upper level PV anomaly, resulting in rapid re-intensification over the 36 hour period following 00 UTC 05 September 1998. This process was accompanied by a cold air intrusion and warm air wrapping up. As well, the behaviour of the operational CMC numerical weather prediction models was examined, particluarly using output from the ensemble forecast system. This study concludes that the initial PV associated with former hurricane Earl (before re-intensification) is essential for the models to capture the strong re-intensification. All the members (except member-2 initialized at 00 UTC 3 September) which reached a minimum sea level pressure of less than or equal to 980hPa properly simulated the cold air intrusion and warm air wrapping up process, confirming the importance of baroclinic instability in the rapid re-intensification.

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Session PM1

PLANT/ATMOSPHERE FLUXES 1

Chair: D. Spittlehouse

1. The carbon budget of Canadian forests

Werner A. Kurz
ESSA Technologies Ltd.

Terrestrial carbon (C) budgets should be based on a systems approach that accounts for the dynamics of all significant C stocks. The appropriate indicator for the net change in landscape-level (1 million ha) forest ecosystem C stocks is net biome production (NBP), which is calculated as net ecosystem production (NEP) minus losses from natural and anthropogenic disturbances. Stage of stand development and recent (30 years) disturbance history are the two overriding factors that determine the annual net C balance of a stand. At the landscape-level, age-class structure and disturbance regime are the primary characteristics that determine the annual net C balance. At both the stand and landscape level, environmental conditions (temperature, water balance, etc.) modify the short-term and long-term C dynamics. Carbon budgeting approaches based on forest inventories, such as the Carbon Budget Model of the Canadian Forest Sector, yield estimates of net biome production, but that model does not simulate physiological processes that may be affected by environmental changes. Flux measurements are important to help develop and parameterize models of ecosystem response to environmental conditions. To obtain landscape-level C budgets, results from flux measurements must be put into a systems framework with which to calculate NBP. We will review the estimates of NBP of the forests in Canada, demonstrate the role of changes in disturbance regimes during this century, and discuss some of the key uncertainties in these estimates.

2. Winter measurements of N_2O, NO and NO_2 fluxes using a micrometeorological method, following fall applications of various fertilizers

Selma R. Maggiotto and Claudia Wagner-Riddle
Dept. of Land Resource Science - University of Guelph

Atmospheric nitrous oxide concentration increase is of concern due to its greenhouse effect and its role in the destruction of the stratospheric ozone. Cultivated areas are a major anthropogenic source of this gas. Nitric oxide and nitrogen dioxide are involved in the ground level chemistry of ozone and pollution. Increase in N_2O emissions during winter and spring-thaw have been observed, and seem to be affected by management practices. The effect of winter and early spring conditions on NO and NO_2 fluxes has not received the same attention. The impact of the use of nitrogen fertilizers on gaseous emissions during winter and spring-thaw is not well understood and was the objective of this research. A micrometeorological method was used to measure winter and early spring N_2O, NO and NO_x fluxes from a ryegrass area where three different mineral fertilizers were applied during the previous growing season. The fertilizers used were urea (U), slow-release urea (SRU) and ammonium nitrate (AN), and there was a control plot, with no fertilizers (C). Data collection occurred from November 1997 to March 1998.

Nitrous oxide emissions during December, January and February were small, averaging 2.21, 2.84, 0.25 and 0.11 ng m^{-2} s^{-1} for U, SRU, AN and C plots respectively. March showed an increase of emissions, and the SRU plot had the highest emissions, averaging 25.6 ng m^{-2} s^{-1}, followed by U and AN (13.3 and 1.6 ng m^{-2} s^{-1} respectively). Higher fluxes occurred at the end of the month, when air and soil temperatures increased rapidly. Total amounts of N_2O-N were significantly higher from SRU and U plots, and were related to mineral nitrogen content of the soil.

Nitric oxide fluxes from all plots were small during the measurement period (0.6 ng m^{-2} s^{-1}). NO flux from fertilized plots was significantly higher than from C plot during January to March. NO_x fluxes were always negative (–5 ng m^{-2} s^{-1}) indicating uptake by the surface and some days of high concentration of NO_x (45 ppb) were related to the most negative fluxes calculated. No significant difference in NO_x fluxes among the experimental plots was observed.

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PLANT/ATMOSPHERE FLUXES 1

Chair: D. Spittlehouse

3. Cuvette studies of isoprene emission & $N0_2$ deposition associated with agricultural plants

Christine Rigby[1], T. J. Gillespie[1], and J. Rudolph[2]
[1] *University of Guelph*
[2] *York University*

Isoprene reacts with OH in the presence of NO_x to form ground-level ozone, a secondary pollutant commonly found in photochemical smog. Cuvette studies have been used to monitor emission of isoprene from velvet bean leaves and deposition of NO_2 onto soybean leaves.

Globally, biogenic emissions of isoprene greatly outweigh those from anthropogenic sources, leading to problems associated with source identification and remediation. A study has been carried out to determine the stability of the $^{13}C/^{12}C$ ratio in isoprene from velvet bean leaves under different light, temperature and leaf age regimes. Potentially, an inventory of typical ratios could by collected, allowing for rapid identification of sources and strengths from ambient air samples.

NO emission from soils has been thought to contribute to ozone formation in the troposphere in airsheds affected by urban air pollution. However, NO is rapidly oxidized to NO_2 close to the ground and uptake of NO_2 by leaves of agricultural crops may exceed emission of NO from soil microbes. This would allow for a net sink of NO_x, and a decrease in secondary pollutant formation. This study examines the pathway and rate of deposition of NO_2 onto leaves of soybean plants.

4. Measurement of soil carbon dioxide efflux using soil chambers in a coastal temperate rain forest

Gordon Drewitt, Altaf Arain, Andrew Black, Elyn Humphreys, Eva Jork, Zoran Nesic, and Robert Swanson
University of British Columbia, Faculty of Agricultural Sciences

This paper will discuss some preliminary results obtained using an automated closed loop soil chamber system to measure carbon dioxide efflux from the forest floor in a coastal temperate rain forest near Campbell River, B.C. This research station has been in operation as an Ameriflux site during the last two years with climate measurements and above canopy eddy correlation fluxes measured continuously during this period. The soil chamber system is designed to sequentially measure carbon dioxide accumulation in six chambers during a half hour period by closing the chamber lids for five minutes each. The chambers cover approximately 0.2 square meters which allow emissions from a relatively large patch of soil to be observed while the use of many chambers allow some issues of spatial heterogeneity over a larger scale to be addressed. A method of calibrating the chamber leakage using daily injections of low volumes of carbon dioxide enable unattended measurements to continue for up to a week duration.

While being notoriously difficult to obtain, chamber measurements of soil respiration can provide important insights into the processes affecting forest ecosystem productivity and the factors controlling soil carbon storage. During the month of August 1999 two chambers were in operation at the Campbell River for system testing purposes and to obtain preliminary estimates of soil respiration. Results show that soil temperature, as expected, has a strong influence on respiration rates and that magnitudes of flux can vary substantially over relatively small distances on the forest floor. Results obtained from this study will be compared to those obtained from a boreal forest ecosystem using similar chambers.

1. Climate sensitivity and climate state

G. J. Boer
Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada

The magnitude and nature of the response of the climate system to a change in forcing depends on an array of physical processes. The climate sensitivity, defined as the temperature change that would occur if the amount of CO_2 in the atmosphere were doubled and the system were allowed to come to a new equilibrium, is used to characterize model behaviour, to calibrate simplified models, and to scale model results when applied to a range of forcings.

The equilibrium climate change calculation which gives the climate sensitivity is easily done for models with a slab ocean but is seldom done for models with a full three-dimensional ocean because of the several millennia required to reach a new equilibrium. An effective climate sensitivity may be calculated in the non-equilibrium case and there is evidence that it varies with climate state. This is shown to be the case for the CCCma coupled general circulation model where the effective climate sensitivity increases with forcing level to a value somewhat higher than that indicated by the equilibrium slab-ocean calculation.

2. Cyclones, precipitation, and global warming

Steven Lambert
Canadian Centre for Climate Modelling and Analysis - Meteorological Service of Canada

Climate model simulations predict that the number of mid-latitude winter cyclones will decrease with enhanced greenhouse warming. Although the total number of simulated cyclones decreases, the number of intense cyclone events increases. A possible explanation of this is that the levels of increased moisture accompanying greenhouse warming lead to increased latent heat release and increased development of mature cyclones. Results showing the relationship between precipitation and intensity of simulated cyclones are presented and discussed.

3. Extreme sea-level sensitivity to changes in storminess

Natacha Bernier[1], Keith Thompson[1], Josko Bobanovic[1], Harold Ritchie[2], and Serge Desjardins[2]
[1]*Dalhousie University*
[2]*Environment Canada*

We use a validated storm surge model (Bobanovic 1997) to examine the sensitivity of return period of extreme sea-levels to changes in storminess. The surge model is a 2-D, barotropic and driven by winds and air pressure. It covers the Atlantic Canadian shelves. The wind and air pressure fields were obtained every three hours from September 1996 to February 1997. They are scaled up by factors of 10, 20, and 30% in order to simulate variations in storm intensity. The new fields are then used to drive the surge model. The variance in sea-level is calculated for the present climate and possible future scenarios. Using extremal probability analysis, changes in the sea-level variance are related to the return period of extreme sea-levels. We find that changes in variance are location dependent. The most vulnerable region, the one for which the increase in variance is larger for a given wind increase, is identified to be the Gulf of St. Lawrence.

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Session PM2

CLIMATE VARIABILITY AND CHANGE 3

Chair: T. Shepherd

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Session PM2

CLIMATE VARIABILITY AND CHANGE 3

Chair: T. Shepherd

4. The effects of simulated climate change on the hydrology of major river basins

Vivek Arora and George Boer
Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada

Changes in the climatology of precipitation, evapotranspiration, and soil moisture lead also to changes in runoff and streamflow. The potential effects of global warming on the hydrology of 23 major rivers are investigated. The runoff simulated by the CCCma coupled climate model for the current climate is routed through the river system to the river mouth and compared with results for the warmer climate simulated to occur towards the end of the century. Changes in mean discharge, in the amplitude and phase of the annual streamflow cycle, in the annual maximum discharge (the flood) and its standard deviation, and in flow duration curves are all examined. Changes in flood magnitudes for different return periods are estimated using extreme value analysis.

In the warmer climate there is a general decrease in runoff and in annual mean discharge, although this is not uniform and discharge increases for some rivers. Middle and high latitude rivers typically show marked changes in the amplitude and phase of their annual cycle associated both with a decrease in snowfall and an earlier spring melt in the warmer climate. Low latitude rivers exhibit changes in mean discharge but modest changes in their annual cycle. Changes in flow duration curves characterise the different kinds of behaviour exhibited by different groups of rivers.

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Session PM2

COASTAL OCEANOGRAPHY 2

Chair: R. Pawlowicz

1. The energetics and influence of the M_2 tide on the circulation of a two-silled fjord

Michael W. Stacey[1] and Yves Gratton[2]
[1]*Royal Military College of Canada, Kingston ON*
[2]*INRS-Eau, Sainte-Foy, PQ*

A laterally-integrated, two-dimensional numerical model is used to examine the influence of the M_2 tide on the circulation in the Saguenay Fjord, a two-silled fjord (with a large inner and a small outer basin) located on the north shore of the St. Lawrence Estuary. The influence of freshwater runoff on the circulation in the fjord is also taken into account. The simulated M_2 tidal velocity near the surface in the outer basin can exceed 1 m/s. The M_2 tide in the inner basin is much less vigorous, but it still has velocity amplitudes of about 10 cm/s in the deepest part of the inner basin. The M_2 tide has a significant influence on the sub-tidal circulation because much of the vertical mixing associated with the tidally-generated internal motions occurs in the smaller outer basin. Therefore, the density at depth in the outer basin decreases faster than it does in the inner basin, and the resulting horizontal pressure gradient causes a bottom flow of water from the inner to the outer basin across the inner sill. This reverse renewal is evident in both the available observations and the simulation.

According to the numerical model most of the M_2 energy withdrawn from the surface tide is fed into the internal tide. A significant amount of tidal energy is also advected by the mean flow velocity. The diffusive flux of tidal energy (i.e., the energy flux that is associated with motions that are sub-grid scale according to the model) is small. Most of the dissipation in the fjord occurs in the outer basin and is concentrated near the sills. Because of the sub-tidal circulation, the baroclinic pressure (i.e., the total pressure but with the influence of the surface displacement removed) is associated with energy fluxes greater than 150 MW within the fjord. These fluxes represent a large redistribution of energy within the fjord, and their horizontal divergence along the fjord is almost in balance with the rate of change of potential energy.

2. Seasonal and interannual variability of sea surface heights and slopes on the Scotian and Newfoundland Shelves

Guoqi Han, Charles L. Tang, and Peter C. Smith
Bedford Institute of Oceanography

The TOPEX/Poseidon (T/P) altimeter data from 1992 to 1998 have been used to study seasonal sea surface height variability on the Scotian and Newfoundland Shelves. The altimetric results are compared with steric heights, numerical model solutions and tide gauge data at Halifax and St. John's. The altimetric observations interpolated from nearby T/P data agree favorably with the tide-gauge data. The seasonal variation has a range of about 10 cm, with a maximum in late fall and a minimum in late spring. The comparison also indicates that the seasonal variability consists of steric effect, and local and large-scale wind responses. Along-track sea surface slopes are calculated from T/P sea surface height anomalies. The altimetric sea surface slopes indicate seasonal changes in shelf edge flows. The interannual sea level variability is also examined.

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Session PM2

COASTAL OCEANOGRAPHY 2

Chair: R. Pawlowicz

3. Topographically induced tidal mixing

Burkard Baschek, David Farmer, and Svein Vagle
Institute of Ocean Sciences, Sidney, Canada

Topographically induced tidal mixing processes have been studied in the estuarine regime of Haro Strait, B.C., Canada. Measurements with vessel mounted Acoustic Doppler Current Profiler, Echo Sounder, towed CTD, and measurements of the distribution of gas bubbles along several transects across tidal fronts in that area provide information about the temporal evolution of the fronts and associated eddies.

The strong tidal flow in Spieden Channel forms two front lines as it enters Haro Strait. These two front lines meet as the dense water sinks rapidly under the slowly moving surface water. It spreads at intermediate depths of 50–100m and mixes with the resident water mass. The boundary between the two water masses tilts and stretches with time due to effects of the density gradient and the strong currents. The highly energetic eddies, which are generated in the frontal zone, are stretched by these processes, which increases their circulation intensity, while the corresponding vortex tilting transforms horizontal into vertical circulation. Gas bubbles are trapped by the eddies and are drawn down to depths of up to 120m. The vertical current speed in these downwelling regions sometimes exceeded 0.5 m/s. These violent processes may play an important role in the aeration of the water masses exchanged between semi-enclosed basins and the open ocean.

4. A finite-element model of the Arctic Archipelago

David A. Greenberg[1], Paul S. Chapman[1], and
M.G.G. Foreman[2]
[1]*Coastal Ocean Science, Bedford Institute of Oceanography, Dartmouth, N.S.*
[2]*Ocean Productivity, Institute of Ocean Sciences, Patricia Bay, B.C.*

Some of our early efforts modelling the tides and mean flows in the Arctic Archipelago have been described in past CMOS congresses. To look at the transport through the islands it is necessary to determine the frictional effect from the tidal currents. Modelling the tides in these complex areas has many intricacies. Steps in the process so far have involved: the least squares determination of the open boundaries by fitting to observations, iterating with the linear model to get the nonlinear effect of friction, throwing out obvious bad data, including geopotential effects, considering frictional effects from seasonal ice cover and expanding the domain to include more of the deep Arctic Ocean to properly allow for M_2 shelf waves in these high latitudes. In this presentation we will present the progress in modelling the tides and the tidal friction effects on the mean flow.

5. Influence of a step-like coastline on basin scale vorticity budget, for A-B-C-grid shallow water equation models and a quasi-geostrophic model

Frederic Dupont, David N. Straub, and Charles A. Lin
McGill University, Atmospheric and Oceanic Sciences Dept.

Global vorticity budgets in A-B-C-grid shallow water equation and quasi-geostrophic models of wind driven ocean circulation with free-slip boundary conditions are examined. We first note that for the shallow water models that, vorticity is a higher order variable with respect to velocity. Thus a discretized vorticity equation is only defined only at locations surrounded by velocity nodes. Therefore, the vorticity budget is only defined on a subdomain that excludes boundary grid nodes. At finite resolution, this implies that there can be an advective flux of vorticity across the perimeter of the vorticity-model-domain. For rectangular basins for which grid axes are aligned with the basin walls, this flux tends to zero as resolution is increased—as one would expect. We also consider the case in which the grid is rotated with respect to the basin, so that a step-like coastline results. Increased resolution then leads to more steps and, because of the singular geometry of steps, it is no longer obvious that this flux will vanish with infinite resolution. We note that, for the quasi-geostrophic model, the advective flux is smaller than for the shallow water equation models at the same resolution and that it does not show any strong dependence on the rotation of the grid with respect to the basin. We compare the results of the results of the different shallow water models with those of the quasi-geostrophic model at different resolution and rotation angle.

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Room 307

Session PM2

COASTAL OCEANOGRAPHY 2

Chair: R. Pawlowicz

Monday, 29 May
1540–1720 hrs
Room 309

Session PM2

MESO-SCALE PREDICTION

Chair: L. Neil

1. High-resolution real-time forecast research over W. Canada

Roland Stull, Henryk Modzelewski, Josh Hacker, and Xingxiu Deng
University of British Columbia

Daily, real-time, ensemble forecasts for Western Canada have been made at UBC for over 4 years. Experiments have been run with 3.3 km grid spacing over the Georgia Basin, and with multi-model, multi-IC, multi-physics ensembles. These research findings could be useful for high-res forecasts by operational centers. In particular, output of many traditional weather fields is useless in very-small domain mesoscale forecasts in complex terrain (e.g., isobars, contours, thickness, vorticity). Grid-cell forecasts in steep terrain must be localized during post processing to remove altitude biases. Ensemble forecasts on outer coarser meshes improve predictability upstream over the Pacific, while higher resolution on inner finer meshes is most important over complex terrain. Forecast case studies will be shown for fine mesoscale wind effects, including the Olympic Mountain Convergence Zone over Vancouver and Victoria. Research needs for further improvements at fine resolution will be discussed.

2. Verification of high-resolution numerical weather models for snow avalanche forecasting

Claudia Roeger, David McClung, Roland Stull, Josh Hacker, and Henryk Modzelewski
University of British Columbia

The objective is to determine whether output from high-resolution numerical weather prediction (NWP) models can be used as input for improved snow avalanche forecasting. Two high-resolution, real-time, numerical weather forecast models that are currently running at UBC are verified. The models use grid spacings of 3.3 km for the Whistler/Blackcomb ski area in the British Columbia Coast Mountains, and 2 km for Kootenay Pass in the Columbia Mountains. Standard statistical methods are used to compare the forecasts with surface observations of manual and automatic weather stations. Results of key parameters for avalanche forecasting, such as precipitation rate (snowfall) or wind, will be shown.

3. Heavy precipitation in the Greater Vancouver Regional District: The White Rock storm of 1999.

Brad Snyder[1], Russell Higginson[2], Marc Trudeau[2], and Trevor Smith[3]
[1] *Meteorological Service of Canada, Applications Services.*
[2] *University of British Columbia*
[3] *Meteorological Service of Canada, Pacific Weather Centre.*

Long duration precipitation events are commonplace over coastal British Columbia and are generally well handled by numerical models and by meteorologists. In contrast, short duration very heavy precipitation events are less common and not forecast as well by those concerned. Indeed, mesoscale models which are routinely available to the forecasters, often fall short of capturing such local scale events.

This paper will present a case of heavy rains over south-western British Columbia. Specifically, the case of flooding on 8 June 1999 affecting the city of White Rock will be investigated. The focus of the discussion will be on the particular meteorological processes involved and the predictability of such storms given the tools available to the forecaster. Other similar cases will be described which suggest similar processes at work and further emphasize the difficulty of local scale forecasting.

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Chair: L. Neil

4. Ensemble forecasting a bust

Joshua P. Hacker, S. Krayenhoff, and R. B. Stull
University of British Columbia Atmospheric Sciences

Tuesday, 9 February 1999, residents of the British Columbia (BC), Canada, lower mainland (Vancouver area) began preparing for an intense maritime cyclone that was forecast to bring heavy snow and rain, and strong winds to the area the evening of 10 Feb. The morning of 10 Feb.. the local forecast office issued both a wind warning, with winds forecast to reach 60–80 km per h, and a snowfall warning with accumulations of 4–8 cm that evening. The afternoon forecast update also included wind and snowfall warnings, with the winds expected to increase to 70–90 km per h, and rainfall accumulations of 50 mm on 11 Feb. The low-pressure center was forecast to lay a few hundred km off the central BC coast by that evening, with the associated front (warm occluded) having crossed the lower mainland overnight on 10 Feb. By 1600 PST 11 Feb., the winds at Vancouver International Airport (YVR) were recorded as approximately 20 km/h, and the region did not receive significant precipitation until after 0400 PST 14 Feb.

Model guidance for this storm event was poor, prompting an investigation into the source of error for the forecast. To estimate the effect of initial condition uncertainty, a short-range ensemble system is developed and tested on a LAM grid for a 10-day period surrounding the storm. To estimate the effect of model uncertainty, a physics-based ensemble is run for the same period. Results suggest that the IC-based ensemble is a good first-order estimate of IC uncertainty. The behavior of the ensemble also suggests a fairly good sampling of the IC probability density function. Comparing the results with the physics-based ensemble shows that the IC uncertainty is more important than model uncertainty for this case.

5. Models of coastally trapped disturbances: Validation from realistic simulations

P. L. Jackson[1], K. J. Tory[1], and C. J. C. Reason[2]
[1]*Environmental Studies Program, University of Northern British Columbia*
[2]*School of Earth Sciences, University of Melbourne*

Numerical simulations of the 15–17 May 1985 atmospheric Coastal Trapped Disturbance (CTD) event along the west coast of North America are compared with the schematic model of CTD evolution developed by Skamarock et al. (1999) (SRK99) which was based upon more idealized simulations. It is shown that the general evolution of the May 1985 CTD is consistent with the SRK99 schematic model. It is further shown that secondary effects not contained in the SRK99 simulations, such as diurnal radiation variations and mesoscale topographic variations, can account for the variable CTD initiation and propagation observed both in nature and in the present numerical simulations. Diurnal radiation variations, coupled with differential heating of land and ocean, appear to play an important role in setting up the alongshore temperature gradient necessary for CTD formation and evolution. The modelled CTD is found to change dynamical characteristics from an initial Kelvin wave / bore similar to that discussed in Ralph et al. (1999) to a gravity current, and this change is consistent and coincident with a sharp change in translation speed of the disturbance.

References

Ralph, F.M., L. Armi, J.M. Bane, C. Dorman, W.D. Neff, P.J. Neiman, W. Nuss, P.O.G. Persson, 1998: Observations and analysis of the 10–11 June 1994 coastally trapped disturbance. *Mon. Wea. Rev., 126*, 2435–2465.

Skamarock, W.C., R. Rottuno, J.B. Klemp, 1999: Models of coastally trapped disturbances. *J. Atmos. Sci.*, in press.

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PLANT/ATMOSPHERE FLUXES 2

Chair: D. Spittlehouse

1. Environmental controls of carbon dioxide fluxes above a Pacific Northwest Douglas-fir forest

Eva-Maria Jork[1], T. Andrew Black[1], Gordon B. Drewitt[1], Elyn R. Humphreys[1], Zoran Nesic[1], Nigel J. Livingston[2], M. Altaf Arain[1], Michael D. Novak[1], and Dave L. Spittlehouse[3]
[1]*University of British Columbia, Faculty of Agricultural Sciences*
[2]*University of Victoria, Department of Biology*
[3]*BC Ministry of Forests, Research Branch*

This paper reports carbon sequestration by a 50-year-old, 33-m-tall Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) forest (an Ameriflux site) near Campbell River, Vancouver Island. We investigated environmental controls on CO_2 fluxes (Fc) for 1997–99 and developed empirical models. Because anabatic/katabatic winds and land-sea circulations affect this sloping site, the significance of advective and drainage flows was assessed.

Eddy-covariance fluxes were measured by a 3-dimensional sonic anemometer (R2, Gill Instruments), a krypton open-path hygrometer (KH20, Campbell Scientific Inc.), and an infrared-gas analyzer (6262, LI-COR Inc.), mounted at the 43-m height on a 51-cm triangular tower. The analyzer, which had a 4-m-long heated sampling tube, was temperature-controlled and automatically calibrated daily. Half-hour fluxes were calculated on-line by a PC and transmitted daily to UBC via modem/cellular phone. A 3000 Amp-hour 12-V battery/generator system supplied power.

Photosynthesis occurred throughout the year resulting in CO_2 uptake frequently exceeding 20 and 10 μmol/m^2/s in spring/summer and winter, respectively. Relating daily mean CO_2 uptake to photosynthetically active radiation (PAR), air temperature, saturation deficit and soil moisture (qv) using residual analysis, we developed a model explaining 68 of the total variance. Similarly, a respiration model derived from relationships between nighttime mean Fc (when friction velocity 0.2 m/s) and soil temperature, qv and PAR on the previous day accounted for 67 of the measured variance.

Clearly affected by the El-Niño and La-Niña events, carbon uptake was 31 higher in 1999 (514 gC/m^2) than in 1998 (394 gC/m^2), as a result of lower 1999 temperatures reducing respiratory loss and gross photosynthesis by 12 and 3, respectively. These high uptake rates suggest that West Coast forests play an important role in the global carbon cycle. Climate change, however, is likely to significantly alter their sink capacity because CO_2 exchange between forests and the atmosphere is strongly affected by environmental factors.

2. Carbon fluxes following harvesting and fire in the boreal forest

Brian Amiro
Canadian Forest Service, Northern Forestry Centre

Disturbances by fire and harvesting are thought to control the carbon balance of the Canadian boreal forest. However, there are few direct measurements of carbon fluxes following disturbances to provide data needed to refine mathematical models. The eddy covariance technique was used with paired towers to measure fluxes simultaneously at disturbed and undisturbed sites over periods of about one week during the growing season. The disturbances were: a one-year-old burned jackpine stand that experienced an intense crown fire near Fort Providence, Northwest Territories a one-year-old clearcut aspen area near Peace River, Alberta and a ten-year-old burned, mixed forest near Prince Albert National Park, Saskatchewan. Nearby mature forest stands of the same types were also measured as controls. Daytime CO_2 fluxes were much reduced at the harvested site, but night-time CO_2 fluxes were identical to that of the mature aspen forest. The overall effect was that the harvested site was a carbon source of about 2.4 g carbon m^{-2} day^{-1}, while the mature site was a sink of about –4 g carbon m^{-2} day^{-1}.

The one-year-old burn had a continuous CO_2 efflux of about 0.8 g carbon m^{-2} day^{-1} compared to the mature jackpine forest sink of –0.5 g carbon m^{-2} day^{-1}. The 10-year-old burned site had half-hour CO_2 fluxes that were slightly less than a mature site, but there was no significant difference between the daily integration (–1.3 g carbon m^{-2} day^{-1} at mature site and –2.9 g carbon m^{-2} day^{-1} at 10-year-old burn site). It appears that most of the effect occurs within the first ten years following disturbance, but more data are needed on other forest and disturbance types for the first 20 years following the disturbance event.

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Chair: D. Spittlehouse

3. Water vapour and carbon dioxide fluxes above a boreal deciduous forest

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[1]*Biometeorology, Faculty of Agricultural Sciences, University of British Columbia, Vancouver, BC, Canada*
[2]*Climate Research Branch, Atmospheric Environment Service, Saskatoon, SK, Canada*
[3]*Climate Research Branch, Atmospheric Environment Service, Downsview, ON, Canada*
[4]*Northern Forestry Centre, Canadian Forest Service, Edmonton, AL, Canada*

Water vapour and carbon dioxide fluxes above land surfaces are sensitive to changes in temperature and precipitation patterns and associated feedback processes. In this paper, the responses of these fluxes to interannual climatic variability over the last five years (1994–1999) in a boreal aspen ecosystem in Saskatchewan, Canada will be presented. These fluxes are being measured using the eddy covariance technique as part of the Boreal Ecosystem Research and Monitoring Sites (BERMS) program. The primary climatic control on carbon sequestration was spring temperature. Warm springs caused early leaf emergence and significantly increased ecosystem photosynthesis but had little effect on respiration. Implications of early leaf emergence on evaporation and water use efficiency will be discussed. Results of using the Canadian Land Surface Scheme (CLASS) to simulate the effects of interannual variability on these fluxes will also be reported. A single-layer process-based two-leaf (sunlit and shaded) model of canopy conductance and photosynthesis (based on the Farquhar approach) was incorporated into CLASS.

4. Evaporation from a Canadian West Coast Douglas-fir forest: Seasonal patterns and controls

Elyn R. Humphreys[1], T. Andrew Black[1], Eva-Maria Jork[1], Gordon B. Drewitt[1], Zoran Nesic[1], Dave L. Spittlehouse[2], and M. Altaf Arain[1]
[1]*University of British Columbia, Faculty of Agricultural Sciences*
[2]*BC Ministry of Forests, Research Branch*

This presentation reviews the past two years of eddy covariance measurements of latent and sensible heat flux made above a 50-year-old, 33-m tall Douglas-fir forest near Campbell River, Vancouver Island. This stand is part of the Pacific Northwest seasonal temperate rainforest where winters are typically wet and mild, while summers are warm and dry. These conditions provide a unique opportunity to illustrate how the physical and physiological controls on evaporative water loss and energy exchange may change abruptly between and within the seasons.

One particular challenge with year-round, tower-based eddy covariance measurements is to ensure data quality under extremely challenging weather conditions. High humidity and contaminants in the sampling tube leading to the closed-path infra-red gas analyzer were found to cause water vapour signal attenuation. A convenient correction procedure dealing with the resultant flux underestimation is presented.

Annual water loss to the atmosphere from this canopy was dominated by dry canopy, summer evaporation, primarily through the process of transpiration. Between April and September, total evaporation accounted for 74 and 71 percent of the 415 mm and 375 mm of water lost to the atmosphere in 1998 and 1999, respectively. However, evaporation rates were clearly limited by the surface conductance through physiological control of water loss. Surface conductance became increasingly limiting as soil water potential decreased and atmospheric saturation deficit increased. Winter evaporation rates during November through February were far from negligible ranging from 10.2 to 20.2 mm per month. Sensible heat fluxes were observed to be generally directed downwards toward the canopy as heat was removed from the air to support evaporation of intercepted rainfall. Given a non-zero atmospheric saturation deficit and sufficient turbulence, significant evaporation rates from the wet canopy were observed during both the day and night.

5. Climate change, Douglas-fir growth and carbon sequestration

D.L. Spittlehouse
B.C. Ministry of Forests

The 1.1 million hectares of second growth Douglas-fir forests in coastal BC are sequestering 1 to 5 Mt carbon/yr. Annual growth is strongly related to summer moisture availability. A forest water balance model and forests growth and yield model were used to assess change in growth over the next 50 years due to a change in summer rainfall and evaporative demand. The relationship between summer water availability and growth had a slope of 2 t C in total above and below ground biomass at 50 years per mm of available water. The effect of reduced rainfall and increased temperature on summer water availability and growth was calculated for a transient climate change scenario over 50 years. Growth was reduced during this period by 15 to 25 t C/ha depending on the site, about a 5% reduction in growth. Increased photosynthesis rates due to increased atmospheric carbon dioxide concentration may offset some of this reduction, but further reductions could occur through increased occurrence of fire, disease and pests.

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OBSERVED CLIMATE AND VARIABILITY

Chair: S. Lambert

1. Climate Station History Metadata Project

Anna Deptuch-Stapf and Robert Morris
Climate and Water Products Division, Meteorological Service of Canada

Accurate analysis, application and interpretation of historical climatic data require detailed knowledge of the observing program and instruments from the observing locations. This is true for climate change monitoring and detection research, calculating climatic normals, or conducting other specialized or applied climatological studies. The need for climate station metadata includes instruments and their siting and maintenance, and information about the observation program such as schedules and procedures. Canadian participation in the WMO Global Climate Observing System (GCOS) requires that digital copies of historical climate data and metadata be available at a designated WMO World Data Center.

Paper inspection reports for more than 7000 climate stations, dating back to the 1800s, are archived with the Meteorological Service of Canada in Toronto. Climate Change Action Fund funding was secured for the project – Digitization and Accessibility of Climate Station History MetaData . This project is concerned with digitizing the paper station records, and organizing, indexing and providing access to the resulting information in digital files.

The purpose of this paper is to describe the project for the climate change research community and other users of climate data, and provide an update on its status. Particular attention will be placed on file format and accessibility options with illustrative examples provided for a number of GCOS stations.

2. Gridded climate data for the prairie provinces

R. F. Hopkinson
Environment Canada, Prairie & Northern Region

In contrast to the gridded climate data based on the rehabilitated temperature and precipitation data sets, this set of gridded climate data (monthly mean temperature and total precipitation) uses all of the monthly data in the National Climate Archive. The purpose of this data set is not to detect climate change but rather to provide as much detail as possible on a 50 km grid spacing on a polar stereographic secant projection true at 60°N. Prior to the 1950s, only the southern prairies had sufficient data for complete coverage and prior to 1900, only part of southern Manitoba. Applications of this gridded data include distributed input to hydrologic models, GIS, detailed Palmer Drought Index analysis for various applications, regional water resource assessments and spatial analysis of avian botulism outbreaks to name a few. The paper will describe how the station data were analyzed to the grid, the limitations of the gridded data and a few applications of the gridded climate data.

3. Characteristics of daily and extreme temperatures over Canada

Barrie Bonsal, Xuebin Zhang, Lucie Vincent, and William Hogg
Climate Research Branch, Meteorological Service of Canada

This study examines 20th century trends and variability in Canadian daily minimum and maximum temperature with particular emphasis on extremes. Using recently updated, homogenized daily data, spatial and temporal characteristics of daily and extreme temperature related variables are analyzed on a seasonal basis for the periods 1900–98 (over southern Canada), and 1950–98 (over the entire country). From 1900–98, the majority of southern Canada shows significantly increasing trends to the lower and higher percentiles of the daily minimum and maximum temperature distribution. The results translate into fewer days with

extreme low temperature during winter, spring, and summer and more days with extreme high temperature during winter and spring. No consistent trends are found for the higher percentiles of summer daily maximum temperature indicating little change to the number of extreme hot summer days. Over south-western Canada, increases are larger to the left-hand side of the daily minimum and maximum temperature distribution resulting in significant decreases in intraseasonal daily temperature variability. Results from 1950–98 display substantial regional differences, especially, during winter and spring. This involves significant increases to the low and high percentiles over the west, and decreases over the east.

The largest daily temperature trends (both minimum and maximum) occur during winter and early spring when substantial warming is observed. For summer, increases are only associated with daily minimum temperature. Autumn displays varying results with some late season cooling, mainly over western regions. The observed warming trends have had a substantial effect on several economically sensitive indices. This includes significant increases to the number of growing and cooling degree days, and significant decreases to the number of heating degree days. In addition, the length of the frost free period is significantly longer over most of the country.

4. Bias in the observations of precipitation amounts from AWOS

Ewa Milewska
Meteorological Service of Canada

Meteorological Service of Canada uses Automated Weather Observing System (AWOS) to automate principal weather stations. One-year long (1995/1996) concurrent man and AWOS daily observations are used to detect the presence of systematic biases in precipitation amounts for the purpose of adjusting long-term climatological time series. While AWOS uses modified AES Fisher and Porter Weighing Gauge for precipitation totals, observers read rainfall amounts from the manual AES Standard Type B Rain Gauge, and snowfall amounts from the Nipher Snow Gauge which are sometimes combined with ruler measurements of snow depth. In most cases AWOS is located in open areas close to the runways, usually a few hundred meters away from the old manned site. Preliminary results indicate that, overall, AWOS greatly overestimates, by up to 165%, small precipitation amounts of 5 mm or less, while underestimating, by up to 12%, the amounts higher than 5 mm. The instrumental differences seem to be the major reason for this disagreement.

5. Brief intense rainfalls are becoming more frequent in Vancouver B.C.

Reg Dunkley
Environment Canada

Engineers from the City of Vancouver, British Columbia noticed that the frequency of rainstorm related flooding episodes within the City had increased in recent years. Environment Canada meteorological investigations of some of these flooding episodes revealed that such incidents were usually associated with intense downpours lasting less than one hour. As a result, this study concentrated on rainfall durations of 10 minutes, 15 minutes and 30 minutes in length. The archived tipping bucket rainfall intensity data for Vancouver International Airport from the 36 year period 1961 to 1996 was examined. This dataset consisted of values of the daily maximum rainfall amounts for each of the standard duration periods (5, 10, 15, 30 and 60 minute intervals as well as 2, 6, and 12 hour intervals). For each year, the number of days when the rainfall intensity exceeded 10 mm/hour was determined. It was found that for all duration intervals, there was a substantial increase in rainfall intensity when the decade ending in 1976 was compared to the decade ending in 1986. For 15 and 30 minute durations, this increasing trend continued and the number of days for the decade ending in 1996 were nearly double the number of days for the decade ending in 1976. Histograms of the number of days per year when rainfall intensity exceeded 10 mm/hour suggest that intense rainfalls are more frequent after 1976. This coincides to the time when the North Pacific pressure pattern and Pacific Decadal Oscillation underwent a step like change. A comparison with rainfall measurements taken at airports in Victoria, Abbotsford and Comox did not show a similar trend which suggests that the recent changes in Vancouver were localized. It is not obvious what elevated the frequency of intense rainfall events in the 1980's and through the 1990's in Vancouver but it is conceivable that increased urbanization and development played a role.

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OBSERVED CLIMATE AND VARIABILITY

Chair: S. Lambert

6. An exploration of precipitation variability in the southern Canadian Cordillera over the past four centuries

Emma Watson and Brian Luckman
The University of Western Ontario

Several studies have identified links between conditions in the Pacific Ocean and precipitation and temperature anomalies in western North America. Particular attention has focussed on the widespread impacts of low-frequency variability in the Pacific Ocean. Unfortunately, instrumental records are too short to characterise these low-frequency variations adequately. Tree-ring chronologies provide annually-resolved proxy records of climatic variables that are influenced by conditions over the Pacific and may potentially provide data on this low frequency variability over much longer timescales.

Moisture-sensitive tree-ring chronologies have been used to develop high-quality (i.e., well-verified) precipitation reconstructions for individual meteorological stations in the southern Canadian Cordillera (Banff, Jasper, Cranbrook, Westwold, Kamloops and Penticton). The longest of these extends back to 1430 and explains over half of the variance in the instrumental precipitation record of the last 100 years (Watson, 1998). Similarities in the low-frequency variations in these reconstructions suggest a common, large scale forcing. A dense, irregularly spaced network of 50 tree-ring chronologies has been developed from moisture-stressed sites in the southern Canadian Cordillera in the area between Alexis Creek, Prince George, Jasper and Waterton. Preliminary results suggest that, though often dissimilar at high frequencies, low pass filtered chronologies display coincident intervals of enhanced and reduced growth (i.e. wet and dry conditions) possibly indicative of large-scale circulation anomalies. These analyses also indicate that relationships between the chronologies are not consistent through time suggesting variations in the dominant control of precipitation or possibly interplay between multiple controls. This chronology network can be used to explore spatial patterns of precipitation in the southern Canadian Cordillera over the last 2–3 centuries and the nature and cause(s) of any coherent low-frequency precipitation variability. The reconstructions may also permit the exploration of the variability of precipitation (and possibly its dominant controls) related to changing background climate during this period that can complement modelling experiments.

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THERMOHALINE CIRCULATION

Chair: C. Garrett

1. On a stabilizing feedback to the ocean thermohaline circulation

Stephen C. Newbigging, Lawrence A. Mysak, and Zhaomin Wang
Centre for Climate and Global Change Research and The Deparment of Atmospheric and Oceanic Sciences, McGill University

A coupled ocean-atmosphere one-hemisphere box model of the ocean thermohaline circulation (THC) is presented which is a modification of that investigated by Nakamura, Stone and Marotzke. As in Nakamura et al. the atmospheric heat and moisture transports are parameterized as functions of the atmospheric temperature and temperature gradient. However, in contrast to the Nakamura et al. model, in which the atmospheric surface temperature is diagnosed from the sea surface temperature (SST), here the atmospheric temperature is allowed to vary independently. The effect of this refinement on the behavior of the THC under high latitude freshwater perturbations is shown to be stabilizing. Specifically, the destabilizing effect of atmospheric freshwater and heat transports is shown to be about 25% smaller when surface air temperatures are allowed to vary independently as compared to when they are diagnosed directly from SST.

2. Changes in Northwest Atlantic Deep Water properties in the early 1990's

R.M. Hendry and I.M. Yashayaev
Department of Fisheries and Oceans, Bedford Institute of Oceanography

Northwest Atlantic Deep Water (NWADW) is the densest deep water mass of the northern North Atlantic. NWADW is a diluted form of Denmark Strait Overflow Water (DSOW) that originates in the Greenland Sea and is exported to the North Atlantic through Denmark Strait. Interannual variations in air-sea interaction modulate the formation and export of DSOW, and thus change the thermohaline circulation of the North Atlantic. NWADW moves from its northern source region to the deep North Atlantic via deep boundary flows. A component of the deep boundary current follows a counterclockwise path around the perimeter of the deep Labrador Sea and exits to the south on the western side. The waters carried by this deep flow continue into the Newfoundland Basin and beyond as the classical Deep Western Boundary Current. An analysis of changes in NWADW properties in the deep Labrador Sea based on historical data and annual transects carried out since 1990 shows spatially and temporally coherent patterns of interannual variability. A relative maximum in Labrador Sea NWADW temperature and salinity in the late 1980's was followed by a period of freshening and cooling that produced near-record-low temperatures in 1996. Newfoundland Basin measurements from1990–1995 allow some insight into the downstream evolution of these changes. The temperature and salinity of the densest layers on the continental rise in the western Newfoundland Basin co-varied with the Labrador Sea changes during the 1990–1995 period: changes in source properties appear to move relatively rapidly along the boundary. The temperature and salinity in the deepest waters in the interior of the Newfoundland Basin also varied during this period, but the changes are less easy to interpret.

3. Stability of the Mediterranean's thermohaline circulation under modified flux forcing

Paul Myers[1], Keith Haines[2], and Stephan Matthiesen[2]
[1]*Department of Physics and Physical Oceanography, Memorial University of Newfoundland*
[2]*Department of Meteorology, University of Edinburgh*

A series of experiments with an ocean general circulation model of the Mediterranean forced by surface fluxes of heat and freshwater are performed. The amount of excess evaporative loss from the basin is varied from 20% to 125% of today's value. Small increases (up to 10%) of excess evaporation, similar to what has been suggested to be presently occurring within the basin, produce a linear response, with increased salinity and enhanced circulation, but no major differences in the basic circulation mode. The behavior is also linear for decreases in excess evaporation, with a decrease in salinity, weakening of the circulation and of convection. The deep waters become unventilated (which could lead to sapropel formation in paleoclimatic times) while the main source of intermediate water formation switches to the Adriatic. However, large increases in excess evaporation produce very non-linear behavior, with enhanced mixing at the Strait of Gibraltar leading to rapid salinification of the basin, changes in the convection locations, and then an eventual circulation collapse to produce a mode very similar to that seen in the reduced excess evaporation experiments (albeit with very different hydrography). In all cases, the main west-east thermohaline cell remains stable.

4. Response of the thermohaline circulation to cold climates

Zhaomin Wang and Lawrence A. Mysak
Centre for Climate and Global Change Research and Department of Atmospheric and Oceanic Sciences, McGill University

A simple coupled atmosphere-ocean-sea ice-land surface-ice sheet model (Wang and Mysak, 2000a, 2000b) is employed to study the response of the thermohaline circulation (THC) to various global coolings. The global cooling scenarios are realized by reducing the present day atmospheric CO_2 concentration gradually over a 5000-year period to different values and then maintaining these final values in the model for around 10 ka. Generally, it is found that the response of the THC to global cooling is nonlinear: For a slightly cold climate, the North Atlantic overturning cell (NAOC) and the Pacific upwelling become intensified. For a very cold climate, the NAOC may be weakened or even collapsed. The associated Pacific upwelling for a very cold climate also becomes weak when the NAOC is weakened and intermediate deep water may form in Pacific when the NAOC is collapsed. The results suggest that a very cold climate may lead to a decrease of the meridional density gradient and an increase of the vertical density difference (lower layer density minus upper layer density), which can weaken or shut down the NAOC.

Further sensitivity experiments are done to investigate the haline-only or thermal-only effects on the THC during global cooling. As the climate is cooled in these experiments, the model is adjusted so that there is no effect on the ocean temperature or there is no effect on the ocean salinity. The global cooling induced reduced atmospheric poleward moisture transport and the growing of continental ice masses lead to the intensification of the NAOC. The global cooling induced oceanic cooling may lead to the weakening or shutting down of the NAOC. Therefore, we conclude that the thermal effect is dominant in the weakening or shutting down of the NAOC. Based on the above model results, we propose that the climate during the LGM may favor a not so strong THC mode in contrast, the climate during the initiation and early stages of the last glaciation may favor a stronger THC mode.

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THERMOHALINE CIRCULATION

Chair: C. Garrett

5. A thermally and mechanically driven model of the ACC

Richard Karsten, Helen Jones, and John Marshall
Massachusetts Institute of Technology

Inspired by laboratory experiments and eddy-resolving numerical simulations, a simple theory for the structure of a circumpolar current is developed. Cooling and sucking within a given radius of the center of a rotating cylindrical tank combined with heating and pumping elsewhere are used to generate a temperature front and associated flow. This mirrors the forcing that supports the ACC: up-welling and cooling of polar waters to the south with warming and subduction to the north. Sustained thermal and mechanical forcing promote and strengthen the front which becomes baroclinically unstable, the growing waves feeding off the available potential energy to form vigorous eddies. Once the flux of buoyancy due to these eddies is sufficient to balance the surface buoyancy flux a statistically steady current is observed. Relationships are derived for the depth of penetration, width and strength of this current in terms of the surface buoyancy flux and wind stress. Despite the simplicity of our assumptions, our formulae give surprisingly reasonable predictions of the vertical scale and speed of the ACC.

6. Circulation within the North Water Polynya in Baffin Bay

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The North Water is a recurrent polynya at the northern end of Baffin Bay. As part of the International North Water Project, recording current meters were moored within this polynya during 1997–98 to study the physical reasons for its existence. The North Water is dominated by a strong southward flow of cold water and ice from the Arctic Ocean. Although most of the warm West Greenland Current crosses Baffin Bay to the south of the polynya, a branch provides a modest northward flow of warm water up the eastern side. When the inflow of ice from the north is blocked in Smith Sound, the continued drift out of northern Baffin Bay is sufficient to create the North Water, without oceanic heating. The warm northward flow is diverted by the complex glaciomarine topography near the Carey Islands, where it loses much of its heat through re-circulation into and isopycnal mixing with the Arctic outflow. The remnant that continues north is overrun by cold Arctic waters of lower salinity. However, upwelling near the Greenland coast forced by Ekman transport brings the warm water to the base of the turbulent surface layer where it is entrained. The resulting flux of sensible heat provides about one third of the surface heat loss and reduces ice growth correspondingly. Brine-driven convection provides the energy for entrainment. Therefore, the sensible heat forcing of the polynya is dependent upon freezing. In particular, since the sensible heat flux decreases as ice growth slows in spring, this mechanism cannot explain the early appearance of ice-free waters.

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Session AM2

LONG-RANGE FORECASTING

Chair: L. Lefaivre

1. Skill of seasonal hindcasts as function of the ensemble size

Slava Kharin[1], Francis Zwiers[1], and Normand Gagnon[2]
[1]*Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada*
[2]*Canadian Meteorological Centre, Meteorological Service of Canada*

Forecast skill as function of the ensemble size is examined in a 24-member ensemble of northern winter hindcasts produced with the second generation general circulation model of the Canadian Centre for Climate Modelling and Analysis. These integrations are initialized from the NCEP reanalyses lagged by 6 hours prior to the forecast season. The sea surface temperatures are forecasted by persisting the monthly mean anomaly observed prior to the forecast period. Potential predictability of the lower boundary forced variability is estimated.

The skill maximum of zero time lead forecasts in the first 1–2 weeks, when the skill originates predominately from the initial conditions, is achieved for relatively small ensemble sizes. The forecast skill in the rest of the season increases monotonically with the ensemble size. The skill of DJF Z500 hindcasts in the Northern Hemisphere and in the Pacific/North America sector improves substantially when the ensemble size increases from 6 to 24. The statistical skill improvement is also better for larger ensembles.

2. Probabilistic approach to seasonal forecasting

Normand Gagnon and Richard Verret
Weather Element Division, Development Branch, Canadian Meteorological Centre

Dynamical atmospheric models have been used at the Canadian Meteorological Centre (CMC) to produce temperature and precipitation seasonal forecasts. The models used are the Canadian Climate Centre for modelling and analysis (CCCma) General Circulation Model second generation (GCMII) and the Recherche en Prévision Numérique (RPN) Global Spectral model (SEF). An ensemble of six members of each model is run using different atmospheric initial conditions lagged by six hours. The models are forced by sea surface temperature, sea ice cover and snow field.

The CMC operational products issued are in the form of categorical anomalies (below, normal and above) over Canada. These categorical forecasts are made using, as a predictor, the difference between the 12 member ensemble mean field and a 26 year climate (deterministic method). A probabilistic approach is proposed to try to extract additional information from the ensemble member dispersion. Forecast probabilities are calculated by counting the number of individual members in each of the three categories at every location and then by dividing by the ensemble size.

To estimate the skill of the models, the forecast system was tested in hindcast mode over the period 1969 to 1994 (Historical Forecasting Project). A comparison between the deterministic and probabilistic approaches is done. The performance of the probabilistic forecast based on Relative Operating Characteristics curves were generally equivalent to the deterministic ones. However, it could be concluded from reliability diagrams that the approach based on probability as a clear advantage. The probabilistic forecasts carry more information and therefore could be potentially more useful in decision making processes. A summary of the performance obtained using the two approaches will be presented and discussed.

3. Bootstrap estimation of errors in predicting Niño 3.4 SST anomalies

Yuval
University of British Columbia

A method to estimate the errors of predictions of tropical Pacific SST anomalies is presented. The error estimation process is based on bootstrap resamplings of the data and construction of a large number of bootstrap prediction replicas. A statistic calculated on the set of bootstrap replicas which corresponds to each of the actual predictions is used to estimate upper and lower limits on the predictions. The error estimation process is demonstrated on neural networks prediction of the Niño 3.4 index. It can be applicable to other data prediction problems and in any case where the predicting model can be developed in an automatic manner. The error estimates complement the information provided by the predictions by evaluating their relative uncertainties. Integrated in the error estimation process is a scheme to flag predicted anomalies as significant warm or cold events and it shows a reasonable qualitative capability of sorting predictions into El Niño, La Niña or neutral states up to nine months in advance.

4. Long-lead prediction of summer precipitation over the Canadian prairies – A brief overview and present status

Edmund R. Garnett
University of Saskatchewan

The prairie region of Western Canada is one of the world's major agricultural areas producing an annual average of about 22.9 million tones of spring wheat during 1990–1995. A key determinant of spring wheat yield and protein is June and especially July rainfall. Interannual climatic variability contributes to large deviations in production and poses a threat to the agro ecosystem and rural sustainability especially during times of low prices. The effect of the 1988 drought on agriculture is an indicator of society's vulnerability to such events. Canada's agricultural production decreased by 12.7 in 1988 and the drought was estimated to have caused a direct production loss of 1.8 billion (in 1981 dollars). Advance knowledge of summer weather and reliable estimates of grain production and quality is thus of considerable importance to grain producers, marketers and planners. Specifically, there is a need for a statistical teleconnection based model for the long-lead forecasting of climate, yield and quality.

There are many forcing functions governing the amount of precipitation, that occurs on the Canadian Prairies during the summer months. These include the El Niño/Southern Oscillation phenomenon, the Pacific North American Teleconnection (PNA) flow pattern, the position and strength of the Pacific High, the size, shape and long wave positions associated with the circumpolar vortex, North Pacific sea surface temperatures, North Atlantic Oscillation (NAO) and feedback mechanisms between the surface and atmosphere. Less direct influences are factors such as the QBO, Eurasian snowcover and performance of the Indian monsoon.

Simple empirical analysis as well as statistical regression techniques are being used to investigate various teleconnective linkages. Regression equations are being developed that include a suite of physically sound variables for explaining a large portion of Canadian prairie precipitation and temperature variation and ultimately for developing estimates of Western Canadian spring wheat yield and quality with a lead time of 3 to 6 months.

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Session AM2

LONG-RANGE FORECASTING

Chair: L. Lefaivre

5. Midlatitude Pacific SSTs: Equilibrium and transient atmospheric responses and implications for seasonal forecasting

Nick Hall, Jacques Derome, and Hai Lin
Dept. Atmospheric and Oceanic Sciences, McGill University, Montreal

A global climate model based on dynamical equations and empirical forcing is used to assess the sensitivity of the extratropical circulation to anomalies in the midlatitude Pacific SST.

Long equilibrium integrations show that the response varies widely with the position and strength of the SST anomaly. Comparisons with linear time independent stationary wave calculations reveal that nonlinear transient eddies play an important role in shaping the response. Characteristic patterns of the response bear close resemblance to natural modes of low frequency variability. As well as changing the mean state of the circulation, a Pacific SST anomaly can also skew the probability distribution functions associated with projections onto these natural modes.

Multiple ensemble forecast experiments show that seasonal forecasts are affected by an SST anomaly in a way that is highly sensitive to large scale changes in the initial condition, even when statistically significant ensemble means are considered. While the mean response over all initial conditions resembles the equilibrium solution, there is no guarantee that this response will appear for any given initial condition. Linear analysis fails to provide a reliable link between initial condition and forecast response.

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Session AM2

BOUNDARY LAYERS 1

Chair: I. McKendry

1. Wind and temperature profiles in the radix layer

Roland Stull and Edi Santoso
University of British Columbia

In the large center region of the convective boundary layer is a uniform layer where wind speed and potential temperature are nearly constant with height. Below this uniform layer (UL), wind speed decreases to zero at the ground, while potential temperature increases to the surface skin value. This whole region below the uniform layer was identified by Santoso and Stull (1998) as the radix layer (RxL), and is of order of hundreds of meters thick. Within the RxL lies the classical surface layer (order of tens of meters thick) that obeys traditional Monin-Obukhov similarity theory.

The RxL depth is shown to depend on friction velocity, Deardorff velocity, and boundary layer depth. The wind RxL is usually thicker than the temperature RxL. Using RxL depth, UL wind speed, and UL potential temperature as length, velocity and temperature scales, respectively, one can form dimensionless heights, velocities, and temperatures. When observations obtained within the RxL are plotted in this dimensionless framework, the data collapse into similarity curves. Empirical profile equations are proposed to describe this RxL similarity. When these profile equations are combined with the flux equations from convective transport theory (Stull 1994), the result are new flux-profile equations for a deep region within the bottom of the convective boundary layer.

These RxL profile similarity equations are calibrated using data from four sites with different roughnesses: Minnesota, BLX96-Lamont, BLX96-Meeker, and BLX96-Winfield. The empirical parameters are found to be invariant from site to site, except for the profile shape parameter for wind speed. This parameter is found to depend on standard deviation of terrain elevation, rather than on the aerodynamic roughness length. The resulting parameter values are compared with independent data from a forested fifth site, Koorin, and it is found that displacement height must be subtracted from all the heights in the RxL profile equations.

2. Turbulent fluxes in the very stable nocturnal boundary layer.

Jennifer Salmond
University of British Columbia

Turbulence in the very stable nocturnal boundary layer (NBL) is typically intermittent, existing in isolated layers and pockets that may only sporadically break through to the surface. These characteristics present a challenge to the accurate measurement and calculation of scalar fluxes. Although difficult to characterise and poorly understood, turbulent fluxes in the very stable NBL have significant practical implications for air quality. The resulting vertical mixing can both inhibit the build-up of surface based pollutants and introduce pollutants to the surface from aloft.

During the summer of 1998 a field experiment was undertaken in the Lower Fraser Valley, British Columbia to study nocturnal fluxes of ozone during stagnant anti-cyclonic conditions. Under these conditions, strong radiative cooling near the surface resulted in a shallow very stable boundary layer, frequently capped by a low-level jet. Qualitative analysis of the data showed periodic bursts of turbulence at a variety of scales. However, the characteristics of both the turbulence and the turbulent fluxes were difficult to infer from traditional quantitative analytical techniques. The turbulence was typically non-stationary, dominated by a variety of different frequency regimes, and showed a poorly defined spectral gap. The flux estimates were sensitive to both local and flux averaging lengths and it was hard to identify the periodic scalar fluxes from within the averaged data sets. Further, it was difficult to apply standard spectral analysis techniques without significant data reduction (through quality control) or correction procedures.

This paper explores the potential of a comparatively new analytical tool - wavelet analysis - for evaluating turbulent fluxes. This technique, considered both an extension to and departure from Fourier analysis, is well suited to non-stationary signals containing localised multi-scale features or singularities. It has the potential to make a significant contribution to the evaluation of intermittent fluxes in the very stable nocturnal boundary layer.

3. Predicting joint frequency distributions in the surface layer

Larry Berg and Roland Stull
Atmospheric Science Programme, The University of British Columbia

Joint frequency distributions (JFDs) can be formed using any combination of thermodynamic or dynamic variables, for example vertical velocity vs. temperature or moisture vs. temperature. These JFDs can be a useful tool for investigating turbulent fluxes or cumulus formation in the atmospheric boundary layer. Several authors have proposed theories explaining the shape of JFDs of vertical velocity vs. temperature and moisture vs. temperature. Theoretical JFDs will be compared to those measured with an instrumented aircraft flying near the surface during Boundary Layer Experiment 1996

An extension to the theory for JFDs of vertical velocity vs. temperature will be presented. This extension, which is based on the observed Bowen ratio and the surface energy balance, can be used to generate JFDs using variables that are estimated in numerical models of the atmosphere.

The JFDs of moisture vs. temperature are approximately ellipsoidal, in agreement with theory. Unfortunately, there are differences between the tilt of the theoretical and observed JFDs. However, there appears to be a relationship between the tilt of the observed JFDs and the observed Bowen ratio.

4. Spatial and temporal variability of mixed layer depth and entrainment zone thickness

Pascal Hägeli and Douw Steyn
Atmospheric Science Program, The University of British Columbia

Mixed layer depth and entrainment zone thickness are extracted from two large LIDAR data sets with a recently developed technique. The entrainment flux ratio (which is often used to model entrainment in atmospheric boundary layer models) can be calculated from these two quantities. This ratio is generally believed to be in the range of 0.1 and 0.4. An qualitative analysis of time series (MERMOZ II data set) confirms this range of values under equilibrium conditions (afternoon hours), but also shows that it clearly underestimates the importance of entrainment during the morning hours when the mixed layer depth is growing most rapidly. An examination of the spatial distribution of the entrainment flux ratio (Pacific 93 data set) shows that this parameter is spatially highly variable, even during equilibrium hours in the afternoon. In regions where the boundary layer has to adjust to new boundary conditions at the ground, values much larger than 0.4 can be observed. Although these results can only be interpreted qualitatively, they suggest that currently used entrainment parameterisations in boundary layer models are not sufficient to capture the entrainment process properly.

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Session AM2

BOUNDARY LAYERS 1

Chair: I. McKendry

5. Numerical modelling of sub-grid scale momentum and heat fluxes over a heterogeneous surface

Sreerama Daggupaty and Jianmin Ma
Meteorological Service of Canada, (ARQI)

Surface momentum and heat fluxes over a forest region, located at the southeast of Lake Erie, were investigated by using a three-dimensional boundary layer meteorological model BLFMESO-2-9. To take into consideration of the effects of sub-grid scale transfer of momentum and heat which are not resolved by the model grid spacing, a parameterization scheme was introduced into the model to attempt to relate the spatially averaged fluxes to an aggregate of surface roughness lengths. This parameterization scheme is implemented by applying the concept of effective roughness length and the height scales of momentum and heat transfer over roughness changes. It was found that both spatially averaged momentum and heat fluxes are weighted towards rough surface over the interface between an agriculture land and forest land. The deviations of the grid averaged surface momentum and heat fluxes are estimated for the model grid size (5 km for BLFMESO2-9 and 1 km for sub-grid scale). A comparison of the grid averaged fluxes with the fluxes without averaging are made. Results suggest that the effects of sub-grid scale momentum and heat transfer over heterogeneous terrain on the correct estimation of surface fluxes should be paid great attention.

6. An airborne case study of evolving Kelvin-Helmholtz waves

Fikrettin Celik
University of Wyoming

In a stably stratified atmospheric layer due to shear instability in the flow Kelvin-Helmholtz (KH) waves form and kinetic energy of the flow turns into eddy dissipitation energy (or turbulent kinetic energy).

A KH wave train showing all the stages in the evolution of a KH wave was documented by an instrumented airplane (Wyoming King Air) in the atmosphere. From the aircraft observations, it shown before the breaking stage doubling in wavelength was occurred and billows were formed. It was observed that convective and shear forces in the billows cause development of secondary instability. The secondary instability stage is the breaking of the waves and formation of clear-air turbulence (CAT). Results from the aircraft measurements will be discussed.

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Session PM1

OCEAN AND COUPLED MODELS AND PROCESSES

Chair: G. Flato

1. CMIP1 evaluation and intercomparison of coupled climate models

Steven Lambert and George Boer
Canadian Centre for Climate Modelling and Analysis

The climates simulated by 15 coupled atmosphere/ocean climate models participating in the first phase of the Coupled Model Intercomparison Project (CMIP1) are intercompared and evaluated. Results for global means, zonal averages, and geographical distributions of basic climate variables, and where possible, their departures from observations, are presented.

2. Sensitivities of a global OGCM to variability in surface forcing

Warren Lee, Greg Flato, and George Boer
Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada

The NCAR NCOM 1.3 ocean model (Gent et al. 1998) has been modified for use in the third generation CCCma coupled climate model (CGCM3). A series of ocean-only experiments are conducted to investigate the sensitivity of the model to variability in forcing.

Twenty years of daily ocean surface windstresses, heat and moisture fluxes from a simulation with the AGCM3 atmospheric model with specified observed monthly mean SSTs and sea-ice (following AMIP2) are used. The data are used to force the ocean model in three different ways with:

1. 20 years of individual daily values which are then repeated
2. 1 year of daily climatological mean values (i.e. the average of the 20 values for that day) which are then repeated
3. daily values interpolated from twelve climatological monthly means which are then repeated.

The heat and moisture fluxes into the ocean are also modified by relaxation terms toward observed surface temperature and salinity values.

3. Seasonal variability in the Northwest Atlantic

Jinyu Sheng and Richard Greatbatch
Department of Oceanography, Dalhousie University

A three-dimensional eddy-resolving ocean model was applied to study seasonal variabilities in temperature, salinity (TS) and currents of the Northwest Atlantic. The model resolution is 1/3 degree by 1/3 degree in horizontal and 33 z-levels in vertical. The model was initialized with January mean TS climatology constructed recently by Geshelin et al., 1999 and forced by monthly-mean COADS surface wind and flows through model open boundaries. The model TS fields at sea surface and along open boundaries were restored to the monthly mean climatology with a time scale of about 10 days. The flow across the open boundaries was taken to be the combination of a baroclinic component determined from density using the thermal wind and a barotropic component determined from the large-scale diagnostic calculation of the whole North Atlantic produced by Greatbatch et al., 1991.

We first ran the model in prognostic mode with temperature and salinity evolving freely with the flow. The model results during the first-year simulation reproduced many well-known circulation features in the study region, including the Labrador Current and North Atlantic Current and their interaction over the Newfoundland basin. The model also reproduced reasonably well the seasonal cycle of the mixed layer depth and temperature over the most areas of the study region. The model results however deteriorated gradually with model

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OCEAN AND COUPLED MODELS AND PROCESSES

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simulation, due mainly to a crude and unphysical representation of internal mixing and a relatively coarse model resolution.

To improve the model skill we developed a novel data assimilation technique. The main idea is to adjust the flow field towards climatology, while still permitting a mesoscale eddy field and still allowing the temperature and salinity fields to evolve freely with the flow. The model results produced using this technique will be presented and show a significant improvement over those produced without data assimilation.

4. Coupling between wind-driven currents and mid-latitude storm tracks

François Primeau[1] and Paola Cessi[2]
[1]*Canadian Centre for Climate Modelling and Analysis*
[2]*Scripps Institution of Oceanography*

A model for the interaction between the midlatitude ocean gyres and the wind-stress is formulated for a shallow water, spherical hemisphere with finite thermocline displacement and the latitudinal dependence of the long Rossby wave speed.

The oceanic currents create a temperature front at the midlatitude intergyre boundary which is strongest near the western part of the basin. The intergyre temperature front affects the atmospheric temperature gradient in the storm-track region increasing the eddy transport of heat, and the surface westerlies. The delayed adjustment of the gyres to the wind-stress causes the westerly maximum to migrate periodically in time with a decadal period. There is a linear relationship between the period of the coupled oscillation and the delay time for the adjustment of ocean gyres to changes in the wind-stress. The coupled oscillation involves oceanic temperature anomalies which circulate around the subpolar gyre.

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Session PM1

OCEAN BOUNDARY LAYER

Chair: R. Lueck

1. Turbulence and bubbles in the surf zone

Roblyn Kendall, David Farmer, and Svein Vagle
Institute of Ocean Sciences

The natural surf zone is a very active environment. During an experiment near the Scripps Pier in 1997, an extensive data set was collected by instruments supported by a frame fixed to the sea floor. Measurements of the wave field, turbulent velocity fluctuations, and bubble size distributions were acquired. As the tide receded, observations were obtained from different locations within the surf zone.

During periods of high tide, when the measurements were obtained seaward of the active surf zone, low levels of turbulence were observed. As the water depth decreased and the frequency of breaking increased, the levels of turbulence rose. Air injected into the water by a breaking wave is affected by the turbulence. There is a rapid evolution of the size distribution as bubbles at either end of the size spectrum disappear quickly, due either to dissolution or to buoyancy sorting. However, bubbles of intermediate size are redistributed within the water column by turbulence, and remain in suspension longer than would be expected in the presence of buoyancy forces alone. The evolution of the measured bubble size distributions is analyzed in terms of the observed turbulence levels, both in the presence and in the absence of frequent wave breaking.

2. Numerical modelling studies of processes on the ocean sloping bottom boundary layer

Ming Li
Institute of Ocean Sciences

There is increasing evidence that oceanic sloping bottom boundaries not only affect momentum distribution in ocean circulation but also generate most of the mixing in the ocean interior. However, these effects are poorly represented in Ocean General Circulation Models. To investigate processes on the sloping boundaries, we have developed a hierarchy of numerical models, including 1D turbulence closure model, Large Eddy Simulation model (LES) and Princeton Ocean Model (POM). A solid boundary usually imposes a no-slip boundary condition. However, the cross-slope buoyancy force may shut down the Ekman layer so that the interior flow sees a nearly free-slip boundary condition. We examine the role of sloping interior isopycnals in setting the momentum boundary condition. Interaction between barotropic tides and bottom topography generates internal tides and internal waves, which can break and cause turbulent mixing. We shall present some preliminary results obtained from the POM and LES models. We will also discuss possible ways to incorporate these process studies into Ocean General Circulation Models.

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OCEAN BOUNDARY LAYER

Chair: R. Lueck

3. Calibration of an oceanic mixed layer model for coupling to CRCM

Charles Tang and Brendan DeTracey
Bedford Institute of Oceanography/DFO

To downscale large-scale outputs of global coupled ocean-atmosphere models, a Niiler-Kraus type oceanic mixed layer has been developed for coupling to the Canadian Regional Climate Model (CRCM). The temporal and spatial variations of the mixed layer of the east-coast oceans are studied using oceanographic data taken from the Newfoundland marginal ice zone, the Labrador Sea and the Atlantic. Sea-ice, topography and vertical structure of water properties are found to be the dominant factors of regional-scale air-sea fluxes. The mixed layer model is calibrated using NCEP/NCAR re-analysis and ship data from Ocean Weather Station Bravo and other weather stations in the northwestern North Atlantic. Both monthly and 6-hourly atmospheric data are used to simulate the annual and interannual variations of sea surface temperature. Sensitivity of the results to the model parameters are investigated.

4. Sensitivity of oceanic mixed layer to surface forcing

Serge D'Alessio[1], Kenzu Abdella[2], and Norm McFarlane[3]
[1] *University of Waterloo*
[2] *Trent University*
[3] *Canadian Centre for Climate Modelling and Analysis*

This talk will concentrate on the response of the upper ocean to atmospheric forcing. Specifically, we have examined the sensitivity to different surface flux parameterizations. To accomplish this we have adopted the surface flux parameterizations of Large and Pond (*JPO*, 1982), Martin (*JGR*, 1985) and Abdella and McFarlane (*BLM*, 1996) in conjunction with the one-dimensional, second-order, turbulence closure scheme of D'Alessio, Abdella and McFarlane (*JPO*, 1998). It has been observed that the Abdella and McFarlane scheme is particularly sensitive to the parameterization of the surface roughness length. In order to adequately deal with this sensitivity, a new parameterization has been proposed which is more appropriate than currently used parameterizations and improves the overall agreement between the observed and simulated sea-surface temperature (SST). This parameterization involves modifying the familiar Charnock formula, which relies solely on wind generation, to also include a contribution arising from the thermal stability. The observational data sets used in this investigation include: data from ocean weathership station Papa (OWS P), and data from the LOTUS experiment. Comparisons between simulations and observations, which will be presented, indicate that the SST computed over the year-long simulation at OWS P can be quite sensitive to the surface forcing scheme applied.

1. Keynote address: Societal aspect of weather: Implications for research and policy

Roger A. Pielke
National Center for Atmospheric Research

Weather and climate are resulting in growing impacts on society. At the same time the atmospheric sciences are rapidly developing products - primarily predictive - in hope that decision makers might better cope with weather. Central to improved responses to weather and climate, including an appreciation for the use and value of predictions, is better understanding of the interrelation of human and atmospheric factors in creating vulnerabilities (and opportunities) with respect to weather and climate. This talk will discuss (a) the methods and data used by researchers who study the societal impacts of weather and climate, (b) the reasons underlying the apparent growth in weather-related impacts, and (c) implications of this research for the research and policy communities with particular attention to the use and value of forecasts and the role of multidisciplinary research as a mechanism to better link scientific research with the needs of end users.

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Session PM1

VALUE OF WEATHER SERVICES 1

2. Value of climate and weather products

Valerie Sexton
Environmental Economcs Branch, Environment Canada

Weather and climate products and services should be valued for three reasons. First, the benefits of these products and services can be contrasted to their costs to indicate the level of funding or investment merited. Second, valuation can be used to compare emerging technologies, systems, techniques, services and research which indicate which take priority given limited resources. Third, valuation can make a significant contribution to distinguishing between services and products which constitute the provision of a public good and which merit the charging of fees.

In the final analysis, what we seek to value is weather information and the impact that actions taken in response to that information (or not taken) have. As in all valuation exercises, one can apply the Revealed Preference or Contingent Valuation approaches to determine this. The former encompasses both Directly Observed Values and Indirectly Observed Values used to attach values to weather-related services and products. Actual expenditures on services and products are taken to show their value under the Directly Observed Values approach, whereas it is assumed that the value of weather-related information is capitalized into the prices of certain goods in the Indirectly Observed Values method. Contingent Valuation, on the other hand, is the established non-market valuation method, where by means of a survey, the willingness to pay of individuals for weather information is discerned.

The challenges associated with using these approaches include identification of forecast-sensitive users, estimating user response in the absence of forecasts, and a lack of data on which to base a valuation. The predictive nature of the subject area adds a further wrinkle, as the relationship between accuracy and value must be ascertained and the methodologies for doing so are not fully developed.

Valuation of meteorological services and products is an emerging area of study, both methodologically and in terms of applications of valuation tools. At present the area of study is not a well coordinated one, either in Canada or abroad. A comprehensive and cohesive research plan is required if valuation techniques are to be extended and improved to support the decision-making process. For instance, what is the basis upon which an overall evaluation of these services and products should be done? Is a geographic division best, i.e., by province or region or for the country? Should services be valued according to the type of weather phenomena they relate to or by the type of impact they have? There is at present no established framework for analysis which answers these types of questions.

One possible approach to setting up a framework to guide the valuation process would include the following:

1. Organization of a multidisciplinary Working Group to guide the process which would consist of meteorologists, economists, and users of products and services.
2. Decision on what scope and basis the valuation would be organized and undertaken (geographical, impacts, type of weather event).
3. Review of valuation literature and techniques that would support valuation and identification of knowledge and tools gaps. Group would encourage research in these areas.
4. Valuation on agreed upon basis, according to the impact the information generated has on individuals and their expression of preferences through market behaviour or expressed willingness to pay.

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Session PM1

BOUNDARY LAYER CLOUDS

Chair: P. Austin

1. Satellite measurements of layer-cloud spatial variability

Gregory Lewis [1], Philip Austin [1], and Malgorzata Szczodrak [2]
[1] *Atmospheric Science Programme, University of British Columbia*
[2] *Rosenstiel School of Marine and Atmospheric Science, University of Miami*

The spatial scale dependence of cloud properties like liquid water content and reflectivity has been the subject of much recent work. Aircraft and satellite studies of individual layer clouds have typically found power-law scaling of the power spectrum over a limited spatial domain of the form $k(-b)$, where k is the (one-dimensional) spatial wavenumber and b is the scaling exponent. Knowledge of this scaling behaviour provides information about the underlying physical processes determining cloud variability (advection, precipitation, etc.), and can be used in the development of sub-grid scale parameterizations of cloud variability in climate models.

We have examined the scaling behaviour of visible reflectivity, thermal emission, cloud liquid water path and droplet size in twenty-five 256 × 256 km scenes using radiances measured by the polar-orbiting AVHRR instrument. We compare scaling behaviour in these scenes found by the radially-integrated 2-dimensional power spectrum and the second-order structure function. Both techniques show a scaling regime with an exponent of b –2 ($k(-2)$) for scales between 1–10 km, with a transition at roughly 6–10 km. At scales larger than 10 km, the radially integrated second order structure function shows power law scaling with b –1.3. In our talk we will compare these results with other recent work, and discuss the sensitivity of the scaling measurements to image anisotropy, solar zenith angle, noise and missing data.

2. Entrainment and mixing in buoyancy-sorting cumulus parameterizations

Ming Zhao and Philip Austin
Atmospheric Science Programme/University of British Columbia

Buoyancy-sorting cumulus parameterizations require the specification of the rate of mixing between the undilute plume and its environment. Two important assumptions are generally made in order to close this kind of model. One is an assumption or empirical determination of the amount of undilute sub-cloud air at each of the model levels. The other is an assumption of a uniform probability distribution for mixing between the undilute air and environment air.

We examine the sensitivity of this kind of scheme to these mixing assumptions. Using BOMEX phase III data (non-precipitating case) we focus on the impact of mixing and buoyancy-sorting processes on the equilibrium characteristics of the cloud field and examine additional physical constraints on the assumed mixing distribution. This work will help us with our future design of a new convection scheme in global circulation model.

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Session PM1

BOUNDARY LAYER CLOUDS

Chair: P. Austin

3. The summertime cycle along the central Oregon coast

Soline Bielli[1], P. Barbour[1], R. Samelson[1], E. Skyllingstad[1], and J. Wilczak[2]
[1] *Oregon State University*
[2] *NOAA/ETL, Boulder*

During spring and summer, the west coast of the United States is under the influence of the Pacific High located off northern California coast and a thermal low inland. This typical regime brings persistent northerly winds along the coast. We use the Advanced Regional Predction System (ARPS) mesoscale atmospheric model with a triply nested grid (36/12/4 km) centered over Newport to study the dynamics of the summertime lower atmosphere along the central Oregon coast. Verification of the model against RASS profiler located in Newport and the buoy 46050 located west of Newport during summer 1999 shows a good behavior of the model.

Simulations are presented of four consecutive days in September 1998 during which the winds were northerly and strong along the coast. The strength and position of the coastal low-level jet oscillate diurnally. After reaching a minimum between 1500 and 1800 UTC, the northerly winds strengthen near the coast in late afternoon. A sea breeze circulation develops around 2100 UTC and the cross-shore wind above the marine boundary layer presents a double maximum of offshore flow possibly related to an inertial oscillation and apparently phase-locked to the diurnal forcing. The diurnal variation is three-dimensional with momentum advection important to the along-shore momentum balance. The results for these four days are compared with the Newport wind profiler data.

4. Development and implications of a parameterization for transient shallow cumulus convection

K. von Salzen and N. A. McFarlane
Canadian Centre for Climate Modelling and Analysis

Non-precipitating shallow cumulus clouds contribute considerably to the mixing of heat and moisture in the trade wind regions. Although they are not resolved in large-scale models, these clouds have such a significant impact on the resolved processes that their effects must be parameterized in atmospheric models. Currently, different parameterizations of shallow cumulus clouds in large-scale models exist. In this study, new approaches and a parameterization used in operational models of the European Centre for Medium-Range Weather Forecasts (ECMWF) are considered. Major differences in the parameterizations are the treatment of entrainment processes and cloud life cycles. The implications of the different concepts employed in the parameterizations are discussed with respect to in-cloud properties, entrainment, detrainment, and updraft fluxes for a period during the Barbados Oceanographic and Meteorological Experiment (BOMEX) in 1969. Results of large-eddy simulations (LES) available for this period are used to test and evaluate the approaches.

1. Nonlinear principal component analysis and its extensions

William Hsieh
University of British Columbia

Recent advances in neural network modelling have lead to nonlinear principal component analysis (NLPCA), capable of nonlinearly generalizing the classical multivariate method PCA (also known as EOF analysis). A three-way comparison between PCA, NLPCA and rotated PCA (RPCA) on the tropical Pacific sea surface temperature field revealed that NLPCA had better feature extraction capability than both RPCA and PCA, and was able to improve on the representation of the El Niño-La Niña phenomena.

While PCA cannot represent a propagating wave by one mode, an extension of the NLPCA allows propagating waves to be extracted in a single mode. Further extension of the NLPCA to complex variables (e.g. 2-dimensional velocity fields) will be presented.

2. Nonlinear canonical correlation analysis, and its application to studying ENSO

William Hsieh
University of British Columbia

The canonical correlation analysis (CCA) is widely used to extract the correlated modes between two datasets. A nonlinear generalization of CCA has been achieved through the use of feedforward neural networks. Tested on datasets with correlated nonlinear structures, the nonlinear CCA (NLCCA) method was able to retrieve the underlying nonlinear structures in moderately noisy conditions.

When applied to the tropical Pacific sea level pressure and sea surface temperature fields, the NLCCA extracted a coupled nonlinear ENSO (El Niño-Southern Oscillation) mode. The asymmetry between El Niño and La Niña states was well modelled by the NLCCA.

3. ENSO simulation and prediction using a hybrid coupled model

Youmin Tang and William Hsieh
University of British Columbia

A hybrid coupled model with a nonlinear neural network atmosphere coupled to a dynamical ocean (NHCM) has been developed for the tropical Pacific, and compared with a hybrid coupled model with a linear regression atmosphere (LHCM). The NHCM is found to slightly better capture the cold tongue of the eastern Pacific and the warm pool in the western Pacific Ocean. The POP (Principal Oscillation Pattern) analysis shows that the NHCM can produce more realistic ENSO oscillatory behaviour, with a period of about 57 months in comparison with a period of 87 months in the LHCM. With the gradual increase of coupling strength, both NHCM and LHCM exhibit phase-locking, eventually locking to a biennial oscillation with peaks in winter, indicating that the seasonal cycle is important in the low-frequency oscillations of both coupled models. The NHCM phase-locking is more realistically scattered, in the contrast to the very narrow phase-locking of the LHCM.

Sensitivity experiments show that in the absence of external forcing, neither NHCM nor LHCM displays the irregular behaviour of ENSO oscillations, suggesting that nonlinear chaotic behaviour might not play a central role in ENSO oscillations, and stochastic forcing is likely to cause the irregularity of ENSO.

Some ENSO prediction experiments are being carried out by the NHCM and the LHCM, and the prediction results will be presented.

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Session PM2

CLIMATE VARIABILITY AND CHANGE 4

Chair: J. Fyfe

4. The influence of ENSO and PDO across the Canadian prairies

Dennis Dudley and **Bill Hartman**
Meteorological Service of Canada

The influence of El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) on seasonal weather across the Canadian prairies is investigated. Average standardized temperature and precipitation anomalies at five sites (Calgary, Medicine Hat, Saskatoon, Regina, Brandon) are calculated for all ENSO and PDO episodes between 1933–1993.

In general, the influence of PDO on prairie temperatures is strongest during winter and spring, with little influence on summer or fall temperatures. Warm ENSO episodes (El Niño) produce above average winter temperature anomalies (average here indicates anomalies within 0.32 standard deviations of the mean) across all stations, with positive anomalies increasing eastward. During concurrent El Niño and positive PDO episodes, positive temperature anomalies increase dramatically at all sites in winter and spring. During these times, the PDO explains more of the variance for the observed temperature anomalies than does ENSO.

Cold ENSO episodes (La Niña) produce below average winter temperatures at all stations. These temperature anomalies become much larger (colder) when La Niña years occurred together with negative PDO years, particularly in the spring over the east.

Average precipitation anomalies during various ENSO and PDO phases are smaller and noisier than those found in the temperature data. While all sites show negative precipitation anomalies during El Niño winters and springs, only Calgary shows a statistically significant decrease in winter precipitation. However, when El Niño years combine with positive PDO years, all sites show below average precipitation anomalies in winter and spring, with Calgary much below normal in winter.

Cold ENSO episodes (La Niña) produce a wide variance of anomalies in winter precipitation across the prairies. However, during negative PDO periods, La Niña years produce a clear and consistent precipitation bias with all stations recording much above average precipitation in winter and above average precipitation in summer.

5. Gauging impacts of climate change on the Pacific Northwest using the Pacific Decadal Oscillation and ENSO

Philip Mote, Alan Hamlet, and Nathan Mantua
JISAO/SMA Climate Impacts Group, University of Washington

As a basis for estimating the potential impacts of future climate change on natural resources in the Pacific Northwest, we have performed quantitative analyses of the impacts of past variations. In particular, the low-frequency variations of the Pacific Decadal Oscillation (PDO) provide a useful surrogate for gauging the impacts of possible future climate change. Subtle changes in temperature and precipitation associated with the PDO have had a dramatic impact in the past on the region's water resources, on salmon abundance, and on forest fires. In the PNW, the primary impacts pathway is via the region's water resources.

Scenarios for future climate suggest that changes in temperature and precipitation will raise snow lines and cause snow to melt earlier in the year. Thus, the annual cycle of the water supply and the annual flow amount are expected to change. Similar, albeit probably smaller, changes have been noted on decade-to-decade time scales as a result of PDO climate variations. Such changes in snowpack and summer water supply would cause drought stress in forests, possibly leading to extensive and permanent reductions in forested area, and spawning and rearing difficulties for salmon (in addition to the difficulties posed by rising water temperatures). Winter landslides and flooding could also become more frequent.

For humans, the consequences of climate change extend beyond the abovementioned direct effects on natural resources. Reductions in summer water supply would increase stress on managed watersheds due to unavoidable conflicts among water supply for irrigation and urban uses, instream flow, recreation, hydropower, and other uses that rely on storage of winter snowpack. The effects of increasing regional population are expected to exacerbate conflicts over declining water supplies.

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CLIMATE VARIABILITY AND CHANGE 4

Chair: J. Fyfe

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Session PM2

SURFACE WAVES

Chair: D. Masson

1. Evaluation of the risk of erosion and flooding along coastal British Columbia

Laurie Neil[1], William Crawford[2], Peter Chandler[2], Brad Snyder[1], Mert Horita[1], and Kenneth Chan[1]
[1]*Applications & Services, Meteorological Service of Canada.*
[2]*Institute of Ocean Sciences, Fisheries and Oceans Canada*

We present preliminary results of a climate change project to assess areas at risk to erosion and coastal flooding along the British Columbia coast due to slowly rising sea levels, combined with winds, high tides and El Niño events. The impact of atmospheric forcing on sea level is examined for a set of extreme events that have occurred over the past 30 years. Specific weather patterns conducive to high water levels and coastal erosion are identified, and the impact of ENSO is assessed. We will discuss ways in which this knowledge can be applied to forecasting these events and the impact of climate change. Areas particularly subject to erosion or flooding are identified, along with an assessment of costs of damage and remedial action.

2. Storm Wind Study (SWS II) – Wind and wave evaluation

Ewa Dunlap[1], Val R. Swail[2], Bridget Thomas[3], R. J. Anderson[4], and F. W. Dobson[4]
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[2]*Environment Canada, 4905 Dufferin Street, Downsview, ON Canada M3H 5T4*
[3]*Environment Canada, 45 Alderney Drive, Dartmouth, NS Canada B2Y 2N6*
[4]*Fisheries and Oceans Canada, Bedford Institute of Oceanography, PO Box 1006, Dartmouth, NS Canada B2Y 4A2*

The results of the analysis of marine storm winds and waves measured during the Storm Wind Study II Experiment that took place between 25 October 1997 and 9 April 1998 at the Grand Banks Hibernia site will be discussed. This was a joint project among Environment Canada, Fisheries and Oceans Canada, and the Southampton Oceanographic Centre. The Bedford Institute of the Oceanography vessel CCGS Hudson was present on site during the period of 17 November to 6 December 1997.

An extensive set of well calibrated data gathered during this experiment provides excellent material for the evaluation of a variety of wind and sea state sensors for their ability to function reliably and provide accurate and consistent information in high sea states. The analysis includes time series, scatter diagrams, regression analysis and the interpretation of the inter-comparison results.

This study is focused on the comparison between operational and research type data in high sea states. In particular, the operational wind data include data from a standard meteorological service NOMAD buoy, a Coastal Climate Minimet buoy, the GTS-derived standard WMO observations from CCGS Hudson and the Hibernia and Shoemaker platforms. The research meteorological data are derived from the CCGS Hudson bow mast anemometers and thermistors. The evaluation of wave data is based on the NOMAD buoy wave sensors, GTS-derived standard WMO observations from CCGS Hudson and the Hibernia and Shoemaker drilling platforms and the MIROS wave radar mounted on the Hibernia platform. The research wave data include directional wave data from a Datawell Directional Waverider buoy.

The study provides important information for both climatological and operational applications of data from buoys, ships and drilling platforms.

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SURFACE WAVES

Chair: D. Masson

3. Storm Wind Study II (SWS-II) - the effects of swell on the wind stress

Fred W. Dobson[1], Robert J. Anderson[1], Peter K. Taylor[2], and Margaret J. Yelland[2]
[1]Fisheries & Oceans Canada
[2]Southampton Oceanographic Centre

The second Storm Wind Study (SWS-II) was a joint project among Environment Canada, Fisheries and Oceans Canada, and the Southampton Oceanographic Centre. The experimental area was the Hibernia site on the Grand Banks of Newfoundland, and the experiment covered the period 25 October 1997 9 April 1998. The Bedford Institute of Oceanography vessel CCGS Hudson was at the site from 17 November – 6 December 1997. An extensive set of meteorological and directional wave data were gathered from the Hudson and nearby buoys, often during strong winds and high sea states. These data will be used to investigate the influence of swell on the area rate of momentum transfer from air to sea the wind stress.

Recent work by two of the authors (Taylor & Yelland, The Dependence of Sea Surface Roughness on the Height and Steepness of the Waves, submitted to *JPO*, 2000) has suggested that the aerodynamic roughness of the sea surface, scaled by the significant wave height, can best be characterized as a function of the overall wave steepness as measured by the ratio of significant height to wavelength at the peak of the spectrum. The wave parameters include the influence of the swell. This work predicts the counter-intuitive observation that open-ocean roughnesses are often considerably lower than would be expected for a fully-developed pure wind sea. For SWS-2, good agreement was obtained between average values of the observed and predicted roughness. However, there was significant scatter for individual roughness predictions. This was assumed to be due to the neglect of the directional difference between wind sea and swell, and the use of the peak wavelength to characterise the spectrum.

The present analysis will use the extensive and well-calibrated set of directional wave spectra, wind stress, and wind data from SWS-2, to investigate the detailed effects of the directional properties of the wave field both sea and swell on the observed wind stress values. The results will be presented for several case studies during the experiment period.

4. A validation study of CMC ocean wave forecasting system

Roop Lalbeharry
Meteorological Research Branch, Meteorological Service of Canada

The Canadian Meteorological Centre (CMC) implemented in its operational wave forecasting system regional versions of the third generation global ocean wave model WAM Cycle-4 (WAM4) in February 1996, one for the northeast Pacific and one for the northwest Atlantic, replacing the first generation Canadian Spectral Ocean Wave Model in operation since December 1990. The 10 m level wind forcing is obtained from the CMC global atmospheric model (now GEM-global) for driving the Pacific wave model and from its regional model for driving the Atlantic wave model.

Analyzed and forecast model wave and wind parameters are evaluated against moored buoy-measured data in the coastal and shelf regions in the Atlantic and Pacific coasts of North America for the period December 1996 to August 1999. The evaluation is presented in the form of seasonal scatter plots and summary tables, time histories of the seasonal verification statistics and time series of individual model and buoy data at selected buoy locations and periods to highlight seasonal differences in model performance and impacts due to atmospheric model replacement and grid changes. The results were further compared with the results obtained from other recent studies to assess the performance of the CMC regional wave models with respect to the global wave models running in operational mode at other international wave forecasting centres.

The observations suggest that the Pacific Ocean has more wave and wind variability and swells than the Atlantic Ocean and that there is seasonal variation of this variability. This study will examine the model's ability to depict this greater variability. The evaluation results indicate that there is some positive impact on the performance of the wave model resulting from the replacement of the CMC global and regional atmospheric models and from the changes made to these models.

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Session PM2

VALUE OF WEATHER SERVICES 2

1. Weather prophets: The private industry perspective

Ron Bianchi
The Weather Network/MeteoMedia

The economic value of forecasts and meteorological services are the raison d'etre in any weather-based private enterprise. This presentation will use a business model to discuss the current state of the market, different types of customers, and customer expectations regarding meteorological products and services. The role of verification as a competitive advantage, and the industry's need to put an increased emphasis on verification will be discussed. As well, discussion regarding competing interests between "science" and "entertainment", and their respective economic values, will be introduced. And finally, provocative discussion will be provided regarding the economic value to society of forecasts that stimulate economic activity, such as forecasts that generate the purchasing of snow shovels, batteries, air-conditioners, etc.

2. The economic context of weather information generation and dissemination

Kim Rollins and Jeremy S. Brown
University of Guelph

Weather information, improvements in forecasting, and dissemination services are highly valued by society. The basic economic reasoning is that weather events generate some risk, and most members of society are risk averse. Thus, forecasting information that can reduce uncertainty is as valuable as the costs avoided by reducing risk. Technological advances are continually increasing the options available to produce and disseminate information to user groups, which are becoming more specialized. There has been much interest and applied research in estimating the economic value of weather information. These values indicate that the benefits to society are substantial. But what do these values indicate in the larger context of public sector weather policy and decision-making? What are appropriate goals for public agencies that generate and provide weather information? Should all attempts be made to provide the highest quality services to the public in all situations? The costs of some services might not justify their use in every situation in which they are technically feasible. What services should the public pay for and what are appropriate prices? Public sector budgets ideally reflect the opportunity cost of the same dollars spent in other areas, such as health and education. An additional dollar invested in any one area reflects the opportunities lost in investing it elsewhere. Economic analysis offers much more than simply a means of accounting for benefits and costs, and is most useful in providing decision rules for investing to optimize public and private welfare in the long term. This paper will review the basic economic framework in which public and private goods are produced and disseminated to the public so as to maximize societal benefits over a broad mix of goods and services within the context of weather information provision.

3. Panel discussion: Value of weather services

Moderator: Richard Berry
Meteorological Service of Canada

PANEL: Roger Pielke Jr., Valerie Sexton, Ron Bianchi, and Kim Rollins

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Session PM2

BOUNDARY LAYERS 2

Chair: P. Taylor

1. Convective transport theory for surface fluxes

Roland Stull and Edi Santoso
University of British Columbia

Convective transport theory (CTT) estimates near-surface turbulent fluxes from differences of mean variables between the surface skin and the mid-mixed layer (ML). The rate of this turbulent transport is proportional to the product of a convective velocity times an empirical transport coefficient (Stull 1994). To further investigate CTT, five topics are discussed:

1) New data from three different sites within Boundary Layer Experiment – 1996 (BLX96) are presented, and used to evaluate CTT.

2) Old data from six other field programs (BLX83, Koorin, FIFE, Monsoon 90, HAPEX-MOBILHY, and TOGA-COARE) are re-analyzed to test CTT.

3) Evidence from virtually all of these experiments indicates that the empirical transport coefficients for momentum fluxes depend on surface roughness, while those for heat fluxes do not.

4) Positive turbulent heat fluxes are observed to exist near the bottom of the ML even when there is zero potential temperature difference between the surface skin and the mid-ML. Evidence suggests that positive heat fluxes could also occur when the surface skin has a slightly colder potential temperature than the mid-ML, implying a flux that is opposite or counter to the potential-temperature difference.

5) Such counter-difference fluxes could be explained by an infrared radiative transfer from the surface skin, or by non-equilibrium conditions during rapidly-changing insolation near sunset.

2. An algebraic heat flux turbulence model for flows dominated by buoyancy effects

Slavko Vasic[1], Charles Lin[2], and Yves Delage[3]
[1]*CERCA - Centre de Recherche en Calcul Applique, Montréal*
[2]*Centre for Climate and Global Research Change, Department of Atmospheric and Oceanic Sciences, McGill University*
[3]*Division de Recherche en Prévision Numérique, Service de l'Environnement Atmospherique, Dorval*

Accurate prediction of complex transport processes usually requires an application of advanced turbulence models. Essentially, all turbulence models that account for the contribution of different physical effects in turbulence excitation and its damping belong to this category. Second-moment closure models are the most prominent advanced models. Models of this type incorporate the effects of stress anisotropy, streamline curvature, buoyancy and cross-interactions between fluctuating and mean fields. These facts enable the advanced turbulence models to simulate transport processes more precisely. Direct numerical simulations and large-eddy simulation techniques are still very expensive to use as predictive tools. The second moment closure approach is inexpensive and, more importantly, capable of predicting the most significant flow and heat transfer characteristics with required high accuracy. However, a variety of physical and thermodynamical processes that occur in most geophysical turbulent flows may pose substantial difficulties in the consistent application of this approach. Simpler model formulations are thus necessary.

At present, algebraic models of turbulent heat flux may be regarded as a good compromise between simple eddy-viscosity/diffusivity models and the advanced second-moment closure turbulence models. By a suitable truncation of the differential second-moment closure models, derived algebraic models retain most characteristics of their parent models. Reasonable prospect is then held for predicting specific features of buoyant turbulent flows. In the prediction of the well-known Deardorff's experimental case of unsteady turbulent penetrative convection of an unstable mixed layer, we show that a particular variant of an algebraic heat flux model is able to accurately predict such buoyancy dominated flows.

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BOUNDARY LAYERS 2

Chair: P. Taylor

3. Third-order moment closure through a mass-flux approach

Kenzu Abdella[1] and Arthur Petersen[2]
[1] *Trent University, Peterborough, Canada*
[2] *Vrije Universiteit, Amsterdam, The Netherlands*

The parameterization of the third moments, the flux of the heat flux and the flux of the potential temperature variance is considered. It is shown that parameterizations of these moments using the mass-flux approach with top-hat profile assumption lead to a significant underestimation resulting in an inaccurate representation of second moments in the convective boundary layer. It is also shown that the underestimation is a result of the top-hat profile assumption in which the sub-plume contributions to the total fluxes are ignored. By including these contributions a new parameterization is proposed. The proposed parameterization satisfies the physical requirements of symmetry and realizability and it gives results that are in fair agreement with the large-eddy simulations (LES) data.

4. Lagrangian simulations and eddy diffusivities for blowing snow

Peter A. Taylor, P.Y. Li, and Jingbing Xiao
Department of Earth and Atmospheric Science, York University

We present results from the application of a Lagrangian Simulation Model to inertial particles as part of a study on blowing snow. We limit the model to the neutrally stratified boundary-layer on the basis that blowing snow occurs in high wind speeds and close to the ground so that the ratio of height to the Obukov length will be small. The initial model used in this study was a first-order 1D Langevin equation model for fluid element trajectories plus an added gravitational settling velocity (w_s). The present model allows the option of reducing the velocity auto-correlation timescale for particles. However in the cases of interest for blowing snow modelling the particles are generally close to the ground where the Lagrangian timescale (which controls the timestep in the model) is of a similar magnitude to the inertial timescale associated with the particle adjusting towards its settling velocity. In these circumstances an Inertial Particle Model is more appropriate. In this approach fluid velocities in the neighbourhood of a fluid element are assumed to satisfy the Langevin equation (with a reduced Lagrangian timescale compared to simply following a fluid element) and the equation of motion is solved for the particle with drag based on the difference in velocity between the particle and the surrounding fluid. The eddy diffusivities calculated from the concentration profiles predicted from the present model for a range of w_s/u and z_0 values (where u and z_0 are the friction velocity and roughness length respectively) will be compared with those from Businger's (1965) theory and with our parallel studies with the PIEKTUK model, in which particles are also allowed to sublimate.

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BOUNDARY LAYERS 2

Chair: P. Taylor

5. An object-oriented approach to micrometeorological modeling

Brian Crenna
Department of Earth & Atmospheric Sciences, University of Alberta

Despite a decade of propaganda promoting object-oriented design in computer programming, it is likely that much of that done in meteorological research is still procedural in style. The newer approach may be unfamiliar and its benefits in scientific programming unclear. An object-oriented microscale transport simulation tool being developed will be presented, as well as some results obtained using it. Its design imparts flexibility in configuring the underlying numerical models, while providing structural clarity and simplifying enhancements to the program.

1. Shaken, or stirred? Transport and mixing in the atmosphere

Theodore G. Shepherd
Department of Physics, University of Toronto

The nature of transport and mixing in the atmosphere depends very much on the spectrum of atmospheric motions. In the upper troposphere and lower stratosphere, the dominance of large-scale motions means that tracer fields are stirred, leading to the formation of filamentary structures and coarse-grain homogenization (in spite of small-scale inhomogeneity). This is the opposite limit to Fickian diffusion, where the dominant motions are presumed to be subgridscale and where tracer homogenization is achieved first at small scales and only later at large scales. In the mesosphere, the emergence of a shallow spectrum of gravity-wave energy at synoptic scales leads to an intermediate regime, where diffusivity is expected to be length-scale dependent and where Richardson's law is expected to hold. In such a regime, the tracer fields are more shaken than stirred.

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Session AM2

DYNAMICS AND BALANCES

Chair: N. McFarlane

2. A fine balance: Constraints on vortical/gravity-wave interactions

Theodore G. Shepherd
Department of Physics, University of Toronto

Although the atmosphere supports a wide range of frequencies, it is an observed fact that (at least below the mesosphere) the low-frequency vortical motion dominates over high-frequency inertia-gravity waves. Understanding why this is the case remains an open question. There has been much work on identifying a slow manifold, but virtually none on its stability. It is proposed that the atmosphere remains close to balance because of constraints arising from the Hamiltonian structure of geophysical fluid dynamics, akin to the KAM (action) surfaces that prevent thermalization in the classic Fermi-Pasta-Ulam system of coupled oscillators. Results from low-order models are described and the connection to the fluid equations discussed.

3. Empirical normal mode diagnosis of variability in dynamical core experiments

Ayrton Zadra[1], Gilbert Brunet[2], Jacques Derome[1], and Bernard Dugas[2]
[1]*Department of Atmospheric and Oceanic Sciences, McGill University*
[2]*Numerical Prediction Research Division, Atmospheric Environment Service*

A diagnostic algorithm based on the Empirical Normal Mode (ENM) decomposition technique (Brunet, 1994 *J. Atmos. Sci. – JAS*; Brunet and Vautard, 1996 *JAS*; Charron and Brunet, 1999 *JAS*) is used in a comparative study of variability in two dynamical core experiments. Data are provided by the Canadian Global Environmental Multiscale (GEM) model, forced according to the benchmark calculations proposed by Held and Suarez (1994 *Bull. Amer. Meteor. Soc.*) and Boer and Denis (1997 *Climate Dyn.*). We expect this diagnostic study to provide an objective assessment of properties of the model's dynamical core. The ENM algorithm begins by expanding data in a zonally symmetric basic state plus a sum of empirical modes of wind, pressure, specific volume and potential vorticity, classified according to their wave-activities and propagation properties. A simple stochastic modelling is used to explain characteristics of the frequency spectrum of large-scale modes. Properties of some energetic, mid-latitude, upper-tropospheric ENMs are compatible with those of quasi-modes, defined by Rivest et al. (1992 *JAS*) as superpositions of singular modes sharply peaked in the phase-speed domain. Results are also compared with an ENM diagnosis of analyzed winter data, provided by the National Centers for Environmental Prediction (NCEP) reanalyses. This comparison shows that the Boer-Denis forcing is successful in reproducing many features of the observed atmospheric variability.

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DYNAMICS AND BALANCES

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4. Dynamics and predictability of ensemble forecasts

Bill Merryfieldand Greg Holloway
Institute of Ocean Sciences

Geophysical fluid predictability is approached by considering moment equations for the evolution of quasigeostrophic flows. We consider evolution of mean potential vorticity and of variance about the mean for ensembles whose members are randomly distributed about some initial state. Advective effects are represented by conservative terms describing advection of moment fields by the mean velocity, as well as non-conservative terms which generate variance and dissipate mean potential vorticity. These non-conservative terms depend on fluctuations from the mean and amplify rapidly as ensemble dispersion increases. General properties of these equations are examined from ensemble numerical simulations and from the perspective of nonequilibrium statistical mechanics.

5. Comparison of western and eastern North Pacific cold-season cyclones in terms of kinetic energy and eddy energy conversion

Richard Danielson, John Gyakum, and David Straub
McGill University

Local quasi-Lagrangian kinetic energy budgets, as well as a set of eddy/mean energy budget equations which reveal the importance of energy dispersion in the process denoted downstream baroclinic evolution by Orlanski and coauthors, are applied to more than 40 cold-season cyclones over each of the eastern and western North Pacific Ocean regions. Composites made from the two groups of budget calculations using NCEP reanalyses are grouped relative to the onset of maximum surface deepening but follow the associated tropopause depressions (defined as pressure maxima on the dynamic tropopause).

In terms of the total kinetic energy budget, balance at upper-levels is largely between energy generation and horizontal flux convergence, whereas at the surface it is between generation and friction. Differences in our two groups are related to a positive energy tendency and generation during periods when the western group is mainly over land. Otherwise over the ocean both groups are associated with a negative energy tendency and generation, and positive flux convergence at upper levels. In including friction with the budget residual, positive values at upper levels at the end of surface deepening are suggestive of a subgrid-scale energy source.

Related to the western cyclones, another composite cyclone appears to form downstream, whereas for the eastern group a preexisting upstream composite cyclone appears to have been present. Eddy energy conversion in the western cases is quite weak initially and increases dramatically ($20 W/m^2$ or $30 W/m^2$) during surface deepening. By contrast the eddy energy conversion of the eastern cases is weak ($5 W/m^2$ or $10 W/m^2$) but relatively constant from 2.5 days prior to surface deepening.

6. Are changes in temperature over the Mackenzie River Basin affected by global-scale energy fluctuations?

Werner Wintels and John R. Gyakum
Department of Atmospheric and Oceanic Sciences, McGill University

We have shown in previous studies that approximately half of all collapses of Northern Hemisphere available potential energy (APE) over a 17-year period are characterized by midlatitude surges of warm air over the Bering Sea. Intense warm advection is generated by the baroclinic intensification of stationary upstream cyclones near Eastern Siberia and large-scale anticyclones centered near the Alaska/Yukon border. The objectives of this case study are to 1) quantify the contribution of this regional circulation to the observed APE collapses and 2) assess the potential of variations in this circulation's frequency and intensity for affecting changes in the climate of the Mackenzie River Basin (MRB).

We perform energy and thermal budgets on two consecutive APE collapses during a remarkable two-week fall of global APE between 24 Jan and 5 Feb 1989 using the National Centers for Environmental Prediction (NCEP) reanalysis. An original budget algorithm that includes the effect of orography is employed. The second collapse is dominated by a large-scale regime that features a surge of warm air over the Bering Sea that extends into the high arctic before wrapping around a record-breaking Alaska/Yukon anticyclone into the MRB.

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DYNAMICS AND BALANCES

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Session AM2

EDDIES AND WAVES

Chair: H. Freeland

1. Generation of eddies in winter along the northwest coast of North America

William Crawford and Josef Cherniawsky
Canadian Hydrographic Service, Institute of Ocean Sciences

Mesoscale eddies are formed in winter at several regions along the West Coast of Canada and the Alaskan Panhandle and migrate into the Gulf of Alaska, carrying nutrients and coastal waters. Some of the largest eddies were observed during the 1997/98 El Niño winter. To determine the influence of El Niño events on eddy size and numbers we investigated the historical XBT measurements, drifter tracks, satellite altimeter data, and historical profiles of temperature and salinity measured from research vessels. Data since 1992 indicate that the largest eddies are generally formed in strong El Niño winters. We will present results on the typical water type of these eddies and their impact on the water mass in the Gulf of Alaska.

2. Parameterization of the effect of sub-grid-scale buoyancy forcing variability in an OGCM convection scheme

Konstantin Zahariev, Norm McFarlane, and George Boer
Canadian Centre for Climate Modelling and Analysis

Previous studies have shown that the thermohaline circulation in ocean general circulation models exhibits sensitivity to the parameterization of convection and to its location and amount. These models typically use a convective adjustment scheme to remove gravitational instabilities resulting from surface heat losses due to buoyancy forcing. The convective scheme operates on values of buoyancy forcing, model temperature, and salinity, which represent averages over a grid square. However, buoyancy forcing would typically vary on spatial scales much smaller than that resolved by the ocean models; consequently there might be events on a sub-grid scale where convection would occur even though the horizontally-averaged buoyancy loss is not large enough to trigger convection in the model for the entire grid square. We propose a parameterization scheme to account for this variability of buoyancy forcing, for use in OGCMs, and present model results using this modified convective adjustment scheme.

3. Could ocean eddies set the stratification of the main thermocline?

John Marshall[1], Helen Jones[1], **Richard Karsten**[1], and Richard Wardle[2]
[1] *Massachusetts Institute of Technology*
[2] *University of Chicago*

In previous work we have shown that localized surface cooling can be balanced by lateral geostrophic eddy flux in the creation of deep convective chimneys. Now, in a series of laboratory and numerical experiments, we study the simultaneous heating and pumping of fluid downward from the surface, as an analogue of a sub-tropical gyre. A stratified warm lens of fluid is formed and its ensuing baroclinic instability produces a lateral eddy flux which balances the surface forcing and equilibrates the lens setting, in the statistically steady state, its depth and temperature. A simple theory successfully explains the temperature and depth of penetration of the warm lens.

In this paper we discuss the ramifications of these ideas for our understanding of the processes that set the stratification and depth of the main thermocline. We hypothesize that, on the scale of ocean gyres, the tendency to overturn isothermal surfaces induced by persistent differential heating and Ekman pumping, is balanced by their flattening by baroclinic instability. If the rate of working of ocean eddies is the same as that observed in our laboratory and numerical experiments, then this mechanism could account for the observed depth and stratification of the main thermocline.

Wednesday, 31May
1020–1220 hrs
Room 307

Session AM2

EDDIES AND WAVES

Chair: H. Freeland

4. Shelf waves in the Gulf of Alaska

Josef Cherniawsky, Michael Foreman, William Crawford, and Falconer Henry
Fisheries and Oceans Canada, Institute of Ocean Sciences

We observe diurnal shelf waves in Northeast Pacific from the TOPEX/Poseidon derived tidal constituents K_1 and O_1. The location and amplitudes of these waves in the altimeter sea level data agree quite well with those obtained from a large-scale finite-element tidal model. Examples of these waves are presented for two areas: (1) near the mouth of Juan de Fuca Strait and (2) off Cook Inlet and Kodiak Island in the northern Gulf of Alaska. In addition to the long-wavelength (500 to 1000 km) prograde shelf waves, the model also predicts smaller-amplitude (about 1 cm) retrograde waves along the shelf-break off Cook Inlet, with a wavelength of about 100 km.

5. Large amplitude internal wave excitation below a turbulent mixing region

Kathleen Dohan and **Bruce Sutherland**
University of Alberta

Laboratory experiments have been performed to examine the excitation of internal waves from the base of a turbulent mixing region and to study how the structure of the turbulence is itself modified by the wave excitation process. We report on a variation of the classical oscillating grid experiments in which the mixing box, filled with uniformly stratified salt water, has a large (4:1) aspect ratio. A non-intrusive technique is used both to characterize the turbulence time and length scales and to measure accurately the internal wave amplitudes and frequencies. Pearlescent dye reveals the evolution of small-scale coherent structures in the turbulent mixing region. The small-scale structures become embedded within two large-scale oppositely rotating vortices with the vorticity vector directed horizontally out the wide side of the tank. The structure in the mixing region is thus similar to that for Langmuir cells except that there is no mean vertical shear in the experiments. Below the mixing region standing internal waves are generated with wavelengths comparable to the size of the large-scale vortices in the mixing region. In typical experiments the measured amplitude of the waves is as large as five percent of their horizontal wavelength. In moderately stratified fluid the amplitude decreases with increasing stratification.

6. Internal wave transmission across a reflecting level in uniform shear

Bruce Sutherland
University of Alberta

Recent laboratory experiments and numerical simulations have demonstrated that the surface mixing region of the ocean may generate internal waves with large amplitudes. Such waves propagate with frequency close to the background buoyancy frequency. Subsequently, a series of fully nonlinear numerical simulations have been performed to examine the propagation of large amplitude internal waves into weakly stratified fluid and through shear layers. This work will report on the results of simulations of internal wavepackets propagating in uniform shear and uniform stratification. The sign of the shear is established so the intrinsic frequency of the waves increases with depth. The simulations show that downward propagating small amplitude wavepackets reflect upward at the depth predicted by linear theory. For horizontally periodic large amplitude waves, they are found to reflect well above this depth. Surprisingly, however, large amplitude horizontally compact waves are found to propagate well below the reflection level. Particularly for waves with intrinsic frequency close to the background buoyancy frequency, weakly nonlinear effects continually modulate the waves so that they propagate steadily downward with negligible reflection. A simple analytic theory is derived to predict at what amplitude transmission through a reflecting level should occur.

Wednesday, 31May
1020-1220 hr
Room 309

Session AM2

OPERATIONAL METEOROLOGY

Chair: P. Chen

1. Improving the GEM model for medium-range forecasting and analysis

Sylvie Gravel[1], Michel Roch[1], Bernard Dugas[1], and Anne-Marie Leduc[2]
[1] *Division de la recherche en prévision numérique, Meteorological Service of Canada*
[2] *Canadian Meteorological Centre, Meteorological Service of Canada*

The newest version of the Global Environmental Multiscale (GEM) model for medium-range applications is described. Emphasis is given to the features of the new model that differ from those of the model that became operational in October 1998. Results from assimilation cycles, and large ensembles of simulations are presented, along with the diagnostics that identify some of the weaknesses of the old system.

2. Automated model validation of clouds, radiation and diurnal cycle using satellite data

Louis Garand and Marc Larocque
MSC

GOES-EAST and GOES-WEST data from full disks are used to automatically validate clouds, radiation and skin temperature for 18-h, 24-h, 30-h and 36-h forecasts daily. Satellite data are then used every 6-h to evaluate the diurnal cycle. A web site has been created to display the results on a case-by-case basis as well as on monthly statistics. The variables which are validated are cloud amount, cloud height, outgoing brightness temperature (the equivalent of the satellite image) and surface skin temperature. The system is in the state of relatively advanced development. The presentation will show its important application, especially to physics modelers who wish to objectively evaluate the impact of new parameterizations. So far the system has been developed for the global model at $1° \times 1°$ resolution. It will eventually be extended to validate the regional model and the expected scale for this will be about 13 km.

3. An update on updateable MOS

Pierre Bourgouin[1], Laurence J. Wilson[1], Franco Petrucci[2], and Richard Verret[2]
[1] *Recherche en Prévision Numérique*
[2] *Centre Météorologique Canadien*

The Canadian updateable model output statistics (UMOS) became fully operational this spring. The essence of UMOS is that most of the preparation for the statistical processing is carried out in real time, allowing frequent and rapid redevelopment of the equations. A weighting scheme is attached to the system to ensure smooth transition during a significant model change where latest data from the newer model are given higher priority, while retaining enough data to ensure generation of stable statistical relationships. A second weighting scheme is also included to ensure smooth transition from one season to another.

The current operational version of UMOS uses multiple linear regression with forward stepwise predictor selection applied to predictands 3h spot temperature, 3h wind direction and wind speed and 6h probability of precipitation greater or equal than .2mm. Equations have been developed and updated for nearly 800 forecast sites in Canada. Where sample sizes are too small to support stable statistical relationships, stations with similar predictand climatology were grouped together for equation development.

Current UMOS research work is focused on extending the system to prediction of multi-category perdictands such as cloud amounts. Following comparison results which show that

MDA works better than CART for cloud amount, we have started to implement MDA into the UMOS framework.

This presentation will give an overview of the various aspects of the UMOS system and its current operational setting as well as the newest multi-category tools. Some verification statistics will also be shown.

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Session AM2

OPERATIONAL METEOROLOGY

Chair: P. Chen

4. TAF tools: Development of TAF guidance – Part I: Very-short range forecast

Pierre Bourgoin[1], Richard Verret[1], Lawrence Wilson[2], and Jacques Montpetit[2]
[1]*Centre météorologique canadien, Dorval, Canada*
[2]*Recherche en prévision numérique, Dorval, Canada*

Terminal aviation forecasts (TAFs) are site-specific forecasts that are currently prepared every 6h manually, using guidance from the operational numerical weather prediction (NWP) models and available observations. TAFs include forecast information on ceiling, visibility, weather, obstructions to visibility and wind. It is believed that gains in forecast production efficiency can be realised by automating as much of the production process as possible, leaving the final control of the forecast contents with the operational forecaster. We use statistical methods because they are cheap compared to other solutions. There are three major components of the project, one for very-short range forecasts, one for the short range and finally, one that will blend the two techniques together and possibly incorporate other available information.

Numerical weather prediction models have difficulties forecasting precise weather elements for a specific site as needed for a TAF. Persistence, especially conditional climatology, is in fact very difficult to beat during the first few hours. It has been shown that a system based on observations is superior to persistence climatology and to NWP-based statistical systems. To take advantage of these results, we are developing a very short-term forecasting technique based solely on current available observations. We will use about 40 years of hourly observations to develop forecast equations relating observations at a time to observations at a later time $T_0 + dT$. The equations will be developed using a Multiple Discriminant Analysis (MDA) technique. MDA has recently been shown to give superior forecasts to CART for cloud amount. Most of the work so far has been devoted to the construction of a large database consisting mainly of hourly observations.

5. TAF tools: Development of TAF guidance – Part II: Short range forecast

Jacques Montpetit[1], Lawrence Wilson[1], Pierre Bourgoin[2], and Richard Verret[2]
[1]*Recherche en prévision numérique, Dorval, Canada*
[2]*Centre météorologique canadien, Dorval, Canada*

Terminal Aviation Forecasts (TAFs) are site-specific forecasts that are currently manually prepared every 6h, using guidance from the operational Numerical Weather Prediction (NWP) models and available observations. TAFs include forecast information on ceiling, visibility, weather and wind. It is believed that gains in forecast production efficiency can be realised by automating as much of the production process as possible, leaving the final control of the forecast contents with the operational forecaster. We use statistical methods because they are cheap compared to other solutions. There are three major components of the project, one for very-short range forecasts, one for the short range and finally, one that will blend the two techniques together and possibly incorporate other available information.

Numerical weather prediction models have difficulties forecasting precise weather elements for a specific site as needed for a TAF. Observation-based systems may provide the best possible forecast at very-short ranges but their skills degrade rapidly in time. For that reason, a technique based on NWP output should prove to be superior for short range forecasts beyond about 6h. It was decided to develop a perfect-prog system to forecast the different elements required to write a TAF. Reanalyses from the National Centre for Environmental Prediction are used to derive site-specific predictors such as temperature, vorticity, moisture advection, stability indices, etc. The predictors are paired with observations which have been processed to be representative of a time-step of 3h. The same Multiple Discrimant Analysis technique described in Part I: Very-Short Range Forecast is used to develop equations relating predictors and observations. The presentation will describe the technique design and results to date.

6. The Cooperative Program for Operational Meteorology, Education and Training (COMET)

Patrick Dills[1], Timothy Spangler[1], Wendy Schreiber-Abshire[1], and Richard Cianflone[2]
[1] *University Corporation for Atmospheric Research / COMET, Boulder, CO*
[2] *National Weather Service, Office of Meteorology, Boulder, CO*

The COMET Program was established in 1989 by the University Corporation for Atmospheric Research. Its primary sponsors are the National Oceanic and Atmospheric Administration, the Air Force Weather Agency, and the Naval Meteorology and Oceanography Command. COMET Program objectives are to provide intensive education and training for operational meteorologists, increased collaboration between the operational and research communities, and improved formal university education to provide future meteorologists with enhanced educational and professional qualifications.

The COMET Education and Training Program consists of in-residence and teletraining courses, multimedia-based learning modules, and on-line resources. A variety of residence courses, 1 to 7 weeks in length, are offered on topics in mesoscale meteorology and hydrology. Shorter teletraining sessions are offered on specialized mesoscale topics. The courses are taught by university faculty and operational weather forecasters and combine conceptual lecture presentations with case-based laboratory exercises. Students are primarily National Weather Service (NWS) operational forecasters, but seats are made available to the university community, AES Canada, and the private sector as well. Multimedia-based learning (MBL) modules, delivered via CD-ROM or the World Wide Web, provide professional development for operational forecasters and others in the atmospheric science community. These MBL modules are developed in consultation with subject matter experts from the academic and operational meteorology communities. The COMET Program, in collaboration with the NWS Training Center in Kansas City and the Operational Support Facility in Norman have made on-line resources available to the larger meteorological community via a meteorology education and training Web site:

http://meted.ucar.edu/

These resources include a rich library of case study materials that has been developed to support courses and MBL module development. The MetEd Web site is the primary location for all Web-based materials produced by the three NWS training programs, and includes other information and resources pertinent to meteorology training and education. Additional meteorological education and training products are currently under development, including live and archived Webcasts of residence classroom presentations.

The COMET Outreach Program sponsors cooperative and partners projects and fellowships aimed at the advancement of applied research in mesoscale meteorology by fostering collaborative research between academic researchers and operational forecasters. This program also sponsors regional meteorology workshops and symposia.

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Session AM2

RADIATION MEASUREMENTS

Chair: T. Ackerman

1. Determination of integrated water vapour using a GPS sensor in southern Ontario: Initial results

Frank Seglenieks[1], Brian Proctor[2], Erika Klyszejko[1], Craig Smith[2], and Eric Soulis[1]
[1]*Department of Civil Engineering, University of Waterloo, Waterloo, ON, Canada*
[2]*Environment Canada, NHRC, Saskatoon, SK, Canada*

Although a relatively new science, the measurement of atmospheric water vapor using GPS receivers has been demonstrated to give results comparable to more conventional forms of water vapour measurement. Most of the studies involving this type of technology have taken place in the southern United States. This study involves comparing integrated water vapour measurements using a GPS receiver located north of the University of Waterloo in Waterloo, Ontario.

The method is based on the GPS signal being delayed as a result of passing through the atmosphere. This delay is caused by the dipole moment of water molecules that impedes the propagation of electromagnetic radiation through the atmosphere. The effects of the ionosphere can be removed using characteristics of the GPS signal, and the residual delay can be split into the hydrostatic delay and the wet delay.

The hydrostatic delay can be independently calculated using surface pressure measurements. The integrated water vapour can then be related to the wet delay using a proportionality constant. This constant varies depending on atmospheric conditions with the most significant factor related to the mean temperature of the atmosphere. The mean temperature can be estimated using ground temperature measurements, however a more accurate value of the constant can be found using a temperature profile of the atmosphere.

The location of the GPS receiver used in this study is near a weather station on the north campus of the University of Waterloo. This allows accurate measurement of surface meteorological parameters to be used in the calculation of integrated water vapour.

This study presents the initial comparisons of integrated water vapour measured from the GPS receiver and profiles produced by the corresponding CMC GEM model runs

2. Measurements Of Pollution In The Troposphere (MOPITT) global measurements of tropospheric composition

James R. Drummond[1] and MOPITT Science Team[2]
[1]*Department of Physics, University of Toronto*
[2]*Several Institutions*

The MOPITT instrument was launched on NASA's Terra spacecraft on December 18, 1999. The contamination covers were opened on February 18, 2000. By the end of June, the instrument will be producing scientific data.

MOPITT is designed to measure carbon monoxide and methane over the entire globe for a period of five years. The horizontal resolution will be 22km × 22km and carbon monoxide data will be resolved into three levels in the troposphere. Other instruments on the Terra spacecraft will measure the surface properties, giving a unique view of the atmosphere/surface interaction.

This paper will present some preliminary results from the first few months of operation. Although at the time of the Congress, much will still remain to be done with the data and with the quality control process, it is hoped that the quality will be sufficient to demonstrate the potential of these measurements.

The MOPITT instrument has been financed by the Canadian Space Agency and was constructed by COMDEV International of Cambridge, Ontario.

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Session AM2

RADIATION MEASUREMENTS

Chair: T. Ackerman

3. Measurements of the A-band on the AIRS/CLOUDSAT Simulator Experiment

W.F.J. Evans[1], E. Puckrin[1], G. Isaac[2], and H. Barker[2]
[1] *Trent University*
[2] *Meteorological Service of Canada*

Clouds can enhance the path of solar photons by up to factor of 10. Measurements of the absorption spectrum of solar radiation by the Atmospheric or A-band of molecular oxygen at 762 nm can be used to derive cloud top altitude and photon path length. A NASA satellite called CLOUDSAT will fly an A-band spectrometer, a LIDAR and a cloud RADAR in 2003. An CMS experiment to simulate the CLOUDSAT data set was flown at Ottawa in the December, 1999 through February, 2000 period. On the aircraft, nadir measurements as well as upward viewing spectral measurements were made. On the ground at Mirabel, a BOMEM DA8 was used to take high resolution spectra of clouds as the aircraft flew an overpass pattern. Spectra and photon path length measurements will be presented. The future application of the A-band to obtain path lengths for cloud studies will also be discussed.

4. Using scanning radars as radiometers: Why not?

Frederic Fabry and Isztar Zawadzki
Dept. Atmospheric & Oceanic Sciences, McGill University

Many meteorologists and scientists studying the atmosphere use radars to obtain information on the location and severity of precipitating systems, and obtain information on winds from the scattering of microwaves on targets. Others use radiometers to measure the integrated vapor and integrated liquid water content of the atmosphere from the emission of microwaves in the atmosphere. Although both types of instruments use microwaves to make their measurements, they obtain different and sometimes complementary information by different methods. Yet the hardware present in the two instruments has many similarities, and radars have essentially all the equipment needed to make radiometric measurements, albeit at different frequencies than radiometers typically function. In this presentation, I will show some initial radiometric-like measurements made by several radars owned by McGill and how these complement the more classic active measurements.

5. Polarization diversity at the remote sensing facilities of McGill University

Isztar Zawadzki[1], Frédéric Fabry[1], Abnash Singh[1], Alamelu Kilambi[1], Marielle Gosset[2], and Fédéric Cazenave[2]
[1] *MRO, McGill University*
[2] *Laboratoire d'Etude des Transferts en Hydrologie et Environnement France.*

The McGill S-band radar has been upgraded to add polarization diversity capability. In addition a small low-cost, transportable X-band RHI radar with Doppler and dual polarization (called X-POLITO) was build at MRO. The latter is intended for microphysical studies and as a test-bed for evaluation of microwave attenuation studies and possible hydrological use of radar operating at attenuating frequencies. The polarization diversity in both systems is based on the transmission at 45 degrees and reception of the separated vertical and horizontal components. The reception is simultaneous in the S-band radar and alternate in X-POLITO with the switching between the two components done by a low power switch at the reception. While the scanning rate of the S-band radar is determined by the requirements of its operational use X-POLITO has no restrictions. It is intended as a tool for special studies and as a complementary instrument to the S-band radar. If collocated the two radars can be operated as a dual wavelength, dual polarization system. Located at a distance the system can provide dual Doppler observations as well as some of the advantages of the dual polarization dual wavelength.

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1330–1510 hrs
Room 207

Session PM1

CRCM

Chair: J. Scinocca

1. The new version of the Canadian Regional Climate Model. Part I: Model formulation and its simulation of current climate.del

Daniel Caya, René Laprise, Michel Giguère, Hélène Coté, Sébastien Biner,
Dominique Paquin, and Anne Frigon
Département des sciences de la terre et de l'atmosphère, Université du Québec à Montréal

A new version of the Canadian RCM has been developed and used to produce a new set of climate change scenario simulations. Improvements in the new version of the Canadian Regional Climate Model (CRCM) include, among others, the use of Kain-Fritsch cumulus parameterisation, reduced lateral diffusion, a larger computational domain and a more frequent lateral boundary nesting. A ten-year long simulation driven by the Canadian CGCM-I for conditions corresponding to the current climate will be compared to different observed climatologies.

Results from a five-year simulation employing a different nesting technique in which the CRCM large scale circulation is forced toward the large-scale circulation of the driven data will also be presented. We will compare the obtained climate with the one produced by the conventional lateral boundary nesting technique.

2. The new version of the Canadian Regional Climate Model. Part II: Transient greenhouse gases concentration and aerosols forcing simulations.

René Laprise, Daniel Caya, Michel Giguère, Hélène Coté, Sébastien Biner,
Dominique Paquin, and Anne Frigon
Département des sciences de la terre et de l'atmosphère, Université du Québec à Montréal

The recently developed version of the Canadian RCM is driven by the Canadian Coupled GCM version I (CGCM-I) to produced transient greenhouse gases (GHG) and aerosols scenario. The CRCM is used for time-slice simulations covering the periods 2040 to 2050 and 2080 to 2090 when driven by the corresponding periods of a CGCM-I 250-year coupled simulations. Results will be presented for these two time slices corresponding to periods with roughly double and triple current GHG concentrations, and compared with corresponding GCMii results.

3. Various convection schemes applied on short climate simulations with the CRCM

Dominique Paquin, Daniel Caya, and Michel Giguère
Département des sciences de la terre et de l'atmosphère, Université du Québec à Montréal

Three convective schemes are now available in the Canadian Regional Climate Model (CRCM): the moist convective adjustment taken from the Canadian General Circulation Model version ii, the Kain-Fritsch scheme, and the Meso-NH deep convection parameterization scheme developed by Peter Bechtold (Lab. d'Aèrologie, Toulouse). The Kain-Fritsch and the Meso-NH are mass flux schemes using the same general frameworks, a CAPE removal convective closure, but the Meso-NH SCHEME also applies this assumption to shallow convection. In order to see the influence of various convection schemes, July monthly simulations with the three schemes and various options were made over a domain covering the western part of Canada. Results and analysis of these simulations will be presented.

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Session PM1

CRCM

Chair: J. Scinocca

4. Large-scale forcing for the Canadian RCM

Sébastien Biner, Daniel Caya, and René Laprise
Département des sciences de la terre et de l'atmosphère, UQAM

A new nesting strategy has been implemented in the Canadian RCM (CRCM). This strategy consists in forcing the large-scale circulation of the RCM toward the corresponding large-scale circulation of the driving data. The forcing is only applied to the large large-scale and therefore does not directly affect the fine-scale details produced by the CRCM.

The methodology used to force the CRCM large-scale circulation is presented. The large-scale component of selected CRCM fields is extracted by using a low-pass filter. The corresponding fields from the driving data are treated using the same filter. A forcing proportional to the difference between the two large-scale fields is then applied to the CRCM field. The method is controlled by parameters defining the low-pass filter and by the amplitude and vertical distribution of the forcing coefficient. The results of different sensitivity tests are showed.

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1330–1510 hrs
Room 307

Session PM1

CANYON AND CHANNEL FLOW

Chair: P. Cummins

1. Dynamics of advection-driven upwelling over a submarine canyon

Susan Allen[1] and Barbara Hickey[2]
[1]*Dept. Earth and Ocean Sci., Univ. of BC*
[2]*School of Oceanography, Univ. of Washington*

During upwelling favourable conditions, submarine canyons are regions of enhanced upwelling. During a several day upwelling event, the response over the canyon can be separated into two phases: an initial, very strong, transient response and a later, much longer, "steady" advection-driven response. The latter phase is considered here. Recent observational evidence has shown that the flow around submarine canyons of quite different geometry (Barkley Canyon: 6 km long, 400 m deep, 8 km wide versus Astoria Canyon: 22 km long 450 m deep 9 km wide) is qualitatively similar. We present a scale analysis to estimate the depth of upwelling, the flux of upwelled water and the vorticity in various parts of the water column. For three measurable quantities: the depth of upwelling, the vorticity deep in the canyon and the presence or absence of a rim-level eddy, the results from the scale analysis are compared to observations and results from laboratory models.

Scale analysis shows that the dynamics of upwelling over a canyon is determined by combinations of several non-dimensional numbers: a Rossby number ($Ro = U/fr$), a Froude number ($Fr = U/NH$) and a Burger number ($S = NH/fL$) and a combination of geometric parameters (Ge) where U is the inflow velocity at rim depth, f is the Coriolis parameter, r is the radius of rotation of the isobaths around the head of the canyon, N is the buoyancy frequency at rim depth, H is the depth of the shelf-break and L is the length of the canyon. Ge is function of the length of the canyon, the width of the canyon at the mouth and the width of the canyon mid-way along the length. The depth of upwelling is determined by $(F(Ro)\ Fr/S))^{1/2}$ where F is a tanh-like function. The vorticity of the deep water within the canyon is determined by $(F(Ro)\ Fr\ S)^{1/2}$. The presence or absence of eddy at rim level is determined by $Ge/(F(Ro)Fr^{1/3})$. The comparison to the observations support the scale analysis.

2. Approximating submarine canyon upwelling through laboratory spin-up experiments

Ramzi Mirshak and Susan Allen
University of British Columbia

Submarine canyons are common bathymetric features that cut into the continental shelf from the continental slope. Canyons are areas of enhanced upwelling and downwelling. We estimate the flux of water upwelled onto the continental shelf through a submarine canyon by means of laboratory spin-up experiments.

The laboratory setup is designed to mimic a submarine canyon cutting into the shelf/slope topography of the coastal ocean. A forcing is induced by varying the rotation rate of the tank such that scaled flow rates are comparable to those found over a submarine canyon, such as Astoria canyon. An axisymmetric (canyon-free) case is used as a benchmark and these results are compared to theoretically predicted spin-up rates. It is found that the introduction of a submarine canyon to the system can accelerate the rate at which the water in the tank achieves solid body rotation. Upwelling observed within the canyon during spin-up as a result of vortex stretching enhances the radially outward flow generated by Ekman pumping.

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Session PM1

CANYON AND CHANNEL FLOW

Chair: P. Cummins

3. Observations of the flow of abyssal water through the Samoa Passage

Howard Freeland
Institute of Ocean Sciences

During the fall of 1994 a conductivity-temperature-depth/hydrographic survey was carried out as part of the World Ocean Circulation Experiment one-time survey, Line P15N. The survey included standard water properties required by WOCE. Line P15N extended southwards from the Aleutian Islands along 165°W into the vicinity of the Samoa Passage. The line was adjusted to follow the axis of the Passage, and time was found to complete a cross-section survey across the Passage. This paper will present geostrophic computations of flow velocities through the Samoa Passage, including transport estimates, and will present longitudinal plots of properties. The longitudinal plots show evidence of hydraulic control at the sill in the Samoa Passage. We determine a best estimate of northward transport of water colder than 1.2°C (potential temperature) to be 8.4 Sv with an average current speed of 6.7 cm/s. This is consistent with the hypothesis that the flow is controlled.

4. Mixing and exchange in the Bosphorus

Frank Gerdes[1], David Farmer[1], Huseyin Yuce[2], and Erhan Gezgin[3]
[1]*Institute of Ocean Sciences*
[2]*Institute of Marine Sciences, University of Istanbul*
[3]*Dep. of Navigation, Hydrography and Oceanography, Istanbul*

We describe results of a study of circulation in the Bosphorus. Measurements were acquired with a 300kHz acoustic Doppler profiler, a 100kHz echo-sounder and a profiling CTD, with differential GPS reference.

In the Bosphorus a two layer-exchange flow occurs with fresher Black Sea water moving South over a deeper more saline layer moving North. The exchange is hydraulically controlled by a contraction and a sill. Contrary to predictions from inviscid hydraulics the interface in the subcritical flow is not horizontal but slopes steeply throughout the strait. Our observations indicate that fluid exchange between the layers and frictional effects contribute to the balance of forces within the strait.

Observations from transverse runs from one bank to the other show significant variability associated with channel curvature. Echo-sounder images reveal the presence of shear flow instability at various locations. At these the gradient Richardson was found to be smaller or of the order of 1/4.

The upper layer and lower layer transports are influenced by a daily land/sea breeze. Net volume fluxes increase from 5000 to 10,000 m^3/s within a few hours.

Analysis of the velocity and density fields in terms of volume and salt conservation provides a basis for inferring the effects of turbulent transport between the layers. We estimated an upward flux of 1200 m^3/s and a downward flux of 300 m^3/s over the southern 10km of the Bosphorus.

5. Western Mediterranean sea-level rise: Changing exchange flow through the Strait of Gibraltar

Tetjana Ross[1], Chris Garrett[1], and Pierre-Yves Le Traon[2]
[1] *University of Victoria*
[2] *CLS Space Oceanography Division, France*

Sea-level rise caused by climate change is a matter of concern all around the world and particularly in the Mediterranean, where there have been many studies of sea-level changes. Most studies consider the Mediterranean as a closed basin, thus overlooking the exchange flow through the Strait of Gibraltar as a possible cause of Mediterranean sea-level changes.

We show how a western Mediterranean sea-level rise of more than 10 mm/year from 1994 through 1997, found in monthly mean sea-level data from tide-gauges and Topex/Poseidon satellite altimetry, can be interpreted as a change in the Gibraltar exchange flow. The rise was accompanied by a four year decrease of nearly 40% in the sea-level drop along the Strait, which suggests a move to more submaximal exchange flow, since the predicted along-strait sea-level drop for submaximal flow is half that for maximal. A decrease in the cross-strait sea-level drop was also seen, suggesting the decreased surface inflow velocities that would accompany more submaximal flow. Thus, it seems a switching of hydraulic flow states in the Strait, likely triggered by changes in Mediterranean deep water formation, caused the rise.

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Session PM1

CANYON AND CHANNEL FLOW

Chair: P. Cummins

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Session PM1

THE ATLANTIC STORM OF 21 JANUARY, 2000

Chair: H. Ritchie

1. Synoptic description of the Atlantic storm of January 21, 2000

John MacPhee[1], Bill Richards[2], and Ted McIldoon[3]
[1]*Newfoundland Weather Centre, Gander, NF*
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Atlantic Canada was battered by a winter storm on Friday and Saturday, January 21st and 22nd, 2000. This Cape Hatteras Low dropped to an exceptionally low 94.6 kpa when it was 90 nautical miles south of Halifax. The central pressure remained below 95.0 kpa as it tracked northward across the Central Gulf of St. Lawrence, making it one of the few storms known to have been below 95.0 kpa while over Gulf waters. This storm was well handled by the Numerical Weather Products (NWP) which forecast its formation and movement (several days) in advance. The forecasts issued by all three Weather Centres in Atlantic Region accurately predicted the depth of the low, wind speeds and, for the most part (with the exception of being a little light for the 22–0600Z period) significant wave heights associated with the storm.

We will show how this low developed, discuss the return period for a low of this depth over the Gulf of St. Lawrence, and consider what warnings were issued and how well were they distributed and understood. The effort put into a Storm Damage Survey turned up some complaints about the Warnings issued for Higher than Normal Water Levels. What have we learned from this feedback? What changes could or should be made? An overview of the snowfall/rainfall amounts will the wrap-up the presentation.

2. Storm-surge, sea-ice, and wave impacts of the 21–22 January 2000 storm in coastal communities of Atlantic Canada

Donald Forbes[1], **George Parkes**[2], Charles O'Reilly[3], Réal Daigle[4], Robert Taylor[1], and Norm Catto[5]
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A deep low passing northward over the Maritimes on 21–22 January 2000 caused severe impacts at numerous coastal locations. With minimum central pressure of 94.5 kPa at 1800 UTC 110 km SSE of Halifax, the storm passed 55 km east of Charlottetown at 0000 UTC and thence north across the Gulf. Coincidence of a 1.2 m storm surge with perigean high tides intensified the impact of the storm at many sites. Waves of 5–7 m significant height in the Cabot Strait area, with much higher extremes, caused very severe impacts in southwest Newfoundland (MacPhee, this session) and eastern Nova Scotia. Flooding and wave damage to coastal infrastructure were recorded at several communities on the Burin Peninsula, but damage in eastern Newfoundland was largely restricted to sites that sustained more severe impacts from hurricanes in 1999. Combined waves and surge overtopped the barrier beach and main road access at Souris PEI, causing serious erosion, and significant damage was sustained at other sites in eastern and western PEI. The storm surge was most severe in Northumberland Strait, causing record high water levels and flooding parts of the downtown core in Charlottetown, as well as serious flooding in Mt Stewart PEI, Summerside PEI, and Shediac Bay NB. Buildings were floated off their foundations and transported alongshore at Malagash NS. A striking feature of this storm was the extent of sea-ice ride-up and pile-up onshore in PEI and NB. While sea ice limited wave action and protected the north shore of PEI (where the storm of 22 December 1998 was more severe), ice ride-up dislodged a lighthouse in Charlottetown and devastated the wharf at Robichaud NB. Shore-ice pile-up along the Gulf coast of NB, in places over the crest of coastal dunes, caused significant damage and exceeded anything in the recollection of coastal residents.

3. Real-time forecasts of the January 21st storm surge in Atlantic Canada

Josko Bobanovic[1], Keith Thompson[1], Serge Desjardins[2], and Hal Ritchie[2]
[1] *Dalhousie University, Oceanography Department*
[2] *Environment Canada*

During January 20–22, the Atlantic provinces were hit by an extremely powerful storm that resulted in large amounts of snow and virtually paralyzed the life on January 21. The storm was associated with an extra-tropical system that moved along the east coast of the US with very strong winds (storm to hurricane force wind or recorded peak wind of Southerly 96 km/h gusting to 137 km/h and central pressure of 944 mb). Strong winds and low pressure provided forcing for a dramatic storm surge (in excess of 1.4 meters) in the Gulf of Saint Lawrence that resulted in serious flooding along northern shore of Nova Scotia, around PEI and New Brunswick.

We attempt to analyze the conditions and consequences of such a powerful storm surge from the atmospheric and oceanographic points of view. Atmospheric forecasts (wind and pressure) are compared to the CMC (Canadian Meteorological Centre) surface analyses, surface observations to examine the skill of the forecast model for 24 and 48 hours. The operational storm surge model for the Atlantic Canada has been available in research mode for over a year through a joint effort by Dalhousie and Environment Canada. Here, we analyze the 24 and 48 hour forecast skill for the January 21 storm surge. We compared tide gauge observations against model predicted sea level and found that model was capable of forecasting the surge event with high degree of skill.

4. The wave in Channel Head

John MacPhee
Newfoundland Weather Centre, Gander, NF

The Channel Head portion of Port Aux Basques was hardest hit of all Newfoundland communities by the January storm. Here lives were almost lost and many people suffered great financial loss. Two events battered this area in the morning hours of Saturday, January 22. There were storm to hurricane force winds in the area Friday night and into Saturday morning. The recorded peak wind of 1852G74 KTS (Southerly 96 KM/H gusting 137 KM/H) was at 01:30 AM NST (22–0500Z). The sea state had increased sharply with the significant wave running at 6 to 8 metres from the south. In the greater Port Aux Basques region the water levels were running well above the tidal normals, resulting from a combination of tide, large significant wave heights and storm surge. In short, the area was experiencing storm conditions. On top of these storm conditions, which existed along the full southwest and south coasts of Newfoundland, at approximately 3:00 AM NST Saturday the first of two large waves struck the Channel Head area. This first wave did damage to homes and vehicles and was both large and unusual enough to draw people out of their homes. A second wave struck the area about 10 minutes after the first large wave, causing great personal loss (insurance will not cover the damage) and nearly taking lives.

This presentation will discuss the first notification of this event and the steps followed in investigating it. Why was there a delay in acknowledging that the area was struck by a large wave? Why is it hard to conduct a damage investigation by phone? An explanation of how the wave height was determined will also be presented.

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Session PM1

THE ATLANTIC STORM OF 21 JANUARY, 2000

Chair: H. Ritchie

5. Dynamic fetch and the "rogue" wave event at Port-aux-Basques

R. Bigio[1], R. Lalbeharry[2], and B. R. Thomas[3]
[1] *Meteorological Service of Canada, Environment Canada, Halifax*
[2] *Meteorological Service of Canada, Environment Canada, Downsview*
[3] *Meteorological Service of Canada, Environment Canada, Dartmouth*

During the storm of January 20–22, 2000, at least two large rogue waves hit Port-aux-Basques in southwestern Newfoundland causing an estimated 500K damage. Environment Canada personnel who inspected the damage concluded that the crest of the bigger of the two waves was about 9 m at the Channel Head residential area of Port-aux-Basques, and was at least 15 m at the lighthouse on Channel Head Island. Heights are referenced to the low tide level. Damage was caused by both heavy surf and storm surge. Other communities on the south coast of Newfoundland and the eastern shores of Nova Scotia also experienced destructive waves and storm surge.

Dynamic (or trapped) fetch occurs when the generating area moves with the wave group it generates (Bigio, 1996). In such conditions, waves can grow without limit until the generating area changes speed or direction.

The motion of the storm centre and the presence of long-period waves suggest that dynamic fetch was involved. Buoy data are examined to test this hypothesis. Possible causes of the rogue waves at Channel Head are examined.

The track of this storm and the associated dynamic fetch brought high-energy long-period waves across the continental shelf to the east coast of Nova Scotia and the south coast of Newfoundland. The combination of high heights and long periods also created very dangerous wave conditions over the shallower banks of the Scotian Shelf. The long period, and hence the long wavelength, of the waves meant that they were in transitional-depth water as they passed over these banks. The effects of shoaling and refraction are discussed. The deep-water storm waves are compared to wave climate statistics.

Wave simulations from the operational ocean wave model WAM are also compared with the buoy observations to examine how well the WAM performed in generating the extreme sea states observed for this storm case.

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Room 311

Session PM1

CLOUDS, AEROSOLS AND RADIATION

Chair: U. Lohmann

1. Cloud droplet size formation by ripening process: Roles of radiative processes

Fikrettin Celik
Enviro-Meteo Services Inc.

Initiation of rain in warm clouds requires broad droplet size spectra and existence droplets with diameter 40 micrometers for the onset of collision-coalescence processes. Large number of studies were devoted for this problem, however, this is still an unsolved problem.

Cloud droplet size spectra are unstable due to presence of droplets with different size and salinity. Inside of a cloud, curvature and the salinity effects of the droplets are the driving forces for the instability. Because of this instability droplet spectra broaden to large and small sizes without any external forcing mechanism (ripening process). Radiative cooling near the top of a cloud is another process that modifies the formation of droplet size spectra. The roles of radiative processes on the ripening process will be discussed. Aircraft observations and numerical simulations will be presented.

2. The absorption of NIR solar radiation by liquid water in clouds

W.F.J. Evans and E. Puckrin
Trent University

In current climate models, clouds do not absorb much more solar radiation than a clear atmosphere. Spectral measurements with FTIR spectroscopy of the transmission of solar infrared radiation through clear and cloudy skies has indicated that clouds absorb unexpectedly large amounts of near-infrared (NIR) radiation. The amounts are unexpected in the sense that radiation codes, including sophisticated algorithms such as MODTRAN4, cannot model this strong absorption effect. The absorption fingerprint of the mystery absorber in the cloud transmission spectra matches the spectrum of liquid water. We also have observed the spectrum of liquid water absorption in the transmission spectrum of fog, which has a composition similar to clouds, suggesting that it is possibly associated with drizzle in clouds. The same spectral signature of liquid water in the cloud NIR absorption has been observed from an aircraft on the AIRS project.

The liquid water absorption is not explained by Mie theory for cloud droplets in the size range from 10 to 20 microns. The absorption cannot be simulated using MODTRAN4 or other radiation codes. We postulate that the liquid water in the form of drizzle in clouds is absorbing the NIR solar radiation. The effect seems to be associated with precipitating clouds and includes Virga in many clouds which does not reach the ground. A possible explanation is that there is a bimodal droplet distribution with water droplets greater than 200 microns radius causing the absorption drizzle consists of droplets around 500 microns. Daily measurements over the last 4 years, utilising separate filtered pyranometers to determine the ratio of NIR absorption to visible absorption, have been used to further investigate and quantify this effect. The absorbed flux is strongly dependent on the cloud type, and the size of the absorbed flux is in the 50 to 100 W/m^2 range at solar noon. Under clear conditions, the ratio of NIR to Total short wave is usually about 40 %. Under cloudy conditions this ratio can be reduced from 40% to 15 %. In terms of fluxes, this ratio can be reduced from 350/900 W/m^2 down to 60/350 W/m^2. The absorption of NIR flux can be up to 150 W/m^2 by a particular cloud deck. On a globally averaged basis this corresponds to 13 to 25 W/m^2, in comparison to the 3 W/m^2 flux imbalance due to the increase in all of the greenhouse gases. Overall, clouds have been estimated to produce a net cooling effect of about 20 W/m^2. Our measurements indicate that cloud absorption can be over 100 W/m^2 for individual clouds, implying some clouds have a net warming instead of a cooling effect. The energy absorption of NIR short wave by clouds on a global basis may be a missing factor in GCMs, important to modelling the climate problem. This NIR absorption effect is not reproduced by the current radiation schemes in climate models.

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Session PM1

CLOUDS, AEROSOLS AND RADIATION

Chair: U. Lohmann

3. Sea salt radiative forcing in CCC GCM

Steven Dobbie[1], **Jiangnan Li**[2], Richard Harvey[2], and Peter Chylek[1]
[1]*Dalhousie University*
[2]*Canadian Centre for Climate Modelling and Analysis*

The single scattering optical properties of sea salt solution particles are parameterized as function of relative humidity for various dry size distribution. The accuracy of the parameterization is typically within 10% as compared to exact Mie calculation. In addition to the optical properties, the growth of droplet mass ratio and effective radius of the size distribution are also parameterized in terms of the relative humidity. The parameterization was implemented in the Canadian General Circulation Model GCMIII, and an estimate of the first order globally and yearly averaged solar direct radiative forcing due to sea salt is estimated to be $-0.15 W/m^2$ (cooling). The monthly trends in the two hemispheres are presented and discussed.

4. Simulations of aerosol optical depth using the CCCma GCM as compared to AERONET and AVHRR data

Ulrike Lohmann and Glen Lesins
Dalhousie University

The general circulation model (GCM) of the Canadian Centre for Climate Modelling and Analysis (CCCma) solves prognostic equations for the mass mixing ratios of sulfate aerosols, hydrophobic and hydrophilic organic and black carbon, dust and sea salt. Sources due to fossil fuel use, biomass burning, volcanoes, oceanic DMS emissions, deserts, forests emitting organic carbon precursors and bursting of white-cap bubbles are given from different source inventories. The aerosols are subject to transport, dry and wet deposition and chemical transformation in case of sulfates. For radiative purposes we consider each species to be distributed log-normally following the OPAC climatology (Hess et al. 1998). Since some aerosol species swell as the relative humidity increases, while others like black carbon and dust do not, the optical properties can be different if the various aerosol species are assumed to be externally mixed or internally mixed. The AERONET (Aerosol robotic network) data (Holben et al. 1999) provide measurements of aerosol optical depth at different continental sites complementing nicely the information over the oceans obtained by AVHRR (Husar et al. 1997). The comparison with AVHRR and AERONET data will tell us if the simulated aerosol optical depth is in closer agreement with the observations when the species are externally or internally mixed. Sensitivity studies with different mixing assumptions, mode radii and widths of distributions will also be carried out.

5. Cirrus horizontal inhomogeneity and solar albedo bias

Betty Carlin[1], Qiang Fu[1], Ulrike Lohmann[1], Gerald G. Mace[2], Jennifer M. Barnett[2], and Kenneth Sassen[2]
[1]*Dalhousie University*
[2]*University of Utah*

Cloud subscale variability within typical grid cells of large scale models (such as climate models) may introduce a significant cloud albedo bias because of the plane parallel assumption for the cloud. In the last few years, research efforts have been focusing on the solar albedo bias related to the subtropical marine boundary layer clouds. In this study, we have investigated the horizontal inhomogeneity of cirrus clouds and the related solar albedo bias using the time series of cirrus microphysical and optical properties derived from the cloud radar and lidar at the SGP ARM site and Salt Lake City, respectively. We consider the gamma probability density function as a fit to the observed cirrus cloud optical depth distribution and then demonstrate that the gamma weighted (GW) radiative transfer method as proposed by Barker (1996) can reduce the albedo bias. We also discuss possible parameterizations of the standard deviation of cirrus optical depths (which is needed for the GW method) by using parameters provided by large scale models.

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Session PM1

CLOUDS, AEROSOLS AND RADIATION

Chair: U. Lohmann

Wednesday, 31 May
1540–1740hrs
Room 207

Session PM2

REGIONAL ANALYSIS AND VERIFICATION

Chair: R. Laprise

1. A spectral analysis technique suitable for limited area grids

Bertrand Denis[1], Jean Coté[2], and René Laprise[1]
[1] *Université du Québec à Montréal*
[2] *Recherche en prévision numérique, Service météorologique du Canada*

Two-dimensional spectral analysis is a popular way of analyzing atmospheric data on the globe. This is because the sphere is a suitable domain for spectral transforms that work on periodic data. On the other hand, meteorological fields on limited area grids are non-periodic and the direct application of the periodic Fourier transform produces spectra with distorted tails. To avoid that problem, we use a transform called the discrete cosine transform (DCT). The DCT is a widely used transform for compression of digital images such as MPEG and JPEG, but its use for atmospheric spectral analysis is novel.

We will show how this technique compares to another technique that consists in detrending the data before applying a periodic Fourier transform (Errico, 1985). Some spectra from the Canadian Regional Climate Model (CRCM) will be displayed. Finally, we will show how the DCT transform can be used advantageously for extracting information at specific spatial scales by spectrally filtering the atmospheric fields.

2. Correlation between various CRCM and CGCMII fields over western Canada under different greenhouse gases concentrations

Hélène Côté, René Laprise, and Daniel Caya
Département des Sciences de la Terre et de l'Atmosphère, Université du Québec à Montréal

The limited area Canadian Regional Climate Model (CRCM) is nested in the Canadian GCM to produce time-slice experiments in a transient greenhouse gases concentration scenario. CRCM simulations have been performed for three ten-year time windows. These three periods correspond approximately to contemporary, doubled and 3 time GHG concentrations. The one-way nesting technique consists in providing some GCM fields at the boundary of the regional domain. Beyond a narrow transition zone, the CRCM is free to develop its own circulation.

In order to quantify how much the CRCM simulated climate is controlled by the driving CGCMII simulation, the correlation coefficients between the two climates has been computed for each grid point of the regional domain. Spatial distribution of the correlation coefficient for some selected variables will be shown for each of the three time windows. The correlation coefficient will also be used to compare two CRCM contemporary GHG concentration simulations nested by the same CGCMII integration but with different nesting techniques.

3. A permutation approach to the validation of short regional climate model simulations

Murray D. MacKay
Climate Processes and Earth Observation Division, MSC

Short regional climate model simulations are routinely compared with observations, though because of extremely small sample sizes (often only a single season or year is simulated) it is generally difficult to establish whether any model-reality differences are statistically significant. In the following, a permutation technique based on the Pool Permutation Procedure of Preisendorfer and Barnett is proposed to estimate the statistical significance of similarities between spatial fields as simulated by a regional climate model, and observations, when the climate model is nested within operational analyses (i.e. perfect lateral boundary conditions). To illustrate the technique, we consider a short simulation over the Mackenzie River Basin of northwestern Canada made using the Canadian Regional Climate Model, and focus our attention on accumulated monthly precipitation and monthly average screen temperature. For comparison we have a 45 year gridded, monthly climate dataset produced by the Meteorological Service of Canada over the same region, based on adjusted operational climate station data.

4. Evaluation of the performance of a mesoscale model during FIRE.ACE

Bernard Bilodeau[1], Jocelyn Mailhot[1], André Tremblay[2], Anna Glazer[2], and Stéphane Bélair[1]
[1]*Recherche en prévision numérique*
[2]*Cloud Physics Research Division*

In support of the FIRE.ACE field project, a special modeling system had been set up in Inuvik, NWT, from 6 April to 1 May 1998 to provide forecast guidance for the Convair flight operations. The MC2 (Mesoscale Compressible Community) model was run at high-resolution (10 km) everyday to give an accurate picture of mesoscale features, especially with regards to the Arctic cloud structure and distributions, near-surface winds and temperatures. Prior to the experiment, changes had been made to the physics package in order to improve the treatment of surface processes over land and ice-covered oceans, and to refine the treatment of Arctic stratus clouds. A preliminary evaluation of this package has been done recently. Since then, we have refined further the definition of surface properties in the model physics. Moreover, we have fine-tuned the coupling of the condensation scheme with the radiation modules. A model rerun for the entire experiment period was performed, in order to generate a reliable database that will be used for further studies.

An overview of the various aspects of the modeling system will be presented at the Congress. Verification statistics against surface and radiosonde observations for the entire period will be shown, as well as detailed comparisons of model and observed surface energy budgets over SHEBA ice station

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Session PM2

REGIONAL ANALYSIS AND VERIFICATION

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Session PM2

CRYOSPHERE

Chair: H. Melling

1. The warm summer of 1998 and its effect on sea ice and glacier melt in the Canadian Arctic Islands

Tom Agnew[1], Bea Alt[2], Roger DeAbreu[3], Sharon Jeffers[3], and Roy Koerner[4]
[1] *Climate Research Branch, Meteorological Service of Canada*
[2] *Balanced Environments Associates*
[3] *Canadian Ice Service , Meteorological Service of Canada*
[4] *Geological Survey of Canada*

The globally warm summer of 1998 has been characterized by record reductions in sea ice cover over the Beaufort and Chukchi Seas (McPhee, et al., 1999, Maslanik et al., 1999, Agnew et al., 1999). It also had a major impact on sea ice and glacier melt in the Canadian Arctic Islands especially the Queen Elizabeth Islands. In 1998, for the first time since 1962, both the multi-year fast ice plugs in Sverdrup Basin and Nansen Sound broke up. However analysis of the historic records of composite sea ice charts in the High Arctic Islands indicates the summer of 1962 (and possibly 1981) was just as extreme as 1998 in both sea ice and glacier mass balance and the 35 year record of maximum open water percent and glacier mass balance have to date shown no significant trends. The maximum open water record for 1961-1998 suggests a possible change in the Queen Elizabeth Islands ice regime starting in the early 1980's which may explain the lack of trend. The summer of 1998 was none the less the first year in the latter period to experience extremely light sea ice conditions in the high arctic islands (as well as in the eastern arctic islands) and provides a glimpse of what the future may hold for cryospheric conditions in the area.

The paper combines research and operational methods to investigate these phenomena and examines in particular the extreme summers of 1998, 1962 (and 1981) as well as the trends in sea ice extent, the ice motion in the vicinity of the multiyear ice plugs, the change in regime in the early 1980's and the relationship of the complex Queen Elizabeth Island sea ice regime to change at the hemispheric scale. This paper is a report on work to date and proposed future work.

2. Interannual variability of accumulated snow in the Columbia basin, British Columbia

William Hsieh[1] and Benyang Tang[2]
[1] *Univeristy of British Columbia*
[2] *Jet Propulsion Lab*

Snow water equivalent anomalies (SWEA) measured around April 1 by stations in the Columbia basin area in British Columbia, Canada were studied for their interannual variability during the period 1950–1999, particularly in relation to El Niño/La Niña events and to high and low PNA (Pacific-North American) atmospheric circulation patterns. Composites of the SWEA showed that SWEA were negative during El Niño years, positive during La Niña years, negative during high PNA years, and positive during low PNA years. High PNA appeared to have the most impact on the SWEA, followed by La Niña, then El Niño, and finally by low PNA. In the Columbia basin area, La Niña effects (relative to El Niño effects) on SWEA decrease northward and eastward, but strengthen with elevation.

Composites of the Pacific sea surface temperature anomalies (SSTA) during the ten lowest SWEA years revealed weak signals, with El Niño warm SSTA present only during spring and early summer in the preceding year, and the SSTA pattern consistent with a high PNA present by fall and winter. In contrast, composites of the SSTA during the ten highest SWEA years showed strong La Niña cool SSTA starting around May in the preceding year and lasting onto winter.

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Session PM2

CRYOSPHERE

Chair: H. Melling

3. A comparison of modelled sea-ice concentration with observational data from 1958 to 1998

Anne E. Armstrong[1], Lawrence A. Mysak[1], and L.-Bruno Tremblay[2]
[1]*Dept. of Atmospheric and Oceanic Sciences and Centre for Climate and Global Change Research, McGill University*
[2]*Lamont-Doherty Earth Observatory, Columbia University*

A comparison between observed and simulated sea-ice concentration (SIC) is presented. The observations come from the GISST data set and the simulated data was obtained from a 41-year simulation using a sea-ice dynamic model based on a granular material rheology. EOF analysis is employed initially to validate the modelled SIC. Results show a good agreement between simulated and observed SIC EOF patterns: centers of action in the Greenland, Barents, Beaufort and East Siberian seas are well reproduced. The model is then used to obtain a better physical understanding of the processes responsible for these modes.

4. Decadal variability of the Arctic sea ice thickness.

Blandine L'heveder[1] and Marie-Noelle Houssais[2]
[1]*Department of Oceanic and Atmospheric Sciences, McGill, Montreal.*
[2]*LODYC, UPMC, Paris.*

The natural low frequency variability of the sea ice thickness in the Arctic is investigated based on a 10 000 years simulation with a one-dimensional thermodynamic sea ice model forced by random perturbations of the air surface temperature and solar radiation. The simulation results suggest that atmospheric random perturbations are integrated by the sea ice. Moreover those perturbations occurring at the onset of melting may result in a global shift of the melting season and therefore force the largest ice thickness anomalies, which are successively amplified in summer by the albedo feedback and damped in winter by the feedback of the heat conduction through the ice.

The power spectrum of the ice anomalies suggests that the thickness of the perennial ice should vary preferentially on a timescale of approximately 20 years. The shape of the spectrum is consistent with that of a first order Markov process in which the characteristic time scale of the ice fluctuations would be the relaxation time scale associated with the linear feedback. The equivalent Markov model is constructed by linearizing the ice growth rate anomaly equations and allows us to derive an analytical expression of the feedback. The characteristic time scale depends explicitly on those model parameters involved in the atmosphere-ice interaction but also on the mean seasonal characteristics of the forcing and of the ice thickness.

5. Sea-ice variability in the CCCma CGCM2 Coupled Model

Gregory Flato
Canadian Centre for Climate Modelling and Analysis, Meterological Service of Canada

The CCCma's second generation coupled model, CGCM2, includes a simplified sea-ice dynamics scheme. The resulting ice motion allows for net ice growth in some areas and net ice melt in others (notably the northern North Atlantic). Wind-driven variability in ice motion can therefore be reflected in variability in surface freshwater (and heat) fluxes, which can in turn drive variability in ocean properties and circulation. The talk will illustrate variability in modelled ice coverage, thickness and export from the Arctic obtained from a 1000 year control integration of the model. Correlations with variability in other climate quantities will be examined and comparisons to available observations will be made. The talk will end with some results from a simulation with changing greenhouse gas and aerosol forcing to illustrate potential future changes in Arctic ice cover and its variability.

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Session PM2

CRYOSPHERE

Chair: H. Melling

6. Is there a dominant timescale of natural climate variability in the Arctic?

Silvia A. Venegas[1] and **Lawrence A. Mysak**[2]
[1] *Danish Center for Earth System Science (DCESS), Niels Bohr Institute for Astronomy, Physics and Geophysics, University of Copenhagen, Copenhagen, Denmark*
[2] *Centre for Climate and Global Change Research and Department of Atmospheric and Oceanic Sciences, McGill University, Montreal, Quebec*

A frequency-domain singular value decomposition performed jointly on century-long (1903–1994) records of North Atlantic sector sea ice concentration and sea level pressure poleward of 40°N reveals that fluctuations on the interdecadal and quasidecadal timescales account for a large fraction of the natural climate variability in the Arctic. Four dominant signals, with periods of about 6–7 years, 9–10 years, 16–20 years and 30–50 years, are isolated and analyzed. These signals account for about 60–70 % of the variance in their respective frequency bands. All of them appear in the monthly (year-round) data. However, the 9–10-year oscillation especially stands out as a winter phenomenon.

Ice variability in the Greenland, Barents and Labrador Seas is then linked to coherent atmospheric variations and certain oceanic processes. The Greenland Sea ice variability is largely due to fluctuations in ice export through Fram Strait and to the local wind forcing during winter. It is proposed that variability in the Fram Strait ice export depends on three different mechanisms, occurring on the 6–7 year timescale, the 9–10 year timescale and the 16-20 year timescale. Also, a marked decreasing trend in ice extent since around 1970 (30–50-yr timescale) is linked to a recently reported warming in the Arctic. The Barents Sea ice variability is associated with the nature of the penetration of Atlantic waters into the Arctic Basin, which is affected by two distinct mechanisms, one of which is related to the NAO pattern (9–10 year timescale) and the other to the ocean gyres (16–20 year timescale). Ice variability in the Labrador Sea, on the other hand, appears to be determined by thermodynamical effects produced by the local wind forcing, which is closely related to the 9-10 year NAO timescale, and by advection of ice anomalies into this sea from the Greenland-Irminger Sea (6–7-yr timescale).

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Session PM2

GEWEX/MAGS

Chair: R. Stewart

1. Twin Otter flux measurements in the Mackenzie GEWEX Study (MAGS)

Ian MacPherson[1], Peter Schuepp[2], and Raymond Desjardins[3]
[1]*National Research Council Canada, Ottawa, Ontario*
[2]*McGill University, Montreal, Quebec*
[3]*Agriculture and Agri-Food Canada, Ottawa, Ontario*

This paper describes the operation of the NRC Twin Otter atmospheric research aircraft as part of the university component of the Canadian GEWEX Enhanced Study (CAGES), an intensive observation period of MAGS. The aircraft was instrumented to measure the vertical fluxes of sensible and latent heat, momentum and CO_2 and supporting meteorological and radiometric data. The focus of the aircraft program was the measurement of the heat and moisture exchange between the surface and the atmosphere, for comparison with ground-based flux data and, ultimately, the improvement of models used to predict these exchanges over extended areas of the Mackenzie basin. Twenty-five project flights were flown from Inuvik, NWT, over well-defined and repeatable ground tracks, including a 16×16-km grid pattern, a 100-km regional run, and tracks over forest and the Mackenzie Delta. Flights from May 21–June 8, 1999 captured the critical snow-melt period and initial greening of the vegetation, and a second series from July 5–14 provided comparative summer data when transpiration from the vegetation contributed a greater portion of the latent heat flux. Details of the flight program and a summary of the resulting flux measurements will be presented.

2. Analysis of airborne flux observations in the Mackenzie GEWEX Study (MAGS)

Peter H. Schuepp[1], J. I. Macpherson[2], S. O. Ogunjemiyo[3], N. Neumann[4], P. Yau[1], and B. Nagarajan[1]
[1]*McGill Universty, Montreal*
[2]*National Research Council, Ottawa*
[3]*University of California at Santa Barabara*
[4]*National Water Research Institute, Saskatoon*

This paper will complement a parallel paper submitted by MacPherson et al., which describes the operation of the Canadian Twin Otter flux research aircraft in MAGS, and resulting flux estimates of sensible heat, latent heat and carbon dioxide over tundra, delta and forested regions in the northern Mackenzie Basin. It will focus on the following aspects: (a) Energy balance closure and partitioning: The proportion of available energy allocated to sensible and latent heat flux, as opposed to that used in storage and ground flux, varied by factors up to 10 during the observation period (snow-melt to early summer conditions), and the partitioning between sensible and latent heat flux (Bowen Ratio) by factors up to 5. The physical and physiological processes that must be understood in modelling such variability in the surface boundary condition for biosphere-atmosphere exchange will be discussed (b) Link to remote sensing: The spatial distributions of observed fluxes will be compared against radiometric surface characteristics from satellites in an attempt to determine the potential of using satellite-based remote sensing for estimation of surface-atmosphere exchange in northern ecosystems (c) Link to boundary-layer modelling: Airborne data obtained over regional, forested transects with and without presence of small lakes will be examined against preliminary results of 3-d MC2 modelling in an attempt to assess the effects of small lakes on regional evaporation.

3. Solar radiation budgets for the Mackenzie GEWEX Study (MAGS) from ScaRaB and AVHRR measurements

J. Feng[1], H.G. Leighton[1], M.D. Mackay[2], N. Bussières[2], P.H. Schuepp[3], and I. Macpherson[4]
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Solar radiation budgets at the top of the atmosphere and at the surface are determined for the Mackenzie GEWEX Study from radiances measured by the ScaRaB instrument on the METEOR 3/7 satellite and the AVHRR on NOAA polar orbiters. Data from two periods are analyzed: the summer of 1994 when data from both the ScaRaB and AVHRR were available, and 1998–99, which was the project period of detailed study for a full water year but for which only AVHRR data are available.

ScaRaB, with its simultaneous measurements of narrowband and broadband radiances from the same pixels is ideally suited for generating narrowband to broadband conversions. Conversion functions specific to the Mackenzie Basin are determined for eight different surface types, clear and overcast conditions, and a wide range of sun and viewing geometries. Relationships between AVHRR channel 1 and ScaRaB narrowband radiances are deduced from radiative transfer calculations. These two steps are combined to provide conversions of AVHRR channel-1 radiances to broadband radiances. Top-of-the-atmosphere (TOA) fluxes are obtained from the broadband radiances and ERBE angular distribution models. TOA fluxes deduced from the AVHRR measurements in 1994 show very good agreement with the fluxes determined from ScaRaB giving confidence in the narrowband to broadband conversions.

Surface fluxes are deduced from the TOA fluxes using the algorithm of Li et al. (1993), which in addition to the TOA flux requires the column water vapour amount and the solar zenith angle. Surface fluxes for both the 1994 and 1998–99 measurement campaigns are compared with net solar fluxes measured from instrumented towers and a low-flying instrumented aircraft. Results for the 1994 data showed good agreement between the net solar fluxes deduced from the satellite measurements and the aircraft and tower measurements.

Monthly averages of the hourly fluxes deduced from the satellite measurements are compared with the corresponding fluxes from the Canadian Regional Climate Model (CRCM). For the summer of 1994 the agreement between the fluxes from the model and the satellite data at the TOA is good, with the mean difference in the daily average fluxes being 0.82 W m^{-2}, −19.4 W m^{-2}, −5.5 W m^{-2} and 2.6 W m^{-2}. This indicates primarily that the model is doing a good job of reproducing the observed cloud amounts and albedos. However, there are significant differences between model and satellite-derived values of the partitioning of the solar flux absorbed at the surface and in the atmosphere. The current version of the CRCM overestimates the net surface solar radiation budgets by about 15%. There is evidence that suggests that this discrepancy will be reduced with the next version of the CRCM, which will include an improved physics package.

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Session PM2

GEWEX/MAGS

Chair: R. Stewart

4. Closing the MAGS water budget

G.S. Strong[1], Brian Proctor[2], Muyin Wang[3], and Ric Soulis[4]
[1] *GEWEX/MAGS Secretariat*
[2] *Meteorological Service of Canada*
[3] *Dalhousie University*
[4] *University of Waterloo*

A particularly elusive science problem for MAGS (The Mackenzie GEWEX Study) has been the closure of the atmospheric moisture budget and rationalizing it against the surface water budget. Two major sources of error are recognized: the difficulty in estimating inter-annual surface water storage, resulting in poor estimates of evapotranspiration (using $P - R = E$) and, the inability of two soundings per day to properly account for evapotranspiration in atmospheric estimates of $P - E = R$ (through computations of flux convergence and the local rate of change of vertically-integrated precipitable water).

This presentation will show how MAGS is overcoming these problems through the use of hydrologic and atmospheric models to estimate inter-monthly basin storage, and through additional daily soundings at select sites to better estimate the diurnal signature in precipitable water resulting from local evapotranspiration. In this way, closure of monthly water budgets is now possible within acceptable error limits.

5. Precipitation recycling over the Mackenzie basin

Kit K. Szeto
Climate Processes and Earth Observation Division, Meteorological Service of Canada

The study of precipitation recycling (PR), i.e., the contribution of local evaporation to local precipitation, is essential to the quantification of regional water cycles and in understanding the roles of land-atmosphere interactions in governing the regional climate. The precipitation recycling ratio, defined as the relative contribution of recycled precipitation to total precipitation, is estimated for the Mackenzie basin by using the NCEP reanalysis data. The spatial and temporal variability of PR over the basin will be presented and compared to those previously estimated for other major river basins. This study is the first systematic investigation of PR over the Mackenzie basin. Both the importance of high-latitude climate processes in governing PR over the region and the roles of PR plays in affecting the discharge from the basin will be discussed.

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Session PM2

AEROSOLS AND ATMOSPHERIC CHEMISTRY

Chair: P Ariya

1. Are chlorine and bromine cycles involved in atmospheric S (IV) to S (VI) conversion?

P. A. Ariya, A. Khalizov, and B. Viswanathan
Departments of Atmospheric and Oceanic Sciences and Chemistry, McGill University

Although acidification of atmospheric waters acid-rain is amongst the most important area of environmental sciences, contemporary chemical models fail to explain the large observed concentration of S(VI) species resulted from the oxidation of S(IV) in the atmosphere. Kinetics and mechanistic investigations of the reaction between atomic chlorine and sulfur dioxide have depicted that sulfur and chlorine cycles may indeed be interconnected. However, there are very limited thermodynamics and kinetics data available to determine the extent of this interaction. In this paper, we present our preliminary results on theoretical (*ab initio*) and kinetics and mechanistic (FTIR/MS) investigation of SO_2 and Cl/ClO, Br/BrO reactions. The relevance of chlorine and bromine cycles in the atmospheric conversion of sulfur (IV) into sulfur (VI) will be discussed.

2. Simulations of sulphur dioxide, sulphate and aerosol concentrations with NARCM for the North Atlantic Regional Experiment (NARE)

Henry Leighton[1], Andrew Teakles[1], Richard Leaitch[2], and Knut von Salzen[3]
[1]*Department of Atmospheric and Oceanic Sciences, McGill University*
[2]*Meteorological Service of Canada, Downsview*
[3]*Canadian Centre for Climate Modelling and Analysis, Victoria*

As part of the North Atlantic Regional Experiment (NARE), an intensive field experiment was held in 1993 off the coast of Nova Scotia. Although the main goals of the experiment were to understand the influence of eastern North America on ozone over the North Atlantic and to learn more about the chemistry of the marine clouds in the area, the extensive data that were collected provide a useful test of the Northern Aerosol Regional Climate Model (NARCM). Researchers from the MSC, in co-operation with scientists from the National Research Council of Canada (NRC), Ottawa, made a number of chemical, microphysical and thermodynamic measurements from the NRC DHC-6 Twin Otter aircraft in the vicinity of Yarmouth, Nova Scotia. The study covered the period from August 6 to September 8, 1993 and included a total of 48 Twin Otter flights.

NARCM is being developed as a tool for studying the impact of aerosols on climate. It is a three-dimensional limited-area model with the feature that includes explicit size-distributed aerosols as prognostic and interactive constituents. For the purpose of comparing NARCM output with data from NARE, NARCM was run for a 2-week period from August 24 to September 8 over a domain that included eastern North America and the western Atlantic. Results of the comparisons show considerable variability. SO_2 concentrations from the model tend to be greater than those from the observations, particularly at higher altitudes. The reverse is true for sulphate, where concentrations from the model tend to smaller than those observed. Possible explanations for these differences will be presented.

3. The continuity equation for the stratospheric aerosol and its characteristic curves

Jiangnan Li and George Boer
Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada

A four-dimensional continuity equation for particles undergoing growth process in the atmosphere is introduced. It is applied to the stratospheric aerosol in the simplified case of two dimensions under the assumption of horizontal homogeneity. In the radius range beyond which coagulation is important, the analytical solution of the equation gives the characteristic curve for the aerosol in the stratosphere and determines the relation between the growth and the settling distance of the particle. This relation, which includes the effect of a background vertical motion, essentially determines the aerosol size distribution. The resulting size distribution is too narrow in comparison with observations but introducing diffusive processes into the governing continuity equation results in a size distribution close to that observed. The approximate analytic results give insight into the relative roles of condensation, particle fall velocity, vertical motion, and diffusion in determining the aerosol size distribution which are verified by numerical calculation.

4. Measurements of the accumulation size aerosols during NODEM

Martin Montero[1], **Ulrike Lohmann**[2], and Glen Lesins[2]
[1]*Instituto Mexicano de Tecnologia del Agua*
[2]*Dalhousie University*

As part of the Northern Oceans DMS Emission Model (NODEM) project, aerosol sampling was taken during a cruise in the North Atlantic from September 18 to October 2, 1999, covering a large part of the remote North Atlantic, the Labrador Sea, and the southwest of the Canadian coast. The measurements were conducted using a PCASP-100X probe which counts and sizes the particles into 15 size bins between 140 and 3000 nm using a light scattering technique. The accumulation mode particles studied here are important because in this mode contributions from both the non-sea-salt sulfate (related to DMS) and the sea-salt component of the marine aerosols can be found. First analyses have shown that a possible correlation between aerosol number concentration and actual wind speed (measured at the ship) is far from evident. This correlation is very well known for sea-salt aerosols but here we are dealing with accumulation mode sea-salt particles which have a residence time of about 60 hours (Gong and Barrie, 1997) and therefore depend less on instantaneous wind speed than larger particles. Back trajectory analysis allows us to categorize the aerosol data according to their different origins. Aerosol size distribution for the different categories, correlations with wind speed and a classification according to DMS or sea-salt particles will be presented during the talk.

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Session PM2

AEROSOLS AND ATMOSPHERIC CHEMISTRY

Chair: P Ariya

5. Sulphur budget in Northern Aerosol Regional Climate Model (NARCM)

Lubos Spacek[1], Jean-Pierre Blanchet[1], Knut von Salzen[2], Henry Leighton[3], Sunling Gong[4], and Len Barrie[5]
[1] *University of Quebec at Montreal*
[2] *Canadian Centre for Climate Modelling and Analysis*
[3] *McGill University*
[4] *Atmospheric Environment Service, Toronto*
[5] *Pacific Northwest National Laboratory*

The Northern Aerosol Regional Climate Model underwent severe tests last year. Model performance was compared with meteorological analyses, ground-based atmospheric chemistry observations, and LIDAR vertical profiles for the period from 13 to 19 September 1994. A sulphur budget for eastern North America calculated for this period showed that the sulphur cycle of the model is closed with the precision of 7%. The fraction of SO_x emitted that was deposited, dry deposited and horizontally transported out of the domain were 23, 22 and 55% respectively. The fraction of SO_2 oxidized to $SO_4^{=}$ within the domain in clear air and within the clouds was 36 and 16%. A detailed analysis of these results with respect to their precision will be given.

6. Development of a global atmospheric mercury model

Ashu P. Dastoor
Air Quality Research Branch, Meteorological Service of Canada

During the last decade, a number of large-scale numerical regional models with varying degree of complexity have been developed for the transport and transformation of mercury in the atmosphere. However, unlike other heavy metals, mercury has been identified to have a long residence time (of the order of one to two years) which makes it a global pollutant. This is due to the fact that the most significant form of mercury in the atmosphere, namely elemental mercury exists in gaseous form, it is chemically least reactive, has low solubility in water and takes part in volatilization process at the earth surface. Therefore, although very useful in analyzing episodic situations, the regional scale models developed thus far are limited in their capability in providing insights into mercury budgets, long term trends, trans-boundary exchanges and polar mercury pollution because they have to depend on prescribed background concentrations and lateral boundary fluxes of mercury. Global atmospheric mercury model is a more appropriate tool to address the questions related to mercury cycle in the atmosphere.

Recently at Meteorological Service of Canada (MSC), we have developed a Global/Regional Atmospheric Heavy Metals Model (GRAHM). GRAHM is an Eulerian Multiscale model. It has been developed starting from Canadian Meteorological Centre (CMC) operational weather forecasting model GEM (Global Environmental Multiscale Model). The model integrates dynamic equations for all meteorological processes and physio-chemical processes for mercury species in the atmosphere. The model has variable resolution in vertical as well as horizontal. The model uses hybrid vertical levels with 3-D finite element spatial discretization. The time discretization is two-time-level semi-Lagrangian scheme. The transport scheme for the tracers in the atmosphere employs a mass conserving 3-D quasi-monotonic semi-Lagrangian scheme. By making use of the variable resolution grid in horizontal, the model could be used for simulations on scales from global to urban. Gas and aqueous phase chemistry parameterizations for mercury in the model are adapted from Petersen et al. 1998 (TCM). Global emissions for 1990 for anthropogenic sources of mercury available from Global Emission Inventory Activity (GEIA) have been used for the model development. The model and the results on the global distribution of mercury from model integrations will be presented at the conference.

1. A renewed community for mesoscale modeling

Robert Benoit, **Stéphane Chamberland**, and Wei Yu
Recherche en Prévision Numérique, MSC

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Session AM2

MC2

Chair: R. Stull

In 1994, the Meteorological Research Branch (MRB) of Environment Canada delivered MC2 as the first mesoscale model to the community of Canadian modelers. A rather large community benefited from the coupling of MC2 to a comprehensive physics library this spurred many experiments and mesoscale case studies. Then came a time when the central support could no more be given.

In the current context, MRB sees again the value of the community mesoscale modeling effort and created a group dedicated to it. The main goals of this group are to promote, unify and support mesoscale research done in universities and other laboratories with the MRB-CMC modeling developments in that matter. As the new LAM version of the GEM model becomes fully tested, the model proposed to the community will change from the MC2 at first, to the GEM-LAM.

The group will seek modern and efficient ways to disseminate up to date information on the models and on the ongoing projects of the community. While users' problem-solving has to remain, the accent will be put on keeping the mesoscale community well-connected and well-equipped with performing research tools.

An outline of the models, the type of services offered by the group, and examples of planned developments will be presented.

2. Canadian participation to the Mesoscale Alpine Programme (MAP)

Robert Benoit, Wei Yu, and **Stéphane Chamberland**
Recherche en Prévision Numérique, MSC

After four years of preparation, MSC and other Canadian researchers recently completed their participation to the field phase of the Mesoscale Alpine Programme (MAP) – an experiment designed to improve weather forecasting in mountainous regions. This international meteorological experiment, based in the densely instrumented European Alps, is unique because of the region's physical geography and the proximity to the Mediterranean that together lead to extreme meteorological phenomena.

As a partner of the MAP, Canada provided support in validating fine-scale models in collaboration with Alpine European countries. The Numerical Prediction Research Division (RPN, Dorval) has adapted its MC2 weather forecasting model for MAP and combined it with the Swiss national forecasting system, to ensure complete and very finescale (3 km mesh) coverage of daily changes in all phenomena across the Alpine mountains – a world first in the 'operational' forecasting field. The project was a collaborative project with the Swiss Meteorological Institute (SMI Zurich) and the Swiss Federal Institute of Technology (ETH Zurich).

Nature was cooperative and 17 IOPs took place to measure the influence of topography on precipitation in the Alps, the alpine atmospheric flow, the boundary layer near ground level, cloud processes, strong valley winds, and turbulence/waves aloft. An overview of the model configuration and overall performance is presented along with simulation and early validation results from selected MAP cases. Some critical aspects that require particular attention in future research are also addressed.

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3. High resolution mesoscale modeling for air quality in southern Ontario

Xin Qiu[1], Peter A. Taylor[1], and Fred Conway[2]
[1] *Department of Earth and Atmospheric Science, York University*
[2] *Atmospheric Science Division, Environment Canada, Toronto*

The Canadian Mesoscale Compressible Community (MC2) with certain selfnesting strategies is applied to air pollution meteorology studies in the Hamilton Region of Southern Ontario. The frequency and magnitude of exceedances of the ozone air quality objective are strongly affected by the presence of the Great Lakes. Ground-level ozone concentrations are observed to be higher within relatively narrow bands along the shorelines of the Lower Great Lakes. It has been argued that ozone and fine particulate pollution in Southern Ontario are very strongly linked to the influence of lake breezes. However, there are known deficiencies in the current state of modeling of lake breeze circulations, and of associated convective structures. MC2 high resolution simulation (1–2km) is able to illustrate detailed meteorological fields in the Lower Great Lakes area, including the development and evolution of land and lake breezes with different flow patterns, the effect of varying roughness and heat/moisture sources within an urban environment, the development and evolution of thermal internal boundary layers and the geographic and temporal variation of the boundary layer height. Additionally, a passive tracer has been used in the modelling to illustrate the combined effects of mesoscale flow and local thermal circulations on the transport of air pollution.

4. The Asian dust event of April 1998: 1. Impact on the Lower Fraser Valley, B.C.

Ian McKendry
The University of British Columbia

For the first time, long-range transport of mineral aerosol (Kosa) from Western China of southwestern British Columbia is documented. This late April 1998 event coincided with an episode of reduced dispersion and photochemical smog in the Lower Fraser Valley. Filter samples in the region show a massive injection of crustal elements (Si, Fe, Al and Ca) with concentrations of Si approximately double those previously recorded. Ratios of these elements to Fe are shown to be statistically similar to ratios observed in Kosa aerosol events in Hawaii and China. On the basis of the difference between observed and expected elemental concentrations and reconstructed soil mass in the episode, it is estimated that Asian dust contributed up to 50 of observed PM10 in the LFV, the remainder being attributed to local sources. Comparison of the April 1998 event with two spring meteorological analogues is consistent with this estimate.

Given the expected growth in fossil fuel consumption in Asia and recent observations of anthropogenic pollutants reaching western Washington State, this event illustrates the extent to which air quality in wsetern North America may be increasingly affected by Asian pollutant emissions.

5. The Asian dust event of April 1998: 2. MC2 simulations of downmixing

Josh Hacker and Ian McKendry
University of British Columbia

The MC2 model is used to investigate the transport of tropospheric mineral aerosol emanating from a dust storm in western China into the boundary layer over western North America. MC2 was modified to permit tracking of passive tracers and was initialised with an aerosol distribution based on satellite and lidar data. Simulations suggest that mineral dust was incorporated into the planetary boundary layer as a result of strong subsidence and mountain wave activity that permitted interception of lower tropospheric elevated aerosol layers by surface based mixing processes over the mountainous interior of the southern BC and Washington State. Surface easterly (outflow) winds then transported this material into the Lower Fraser Valley where it contributed significantly to total particulate loadings and an intense haze. This mechanism is consistent with the observed spatial and temporal distribution of PM10.

The mechanisms identified over the mountainous regions of western North America are also likely to contribute to the interception of anthropogenic pollutants that cross the North Pacific in the free troposphere.

6. On the GWD parametrization scheme in MC2

Wensong Weng and Peter Taylor
Depart of Earth & Atmospheric Science, York University

When stably stratified air flows over orography, gravity waves may be excited. Such waves may propagate to considerable altitude before being dissipated or absorbed. They can play an important role in transporting momentum vertically between source and sink regions where it dissipates or absorbs, and may significantly affect the large-scale mean flow. In large-scale models these effects are described by a so-called Gravity Wave Drag (GWD) parametrization scheme.

The present scheme in MC2 (v4.7) is based on simplified linear theory for vertically propagating gravity waves generated in statically stable flow and make use of a representation of the subgrid-scale topography for exciting the mesoscale gravity waves and a wave saturation concept proposed by Lindzen (1981) (see McFarlane, 1987 and McLandress and McFarlane, 1993).

In our present study, experimental runs with and without this scheme are carried out over the Appalachian area. The results and the impact of the parametrization scheme and of a coding error found in the GWD implementation are discussed, together with a discussion of the topographic input.

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Session AM2

BIO-PHYSICAL INTERACTIONS

Chair: D. Mackas

1. Modeling dynamical circulation and nutrient pathways on the eastern Scotian Shelf

Guoqi Han and John Loder
Bedford Institute of Oceanography

A three-dimensional finite element model with an advanced turbulence closure scheme is used to compute climatological seasonal-mean and tidal currents over the eastern Scotian Shelf. The model circulation fields are then used to simulate nutrient pathways from Cabot Strait onto the Scotian Shelf. The circulation model solution consists of density-, wind-, and boundary-driven flows. Major tidal constituents are also specified as elevation boundary conditions to better represent turbulent mixing, bottom friction, and to account for contribution of tidal rectification to the mean flow. The model solutions indicate prominent seasonal and longshore changes of the shelf-scale currents and persistent topographic-scale circulation over banks and basins and along cross-shelf trenches. The computed currents compare favorably with observations. Lagrangian particle-tracking experiments are carried out to model nutrient pathways over the eastern Scotian Shelf.

2. Current and nutrient pathway simulations for the western continental margin of Vancouver Island

Michael Foreman and Peter Chandler
Institute of Ocean Sciences

As part of the Global Ocean Ecosystem Dynamics research programme (GLOBEC), a three-dimensional finite element model has been used to simulate summer currents and nutrient pathways off the west coast of Vancouver Island, Canada. The current calculations were forced with seasonal winds, climatological ocean density fields, and elevation-specified boundary conditions that were adjusted via inversion to more accurately represent the California Undercurrent and estuarine flow in Juan de Fuca Strait. Tides were included in the simulations in order to correctly represent turbulent mixing, bottom friction, and the contribution of tidal rectification. The model currents compared favourably with observations, capturing strong shears both vertically in Juan de Fuca Strait, and horizontally and vertically across the continental shelf and slope. Several Lagrangian particle-tracking experiments were conducted to simulate nutrient pathways and to explain biological productivity on the continental shelf.

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BIO-PHYSICAL INTERACTIONS

Chair: D. Mackas

3. Wind-driven circulation and lobster larvae dispersion around the Magdalen Islands, Gulf of St. Lawrence

Denis Lefaivre, Patrick Ouellet, and François J. Saucier
Institut Maurice-Lamontagne, Min. Pêches et Océans

The dispersion of the early life stages by currents is often though of as a key process for good year-class in marine populations. Depending on the circulation, the larvae may remain near the coast and settle in great numbers to favourable bottom habitats, or otherwise be transported away. This hypothesis is tested for lobster near the Magdelen Islands using field measurements and the results of a circulation model. The interannual variability of the wind-driven currents and Lagrangian trajectories of larvae in the coastal region were examined through numerical experiments.

A three-dimensional coastal ocean model is developed for the Magdalen Shallows. The model is driven by hourly wind observations. New measurements from near surface drifters, an on-board Doppler current meter, and near-bottom anchored current meters, were used to calibrate the model. Sensitivity analyses and the comparisons with the observations showed that four key parameters control the circulation patterns: 1) The time response of the ocean currents to the wind stress, 2) The wind stress threshold to generate the currents, 3) The contribution of the direct wind stress to the current in the top meter of the water column, and 4) The influence of the coastal topography on the wind stress direction and intensity. After calibration, Lagrangian experiments accounting for the vertical migration behaviour were carried out to reproduce the larvae's trajectories from their sites of emergence to settlement. The model results are compared with observations of larvae concentrations for the years 1996 and 1997, for which significant differences are found in post-larvae abundance.

4. The effect of diurnal zooplankton migration on acoustically-measured currents

Michael Ott
School of Earth and Ocean Sciences, University of Victoria

Acoustic Doppler Current Profilers (ADCPs) have been used for more than twenty years to measure three-dimensional velocities in a wide range of oceanic environments. Backscatter intensity data have also been used to measure not only the abundance and distribution of various species of zooplankton, but also to follow their vertical diurnal migration. With speeds of up to 0.05 m/s and depth excursions of up to 500 m, zooplankton can be actively swimming at speeds comparable to the vertical velocity over large depths and for significant proportions of the day. While there have been elaborate analyses of the errors and biases inherent within the ADCP technique itself, the effect of these migrating zooplankton on the measured velocities has not yet been entirely determined.

ADCP velocity and backscatter data from Juan de Fuca Strait are used to compare the accuracy of the measured vertical velocity during periods and over timescales at which zooplankton are believed to be passively advected with that during times of active migration. Integrations of the vertical velocity, measured during the passage of internal waves closely match the corresponding vertical oscillations in the backscatter record, indicating that biases inherent in the vertical velocity are better than 0.003 m/s when zooplankton are passively advected. This bias is compared to the effect that zooplankton have on the measured vertical velocity during their morning and evening migrations.

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Session AM2

LAND SURFACE AND HYDROLOGY

Chair: S. Hamilton

1. The evaluation of land surface moisture budget in the CCCma GCM3 AMIP2 simulation

Vivek Arora and George Boer
Canadian Centre for Climate Modelling and Analysis

Moisture budget at the land surface is analyzed in the Canadian Centre for Climate Modelling and Analysis (CCCma) third generation general circulation model's (GCM3) AMIP2 simulation using monthly data. GCM3 is similar to GCM2 in many respects, however, also includes several new key features. A new module for treatment of land surface processes, CLASS, is also introduced in GCM3. CLASS includes 3 soil layers, a snow layer where applicable, and a vegetative canopy treatment. In the AMIP2 simulation, GCM3 is integrated for a 17 year period (1979–1995) with specified observed monthly mean sea surface temperatures (SST) and sea-ice concentrations.

The analysis show that over the land surface globally averaged mean annual precipitation and runoff rates compare well with observations, although there are discrepancies in the simulation of regional precipitation, and consequently runoff, estimates. Moisture at the land surface, in CLASS, is processed via three moisture reservoirs – the canopy, the snow, and the ground. Moisture fluxes for these reservoirs are investigated and show that the canopy plays a major role in determining the partition of precipitation into evapotranspiration and runoff at the land surface. On a global average it contributes to 72% of the total evapotranspiration.

The analysis of moisture fluxes for the ground moisture reservoir show that the precipitation is the primary contributor to the variability of soil moisture. This variability is dissipated by runoff and evapotranspiration, however, runoff plays a much larger role here because evapotranspiration estimates show little variability. In regions where evapotranspiration is controlled by the atmospheric conditions (as opposed to soil moisture), it contributes to soil moisture variability rather than dissipating it. Overall the results suggest that evapotranspiration does not significantly contributes to soil moisture variability, and that most of the variability in soil moisture and runoff is contributed by variability in precipitation.

2. Enhancing soil moisture simulation in land surface models: Testing of WatCLASS with the BOREAS Data Archive

K. R. Snelgrove[1], E. A. Whidden[2], E. D. Soulis[1], and N. Kouwen[1]
[1]*Dept. of Civil Engineering, University of Waterloo*
[2]*Dept. of Geography, McGill University*

The BOREAS Project undertaken in Manitoba and Saskatchewan had as its major goal to improve our understanding of the interactions between the boreal forest biome and the atmosphere. Measurements taken during this field experiment provide a unique opportunity to validate theories developed for Canadian land surface models. One area under development within CLASS (Canadian Land Surface Scheme) has been the addition of a streamflow generation component by the completion of an interface with the WATFLOOD hydrologic model. Testing of this model, called WatCLASS, centers on the partitioning of precipitation into runoff, evaporation and moisture storage. While runoff data in the form of streamflow are widely measured, other quantities such as evaporation and storage are not. Of primary concern in the WatCLASS linkage is the ability to calibrate on streamflow data alone and provide improved representation of latent heat flux to atmospheric models. With both evaporation and runoff measured (and to a limited extent storage) during the BOREAS project, a program has been developed to determine whether evaporation simulations are enhanced as refinements in streamflow generation are made.

The test program involves the use of WatCLASS with data from three scales namely tower scale, study area scale and BOREAS transect scale. Meteorological forcing data sets for each of these scales have been developed as part of the BOREAS Follow-On Project and involves the interpolation of available point data to form a new spatial data set and the filling-in of missing point data in a consistent manner. This new data set provides 3 complete years of hourly data for 4 study area towers, for the North and South Study areas at a 2 kilometer resolution and for the BOREAS Hydromet Region at 50 kilometer resolution. Because a majority of the validation data are available at the point scale, streamflow generation theory and controlling parameters will be developed at this fine scale and used at progressively large scales. The goal of the study is to have parameters, developed at fine scales, transferable to the larger modelling area such that streamflow, the most widely available validation data set, is well represented.

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LAND SURFACE AND HYDROLOGY

Chair: S. Hamilton

3. Generation of streamflow with WatCLASS: Theories and impacts on the soil moisture budget

E.D. Soulis, **K.R. Snelgrove**, F.R. Seglenieks, and N. Kouwen
Dept. of Civil Engineering, University of Waterloo

Improved soil moisture simulation using modern land surface process models have provided atmospheric simulations with an enhanced lower boundary condition. Validation of soil moisture improvements within these models has proven to be problematic because of the spatial heterogeneity of soil water and the difficulty in its direct measurement over large areas. One approach toward soil moisture validation has been the incorporation of streamflow hydrology within land surface models and the exploitation of the connection between soil moisture storage and observed streamflow. While the ability to validate on streamflow provides important evidence related to soil moisture, it is not absolute since streamflow is an integration of the various upstream moisture stores. The distribution of soil moisture within the soil column must be considered since it is important for both atmospheric energy partitioning and streamflow generation. High moisture levels near to the surface are likely to produce both enhanced runoff and evaporation while, at depth, soil moisture becomes less available for evaporation and lower soil hydrologic conductivities restrict runoff generation.

Efforts at the University of Waterloo have been directed toward the improvement in the soil moisture simulations with CLASS (Canadian Land Surface Scheme) by providing a direct linkage with the hydrologic model WATFLOOD. This linkage is directed at the CLASS soil column and the removal of water from its topmost soil layer in a hydrologically sound manner. Providing this mechanism for runoff generation reduces near surface soil moisture during and immediately following rainfall events. Data from the BOREAS Northern Study Area Old Black Spruce Tower Site (NSA-OBS) will be used to demonstrate the benefits of the new runoff generation mechanisms for particular storm events. The goal of this poster is to present the revised runoff generation theories proposed for CLASS and assess their impact on the evaporation and runoff generation.

A new program, called WatCLASS, is being used to test the scheme. The code uses WATFLOOD streamflow routing and the modified version of CLASS for the vertical water budget calculations.

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4. The simulation of complex land cover in regional climate studies

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The land surface exhibits small-scale heterogeneities at scales far smaller than even regional climate models are generally run. The degree of scale mismatch can range from relatively slight, as in the case of the HAPEX-Mobilhy study area, to extreme, as in the case of the BOREAS region. In the HAPEX-Mobilhy study area, the two main land cover types were coniferous forest and agricultural areas, with relatively minor sub-grid scale heterogeneity. In the case of the BOREAS area, the land cover consisted of a highly complex mixture of coniferous forest, deciduous forest, wetlands, lakes and burned areas, at scales often considerably below that of regional modelling grids. Land surface models attempting to address such a modelling problem must adopt some form of a mosaic approach to characterize the different land cover types present however, the model physics must also be capable of handling the highly distinctive energy and moisture transfer processes within such sub-grid elements. Satellite data must be relied upon to provide key input variables, and the limitations of such data must be recognized. This presentation will describe improvements that have been made to CLASS, the Canadian Land Surface Scheme, to handle such modelling challenges, and work that is underway to begin modelling studies over the BOREAS area using CLASS coupled with the Canadian Regional Climate Model.

5. A modeling study of soil damping effects on runoff generation during a flash flood event

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A common theory in runoff generating processes in humid and semi-humid regions is that runoff may not be produced until the soil moisture content of the aeration zone reaches field capacity, and thereafter runoff equals the excess almost without further loss for clay-type soils. For sandy-type soils, further loss would occur with a steady infiltration rate. Using Horton's runoff generation and Kirkby interflow theory, a hydrograph at the watershed outlet can be separated into three components, overland flow, interflow, and ground flow. These hypotheses have been validated and supported by many field observations.

In this study, we examine results from a regional atmospheric model (MC2, Mesoscale Compressible Community Model) coupled to a land surface model (CLASS, Canadian Land Surface Scheme) for the 1996 Saguenay severe precipitation event. The three flow components are simulated for this event. Runoff generated for the Ha Ha River basin, a Saguenay sub-basin, is compared with a reconstructed hydrograph. The results show some damping effects on runoff generation for clay-type soils, consistent with the theory. Further modification of CLASS is needed for sandy-type soil for runoff generation.

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6. The Bear Creek Hydrometeorological Project

Robert Nissen, Laurie Neil, David Hutchinson, and Stuart Hamilton
Applications and Services, Environment Canada

One of the main objectives of the Bear Creek Hydrometeorological Project is to improve stream runoff predictions in the Greater Vancouver Regional District. A major problem has been to accurately quantify the precipitation input to these watersheds in a timely fashion. The existing network of rain gauges does not accurately reflect the spatial and temporal distribution of precipitation inputs. A Doppler weather radar located in Aldergrove can provide more detailed estimates of the precipitation inputs. However, the success of radar in accurately estimating precipitation depends on choosing an appropriate radar reflectivity-rainfall rate (Z-R) relation to fit local meteorological conditions. Since the conversion of radar reflectivities to rainfall rates is dependent on the raindrop size distribution, a Joss-Waldvogel disdrometer has been installed in the Bear Creek watershed to assist in choosing suitable Z-R relations. Stream hydrographs and rain gauge network data are used to estimate precipitation event volumes for the basin, and these event volumes are compared to derived values from the radar data. In this presentation, preliminary results obtained during the winter and spring of 2000 will be shown.

7. Georgia Basin climate and hydrology – From time to space and the future

Paul Whitfield, Norm Wade, and Jillian Martin
Environment Canada

Water plays a primary role in the determining of the nature of ecosystems. This study considers the nature of inputs and outputs of water within the Georgia Basin. This is accomplished through the analysis of climate and hydrologic records. These records are time series of observations at specific locations within the basin. Climate data from stations in the Georgia Basin were assessed to determine summer and winter temperature ranges, rainfall and snowfall amounts. Stream discharge and watershed runoff from a selection of hydrologic stations throughout the Georgia Basin were assessed to determine the dominant form or forms of runoff that contributed to the stream discharge of a given drainage area. Hydrological and meteorological stations have a tendency to be located where it is convenient to maintain them, near settlements and in valley bottoms. Therefore, away from cities and at higher elevation there are no data and thus estimates need to be made based upon spatial interpretation. Derived climate and hydrologic information has been extrapolated or interpolated to the spatial extent of the study area using knowledge of the geography of the basin and the physiography of the particular stations and their drainage areas. This resulted in delineated regions in the Georgia Basin. From a climate perspective, a particular form of precipitation dominates in the winter either snow or rain. The complexity of the landscape results in a broad transition zone where either snow or rain can be expected during winter. From a hydrologic perspective, the relative roles of rainfall and the melting of the snowpack in the generation of the hydrograph at a particular point are assessed. Streamflow has spatial memory, the point where streamflow is measured is at the boundary of an area which generates the observed signal. Strong snowmelt signal frequently persists downstream into regions where rainfall dominates the climate. Extrapolation of these results into the future based upon future climate scenarios is discussed.

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SURFACE ENERGY BALANCE AND MICROCLIMATE

Chair: T. Oke

1. Net radiation at the BERMS sites

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Environment Canada - Climate Research Branch

The Boreal Ecosystems Monitoring Sites (BERMS) are an opportunity to study the functioning of Boreal ecosystems as a whole and net radiation is most of the system energy input. Net radiation is measured at each of the three ecosystem representative sites with simple net radiometers and with a suite of short-wave and long-wave radiometers. This provided both good system back-up and an opportunity to study the performance of both measurement systems. In addition, an intercomparison of five types of net radiometer instrument was undertaken over 10-month period in the field.

The characteristics of the five net radiometer instruments were determined. The implications of these characteristics are discussed with respect to the precise measurement of system net radiation. Some suggested routes to more accurate estimates are made, using all or most of the components of the system available.

2. Needle shading and bark reflectivity to solar radiation at the surface of spruce leaders for leader temperature modelling

Brian G. Sieben
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Knowledge of spruce leader temperatures is required to predict the temperature dependent development potential of the spruce weevil, *Pissodes strobi*, which develops inside young leaders. The temperature dependent development potential of the spruce weevil as measured in accumulated degree-days can be utilised for hazard rating purposes. The solution of an energy balance equation to predict leader temperatures required the determination of the bark albedo and the evaluation of the role of needles in reducing the amount of available solar radiation at the surface of the bark.

The leader bark albedo of interior spruce, *Picea glauca x engelmannii*, was determined by measuring bark reflectivity every 10 nm over a 250 to 2500 nm range in an integrating sphere and by weighting the reflectivity values by the modelled solar spectrum at ground level. The solar spectrum was found to change throughout the day as the solar path length changed with solar elevation, thus, the relative weighting of the individual measured bark reflectivity values changed throughout the day. The albedo or average weighted reflectivity of the leader bark to global solar radiation was approximately 43% at noon during summer in Vancouver, BC. The albedo of the leader bark was approximately 54% in the morning and afternoon during summer in Vancouver, BC.

The amount of needle shading on the spruce leader bark surface was determined using a ray tracing computer simulation. The amount of needle shade was found to vary by needle angle, needle length, needle density and by solar elevation. Minimum needle shading occurred when the solar elevation was equal to the needle angle. Maximum needle shading occurred when the solar elevation was greater than the needle angle where multiple needle shading resulted in near total shading. Multiple needle shading may partly explain the observed decrease in leader temperatures near noon. At solar elevations below the needle angle, shading was typically 40 to 60% depending on needle angle, needle density and needle length.

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3. Observation and modelling of heat storage fluxes in roofs

Stephanie Meyn and Tim Oke
University of British Columbia

Heat storage uptake and release constitutes a large term in the heat balance of cities. This flux is difficult to measure but can be parameterized using relations between the net radiation and the heat flux conducted into and out of the typical materials that form the surface of cities. When weighted by the abundance of such surfaces in a given urban area, these relations have been found to give storage values in broad agreement with those found as a residual in the heat balance, if all other terms are measured directly (Grimmond and Oke, 1999, *JAM*; *38*, 922–940). The urban heat storage parameterization could be improved if there were more and better estimates of the net radiation vs storage relation for typical roofs. In order to accomplish this the heat storage characteristics of 6 different roof assemblies (typical of many North American residential and industrial/commercial buildings) in Vancouver, B.C. were studied. Field observations of the radiative and conductive fluxes and the concurrent thermal and wind conditions were gathered and analyzed. The daily net radiation vs heat conduction relations showed hysteresis loop behaviour similar to that shown and statistically-described by Camuffo and Bernardi (1982). The statistical coefficients necessary to the parameterization scheme were extracted. The observations were also used to verify the Simple Transient Analysis of Roofs (STAR) model developed at the Oak Ridge National Laboratory (ORNL). The ORNL model was then used to estimate Camuffo and Bernardi-type coefficients for other roof types, thereby potentially extending the usefulness of the scheme to a wider range of cities.

4. An algorithmic scheme to predict hourly urban heat island magnitude

Tim Oke
University of British Columbia

The ability to predict and retrodict the magnitude of urban heat islands (UHI) in the urban canopy layer (UCL) is of utility to those involved in correcting long-term temperature records, heating and air-conditioning, air pollution photochemistry, assessing urban mixing depths, etc. At present there is no operational scheme for the UHI which has the merits of simplicity and universality. One approach is to construct a purely statistical formula similar to that pioneered by Sundborg, but the coefficients must be derived from pre-existing observations and are geographically specific to the city, and there is no temporal component. Another approach is to run a full numerical model but the input data requirements and expertise to run it are often too large for operational purposes and the output may not be applicable to the UCL.

A method to estimate the magnitude of the hourly urban heat island (UHI). It derives from empirical evidence regarding the maximum magnitude of UHIs from many cities, their typical diurnal variation, and their modulation by weather controls. The maximum UHI for a given city on extensive flat terrain is known to occur at night in ideal (calm, cloudless) weather, and its magnitude is primarily related to urban-rural differences of horizon screening (sky view factor) and thermal properties (thermal admittance) of the substrate. Increasing wind speed (a surrogate for turbulent mixing and advection), and increasing cloud amount / decreasing cloud height (surrogates for radiative exchange), diminish the magnitude of the maximum UHI according to known empirical relations. The temporal variation of the UHI through a day is shown to follow a broadly generalizable pattern that is also incorporated. Universality is introduced by normalizing both the UHI magnitude (to that of the maximum for the city), and the temporal pattern (to the times of sunset and sunrise). The aim is to retrodict UHI magnitude in the UCL for any city, in all weather conditions, and at any time of day within about one Celsius degree in the mean, or up to about two degrees on an hourly basis. The predictive capability will degrade depending on the forecast accuracy. The present scheme is thought to be relevant to the case of a compact city in extensive flat terrain. The algorithms are not yet capable of handling cases where thermal advection (synoptic or mesoscale fronts, cold air drainage, leading edge effects) or anthropogenic heating play a large role in thermal fields.

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5. Tests of the performance of an algorithmic scheme of the hourly urban heat island.

Mark Barton and Tim Oke
University of British Columbia

The central areas of cities are on average warmer than their surrounding rural areas - this is the so-called Urban Heat Island (UHI) effect. The genesis of this thermal phenomenon is attributable to the modification of the surface heat balance, which in turn is due to changes in surface and atmospheric properties, accompanying urban development. Current approaches to predicting the magnitude of the UHI at screen-level (within the urban canopy layer) are either complex energy balance models or simple multiple linear regression relations. Here we present tests of the simple algorithmic scheme of Oke (1998) that takes an intermediate path. It uses empirical algorithms relating the UHI to measures of urban structure, weather, rural surroundings and time to estimate the magnitude of the hourly UHI in most weather conditions and all seasons for a city in the temperate latitudes. At this time it does not account for the influences of frontal passage, coasts, topographic form or large anthropogenic heat fluxes that also affect temperature differences across the landscape.

The performance of the scheme is tested using three data sets. The first consists of semi-continuous hourly UHI and standard weather station data from an observational programme in Uppsala, Sweden by Taesler in 1976–77. The second makes use of a classic set of vehicle traverse data, also from Uppsala. It was collected by Sundborg in 1948–49 on more than 200 occasions, at all times of day and night, and under a wide range of weather conditions. The third set consists of 3 years (1997–99) of continuous hourly data from Lodz, Poland gathered by Klysik and Fortuniak. Preliminary results of the performance of the scheme are presented.

6. Modelling the 3-D surface temperature of urban areas viewed by remote sensors.

Andres Soux[1], Tim Oke[1], and James Voogt[2]
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The nature of the surface controls many of the climatic features of the urban environment. There is much interest in using remotely-sensed data to interpret and analyze urban surface characteristics. Uncritical acceptance of such data can lead to erroneous conclusions regarding surface characteristics. For example, in areas of well-defined three-dimensional surface structure, such as cities, remote sensors viewing at nadir tend to oversample horizontal surfaces at the expense of vertical ones. Conversely, off-nadir sensors disproportionately view vertical surfaces. These biases induce a directional dependence on the measured surface emittance which in turn can lead to imprecise parameterizations of climatically important variables such as surface temperature (and the associated turbulent fluxes) if these effects are not taken into account.

The unique nature of the urban surface and its impact on the interpretation of remotely-sensed data are discussed. A numerical model that attempts to portray the three-dimensional structure of the urban surface is presented, and its role in influencing sensor view factors is demonstrated. In conjunction with an urban canopy layer energy balance model, remotely-sensed surface temperatures are predicted. Output from the scheme is tested using observations obtained in a light industrial area of Vancouver, B.C. Results show very good agreement between measured and modelled temperatures over a range of sensor orientations and times.

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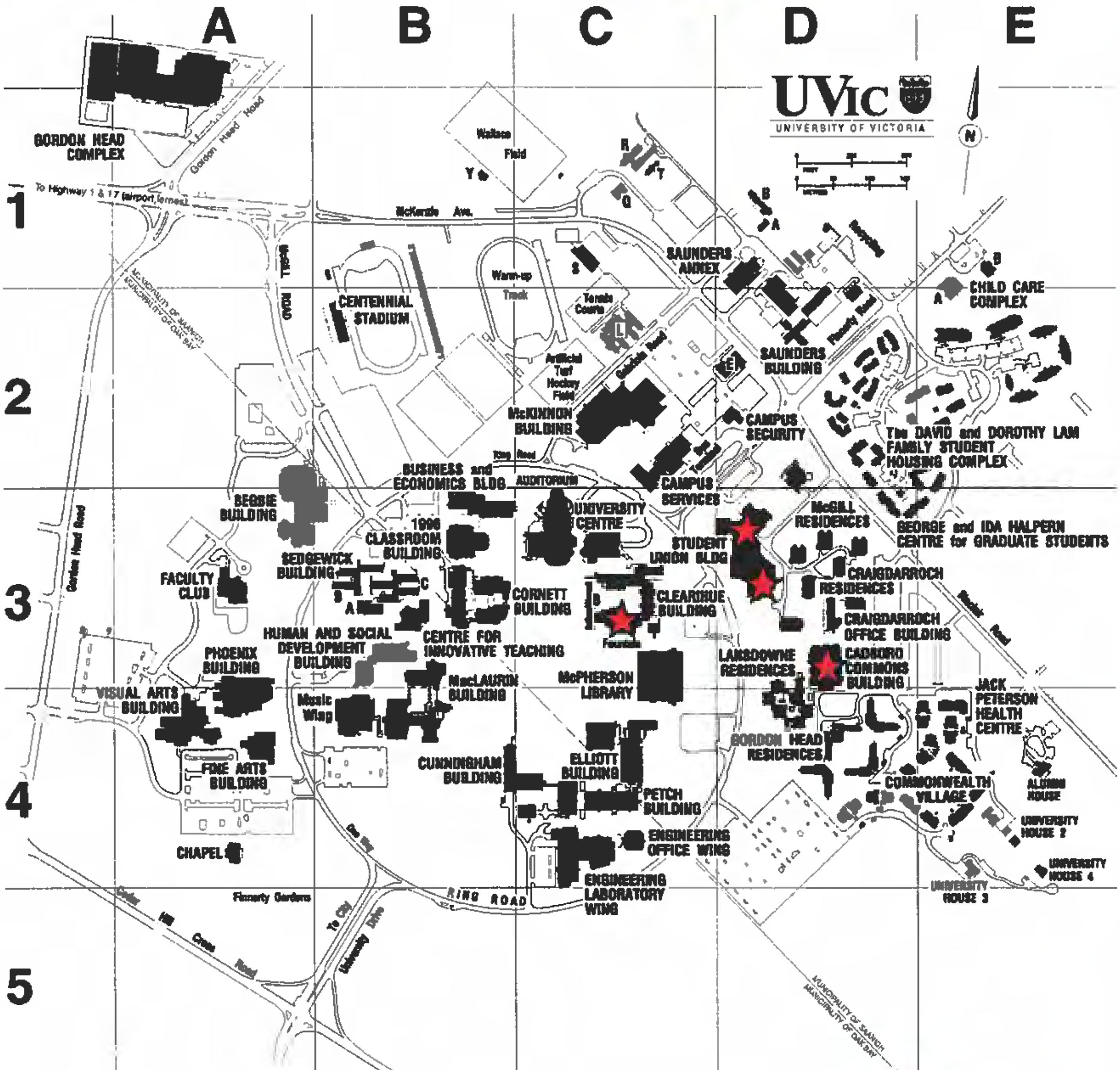

LOCATION OF VICTORIA 2000 VENUES – shown with a ★

Plenary Sessions	Monday, May 29 – Thursday, June 1	Cinecenta, Student Union Bldg.
Scientific Sessions	Monday, May 29 – Thursday, June 1	Clearihue Bldg., Wing A, 3rd floor
Health Breaks	Monday, May 29 – Thursday, June 1	Michele Pujol Room, Student Union Bldg.
Ice Breaker	Sunday, May 28, 1800-2000 hrs	Michele Pujol Room, Student Union Bldg.
Awards Luncheon	Tuesday, May 30, 1220-1340 hrs	Cadboro Dining Room, 2nd floor, Cadboro Commons Bldg.
Cocktails	Wednesday, May 31, 1830-1930 hrs	Caddy's Lounge, 1st floor , Cadboro Commons Bldg.
Banquet	Wednesday, May 31, 1930-2130 hrs	Cadboro Dining Room, 2nd floor, Cadboro Commons Bldg.

Note: Michele Pujol Room and Cinecenta are located towards the south and north end of the Student Union Bldg. respectively.