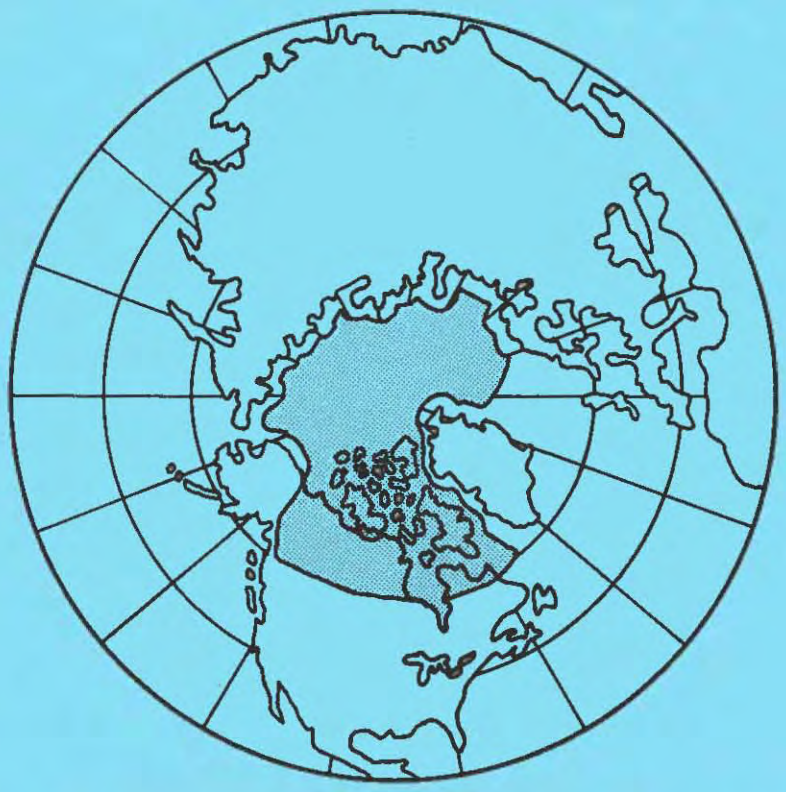
Program and Abstracts/Programme et Résumés
25th Annual Congress / 25e Congrès Annuel

Canadian Meteorological and Oceanographic Society/
la Société canadienne de météorologie et
d'océanographie

Theme: Northern Meteorology and Oceanography



Thème: Météorologie et océanographie nordiques

Delta Hotel
Winnipeg, Manitoba
3-7 June 1991
3-7 juin 1991

25th Annual Congress of The Canadian Meteorological and Oceanographic Society

25e Congres Annuel de La Societe Canadienne De Meteorologie et Ocean

Northern Meteorology and Oceanography
Meteorologie et Oceanographie Nordiques

3 June/Juin - 7 June/Juin 1991

Editor
R.G. Lawford

Technical Editors
E. Truhlar G. Schaefer

Program and Abstracts/Programme et Résumés

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Archivist's note:

Pages 1, 118 and 119 were missing from all copies of this 1991 Program & Abstracts Book

This page contains some of the missing information mentioned in the Table of Contents.

Bob Jones
August 2018

LAC EXECUTIVE

Chairperson
Bevan Lawson
62 Glenbrook Crescent
Winnipeg, Manitoba
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18 Alburg Drive
Winnipeg, Manitoba
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Facilities/Facilités:
B. Atkinson, Atmospheric Environment Service, Central Region, Winnipeg, Manitoba
H. Fraser, Consulting Meteorologist, Winnipeg, Manitoba

Publicity & Grants/Publicité et subventions:
J. Anderson, Atmospheric Environment Service, Central Region, Winnipeg, Manitoba

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SCIENTIFIC PROGRAM COMMITTEE/COMITE DU PROGRAMME SCIENTIFIQUE

Chairman/Président:
R.G. Lawford, Canadian Climate Centre, Saskatoon, Saskatchewan

Physical Oceanography/Océanographie physique:
H. Freeland, Institute of Ocean Sciences, Sidney, British Columbia

Climatology/Climatologie:
B. Maxwell, Canadian Climate Centre, Downsview, Ontario

Operational and Appplied Meteorology//Météorologie d'exploitation et d'appliqué:
G. Schaefer, Atmospheric Environment Service, Central Region, Winnipeg, Manitoba

Meso-Scale Meteorology/Méso-météorologie
R. Stewart, Research Directorate, Atmospheric Environment Service

Fisheries Oceanography/Océanographie des pêches:
K. Thompson, The University of British Columbia, Vancouver, British Columbia

Air Quality/Qualité de l'air:
Y. Zhuang, AECL Research, Pinawa, Manitoba

PUBLIC, PLENARY AND INVITED SPEAKERS
CONFERENCIERS PUBLICS, PLENIERS ET INVITES

K. Aagaard, National Oceanic and Atmospheric Administration, Pacific Marine Environmental Laboratory, Seattle, Washington
L.A. Mysak, Centre for Climate and Global Change Research, Department of Meteorology, McGill University, Montréal, Quebec
V. Alexander, University of Alaska-Fairbanks, Fairbanks, Alaska
T. Prowse, National Hydrology Research Institute, Saskatoon, Saskatchewan

M. Balshaw, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba
D. Stossel, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba
J.E. Walsh, University of Illinois, Urbana, Illinois
M.K. Thomas, Climatologist Emeritus, Downsview, Ontario
D. Phillips, Senior Climatologist, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario
E. Rasmussen, University of Copenhagen, Copehnagen, Denmark; Colorado State University, Fort Collins, Colorado
J.-P. Blanchet, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

COMMERCIAL EXHIBITORS/EXPOSANTS COMMERCIAUX

Vaisala Inc., Woburn, Massachusetts, U.S.A.
Ocean Routes, Dartmouth, Nova Scotia
Campbell Scientific Canada Corp., Edmonton, Alberta
Wx Research House Inc., Downsview, Ontario
Canadian Environmental Monitoring Inc., Calgary, Alberta
Guildline Instruments, Smith Falls, Ontario
Aanderaa Instruments Ltd. and Intermarine, Victoria, British Columbia
World Weather Watch, Markham, Ontario

SPONSORS/PARRAINS

City Of Winnipeg
Province of Manitoba
Campbell Scientific Canada Corp., Edmonton, Alberta
MacDonald-Dettwiler and Associates, Richmond, British Columbia

CMOS '91 CONGRESS SCHEDULE

(Version francaise à la page 8)

Time	Activity/ Committee	Location in the Delta Hotel
Sunday, June 2		
1800-2100	Registration	12th Floor
Monday, June 3		
0800-2100	Registration	12th floor
0800-1300	OPEN Scientific Management Committee	Winnipeg Board Room
0900-1200	Scientific Committee on Ocean Research I	Prairie North
0900-1200	Climatological Bulletin Editorial Board	Prairie South
0900-1200	Scientific Committee	Manitoba West
0900-1200	Membership Committee	Delta B (1)
0900-1200	Operational Meteorology SIG	Manitoba East
0900-1200	Agriculture and Forestry SIG	Delta B (1)
0900-1200	Education in Meteorology	Crocus
(1) Several Committees will share this room.		
1200-1300	Lunch (Up to Participants)	
1300-1800	Setup time for Exhibitors	Kennedy's
1300-1600	Professionalism Committee	Crocus
1300-1600	Publications Management Board	Prairie South
1300-1600	Mesoscale SIG	Manitoba West
1300-1600	Air Pollution SIG	Delta B (1)
1300-1600	Fisheries Oceanography SIG	Manitoba East

1300-1600	Centre Chairs and Chapter Executive Committee	Assiniboine
1300-1600	Scientific Committee on Ocean Research II	Prairie North
1300-1600	Broadcast Endorsement	Delta B (1)
1300-1600	World Ocean Circulation Experiment	Winnipeg Board Room
1500-1600	Atmosphere-Ocean Editorial Board	Delta B (1)

(1) Several Committees will share this room.

1600-1800	Setup time for posters	Kennedy's
1800-2000	Ice Breaker	Delta A
2000-2300	Council Meeting	Portage

<u>Tuesday, June 4</u>

0700-1700	Registration	12th floor
0830-1700	Exhibits Open	Kennedy's
0830-0930	Opening Ceremonies	Delta Ballroom
0930-1000	Session 1A: Plenary I	Delta Ballroom
1000-1030	Coffee Break	
1030-1200	Session 1B: Plenary I (contd.)	Delta Ballroom
1200-1300	Lunch (up to participants)	
1300-1500	Session 2A: Ocean Production Enhancement Network (OPEN)	Manitoba East
	Session 2B: Operational Meteorology	Manitoba West
	Session 2C: Sea Ice	Portage
1500-1530	Floating Ice SIG	Portage
1500-1530	Coffee Break	

1500-1630	Session 3A: Poster Session	Kennedy's
1530-1710	Session 3B: Radiation and Cloud Physics (Ends 1650)	Portage
	Session 3C: Fisheries Oceanography I	Manitoba
1900-2000	Wine and Cheese	Delta A
2000-2230	CMOS Annual General Meeting	Delta B

Wednesday, June 5

0700-1700	Registration	12th Floor
0830-1700	Exhibits Open	Kennedy's
0830-0950	Session 4: Plenary II	Delta Ballroom
0950-1020	Coffee Break	
1020-1200	Session 5A: Numerical Weather Prediction I	Manitoba West
	Session 5B: Fisheries Oceanography II	Manitoba East
	Session 5C: Storms and Associated Features I	Portage
1200-1400	CMOS 25th Congress Luncheon Speaker: M.K. Thomas (AES Patterson medal, the Tully medal and B. Lowe memorial award will also be presented)	Delta Ballroom
1400-1500	Session 6A: Oceanography of the North I	Manitoba East
	Session 6B: Storms and Associated Features II	Portage
	Session 6C: Remote Sensing and Applications	Manitoba West
1500-1530	Coffee Break	
1530-1730	Session 7A: Oceanography of the North II	Manitoba East
	Session 7B: Northern Climate	Portage
	Session 7C: Numerical Weather Prediction II(Ends 1630)	Manitoba West
1640-1740	Session 7D: Oceanic Processes in the North Atlantic Basin	Manitoba West
1915-2100	Public Lecture (Lecturer: D. Phillips)	Winnipeg Public Library
1930-2200	Planning meeting for CASP II	Crocus

Thursday, June 6

0700-1700	Registration	12th Floor
0830-1530	Exhibits Open	Kennedy's
0830-0930	Session 8: Plenary III	Delta Ballroom
0930-1000	Coffee Break	
1000-1200	Session 9A: Oceanography of the North Pacific	Portage
	Session 9B: Climatology/ Hydroclimatology I	Manitoba East
	Session 9C: Dynamic Meteorology and Numerical Models (Ends 1100)	Manitoba West
1200-1300	Lunch (up to participants)	
1300-1420	Session 10A: Ocean Dynamics and Models I	Delta B
	Session 10B: Climate Models	Manitoba
1420-1445	Coffee Break	
1445-1645	Session 11A: Ocean Dynamics and Models II	Delta B
	Session 11B: GEWEX Programme Discussion	Manitoba
1530-1800	Exhibit and poster takedown	Kennedy's
1700-1800	Hydrology SIG	Manitoba
1800-1900	Reception	Portage/ Manitoba Ballroom
1900-2300	CMOS Annual Banquet and Awards	Delta Ballroom

Friday, June 7

0830-1010	Session 12A: Climatology/ Hydroclimatology II	Delta A
	Session 12B: Air Quality and Boundary Layer Meteorology I	Delta B
	Session 12C: Ocean Dynamics and Models III	Manitoba
1010-1040	Coffee Break	

1040-1200	Session 13A: Human Impacts on Climate	Delta A
	Session 13B: Air Quality and Boundary Layer Meteorology II	Delta B

SCHEDULE DU CONGRES '91 DE LA SCMO

Heure	**Activité/Comité**	**Endroit**
<u>Dimanche, 2 juin</u>		
18h00-21h00	Enregistrement	12^{e} étage
<u>Lundi, 3 juin</u>		
08h00-21h00	Enregistrement	12^{e} étage
08h00-13h00	Comité de gestion scientifique de l'OPEN - (Ocean Production Enhancement Network)	Winnipeg Board Room
09h00-12h00	Comité de rédaction de la recherche océanique I	Prairie North
09h00-12h00	Comité de rédaction du Bulletin climatologique	Prairie South
09h00-12h00	Comité Scientifique	Manitoba
09h00-12h00	Comité de situation des membres	Delta B (1)
09h00-12h00	GIS: Météorologie d'exploitation	
09h00-12h00	GIS: Météorologie Agricole et Forestière	Delta B (1)
09h00-12h00	Comité d'education en Météorologie	Crocus
	(1) Plusieurs comités partageant cette salle	
12h00-13h00	Déjeuner (à votre choix)	
13h00-18h00	Organisation des exhibitions	Kennedy's
13h00-16h00	Professionnalisme	Crocus

13h00-16h00	Comité de gestion des publications de la SCMO	Prairie South
13h00-16h00	GIS: Météorologie de la Pollution l'Air	Delta B (1)
13h00-16h00	GIS: l'Echelle moyenne	Manitoba West
13h00-16h00	GIS: Océanographie des pêches	Manitoba East
13h00-16h00	Comité des présidents des centres et des correspondants des sections de la SCMO	Assiniboine
13h00-16h00	Comité scientifique de la recherche océanique II	Prairie North
13h00-16h00	Comité d'approbation des présentateurs météo	Delta B (1)
14h00-22h00	Expérience mondiale concernant la circulation océanique (WOCE)	Winnipeg Board Room
15h00-16h00	Comité de rédaction d'Atmosphère-océan	Delta B (1)
16h00-18h00	Organisation de l'affichage	Kennedy's
18h00-20h00	Faisons connaissance	Delta A
20h00-23h00	Réunion du Conseil	Portage

(1) Plusieurs comités partageant cette salle.

<u>Mardi, 4 juin</u>

07h00-17h00	Enregistrement	12^{e} étage
0830h-17h00	Exhibition	Kennedy's
0830h-09h30	Cérémonies d'overture	Delta Ballroom
0930h-10h00	Session 1A: Plénière I	Delta Ballroom
10h00-10h30	Pause-café	
10h30-12h00	Session 1B: Plénière I	Delta Ballroom
12h00-13h00	Déjeuner (à votre choix)	

13h00-15h00	Session 2A: OPEN - (Réseau de mise en valeur des ressources maritimes)	Manitoba East
	Session 2B: Météorologie d'exploitation	Manitoba West
	Session 2C: Glace de mer	Portage
15h00-15h30	GIS: Glaces Flottantes	Portage
15h00-15h30	Pause-café	
15h00-16h30	Session 3A: Affichages	Kennedy's
15h30-17h10	Session 3B: Rayonnement et physique des nuages (Fin 16h50)	Portage
	Session 3C: Océanographie des pêches I	Manitoba
19h00-20h00	Vins et fromages	Delta A
20h00-22h30	Assemblée générale annuelle	Delta B

Mercredi, le 5 juin

07h00-17h00	Enregistrement	12^{e} étage
08h30-17h00	Exhibition	Kennedy's
08h30-09h50	Session 4: Plénière II	Delta Ballroom
09h50-10h20	Pause-café	
10h20-12h00	Session 5A: Modèles numérique de prévision I	Manitoba West
	Session 5B: Océanographie des pêches II	Manitoba East
	Session 5C: Tempêtes et éléments associés I	Portage
12h00-14h00	Déjeuner du 25^{e} Congrés de la SCMO - Conférencier: M.K. Thomas (Les médailles Patterson et Tully et le prix commaémoratif de B. Lowe seront aussi présentées)	Delta Ballroom
14h00-15h00	Session 6A: Océanographie du Nord I	Manitoba East
	Session 6B: Tempêtes et éléments associés II	Portage
	Session 6C: Télédétection et ses applications	Manitoba West
15h00-15h30	Pause-café	

15h30-17h30	Session 7A: Océanographie du Nord II (Fin: 1710)	Manitoba East
	Session 7B: Climat nordique	Portage
	Session 7C: Modèles numériques de prévision II (Fin: 1630)	Manitoba West
16h40-17h40	Session 7D: Processus océaniques dans le basin de l'Atlantic Nord	Manitoba West
19h15-21h00	Conférence publique par D. Phillips à la Bibliothèque de Winnipeg	
19h30-22h00	Réunion de plannification pour PCETA II	Crocus

Jeudi, le 6 juin

07h00-17h00	Enregistrement	12^{e} étage
08h30-15h30	Exhibition	Kennedy's
08h30-09h30	Session 8: Plénière III	Delta Ballroom
09h30-10h00	Pause-café	
10h00-12h00	Session 9A: Océanographie du Pacifique Nord	Portage
	Session 9B: Climatologie/ Hydroclimatologie I	Manitoba East
	Session 9C: Météo dynamique et Modèles numériques (Fin 1100)	Manitoba West
12h00-13h00	Déjeuner (à votre choix)	
13h00-14h20	Session 10A: Dynamique océanique et modèles I	Delta B
	Session 10B: Modèles climatiques	Manitoba
14h20-14h45	Pause-café	
14h45-16h45	Session 11A: Dynamique océanique et modèles II	Delta B
	Session 11B: Discussion du GEWEX	Manitoba
15h30-18h00	Fin de l'exhibit et de l'affichage	Kennedy's
17h00-18h00	GIS: Hydrologie	Manitoba
18h00-19h00	Réception	Portage/ Manitoba Ballroom

19h00-23h00	Banquet annuel de la Société et présentation des prix	Delta Ballroom

Vendredi, le 7 juin

08h30-10h10	Session 12A: Climatologie/ Hydroclimatologie II	Delta A
	Session 12B: Qualité de l'air et météorologie de la couche limite I	Delta B
	Session 12C: Dynamique océanique et modèles III	Manitoba
10h10-10h40	Pause-café	
10h40-12h00	Session 13A: Impacts anthropogéniques sur la climat	Delta A
	Session 13B: Qualité de l'air et météorologie de la couche limite II	Delta B

CMOS '91 Congress Program
Programme pour la Congrès '91 de la SCMO

TUESDAY, JUNE 4/MARDI LE 4 JUIN

OPENING REMARKS AND CEREMONY/SEANCE D'OVERTURE
0830-0930 Delta Ballroom

Chair/Chef: B. Lawson, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba

Greetings from the City of Winnipeg (His Worship Bill Norrie)
Greetings from the CMOS President (N. Cutler)
Housekeeping announcements (B. Atkinson)
Introduction to the Congress theme (R.G. Lawford)

SCIENTIFIC PROGRAM/PROGRAMME SCIENTIFIQUE

SESSION 1: PLENARY I/SESSION PLENIERE I
0930-1200 Delta Ballroom

Chair/Chef: R.G. Lawford, Canadian Climate Centre, National Hydrology Research Centre, Saskatoon, Saskatchewan

0930 The Arctic Ocean and Climate Change
K. Aagaard, Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, Seattle, Washington

1000-1030
Coffee/Pause-café

1030 Interdecadal Variations in Climate and Ice Cover of the Arctic Ocean and Greenland Sea
L.A. Mysak, McGill University, Montréal, Québec

1100 The Biology of the Arctic Ocean
V. Alexander, University of Alaska-Fairbanks, Fairbanks, Alaska, U.S.A.

1130 Canadian Northern Hydrology: Present and Future Tasks
T. Prowse, National Hydrology Research Institute, Saskatoon, Saskatchewan

1200-1300
Lunch/Déjeuner
(Up to participants/A votre choix)

CONCURRENT SESSIONS/SEANCES SIMULTANEES

SESSION 2A: OCEAN PRODUCTION ENHANCEMENT NETWORK (OPEN)
RESEAU DE MISE EN VALEUR DES RESSOURCES MARITIMES (OPEN)

1300-1500 **Manitoba East**

Chair/Chef: A.M. Oake, Fisheries Resource Development Ltd., Halifax, Nova Scotia

1300 The Ocean Production Enhancement Network - OPEN
P.H. LeBlond, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia

1320 OPEN and Its Biological Oceanographic Focus on the Fisheries
C.T. Taggart, Dalhousie University, Halifax, Nova Scotia

1340 The Influence of Physical and Biological Conditions on Productivity in the Giant Scallop (Placopecten magellanicus)
B.A. MacDonald, Marine Sciences Research Laboratory, Memorial University of Newfoundland, St. John's, Newfoundland

1400 The Marine Gene Probe Laboratory (MGPL) Component of OPEN
R.W. Doyle, Dalhousie University, Halifax, Nova Scotia

1420 Physical Oceanography and OPEN
K.R. Thompson, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

1440 OPEN Physiology: Heritability of Bioenergetic Processes
R.G. Boutilier, Department of Biology, Dalhousie University, Halifax, Nova Scotia

SESSION 2B: **OPERATIONAL METEOROLOGY**
METEOROLOGIE D'EXPLOITATION
1300-1500 **Manitoba West**

Chair/Chef: K. Fluto, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba

1300 Wind Profiler Operation in Alaska and Status of Network in the United States
E.F. Hudson, Unisys Corp., Great Neck, New York, U.S.A.

1320 Updating Weather-Element Forecasts Through Post-Processing Techniques
R.Verret and N. Yacowar, Canadian Meteorological Centre, Atmospheric Environment Service, Dorval, Québec

1340 Using Statistical Weather-Element Forecast Verifications to Assess Model Systematic Errors and the Limit of Predictability
R. Verret, Canadian Meteorological Centre, Atmospheric Environment Service, Dorval, Québec

1400 The Blizzard of January '89 in Alberta - Another Perspective
R. Perron and G. Babin, Meteorological Training Centre, Atmospheric Environment Service, Cornwall, Ontario

1420 A National Summer Severe Weather Verification System
L. Legal and B. Lawson, Prairie Weather Centre, Atmospheric Environment Service, Winnipeg, Manitoba

1440 A Microcomputer-Based Climatological Information System for Terminal Forecast Production
R.A. Stuart, Weather Research House, Downsview, Ontario
W.L. Ranahan, Department of National Defence, Ottawa, Ontario

SESSION 2C: **SEA ICE**
GLACE DE MER
1300-1500 **Portage**

Chair/Chef: R.G. Ingram, McGill University, Montréal, Québec

1300 Snow Effects on Ice Growth Along the Canadian East and Arctic Coasts
S.J. Prinsenberg, Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Nova Scotia

1320 An Examination of Isentropic Potential Vorticity and the Surface Enthalpy Flux as Possible Mechanisms for the Annual Reversal of the Beaufort Sea Ice-Field
E.F. LeDrew and D. Johnson, University of Waterloo, Waterloo, Ontario
J.A. Maslanik, University of Colorado, Boulder, Colorado, U.S.A.

1340 Ice Drift off Southern Labrador during LIMEX '89
I.K. Peterson and S.J. Prinsenberg, Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Nova Scotia

1400 Interannual Variability of the Arctic Ice-Sheet Using a Coupled Ice-Ocean Numerical Model
D.M. Holland and L.A. Mysak, McGill University, Montréal, Québec

1420 Interannual Variability of Atmospheric Circulation and Sea-Ice Cover in Hudson Bay
J. Wang, L.A. Mysak and R.G. Ingram, McGill University, Montréal, Québec

1440 Simultaneous Winter Sea-Ice and Atmospheric Circulation Anomaly Patterns
T.A. Agnew, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

1500-1530
Coffee/Pause-café

1500-1530
The Floating Ice SIG Meeting/GIS: Glaces Flottantes
Portage Room

SESSION 3A: **POSTER SESSION**
SESSIONS DES AFFICHAGES
1500-1630 **Kennedy's**

PC-Based Radar Display and Encoding Program
S.R. Adams and F.G. Hunter, Central Region, Atmospheric Environment Service, Regina, Saskatchewan

An Attempt at Computerized Handling of Anomalous Propagation Returns in Weather RADAR Maps
F.J. Eley and D. Magosse, Hydrometeorological Processes Division, Canadian Climate Centre, National Hydrology Research Centre, Saskatoon, Saskatchewan

SAR Interpretation Techniques to Distinguish Between Multi-Year and First-Year Ice in the Eastern Arctic
M. Gauthier and D. Hagen, Ice Centre, Environment Canada, Ottawa, Ontario

On the Increase in Polar-Low Activity over the Beaufort Sea As a Result of Global Warming
N. Parker, Western Region, Atmospheric Environment Service, Edmonton, Alberta

Performance of an Acoustic Doppler Current Profiler in Knight Inlet, British Columbia
K. Greenwood, R. Marsden and J. Buckley, Royal Roads Military College, Victoria, British Columbia

Internal Hydraulics, Solitons and Associated Mixing in a Stratified Sound
J. Gan and R.G. Ingram, McGill University, Montréal, Québec

SESSION 3B: **RADIATION AND CLOUD PHYSICS**
RAYONNEMENT ET PHYSIQUE DES NUAGES
1530-1650 **Portage**

Chair/Chef: G.A. Isaac, Atmospheric Environment Service, Downsview, Ontario

1530 A Parameterized Model for the Estimation of Net Surface Solar Radiation at High Latitudes
Z. Li and H.G. Leighton, McGill University, Montréal, Québec

1550 Moisture and Heat Budget of a Cirrus Cloud From FIRE Field Experiment: Implications for Radiative Cooling and Advection
I. Gultepe, Istanbul Technical University, Maslak, Istanbul, Turkey

1610 Surface Temperature Measurements of Graupel During Growth
S. Cober and R. List, University of Toronto, Toronto, Ontario

1630 A Review of Hail Climatology on the Great Plains
A.C. Paul, University of Regina, Regina, Saskatchewan

SESSION 3C: **FISHERIES OCEANOGRAPHY I**
OCEANOGRAPHIE DES PECHES I

1530-1710 **Manitoba**

Chair/Chef: K.A. Thomson, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia

1530 Climate Change and Exceptional Fish Production off the West Coast of North America
R.J. Beamish, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia

1550 A Theory for the Production of Strong Year-Classes in a Long-lived Marine Fish and Relevance to Fisheries Management
G.A. McFarlane and R.J. Beamish, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia

1610 Species Succession Among Planktonic Diatoms in Turbulent and Stratified Temperate Marine Waters
L.A. Hobson, University of Victoria, Victoria, British Columbia
K. Denman, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

1630 Mercury in Fish in Canadian Shield Lakes: Implications of Climate Warming
R.A. Bodaly, J.W.M. Rudd and R.J.P. Fudge, Freshwater Institute, Department of Fisheries and Oceans, Winnipeg, Manitoba
C.A. Kelly, University of Manitoba, Winnipeg, Manitoba

1650 Ocean Climate and Northern Cod
A.M. Oake, Fisheries Resource Development Limited, Halifax, Nova Scotia

1900-2000
Wine and Cheese/Vins et Fromages
Delta A

2000-2230
CMOS Annual General Meeting/Assemblée générale annuelle de la SCMO
Delta B

WEDNESDAY JUNE 5/MERCREDI LE 5 JUIN
CONCURRENT SESSIONS/SESSIONS SIMULTANEES

SESSION 4: **PLENARY II/SESSION PLENIERE II**
0830-0950 **Delta Ballroom**

Chair/Chef: R. Daley, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontatio

0830 Research Activities and Meteorological Infrastructure in the Canadian Arctic
M. Balshaw and D. Stossel, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba

0910 Short-Term Climate Variability of the Arctic
J.E. Walsh, University of Illinois, Urbana, Illinois, U.S.A.

0950-1020
Coffee/Pause-café

SESSION 5A: **NUMERICAL WEATHER PREDICTION I**
MODELES NUMERIQUES DE PREVISION I
1020-1200 **Manitoba West**

Chair/Chef: J. Derome, Department of Meteorology, McGill University, Montréal, Québec

1020 Implementation of a Global Data Assimilation Procedure at the Canadian Meteorological Centre (CMC)
H. Mitchell and C. Charette, Recherche en prévision numérique (RPN), Service de l'environnement atmosphérique, Dorval, Québec
J. Hallé, Canadian Meteorological Centre, Service de l'environnement atmosphérique, Dorval, Québec

1040 Optimized Formulation of a Baroclinic Global Semi-Lagrangian Spectral Model
H. Ritchie and C. Beaudoin, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

1100 Physical Parameterization for the First Canadian Global Forecast Model
C. Girard, Y. Delage, J. Mailhot, L. Garand and B. Bilodeau, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec
N. Brunet and G. Pellerin, Centre Météorologique Canadien, Service de l'environnement atmosphérique, Dorval, Québec

1120 History and Present Status of the French Peridot NWP System
R. Juvanon du Vachat, Direction de la Météorologie, EERM/CRMD, Paris, France

1140 Variational Implicit Normal Mode Initialization for a Multilevel Model
L. Fillion, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

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SESSION 5B: **FISHERIES OCEANOGRAPHY II**
OCEANOGRAPHIE DES PECHES II
1020-1200 **Manitoba East**

Chair/Chef: R.J. Beamish, Pacific Biological Station, Nanaimo, British Columbia

1020 Variations in Wind-Induced Coastal Upwelling off the West Coast of North America From 1899 to 1982 and the Consequences to Fisheries
W.W. Hsieh, The University of British Columbia, Vancouver, British Columbia
D. Ware, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia
R.E. Thomson, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

1040 Investigating the Influence of the Barotropic Tidal Circulation on Herring Larvae Dispersal in the Southwest Nova Scotia Region Using a 3-D Lagrangian Particle-Tracking Model
F.H. Page, K.- T. Tee and P.C. Smith, Bedford Institute of Oceanography, Dartmouth, Nova Scotia
R.L. Stephenson, Biological Station, St. Andrews, New Brunswick

1100 The Fraser River Plume: Effects on the Distribution of Juvenile Salmonids, Herring, and their Prey
M.A. St. John and P.J. Harrison, The University of British Columbia, Vancouver, British Columbia
J.S. MacDonald and E. Choromanski, West Vancouver Laboratories, West Vancouver, British Columbia
R.J. Beamish, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia

1120 The Influence of Open-Ocean Currents on Sockeye Salmon Returning to the Fraser River
K.A. Thomson, P.H. LeBlond and M.C. Healey, The University of British Columbia, Vancouver, British Columbia
W.J. Ingraham, Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington
C. Groot, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia

1140 A Microcomputer System for Simulating Alternative Hypotheses About Effects of Advection on Larval Fish Distributions
C.J. Walters and C.G. Hannah, The University of British Columbia, Vancouver, British Columbia

Reserve Paper:
Tidal Model Studies of Particle Retention Around a Shallow Coastal Bank
M.G.G. Foreman, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia
A.M. Baptista, Oregon Graduate Institute of Science and Technology, Beaverton, Oregon
R.A. Walters, U.S. Geological Survey, Tacoma, Washington

SESSION 5C: STORMS AND ASSOCIATED FEATURES I
TEMPETES ET ELEMENTS ASSOCIES I
1020-1200 Portage

Chair/Chef: R.E. Stewart, Atmospheric Environment Service, Downsview, Ontario

1020 Temporal Variability of North Pacific Ocean Surface Cyclones
T. Li and J.R. Gyakum, Department of Meteorology, McGill University, Montréal, Québec

1040 The Role of the Vertical Distribution of Forcing and Static Stability on the Development Rate of Extratropical Cyclones
P. Zwack, J. St-James, F. Martini, and S. Wigniolle, Université du Québec à Montréal, Montréal, Québec

1100 Antecedent Surface Vorticity Development and Explosive Cyclone Intensification
J.R. Gyakum, Department of Meteorology, McGill University, Montréal, Québec

1120 Conditional Symmetric Instability in ERICA Cyclones
G.W. Reuter, Department of Geography, University of Alberta, Edmonton, Alberta

1140 Aspects of the Surface Structure of Canadian East Coast Winter Storms
P.A. Taylor, York University, North York, Ontario
J.R. Salmon, CMOS Accredited Consultant, Burlington, Ont.
R.E. Stewart, Atmospheric Environment Service, Downsview, Ontario

1200-1400
CMOS 25th Congress Luncheon/Diner du 25^{e} congrés de la SCMO
Delta Ballroom
(The Patterson and Tully medals and the B. Lowe memorial award will be presented at this luncheon)
(La médailles Patterson et Tully et le prix commaémoratif de B. Lowe seront aussi présentées à cet diner)

SESSION 6A: **OCEANOGRAPHY OF THE NORTH I**
OCEANOGRAPHIE DU NORD I
1400-1500 **Manitoba East**

Chair/Chef: D. R. Topham, Institute of Ocean Sciences, Sidney, British Columbia

1400 Currents, Variability and Transport Above the Baffin Island Slope
C.K. Ross, Bedford Institute of Oceanography, Dartmouth, Nova Scotia

1420 Winter Circulation Patterns in Southeastern Hudson Bay
S. Lepage, Fontenelle, Québec
P. Larouche, Institut Maurice-Lamontagne, Ministère des Pêches et des Océans, Mont-Joli, Québec

1440 Dynamics of Currents in the Labrador Sea: Preliminary Results
T. Reynaud and A. Weaver, McGill University, Montréal, Québec
R. Greatbatch, Memorial University of Newfoundland, St. John's, Newfoundland

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SESSION 6B: STORMS AND ASSOCIATED FEATURES II
TEMPETES ET ELEMENTS ASSOCIES II
1400-1500 Portage

Chair/Chef: R.L. Raddatz, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba

1400 Organization of Cloud and Precipitation in a Prairie Storm
C.D. Nguyen and G.W. Reuter, Department of Geography, University of Alberta, Edmonton, Alberta

1420 On the Organization of Winter Precipitation Types
R.E. Stewart, N.R. Donaldson and G.B. Raga, Atmospheric Environment Service, Downsview, Ontario

1440 A Study of Possible Microbursts in the Toronto Area
D. Yiu and P. Taylor, York University, North York, Ontario

SESSION 6C: REMOTE SENSING AND APPLICATIONS
TELEDETECTION ET SES APPLICATIONS
1400-1500 Manitoba West

Chair/Chef: D.G. Steyn, The University of British Columbia, Vancouver, British Columbia

1400 Use of SATEM Thicknesses in the Canadian Meteorological Centre (CMC) Global Objective Analysis
R. Lalbeharry, Atmospheric Environment Service, Downsview, Ontario
C. Chouinard, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

1420 Development of Three-Dimensional Synthetic CO-Data Sets
D.V. Michelangeli and J. Drummond, University of Toronto, Toronto, Ontario

1440 Sea-Surface Insolation Estimation Using NOAA Advanced Very High Resolution Radiometer Data
J. Gu and P. Austin, The University of British Columbia, Vancouver, British Columbia

1500-1530
Coffee/Pause-Café

SESSION 7A: **OCEANOGRAPHY OF THE NORTH II**
OCEANOGRAPHIE DU NORD II
1530-1710 **Manitoba East**

Chair/Chef: H.J. Freeland, Institute of Ocean Sciences, Sidney, British Columbia

1530 Observations of the Estuarine, Wind-Driven Circulation in the Coastal Beaufort Sea
R.K. Dewey, SAIC, Bellevue, Washington, U.S.A.

1550 The Upper-Ocean Temperature and Salinity Fields During Strong Cooling in the Central Greenland Sea in February, 1989
R.A. Clarke, Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Nova Scotia

1610 An Observational Study of Interdecadal Sea-Surface Temperature Anomalies in the Northern North Atlantic - Greenland Sea
S. Peng and L.A. Mysak, McGill University, Montréal, Québec

1630 Baroclinic Circulation under Ice
B.C. Kenney, National Hydrology Research Institute, Saskatoon, Saskatchewan

1650 A Numerical Study of Two-Layer Flow Under an Ice Keel
M.I. Jameel and R.D. Rowe, The University of Calgary, Calgary, Alberta

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SESSION 7B: **NORTHERN CLIMATE**
CLIMAT NORDIQUE
1530-1730 **Portage**

Chair/Chef: B. Maxwell, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

1530 Polar-Low Handbook for Canadian Waters
N. Parker, Scientific Services Division, Western Region, Atmospheric Environment Service, Edmonton, Alberta

1550 Mesoscale Studies of Climate Change in a Data-Sparse Arctic Region
J.D. Jacobs, Memorial University of Newfoundland, St John's, Newfoundland

1610 Three General Circulation Model Scenarios for the Mackenzie Valley Area of Northern Canada
R.A. Stuart, Weather Research House, Downsview, Ontario

1630 The MacKenzie Basin Impact Study: Development and Application of Global Warming Scenarios
S.J. Cohen, W.R. Skinner, and K.M. Holden, Canadian Climate Centre, Atmospheric Environment Centre, Downsview, Ontario

1650 Trends in Severity of Winter Weather and Population Dynamics of Caribou on Banks Island, Northwest Territories
A. Maarouf, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario
A. Gunn, Government of the Northwest Territories, Coppermine, Northwest Territories
B. McLean, Government of the Northwest Territories, Inuvik, Northwest Territories

1710 Impacts of Climatic Change on the Beaufort Sea-Ice Regime
D.G. McGillivray, The MEP Company, Markham, Ontario
T. Agnew, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario
M.C. Hill, CANATEC Consultants Ltd., Calgary, Alberta
G.A. McKay, Meteorological Consultant, Thornhill, Ontario
E.F. LeDrew, University of Waterloo, Waterloo, Ontario

SESSION 7C: NUMERICAL WEATHER PREDICTION II
MODELES NUMERIQUES DE PREVISION II
1530-1630 Manitoba West

Chair/Chef: Y. Delage, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

1530 Evaluation of Medium-Range Forecasts with the Canadian Global Forecasting System
H. Ritchie, H. Mitchell, C. Girard and M. Béland, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

1550 Time Integration Technique, Domain, and Resolution Sensitivity Experiments with a Finite-Element Spectral Model
H. Ritchie and C. Beaudoin, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

1610 Zonal and Global Mean Diagnostics of the Thermal and Hydrological Behaviour of the Canadian Global Forecast Model
C. Girard, R. Benoit and B. Bilodeau, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

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SESSION 7D: OCEANIC PROCESSES IN THE NORTH ATLANTIC BASIN
PROCESSUS OCEANIQUES DANS LE BASIN DE L'ATLANTIC NORD
1640-1740 Manitoba West

Chair/Chef: B. Ruddick, Dalhousie University, Halifax, Nova Scotia

1640 Laboratory Simulations of Deep Convection
D. Brickman, Dalhousie University, Halifax, Nova Scotia

1700 What Drove the Intrusions That Mixed Meddy "Sharon"?
B. Ruddick, Dalhousie University, Halifax, Nova Scotia

1720 Hydrography and Deep Convection in the Labrador Sea
D. Kelley, Dalhousie University, Halifax, Nova Scotia

1915-2100
Public Lecture/Discours publique
The Truth about Canadian Winter: "Canada's climate is nine months winter and three months late in the fall"

Auditorium, Main Library
Donald and Graham
D. Phillips, Senior Climatologist, Canadian Climate Centre, Atomspheric Environment Service, Downsview, Ontario

1930-2200
CASP II Planning Meeting/Réunion de la PCETA II
Crocus Room

THURSDAY JUNE 6/JEUDI LE 6 JUIN

SESSION 8: **PLENARY III/SESSION PLENIERE III**
0830-0930 **Delta Ballroom**

Chair/Chef: L.A. Hobson, University of Victoria, Victoria, British Columbia

0830 Polar Lows
E. Rasmussen, Permanent affiliation: University of Copenhagen, Copenhagen, Denmark; (Temporary affiliation: Colorado State University, Fort Collins, Colorado)

0900 The Influence of Arctic Haze and Radiatively Active Trace Gases on the Arctic Climate
J.-P. Blanchet, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

0930-1000
Coffee/Pause-café

CONCURRENT SESSIONS/SESSIONS SIMULTANEES

SESSION 9A: **OCEANOGRAPHY OF THE NORTH PACIFIC**
OCEANOGRAPHIE DE L'OCEAN PACIFIQUE NORD
1000-1200 **Portage**

Chair/Chef: R.K. Dewey, Science Applications International Corporation, Seattle, Washington

1000 WOCE Surface Drifters in the North Pacific
D. Krauel, Royal Roads Military College, Victoria, British Columbia
W. Large, National Center for Atmospheric Research, Boulder, Colorado
P.H. LeBlond, The University of British Columbia, Vancouver, British Columbia
G.E. Swaters, University of Alberta, Edmonton, Alberta
R. Thomson, Institute of Ocean Science, Department of Fisheries and Oceans, Sidney, British Columbia

1020 Residual Currents in a Depth-averaged Model of the Central Strait of Georgia, British Columbia
S.G. Marinone and J.C. Fyfe, The University of British Columbia, Vancouver, British Columbia

1040 A Finite-Element Tidal Model for Northern British Columbia Waters
M.G.G. Foreman and R.F. Henry, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

1100 The Internal Tide off the West Coast of Vancouver Island
P.G. Drakopoulos and R. Marsden, Royal Roads Military College, Victoria, British Columbia

1120 Low-Frequency Residual in Knight Inlet - A Fjord of Coastal British Columbia
P.D. Baker and G.S. Pond, The University of British Columbia, Vancouver, British Columbia

1140 A Topographically Trapped Eddy over Cobb Seamount
H.J. Freeland, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

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SESSION 9B: **CLIMATOLOGY/HYDROCLIMATOLOGY I**
CLIMATOLOGIE/HYDROCLIMATOLOGIE I

1000-1200 **Manitoba East**

Chair/Chef: G. Schaefer, Scientific Services Division, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba

1000 The Impacts of Climate Extremes on the Prairies
K. Jones and K. Hill, Scientific Services Division, Central Region, Atmospheric Environment Service, Regina, Saskatchewan

1020 The Impact of Large-scale Atmospheric Circulations and Anomalies on South Asian Monsoon Drought and Floods and on World Grain Yields
R. Garnett, Canadian Wheat Board, Winnipeg, Manitoba
M.L. Khandekar, Atmospheric Environment Service, Downsview, Ontario

1040 North Pacific SST Anomalies and Drought on the Canadian Prairies
B.R. Bonsal and A.K. Chakravarti, University of Saskatchewan, Saskatoon, Saskatchewan
R.G. Lawford, Canadian Climate Centre, National Hydrology Research Centre, Saskatoon, Saskatchewan

1100 The Dependence of Daily Precipitation Upon Temperature
G.A. Isaac, Atmospheric Envrironment Service, Downsview, Ontario
R.A. Stuart, Weather Research House, Downsview, Ontario

1120 The Regional Evaporation Study. Part I: Design and Preliminary Field Test Results
G.S. Strong, Canadian Climate Centre, National Hydrology Research Centre, Saskatoon, Saskatchewan

1140 An Automated Recording Class A Evaporation Pan Comparison Study
S.R. Shewchuk and B.J. Smith, Saskatchewan Research Council, Saskatoon, Saskatchewan

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SESSION 9C: DYNAMIC METEOROLOGY AND NUMERICAL MODELS
METEO DYNAMIQUE ET MODELES NUMERIQUE
1000-1100 Manitoba West

Chair/Chef: H. Ritchie, Service de l'environnement atmosphérique, Dorval, Québec

1000 The Effects of Synoptic Scale Eddies on the Low-Frequency Flow in the Atmosphere
J. Sheng and J. Derome, McGill University, Montréal, Québec

1020 Non-linear Interactions in Coupled Atmosphere-Ecosystem Models
R.A. Pielke, X. Zeng and R. Eykholt, Colorado State University, Fort Collins, Colorado

1040 On Supercritical Bifurcation Due to Nonmodal Instability in Planetary Scale Motion of a Barotropic Atmosphere
J. Zou and W. Hsieh, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia

1200-1300
Lunch/Déjeuner
(Up to Participants/A votre choix)

SESSION 10A: **OCEAN DYNAMICS AND MODELS I**
DYNAMIQUE OCEANIQUE ET MODELES I
1300-1420 **Delta B**

Chair/Chef: M.G.G. Foreman, Institute Of Ocean Sciences, Sidney, British Columbia

1300 Evidence for Internal Variability with Decadal Timescale in an Ocean General Circulation Model
A.J. Weaver, McGill University, Montréal, Québec
E.S. Sarachik, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, Washington

1320 3-D Modelling of Tides in the Gulf of St. Lawrence
H.M. Skåtun, V.G. Koutitonsky and C. Toro, INRS-Océanologie, Rimouski, Québec

1340 On the Global Stability of Forced and Dissipated Barotropic Flow
J. Zou and J. Fyfe, The University of British Columbia, Vancouver, British Columbia

1400 On the Baroclinic Instability of Cold-Core Coupled Density Fronts on a Sloping Continental Shelf
G.E. Swaters, Applied Mathematics Institute, University of Alberta, Edmonton, Alberta

SESSION 10B: **CLIMATE MODELS**
MODELES CLIMATIQUES
1300-1420 **Manitoba**

Chair/Chef: G. McBean, The University of British Columbia, Vancouver, British Columbia

1300 Changes in the Moisture Budget in a $2XCO_2$ Simulation with the CCC GCM
G.J. Boer, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

1320 Vegetation Modelling in GCMs
D. Verseghy, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

1340 Cyclones and the Greenhouse Effect
S.J. Lambert, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

1400 The Canadian GEWEX Programme
R.G. Lawford, Canadian Climate Centre, National Hydrology Research Centre, Saskatoon, Saskatchewan

1420-1445
Coffee/Pause-café

SESSION 11A: **OCEAN DYNAMICS AND MODELS II**
DYNAMIQUE OCEANIQUE ET MODELES II
1445-1645 **Delta B**

Chair/Chef: D. Krauel, Royal Roads Military College, Victoria, British Columbia

1445 Topographic Upwelling in Coastal Waters
K.-T. Tee and P.C. Smith, Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Nova Scotia
D. Lefaivre, Institut Mauricé Lamontagne, Department of Fisheries and Oceans, Mont-Joli, Québec.

1505 Experiments with Non-Normal Mode Initialization of a Shallow-Water Limited-Area Scheme
R. Juvanon du Vachat, EERM/CRMD, Paris, France

1525 The Role of Mixed Boundary Conditions in Numerical Models of the Ocean's Climate
A.J. Weaver, McGill University, Montréal, Québec
E.S. Sarachik, University of Washington, Seattle, Washington, U.S.A.

1545 Sensitivity Studies of a Relaxation-Type Open Boundary Condition For Ocean Models
H.M. Skåtun, INRS-Océanologie, Rimouski, Québec

1605 Development and Application of a Three-Dimensional Circulation Model Using a Direct Stress Solution Over the Vertical
R.A. Luettich Jr. and S. Hu, University of North Carolina, Morehead City, North Carolina, U.S.A.
J.J. Westerink, University of Notre Dame, Notre Dame, Indiana, U.S.A.

1625 Closure Modelling of Forced-Dissipative Statistical Equilibrium of Large-Scale Quasi-geostrophic Flows over Random Topography
J. Zou, The University of British Columbia, Vancouver, British Columbia
G. Holloway, Institute of Ocean Science, Department of Fisheries and Oceans, Sidney, British Columbia

SESSION 11B: **GEWEX PROGRAMME DISCUSSION**
DISCUSSION DU CYCLE D'EAU ET DE L'ENERGIE GLOBALE DE L'ATMOSPHERE (GEWEX)

1445 - 1645 **Manitoba**

1700-1800
Hydrology SIG Meeting/GIS Hydrologie
Manitoba

1800-1900
Reception/Réception: Portage and Manitoba Ballroom

1900-2300
CMOS Annual Banquet and Awards/Banquet annuel de la SCMO et présentation des prix
Delta Ballroom

FRIDAY JUNE 7/VENDREDI LE 7 JUIN
CONCURRENT SESSIONS/SESSIONS SIMULTANEES

SESSION 12A: **CLIMATOLOGY/HYDROCLIMATOLOGY II**
CLIMATOLOGIE/HYDROCLIMATOLOGIE II

0830-1010 **Portage**

Chair/Chef: H. Fraser, Meteorological Consultant, Winnipeg, Manitoba

0830 The Relationship Between Regional Freeze-up and Break-up of Lakes and Mean Air Temperatures in Canada
W.R. Skinner, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

0850 New Weather Normals for the Eastern Prairies: Warmer and Cooler, Wetter and Drier Than It Used to Be
R.L. Raddatz, J. Maybank and G.B. Atkinson, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba

0910 Blowing Snow Transport and Sublimation on the Prairies
J.W. Pomeroy, National Hydrology Research Institute, Saskatoon, Saskatchewan
D.M. Gray, University of Saskatchewan, Saskatoon, Saskatchewan

0930 Simulation of a Prairie Snowpack: Snowmelt Revisited
C. Fisher and R.F. Hopkinson, Scientific Services Division, Central Region, Atmospheric Environment Service, Regina, Saskatchewan

0950 The Influence of Spring Weather on Red River Floods
A. Warkentin, Manitoba Department of Natural Resources, Winnipeg, Manitoba

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SESSION 12B: AIR QUALITY AND BOUNDARY LAYER METEOROLOGY
QUALITE DE L'AIR ET METEOROLOGIE DE LA COUCHE LIMITE I
0830-1010 Delta B

Chair/Chef: Y. Zhuang, Environmental Science Branch, AECL Research, Pinawa, Manitoba

0830 A Gas-Phase Chemistry Module for a Regional Transport Model: Numerical Schemes and Applications
W. Gong and H.-R. Cho, University of Toronto, Toronto, Ontario

0850 LRTAP: "P" Could Also Stand for Pathogenic Viruses
R.L. Raddatz, Atmospheric Environment Service, Winnipeg, Manitoba
G.W. Hammond, University of Manitoba and Cadham Provincial Laboratory, Winnipeg, Manitoba

0910 Factors Influencing Precipitation Chemistry
N.C. Treloar, Scientific Service Division, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba

0930 Micrometeorology in the Fraser Valley Near Prince George B.C., and the Effect on Air Quality
W. McCormick, Ministry of the Environment, Province of British Columbia, Prince George, British Columbia

0950 Aerial Inputs of Polycyclic Aromatic Hydrocarbons to Lake Sediments along a transect from the U.S. Border to Northern Ellesmere Island.
W. L. Lockhart, G.S. Brunskill, P. Wilkinson and B.N. Billeck, Freshwater Institute, Department of Fisheries and Oceans, Winnipeg, Manitoba.

SESSION 12C: OCEAN DYNAMICS AND MODELS III
DYNAMIQUE OCEANIQUE ET MODELES III
0830-1010 Manitoba

Chair/Chef: A.J. Weaver, McGill University, Montréal, Québec

0830 Laboratory Measurements of the Drag of Two-dimensional Obstacles in a Two-Layer Flow
H.D. Pite and D.R. Topham, Institute of Ocean Science, Sidney, British Columbia
B.J. van Hardenberg, Dalhousie University, Halifax, Nova Scotia

0850 Tidal Circulation Computations for the Western Atlantic Shelf and Gulf of Mexico
J.J. Westerinck, Department of Civil Engineering, University of Notre Dame, Notre Dame, Indiana
R.A. Luettich Jr., Institute of Marine Sciences, University of North Carolina at Chapel Hill, Morehead City, North Carolina
A.M. Baptista, Department of Environmental Sciences and Engineering, Oregon Graduate Institute, Beaverton, Oregon
N.W. Sheffner, Coastal Engineering Research Center, Department of the Army, Waterways Experiment Station, Vicksburg, Mississippi

0910 Non-Linear Propagation of Locally Generated Tsunamis in the Pacific Northwest Coast: Sensitivity Analysis
A.M. Baptista, Oregon Graduate Institute, Beaverton, Oregon
C.D. Peterson, Portland State University, Portland, Oregon,
J.J. Westerink, Civil Engineering Department, University of Notre Dame, Notre Dame, Indiana

0930 Indonesian Throughflow and Its Effect on the Climate of the Indian Ocean
T. Hughes and A.J. Weaver, McGill University, Montréal, Québec
J.S. Godfrey, CSIRO Division of Oceanography, Hobart, Tasmania, Australia

0950 Time and Space Variability of Thermal Fronts in Hecate Strait, British Columbia
I.D. Jardine and K.A. Thomson, The University of British Columbia, Vancouver, British Columbia
M.G.G. Foreman, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

1010-1040
Coffee/Pause-café

SESSION 13A **HUMAN IMPACTS ON CLIMATE**
IMPACTS ANTHROPOGENIQUE SUR LA CLIMAT
1040-1200 **Portage**

Chair/Chef: G.J. Boer, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

1040 Will Kuwait Oil Fires Cause Early Frosts in Western Canada?
W.F.J. Evans, Environmental Resource Studies, Trent University, Peterborough, Ontario

1100 The Potential Climatic and Other Atmospheric Effects of Middle-East Oil Fires
R.K.R. Vupputuri and J.-P. Blanchet, Canadian Climate Centre, Downsview, Ontario

1120 Assessment of the Effects of Middle-East Extensive Oil Burning using 1-D and CCC/GCM2 Models
J.-P. Blanchet and R.K.R. Vupputuri, Canadian Climate Centre, Downsview, Ontario

1140 A Strategy to Compensate for Global Warming
W.F.J. Evans, Environmental Resource Studies, Trent University, Peterborough, Ontario

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SESSION 13B: **AIR QUALITY AND BOUNDARY LAYER METEOROLOGY II**
QUALITE DE L'AIR ET METEOROLOGIE DE LA COUCHE LIMITE II
1040-1200 **Delta B**

Chair/Chef: J. Maybank, Atmospheric Environment Service, Winnipeg, Manitoba

1040 Atmospheric Wave Motions Above and Within a Natural Black Spruce Forest Canopy
P.A. Davis, Chalk River Laboratories, Chalk River, Ontario
B.D. Amiro and F.L. Johnston, Environmental Science Branch, Whiteshell Laboratories Research, Pinawa, Manitoba

1100 Boundary-Layer Exchange and the Free Convection Limit
Y. Delage, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

1120 Hodograph Rotation in the Sea Breezes of the Attic Peninsula, Greece
D.G. Steyn, The University of British Columbia, Vancouver, British Columbia
G.B. Kallos, University of Athens, Athens, Greece

1140 Flow in Complex Terrain - Recent Results and Developments
P. Taylor, D. Xu, K. Ayotte, L. Chan and W. Gong, Department of Earth and Atmospheric Science, York University, North York, Ontario

TUESDAY, JUNE 4/MARDI LE 4 JUIN

SESSION 1: PLENARY I/SESSION PLENIERE I
0930-1200 DELTA BALLROOM TUESDAY/MARDI

The Arctic Ocean and Climate Change
K. Aagaard, Pacific Marine Environmental Laboratory, National Oceanic Atmospheric Administration, Seattle, Washington

The Arctic Ocean is characterized by a permanent ice cover, low internal kinetic energy, and very large and shallow stratification, which effectively isolates the bulk of the ocean from the atmosphere. Nevertheless, the Arctic Ocean plays an active and important role in ocean climate. A key factor is the functioning of the Polar Basin as a reservoir in which large quantities of fresh water are impounded, and then selectively released to the North Atlantic. In the northern extensions of the Atlantic, this buoyancy supply may interact with and alter the convective gyres that feed the large-scale meridional circulation in the ocean. A significant alteration of this kind appears to have occurred at least once during this century. The stratification in the Arctic Ocean itself, which is vital to maintaining its ice cover, shows large differences between the two major basins, the Canadian and Eurasian. The latter may be particularly sensitive to perturbation. The saline deep waters of the Canadian Basin appear to be a relic of climatic conditions a millennium ago, whereas those in the Eurasian Basin are of modern origin and play an important role in maintaining and altering the deep structure of the basins to the south, which in turn control the overflow to the North Atlantic and the rest of the world ocean. Canada has a pivotal role in illuminating these research issues from the perspective of global and climate change.

Interdecadal Variations in Climate and Ice Cover of the Arctic Ocean and Greenland Sea
L.A. Mysak, Centre for Climate and Global Change Research, Department of Meteorology, McGill University, Montréal, Québec

Evidence is rapidly accumulating that interdecadal variability, as seen, for example, in the SSTs of the Gulf of Alaska (Royer, 1989) and the North Atlantic (Sarachik and Gammon, 1989), surface salinity in the northern North Atlantic (Dickson et al., 1988) and ice cover in the Greenland Sea (Mysak et al., 1990), may be the next most important ocean-climate signal after ENSO. Given the high latitude location of these fluctuations, it is natural to ask whether they are also related to atmospheric and hydrological variations in the Arctic and subArctic regions. An examination of extensive records of Arctic and subArctic sea ice, SST and salinity, runoff into the Arctic and

Northern Hemisphere atmospheric circulation, reveals a sequence of air-ice-sea interaction events that can be linked together by a negative feedback loop. In the absence of other damping factors this loop suggests the existence of a self-sustained interdecadal climatic signal. In the Greenland Sea, this signal is characterized by a state of large sea-ice extent overlying a layer of cool, fresh water that suppresses deep convection in winter, which alternates with a state of small sea-ice extent and more saline water that frequently exhibits deep convection. As a consequence, this cycle could introduce decadal variability into the rate of deep water formation in the North Atlantic and, hence, decadal variability in global climate through the thermohaline circulation.

The Biology of the Arctic Ocean

V. Alexander, School of Fisheries and Ocean Sciences, University of Alaska-Fairbanks, Fairbanks, Alaska, U.S.A.

The biological regimes of the Arctic Ocean reflect extreme conditions of light and temperature, and, especially, the presence of sea ice as a dominant feature of the marine environment. Although the problem of accessibility has precluded extensive marine ecological field studies in the Arctic, a body of information is now accumulating that has revised markedly our perspective on the nature and extent of arctic marine biological productivity. Although large areas of the Arctic Basin are believed to have very low primary productivity, we now recognize areas of very high seasonal primary production along the Arctic continental shelves and also in connection with sea-ice boundaries. Rich and diverse marine communities develop in conjunction with these "hot spots". Another feature of Arctic systems is a large migratory component to the higher trophic levels.

In this paper, the nature of the Arctic marine biological communities will be examined in the context of the oceanographic and climatological regimes.

Canadian Northern Hydrology: Present and Future Tasks

T. Prowse, National Hydrology Research Institute, Saskatoon, Saskatchewan

The water resources of northern Canada (north of 60°N) are immense. For example, they contain 18% of Canada's freshwater storage, 23% of its wetlands and 75% of its glacierized area. More generally, almost 85% of the total land mass of Canada is drained by northward-flowing rivers. Despite the magnitude of this resource, it has received a disproportionately small amount of study, largely because of its isolation from Canada's major population zones in the South.

Within the North, water holds special value ranging from its uniting role in delicate northern ecosystems to its significance in traditional lifestyles. It has also been the key to the North's exploration and now, while being one of the main economic resources for the North's future, it is

also the focus of concerns related to local development and long-range pollution. In view of the fragility and contaminant-sensitivity of northern water ecosystems, pernicious effects from development disturbances and contaminant inputs are likely to be extensive and protracted. A comprehensive knowledge of northern hydrologic systems is, therefore, essential to ensure adequate environmental protection of the North. Unfortunately, however, our understanding of cold regions hydrologic processes is relatively poor and precludes accurate assessments of potential disturbances.

This paper analyses our knowledge of northern hydrologic processes, reviews the major uses and development demands on northern water supplies and discusses some of the evolving issues for northern hydrology, specifically northern pollution and global change.

SESSION 2A: OCEAN PRODUCTION ENHANCEMENT NETWORK (OPEN)
RESEAU DE MISE EN VALEUR DES RESSOURCES MARITIMES (OPEN)
1300-1500 MANITOBA EAST
TUESDAY/MARDI

The Ocean Production Enhancement Network - OPEN
P.H. LeBlond, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia

The central objective of OPEN is to provide an information base to enhance the competitive position of Canada's fishery industries. Fisheries science is not a discrete, self-contained discipline. As with its parent science of oceanography, it is a complex amalgam of disciplines. For that reason, OPEN was conceived as a network of interaction and cooperation among the various disciplines. Recent scientific advances, including subjects as disparate as 3-dimensional hydrodynamic modelling, molecular genetics, bioenergetics, and ecological theory, have brought us to a point where synthesis and profitable application are inevitable. OPEN is intended to hasten and facilitate this transdisciplinary integration.

The design of OPEN represents a deliberate compromise. Its breadth in scope and scale is sufficient to attack and resolve problems of real importance. It is also sufficiently focused to optimize the resources available. Two model systems serve as paradigms for the study of production processes in marine systems of commercial interest. The cod-centred model deals primarily with events in the pelagic zone; the scallop-centered model focuses on benthic production processes. Apart from their roles as explicit models of characteristic production systems, they also serve as general models for the formulation of new approaches to integrated analysis of marine systems. Both systems embody elements of direct relevance to aquaculture and traditional capture fisheries. Neither is seen as an

end in itself. Rather, both models are foci that will lead to tangible deliverables while serving as guides to the subsequent analysis of comparable productions systems.

The research program of OPEN comprises 40 projects, with investigators from Dalhousie, Memorial, McGill, Laval, Rimouski, UBC, SFU and the Department of Fisheries and Oceans. The program was funded as one of 14 National Centres of Excellence, with industrial support from Clearwater Fine Foods Limited, Fishery Products International Limited and National Sea Products Limited.

OPEN and Its Biological Oceanographic Focus on the Fisheries
C.T. Taggart, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

Various research initiatives in OPEN are employing new approaches to resolving: (1) recruitment processes in larval (small-scale) and juvenile (meso to large-scale) fish that lead directly to enhanced recruitment predictions; and (2) the biomass and density distribution of adult fish (meso and large-scale) and their relationship to physical oceanographic variations. The first is focused partly on quantifying the phenological, genetic, phenotypic, biochemical, behavioural and physiological characteristics that enable the minority of cod larvae to survive and recruit to the fishery, and partly on covariation in growth, survival, maturation and recruitment among Pacific salmon stocks and their relationship to variations in oceanographic conditions during the juvenile stage in the marine environment. The second initiative is designed to employ modern acoustic techniques on the Scotian Shelf and Labrador Shelf to establish the relationships among adult cod numerical distribution, density and size distribution, movement, and water mass structure and variation at a variety of spatial and temporal scales. I will demonstrate the interdisciplinary nature of the research (see other OPEN abstracts), and will show how the efforts are employing new techniques (e.g. otolith aging and lipid condition assessment) and their integration with the latest advances in recombinant DNA technology, phenotypic and biochemical analyses, and real-time high-resolution (time and space) biological and oceanographic monitoring and modelling.

The Influence of Physical and Biological Conditions on Productivity in the Giant Scallop (Placopecten magellanicus)
B.A. MacDonald, Marine Sciences Research Laboratory, Ocean Sciences Centre, Memorial University of Newfoundland, St. John's, Newfoundland

One of the major goals of the scallop component in OPEN is to understand the factors, including genetic make-up, that influence the distribution, settlement and growth of individuals in order to predict their behaviour and performance under different conditions. Emphasis is placed on integration of the relevant processes that affect production in the different stages of the life cycle,

including the pelagic phase of the planktonic larvae and the more sedentary benthic phases of juveniles and adults. Studies are under way to identify and measure oceanographic conditions that determine the large-scale dispersion or concentration of larvae, including advection towards favourable sites, and small-scale hydrodynamic conditions near the bottom that will determine settlement and survival. Oceanographic conditions may also act directly on scallop production by influencing the transport and distribution of phytoplankton and other suspended matter that this species utilizes as a food resource. The relationships between capture and ingestion of particles as a function of temperature, particle concentration and quality, and current velocity will be used to model growth and select appropriate aquaculture sites and their carrying capacity.

The Marine Gene Probe Laboratory (MGPL) Component Of OPEN
R.W. Doyle, Marine Gene Probe Laboratory, Dalhousie University, Halifax, Nova Scotia

The general mandate of the Marine Gene Probe Laboratory (MGPL) is to apply recombinant DNA technology to problems in fisheries and aquaculture. One of the major activities of the MGPL is developing "DNA fingerprint" probes for identification of individuals, families, populations and species. Within OPEN, fingerprint probes are used in the estimation of quantitative genetic variation in traits that determine larval settlement, metamorphosis, growth, and behavioural responses to environmental gradients.

The use of DNA fingerprint probes to identify the genotype of "survivors" and "non-survivors" of an oceanographic event will be described briefly. We will then outline our ideas for merging the biological data with the physical oceanographic models developed in OPEN. The essential notion is that in each generation the physical oceanography acts as a selective "filter" to modify the genetic composition of the next generation.

Physical Oceanography and OPEN
K.R. Thompson, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

The Ocean Production Enhancement Network (OPEN) supports seven physical oceanographic projects. They all aim to monitor and model the ocean on scales important to the survival, growth and distribution of the targeted species - cod and scallop on the East Coast, and salmon and English sole on the West Coast. The models range from simple box models for scallop growth, through process-orientated models for the reconstruction of oceanographic conditions in Hecate Strait over the last 40 years, to three-dimensional models of the Baie des Chaleurs and Labrador Shelf density and flow fields. The modelling studies will be complemented by extensive field programs, most notably in the Baie des Chaleurs, in Lunenburg Bay (Nova Scotia) and on the Scotian and Labrador Shelves. In addition, the Scotian Shelf larval

tracking program will require "nowcasts" of the state of the ocean. This will be achieved by assimilating observations into a numerical circulation model.

This presentation will focus on the physical oceanography components of OPEN, highlighting the new measurement technologies and numerical models.

OPEN Physiology: Heritability of Bioenergetic Processes
R.G. Boutilier, Department of Biology, Dalhousie University, Halifax, Nova Scotia

Effective application of bioenergetic models for the analysis of fish production systems in the northwest Atlantic have been hampered by our limited knowledge of the physiology and bioenergetics of the various fish species. We are focusing on the growth and activity metabolism of cod, a species that is commercially important in itself as well as being a representative or "model" of a key component of northern marine ecosystems. The objective is to analyse the physiological variation amongst individuals in fish populations in relation to its environmental and genetic (heritable) components. In this way, we hope to understand how physiological performance is selected for and fixed into genotypes. The combined physiological/genetic research in the OPEN programme has become possible because of the development of a suite of new molecular techniques called genetic fingerprinting. Such techniques enable the unique identification of each individual and its parents in an experimental population, even at the larval stage. Fingerprinting allows us to conduct experiments that have never been feasible before. For example, it is possible to breed parents collected from different environments, and then study the physiology, growth, and development of the fry as they are raised communally in various experimental conditions. The environments can be manipulated so as to test specific hypotheses about the role of temperature, oxygen, response to haloclines, etc., that arise from the ecological and physical oceanographic parts of the OPEN programme. Our long-term objectives are to elucidate the physiological energetics that underlie the dynamics of fish production and survivorship.

SESSION 2B: OPERATIONAL METEOROLOGY
METEOROLOGIE D'EXPLOITATION
1300-1500 MANITOBA WEST
TUESDAY/MARDI

Wind Profiler Operation in Alaska and Status of Network in the United States

E.F. Hudson, Unisys Corporation, Great Neck, New York, U.S.A.

When the Redoubt Volcano began erupting in December 1989, ash clouds from the volcano caused severe disruption of air traffic in the Anchorage airspace, including an incident in which a KLM 747 lost power in all four engines after encountering the ash cloud at 25,000 feet. The aircraft dropped to 13,000 feet before it was able to restart its engines.

At the urging of Senator Ted Stevens of Alaska, the National Oceanic and Atmospheric Administration (NOAA) has taken a number of steps to upgrade the ability of the National Weather Service (NWS) forecast office in Anchorage to predict the path and movement of volcanic plumes. One of the steps has been the installation of a wind profiler at a site near Homer, Alaska. This system is the same as those currently being installed in NOAA's 30-station demonstration network in the central United States.

The status of the demonstration network will be presented. It is anticipated that by the time of the CMOS Congress, it will be more than half completed, with the entire network installed and operating by the end of 1991. Data from several of the Wind Profilers in the completed portion of the network will be presented.

The advantages of Wind Profilers over balloon-sounding systems (radiosondes and rawinsondes) will also be discussed. These include a higher data rate (24 wind profiles per day vs. 2 per day), better accuracy (profiles are always vertical and winds are measured simultaneously at all altitudes), and lower operating costs (Wind Profilers can be installed in the Arctic without having to have support for a crew because they can operate unattended).

Updating Weather-Element Forecasts Through Post-Processing Techniques

R. Verret and N. Yacowar, Canadian Meteorological Centre, Atmospheric Environment Service, Dorval, Québec

Weather-element forecasts may be available from different sources and may be based on the output of different driving models. The sources may include direct model output and statistical-dynamical schemes based on Model Output Statistics (MOS), Perfect Prog (PP) or Analog techniques.

As model changes become more numerous and more frequent, our ability to depend on MOS techniques will be

severely curtailed because the MOS statistical relationships between the predictors are based on model output data produced over time. To overcome that problem, the Canadian Meteorological Centre's approach has been to develop Post-treated Perfect Prog (PPP) statistical forecasting systems that will allow the PP forecasts to take on many of the desired MOS attributes. Calibration, bias correction, error feedback and anomaly reduction techniques have been imposed to reduce the biases in the forecasts as well as the departures from normal with time. The frequency distribution of forecast ranges is made to resemble that of the observed data. The merging of forecasts using PP systems and direct model variables, through calibration techniques and rule-based systems, provides the forecasts a dimension to show increased sharpness and reliability.

These techniques are model-dependent and must be updated continuously. However, the manipulations are simple to perform, are not nearly as cumbersome as regression schemes, and can be automated. The adaptations are dependent on forecast type, projection time, forecast range, time of year and location. This provides an efficient and inexpensive replacement for a full-scale MOS system.

Using Statistical Weather-Element Forecast Verifications to Assess Model Systematic Errors and the Limit of Predictability

R. Verret, Canadian Meteorological Centre, Atmospheric Environment Service, Dorval, Québec

Comparative verifications of Perfect Prog (PP) statistical forecasts of total cloud opacity, six- and twelve-hour probability of precipitation and spot surface temperatures produced using the Canadian Regional Finite Element model and the Canadian Hemispheric Spectral model, show that the former performs slightly better than the latter as the driving model. That advantage is attributable to the fact that the drift in the Regional model, characterized by increasing specific humidity and falling temperatures during model integration, is controlled to a large extent, which is not so in the Hemispheric model. It also turns out that the Regional model is drier and that it underestimates the diurnal temperature cycle compared to the hemispheric model. On the other hand, the hemispheric model is slightly too cold.

A forecasting system reaches its predictability limit when the forecasts no longer have any relationship with the verifying observations or, in other words, when the forecasts become random variables with respect to the observations. Extrapolation of the Brier score of the Perfect Prog (PP) probability of precipitation forecast produced from the hemispheric model, as a function of projection time, indicates that the limit of predictability is about 8 days in winter and about 10 days in summer. These figures appear to be upper limits, since the forecasts will lose all value when the skill score of the forecasts no

longer depends on the projection time, which is likely to happen sooner.

The Blizzard of January '89 in Alberta - Another Perspective
R. Perron and G. Babin, Meteorological Training Centre, Atmospheric Environment Service, Cornwall, Ontario

An approach developed by Zwack-Kabil to estimate the lower tropospheric vertical motion is applied in a semi-quantitative way to study a storm that produced nearly 30 cm of snow on the eastern foothills of the Rockies.

The study focuses on a diagnosis of orographic forcing, mainly due to the Rockies and also on the estimation of divergence/convergence in the lower free atmosphere. An assessment of convergence/divergence based on the surface winds is used to obtain the vertical motion at the top of the boundary layer. An additional estimation of the vertical motion in the lower free atmosphere (below the 600-mb level) is obtained using the distribution of the surface pressure tendencies. An analysis of the horizontal propagation of the vertical motion based on the surface data and its relationship to the precipitation amounts is also performed.

A National Summer Severe Weather Verification System
L. Legal and B. Lawson, Prairie Weather Centre, Atmospheric Environment Service, Winnipeg, Manitoba

As a result of a series of meetings over the last couple of years, AES summer severe weather experts have agreed on a verification system for the Prairie Weather Centre's summer severe weather programs. The standard rare event verification statistics, Probability of Detection (POD) and False Alarm Ratio (FAR), are simple ideas, but there were also many other concepts and terms to be considered and defined. For example, the group eventually agreed that a severe weather event was an occurrence that was separated from other occurrences in space and time by 30 km and/or 30 min. The verification scheme is objective; however, the need to be "strictly proper" was relaxed slightly. This presentation explains the system that will be implemented in the Spring of 1992.

A Microcomputer-Based Climatological Information System for Terminal Forecast Production
R.A. Stuart, Weather Research House, Downsview, Ontario
W.L. Ranahan, Department of National Defence, Ottawa, Ontario

Microcomputer software has been developed that provides approximately 55,000 graphs and associated data sheets on the climatology of airports. The software runs on any microcomputer with an MS DOS 3.2 operating system or higher.

A hard disk is required to store the main program (200 K) and the data files for each station that is to be supported (1300 K per station). Graphs are produced in colour on EGA or VGA monitors.

Statistics are provided for each month of the year and for three 10-day periods in each month. The weather elements supported include ceiling height, visibility, surface temperature, wind speed, relative humidity, total cloud opacity, wind direction and seven types of precipitation including rain, drizzle, freezing rain, freezing drizzle, snow, ice pellets and hail/thunderstorms. All calendar periods and weather element combinations may be stratified by time of day or wind direction. In addition, ceiling height and visibility observations may be further stratified by the occurrence of either liquid or solid precipitation; duration statistics are presented for four combinations of low ceiling height and visibility values that could be hazardous for aircraft operations. Output formats for continuous variables include probability distribution functions or percentile plots, whereas statistics for discrete variable are presented as stacked bar charts. Diurnal variations as well as annual and seasonal overviews are available for all parameters.

The program was written to provide any required graph or table as quickly as possible, with a minimum of expertise demanded of the user. Graphs and tables are accessed via a menu system that is modified as user selections are made. Once the menu selections have been entered the desired graph is produced in less than five seconds.

It is anticipated that this software will be useful in the preparation of aviation forecasts, as well as in the training of forecast personnel. The wide array of statistics will also be of particular assistance in the preparation of forecasts for stations unfamiliar to the forecaster.

This presentation will describe the procedures used for the creation of the statistics followed by a brief demonstration of the package. A complete hands-on demonstration of the software will be available throughout the Congress at the Weather Research House commercial display.

SESSION 2C: SEA ICE/GLACE DE MER
1300-1500 PORTAGE
TUESDAY/MARDI

Snow Effects on Ice Growth Along the Canadian East and Arctic Coasts

S.J. Prinsenberg, Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Nova Scotia

Since for the same temperature gradient, the upward heat conduction through snow is an order of magnitude slower than through ice, the depth and density of the snow cover is

important in determining the ice growth rates in simple Freezing-Degree-Day models and sophisticated numerical ice growth models. Snow depths and snow densities (water content) vary along the Canadian East Coast and across the Arctic, so that snow parameters used in ice growth models vary from location to location and vary at any one location in time. The spatial and temporal variations in snow parameters applicable to heat conduction through snow are obtained from climatic ice and snow thickness data collected by the Canadian Ice Centre at land-fast ice stations. As expected the drier snow in the High Arctic conducts heat more slowly than the wetter snow found in lower latitudes. This causes the constants of Freezing-Degree-Days models to vary as one moves north.

An Examination of Isentropic Potential Vorticity and the Surface Enthalpy Flux as Possible Mechanisms for the Annual Reversal of the Beaufort Sea-Ice Field

E.F. LeDrew and D. Johnson, Department of Geography, University of Waterloo, Waterloo, Ontario
J.A. Maslanik, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado, U.S.A.

The late-summer reversal of the Beaufort Sea Gyre and the overlying sea-ice cover is an intriguing phenomenon that may reveal some insight into atmosphere-cryosphere interactions through a detailed diagnostic analysis.

In this study we examine the atmospheric processes that may give rise to this reversal and maintain it through a case-by-case study of selected days during the late-August/early-September reversal in 1980. We inspect the fields of total vertical motion and the contributions by advective, diabatic and frictional mechanisms as well as the isentropic potential vorticity to identify the forcing functions.

This episode is an example of the classic cold low with a central cold pool, the surface and 500-mb fields aligned vertically, significant potential for baroclinic development and a depression that remains anchored in the region for a significant period (27 days).

The episode occurs during a transition period from the summer regime with a sluggish upper-air anticyclonic circulation to the vigorous winter regime with a cyclonic vortex extending up through the stratosphere having a concomitant increase of potential vorticity available for surface development. This transition, which appears to occur during a period that typically experiences rapid upper atmosphere cooling, may be the trigger for the creation of the low.

The surface heat flux appears to be a significant factor in the maintenance of the low although there are two factors at work. The first is the anomalous heat flow from the ocean along the ice-ocean boundary and from open water in the diverging ice-pack but this primarily appears to result in a regional modulation of the synoptic-scale

effect. At the synoptic scale, significant heat flux is associated with the very cold core of the depression; and the associated pattern of the lower atmospheric heating moves with the wandering migration of the system within the region. In addition, there is an important dynamic contribution to development due to the ageostrophic advection and convergence of cold air out of the core. The long duration of this feature within the Canada Basin must be traced to a complex interplay of heat flow processes related to the nature of the surface as well as the formation of the cold core of the depression, dynamic properties of mid-tropospheric air flow, and the increase of upper-air potential vorticity.

Ice Drift off Southern Labrador During LIMEX '89

I.K. Peterson and S.J. Prinsenberg, Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Nova Scotia

The drift of sea ice over the southern Labrador shelf in March and April 1989 was investigated using satellite-tracked ice beacons and sequential NOAA/AVHRR visible imagery. During this period, geostrophic wind accounted for 40% of the variance of daily ice velocity from the beacons. The response of alongshore and offshore ice velocities to geostrophic wind will be discussed. Major oceanographic features influencing the ice beacon trajectories were (1) anticyclonic eddies near the shelf break and (2) an eastward jet along the northern flank of Belle Isle Bank. On the east side of Hamilton Bank, ice floes became entrained in anticyclonic eddies with a diameter of about 70 km. A detailed description of the flow in the vicinity of these ice-edge eddies was obtained from images several hours apart, and from one of the beacons. In open water east of the shelf break, cyclonic eddies could be seen in the infrared imagery. The eastward jet north of Belle Isle Bank resulted in the advection of 4 of the 6 beacons to the shelf break at various times over a 2-month period. Streak patterns sometimes observed in the visible imagery were a good indicator of the direction of ice beacon movement.

Interannual Variability of the Arctic Ice-Sheet Using a Coupled Ice-Ocean Numerical Model

D.M. Holland and L.A. Mysak, Centre for Climate and Global Change Research, Department of Meteorology, McGill University, Montréal, Québec

A coupled ice-ocean numerical model is used to study interannual variations in the Arctic ice-pack. The sea-ice component of the model includes both dynamics and thermodynamics based on Hibler and Oberhuber, respectively. The ocean component is a diabatic isopycnal ocean circulation model with prognostic temperature and salinity fields and realistic topography (Oberhuber). The models are coupled through an ocean mixed layer. The coupled model is forced using monthly atmospheric fields spanning several

decades. The simulation of sea-ice thickness, concentration and circulation is compared with observations. In particular, the model is used to hindcast the great ice and salinity anomaly of the 1960's.

Interannual Variability of Atmospheric Circulation and Sea-Ice Cover in Hudson Bay

J. Wang, L.A. Mysak and R.G. Ingram, Centre for Climate and Global Change Research, Department of Meteorology, McGill University, Montréal, Québec

The relationship between sea ice and atmospheric forcing is examined by the analysis of the sea-level pressure (SLP), surface air temperature (SAT) and ice concentration (IC) from 1953 to 1988. Over the Hudson Bay region, the Pacific North America (PNA) pattern and North Atlantic Oscillation (NAO) are two major atmospheric circulation patterns that interact and influence the sea-ice regimes in Hudson Bay. During the PNA years, the SLP has a strong positive anomaly over Hudson Bay. During the PNA years, the SLP has a strong positive anomaly over Hudson Bay during the winter and also persists into the spring. Hence, the response of sea ice to the PNA pattern consists of completely ice-covered conditions with especially thick ice during the winter. Also, the sea-ice melting dates are delayed in the spring, and less precipitation occurs during the PNA years.

During the extremely strong NAO years, the deepened Icelandic low is efficient in advecting the Arctic cold/dry air toward the Hudson Bay region. Thus, positive ice anomalies in terms of the IC occur, because the SAT has a negative anomaly over Hudson Bay.

Four regimes of sea ice are defined according to the atmospheric circulation patterns: strong PNA and weak NAO; both strong PNA and NAO; weak PNA and strong NAO; and both weak PNA and NAO. The four sea-ice regimes are discussed in detail and are shown to characterize the interannual variability in Hudson Bay.

Simultaneous Winter Sea-Ice and Atmospheric Circulation Anomaly Patterns

T.A. Agnew, Arctic Climatology Section, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

Thirty-six years (1953/88) of Arctic sea-ice cover data have been used in conjunction with 100-kPa height and 50-100-kPa thickness data to establish concurrent winter atmospheric circulation patterns for extreme sea-ice months for the Arctic as a whole, as well as the Davis Strait/Labrador Sea, and the Greenland Sea regions. For the Arctic as a whole, heavy sea-ice months are accompanied by a weakening of the Aleutian Low. Both heavy ice months in the Davis Strait/Labrador Sea and light ice months in the Greenland Sea are accompanied by a deepening of the Icelandic Low with temperature advection playing an important role in the extremes of ice in both seas. Heavy ice months in the

Greenland Sea are accompanied by a weakening of the Icelandic Low and by a strong geostrophic flow over the North Greenland Sea parallel to the Transpolar Drift. This accelerates the advection of sea ice into the Greenland Sea. No strong cooling seems to be associated with these heavy ice conditions.

SESSION 3A: POSTER SESSION/SESSIONS DES AFFICHAGES
1500-1630 KENNEDY'S TUESDAY/MARDI

PC-Based Radar Display and Encoding Program
S.R. Adams and F.G. Hunter, Central Region, Atmospheric Environment Service, Regina, Saskatchewan

In 1989, a computerized radar data processing (RDP) system was added to the Enterprise (CWSR-81) weather radar at Elbow, Saskatchewan. This system was installed by McGill University, Montréal, Quebec, and is operated by the Hydrometeorological Processes Division of the Canadian Climate Centre located at Saskatoon, Saskatchewan. Although the primary goal of the RDP was to facilitate data archiving and post-event data analysis, it also offered a unique opportunity to support the ongoing weather services of Environment Canada/AES. Simon Adams, a University of Regina Co-op computer science student, was hired by AES, Regina, to develop a PC-based display system which would include the capability of creating "semi-automatic" SD reports. His product display system (PDS) program offers user-friendly access to the RDP system in addition to allowing "on-screen" preparation and delivery of coded radar reports (SDCN1's).

A microcomputer will be set up to allow for demonstration of both the RDP and PDS systems and their applications in operational meteorology.

An Attempt at Computerized Handling of Anomalous Propagation Returns in Weather RADAR Maps
F.J. Eley and D. Magosse, Hydrometeorological Processes Division, Canadian Climate Centre, Saskatoon, Saskatchewan

In weather radar systems that handle only reflectivity, anomalous propagation often results in ambiguous mapping of ground echoes. Short time series of ground echo and weather echo patches have different properties which are used by a human operator to discriminate between them. An attempt was made to use a computer analysis to discriminate ground echo and eliminate it from weather radar maps.

The presentation will illustrate the echo properties and the computer process used and some test results.

SAR Interpretation Techniques to Distinguish Between Multi-Year and First-Year Ice in the Eastern Arctic
M.-F. Gauthier and D. Hagen, Ice Centre, Environment Canada, Ottawa, Ontario

Environment Canada Ice Centre has equipped their latest ice reconnaissance aircraft with an SAR (Synthetic Aperture Radar) for sea ice. However, a special knowledge-based system had to be developed to assist the Ice Forecaster and the Ice Service Specialist in their analysis of SAR imagery. Radar image parameters such as the image pulse response, image texture, image pattern, image shadow and image tone, are the primary elements for the construction of information about a target on an image. Other sources of information that are a prerequisite are time of year and geographic location. This poster presentation will display some guidance to distinguish between two ice types on SAR imagery in the Eastern Arctic.

On the Increase in Polar-Low Activity Over the Beaufort Sea As a Result of Global Warming
N. Parker, Scientific Services Division, Western Region, Atmospheric Environment Service, Edmonton, Alberta

The impact that global climate change may have on the occurrence of polar lows in the Beaufort Sea has been investigated. Twenty-four-hour integrations of the operational version of the Canadian Regional Finite Element (RFE) model were performed at a 25-km resolution on actual synoptic situations, previously assessed as being favourable for polar-low development. Ice conditions were modified according to data obtained from the 2 x CO_2 run of the Canadian Global Climate Model (GCM). Results show that under the modified ice scenarios, both surface vorticity and precipitation amounts increase. The resulting forcing suggests that an increase in polar-low cyclogenesis should be expected.

Performance of an Acoustic Doppler Current Profiler in Knight Inlet, British Columbia
K. Greenwood, R. Marsden and J. Buckley, Royal Roads Military College, Victoria, British Columbia

An RD Instruments 150 kHz vessel mounted Acoustic Doppler Current Profiler (ADCP) was deployed in Knight Inlet, British Columbia from 26 June to 20 July, 1989. Results from an intercomparison between the ADCP and four Cyclesondes moored in the Inlet showed correlations on the order of 0.87 for depths between 21 and 125 metres. The observed ACP single ping uncertainty was estimated to be 63.2 cm sec^{-1}. A comparison to a simple model of the sectionally averaged flow in the Inlet revealed an error of 4.2 cm sec^{-1}. Residual profiles show clear evidence of an internal tide, with phase speeds suggestive of a second mode progressive wave.

Internal Hydraulics, Solitons and Associated Mixing in a Stratified Sound

J. Gan and R.G. Ingram, Department of Meteorology, McGill University, Montréal, Québec

Observations of tidally forced flow in a constricted and sill-like region of a highly stratified sound are examined as a problem of two-layer hydraulic exchange. Based on the current and salinity data, time and space dependent hydraulic conditions along the sound are discussed. It will be shown that the sound was subject to internal hydraulic controls at several locations, which account for the generation of the strong internal hydraulic bore and drop at upper layer. Internal solitary waves with 3-6 minute periods were decomposited from the upstream propagating bore. Using results from different models of the solitary wave based on the KdV equation, it is shown that the second-order non-linear term must be included in the two-layer model. The results from a first-order continuously stratified model, solved using the lowest mode eigenfunction, gave similar results as the second order two-layer model. This implies that two-layer models may ignore some properties of the real fluid and that the internal solitons are also sensitive to the stratification characteristics of the water column. Several possible mixing mechanisms are investigated.

SESSION 3B: RADIATION AND CLOUD PHYSICS
RAYONNEMENT ET PHYSIQUE DES NUAGES

1530-1650 PORTAGE
TUESDAY/MARDI

A Parameterized Model for the Estimation of Net Surface Solar Radiation at High Latitudes

Z. Li and H.G. Leighton, Department of Meteorology, McGill University, Montréal, Québec

Observations of radiation budgets, both at the top of the atmosphere (TOA) and at the surface are essential for an understanding of the earth's climate. The TOA budgets can be measured from satellites and there have been many attempts to infer the surface solar budgets from the TOA budgets. Most methods are applicable to certain scene types or geographic locations and none is valid over highly reflective surfaces such as ice and snow. In addition, the majority of models require inputs that are not readily available from current satellite-borne instruments. Based on extensive radiative transfer modelling over ocean and ice surfaces with various crystal sizes, a simple parameterized model has been developed to estimate the solar radiation absorbed at the surface from the TOA flux such as may be obtained from ERBE. The present model is simple to apply, and most importantly is only weakly sensitive to the absence

or presence of clouds, cloud optical thickness and cloud type. Calculations are under way to test the parameterization for various land surface types.

Moisture and Heat Budget of a Cirrus Cloud From FIRE Field Experiment: Implications for Radiative Cooling and Advection
I. Gultepe, Aeronautics and Astronautics Department, Meteorology Division, Istanbul Technical University, Maslak, Istanbul, Turkey

The purpose of this study is to understand microphysical, dynamical and radiative characteristics of cirrus clouds formed over Wisconsin on 31 October 1986. During FIRE (First International Regional Experiment), data were collected from step-up and Lagrangian flight patterns. In the step-up flight pattern, six constant-altitude flight legs separated by approximately 300 m were made. Each leg was about 30 Km long. Two Lagrangian spirals were made to get the vertical profile of cirrus cloud characteristics. The time difference between them was 43 min. The terms in the budget equations were estimated from instruments mounted on an aircraft. The results showed that advection terms in the horizontal and vertical were found to be important in the mid- and low-levels of cirrus. Latent heat release and radiative cooling were estimated to be important in the upper layers where the vertical velocity was small. Advection terms and radiative cooling terms also played an important role for cirrus cloud formation and maintenance on 31 October 1986 during the FIRE project.

Surface Temperature Measurements of Graupel During Growth
S. Cober and R. List, Department of Physics, University of Toronto, Toronto, Ontario

Experiments conducted in a wind tunnel, using an infrared-detecting thermal imaging system, measured the surface temperature elevations above the ambient cloud temperature, of graupel growing under a range of cloud conditions. These measurements allowed a determination of the Nusselt number, which represents the convective heat transfer occurring at the surface. A parameterization of the Nusselt number in terms of the Reynolds number allows the effects of sublimation and evaporation of graupel to be simulated numerically. The surface roughness of the accreted ice was found to enhance the evaporation or sublimation by 50%.

A Review of Hail Climatology on the Great Plains
A.C. Paul, Department of Geography, University of Regina, Regina, Saskatchewan

Although knowledge of the hail climatology of the North American Great Plains, including the Canadian Prairies, has vastly improved in the past twenty-five years, some gaps still exist. This paper is an attempt to summarize what has been done to date, to identify work that is still needed,

and to contribute some previously unpublished research on the Canadian Prairies and parts of the U.S. Great Plains. The paper is intended to be as much a review essay as a research report, and it concludes with some critical commentary on the role of studies in hail climatology to contribute to the reduction of hail damage.

SESSION 3C: FISHERIES OCEANOGRAPHY I
OCEANOGRAPHIE DES PECHES I
1530-1710 MANITOBA
TUESDAY/MARDI

Climate Change and Exceptional Fish Production off the West Coast of North America

R.J. Beamish, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia

From 1976 to 1978 there was a change in the climate in the North Pacific. Aleutian lows intensified and there was a warming of the sea surface adjacent to North America and a cooling offshore. Associated with this change was a period of exceptional fish production. Synchronous strong year-classes were identified in many stocks of commercially important species all along the West Coast of Canada and the United States. Trends in total salmon catches changed abruptly primarily from increased salmon production in Alaska. Improved survival of some stocks of some species occurred in Canada while decreased catches occurred at the southern limit of the distribution of salmon. In Canada, maturing pink, coho and chinook salmon had exceptionally good growth in 1977. Exceptional survival of many fishes appears to be related to improved production of copepods as a result of improved ocean productivity. Large-scale increases in ocean productivity may occur when large-scale changes in climate cool the ocean mixing layer bringing nutrients into the euphotic zone. In 1976, the change in climate was associated with a change in the Southern Hemisphere from an intense La Niña to a moderate El Niño.

A Theory for the Production of Strong Year-Classes in a Long-lived Marine Fish and Relevance to Fisheries Management

G.A. McFarlane and R.J. Beamish, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia

Sablefish (Anoplopoma fimbria) in the northeast Pacific Ocean produce occasional strong year-classes. In recent years strong year-classes were produced in 1941, 1952, 1957 or 1958, 1967 and 1977. We propose that these strong year-classes were associated with large-scale increases in copepod abundance. Increased copepod abundance occurred during periods of abrupt change in the ocean climate from a period of cooling to a period of warming along continental

waters of the northeast Pacific Ocean. We propose that increased primary productivity in the central North Pacific Ocean associated with cool ocean temperatures and increased winds is transferred to warmer continental slope waters along the coast of North America through increased onshore transport. This transport of nutrient-rich waters results in large increases in copepod abundance the following year. The critical process regulating ocean productivity reflects heat storage (energy transfer) in the water of the mixed layer above the thermocline. Periods of climate change from cool to warm ocean temperatures along the continental slope occurred in 1940-41, 1951-52, 1957-58, 1964-66 and 1976-77, coinciding with the production of strong sablefish year-classes.

Species Succession Among Planktonic Diatoms in Turbulent and Stratified Temperate Marine Waters

L.A. Hobson, Department of Biology, University of Victoria, Victoria, British Columbia
K. Denman, Ocean Physics, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

A study of the taxonomic composition of the phytoplankton in the tidally-mixed waters of parts of the Strait of Georgia, British Columbia, was carried out to test the null hypothesis that no seasonal succession among the diatom flora would occur. Temperature, salinity and concentrations of $Si(OH)_4$-Si, NO_3-N and PO_4-P were measured in the upper 20 m of the water column in well-mixed, thermally stratified, and frontal regions in the Strait, from April to October during 1983 and 1984, and values of buoyancy frequency were calculated. Temporal variations in phytoplankton assemblages were described by the Shannon diversity index and by association coefficients.

As expected, diatoms dominated phytoplankton biomasses throughout the study period in well-mixed waters, where seasonal variations in the physical and chemical properties of the near-surface water were small, in contrast to stratified waters where flagellated cells dominated crops when nutrient levels were low. Diversity of diatom assemblages increased from early spring to late summer in well-mixed waters, while it was reduced in the fjord when diatom dominance declined. Also, similarity measurements, based on association coefficients, formed a temporal progression in well-mixed waters, which was more difficult to discern for the fjord environment. These observations, and others based on a qualitative analysis of diatom taxonomy are consistent with the conclusion that species succession occurs among many diatom species even in well-mixed waters, where only small variations in physical and chemical properties occur. Potential causes of succession are discussed.

Mercury in Fish in Canadian Shield Lakes: Implications of Climate Warming

R.A. Bodaly, J.W.M. Rudd and R.J.P. Fudge, Freshwater Institute, Department of Fisheries and Oceans, Winnipeg, Manitoba
C.A. Kelly, Department of Microbiology, University of Manitoba, Winnipeg, Manitoba

A strong inverse relationship between mercury concentrations in planktivorous, omnivorous, and piscivorous fishes and lake size was observed for a size series of six northern Ontario lakes on the Canadian Shield. The lakes are remote from direct anthropogenic influences and range in surface area from 89 to 35,000 ha. Physical characteristics such as water renewal times and mercury levels were not related to lake productivity, pH, alkalinity, or calcium concentrations or to the concentration of mercury in lake sediments. Rates of mercury methylation (M) were found to be positively dependent on temperature, whereas rates of methylmercury demethylation (D) were inversely related to temperature. Thus, M/D was strongly temperature dependent. Mercury concentrations in four fish species were significantly positively correlated with mean epilimnetic water temperatures (R^2 valves ranged from 0.69 to 0.90). We, therefore, hypothesize that water temperatures, which were higher in the smaller lakes over most of the open water season, were controlling M/D ratios and were the cause of higher fish mercury levels in the smaller lakes. If this hypothesis is correct, significant increases in fish mercury levels in shield lakes may be expected as a result of climate warming.

Ocean Climate And Northern Cod

A.M. Oake, Fisheries Resource Development Limited, Halifax, Nova Scotia

The intensity and extent of the Cold Intermediate Layer (CIL) of the Labrador Current sampled at fixed locations and times throughout the year may serve as an indicator of the ocean climate for the Labrador/Newfoundland coast. The intensity and extent of this feature has increased over the period from fall 1986 to fall 1990.

Migration patterns of northern cod, both along the slope during the winter and inshore/offshore during spring/fall, have shown significant spatial and temporal variability that appears to be related to the climate cycle in the CIL. In addition, timing of the late spring/early summer inshore cod migration has been linked to the heating cycle in the surface layer.

Major fisheries management decisions are based in large measure on statistical analysis of research vessel trawl survey data. At present there is no attempt to determine if the year-to-year variability in survey results can be attributed to physical rather than biological factors. It is suggested that a reliable index of ocean climate must

become an integral part of the statistical analysis if industry is to have confidence in the management advice derived from the trawl surveys. From an oceanographic perspective, the requirement remains to determine an effective sampling strategy to establish ocean climate cycles.

WEDNESDAY, JUNE 5/MERCREDI LE 5 JUIN

SESSION 4: PLENARY II/SESSION PLENIERE II
0830-0950 DELTA BALLROOM WEDNESDAY/MERCREDI

Research Activities and Meteorological Infrastructure in the Canadian Arctic
M. Balshaw and D. Stossel, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba

An audio-visual presentation will be made to familiarize attendees with AES operations at Alert, Eureka, Mould Bay, Resolute, Hall Beach and Baker Lake. The operation of an automatic weather station at the decommissioned Isachsen site and the conduct of a Polar Psychology Project there will be briefly described. Other facilities and operations, including the Canadian Parks Service Reception Centre at Tanquary Fjord, the North Pole expedition departure site at Ward Hunt Island, and the Lake Hazen automatic weather station, all within the Northern Ellesmere Island Park Reserve, will be described.

A number of significant projects and initiatives planned or under way at the HAWS will be discussed. These include the construction of a Prototype Operational Polar Station (POPS) or major refurbishment at Mould Bay on Prince Patrick Island, a diesel fuel storage tank farm with a capacity of over one million litres at Eureka, a stratospheric ozone detection observatory near Eureka as announced in the Green Plan, and a Special Studies Laboratory (SSL) and an expanded Background Air Pollution Monitoring Laboratory (BAPMON) at Alert. Reference will also be made to a mesosphere auroral study to be undertaken by the Institute for Space and Atmospheric Studies (ISAS) of the University of Saskatchewan. Research support opportunities made available by the Atmospheric Environment Service at Eureka and Mould Bay to graduate students in the physical and/or biological sciences will be discussed.

Short-Term Climate Variability of the Arctic
J.E. Walsh, Department of Atmospheric Sciences, University of Illinois, Urbana, Illinois, U.S.A.

On time-scales of months to years, the near-surface atmospheric fields of the Arctic undergo large excursions from their climatic means. We will attempt to place these excursions into a temporal perspective by first reviewing

the normal seasonal cycle of atmospheric sea level pressure and temperature. These fields are of central importance in the coupling of the Arctic atmosphere and the underlying ice/ocean. Departures from normal pressure in the Arctic show a relatively strong association with concurrent anomalies in the North Atlantic, especially during the winter half of the year. Pressure anomalies over time-scales of one to several years are surprisingly large and appear to contribute to subsequent anomalies of sea ice, ocean temperature and salinity in the North Atlantic.

During the past several decades, areally averaged temperature over the Arctic has increased. However, this warming is weaker than in the early twentieth century, and some regions within the Arctic have actually cooled over the past 20-30 years. The recent warming has been strongest over Alaska, the North Atlantic marginal ice zone, and north central Asia. Ocean surface temperatures support the pattern of temperature change derived from land station data. The pattern of recent high latitude temperature change is consistent with, and at least partially attributable to, corresponding changes in the sea-level pressure (gradient wind) field. The possible role of recent changes of air mass frequency will also be addressed.

SESSION 5A: NUMERICAL WEATHER PREDICTION I
MODELES NUMERIQUES DE PREVISION I
1020-1200 MANTIOBA WEST WEDNESDAY/MERCREDI

Implementation of a Global Data Assimilation Procedure at the Canadian Meteorological Centre (CMC)

H. Mitchell and C. Charette, Recherche en prévision numérique (RPN), Service de l'environnement atmosphérique, Dorval, Québec
J. Hallé, Canadian Meteorological Centre (CMC), Service de l'environnement atmosphérique, Dorval, Québec

A global data assimilation procedure has been in operation at the CMC since late May 1990. The procedure, running in a 6-h cycle, consists of three steps: analysis, non-linear normal mode initialization, and forecast. The analysis step uses a split three-dimensional multivariate statistical interpolation method to analyze horizontal wind components, height, temperature and dew-point depression on a 180 x 90 global Gaussian grid. The 6-h forecasts, used as trial fields, are produced by a global primitive equations forecast model, which is described in detail in the companion presentation by Ritchie and Beaudoin. The model uses the spectral method (truncated at T79) in the horizontal, linear finite-elements (21 levels) with a terrain-following coordinate in the vertical, a semi-implicit semi-Lagrangian (30-min timestep) time-integration scheme and a fairly complete physics package.

Other differences between the global system and the previous hemispheric procedure will also be discussed. For

example, the global procedure produces analyses at 15 isobaric levels extending up to 10 mb, whereas the hemispheric procedure with 11 levels extended only to 50 mb. Another difference is the implementation of a procedure that interpolates analysed increments, and replaces the vertical interpolation of full fields from isobaric to model surfaces, allowing for better preservation of the model's vertical structure.

To evaluate the performance of the global procedure, and compare it with that of the previous hemispheric system, various objective measures of data-assimilation performance will be presented.

Optimized Formulation of a Baroclinic Global Semi-Lagrangian Spectral Model

H. Ritchie and C. Beaudoin, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

The semi-Lagrangian semi-implicit time integration technique permits the integrations of numerical weather prediction models using time steps that far exceed the CFL limit for the corresponding Eulerian models. However, because of the overhead of the extra calculations required by the semi-Lagrangian technique for each time step, the net gain in efficiency can be significantly less than the factor by which the time step is increased. In particular, in the context of a baroclinic semi-Lagrangian spectral model, the initial study by Ritchie used cubic three-dimensional interpolations throughout and also used very accurate algorithms for the trigonometric calculations in finding the upstream positions, and in the transformations required to treat the vector form of the equation of motion. This study examines the impact of using lower order interpolators for some of the terms, and presents alternate formulations of the trajectory calculations and coordinate transformations that significantly increase efficiency without degrading the quality of the forecast.

Results are presented for a global model with triangular 79-wave truncation in the horizontal and 21 levels in the vertical. The time-step limit for an Eulerian model with this configuration is about 12 min, whereas for the semi-Lagrangian version it is 30 min. The optimized calculations currently give an overhead of somewhat less than 50% per time step, which is more than offset by the increase that they permit in the size of the time step. Even greater efficiencies are anticipated with further optimization and increases in spatial resolution.

Physical Parameterization for the First Canadian Global Forecast Model

C. Girard, Y. Delage, J. Mailhot, L. Garand and B. Bilodeau, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec
N. Brunet and G. Pellerin, Centre Météorologique Canadien, Service de l'environnement atmosphérique, Dorval, Québec

During the past year, a global data assimilation and medium range forecasting system has been completed at Recherche en prévision numérique for implementation at the Canadian Meteorological Centre.

An important component of the system is the physical effects package included in the forecast model. This package was originally developed for the Canadian Regional Model used for short-range forecasting over North America and adjacent areas. It included the following options that were operational at that time in the Regional model: relatively simple infrared and terrestrial radiation schemes, a surface-layer parameterization based on similarity theory, planetary boundary-layer fluxes with diffusion coefficients as functions of turbulent kinetic energy, a moist convective adjustment scheme, large-scale condensation and a diagnostic cloud parameterization. In addition, a more sophisticated radiation package, a Kuo-type convection scheme and a gravity wave drag scheme were available.

One of our main concerns in going global and extending the forecast range was the model's ability to maintain a satisfactory thermal and hydrological global balance. Experimental forecasts with the then operational physical package on FGGE analyses showed an unacceptable 0.5 K/day net cooling and an associated net absolute drying. Precipitation amounts were very low in the first day over the tropics and increased rather slowly. The introduction of a Kuo scheme did not improve the situation. The more sophisticated radiation scheme gave worse results pointing to a serious feedback problem with our cloud parameterization. Gravity wave drag had a positive impact on the forecasts in general but of course not on the cooling problem. On the other hand, the model appeared very sensitive to initial data, as evident from a comparison of forecasts made from new versus old FGGE analyses, and to the introduction of enhanced vertical diffusion of moisture, no doubt an indication of the lack of and need for improved parameterization of shallow convection.

History and Present Status of the French Peridot NWP System

R. Juvanon du Vachat, Direction de la Météorologie, EERM/CRMD, Paris, France

We present briefly the history of the research project PERIDOT (Prévision à Echeance Rapprochée Intégrant des Données Observées et Télédétechtées) that led to a fine-mesh

(35 km) operational NWP system at the beginning of 1985 in the French Meteorological Service. This research project was in the context of high-resolution dynamical adaptation studies but were trying to improve prediction by using the fine-scale information available. We discuss the experiments performed in a research mode concerning the assimilation of radiances, non-linear normal mode initialization and the use of different physical packages. We then describe the necessary trade-offs to put these elements in a coherent operational model and the main changes made to the operational suite through the years. Also presented are the verifications of the fine-mesh model with the surface weather observations that explain how well the low-level meteorological parameters are predicted. The different results at higher resolution (10 km) are also presented, indicating a way to improve the predictability of the whole system. Finally, a tentative evaluation is given indicating the success of the PERIDOT system for forecasters but also the areas where more research must be carried out.

Variational Implicit Normal Mode Initialization for a Multilevel Model

L. Fillion, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

One important problem still remaining in the field of non-linear normal mode initialization for NWP models is the lack of control on the changes made to reliable data captured by the analysis scheme during the balancing process. Using a variational framework, it is possible to constrain the initialization scheme to balance the high-frequency gravity-inertial oscillations while remaining as close as possible to the original analyzed fields. We formulated and tested such a scheme which is called Variational implicit non-linear normal mode initialization (VINMI). This scheme works in physical space (instead of normal mode space), thus permitting a fully three-dimensional control on mass and wind field changes. The new scheme has been tested with the Canadian operational finite-element regional model (RFE), and the principal results obtained will be presented. In terms of the computer time required to make a 48-h forecast, the 3-D VINMI scheme typically requires 5% of this time compared with 2% for the unconstrained INMI scheme using the operational version of the model, and is thus not excessive. Future directions of research using this technique will be discussed briefly.

SESSION 5B: FISHERIES OCEANOGRAPHY II
OCEANOGRAPHIE DES PECHES II
1020 - 1200 MANITOBA EAST WEDNESDAY/MERCREDI

Variations in Wind-Induced Coastal Upwelling Off the West Coast of North America From 1899 to 1982 and the Consequences to Fisheries

W.W. Hsieh, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia
D. Ware, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia
R.E. Thomson, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

Using the 5° x 5° monthly surface air pressure from 1899 to 1982 prepared by Kevin Trenberth at NCAR, we have constructed the geostrophic wind along the west coast of North America from 22.5°N to 57.5°N. The alongshore component of this windstress indicates the monthly coastal upwelling/downwelling from 1899 to 1982. We have found substantial long-term changes in the wind-induced upwelling/downwelling that seem to coincide with the rise and fall of fisheries along the West Coast. We examine the relationship between the wind variations and the variations of several long fishery time series - e.g. the sardine fatness, the herring size at age and the herring recruitment. Long-term relationships between the wind and other physical variables such as coastal sea level and sea-surface temperature are being sought.

Investigating the Influence of the Barotropic Tidal Circulation on Herring Larvae Dispersal in the Southwest Nova Scotia Region Using a 3-D Lagrangian Particle-Tracking Model

F.H. Page, K.-T. Tee and P.C. Smith, Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Nova Scotia
R.L. Stephenson, Biological Station, St. Andrews, New Brunswick

In spite of a strong residual flow, Atlantic herring larvae remain aggregated off southwest Nova Scotia for a period of months. Their persistence has been hypothesized to be due to an interaction between the migrations. Field sampling has demonstrated that larvae migrate vertically throughout the water column but how this modulates the horizontal dispersal of the larvae remains unclear - in part because of uncertainties and inconsistencies in the timing and pattern of migration. A 3-D Lagrangian particle-tracking model is used to help clarify the influence of the interaction between larval vertical migrations and tidal currents on the horizontal dispersal of the larvae. The model is based on a 3-D barotropic M2 tidal model. The sensitivity of horizontal particle displacements to patterns of vertical

migration is examined with emphasis on observed migration patterns. Predicted and observed patterns of the horizontal distribution of herring larvae are compared and the potential for vertical migration schemes to counter and residual drift is discussed.

The Fraser River Plume: Effects on the Distribution of Juvenile Salmonids, Herring, and their Prey

M.A. St. John and P.J. Harrison, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia
J.S. MacDonald and E. Choromanski, West Vancouver Laboratories, Department of Fisheries and Oceans, West Vancouver, British Columbia
R.J. Beamish, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia

The Fraser River empties into the Strait of Georgia, resulting in a large riverine plume that causes an increase in primary production and phytoplankton standing stocks. Samples were taken to determine if similar changes in zooplankton and fish densities accompanied these increases. Three sampling regimes were selected (i.e. riverine plume, estuarine plume and a site beyond the plume influence representative of the Strait of Georgia), and zooplankton and fish were sampled using vertical hauls and trawls, respectively. In conjunction with these regimes, a fourth region representing the outer edge of the estuarine plume was sampled to determine fish densities.

The estuarine plume had the highest zooplankton densities which coincided with the region of highest primary production. Vertical net hauls in the euphotic zone revealed that copepods, amphipods and euphausiids were significantly more abundant in the estuarine plume than in samples from the riverine plume and the Strait of Georgia.

The estuarine plume and the riverine plume had significantly higher fish densities (adult and juvenile herring, and juvenile salmonids) than the Strait of Georgia region. Zooplankton specimens found in the stomach contents of both adult and juvenile herring suggested that these organisms were filter feeding on the zooplankton occurring in the estuarine plume. Juvenile salmonids fed primarily on small unidentifiable juvenile fish. The highest densities of salmonids were captured in the region of the leading edge of the estuarine plume where potential food particles were not sampled.

The Influence of Open-Ocean Currents on Sockeye Salmon Returning to the Fraser River

K.A. Thomson, P.H. LeBlond and M.C. Healey, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia
W.J. Ingraham, Alaska Fisheries Science Centre, National Oceanic and Atmospheric Administration, Seattle, Washington
C. Groot, Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia

The OSCURS (Ocean Surface Circulation Simulation) model, which simulates surface Lagrangian drifters using mean geostrophy and daily surface winds, was used to simulate the return migration paths of sockeye by seeding the model with non-passive drifters. The focus was on two years with significantly different Johnstone Strait Diversions (JSD): 1982 (22% JSD) and 1983 (80% JSD). Simulations of passive drifters confirmed that the magnitudes of the surface currents were sufficient to influence the migrating sockeye. The average net east-west current drifts during May and June were 5.9 and 4.5 km/d for 1982 and 1983, respectively. These currents provide a substantial eastward assist to sockeye migrating to the Fraser River at a mean migration speed of 22.8 km/d. The average net north-south current drifts were 2.4 and 5.1 km/d for 1982 and 1983, respectively. Over a migration period of 60 days, the difference between these drifts could account for a sockeye landfall in 1983 of up to 150 km farther north than in 1982. Fifty-four simulations of compass-orientated sockeye were run, using an array of swim speeds and compass orientations. Each simulation "released" 174 sockeye, distributed over their Northeast Pacific subarctic habitat.

The results show that the interannual variability of the latitude and date of landfall of compass-orientated sockeye are clearly influenced by open-ocean currents. The results further suggest that the full array of sockeye distributed over the sub-arctic habitat cannot successfully return to the Fraser River using compass orientation alone, such that sockeye must migrate with bicoordinate orientations and/or utilize environmental clues (i.e. temperature and salinity) to delineate their premigration habitat and/or the oceanic boundaries of their migration regime. Further simulations are planned to investigate the impacts of these direction-finding mechanisms and oceanic clues.

A Microcomputer System for Simulating Alternative Hypotheses About Effects of Advection on Larval Fish Distributions

C.J. Walters, Department of Zoology, The University of British Columbia, Vancouver, British Columbia
C.G. Hannah, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia

We have developed a microcomputer data management and simulation package for tracking fish larvae in advection

fields generated by hydrodynamic models. Coastal characteristics, bathymetry, and fish-spawning distributions can be easily entered via simple map editing routines. Advection fields can be defined from data files and/or manipulated with a visual vector editing routine; changes in advection regimes over time are specified as time series of advection field code numbers and intensities. Individual larvae can be "spawned" into the advection fields in arbitrary space/time patterns, and can be assigned times per day spent in different fields to represent vertical migration behaviour. Various attributes of individual larvae (e.g. size, settlement behaviour, physiological state) can be simulated along with position changes. Advection patterns can be applied backward in time to predict spawning locations from larval settlement distributions. The program can track 1000 larvae for 60 days, while presenting their movements in a visual animation, in about two minutes of computer time on a 20-MHz, 80386-based PC. Such fast execution allows the program to be used as a "game" to quickly evaluate predicted consequences of alternative hypotheses about larval behaviour and effects of advection on distribution and survival.

This presentation will use a PC overhead projector display to demonstrate the model's data management capabilities and an application of the model with simulated English sole larvae in Hecate Strait, British Columbia. This simulation will use advection fields generated by a wind-driven barotropic model. Different larval advection and settlement patterns are shown, given a range of different advection fields and larval behaviour hypotheses.

Reserve Paper:
Tidal Model Studies of Particle Retention Around a Shallow Coastal Bank

M.G.G. Foreman, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia
A.M. Baptista, Oregon Graduate Institute of Science and Technology, Beaverton, Oregon
R.A. Walters, U.S. Geological Survey, Tacoma, Washington

Barotropic tidal and tidal residual currents calculated with a finite-element model of the southwest coast of Vancouver Island are combined with Lagrangian particle-tracking techniques to follow drifters deployed around Swiftsure Bank. Retention characteristics of the bank region are estimated by calculating average Lagrangian residual velocities. A first-order estimate of the average Stokes velocity due to spatial variations in the amplitudes and phases of eight tidal constituent velocities suggests cancellation of the Eulerian residual eddy due to tidal rectification, and no particle retention. These estimates are confirmed with a series of 29-day drifter experiments using the numerical model. The amount of swimming required for a simple fish to remain around Swiftsure Bank is also estimated.

SESSION 5C: STORMS AND ASSOCIATED FEATURES I
TEMPETES ET ELEMENTS ASSOCIES I

1020-1200 PORTAGE
WEDNESDAY/MERCREDI

Temporal Variability of North Pacific Ocean Surface Cyclones
T. Li and J.R. Gyakum, Department of Meteorology, McGill University, Montréal, Québec

This research focuses upon both seasonal and interannual variability of North Pacific Ocean surface cyclone tracks. The objective is to document the relative importance of the interannual variability of this cyclone parameter in defining the relevant climate of the North Pacific. Another objective is to determine relevant precursors to the onset of 30-day circulation regimes, or significant climatic anomalies.

We find that, though January is the most active month for North Pacific surface cyclone activity, the interannual variability is sufficiently strong during this month that climatic means bear little resemblance to the observed state in any individual January. Additionally, we find the interannual variability of surface cyclone activity to be stronger than the seasonal cycle.

Our analyses of objectively defined circulation regimes, based upon a 30-day spatial and temporal clustering of surface cyclones, reveal that regional climatological anomalies of surface cyclone frequency, significant at the 95% confidence level, can be identified as precursors to the onset of these 30-day circulation regimes. This result suggests that large-scale blocking events may have relevant precursors that can be identified with conventional data sources.

The Role of the Vertical Distribution of Forcing and Static Stability on the Development Rate of Extratropical Cyclones
P. Zwack, J. St-James, F. Martini and S. Wigniolle, Département de Physique, Université du Québec à Montréal, Montréal, Québec

The impact of various vertical distributions of thermodynamic and dynamic forcing on development rate and vertical motion will be explored in a simple analytical system. These results will be compared with those from both a primitive equation model (Zwack et al., 1991) and observational studies (Smith et al., 1991). The development rates and vertical motions in the analytical model will be diagnosed using a semi-geostrophic version of the Zwack-Okossi (1986) development equation. The forcings that will be studied include orography, friction, sensible heating, latent heating, vorticity, and temperature

advection. An attempt will be made to clarify the role of the static stability in dampening or enhancing both development and vertical motion.

Vertical structures of the above-mentioned forcings in both a primitive equation model and observational studies of explosively developing storms will be presented. Through comparison with the analytical results, inferences will be made as to their impact on both the development rates and vertical motions observed. Finally, we will look at the forcing responsible for the development and evolution of cold and warm frontal troughs and their associated vertical motions.

Antecedent Surface Vorticity Development and Explosive Cyclone Intensification

J.R. Gyakum, Department of Meteorology, McGill University, Montréal, Québec

The idea that antecedent surface vorticity development is a crucial dynamical conditioning process for rapid surface cyclone intensification (surface central pressure fall of at least 24 mb/24 h, or 1 Bergeron) is examined with a systematic observational study of development in the western North Pacific Ocean. We find that a cyclone's maximum intensification rate, as measured by central pressure fall, is positively and significantly correlated (coefficient > 0.6) with its antecedent intensification. This result is supported by analyses of composite fields of sea-level pressure. Such a strong positive relationship can only be demonstrated with a large sample of cases. We used nearly 800 in this study. Explosively developing cyclones are preferentially characterized by at least 12 h of antecedent development, suggesting its crucial role in dynamically conditioning such cyclones. An examination of 500-mb cyclonic vorticity and surface cyclone tracks shows that deepening cyclones which propagate substantial distances before their maximum development in climatologically favourable regions tend to be explosive deepeners.

A more detailed examination of 62 cases of weakly and rapidly developing surface cyclones occurring over the Kuroshio Current in the western North Pacific basin shows that the environmental relative vorticity, as measured on a 350-km mesh, is typically greater than the planetary vorticity, thus suggesting that relative vorticity stretching must be computed from the onset of the cyclone's most rapid development. There is a negligible positive correlation between this vorticity and the subsequent cyclone development. This small correlation may likely be related to the fact that horizontal scale of the surface vortex ranges from less than 200 km to greater than 1200 km. A significant positive relation is found between the length scale of the cyclone and its subsequent central pressure fall. This result is consistent with the notion that more mature cyclones tend to intensify more rapidly.

Conditional Symmetric Instability in ERICA Cyclones

G.W. Reuter, Department of Geography, University of Alberta, Edmonton, Alberta

Conditional Symmetric Instability (CSI) is a mesoscale instability that arises from an unstable balance of the pressure gradient force, the Coriolis force and the gravitational force. Symmetric instability in saturated air occurs whenever the value of the moist potential vorticity is negative. For moist but unsaturated air, we must consider the energy budget of an air sample undergoing a finite displacement that may result in saturation. Specifically, we can follow a displacement along a surface of constant pseudo-angular momentum. A comparison of the parcel's adiabatic temperature with that of the environment gives its buoyancy and thus its stability properties.

An analysis of CSI properties is made for winter cyclones developing over the Atlantic that were monitored during the Experiment of Rapidly Intensifying Cyclones (ERICA). Our analysis indicates the presence of CSI in the storms' warm sectors, which causes a banded structure in the precipitation field. Also the deep slantwise neutral layers found ahead of each surface storm centre was likely instrumental in the effective "communication" of low-level temperature advection and mid-level vorticity advection that resulted in such dramatic growth of these storms.

Aspects of the Surface Structure of Canadian East Coast Winter Storms

P.A. Taylor, York University, North York, Ontario
J.R. Salmon, CMOS Accredited Consultant, Burlington, Ontario
R.E. Stewart, Atmospheric Environment Service, Downsview, Ontario

During the CASP 1986 field study we were able to observe a number of surface frontal and low-pressure centre passages and will present details of these. We will focus our attention on the data collected from two surface MesoNets (in the Halifax area and on Sable Island) and from rawinsonde ascents (from Shearwater and Sable Island). Statistical aspects of the fronts as well as case studies are presented. The fronts vary substantially in their sharpness. Estimates of the widths of the frontal zones ranged from 31 to 191 km. We observed seven "well-defined" warm frontal passages and six "well-defined" cold frontal passages, plus two cases where the low-pressure centre passed over or close to our MesoNets. The fronts were most clearly defined by wind direction changes. Each of the "well-defined" fronts had near-surface convergence along a line normal to the front, i.e. $\partial v / \partial y$ was negative at all stations, indicating frontogenesis. Of the five cold fronts, four were linked with a split frontal storm organization. We found no simple relationships between the various characteristic parameters of the fronts.

SESSION 6A: OCEANOGRAPHY OF THE NORTH I
OCEANOGRAPHIE DU NORD I
1400-1500 MANITOBA EAST
WEDNESDAY/MERCREDI

Currents, Variability and Transport Above the Baffin Island Slope

C.K. Ross, Bedford Institute of Oceanography, Dartmouth, Nova Scotia

Arrays of subsurface current-meter moorings were deployed for a period of one year over the slope in Baffin Bay. Three moorings were positioned between the 200-m and 1000-m isobaths off northeastern Baffin Island during 1983/84. Four moorings were deployed northwest of Davis Strait along the Baffin Island slope during 1984/85.

The mean currents were directed generally southeastward along isobaths. The magnitudes of the mean currents vary from 2 to 10 cm/s. The largest mean current was measured in the deep water well below the sill depth.

The variability in the currents was investigated over several frequency bands. The northern array shows indications of a seasonal cycle with a minimum in the winter for frequencies lower than 1 cycle per day. The southern array does not show the same level of seasonality at any frequency.

The volume transport at the northern array is found to be dominated by the flow over the slope away from the shelf break. The yearly average is found to be 1.0×10^6 m^3/s with a seasonal signal that shows monthly average transport near zero in winter and as high as 2.5×10^6 m^3/s in summer. At the southern array the annual mean transport was measured to be 0.5×10^6 m^3/s with monthly averaged transport varying from a slight reversal to 1.0×10^6 m^3/s but no indication of a winter minimum.

Winter Circulation Patterns in Southeastern Hudson Bay

S. Lepage, Fontenelle, Québec
P. Larouche, Institut Maurice-Lamontagne, Ministère des Pêches et des Océans Canada, Mont-Joli, Québec

The next major hydroelectric project to take place in the Hudson Bay watershed is the harnessing of the Great Whale River. It is expected that this project will radically change the coastal circulation not only by regulating the freshwater runoff but also by changing the point of freshwater entry along the coast. Baseline studies were made prior to the project start to understand the driving forces of the water circulation between the Belcher Islands and the Quebec coast. The project consisted of installing 13 moorings distributed around the Great Whale River mouth and across the Bay up to the Belcher Islands. This survey was made during the 1986 winter at a time when the area is completely covered by fast ice thus eliminating wind effect

on the circulation. Preliminary analysis showed great temporal and spatial (both horizontal and vertical) variability of the water circulation. The presentation will show these results, try to determine global patterns and investigate possible relationships with cross Hudson Bay pressure patterns as already suggested by Ingram and Larouche (1987) using a more limited data set.

Dynamics of Currents in the Labrador Sea: Preliminary Results

T. Reynaud and A. Weaver, Department of Meteorology, McGill University, Montréal, Québec
R. Greatbatch, Department of Physics, Memorial University of Newfoundland, St. John's, Newfoundland

The physical oceanography of the Labrador shelf and surrounding waters has been the subject of much interest over the last few years. Barotropic modelling studies (e.g., Greatbatch and Goulding, 1988; Hukuda et al., 1989) have been very successful in representing many of the observed features of the region. In order to provide a more complete picture of the circulation in this region a diagnostic calculation is undertaken using both MEDS and NODC archived data. The data are first put onto a suitable grid using an objective analysis scheme similar to that of Levitus (1982). The diagnostic study is done using the technique of Mellor et al. (1982) using realistic bottom topography.

SESSION 6B: STORMS AND ASSOCIATED FEATURES II
PRECIPITATION AND MICROBURSTS
TEMPETES ET ELEMENTS ASSOCIES II

1400-1500 PORTAGE
WEDNESDAY/MERCREDI

Organization of Cloud and Precipitation in a Prairie Storm

C.D. Nguyen and G.W. Reuter, Department of Geography, University of Alberta, Edmonton, Alberta

On 17 July 1986, a cold-core low-pressure system developed over central Alberta that produced heavy rainfall. At Carrot Creek the 24-h rainfall accumulation was 105 mm. A detailed analysis is made of satellite images, C-band radar measurements, synoptic weather maps and sounding data to document the evolution of this heavy rain storm. The emphasis is on identifying the organization of cloud and precipitation and on relating this to the synoptic and mesoscale airflow patterns. The cold low produced a strong easterly flow to the north of its centre, which continued for two days. The air mass was forced to move over increasingly higher ground to the west creating an extensive and thick layer of cloud. Strong precipitation downpours are found to occur in multiple bands caused by slantwise convection in the low-level wind shear.

On the Organization of Winter Precipitation Types
R.E. Stewart, N.R. Donaldson and G.B. Raga, Atmospheric Environment Service, Downsview, Ontario

Winter storms commonly produce a variety of precipitation types such as rain, freezing rain, ice pellets and wet or dry snow. Because several of the precipitation types involve changes of phase, the evolution of the lower tropospheric temperature field leads to a well organized spatial distribution of precipitation types at the surface. Because of varying particle trajectories within the background temperature and wind fields, an organized pattern in the relative concentration of precipitation types is also established. In addition, radar-detected precipitation bands can sometimes be produced through the formation of the different precipitation types.

A Study of Possible Microbursts in the Toronto Area
D. Yiu and P.A. Taylor, Department of Earth and Atmospheric Science, York University, North York, Ontario

Fujita (1985) has established methods and algorithms for detecting microbursts from 1-min MesoNet data. The Pickering MesoNet, operated in the Toronto area for two years from January, 1988, collected data with a 10-min averaging period. Can we use these data to give a first estimate of the microburst climatology in the Toronto area? As a first step we obtained 6 days of 1-min data from the JAWS MesoNet, which was studied by Fujita, reduced it to 10-min data and were able to confirm that identification of microbursts with our modified form of Fujita's algorithm for 10-min data is a possibility, although fewer events are actually detected. From our analyses we were able to detect 31% of the confirmed microburst events found by Fujita's original study (i.e. detected by his algorithm and confirmed by his meso-analysis). Our algorithm for 10-min data flagged approximately as many non-confirmed as confirmed events whereas Fujita's study of data from the May to August 1982 period of the Denver JAWS experiment gave an average of 2.4 confirmed microbursts per month per station.

Applying our algorithms to the two years of Pickering MesoNet data from 8 stations gave a total of 68 possible microburst events, and an average of 0.36 per month per station. Assuming the same percentages of confirmed and non-confirmed events in the Pickering and JAWS data we would thus estimate an annual microburst event rate of 0.64 per station per month. In the May to August summer period this rate is 0.69. We had expected a bigger seasonal difference and are investigating individual events. These preliminary analyses do, however, appear to suggest that Microbursts are not that unusual in the Toronto area.

Reference:
Fujita, T.T., 1985. The Downburst - Microburst and Macroburst, SMRP Research Paper #210, University of Chicago, 122 pp.

SESSION 6C: REMOTE SENSING AND APPLICATIONS
TELEDETECTION ET SES APPLICATIONS
1400-1500 MANITOBA WEST
WEDNESDAY/MERCREDI

Use of SATEM Thicknesses in the Canadian Meteorological Centre (CMC) Global Objective Analysis

R. Lalbeharry, Aerospace Meteorology Division, Atmospheric Environment Service, Downsview, Ontario
C. Chouinard, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec,

The objective of this study is to improve the quality of the CMC global analysis, particularly in the Southern Hemisphere, by making better use of satellite retrievals produced by NESDIS and distributed over the GTS as "SATEM" reports. A temperature profile is described in a SATEM retrieval in terms of thicknesses over 17 layers. The current CMC objective analysis converts the thicknesses to layer mean temperatures, which are interpolated to produce temperatures at the analysis levels, rather than using the thicknesses directly. Research at the European Centre for Medium Range Weather Forecasting has demonstrated that their analysis was improved when the SATEM retrievals were assimilated as thicknesses over fairly thick layers rather than as temperature profiles. This paper describes modifications to the CMC analysis scheme to use SATEM thicknesses for the 7 layers 1000-700-500-300-100-50-30-10-hPa and examines their impact on the CMC analysis/forecast system.

The evaluation is based on two data assimilation runs, a control run that treats the SATEM reports as they are handled now, and an experimental run that treats the SATEMs as thicknesses. Some preliminary results from the parallel sets of analyses and forecasts will be presented with an assessment of the potential impact of integrating the SATEM thicknesses in the assimilation system.

Development of Three-Dimensional Synthetic CO-Data Sets

D.V. Michelangeli and J. Drummond, Department of Physics, University of Toronto, Toronto, Ontario

The study of the chemistry of the earth's atmosphere will advance greatly during the next decade because of the large data sets expected to be available from the instruments of the NASA proposed earth-orbiting platforms (EOS). While developing retrieval algorithms for instruments, and three-dimensional chemical and dynamical models, it is imperative

to consider the quantity and form of the data to be acquired. Synthetic data sets enable us to refine procedures and algorithms in advance of the real data.

At the University of Toronto we are involved with both the modelling of the Chemistry and Dynamics of the Troposphere (CDT project) and the development of the MOPITT (Measurements of Pollution In the Troposphere) instrument selected to be on board the first EOS platform. The primary goal of MOPITT will be to measure CO total column and vertical profiles.

We are in the process of developing synthetic MOPITT CO data sets that include the instrument's viewing geometry while in orbit, cloud fields based on archived DOE/NCAR data, NCAR GCM CO profiles, other gas profiles, surface conditions and the radiative properties of the atmosphere. A discussion of our results and the physics involved in the creation of such data will be presented.

Sea Surface Insolation Estimation Using NOAA Advanced Very High Resolution Radiometer Data

J. Gu, Atmospheric Sciences Programme, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia
P. Austin, Atmospheric Sciences Programme, Department of Geography, The University of British Columbia, Vancouver, British Columbia

We have implemented a simple physical model for the estimation of sea-surface insolation at high latitudes using AVHRR (Advanced Very High Resolution Radiometer) measurements from NOAA polar orbiting satellites. The model, which is based on Gautier's retrieval scheme for geostationary satellite data, employs relationships between cloud radiative properties and AVHRR channel radiances derived using a 24-band two-stream radiative transfer model. Model retrievals of sea-surface insolation under clear and cloudy conditions are compared with surface flux measurements made during the First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment on marine stratocumulus clouds in the western Pacific.

SESSION 7A: OCEANOGRAPHY OF THE NORTH II
OCEANOGRAPHIE DU NORD II
1530-1710 MANITOBA EAST
WEDNESDAY/MERCREDI

Observations of the Estuarine, Wind-Driven Circulation in the Coastal Beaufort Sea

R.K. Dewey, SAIC, Bellevue, Washington, U.S.A.

Hydrographic (CTD), current, water level, river discharge and meteorological measurements have been made during the last six years (1985-90) to study the effects of a man-made causeway on the coastal environment. The Endicott Causeway

is a five-mile long gravel-filled structure, used for oil recovery and production, that extends into the Beaufort Sea near Prudhoe Bay. Measurements have been made during the brief Arctic summer when open water conditions allow monitoring of the shallow sea (< 10 m). The oceanographic regime has been shown to respond strongly to the river discharge and meteorological conditions. The near bi-modal winds (westerly and northeasterly) drive alongshore currents towards the east or west, respectively. A seasonal trend in air temperatures from approximately 15° to -5°C is reflected in the near-shore water temperatures, where the fresh river discharge mixes with the Arctic Ocean water. Salinity concentrations vary as functions of the river discharge and the wind-established upwelling or down-welling conditions. The currents at all depths are frictionally dominated, both from above, where wind stress accelerates the water, and from below, where bottom friction decelerates the water. The measurements have characterized the study area as having a high degree of natural variability, with time-scales ranging from hours to interannual. The research has been funded through the environmental monitoring program supported by British Petroleum Exploration (BPX).

The Upper-Ocean Temperature and Salinity Fields During Strong Cooling in the Central Greenland Sea in February 1989

R.A. Clarke, Physical and Chemical Sciences, Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Nova Scotia

Using a newly developed system (ICETOW) for protecting a faired towing cable from damage due to ice impact, towed CTD measurements (BATFISH) were obtained in the central Greenland Sea as part of CSS Baffin's work within the Arctic Ocean Sciences Board's Greenland Sea Project. The system was deployed in a lead in a region of young and pancake ice located at 75°35'N, 0° 1'W. The CTD was cycled between 75 and 325 m while the vessel steamed southwesterly to 75°N 5°W, then westerly to 75°N 7°30'W and then southeasterly to 74°27'N 5° 46'W thus crossing much of the central Greenland Sea.

At the northern part of the section, one sees a surface layer at the freezing point some 100-m thick separated by a sharp thermocline (halocline) from waters warmer than -0.4°C. This thermocline rapidly deepened southwards reaching depths deeper than the 325-m limit of the tow some 30-45 km into the section. From this point onward, the waters between 75 and 325 m became more and more fully mixed vertically and gradually warmed from the range of -1.6 to -1.8°C to about
-1.2°C. This is consistent with convection being more active towards the central Greenland Sea since this convection will incorporate increasingly larger volumes of the warmer Atlantic layer waters into the surface layer.

An Observational Study of Interdecadal Sea-Surface Temperature Anomalies in the Northern North Atlantic - Greenland Sea

S. Peng and L.A. Mysak, Centre for Climate and Global Change Research, Department of Meteorology, McGill University, Montréal, Québec

The long-term (1854-1979) sea-surface temperature anomalies produced from COADS (Comprehensive Ocean-Atmosphere Data Set) are examined in the North Atlantic from the midlatitudes to the high latitudes. Attention is paid especially to fluctuations on the interdecadal time-scale and to the determination of the spatial structure of the temperature anomalies. Power spectrum analysis is used to describe the features of the interdecadal variations. A preliminary analysis of the sea-level pressure anomalies over the Arctic and the adjacent regions will also be presented.

Baroclinic Circulation Under Ice

B.C. Kenney, National Hydrology Research Institute, Saskatoon, Saskatchewan

The annual occurrence of a baroclinic circulation along the axis of an elongated bay during winter was inferred from temperature profiles taken in three consecutive years. In each year, the water column was inversely stratified under ice. The depth of the (inverse) thermocline varied monotonically along the length of the bay with the most rapid change occurring in the narrow channel forming the mouth of the bay.

The associated two-layer current was measured in this channel using prototype instrumentation. The current near bottom was directed out of the bay. The upper-layer current generally flowed into the bay but was more variable than the bottom current and at times reversed direction. The current in both layers often exceeded 1 cm/s. Although the circulation is relatively weak, the water exchange through the channel makes an important contribution to the residence time of the bay.

A time series of temperature at ten depths showed that the temperature structure was highly variable. Non-linear effects were evident in regions with the largest temperature gradients where temperature fluctuations appeared wavelike but were higher in frequency than the measured Brunt-Väisälä frequency. Temperature fluctuations appeared random in other regions and were accompanied by active overturning events that suggest considerable turbulence is generated by the shear between the baroclinic currents under ice.

A Numerical Study of Two-Layer Flow Under an Ice Keel

M.I. Jameel and R.D. Rowe, Department of Mechanical Engineering, The University of Calgary, Calgary, Alberta

A numerical investigation has been undertaken of the flow of two immiscible stratified fluids under an ice keel (or over

a ridge). Previous numerical investigations of this problem have been limited to simple hydraulic-type solutions, because these computations basically involved the solution of the shallow water equations. The investigation described here utilizes the full two-dimensional Navier Stokes equations for incompressible flow. The solution of these equations has been obtained by the finite volume marker and cell approaches. A major difficulty in modelling this type of problem is the management of the fluid interface. This has been successfully handled by the introduction of a volume-of-fluid function, measured at the centre of each grid cell, as first introduced in the Los Alamos SOLA-VOF code.

It can be shown that the flow of two fluids under an ice keel (or over a ridge) is governed by the following dimensionless parameters:

$$F=\frac{u_0}{\sqrt{g\frac{\Delta\rho}{\rho_1}h}},\quad B_c=\frac{b_c}{h},\quad r=\frac{H}{h}\ \text{and}\ s=\frac{\rho_2}{\rho_1}$$

where $\Delta p = p_1 - p_2$. These flow parameters are identified in the attached figure. The numerical runs have been made for a variety of upstream Froude numbers F ranging from 0.2 to 1.7. These runs have been conducted for a single set of values of $B_c = 0.5$, $r = 7$ and $s = 0.98$.

It has been found that a grid cell whose aspect ratio is $\delta y:\delta x \leq 1:2$ yields stable solutions (δy and δx are the vertical and horizontal dimensions of a finite-difference grid cell). Therefore to minimize computation times $\delta y:\delta x = 1:2$ has been used for the thinner active layer (layer #1) next to the obstacle. A non-uniform grid has been used for the thicker layer (layer #2). Grid size independence has been achieved.

The numerical simulations have been carried out in conjunction with laboratory experiments that have been conducted at the Institute of Ocean Sciences, Sidney, British Columbia. The immediate application of this work is the estimation of the drag force exerted on ice keels by the Arctic Ocean. Very good agreement has been found between the experimental and numerical results for the interface shape between the two layers and for the drag force on a variety of obstacles.

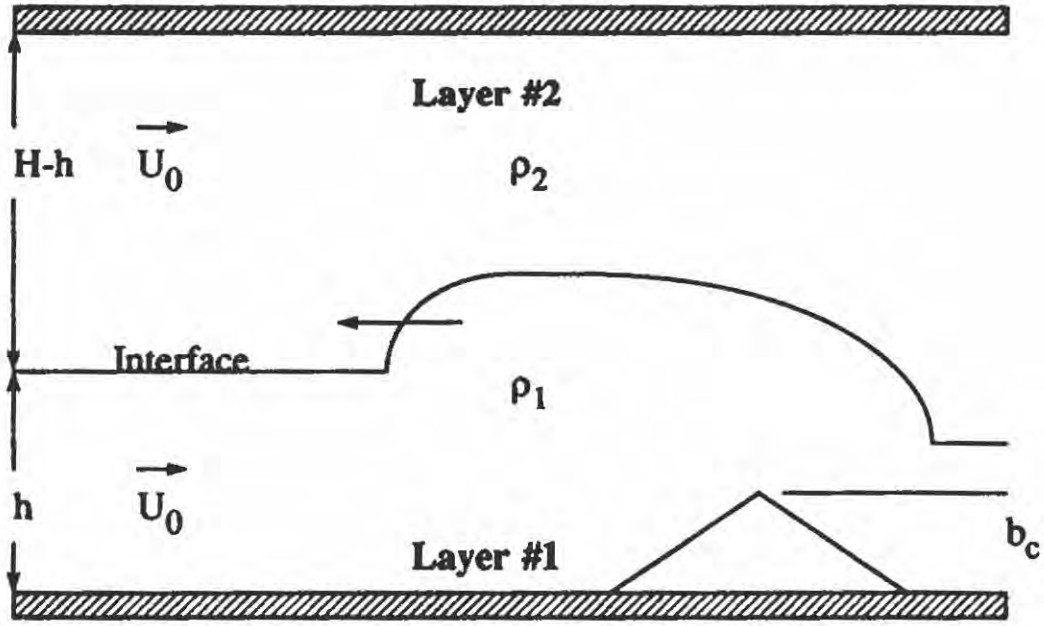

Figure 1: Schematic indicating the physical parameters for two-layer flow over an obstacle.

Polar-Low Handbook for Canadian Waters

N. Parker, Scientific Services Division, Western Region, Atmospheric Environment Service, Edmonton, Alberta

Forecasters in Scandinavia and Britain have long been aware that small vortices frequently develop and intensify deep within cold air masses streaming over warm water surfaces. These small vortices, or polar lows as they are more frequently called, are often accompanied by visibility-reducing heavy snow showers and can be accompanied by rapid wind increases up to gale or even hurricane force at a given location. Additionally, the combination of strong winds, sea spray, snow and temperatures near or below freezing presents the risk of vessel icing.

Conditions conducive to polar low development are met through the winter months in Baffin Bay, Davis Strait, the Labrador Sea and for a period of time in Hudson Bay and the Beaufort Sea prior to freeze-up. However, until the late eighties the only source of information on these systems in Canadian waters was the 1987 paper by Richard Moffet of AES's Training Branch in which he utilized satellite imagery to identify a number of polar events in eastern Canadian waters.

In 1988, realizing the potential for polar lows impacting on the exploration and development of hydrocarbon reserves in Canadian offshore waters, the Canadian Oil and Gas Lands Administration (COGLA) approved a three-year project funded by the Panel on Energy Research and Development (PERD) to study the phenomena. Project objectives were to develop a climatology of polar-low events in Canadian waters, to evaluate the ability of the current operational numerical models to handle polar-low events, to fund projects that might assist in improving the ability of the models to handle such events and to prepare a handbook that would provide Canadian forecasters with a comprehensive document to assist in the forecasting of polar events. The Polar Handbook for Canadian Waters has been finalized and published.

This paper presents an overview of the project and its results. Emphasis is on the contents of the handbook, which is now available for distribution to interested parties.

Mesoscale Studies of Climate Change in a Data-Sparse Arctic Region

J.D. Jacobs, Department of Geography, Memorial University of Newfoundland, St. John's, Newfoundland

The permanent meteorological stations in the Canadian Arctic compose a network that is generally adequate for monitoring regional climatic trends. However, the network is too coarse to resolve most mesoscale features, and it is on this scale that many biophysical impacts of climate change are first evident. The resolution of the network can be increased by short-term use of automated climate stations (autostations) at sites thought to be representative of important mesoscale features.

Geostatistical techniques permit merging the autostation data with the longer-term record of the permanent network to provide a best estimate of the climatological field. The temporary stations then become virtual stations in the permanent network for purposes of future and retrospective analysis. This approach has been used in the interior of Baffin Island, where autostations have been installed with the support of the Canadian Climate Centre. The results of the climatological analysis are presented and problems and limitations of the method are described. Examples of applications are presented: (1) in relation to short-term climate impacts on caribou habitat and (2) in the interpretation of the Holocene record of climate change from the palynological record.

Three General Circulation Model Scenarios for the Mackenzie Valley Area of Northern Canada

R.A. Stuart, Weather Research House, Downsview, Ontario

The Mackenzie Valley area of northern Canada is of interest to global warming impact studies for two reasons: first, it is now generally agreed that any CO_2-related climate change will be more extreme near the poles, and secondly, because of its significance as a transportation corridor, the Mackenzie Valley will be more sensitive to climate change than other areas of the Canadian North. The Government of Canada's Green Plan has specifically targeted the Mackenzie Valley area for detailed studies on the socio-economic effects of global warming.

A study was carried out in which three General Circulation Model (GCM) projections for the Mackenzie Valley area were compared. Because the climate of the area is strongly affected by subgrid-scale topographical features, none of these models is able to simulate current climate conditions with great accuracy. Furthermore, in their projections of future climate conditions assuming a doubling of greenhouse gas concentrations, the models are sharply in disagreement with one another as to the degree of warming to be expected. Possible reasons for these disagreements and their implications for the proposed socio-economic studies will be discussed.

The Mackenzie Basin Impact Study: Development and Application of Global Warming Scenarios

S.J. Cohen, W.R. Skinner and K.M. Holden, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

Global warming scenarios can be derived from a number of sources, including General Circulation Models (GCM), paleoclimate and historical records, and hypothetical cases. During the first year of the 5-year Mackenzie Basin Impact Study (MBIS), regional scenarios of global warming are being developed. These will be applied as direct inputs to physical, biological and empirical models (e.g. hydrology, ecosystem and energy demand), and as indirect inputs in certain study tasks (e.g. impacts on infrastructure, forest industry and regional economy).

Scenario users have a wide range of needs. In most cases, monthly air temperature and precipitation outputs are sufficient. Others are interested in wind, 50-kPa heights and soil moisture. The conventional approach to scenario development has been to add projected anomalies to observations from the 1951-1980 record, rather than using GCMs to simulate the present baseline climate. Applying this approach to the data-sparse Arctic requires careful consideration of station representativeness and the need to provide realistic spatial patterns in areas of complex terrain. For a multi-task study such as MBIS, it is important that all researchers use the same scenarios derived in the same manner, so as to ensure consistency and compatibility. Choices have to be made between gridded or interpolated data sets, and objective or "synoptic" interpolations. Questions related to scale, resolution and sampling procedures are also being addressed.

Trends in Severity of Winter Weather and Population Dynamics of Caribou on Banks Island, Northwest Territories

A. Maarouf, Canadian Climate Centre, Downsview, Ontario
A. Gunn, Renewable Resources, Government of Northwest Territories, Coppermine, Northwest Territories
B. McLean, Renewable Resources, Government of Northwest Territories, Inuvik, Northwest Territories

Winter severity plays a significant role in the population dynamics of caribou (Rangifer tarandus) of the Canadian Arctic Islands. The caribou on Banks Island provide a particular example of the influence of severe winters on the trend in population size, which declined from an estimated size of 11,000 in 1972 to 2,700 ± 340 (S.E.) in 1989. Caribou die-offs in the 1970-71, 1977-78 and 1983-84 winters are attributed to malnutrition while deep snow and ice from freezing rain reduced the availability of forage. An analysis of the meteorological data to determine the trends in winter weather suggests that the frequency of severe winters increased in the 1970s.

Impacts of Climatic Change on the Beaufort Sea-Ice Regime

D.G. McGillivray, The MEP Company, Markham, Ontario
T. Agnew, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario
M.C. Hill, CANATEC Consultants Ltd., Calgary, Alberta
G.A. McKay, Meteorological Consultant, Thornhill, Ontario
E.F. LeDrew, Department of Geography, University of Waterloo, Waterloo, Ontario

There are many uncertainties with regard to the timing, magnitude and regional patterns of climate change; however, most climatologists agree that global warming is likely to occur over the next 30 to 50 years due to an increase in the amount of carbon dioxide and other "greenhouse gases" in the atmosphere. The Beaufort Sea, being in the marginal sea-ice zone, is particularly sensitive to these changes.

The marginal sea-ice zone is characterized by the interaction of atmospheric, cryospheric and oceanographic processes. Simply stated, a global warming trend could result in dramatic changes to the duration and extent of open water in the Beaufort Sea and this would have a considerable impact on the sea-ice and wave climatology in the region. These changes would clearly affect the operation and design activities of the oil and gas industry operating in the Beaufort Sea area.

This exploratory study examines the possible impacts of climate change on the Beaufort Sea Ice regime and the implications for the offshore petroleum industry. Due recognition is given to methodological limitations such as data quality and quantity, cascading errors, and so on. The methodology followed involves:

(1) Constructing three climate change scenarios for the Beaufort Sea region based on two GCMs (CCC and GISS) and one set of instrumental records.

(2) Modelling the sea-ice regime (growth and decay, thickness and concentration) using as input the mean monthly forcing fields (temperature, precipitation and wind) defined in the three scenarios.

(3) Projecting the physical impact of the changes in the sea-ice regime in terms of extent and duration of open water, ice hazards (multi-year and first-year ice ridges, large multi-year floes, ice islands, ice scour and summer multi-year ice incursions) and the deep water wave climate.

(4) Constructing an impact assessment interaction matrix that indicates the sensitivity of petroleum industry activities to the changes identified in the regional climate, the sea-ice regime and the wave regime.

SESSION 7C: NUMERICAL WEATHER PREDICTION II
MODELES NUMERIQUES DE PREVISION II
1530-1630 MANITOBA WEST
WEDNESDAY/MERCREDI

Evaluation of Medium-Range Forecasts with the Canadian Global Forecasting System

H. Ritchie, H. Mitchell, C. Girard and M. Béland, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

During the past year, a global forecasting system has been completed at Recherche en prévision numérique (RPN) and prepared for implementation at the Canadian Meteorological Centre (CMC). This has been a major project involving close collaboration amongst many of the members of RPN and CMC.

The data assimilation and medium-range forecast model is a global primitive equations model using the spectral technique (triangular 79-wave truncation) in the horizontal, linear finite elements (21 levels, variable spacing) in the vertical, with a physical parameterizations that include a planetary boundary layer based on turbulent kinetic energy, a surface layer based on similarity theory, solar and infrared radiation, large-scale precipitation, Manabe-type moist convection, and gravity wave drag. The data assimilation procedure operates in a 6-h cycle and uses a multivariate split three-dimensional statistical interpolation of increments on a global 180 x 90 Gaussian grid to produce analyses of wind components, height and temperature at 15 isobaric levels, and dew-point depression at 6 isobaric levels.

The system has been extensively evaluated in parallel runs at CMC and statistics have been accumulated to assess the impact of converting from the former hemispheric system. Objective verifications will be presented for medium-range forecasts of the conventional fields (pressure, height, temperature, winds and moisture) in comparison with analysed fields, and with radiosonde data for a variety of regions.

Time Integration Technique, Domain, and Resolution Sensitivity Experiments with a Finite-Element Spectral Model

H. Ritchie and C. Beaudoin, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

Recently, Ritchie has shown that the semi-Lagrangian semi-implicit approach can be applied accurately and stably to produce medium-range forecasts in a multilevel spectral primitive equations model using time steps that far exceed the CFL limit for the corresponding Eulerian model. This was demonstrated via intercomparison experiments for a single case using a hemispheric model. This model has been developed further in preparation for implementation as the data assimilation and medium-range forecast model at the

Canadian Meteorological Centre. The present study examines the main extensions made to the model during this work and evaluates their impact through a series of sensitivity experiments on a set of FGGE cases.

The initial control is an Eulerian version of the model with triangular 79-wave truncation and 21 levels with the top at G = 0.01. The changes that are subsequently evaluated are converting from an Eulerian to a semi-Lagrangian time integration scheme, switching between hemispheric and global domains, varying the horizontal resolution, and changing the number of levels and position of the top.

Zonal and Global Mean Diagnostics of the Thermal and Hydrological Behaviour of the Canadian Global Forecast Model

C. Girard, R. Benoit and B. Bilodeau, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

During the past year, a global data assimilation and medium range forecasting system has been completed at Recherche en Prévision Numérique (RPN) for implementation at the Canadian Meteorological Centre (CMC).

An important component of the system is the physical effects package included in the global model. This package was originally developed for the Regional Model used for short-range forecasting over Canada. Hence our concern about the ability of the package to maintain a satisfactory thermal and hydrological balance throughout the extended area covering, in particular, the tropical regions, and for an extended forecast range.

In order to investigate this particular aspect of the forecast performance, we developed a diagnostics package capable of providing zonal and global means of the separate contributions of every physical effect, including infrared and terrestrial radiation, surface and boundary-layer fluxes, convective and stable precipitation and gravity wave drag. Dynamical contributions are obtained as residuals.

SESSION 7D: OCEAN PROCESSES IN THE NORTH ATLANTIC BASIN
PROCESSUS OCEANIQUES DANS LE BASIN DE L'ATLANTIC NORD
1640-1740 MANITOBA WEST WEDNESDAY/MERCREDI

Laboratory Simulations of Deep Convection

D. Brickman, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

Although deep convection is thought to be a regular wintertime phenomenon in particular regions of the ocean, the process itself has rarely been observed. The most successful observations have been in the MEDOC region of the Mediterranean and the Labrador Sea (Gascard, 1978; Clarke

and Gascard, 1983). In all cases a complicated flow field was observed, involving motions on scales from 5 to 50 km. How the various scales develop and interact and how they are affected by rotation are important questions relating to interpretation of observations and our ability to parameterize the downward mixing and spreading associated with the ocean's convecting regions.

A series of laboratory rotating table experiments have been devised to simulate open-ocean convection. These experiments consist of a wire grid heat source at the bottom of a tank of homogeneous fluid. The heat sources range in size from much smaller than the radius of the tank (although not small compared with the external Rossby Radius), to the size of the tank itself. The experiments are designed to study the extent to which the fluid external to the forcing region is involved in the convective process, and how rotation affects open-ocean convection.

An analysis of the relevant non-dimensional parameters for these experiments will be presented, along with a visual presentation of results.

What Drove the Intrusions That Mixed Meddy "Sharon"?
B. Ruddick, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

The intrusions from Meddy "Sharon" were found to be laterally coherent in a sequence of stations extending radially outward. The migration of these intrusions across density surfaces had a distinct pattern, sloping in opposite senses in the upper and lower portions of the Meddy. This pattern was found to be consistent with that expected for the McIntyre (1970) instability for a Prandtl number less than one, in which case mass flux (assumed equal in heat and salt diffusivity) dominates over viscosity. The slopes were also consistent with thermohaline intrusions, in which diffusive fluxes dominate in the upper, diffusively stratified portion of the Meddy, and finger fluxes dominate in the lower, finger-stratified portion. A close examination of the magnitudes of the intrusion slopes shows that these intrusions were outside the range of angles for which the McIntyre mechanism can provide energy to the intrusive motions, so that even a combined "triple-diffusive" instability must have thermohaline double-diffusive fluxes as the energy release mechanism.

Hydrography and Deep Convection in the Labrador Sea
D. Kelley, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

As a background for investigations of deep convection in the Labrador Sea, an analysis was undertaken of the decade-long hydrographic measurements at Ocean Weather Ship Bravo. This site, at the entrance to the Labrador Sea, is seasonally flooded by a surface layer of relatively fresh water. In addition to this seasonal signal, there is considerable

interannual variability, which is of great interest because it might affect wintertime deep convection.

Lazier (1980) noted a strong freshening at Bravo in the early 1970s. The source of the fresh water is thought by Dickson et al. (1988) to mark the arrival in the Labrador Sea of the "Great Salinity Anomaly" (GSA), a pulse of relatively fresh water that propagated cyclonically around the North Atlantic from the late 1960s to the early 1980s. Regardless of the validity of the GSA hypothesis of basin-wide freshening, it is clear that the Labrador Sea freshened significantly in the early 1970s. Theoretically, sufficiently strong freshening can prevent deep convection, so a central question is where the fresh water came from.

Analysis of the OWS Bravo O-S diagrams suggests that the freshwater source was sea ice melted by contact with warm sea water. This possibility can be separated from others, such as precipitation or the melting of ice by solar insolation, by a characteristic signature on the O-S diagram (Moore and Wallace, 1988). The strong signature in the O-S data suggests that the fresh water might have been formed when anomalous wind patterns swept sea ice over warm water. This appears to coincide with an anomalous atmospheric high-pressure cell over Greenland identified by Dickson et al. (1988).

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1915-2100 **WEDNESDAY/MERCREDI**

The Truth About Canadian Winter:
"Canada's climate is nine months winter and three months late in the fall"

D. Phillips, Canadian Climate Centre, Downsview, Ontario

Much of our maligned reputation for climate comes because of our long, harsh winter... Canada's Bogeyman... The Great Canadian Challenge. There is no doubt about it, winter is the dominant season in Canada. But for too long has the myth persisted that winter is nothing but a pain, a curse, and a catastrophe. More often than not, the typical Canadian winter day is invigorating, likeable and liveable.

Winter has helped shape our culture, national identity, Folklore and conversation. It is an economic boon not a bane. The truth is that winters are not what they used to be and certainly not the season-long horrors most Canadians and foreigners perceive them to be. Even a city with a reputation as chilly as Winnipeg can't boast more than 40 tough days each year. Come on Canada, winters aren't so bad!

SESSION 8: PLENARY III/SESSION PLENIERE III
0830-0930 DELTA BALLROOM THURSDAY/JEUDI

Polar Lows
E. Rasmussen, Geophysical Institute, University of Copenhagen, Copenhagen, Denmark
Temporary affiliation: CIRA, Colorado State University, Fort Collins, U.S.A.

Polar lows are small synoptic or subsynoptic cyclonic disturbances that form over the oceans in cold air masses poleward of major jet streams or frontal zones. Baroclinic instability as well as deep convection (CISK) are important physical mechanisms responsible for their development. Depending on the dominant mechanism a whole spectrum of polar low types has been identified ranging from shallow baroclinic waves to "pure" convective systems.

Satellite imagery has shown that polar lows occur much more frequently than previously believed, and that they may be found over large regions of the Northern Hemisphere oceans, including the Davis Strait and the Labrador Sea.

Following a general overview of the dynamics and climatology of polar lows, some polar-low developments over the Davis Strait and the Labrador Sea will be considered, including a discussion of some preliminary results of an investigation applying satellite microwave data from the Special Sensor Microwave/Imager (SSM/I) aboard the U.S. Defense Meteorological Satellite Programme (DMSP) F8 satellite.

The Influence of Arctic Haze and Radiatively Active Trace Gases on the Arctic Climate
J.-P. Blanchet, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

Increasing fossil fuel consumption and industrial activities have raised concerns of possible man-induced climate changes. The changes result mostly from increased radiatively active trace gases (RAGs) and anthropogenic aerosols in the atmosphere. Among the by-products of combustion, carbon dioxide is the leading RAG with an expected global warming of 2° to 4°C within the next century. Due to feedback amplification in high latitudes, most climate models predict that a warming of 8° to 16°C will occur in the Arctic during winter.

Fossil fuel combustion also generates sulphates and soot, the principal constituent of the "Arctic haze". Both CO_2 and Arctic haze interact with radiative processes to produce external climate forcing. Because of their strong affinity to absorb visible solar radiation, soot particles result in strong diabatic heating in the Arctic. With a mixing ratio of 10^{-10}, a concentration 1 million times less than that of H_2O, the solar radiative heating produced by particulate soot is still comparable with that of H_2O.

The Canadian Climate Centre global climate model has been used to simulate climate with a double concentration of atmospheric carbon dioxide scenario. Version II of the CCC-GCM includes a mixed-layer ocean and thermodynamic ice model. It allows for the evaluation of climate changes due to an external forcing. The aim of this paper is to compare the climate changes induced by increasing CO_2 and Arctic haze. Since both signals are occurring simultaneously, we first investigate the individual contributions with a climate model.

SESSION 9A: OCEANOGRAPHY OF THE NORTH PACIFIC
OCEANOGRAPHIE DE L'OCEAN PACIFIQUE
1000-1200 PORTAGE THURSDAY/JEUDI

WOCE Surface Drifters in the North Pacific

D. Krauel, Royal Roads Military College, Victoria, British Columbia
W. Large, National Center for Atmospheric Research, Boulder, Colorado
P.H. LeBlond, The University of British Columbia, Vancouver, British Columbia
G.E. Swaters, University of Alberta, Edmonton, Alberta
R. Thomson, Institute Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

As of January 1991, three deployments of satellite-tracked drifters had already taken place in the North Pacific as part of Canada's contribution to the WOCE Surface Velocity Program. The first deployments took place near Station P in August 1990 and included 7 shallow-drogued (10 m) and 2 deep-drogued (100 m) holey-sock drogues; three more shallow drifters were launched off Kamtchatka by the Akademik Vinogradov in November 1990; five deep drifters were put into the head waters of an Alaskan stream in December 1990.

The fate of drifters launched during the first three deployments as well as others to date will be described; we will discuss what we found, what we plan to do with the data; and our plans for future deployments and coordination with other measurement and modelling programs.

Residual Currents in a Depth-Averaged Model of the Central Strait of Georgia, British Columbia

S.G. Marinone and J.C. Fyfe, Department of Oceanography, University of British Columbia, Vancouver, British Columbia

A one-year numerical simulation using a depth-averaged model of the waters in the Central Strait of Georgia is performed as a first step in a comprehensive modelling study of the three-dimensional residual currents of the area.

Two main features in the model's time-averaged residual currents in the region are a 5-km wide cyclonic eddy bordered on its eastern edge by a relatively strong current

flowing northward in the along-channel direction. A momentum budget analysis reveals that the latter is in near geostrophic balance while the eddy is maintained by a balance between advective and pressure gradient mechanisms. In either case bottom friction effects are negligible presumably because of the large depths in the region. The time-dependent residual behavior is dominated by a fortnightly signal that arises from a non-linear interaction between two diurnal tides, namely K_1 and O_1.

Our model residuals are compared with a seven-month long observational record for currents in the region. The model and observed depth-averaged mean and low-frequency currents have very similar spatial structures and time-variabilities. Despite agreement in these respects the model residual velocities are significantly smaller than the observed. We outline plans for a three-dimensional simulation that will hopefully reconcile these differences and lead ultimately to an improved understanding of the genesis and maintenance of the residual currents in the region.

A Finite-Element Tidal Model for Northern British Columbia Waters

M.G.G. Foreman and R.F. Henry, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

Tides and tidal residuals are calculated with a barotropic finite-element model for Queen Charlotte Sound, Hecate Strait, and Dixon Entrance. All major islands, fjords, and passages are represented with a triangular grid whose resolution ranges from 40 to 1 km. Model results for eight constituents are compared with moored current-meter and tide-gauge observations. Resonance in the region is also examined, and future plans for a three-dimensional model will be discussed.

The Internal Tide off the West Coast of Vancouver Island

P.G. Drakopoulos and R. Marsden, Royal Roads Military College, Victoria, British Columbia

Using data from the Coastal Ocean Dynamics Experiment (CODE) and the Vancouver Island Coastal Current Experiment, the internal tide off the west coast of Vancouver Island was studied. Although the semidiurnal barotropic velocity field in the area was weak, the baroclinic field was found to be relatively strong with speeds up to five times larger. The intermittent nature of the baroclinic field was resolved by estimating the M_2 tidal harmonic coefficients every 24 hours in 15-day overlapping intervals. These time-evolving coefficients were then analysed using spectral analysis methods. For most of the area under investigation, the internal tide was generated mainly at the shelf break and was found to propagate cross shore. For a section off Estevan Point, where the bottom contours are regular, the

beam structure was identified and traced to distances 40 km from the generation region on the slope. The downward-propagating beam was found to follow the seasonal variation of the characteristic propagation paths. An empirical orthogonal function analysis revealed a highly coherent baroclinic field (78% of the M_2 variance). The interaction of a cyclonic eddy, present in the area during August 1980 with the internal tide was also addressed.

Low-Frequency Residual in Knight Inlet - A Fjord of Coastal British Columbia

P.D. Baker and G.S. Pond, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia

Many aspects of the low-frequency response of a stratified inlet have not been previously observed because of the lack of simultaneous observations of wind, currents and density structure over the entire water column. We present here the subtidal response of a high-runoff inlet during the onset of the freshet. Month-long observations throughout the water column, both outside and inside of the sill, were made for the spring of 1988 and the summer of 1989 in Knight Inlet, British Columbia. When diurnal and semi-diurnal tidal energy was removed through harmonic analysis, the dominant response was found to be due to wind, with a coherence of greater than 0.8. A transfer function derived from the cross spectrum was then applied to remove the bulk of the variance due to the wind. The residual current velocity and density structures were then analysed for contributions from both estuarine processes and deep water renewal. Surface layer density decreased with the onset of the freshet, inhibiting entrainment through the resulting increase in stability. Estuarine response was found in the changes to the density structure of the surface layer and in the resulting down-inlet mass transport.

A Topographically Trapped Eddy over Cobb Seamount

H.J. Freeland, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

Cobb Seamount is a shallow seamount in the NE Pacific Ocean. it rises from the ocean floor in 3500 m of water to a plateau about 6 km wide and 150 m deep. The plateau is surmounted by a small pinnacle that rises steeply (bottom slopes up to 40°) to within 24 m of the sea surface. In August 1990, a physical, biological and chemical survey of the waters over and around Cobb Seamount was conducted. This talk will present early results from that survey.

Near-surface drifters show no evidence of trapped features over the seamount, however, an array of three current meter moorings do show evidence of a strong and persistent anticyclonic recirculation around the seamount. The floats sampled the upper water column only; the current meters were all deep.

Water sampling data show clear evidence of an intense layer of high biological productivity, as seen in fluorescence (Chlorophyll A) and light transmission data. Fluorescence and percentage transmission are highly correlated indicating that the light scattering distributions have a biological origin. These distributions show clear evidence of the productivity being tightly bound to the area around the seamount and not being advected into the Pacific interior. This is another indication of a trapped feature around the seamount and suggests a mechanism for the maintenance of the distinct biology around Cobb Seamount and similar features.

Data will also be presented on the evolution of the internal wave spectrum at high frequencies from the slope region over the "shelf-break" and onto the plateau, and with varying distances off the bottom. The current meters show evidence of greatly increased internal wave energy levels near the "break" and very close to the bottom where a large community of filter feeders have been observed.

SESSION 9B: CLIMATOLOGY/HYDROCLIMATOLOGY I
CLIMATOLOGIE/HYDROCLIMATOLOGIE I
1000-1200 MANITOBA EAST THURSDAY/JEUDI

The Impacts of Climate Extremes on the Prairies

K. Jones and K. Hill, Scientific Services Division, Central Region, Atmospheric Environment Service, Regina, Saskatchewan

Climate has significant impacts on numerous areas of socio-economic life in Canada. For example, a prolonged drought can reduce crop yield and hydroelectric production and increase forest fire risk, but on the positive side, it can provide good conditions for construction activities. The impacts can be increased or decreased by other factors such as response mechanisms in the affected sector.

For all sectors, it was found that physical indicators are more strongly dependent on climate than the socio-economic indicators that were analysed. This reflects the fact that, in most sectors of the economy, numerous factors affect economic performance. It was found that there are no "quick and easy" economic indicators of climate extremes. In fact, when climate extreme impacts are looked at, the prevailing situation in the sector or industry, as well as other factors that affect socio-economic performance, should be taken into account.

The Impact of Large-scale Atmospheric Circulations and Anomalies on South Asian Monsoon Drought and Floods and on World Grain Yields

R. Garnett, Canadian Wheat Board, Winnipeg, Manitoba
M.L. Khandekar, Atmospheric Environment Service, Downsview, Ontario

The uncertainties of grain marketing are rooted in the fact that we cannot accurately predict the seasonal weather, which affects the growth of world grain crops and hence the price that the farmers receive for their grain. Reliable climatic precursors for predicting weather over different parts of the world are of considerable economic value in international grain marketing.

Large-scale tropical circulations and anomalies have been shown to have a significant impact on seasonal weather over many parts of the world. In this paper, we have considered the impact of two large-scale features of the tropical atmosphere, namely, the El Niño/Southern Oscillation (ENSO) and statospheric Quasi-Biennial wind Oscillation (QBO) on south Asian monsoon droughts and floods. Our analysis suggest that a large-scale drought in the South Asian monsoon is generally associated with an El Niño condition and an easterly flow in the tropical stratosphere; a large-scale flood, on the other hand is associated with an inverse El Niño condition (known as La Niña) and a westerly flow in the tropical stratosphere.

The impact of ENSO and South Asian monsoon droughts and floods on grain yields has been analysed using world-wide food grains data. It is found that an El Niño event is generally associated with a low grain yield over south Asia and with normal to high yields over the North American Prairies. Implications of this analysis for estimating world grain yields are considered.

North Pacific SST Anomalies and Drought on the Canadian Prairies

B.R. Bonsal and A.K. Chakravarti, Department of Geography, University of Saskatchewan, Saskatoon, Saskatchewan
R.G. Lawford, Canadian Climate Centre, National Hydrology Research Centre, Saskatoon, Saskatchewan

This paper examines the possible teleconnection between North Pacific sea-surface temperatures and synoptic extended dry spells and droughts on the Canadian Prairies. Dry spells are a natural occurrence on the Canadian Prairies. It is a well known fact that extended dry spells often lead to droughts. The major synoptic causes of extended dry spells and droughts on the Canadian Prairies include the presence of a quasi-stationary mid-tropospheric ridge over the area. What causes this ridge to become quasi-stationary is not certain. Some previous studies have shown that sea-surface temperature anomalies over the North Pacific Ocean may be a significant factor in affecting upper atmospheric

long-wave patterns and abnormal weather conditions over North America.

The main purpose of this study is to determine if there is any significant statistical relationship between anomalous North Pacific sea-surface temperatures and the occurrence of a quasi-stationary 500-mb ridge causing extended dry spells and drought on the Canadian Prairies. This analysis is carried out for agricultural growing seasons (May to August) over the period 1948-1988. Individual extended dry spells are identified and then ranked in terms of their severity. Results show a significant correlation between these extended dry spells and a positive sea-surface temperature anomaly gradient located in the east-central North Pacific. They also show that as the persistence of this gradient becomes longer, the probability of an extended dry spell increases.

The Dependence of Daily Precipitation Upon Temperature

G.A. Isaac, Atmospheric Environment Service, Downsview, Ontario
R.A. Stuart, Weather Research House, Downsview, Ontario

Using climatological data from 56 stations across Canada, the dependence of daily precipitation upon temperature has been examined for all seasons. For East and West Coast sites, and for the north, more precipitation occurs with warm and cold temperatures during January and July, respectively. In the middle of the country, the temperature dependence tends to increase towards the Arctic, with strong dependencies in the Northwest Territories and weaker dependencies on the Prairies. Southern Ontario and Quebec show almost no dependence of precipitation upon temperature during July but more precipitation falls during warm weather during the winter. For stations immediately downwind of the Rockies, for all seasons, more precipitation occurs when the temperature is colder. Some physical reasons for these trends have been developed and the implications for climate change will be discussed.

The Regional Evaporation Study Part I: Design and Preliminary Field Test Results

G.S. Strong, Canadian Climate Centre, National Hydrology Research Centre, Saskatoon, Saskatchewan

Areal evaporation is one of the most important hydro-meteorological variables, yet is also one of the most difficult quantities to estimate accurately. For instance, the rate of evaporation from open water on the Canadian Prairies during summer exceeds rainfall by factors of 2 to 6. Since areal evaporation cannot be directly measured operationally, it is usually estimated using various empirical or semi-empirical techniques developed from different sets of physical definitions. Unlike other atmospheric variables, there are, in fact, no measurement standards for areal evaporation.

A series of field studies collectively called the Prairie Evaporation Study, have been proposed to resolve this measurement problem. One such study to be implemented during 1991 is the Regional Evaporation Study (RES). RES will focus on changes in the three-dimensional mesoscale moisture budget, using data from 18 surface datalogger sites in a 25-km grid, and two balloon sounding units providing 2- to 3-hour vertical profiles.

Field tests were conducted during 1990 in order to resolve systematic errors, and to test the concept of using only two sounding systems for vertical fluxes on hot, dry days when horizontal moisture gradients are a minimum. This paper will discuss the validity of the approach proposed in the 1991 RES experimental plan based on results from field tests in 1990.

An Automated Recording Class A Evaporation Pan Comparison Study

S.R. Shewchuk and B.J. Smith, Environment Technology Division, Saskatchewan Research Council, Saskatoon, Saskatchewan

Over the past few years the Saskatchewan Research Council has had a priority to completely automate its climate Reference Station. We have built a prototype automated class A evaporation pan after the procedures of Boughton and McPhee (1987). The water level in the automated Class A pan is detected by a series of electrodes that control a valve that allows water to drain from or be pumped into the Class A pan to maintain a fixed level.

During the summer of 1990, a series of comparison trials were conducted between the SRC automated pan and a co-located manually observed pan. There was quite a good comparison in the data collected, if the comparison was extended over the period of one month or a season. However, the day-to-day direct comparison of data was not as good.

If long-term (monthly) estimates of evaporation are required the SRC automated evaporation pan would be a suitable replacement for the manually observed Class A pan. However, weekly attention must be given to this unit to ensure proper operation and maintenance during the observation period.

SESSION 9C: DYNAMIC METEOROLOGY AND NUMERICAL MODELS
METEO DYNAMIQUE ET MODELES NUMERIQUE
1000-1100 MANITOBA WEST THURSDAY/JEUDI

The Effects of Synoptic-Scale Eddies on the Low-Frequency Flow in the Atmosphere

J. Sheng and J. Derome, Department of Meteorology, McGill University, Montréal, Québec

The interactions between the synoptic-scale eddies (with periods shorter than 10 days) and the slow transients (periods from 10 to 90 days) are studied diagnostically for the winter season. The 300-mb data from 1981 to 1986 analysed by ECMWF are used to calculate the streamfunction tendency of the slow transients due to the vorticity forcing by the synoptic scale eddies. Correlation coefficients between the forcing and the observed fluctuations at different time lags indicate that the interactions between the high- and low-frequency eddies are strongest in the eastern sectors of the Atlantic and Pacific oceans and that the slow transients lag only slightly behind the forcing from the high-frequency eddies. Covariances between the slow transient vorticity and the advection and divergence terms in the vorticity equation are also evaluated. Strong cancellation between the latter two terms is found in the eastern portions of the major oceans, where the influence of the synoptic-scale forcing is significant. A dynamic model is proposed to explain the balance among the effects of advection, divergence, eddy forcing and dissipation.

Non-linear Interactions in Coupled Atmosphere-Ecosystem Models

R.A. Pielke, X. Zeng and R. Eykholt, Colorado State University, Fort Collins, Colorado

Recently as reported in Zeng et al. (1990) we have investigated the non-linear interactions of a simple coupled atmospheric-ecosystem model. Among our results is the conclusion that a chaotic response can occur if the linkage between the biosphere and the atmosphere is sufficiently non-linear. This conclusion is at variance with more traditional ecological concepts including the Gaia hypothesis in which a tendency to equilibrium is supposedly enhanced when the biosphere and atmosphere interact.

At the Congress, we propose to report on our progress in producing a more realistic coupled atmosphere-ecosystem model in which the Colorado State University (CSU) Regional Atmospheric Modelling System (RAMS) is coupled to a CSU regional ecosystem dynamics model.

We also will present results of analyses of atmospheric data in the context of predictability using concepts in non-linear mathematics. Among our results is that temperature

and pressure predictions have error-doubling time-scales of five days and a dimensionality of 10.0.
Reference:
Zeng, X., R.A. Pielke and R. Eykholt, 1990: Chaos in Daisyworld. Tellus, 42B, 309-318.

On Supercritical Bifurcation Due to Non-Modal Instability in Planetary-Scale Motion of a Barotropic Atmosphere
J. Zou and W. Hsieh, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia

A family of equilibrium states, achieved when flow is forced over planetary-scale topography by zonal momentum forcing, is obtained as a function of the momentum forcing strength using the continuation algorithm. Two types of supercritical bifurcation resulting from the instability of these equilibrium states to non-modal disturbances are investigated: (1) periodic equilibrium states from the steady ones and (2) new steady states from the original ones. A sufficient and necessary condition for the existence of such supercritical bifurcation is established. The results are confirmed by the direct numerical simulations.

SESSION 10A: OCEAN DYNAMICS AND MODELS I
DYNAMIQUE OCEANIQUE ET MODELES I
1300-1420 DELTA B THURSDAY/JEUDI

Evidence for Internal Variability With Decadal Time-scale in an Ocean General Circulation Model
A.J. Weaver, Department of Meteorology, McGill University, Montréal, Québec
E.S. Sarachik, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, Washington

A series of numerical experiments involving long time integrations are conducted using the Bryan-Cox Ocean General Circulation Model under mixed surface boundary conditions (i.e. a Newtonian restoring surface boundary condition on temperature and a specified flux boundary condition on salinity). Under steady forcing the system oscillates with significant energy at decadal period. This oscillation is shown to be an advective phenomenon, associated with the propagation of salinity and temperature anomalies from the region between the subtropical and subpolar gyres, where they are generated, to the eastern boundary, where deep water is formed. Furthermore, the oscillation is characterized by the fluctuation of the thermohaline circulation between a state in which deep water is formed and a collapsed state with no deep water formation. Over the period of the oscillation the poleward heat transport changes by as much as a factor of three at certain latitudes. The anomalies are initially formed by the

upwelling of warm, saline waters that are being transported polewards by a western boundary current that has separated from the coast. The observed decadal variability is robust in that it is present in all numerical experiments (12- and 33-vertical-level models; one- and two-hemisphere models; synchronous and asynchronous integrations). Crucial to the existence of the variability is the use of a low vertical eddy viscosity coefficient.

3-D Modelling of Tides in the Gulf of St. Lawrence

H.M. Skåtun, V.G. Koutitonsky and C. Toro, INRS-Océanologie, Rimouski, Québec

A 3-D (multi-level non-linear model is used to study the tidal motion in the Gulf of St. Lawrence. The model is a regular Arakawa C-grid finite-difference model on an f-plane.

The boundaries of the model at Cabot Strait, Belle Isle Strait and in the St. Lawrence Estuary at Taddousac were forced with tidal elevation data (Godin, 1979. Naturaliste Can., 106: 105-121) for the M2 and K1 components in combination with a Flow Relaxation Scheme (Martinsen and Engedahl, 1987. Coastal Engl., 11: 603-637).

We have been able to reproduce the amplitudes and phases well, locating the amphidromic point near Iles de la Madeleine for the M2 component.

We have compared the barotropic response with that of a 4-layer constant-density version of the model to study the vertical structure of the tidal-induced currents at selected stations.

Later stages of the study will include stratified cases, with and without background circulation.

On the Global Stability of Forced and Dissipated Barotropic Flow

J. Zou and J. Fyfe, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia

A truncated spectral model for forced and dissipated barotropic flow in a beta-plane channel is used to derive a necessary and sufficient condition for the monotonic global stability of the model's steady states. Steady states that satisfy the criterion have the distinction that the ratio of disturbance energy to the initial disturbance energy approaches zero monotonically as time approaches infinity, regardless of the size of the initial disturbance energy. Monotonic global stability rules all types of growing disturbances including normal modal, non-modal and finite amplitude growing perturbations.

The method that results in the stability criterion is also used to construct initially fastest-growing disturbances in cases where the criterion is violated. The subsequent time-dependent behaviour of these disturbances is investigated using a non-linear numerical model. The

results are discussed in terms of previous work on multiple equilibria, optimal disturbances and growth-rate bounds.

On the Baroclinic Instability of Cold-Core Coupled Density Fronts on a Sloping Continental Shelf

G.E. Swaters, Department of Mathematics, Applied Mathematics Institute, University of Alberta, Edmonton, Alberta

A theory is presented to describe the linear baroclinic instability of coupled density fronts on a sloping continental shelf. The new baroclinic model equations used to study the instability process corresponds to an "intermediate length-scale" dynamical balance. Specifically, the frontal dynamics although geostrophic are not quasi-geostrophic because frontal height deflections are not small in comparison with the frontal scale height. The evolution of the frontal height is strongly coupled to the geostrophic pressure in the surrounding slope water through the hydrostatic balance, which expresses the continuity of the dynamic pressures across the frontal interface. The deeper surrounding slope water evolves quasi-geostrophically and is coupled to the front by baroclinic vortex-tube stretching/compression associated with the perturbed density front (allowing the release of mean frontal potential energy) and the topographic vorticity gradient associated with the sloping bottom. It is shown that the baroclinic stability characteristics are principally determined by a so-called non-dimensional interaction parameter (denoted μ) that physically measures the ratio of the destabilizing baroclinic vortex-tube stretching/compression to the stabilizing topographic vorticity gradient. For a given along-front mode wavenumber it is shown that minimum μ is required for instability. Several other general stability results are presented: necessary conditions for instability, growth rate and phase speed bounds, the existence of a high wavenumber cutoff, and a semi-circle theorem for the unstable modes. The linear stability equations are solved exactly for a parabolic-coupled density front. A detailed description of the spatial and temporal characteristics of the instabilities is given. For physically realistic parameter values the instabilities are manifested as amplifying topographic Rossby waves in the slope water, and on the density front the unstable perturbations take the form of amplifying anticyclones that have maximum amplitude on the offshore side.

SESSION 10B: CLIMATE MODELS/MODELES CLIMATIQUES
1300-1420 MANITOBA THURSDAY/JEUDI

Changes in the Moisture Budget in a $2XCO_2$ Simulation with the CCC GCM

G.J. Boer, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

The Canadian Climate Centre second-generation atmospheric general circulation model coupled to a mixed-layer ocean incorporating thermodynamic sea ice is used to simulate the equilibrium climate response to a doubling of CO_2. Features of the simulation include the use of higher resolution than for most previous studies of this kind, specification of ocean heat transports for the open ocean and under sea ice, incorporation of information on vegetation and soil type in the treatment of land surface processes and the inclusion of a parameterization of variable cloud optical properties.

The moisture budget of the $1XCO_2$ climate is shown to be reasonably in accord with such observations as exist. Changes to the moisture budget in the $2XCO_2$ case are discussed with attention given to (1) the reasons for the comparatively modest global increase in evaporation and precipitation of 4%, (2) the nature of groundwater changes and the implications of the modified land surface treatment and (3) the behaviour of frozen and liquid components in northern latitudes.

Vegetation Modelling in GCMs

D. Verseghy, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

The development of models to represent the physical behaviour of vegetation within the context of general circulation models has received increasing attention in recent years. An outline is given of a vegetation model that has been incorporated into CLASS ("Canadian Land Surface Scheme"), the new land surface scheme coupled to the Canadian Climate Centre GCM. The vegetation model includes physically based calculations of radiation transmission through the canopy, transpiration, interception of precipitation, and seasonal variation of canopy parameters. A brief summary of these is given, and the impact of the model on simulated values of the terms of the surface heat and moisture budgets is discussed.

Cyclones and the Greenhouse Effect

S.J. Lambert, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

The Northern and Southern Hemisphere winter cyclone climatologies of a $1XCO_2$ simulation and a $2XCO_2$ simulation from the Canadian Climate Centre (CCC) General Circulation Model (GCM) are presented. The climatologies are compared with those of a previous version of the CCC GCM, with observations and with each other in order to determine the effect of increased levels of carbon dioxide on the behaviour of cyclones.

The Canadian GEWEX Programme

R.G. Lawford, Hydrometeorological Processes Division, National Hydrology Research Centre, Saskatoon, Saskatchewan

The World Meteorological Organization through its World Climate Research Programme and the International Council of Scientific Unions are mounting a major long-term study of global energy and water cycles. The programme, known as GEWEX, will involve hydrologists, meteorologists and oceanographers from many countries The global phase of this study (Phase II) will take place over 5 years commencing near the end of this decade after the launch of EOS (Earth Observing System). However, a number of studies will also be undertaken during the first phase of GEWEX between 1992 and the launch of EOS. One major hydrological study involves the GEWEX Continental-scale International Project (GCIP), which will be undertaken in the Mississippi River Basin. Canada is in the process of developing a Science Plan that will complement GCIP and other Phase I international GEWEX projects.

This presentation will outline the needs for a Canadian involvement in GEWEX and the nature and status of plans for a Canadian GEWEX programme. It will also describe the steps being taken to implement a Canadian programme and the opportunities for meteorological and hydrological research within this framework.

SESSION 11A: OCEAN DYNAMICS AND MODELS II
DYNAMIQUE OCEANIQUE ET MODELES II
1445-1645 DELTA B THURSDAY/JEUDI

Topographic Upwelling in Coastal Waters
K.-T. Tee and P.C. Smith, Physical and Chemical Science Branch, Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Nova Scotia
D. Lefivre, Institut Maurice-Lamontagne, Ministère des Pêches et des Océans, Mont-Joli, Québec

Upwelling in coastal waters has frequently been associated with offshore surface and onshore bottom currents. This two-dimensional upwelling can be induced by wind, density and centrifugal forcings. A new upwelling process, named "topographic upwelling", has been found to occur in coastal waters and upwelling is induced by a topographic rectification process. If a tidal current flows over the complex bottom topography, non-linear interactions between the tidal current and the topographic variations produce horizontal and vertical residual currents. The upwelling is generated by the residual currents flowing from deep to shallow waters, and the downwelling by the residual current flowing from shallow to deep waters. This upwelling (or downwelling) involves a three-dimensional process because the water particles, although they are advected onshore from deep to shallow waters in the upwelling regime, may remain in the lower layer and be advected away from the upwelling region by an alongshore current. The vertical transfer of water particles can be very efficient for the topographic upwelling if the area to which the deep water is advected has strong vertical mixing. The combination of the topographic upwelling and strong tidal mixing is the mechanism that produces the observed cold water anomaly off Cape Sable, southwest of Nova Scotia. The existence of this cold-water-producing mechanism is supported by numerical results of a three-dimensional tidal model and field data from hydrographic, current-meter and Lagrangian drift measurements. The mechanism is expected to be important in other coastal areas where strong tidal currents and large variations in bottom topography coexist.

Experiments with Non-Normal Mode Initialization of a Shallow-Water Limited-Area Scheme
R. Juvanon du Vachat, Direction de la Météorologie, EERM/CRMD, Paris, France

A non-normal mode initialization scheme, i.e. an initialization scheme that does not require an explicit computation of the normal modes of the linearized equations, is considered (Temperton 1988; Juvanon du Vachat 1988). Such a scheme is applied to a shallow-water limited-area

model cast on a stereographic projection, for which the computation of the normal modes is too expensive because of non-separability. In the case of a limited-area model the relaxation scheme is used in a boundary zone to prescribe the large-scale evolution. At first a model, the domain of which has a very limited extent (1750 km x 1750 km), is considered and the initialization scheme successfully filters the gravity waves from the simulations. Particular attention is given to the choice of an initialized or uninitialized field for the relaxation target; the coherence of the initialization scheme with the semi-implicit scheme of the model, and the effect of the orography in such a shallow-water model. Then we consider a model with an enlarged domain (10,000 km x 10,000 km), with the preceding regular grid domain at the centre and a stretching grid up to the boundaries. In that case we test the impact of using a linearization including most of the ß-terms, against one without ß-terms for the initialization of such a model. The impact of the comprehensive scheme appears less than the impact of using an initialized field for the relaxation, even with such a large domain. In the two model cases we present the behaviour of the diagnostic quantities used to test the convergence of the initialization scheme during the simulations that confirm the main results of the study (Juvanon du Vachat 1989, 1990).

The Role of Mixed Boundary Conditions in Numerical Models of the Ocean's Climate

A.J. Weaver, Department of Meteorology, McGill University, Montréal, Québec
E.S. Sarachik, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, Washington

Several numerical experiments are conducted, using both single and double hemisphere ocean basins under symmetric steady forcing and using low vertical eddy viscosity, to study the ocean's thermohaline circulation. It is shown that a stable steady state obtained under a restoring surface boundary condition on salinity becomes unstable upon a switch to a flux boundary condition. It is shown that further integration of this collapsed state ultimately yields a steady, stable one-cell circulation with the approach being essentially chaotic.

A single 12 vertical level hemispheric basin, spun up from an initial state of rest under mixed boundary conditions, never reaches a steady state. Three characteristic stages are observed in the integration: a stage where the system oscillates with decadal time-scale, a stage when the system undergoes a violent overturning flush, and a quiescent stage in which either deep water is forming or the thermohaline circulation is in a collapsed state. These three characteristic stages are also present in 33-level single and double hemisphere runs. Upon increasing the resolution to 33 levels a steady state is reached. The

resulting steady state is fundamentally different from the one obtained under the same resolution and restoring boundary conditions.

It is further shown that a steady state that is stable under mixed boundary conditions becomes unstable upon a switch in the surface tracer time-step. Under restoring boundary conditions no such instability arises.

The implications of the present study for future ocean climate models are discussed.

Sensitivity Studies of a Relaxation-Type Open Boundary Condition For Ocean Models

H.M. Skåtun, INRS-Océanologie, Rimouski, Québec

The flow relaxation scheme (FRS), proposed as a semi-open lateral boundary condition for ocean models by Martinsen and Engedahl (1987: Coastal Engl. **11:** 603-637) is studied. This scheme involves a relaxation zone in which the dynamic solution for the interior domain is relaxed to specified values at the boundary.

The FRS is determined by two important parameters: the width of the relaxation zone and the shape of the relaxation parameter, which varies from 1 at the boundary to 0 at the interior domain. The width of the relaxation zone should be kept as small as possible, because wide relaxation zones will increase the computation time and memory requirements.

We have studied the effect of varying these two parameters in two test types: (1) to see how outgoing waves are damped or reflected, and (2) to see how much the specified flow at the boundary is damped before reaching the interior of the domain.

Development and Application of a Three-Dimensional Circulation Model Using a Direct Stress Solution Over the Vertical

R.A. Luettich Jr. and S. Hu, Institute of Marine Sciences, University of North Carolina at Chapel Hill, Morehead City, North Carolina
J.J. Westerink, Department of Civil Engineering, University of Notre Dame, Notre Dame, Indiana

A brief overview will be presented for a new formulation of the direct stress solution (DSS) technique. (The DSS technique allows a numerical solution to be sought for the vertical variation of shear stress rather than velocity in a three-dimensional circulation model.) Whereas the original DSS formulation uses a spectral solution of equations generated by subtracting the vertically integrated governing equations from the three-dimensional governing equations, (Luettich and Westerink 1991), the new formulation uses a linear finite-element solution of equations generated by taking the vertical derivative of the three-dimensional equations. The new formulation yields banded system matrices and greatly simplifies the closed-form recovery of

velocity from stress. Comparisons will be presented of the efficiency and accuracy of the new DSS technique versus a standard finite-element velocity solution for computing velocity profiles, bottom stresses and momentum dispersion terms using simple test cases. An initial application will be presented of a three-dimensional DSS model of the North Sea-English Channel system.

Closure Modelling of Forced-Dissipative Statistical Equilibrium of Large-Scale Quasi-Geostrophic Flows over Random Topography

J. Zou, Department of Oceanography, The University of British Columbia, Vancouver, British Columbia
G. Holloway, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, British Columbia

A closure model is used to study the statistical equilibrium established when flow is forced over random topography by an external uniform zonal momentum source. Two aspects of the equilibrium are singled out for consideration: (1) the correlation between the topography and the vorticity field and the resulting topographic stress acting on the forced-dissipative equilibrium flows; (2) the dynamic balance involved in maintaining such an equilibrium. The closure results are compared with those from an ensemble of direct numerical simulations.

The feasibility of parameterization of topographic stress due to subgrid-scale topographic features in a coarse resolution model is discussion.

SESSION 12A: CLIMATOLOGY/HYDROCLIMATOLOGY II
CLIMATOLOGIE/HYDROCLIMATOLOGIE II
0830-1010 PORTAGE FRIDAY/VENDREDI

The Relationship Between Regional Freeze-up and Break-up of Lakes and Mean Air Temperatures in Canada

W.R. Skinner, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

The Atmospheric Environment Service (AES) database of observed dates of lake surface ice condition is analysed to determine the statistical properties of the lake ice data, to examine the degree of statistical relationship between composite lake ice condition dates and mean air temperatures, to examine composite lake ice condition time series in order to detect any evidence of regional climatic change or variability and to provide baseline climate/cryosphere relationships upon which impact-related hypotheses might be developed. Eight lake ice regions are defined and strong statistical relationships are established between composite lake ice conditions and air temperatures from a station, or stations, in that region.

Regional lake ice conditions appear to be useful indicators of temperature changes in that region during the

transition seasons. From the developed regression equations, a five-day change in the Great Slave Lake freeze-up date represents a 2°C change in mean October air temperature. Similarly, an approximate five day change in break-up date represents a 2°C change in mean May air temperature. A 2°C increase in average spring-fall mean air temperature represents an approximate 10-day reduction in the duration of the regional lake ice season. Similar ice regime changes are found in the other defined lake ice regions.

In future work, surface lake ice data can be used as ground truth for more spatially and temporally consistent satellite monitoring of lake surfaces. Also, they can be used to assist in model development for use with other lakes where there are either no surface data or unreliable data. Subsequently, an evaluation of the impact of observed or suspected trends in regional environmental conditions upon regional lake ice conditions can be made.

New Weather Normals for the Eastern Prairies: Warmer and Cooler, Wetter and Drier Than it Used to Be

R.L. Raddatz, J. Maybank and G.B. Atkinson, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba

Tentative 1961-90 normals of annual and monthly mean daily temperatures have been compiled for nine stations on the eastern Canadian Prairies and compared with 1951-80-normals and to previous values. For 1961-90, the areally averaged annual mean daily temperature normal shows a marked warming - ending a cooling trend that extended through three successive normal periods (1931-60, 1941-70 and 1951-80). The areally averaged monthly normals indicate that warming occurred for the first six months of the year over comparable values for the 1951-80 period. The warming became negligible in July and August, and reversed to cooler weather, on average, for the last four months of the year. The cooling was especially pronounced for December, with the areally averaged 1961-90 monthly mean daily temperature normal being the lowest recorded for any normal period since records began on the eastern Prairies.

Tentative 1961-90 normals of annual and monthly mean precipitation totals have been compiled for the same nine stations. The areally averaged annual totals show a marked inverse relationship with the temperature data, with the warmer 30-year periods tending to be drier, and vice versa. For precipitation there is no "winter reversal"; at nearly all stations the months of November to March have become drier. The spring period has become somewhat drier, but not so for summer where a tendency towards wetter Julys counterbalances the trend toward drier Junes.

Blowing Snow Transport and Sublimation on the Prairies

J.W. Pomeroy, National Hydrology Research Institute, Environment Canada, Saskatoon, Saskatchewan
D.M. Gray, Division of Hydrology, University of Saskatchewan, Saskatoon, Saskatchewan

A physically based simulation of blowing snow transport and sublimation processes over level terrain, the Prairie Blowing Snow Model (PBSM), was used to calculate annual quantities of (a) snow blown to the edge of and (b) snow sublimated whilst blowing off prairie fields. The PBSM used measurements of snowfall, wind speed, temperature and humidity for hours in which blowing or drifting snow occurred at sixteen AES stations for the years 1970-1976. Field conditions of fallow and 25-cm high wheat stubble and various uniform fetch distances were used in the simulation.

The results of the simulation show appreciable amounts of snow are lost to transport and sublimation, though the amounts vary across the prairie region. For example at Yorkton in the relatively wooded parklands, 36% of annual snowfall is removed from a fallow field whilst 23% is removed from stubble. On the southern Prairies losses are greater: at Regina 77% of annual snowfall is removed from fallow and 53% removed from stubble. Whilst the snow removed per unit area does not increase notably as uniform fetch increases, the amount sublimated rather than transported off the fetch increases dramatically with fetch. For instance, at Regina the annual snowfall sublimated and transported off a 1-km fallow fetch is 41% and 36%, respectively; however, on a 4-km fallow fetch sublimation increases to 72% and transport declines to 8%. These findings are useful in relating winter precipitation to the snow supply available for melt in the spring and in evaluating the effect of land-use practises on Prairie water supply.

Simulation of a Prairie Snowpack: Snowmelt Revisited

C. Fisher and R.F. Hopkinson, Scientific Services Division, Central Region, Atmospheric Environment Service, Regina, Saskatchewan

In 1980, Louie and Hogg presented a method for computing extreme snowmelt or rain plus snowmelt events. That formed the basis for a standard product, the 1- to 30-day rain plus snowmelt analysis, which is available from the Canadian Climate Centre (CCC). The analysis uses daily climatological data available from any station with a temperature and precipitation observing program. However, testing of the program on Regina data revealed some unrealistic features.

A thorough review of the assumptions used in the CCC algorithm was conducted including the snowmelt equation and the assumed snow water equivalent of daily snowfall. The sensitivity analysis and the comparison of the simulated

snowpack with actual daily snow on the ground and twice monthly snow-course data led to significant improvements and an algorithm appropriate to the southern Prairies.

The Influence of Spring Weather on Red River Floods
A. Warkentin, Water Resources Branch, Manitoba Department of Natural Resources, Winnipeg, Manitoba

Ever since the earliest known trading posts were established near the junction of the Red and Assiniboine Rivers in 1738, devastating floods have periodically occurred at this location, which is presently the City of Winnipeg. The flood of 1826 devastated the Red River Settlement and did great damage to Fort Garry of the Hudson Bay Company. The more recent flood of 1950 produced damage of 572 million dollars (basis 1990) in the Winnipeg area alone. Completion of major flood control works such as the Red River Floodway and the Portage Diversion in the late 1960s has prevented major flooding in the City of Winnipeg during the last 20 years or so. However, these structures do not ensure that flooding will never again occur in the City.

This presentation will briefly review the hydrometeorology of major historical floods on the Red River in Manitoba as well as that of more recent floods. The effect of major flood control works on Red River levels in the Winnipeg area since 1969 will be shown along with the damages prevented by these works.

There are many causal factors that make the Red River susceptible to spring floods, such as a flat topography, clay soils and a long snow accumulation period. However, one of the most significant factors is the spring weather. Melt rates and rainfall amounts and their spatial and temporal distribution have major effects on the flood potential. The importance of these factors will be described with reference to specific historical events.

SESSION 12B: AIR QUALITY AND BOUNDARY-LAYER METEOROLOGY I
QUALITE DE L'AIR ET METEOROLOGIE DE LA COUCHE LIMITE I
0830-1010 DELTA B FRIDAY/VENDREDI

A Gas-Phase Chemistry Module for a Regional Transport Model: Numerical Schemes and Applications
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An efficient integration scheme is being designed for the gas phase chemistry module of the regional tropospheric chemistry model being developed at the University of Toronto. The chemistry reaction set used in the module is adopted from RADM of NCAR, which consists of 46 chemical species and 81 reactions. The rate equations for these

chemical species are numerically stiff, and the integration of the chemical system in the 3-D regional model is very difficult because it is extremely demanding for efficiency. In this paper a number of numerical schemes that were implemented for the RADM system will be discussed and compared. It will be shown that the chemical species in the system can be grouped into three categories according to their atmospheric lifetime, ie. "quasi-equilibrium species" whose time constants are in seconds or shorter, "slow species" whose time constants are in hours or longer and "intermediate species". By using different numerical schemes in each of these categories, the integration of the chemical system can be carried out quite efficiently with reasonable accuracy. Some applications of the gas-phase chemistry module to special problems will also be presented.

LRTAP: "P" Could also Stand for Pathogenic Viruses

R.L. Raddatz, Scientific Services Division, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba;
G.W. Hammond, University of Manitoba and Cadham Provincial Laboratory, Winnipeg, Manitoba

Pathogenic viruses are responsible for nearly 60% of all the cases of contagious disease in humans and they spread a variety of infections in animals. The success of measures to minimize the health and economic impacts of these diseases depends on an understanding of how viral infections are spread. Atmospheric transport may be the vehicle of the spread of certain infectious viral diseases provided that: (1) there is a high emission of viral aerosols from the source, (2) the virus can survive the aerosolization process and remain viable and airborne long enough to allow transport to a susceptible host, (3) an appropriate atmospheric pathway exists and (4) there is high infectivity at low viral aerosol concentrations. These conditions appear to be met for influenza viruses and certain enteroviruses, among others. It is postulated that intercontinental transport of airborne aerosolized influenza viruses from the Far East to North America may contribute to the spread, persistence and ubiquity of the disease, the explosiveness of epidemics and the prompt region-wide occurrence of outbreaks, and that seasonal changes in circulation patterns and the dispersive capability of the atmosphere may help to explain the regular annual cycle of influenza activity - characteristics not explained by current theories of influenza epidemiology. The apparent out-of-season isolation of the coxsachie A9 virus in Manitoba in 1988 may be explained by the antecedent synoptic weather pattern, lending support to the hypothesis that regional airborne transport may play a role in the seasonality and geographic pattern of non-polio enterovirus infections in North America. These and other investigations, along with the demonstrated microscale dispersion of many viruses, suggest that, like air pollution, the airborne spread of pathogenic viruses may be

a problem that extends from the local to the intercontinental scale.

Factors Influencing Precipitation Chemistry
N.C. Treloar, Scientific Services Division, Central Region, Atmospheric Environment Service, Winnipeg, Manitoba

Networks such as CAPMON (the Canadian Air and Precipitation Monitoring Network) measure the ion content of rain and snow deposited by atmospheric transport processes.

The ion content of these precipitation samples is characteristic of different sources (sea salt, wind-blown soil, land use, anthropogenic sources, etc.). Statistical results are reported that characterize (a) the source type and (b) the extent of meteorological influences.

Micrometeorology in the Fraser Valley Near Prince George, B.C., and the Effect on Air Quality
W. McCormick, Waste Management Branch, Ministry of the Environment, Province of British Columbia, Prince George, British Columbia

Three Kraft pulp mills are located in the Fraser River valley within the city limits of Prince George, British Columbia. The two CanFor mills are located adjacent to the downtown area and the Northwood mill is located about 5 km to the north. Air quality problems due to TRS compounds have plagued the town in spite of reductions in the emissions from the large stacks at the mills. BC Environment has three wind stations between the mills and the town and an analysis of these data has shown that micrometeorological effects (due to the interactions between the valley flows and synoptic forcing) are responsible for some of the long-term air quality problems. This problem could not have been detected beforehand without the use of on-site meteorological monitoring or a detailed PBL-type model.

Aerial Inputs of Polycyclic Aromatic Hydrocarbons to Lake Sediments along a Transect from the U.S. Border to Northern Ellesmere Island
W.L. Lockhart, G.J. Brunskill, P. Wilkinson and B.N. Billeck, Department of Fisheries and Oceans, Central and Arctic Region, Winnipeg, Manitoba

Sediment cores were collected from lakes at the Experimental Lakes Area (ELA) of northwestern Ontario (49N), Saqvaqjuac N.W.T. (63 N), Cornwallis Island, N.W.T. (74 N) and northern Ellesmere Island N.W.T. (82 N). Cores were sliced at the time of collection and slices were analyzed separately for radioisotopes of lead and cesium to allow dating, and for a range of metals, organochlorines and polycyclic aromatic hydrocarbons (PAHs). The total-PAH profiles from two lakes

at the Experimental Lakes Area showed intermediate values in slices from the tops of the cores, peak values a few slices down corresponding to the middle years of this century, with a decline to lower values in deeper, older slices. The profile from Saqvaqjuac was essentially the same, with all values being reduced from those observed at ELA. Similar profiles have been reported from eastern North America, and they have been interpreted as reflecting residential coal heating in North America. The profile from Cornwallis Island had all values below those from Saqvaqjuac with an increase in only the top two slices. The time resolution was poorer due to the low sedimentation rate in these lakes, and so the recent decline in PAHs seen at ELA and Saqvaqjuac may have been obscured. The profile from Lake Hazen on Ellesmere Island was very different from the other arctic sites. The PAH levels were almost as high as those at ELA and there was no evidence either of the recent decline in surface sediments or of the rapid increase in the early part of the century. Rather there was an almost continuous, regular increase in PAHs throughout the century. We interpret this tentatively as indicating that Lake Hazen has been influenced predominately by Eurasian sources with longer histories than North American sources.

SESSION 12C: OCEAN DYNAMICS AND MODELS III
DYNAMIQUE OCEANIQUE ET MODELES III
0830-1010 MANITOBA FRIDAY/VENDREDI

Laboratory Measurements of the Drag of Two-Dimensional Obstacles in a Two-Layer Flow

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B.J. van Hardenberg, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

Drag force measurements are presented for a "Witch of Agnesi" family of two-dimensional topographic models of fixed height with increasing surface slopes in both a two-layer density system and in homogeneous flows. The range of flow speeds explored covers the Froude number range from subcritical through to fully supercritical. The force measurements are augmented by detailed observations of the interface distortion. The results clearly show the large increases arising from the internal systems generated in the stratified flow, and are discussed in the context of simplified theories.

Tidal Circulation Computations for the Western Atlantic Shelf and Gulf of Mexico

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R.A. Luettich, Jr., Institute of Marine Sciences, University of North Carolina at Chapel Hill, Morehead City, North Carolina
A.M. Baptista, Department of Environmental Sciences and Engineering, Oregon Graduate Institute, Beaverton, Oregon
N.W. Sheffner, Coastal Engineering Research Center, Department of the Army, Waterways Experiment Station, Vicksburg, Mississippi

The development of a tidal circulation model which encompasses the entire western North Atlantic continental shelf, the Gulf of Mexico and the Caribbean is discussed. The overall modelling strategy used incorporates the definition of a very large computational domain, a high degree of selective grid refinement and the use of highly accurate and robust finite element discretization techniques.

The concept of applying a computational domain which has an eastern boundary that extends from Glace Bay in Nova Scotia to Port of Spain in Trinidad and includes all waters to the west bounded by the North and South American eastern coastlines has a variety of important advantages. First of all, the use of complex and highly variable cross shelf boundary conditions is avoided. Secondly, the well defined eastern open ocean boundary can be driven using deep ocean results from global tidal and/or current models. Furthermore, regional winds do not dramatically affect sea surface elevation beyond the continental shelf. Therefore, storms such as hurricanes can easily enter the computational domain without necessitating the specification of an adjustment on elevation boundary conditions due to wind. Consequently a simple inverted barometer can be used for regional atmospheric pressure field variations. Finally, longwave energy generated due to non-linear processes on the continental shelf will be for the most part reflected back towards land because of the abrupt bathymetry change at the continental shelf edge. Since the eastern boundary of the computational domain is well beyond the continental shelf, this will again simplify the specification of tidal boundary conditions with respect to their non-linear energy content.

The model applies a very high degree of selective grid refinement. The open ocean is discretized with a relatively coarse mesh; the continental shelves are increasingly more refined, depending on depth; and the near coastal regions are very highly refined. The premise of this strategy is that shallow water waves are shorter and slower in shallow water. Furthermore, the coastal boundary and bathymetry will dominate near coastal circulation pattens and will regionally shift the energy spectrum to a higher wave number content since the flow at the land boundary must, at a minimum, comply to the form of the land boundary. These

concepts have been demonstrated by investigators such as Le Provost and Vincent (1986) and Signell (1989).

Finally, the model applies the finite-element (FE) method to numerically discretize the governing shallow water equations such that a very high degree of grid size variability can be conveniently achieved. The wave-continuity equation (WCE) formulation of Lynch and Gray (1979) has proven to be by far the optimal technique to formulate FE based shallow water equation codes. Thorough testing, extensive analysis and detailed field applications have demonstrated the unique advantages of these formulations in terms of achieving a concurrent high level of computational accuracy and efficiency.

Non-Linear Propagation of Locally-Generated Tsunamis in the Pacific Northwest Coast: Sensitivity Analysis

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C.D. Peterson, Geology Department, Portland State University, Portland, Oregon
J.J. Westerink, Civil Engineering Department, University of Notre Dame, Notre Dame, Indiana

We are currently investigating the propagation of locally generated tsunamis in the Pacific Northwest Coast, using a cross-disciplinary approach that combines hydrodynamic modelling and geologic verification. The main motivation for the study stems from newly found evidence that the Cascadia Subduction Zone, off the Oregon and Washington coasts, has experienced significant, even if infrequent (recurrence period of about 3-4 centuries), seismic events.

The research strategy is to use hydrodynamic models of tsunami generation, propagation, and run-up, to help interpret tsunami and subsidence sediment deposits, which have been systematically identified and characterized in several estuaries and bays along the Oregon and Washington coasts.

This research can be used to estimate the magnitude of past earthquakes, by characterizing the length of the fault from the associated tsunami events. In addition, the research will assist in interpreting (for past events) and eventually predict (for future events) the extent and the time lag (relative to earthquake occurrence) of the inundation in estuaries and coastal embayments from Southern British Columbia to Northern California.

A very unusual challenge posed by this investigation concerns the incompatibility between the time-scales of tsunami propagation (hours to days) and the accuracy of C^{14} dating of sediment deposits (tens to hundreds of years). Also, sediment deposits are best preserved and identified inside estuaries and coastal embayments, i.e. in areas where wave run-up and strong flow non-linearities are expected; yet, tsunami propagation is best understood and has been

best simulated in deep, open waters, where linear processes are dominant.

Two hydrodynamic models for tsunami generation and propagation have been developed, and are being explored. One of the models is 2-D, depth averaged, and is based on the finite-element solution of the shallow water equations, for the entire region of study; land boundaries are currently treated as rigid walls, hence inundation and run-up are not yet described.

The second model is 1-D, based on the same equations (with $v=\partial/(\partial y) = 0$), and is being used as an auxiliary tool, to gain insight on (a) the numerical treatment of the source mechanism, (b) the effect of non-linear mechanisms and couplings (e.g. tides and tsunamis), and (c) the description of inundation and run-up. Results of the 1-D model (in particular, points a and c), will guide further development of the 2-D model.

We will use advanced scientific visualization tools to summarize the results to date of both models, and to discuss the implications of these results to the understanding of the propagation of locally generated tsunamis in the Pacific Northwest Coast. Emphasis will be placed on the effect of the source representation on wave amplitude, and on the importance of non-linear mechanisms.

Indonesian Throughflow and Its Effect on the Climate of the Indian Ocean

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An idealized box model of the Indian Ocean forced by steady winds and Haney-type surface heat fluxes is used to examine the importance of the warm fresh throughflow from the equatorial Pacific on the climate of the Indian Ocean. In particular, the hypothesis proposed by Godfrey and Weaver (1991), that the buoyancy-forced Leeuwin Current off the west coast of Australia is a manifestation of a basinwide thermohaline circulation driven by the Indonesian throughflow, is examined.

The stronger Sverdrup circulation dominates the thermohaline circulation in most of the model ocean except near the eastern boundary. The effects of the throughflow can, however, be determined by comparing two runs forced by a Pacific Ocean with either the warm, fresh profile of the western equatorial Pacific or a cooler, more saline profile more typical of the eastern equatorial Pacific. It is found that heat imported from the Pacific is transported zonally all the way across the Indian Ocean to the western boundary by the South Equatorial Current (SEC). The enhanced meridional steric height gradient south of the SEC drives an eastward return flow back to the eastern boundary, where it turns south to form the poleward Leeuwin Current. The reverse path is traced out by the waters immediately below

the thermocline. None of these features are observed when the Pacific has the cooler profile typical of the eastern boundaries of other oceans.

The poleward western boundary current along the coast of Africa appears to play only a very minor role in this basinwide thermohaline circulation unlike in the "warm water route" proposed by Gordon (1986), where heat is returned to the South Atlantic past the Agulhas Retroflection.

Indonesian throughflow is shown to affect the surface heat fluxes significantly and the meridional heat transport in the Indian ocean. The role of the throughflow in maintaining the very warm climate of the Indian Ocean (a net exporter of heat) is described.

Time and Space Variability of Thermal Fronts in Hecate Strait, British Columbia

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Surface thermal fronts in the Hecate Strait region are readily visible in AVHRR (Advanced Very High Resolution Radiometer) satellite images. The position and gradients of these fronts vary in time and space. The extent to which tidal mixing contributes to the formation and evolution of these fronts is examined by mapping the stratification parameter, $\log(h/u^3)$, where h is the water depth and u is an rms tidal speed. This parameter is the ratio of the vertical stabilizing effects of buoyancy fluxes (i.e. solar insolation, precipitation and runoff - presumed to be time and space invariant, for now) to the vertical mixing effects of tidal currents. The location of tidally mixed fronts, the boundaries between vertically mixed and stratified regimes, may be inferred from contours of the stratification parameter.

A finite-element tidal model of Hecate Strait provides rms magnitudes of the M_2 tide, "total" tide (eight constituents), and total tide at the spring and neap phases. Maps of the stratification parameter, using each of these rms tidal speeds are presented and compared with thermal gradients observed in over 50 AVHRR images obtained from 1987 to 1991. The time and space variability of the observed fronts are discussed with respect to the variability of mechanisms forcing the "tidally-mixed" fronts (i.e. tides, winds and buoyancy fluxes).

SESSION 13A: HUMAN IMPACTS ON CLIMATE
IMPACTS ANTHROPOGENIQUE SUR LA CLIMAT
1040-1200 PORTAGE FRIDAY/VENDREDI

Will Kuwait Oil Fires Cause Early Frosts in Western Canada?
W.F.J. Evans, Environmental Resource Studies, Trent University, Peterborough, Ontario

The possibility that the Kuwait oil fires will cause early frosts in western Canada this fall is examined. Smoke is being emitted into the troposphere at over 30 kt per day from over 800 oil well fires. If these smoke particles do not rain out rapidly, the entire troposphere may become filled with carbon smoke particles and the associated optical depth may be increased by 0.3 to 3%. Although daytime temperatures may not be noticeably reduced, the resulting attenuation of sunlight may result in earlier frosts in the fall. A radiation energy balance model has been used to calculate the change in minimum night-time temperatures. If the optical depth increases by 1%, a 0.4°C cooling may occur, which could cause a 3-day advance in the date of first frost. However, considering the standard deviation of the natural variability, if a 3% increase in optical depth occurs, there would be two chances in three of a frost one week earlier than usual; this could cause minor crop damage in western Canada. Although this is expected to be a marginal effect, a project to monitor the optical depth of the smoke using satellite data should be commenced immediately because of the uncertainties in the situation.

The Potential Climatic and Other Atmospheric Effects of Middle East Oil Fires
R.K.R. Vupputuri and J.-P. Blanchet, Climate Modelling and Diagnostic Studies Division, Canadian Climate Centre, Downsview, Ontario

A coupled 1-D radiative-convective-photochemical diffusion model that takes into account the wavelength-dependence of the interaction between the aerosols and solar radiation is used to investigate the possible climatic and other atmospheric effects of smoke generated from the burning of Kuwaiti oil fields in the Gulf War. The 1-D experiments were carried out using five levels of smoke concentration with optical depths ranging from 0.006 to 5.0. The results indicate that the absorption of solar radiation by soot aerosols with optical thicknesses greater than one, would lead to intense heating of the upper troposphere (up to 70 K) with substantial cooling near the ground (up to 30 K) thus creating strong thermal stability in the smoke-polluted atmosphere. At a lower smoke optical depth, the results support the concept of threshold smoke loading below which the soot aerosols would lead to slight warming rather than cooling near the ground. Also discussed are the

implications of high levels of CO and NO_X in the smoke-polluted atmosphere to changes in vertical ozone distribution and climate at the surface.

Assessment of the Effects of Middle East Extensive Oil Burning Using 1-D and CCC/GCM2 Models

J.-P. Blanchet and R.K.R. Vupputuri, Climate Modelling and Diagnostic Studies Division, Candian Climate Centre, Downsview, Ontario

Extensive oil burning in Kuwait generates about one megaton of oily soot per month. This dense black smoke considerably reduces the insolation at the surface and alters the regional weather conditions. In an initial stage the CCC/GCM2 and the 1-D radiative-convective model have been used to evaluate the strength of the radiative and climate forcing terms at five space scales of dimension ranging from local to global scale. The resulting surface temperatures from the two models are consistent. In the second stage, the GCM calculations are extended over seven months integration for an assessment of the response of the monsoon to consequent changes of temperature and snow cover.

A Strategy to Compensate for Global Warming

W.F.J. Evans, Environmental Resource Studies, Trent University, Peterborough, Ontario

The greenhouse warming is now recognized to be imminent by many climate experts. It appears that in the future, it may be necessary to intercede in the climate balance of the earth in order to compensate for the warming expected due to the buildup of greenhouse gases in the atmosphere. There may be a practical means to compensate for this increased greenhouse effect; this could be achieved by enhancing the natural aerosol layer in the stratosphere to cool the surface by a corresponding amount. This would be accomplished by adding about 25 Mt of COS to the troposphere each year. This would increase the tropospheric COS levels from current levels of 0.5 ppbv to 25 ppbv. It is demonstrated that it is feasible to augment the stratospheric layer by at least an order of magnitude for a reasonable cost.

A research program should be commenced as soon as possible in order to explore the feasibility of this option. This would require experimental measurements as well as specialized modelling. However, the problem of climate warming appears to be so grave that this approach should be considered very seriously because efforts to reduce CO_2 emissions seem to be progressing little. Anthropogenic emission increases of OCS may already be enhancing the aerosol layer; it is estimated that an increase of 0.1% in the optical thickness of the atmosphere has occurred already. Thus, we may already be partially compensating for the greenhouse effect inadvertently. A review of other

environmental impacts would have to be conducted before action is commenced, even though the action would be within the technical capability of several of the larger nations.

SESSION 13B: AIR QUALITY AND BOUNDARY LAYER METEOROLOGY II
QUALITE DE L'AIR ET METEOROLOGIE DE LA COUCHE LIMITE II
1040-1200 DELTA B FRIDAY/VENDREDI

Atmospheric Wave Motions Above and Within a Natural Black Spruce Forest Canopy

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B.D. Amiro and F.L. Johnston, Environmental Science Branch, Whiteshell Laboratories, AECL Research, Pinawa, Manitoba

Fast-response measurements of wind velocity and air temperature were made under stable atmospheric conditions at various heights above and within a natural black spruce canopy in southeastern Manitoba. Downwind, crosswind and vertical (w) wind velocity components were measured at heights of 2 and 6 m on an 18-m tower using sonic anemometers, and at 12 and
18 m using propeller anemometers. A profile of mean air temperature was obtained from seven thermocouples mounted between 1.4 and 18 m on the tower. Vertical wind velocities were also measured using one-dimensional sonic anemometers mounted at the 6-m level on two additional towers located about 15m on either side of the main tower. Tree crown heights in the canopy were less than 12 m.

About 70 runs lasting from 30 to 45 minutes were made at night and in the winter when the atmosphere was stably stratified. In 11 of these runs, periodic motions were clearly evident in some time series, particularly in the signals from the 6-m level and, to a lesser extent, the 2-m level. Individual wave events lasted from a few minutes to the full length of a run. Preliminary analysis of the time series indicates that the wave period is typically about 35 s. Cross-correlation of the w time series from the main tower and the two satellite towers suggests that the phase speed of the waves is about 1 m/s, so that the wavelength is about 35 m.

The waves tend to occur when the mean wind speed and air temperature profiles within and above the canopy have characteristic shapes. The temperature profile is typically isothermal within the canopy, with a strong inversion across the top of the canopy and a weaker inversion aloft. The maximum gradient occurs at about 8 to 9 m. Mean wind speeds are generally very low within the canopy, but increase steadily above the canopy to values of 2 m/s or more at 18 m. Wind speed gradients are largest at about 12 m, where an inflection point in the profile occurs. The speed at the inflection point is about equal to the phase speed of the wave. The wind speed and temperature profiles combine to

produce a Richardson number less than 0.25 at the inflection point height.

This atmospheric structure is dynamically unstable and the observed waves have properties that are characteristic of dynamic instabilities. Accordingly, we hypothesize that the waves are generated by dynamic instability of the shear layer produced by the canopy. The wave amplitude appears to be small and is largely masked at the 18- and 12-m levels by the relatively high turbulence in the background flow. The waves are most evident at 6 m where ambient turbulence levels are low; at 2 m, the amplitude is reduced since the waves are farther from their source region and closer to the ground. The instabilities could play a role in heat and momentum transfer within and above forest canopies when the atmosphere is stably stratified.

Boundary-Layer Exchange and the Free Convection Limit

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Monin-Obukhov similarity theory does not include the case where the mean wind vanishes. On the other hand, such a situation does occur in atmospheric circulation models, and the parameterization of turbulent exchange must take it into account. A common means to accommodate the free convection is to introduce a convective velocity scale or to simply impose a lower bound on the wind speed. Another approach is proposed here in which the stability functions used in the Monin-Obukhov theory naturally include the free convection limit. Such functions are shown not to significantly depart from more traditional formulations, while bringing simplicity and removing arbitrariness in parameter-izations of turbulent transfer.

Hodograph Rotation in the Sea-Breezes of the Attic Peninsula, Greece

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The classic Haurwitz (1947) theory of sea breezes requires a Coriolis-induced veering in the Northern Hemisphere. It has subsequently been shown that many locations experience sea breezes that exhibit both backing and veering. Much has been written about the sea breezes experienced around the Attic Peninsula, which have both historical and contemporary significance, and exhibit regionally variable rotation senses. The studies that note the backing are unable to provide an explanation for the apparently anomalous sense of rotation. In the present study we investigate the rotation of these sea breezes by performing a term analysis of the velocity tendency equation using a three-dimensional, fully non-linear numerical model. The results show that the sense of rotation is dominated by relatively small differences

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26 ième Congrès Annuel de la SCMO
Université Laval
Québec

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L'Université LAVAL est l'hôte officiel du Congrès qui sera organisé sous l'égide de la Société de météorologie de Québec.

Le 26ième Congrès Annuel aura pour thème: **"Météorologie et océanographie à la méso-échelle"**

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