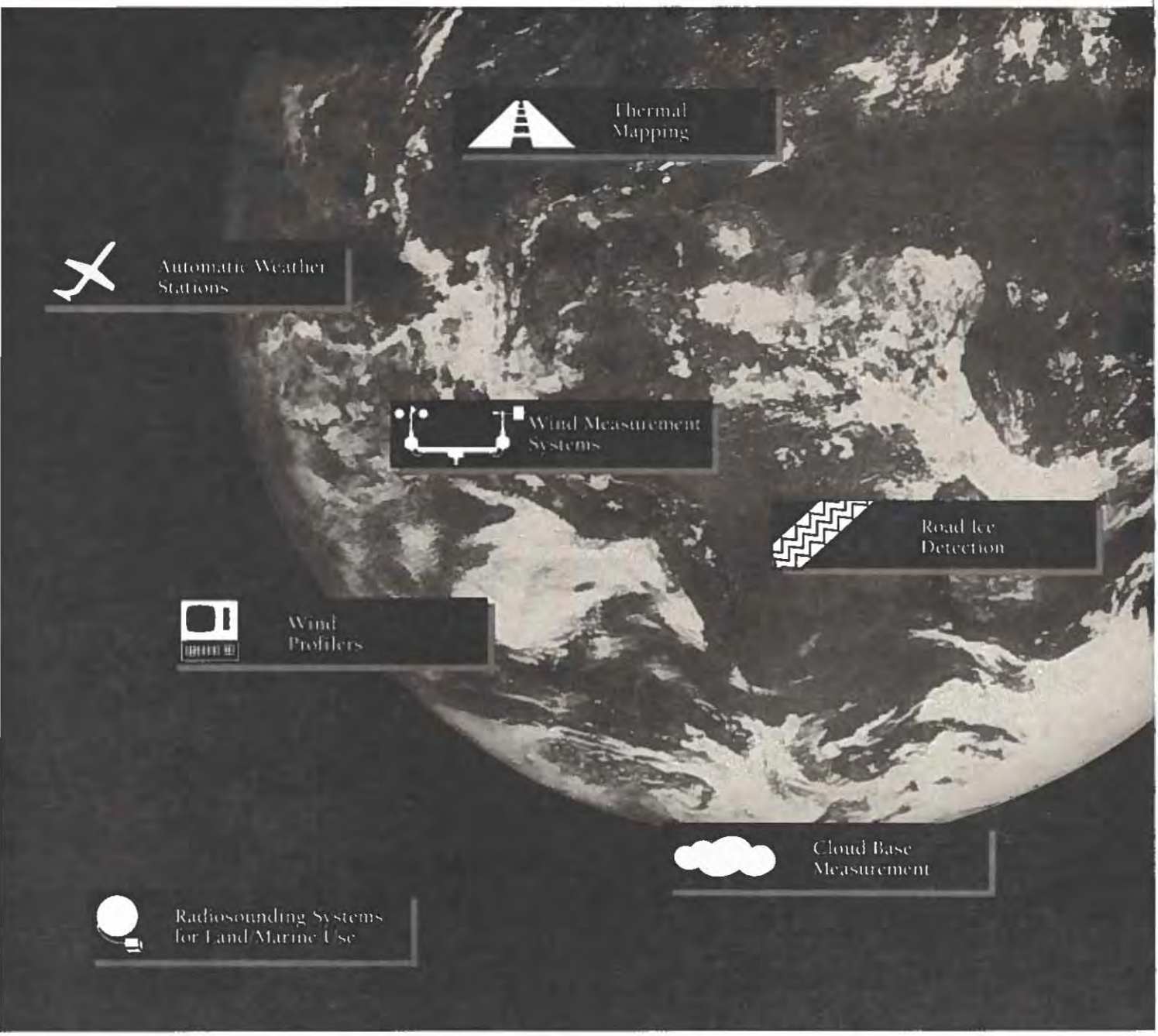
24TH ANNUAL CONGRESS OF THE CANADIAN METEOROLOGICAL AND OCEANOGRAPHIC SOCIETY

CLIMATE VARIABILITY: CAUSES AND CONSEQUENCES
PROGRAM AND ABSTRACTS
28TH MAY - 1ST JUNE 1990

24e CONGRES ANNUEL DE LA SOCIETE CANADIENNE DE METEOROLOGIE ET OCEANOGRAPHIE

VARIABILITE DE CLIMAT: CAUSES ET CONSEQUENCES
PROGRAMME ET RESUMES
28 MAY - 1 JUNE 1990



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24TH ANNUAL CONGRESS OF
THE CANADIAN METEOROLOGICAL AND OCEANOGRAPHIC SOCIETY

24e CONGRES ANNUEL DE
LA SOCIETE CANADIENNE DE METEOROLOGIE ET OCEAN

CLIMATE VARIABILITY: CAUSES AND CONSEQUENCES
VARIABILITE DE CLIMAT: CAUSES ET CONSEQUENCES

28 MAY/MAI - 1 JUNE/JUIN 1990

EDITORS

M.G.G. FOREMAN H.J. FREELAND

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R.M. RUTKA

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XXIV ANNUAL CONGRESS OF THE CANADIAN METEOROLOGICAL AND OCEANOGRAPHIC SOCIETY

XXIV CONGRES ANNUEL DE LA SOCIETE CANADIENNE DE METEOROLOGIE ET D'OCEANOGRAPHIE

WELCOME/BIENVENU

The Vancouver Island Centre of the Canadian Meteorological and Oceanographic Society (CMOS) is hosting the 24th annual CMOS Congress and Annual General Meeting at Royal Roads Military College from May 28 to June 1, 1990. The theme of this year's Congress is CLIMATE VARIABILITY: CAUSES AND CONSEQUENCES.

Le Centre d'Ile Vancouver de la Societé canadienne de météorologie et d'océanographie (SCMO) est l'hôte du 24^{e} Congès annuel et de l'Assemblée générale annuelle à le Collège Militaire Royal Roads du 28 mai au 1 juin, 1990. Le thème pour cet an est LA VARIABILITE DU CLIMAT: CAUSES ET CONSEQUENCES.

LOCAL ARRANGEMENTS COMMITTEE/COMITE ORGANISATION LOCALE

Chair/Chef: R.F. Marsden, Royal Roads Military College, Victoria

J.R. Buckley, Royal Roads Military College, Victoria
W.R. Crawford, Institute of Ocean Sciences, Sidney
G. Fleming, Royal Roads Military College, Victoria
H.J. Freeland, Institute of Ocean Sciences, Sidney
G. Gabel, Aanderaa Instruments Ltd., Victoria
A. Gast, Institute of Ocean Sciences, Sidney
K. Keen, Royal Roads Military College, Victoria
D.P. Krauel, Royal Roads Military College, Victoria
T.S. Murty, Institute of Ocean Sciences, Sidney
R.M. Rutka, Institute of Ocean Sciences, Sidney
M. Stacey, Royal Roads Military College, Victoria
S.R. Waddell, Royal Roads Military College, Victoria

SCIENTIFIC COMMITTEE/COMITE DU PROGRAMME SCIENTIFIQUE

Chair/Chef: T.S. Murty, Institute of Ocean Sciences, Sidney

S.E. Calvert, University of British Columbia, Vancouver
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K.L. Denman, Institute of Ocean Sciences, Sidney
M.G.G. Foreman, Institute of Ocean Sciences, Sidney
H.J. Freeland, Institute of Ocean Sciences, Sidney
D.P. Krauel, Royal Roads Military College, Victoria
P.H. LeBlond, University of British Columbia, Vancouver
G.A. McBean, University of British Columbia, Vancouver
R.F. Marsden, Royal Roads Military College, Victoria
T.F. Pedersen, University of British Columbia, Vancouver
M. Rafiq, B.C. Ministry of Environment, Surrey

PUBLIC, PLENARY AND INVITED SPEAKERS
CONFERENCIERS PUBLIQUES, PLENIERES ET INVITES

K.E. Trenberth, National Center for Atmospheric Research, Boulder, CO, U.S.A.
G. Philander, Princeton University, Princeton, NJ, U.S.A.
J. Steele, Woods Hole Oceanographic Institution, Woods Hole, MA, U.S.A.
L. Legendre, Département de Biologie, Université Laval à Québec
R. Methot, Alaska Fisheries Science Center, NMFS, Seattle, WA, U.S.A.
K.W. Bruland, University of California, Santa Cruz, CA, U.S.A.
F. Dobson, Bedford Institute of Oceanography, Dartmouth, N.S.
A.J. Semtner, Jr., Naval Postgraduate School, Monterey, CA, U.S.A.
P. Malanotte-Rizzoli, Massachusetts Institute of Technology, Cambridge, MA, U.S.A.
V. Klemeš, International Association of Hydrological Sciences, c/o Centre for Earth and Ocean Research, University of Victoria, Victoria, B.C.
D.F.W. Pollard, Forestry Canada, Pacific Forestry Centre, Victoria, B.C.
J.C. Schaake, National Weather Service, Office of Hydrology, Silver Spring, MD, U.S.A.
R.G. Fairbanks, Lamont-Doherty Geophysical Observatory of Columbia University, Palisades, NY, U.S.A.
W.R. Peltier, University of Toronto, Toronto, Ont.
R.J. Reed, University of Washington, Seattle, WA, U.S.A.

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SUMMARY OF MEETINGS FOR CMOS '90

COMMITTEE	TIME	LOCATION
Monday May 28		
†Accreditation	0900–1200	Castle
Publications	0900–1200	Room 306, Grant Block
†CHOGUN	0900–1200	Library
Education in Meteorology	0900–1200	Room 331, Grant Block
†Membership	0900–1200	Room 207, Grant Block
†Professionalism	0900–1200	Room 208, Grant Block
Scientific	0900–1200	Room 205, Grant Block
†CNC/SCOR	0900–1200	Room 206, Grant Block
Atmosphere-Ocean and Climatological Bulletin Editorial Board	1330–1700	Room 205, Grant Block
Mesoscale Subcommittee	1330–1700	Room 206, Grant Block
Agricultural and Forest Meteorological SIG	1330–1700	Room 207, Grant Block
†Air Pollution Meteorology SIG	1330–1700	Room 208, Grant Block
Operational Meteorology SIG	1330–1700	Library
Fisheries SIG	1330–1700	Mess Decks
†CMOS Chairs	1330–1600	Castle
CMOS – National Council I	1600–1700	Castle
CMOS – National Council II	1600–1700	Castle
Ice Breaker	1830–2200	Castle Ante-Room
Tuesday May 29		
Annual General Meeting	2000–2400	Gymnasium

† if necessary

RESUME DES REUNIONS POUR SCMO '90

COMITE	HEURE	LOCAL
Lundi le 28 Mai		
†Accreditation	0900–1200	Château
Publications	0900–1200	Salle 306, Grant Block
†CHOGUN	0900–1200	Bibliothèque
Education en Météorologie	0900–1200	Salle 331, Grant Block
†Situation des membres	0900–1200	Salle 207, Grant Block
†Professionalisme	0900–1200	Salle 208, Grant Block
Scientifique	0900–1200	Salle 205, Grant Block
†CNC/SCOR	0900–1200	Salle 206, Grant Block
Comité de rédaction d'Atmosphère-Ocean et/ Bulletin Climatologique	1330–1700	Salle 205, Grant Block
Sous-comité sur l'Echelle moyenne	1330–1700	Salle 206, Grant Block
GIS: Météorologie Agricole et Forestière	1330–1700	Salle 207, Grant Block
†Météorologie de la Pollution l'Air	1330–1700	Salle 208, Grant Block
GIS: Météorologie d'exploitation	1330–1700	Bibliothèque
GIS: La pêche	1330–1700	Mess Decks
†Chefs des centres	1330–1600	Château
SCMO – Conseil national I	1600–1700	Château
SCMO – Conseil national II	1600–1700	Château
Réception d'acceuil	1830–2200	Château Anté-Room
Mardi le 29 Mai		
Assemblée générale annuelle	2000–2400	Gymnase

† si nécessaire

CMOS '90 SCHEDULE

TIME	EVENT	LOCATION
Monday May 28		
0800–2000	Registration	Grant Block
0900–1700	Committee Meetings	Conference Rooms
1500–1700	Poster Set-up	Mess Decks
1600–1700	CMOS Executive Meeting	Castle Conference Room
1700–1800	Dinner	Dining Hall (No Host)
1830–2200	Ice Breaker	Castle Wardroom
2000–2400	CMOS Executive Meeting	Castle Conference Room
Tuesday May 29		
0800–1700	Registration	Grant Block
0900–0930	Congress Opening	Gymnasium
0930–1015	Plenary–1	Gymnasium
1015–1045	Health Break	Mess Decks
1045–1215	Plenary–1, continued	Gymnasium
1215–1345	Lunch	Mess Decks
1345–1525	Fisheries Oceanography–1 Plankton	Room 331, Grant Block
	Atmospheric Chemistry	Room 306, Grant Block
	Ice and Snow Research–1	Room 206, Grant Block
	Turbulence and Diffusion in the Ocean	Room 205, Grant Block
	Cloud Physics	Room 208, Grant Block
	Atmospheric Dynamics–1	Room 207, Grant Block
1525–1555	Health Break	Quarter Deck, Grant Block
1555–1715	Fisheries Oceanography–2 Ocean-Fish Climate and Correlations	Room 331, Grant Block
	Marine Chemistry–1	Room 306, Grant Block
	Mesoscale Dynamics and Climate	Room 208, Grant Block
	Ice and Arctic Oceanography	Room 206, Grant Block
	The Rimouski Eddy Experiment	Room 207, Grant Block
	Oceanography–1 and Internal Waves	Room 205, Grant Block
1730–2000	Wine and Cheese Party	Mess Decks
1800–2000	Poster Session	Mess Decks Lounge
2000	Annual General Meeting	Gymnasium
Wednesday May 30		
0800–1700	Registration	Grant Block
0830–1010	Fisheries Oceanography–3	Room 331, Grant Block
	Dispersion of Pollutants and Oil Slicks	Room 206, Grant Block
	Ocean Surface Waves–1 and Processes	Room 207, Grant Block
	Large-Scale Ocean Circulation–1	Room 205, Grant Block
	Ice and Snow Research–2	Room 208, Grant Block
	The Upper Atmosphere Research Satellite Program	Room 306, Grant Block
1010–1040	Health Break	Quarter Deck, Grant Block

TIME	EVENT	LOCATION
1040–1220	Ocean Surface Waves–2	Room 207, Grant Block
	Large-Scale Ocean Circulation–2	Room 205, Grant Block
	The Canadian WINDII Program–1	Room 206, Grant Block
	Wind Analysis and Measurement	Room 208, Grant Block
	The Lagrangian Ocean–1	Room 331, Grant Block
	Ice and Waves	Room 306, Grant Block
1220–1350	Lunch	Mess Decks
1350–1530	Oceanography–2	Room 205, Grant Block
	Hydrology–1	Room 207, Grant Block
	Fisheries Oceanography–4	Room 331, Grant Block
	Atmospheric Dynamics–2	Room 208, Grant Block
	Sediment Chemistry	Room 306, Grant Block
	The Canadian WINDII Program–2	Room 206, Grant Block
1530–1600	Health Break	Quarter Deck, Grant Block
1600–1740	Oceanography–3	Room 205, Grant Block
	Atmospheric Dynamics–3	Room 208, Grant Block
	Marine Chemistry–2	Room 306, Grant Block
	Ocean Acoustics and Remote Sensing	Room 331, Grant Block
	The Lagrangian Ocean–2	Room 206, Grant Block
1900	Bus transportation from Royal Roads to Royal B.C. Museum	
1930	Public Lecture by D.F.W. Pollard, Forestry Canada	Royal B.C. Museum
Thursday May 31		
0800–1700	Registration	Grant Block
0830–1015	Plenary–2	Gymnasium
1015–1030	Health Break	Mess Decks
1030–1200	Plenary–3	Gymnasium
1200–1330	Lunch	Mess Decks
1330–1530	Hydrology–2	Room 207, Grant Block
	Paleoceanography	Room 306, Grant Block
	Oceanography–4	Room 205, Grant Block
	Fisheries Oceanography–5	Room 331, Grant Block
	Atmospheric Variability–1	Room 208, Grant Block
1530–1600	Health Break	Quarter Deck, Grant Block
1600–1740	Fisheries Oceanography–6	Room 206, Grant Block
	Hydrology–3	Room 207, Grant Block
	Oceanography–5	Room 205, Grant Block
	Atmospheric Variability–2	Room 208, Grant Block
1800	Bus transportation from Royal Roads to Banquet	Sooke
Friday June 1		
0830–1200	Registration	Grant Block
0900–1020	Oceanography–6	Room 205, Grant Block
	Meteorological Applications	Room 208, Grant Block
1020–1050	Health Break	Quarter Deck, Grant Block
1050–1230	Oceanography–7	Room 205, Grant Block
	Climate Variations	Room 207, Grant Block
1230	Lunch (No Host)	Mess Decks

PROGRAMME POUR SCMO '90

HEURE	EVENEMENT	LOCAL
Mardi le 28 mai		
0800–2000	Inscription	Grant Block
0900–1700	Réunions de commité	Salle de conférence
1500–1700	Arrangement des affichages	Mess Decks
1600–1700	Réunion de commité exécutif de SCMO	Salle conférence
1700–1800	Diner	Réfectoire (payant)
1830–2200	Réception d'acceuil	C'astle Wardroom
2000–2400	Réunion de commité exécutif de SC'MO	Salle de conférence
mardi le 29 mai		
0800–1700	Inscription	Grant Block
0900–0930	Ovèrture du congrès	Gymnase
0930–1015	Séance plénière–1	Gymnase
1015–1045	Pause de santée	Mess Decks
1045–1215	Séance plénière–1, continué	Gymnase
1215–1345	Déjeuner	Mess Decks
1345–1525	Océanographie de la pêche–1, plancton	Salle 331, Grant Block
	C'hémie atmosphérique	Salle 306, Grant Block
	Recherche de la glace et de la neige–1	Salle 206, Grant Block
	Turbulence et diffusion dans l'ocean	Salle 205, Grant Block
	Physique des nuages	Salle 208, Grant Block
	Dynamiques atmosphériques–1	Salle 207, Grant Block
1525–1555	Pause de santée	Quarter Deck, Grant Block
1555–1715	Océanographie de la pêche–2 océan-pêche, climat et correlations	Salle 331, Grant Block
	C'hémie océanographie–1	Salle 306, Grant Block
	C'limat et la dynamique de l'échelle moyenne	Salle 208, Grant Block
	Océanographie des glaçons et de l'Artique	Salle 206, Grant Block
	Expérience du tourbillon de Rimouski	Salle 207, Grant Block
	Océanographie–1 et vagues internes	Salle 205, Grant Block
1730–2000	Vins et fromages	Mess Decks
1800–2000	Séance des affichages	Mess Decks Lounge
2000	Assemblée générale annuelle	Gymnase

HEURE	EVENEMENT	LOCAL
Mercredi le 30 mai		
0800–1700	Inscription	Grant Block
0830–1010	Océanographie de la pêche–3	Salle 331, Grant Block
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	Vagues et processus–1	Salle Salle 207, Grant Block
	Circulation océanique à grande échelle–1	Salle 205, Grant Block
	Recherche de la glace et de la neige–2	Salle 208, Grant Block
	Programme des satellites de recherche dans l'atmosphère supérieure	Salle 306, Grant Block
1010–1040	Pause de santée	Quarter Deck, Grant Block
1040–1220	Vagues–2	Salle 207, Grant Block
	Circulation océanique à grande échelle–2	Salle 205, Grant Block
	Le programme canadien WINDII–1	Salle 206, Grant Block
	Analyse et mesure des vents	Salle 208, Grant Block
	L'océan lagrangien–1	Salle 331, Grant Block
	Glace et vagues	Salle 306, Grant Block
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1350–1530	Océanographie–2	Salle 205, Grant Block
	Hydrologie–1	Salle 207, Grant Block
	Oceanographie de la pêche–4	Salle 331, Grant Block
	Dynamiques atmosphérique–2	Salle 208, Grant Block
	Chémie des sediments	Salle 306, Grant Block
	Le programme canadien WINDII–2	Salle 206, Grant Block
1530–1600	Pause de santée	Quarter Deck, Grant Block
1600–1740	Océanographie–3	Salle 205, Grant Block
	Dynamiques atmosphériques–3	Salle 208, Grant Block
	Chemie océanographique–2	Salle 306, Grant Block
	Acoustique océanique et télédétection	Salle 331, Grant Block
	L'océan lagrangien–2	Salle 206, Grant Block
1900	Transport en autobus du Royal Roads au Musée royal de la Colombie Britannique	
1930	Lecture publique par D.F.W. Pollard, Forestry Canada	Musée royal de la Colombie Britannique

HEURE	EVENEMENT	LOCAL
Jeudi le 31 mai		
0800–1700	Inscription	Grant Block
0830–1015	Séance pléniére–2	Gymnase
1015–1030	Pause de santée	Mess Decks
1030–1200	Séance pléniére–3	Gymnase
1200–1330	Déjeuner	Mess Decks
1330–1530	Hydrologie–2	Salle 207, Grant Block
	Paleocéanographie	Salle 306, Grant Block
	Océanographie–4	Salle 205, Grant Block
	Océanographie de la pêche–5	Salle 331, Grant Block
	Variabilité atmosphérique–1	Salle 208, Grant Block
1530–1600	Pause de santée	Quarter Deck, Grant Block
1600–1740	Océanographie de la pêche–6	Salle 206, Grant Block
	Hydrologie–3	Salle 207, Grant Block
	Oceanographie–5	Salle 205, Grant Block
	Variabilité atmosphérique–2	Salle 208, Grant Block
1800	Transport en autobus du Royal Roads au banquet	Sooke
Vendredi le 1 juin		
0830–1200	Inscription	Grant Block
0900–1020	Océanographie–6	Salle 205, Grant Block
	Applications metéorologiques	Salle 208, Grant Block
1020–1050	Pause de santée	Quarter Deck, Grant Block
1050–1230	Océanographie–7	Salle 205, Grant Block
	Variations climatique	Salle 207, Grant Block
1230	Déjeuner payant	Mess Decks

TUESDAY MAY 29/MARDI LE 29 MAI

CONGRESS OPENING/OVERTURE DU CONGRES
Gymnasium

0900 Col. J.E.C. Naud, Commandant, Royal Roads Military College, Victoria, B.C.

0910 J.C. Davis, Director of Science, Pacific Region, Department of Fisheries and Oceans, Sidney, B.C.

0920 Administrative Announcements

PLENARY-1/SEANCE PLENIERE-1
Gymnasium

Chair/Chef: J.F. Garrett, Institute of Ocean Sciences, Sidney, B.C.

0930 K.E. Trenberth, National Center for Atmospheric Research, Boulder, CO, U.S.A.
METEOROLOGICAL ASPECTS OF CLIMATIC VARIATIONS

1015–1045
Health Break/Pause de santée, Mess Decks

1045 G. Philander, Princeton University, Princeton, NJ, U.S.A.
EL NINO, LA NINA AND THE SOUTHERN OSCILLATION

1130 J. Steele, Woods Hole Oceanographic Institution, Woods Hole, MA, U.S.A.
COMPARISON OF TERRESTRIAL AND MARINE ECOSYSTEMS

1215–1345
Lunch/Déjeuner, Mess Decks

CONCURRENT SESSIONS/SEANCES SIMULTANEES

FISHERIES OCEANOGRAPHY–1, PLANKTON
OCEANOGRAPHIE DE LA PECHE–1, PLANCTON
Room/Salle 331, Grant Block

Chair/Chef: R.E. Thomson, Institute of Ocean Sciences, Sidney, B.C.

1345 **Invited Speaker:** L. Legendre, Département de Biologie, Université Laval à Québec
THE SIGNIFICANCE OF MICROALGAL BLOOMS FOR FISHERIES AND FOR THE EXPORT OF PARTICULATE ORGANIC CARBON IN OCEANS

1425 SPATIAL AND TEMPORAL VARIABILITY OF ZOOPLANKTON BIOMASS AND COMMUNITY COMPOSITION OFF SOUTHERN VANCOUVER ISLAND
D.L. Mackas, Inst. Ocean Sci., Sidney, B.C.

1445 BIOLOGICAL STUDIES ON THE GEORGES BANK TIDAL FRONT: ZOOPLANKTON DISTRIBUTIONS AND FRONTAL DYNAMICS
R.I. Perry, Biol. Stn., St. Andrews, N.B.
G. Harding, K. Drinkwater, Bedford Inst. Ocean., Dartmouth, N.S.
M.J. Tremblay, Dept. Fish. Oceans, Halifax Lab., Halifax, N.S.
C. Taggart, Dalhousie Univ., Halifax, N.S.

1505 UNUSUALLY RAPID GROWTH OF COASTAL 0^+ DUNGENESS CRAB MAY LEAD TO STRONG FISHERIES
D. Armstrong, D. Gunderson, Univ. of Washington, Seattle, WA, U.S.A.

ATMOSPHERIC CHEMISTRY
CHEMIE ATMOSPHERIQUE
Room/Salle 306, Grant Block

Chair/Chef: R. Laprise, Université du Québec à Montréal, Qué.

1345 HIGH ELEVATION FOG AND PRECIPITATION CHEMISTRY IN SOUTHWESTERN BRITISH COLUMBIA
M.S. Kotturi, Min. Envir., Victoria, B.C.

1405 SIMULATION OF ATMOSPHERIC RADON DISTRIBUTION IN A DIURNALLY-VARYING VERSION OF THE GFDL "SKYHI" GENERAL CIRCULATION MODEL
R.J. Wilson, K. Hamilton, Princeton Univ., Princeton, NJ, U.S.A.

1425 MONITORING OF STRATOSPHERIC OZONE IN CANADA
J.B. Kerr, Atmos. Envir. Ser., Downsview, Ont.

1445 TRANSPORT DE SUBSTANCES EN TRACE DANS UN MODELE SPECTRAL DE LA CIRCULATION GENERALE DE L'ATMOSPHERE
J. de Grandpré, R. Laprise, Univ. du Québec à Montréal, Qué.

1505 EFFECTS OF FOLIAGE WETNESS ON THE DEPOSITION OF OZONE
J.D. Fuentes, T.J. Gillespie, Univ. of Guelph, Guelph, Ont.

ICE AND SNOW RESEARCH–1
RECHERCHE DE LA GLACE ET DE LA NEIGE–1
Room/Salle 206, Grant Block

Chair/Chef: V.R. Neralla, Atmospheric Environment Service, Downsview, Ont.

1345 STABILITY ENHANCEMENT OF SEA ICE IN THE GREENLAND AND LABRADOR SEAS
R.F. Marsden, Royal Roads Mil. Coll., Victoria, B.C.
L.A. Mysak, McGill Univ., Montreal, Que.,
R.A. Myers, Dept. Fish. Oceans, St. John's, Nfld.

1405 RADIATION AND ENERGY BUDGETS OF ALPINE TUNDRA, BRITISH COLUMBIA, CANADA
I.R. Saunders, W.G. Bailey, Simon Fraser Univ., Burnaby, B.C.

1425 LABRADOR SEA MODELING WITH ICE COVER
M. Ikeda, Bedford Inst. Ocean., Dartmouth, N.S.

1445 EVALUATION OF AN OPERATIONAL VERSION OF THE SEA ICE DYNAMICS MODEL OVER THE GULF OF ST. LAWRENCE DURING THE CANADIAN ATLANTIC STORMS PROGRAMME
V.R. Neralla, Atmos. Envir. Ser., Downsview, Ont.

1505 DETERMINATION OF WET SNOW AT EDMONTON USING SURFACE WEATHER PARAMETERS
K.J. Finstad, Weather Research House Inc., Downsview, Ont
E.P. Lozowski, M. Bourassa, Univ. of Alberta, Edmonton, Alta.

TURBULENCE AND DIFFUSION IN THE OCEAN
TURBULENCE ET DIFFUSION DANS L'OCEAN
Room/Salle 205, Grant Block

Chair/Chef: A.E. Gargett, Institute of Ocean Sciences, Sidney, B.C.

1345 ISOPYCNAL AND LATERAL DIFFUSION IN A BOX OCEAN CIRCULATION MODEL
W.A. Gough, C.A. Lin, McGill Univ., Montreal, Que.

1405 A THERMOCLINE OCEAN MODEL FOR CLIMATIC STUDIES
S. Zhang, C.A. Lin, McGill Univ., Montreal, Que.
R. Greatbatch, Memorial Univ., St. John's, Nfld.

1425 REMOTE MEASUREMENT OF TURBULENT VELOCITY FIELDS IN THE COASTAL ENVIRONMENT
A. Gargett, Inst. Ocean Sci., Sidney, B.C.

1445 UPPER OCEAN THERMAL RESPONSE TO AN AUTUMN STORM
G.B. Crawford, Univ. of British Columbia, Vancouver, B.C.
W.G. Large, Nat. Center Atmos. Res., Boulder, CO, U.S.A.

1505 EVOLUTION OF FINESTRUCTURE IN A TIDAL-SHEAR FLOW
P.S. Galbraith, Dalhousie Univ., Halifax, N.S.

CLOUD PHYSICS/PHYSIQUE DES NUAGES
Room/Salle 208, Grant Block

Chair/Chef: L.O. Mapanao, Atmospheric Environment Service, Downsview, Ont.

1345 CLOUD MICROPHYSICS IN CANADIAN ATLANTIC STORMS
G.A. Isaac, Atmos. Envir. Ser., Downsview, Ont.

1405 ANNUAL VARIABILITY IN HAIL DAMAGE IN SASKATCHEWAN
A.H. Paul, Univ. of Regina, Regina, Sask.

1425 THE SAGA OF THE THREE-PEAK RAINDROP SIZE DISTRIBUTION IN TROPICAL RAIN
R. List, G. McFarquhar, Univ. of Toronto, Toronto, Ont.

1445 THE INFLUENCE OF SMALL SCALE RAIN RATE VARIABILITY ON RADAR HYDROLOGY
I. Zawadzki, M. Besner, Univ. du Québec à Montréal, Qué.

1505 ENERGY BUDGETS FOR STRATOCUMULUS CLOUDS USING CONSERVED THERMODYNAMIC VARIABLES
P. Austin, Univ. of British Columbia, Vancouver, B.C.

ATMOSPHERIC DYNAMICS–1
DYNAMIQUES ATMOSPHERIQUES–1
Room/Salle 207, Grant Block

Chair/Chef: J. Derome, McGill University, Montreal, Que.

1345 APPLICATION OF THE SEMI-LAGRANGIAN METHOD TO A MULTILEVEL SPECTRAL PRIMITIVE EQUATIONS MODEL
H. Ritchie, Ser. de l'envir. atmos., Dorval, Qué.

1405 A THREE-DIMENSIONAL GENERALIZATION OF ELIASSEN'S BALANCED VORTEX EQUATIONS
G. Craig, H.-R. Cho, Univ. of Toronto, Toronto, Ont.

1425 FORECASTING POLAR LOWS WITH MESO-SCALE VERSIONS OF THE CANADIAN REGIONAL FINITE ELEMENT MODEL
M. Roch, R. Benoit, Ser. de l'envir. atmos., Dorval, Qué.
N. Parker, Atmos. Envir. Ser., Edmonton, Alta.

1445 EXPERIMENTS ON TROPICAL STRATOSPHERIC WIND VARIATIONS IN A HIGH VERTICAL RESOLUTION SPECTRAL MODEL
K. Hamilton, Li Yuan, Princeton Univ., Princeton, NJ, U.S.A.

1505 A COMPARISON OF THE NONLINEAR INSTABILITY OF EASTERLY AND WESTERLY JETS IN A TWO-LAYER β-PLANE MODEL
S. Feldstein, York Univ., North York, Ont.

1525–1555
Health Break/Pause de santée, Quarter Deck

FISHERIES OCEANOGRAPHY–2
OCEAN-FISH CLIMATE AND CORRELATIONS
OCEANOGRAPHIE DE LA PECHE–2
OCEAN-PECHE, CLIMAT ET CORRELATIONS
Room/Salle 331, Grant Block

Chair/Chef: R. Beamish, Pacific Biological Station, Nanaimo, B.C.

1555 Invited Speaker: R. Methot, Alaska Fisheries Science Center, NMFS, Seattle, WA, U.S.A.
ENVIRONMENTAL INFLUENCES ON ASSESSMENT AND MANAGEMENT OF WEST COAST FISH POPULATIONS

1635 CORRELATIONS BETWEEN RECRUITMENT AND ENVIRONMENTAL FACTORS MAY DEPEND ON THE NATURAL MORTALITY RATE USED TO RECONSTRUCT FISH ABUNDANCES
M.F. Lapointe, R.M. Peterman, Simon Fraser Univ., Burnaby, B.C.

1655 AN EMPIRICAL SIMULATION OF LAGRANGIAN SURFACE CURRENTS: PART I – INTERANNUAL CHANGES IN THE NORTHEAST PACIFIC DIVERGENCE
W.J. Ingraham, Jr., Alaska Fish. Sci. Center, NMFS, Seattle, WA, U.S.A.

MARINE CHEMISTRY–1
CHEMIE OCEANOGRAPHIQUE–1
Room/Salle 306, Grant Block

Chair/Chef: M. Clark, Ministry of Environment, Victoria, B.C.

1555 Invited Speaker: K.W. Bruland, University of California, Santa Cruz, CA, U.S.A.
THE IMPORTANCE OF ORGANIC COMPLEXATION TO THE OCEANIC CHEMISTRY OF BIOACTIVE TRACE METALS

1635 ON THE REMOVAL OF DISSOLVED ALUMINUM IN SEAWATER
S.B. Moran, R.M. Moore, Dalhousie Univ., Halifax, N.S.

1655 METAL DISTRIBUTIONS AND TRANSPORT ON THE SCOTIAN SHELF
P.A. Yeats, Bedford Inst. Ocean., Dartmouth, N.S.

MESOSCALE DYNAMICS AND CLIMATE
CLIMAT ET LA DYNAMIQUE DE L'ECHELLE MOYENNE
Room/Salle 208, Grant Block

Chair/Chef: R. List, University of Toronto, Toronto, Ont.

1555 MESOSCALE VORTICITY DYNAMICS IN A WEAK OCEANIC CYCLONE IN ERICA
O. Hertzman, Dalhousie Univ., Halifax, N.S.

1615 IMPACTS OF PROJECTED GLOBAL WARMING: A RESEARCH PROPOSAL FOR THE MACKENZIE BASIN
S.J. Cohen, Atmos. Envir. Ser., Downsview, Ont.

1635 FINITE-TIME THERMODYNAMICAL TREATMENT OF WATER IN ATMOSPHERIC CIRCULATIONS
G.B. Lesins, Dalhousie Univ., Halifax, N.S.

1655 A NUMERICAL STUDY OF ROSSBY WAVEBREAKING: WHERE AND WHEN?
J. Fyfe, Univ. of British Columbia, Vancouver, B.C.

1715 RECENT ANTICYCLONIC SYSTEMS IN SOUTHEASTERN UNITED STATES
G.L. Plummer, Univ. of Georgia, Athens, GA, U.S.A.

ICE AND ARCTIC OCEANOGRAPHY
OCEANOGRAPHIE DE LES GLACONS ET DE L'ARCTIQUE
Room/Salle 206, Grant Block

Chair/Chef: R.A. Lake, Institute of Ocean Sciences, Sidney, B.C.

1555 ACOUSTIC RADIATION OF ICE CRACKING SOUND IN THE ARCTIC OCEAN
Y. Xie, Inst. Ocean Sci., Sidney, B.C. and Univ. of British Columbia, Vancouver, B.C.

1615 GREENLAND SEA ICE ANOMALIES DURING 1901–1984 AND THEIR RELATION TO AN INTER-DECADAL ARCTIC CLIMATE CYCLE
L.A. Mysak, D.K. Manak, McGill Univ., Montreal, Que.
R.F. Marsden, Royal Roads Mil. Coll., Victoria, B.C.

1635 PLUME LIFT-OFF UNDER A COMPLETE SEA ICE COVER IN HUDSON BAY
R.G. Ingram, L. Veilleux, McGill Univ., Montreal, Que.

1655 LARGE SCALE VARIABILITY OF ICE COVER ON MONTHLY AND SEASONAL TIME SCALES
T. Agnew, Can. Clim. Centre, Atmos. Envir. Ser., Downsview, Ont.

1715 SOME ASPECTS OF SPRAY ICING MODELLING OF SHIPS
E.P. Lozowski, W.P. Zakrzewski, Univ. of Alberta, Edmonton, Alta.

THE RIMOUSKI EDDY EXPERIMENT
L'EXPERIENCE DU TOURBILLON DE RIMOUSKI
Room/Salle 207, Grant Block

Chair/Chef: Y. Gratton, Institut Maurice-Lamontagne, Mont-Joli, Qué.

1555 THE RIMOUSKI EDDY EXPERIMENT
Y. Gratton, Inst. Maurice-Lamontagne, Mont-Joli, Qué.

1615 PRIMARY PRODUCTION, NEW PRODUCTION AND EDDY CIRCULATION IN THE LOWER ST. LAWRENCE ESTUARY
A.F. Vézina, Univ. du Québec à Rimouski, Qué.

1635 SPATIAL AND TEMPORAL PATTERNS IN THE VERTICAL FLUX OF PARTICULATE MATTER IN THE LAURENTIAN TROUGH
N. Silverberg, Inst. Maurice-Lamontagne, Mont-Joli, Qué.

1655 SHORT-TERM VARIATIONS OF GEOCHEMICAL PROFILES IN PORE WATERS OF LAURENTIAN TROUGH SEDIMENTS
G.-H. Tremblay, N. Silverberg, Inst. Maurice-Lamontagne, Mont-Joli, Qué.

1715 BACTERIAL PRODUCTION IN DEEP-WATER SEDIMENTS OF THE LOWER ST. LAWRENCE ESTUARY DURING THE EARLY SUMMER PHYTOPLANKTON BLOOM
S.K. Juniper, Univ. du Québec à Rimouski, Qué.

OCEANOGRAPHY–1 AND INTERNAL WAVES
OCEANOGRAPHIE–1 ET VAGUES INTERNES
Room/Salle 205, Grant Block

Chair/Chef: M. Stacey, Royal Roads Military College, Victoria, B.C.

1555 OBSERVATIONS OF CURRENTS IN THE NORTHEAST PACIFIC
H.J. Freeland, P.F. Cummins, Inst. Ocean Sci., Sidney, B.C.

1615 LOW FREQUENCY SUBSURFACE CURRENTS OF THE NORTHEAST PACIFIC
D.E. Williams, Royal Roads Mil. Coll., Victoria, B.C. and Can. Forces Fleet Sch., Halifax, N.S.
D.P. Krauel, Royal Roads Mil. Coll., Victoria, B.C.

1635 THE NONLINEAR CRITICAL LAYER FOR TOPOGRAPHICALLY FORCED INTERNAL WAVES
J.F. Scinocca, W.R. Peltier, Univ. of Toronto, Toronto, Ont.

1655 TRANSITION TO TURBULENCE VIA KELVIN-HELMHOLTZ AND HOLMBOE INSTABILITIES
W.D. Smyth, W.R. Peltier, Univ. of Toronto, Toronto, Ont.

1715 SHELF WAVE SCATTERING BY ESTUARIES AND HEADLANDS
T.F. Stocker, McGill Univ., Montreal, Que.
E.R. Johnson, Univ. College, London, England

1730–2000
Wine and Cheese Party/Vins et Fromages, Mess Decks

1800–2000
Poster Session/Séance des affichages, Mess Decks Lounge/Salon

2000
Annual General Meeting/Assemblée générale annuelle, Gymnasium/Gymnase

POSTER SESSION
SEANCE DES AFFICHAGES
Mess Decks Lounge

1800–2000

1. TRIGRID — AN INTERACTIVE GRAPHICAL SOFTWARE PACKAGE FOR GENERATION AND EDITING OF IRREGULAR TRIANGULAR GRIDS
   R.F. Henry, Inst. Ocean Sci., Sidney, B.C.
   R.A. Walters, U.S. Geological Survey, Tacoma, WA, U.S.A.

2. RELATIONSHIP BETWEEN INFRARED AVHRR SATELLITE AND SHIP TEMPERATURE DATA IN THE GULF OF ST. LAWRENCE
   D. Lefaivre, Inst. Maurice-Lamontagne, Mont-Joli, Qué.
   A.R. Condal, M. Lavoie, Univ. Laval, Québec, Qué.
   V.G. Koutitonsky, INRS-Océanol., Rimouski, Qué.

3. AN UPPER LAYER MODEL FOR THE ST. LAWRENCE ESTUARY
   J.A. Stronach, Seaconsult Marine Research Ltd., Vancouver, B.C.
   T.S. Murty, Inst. Ocean Sci, Sidney, B.C.
   B. Tessier, Inst. Maurice-Lamontagne, Mont-Joli, Qué.
   M.I. El-Sabh, Univ. du Québec à Rimouski, Qué.

4. THE INFLUENCE OF FRESH WATER FORCING ON THE LOW FREQUENCY DYNAMICS OF COASTAL WATERS
   J.D. Pietrzak, P.H. LeBlond, Univ. of British Columbia, Vancouver, B.C.

5. LOCALLY GENERATED TSUNAMIS IN THE STRAIT OF GEORGIA
   D. Dunbar, Seaconsult Marine Research Ltd., Vancouver, B.C.

6. NUMERICAL MODELLING AND BENTHIC BOUNDARY LAYER
   A.K. Ray, Fundamental Res. Inst., Ottawa, Ont.

7. CANADIAN FORCES WEATHER SERVICES – 50 YEARS AND GROWING
   D.W. Bancroft, Mar. Forces Pac. H.Q., Esquimalt, B.C.
   R.K. Cross, Nat. Def. H.Q., Ottawa, Ont.

8. OCEANIC CLIMATOLOGICAL INFORMATION FROM SPECIAL SENSOR MICROWAVE/IMAGER DATA
   A.F. Davies, I.G. Rubinstein, R.O. Ramseier, Atmos. Envir. Ser./Centre Res. Earth Space Sci., Inst. Space Terr. Sci., North York, Ont.

POSTER SESSION, Continued
SEANCE DES AFFICHAGES, Continué
Mess Decks Lounge

9. FIELD INTERCOMPARISON OF THREE CURRENT METERS IN AN ENVIRONMENT FREE FROM HIGH FREQUENCY MOTION
P. Larouche, Inst. Maurice-Lamontagne, Mont-Joli, Qué.

10. THE ROLE OF ICE PHASE PROCESSES IN CYCLONIC STORMS
S.R. Macpherson, Univ. of British Columbia, Vancouver, B.C.

11. THERMOHALINE STRUCTURE IN THE RIMOUSKI EDDY REGION: SUMMER OF 1989
P. Vinet, Univ. de Québec à Rimouski, Qué.
Y. Gratton, Inst. Maurice-Lamontagne, Mont-Joli, Qué.

12. VARIATIONS SPATIO-TEMPORELLES DANS L'ACTIVITE ENZYMATIQUE BACTERIENNE DANS LES SEDIMENTS PROFONDS DU CHENAL LAURENTIEN
C. Lavigne, K. Juniper, Univ. de Québec à Rimouski, Qué.

13. UTILISATION D'INDICES BIOCHIMIQUES DANS L'ETUDE DES INTERACTIONS BENTHO-PELAGIQUES, TOURBILLON DE RIMOUSKI (RIMOUSKI EDDY)
P. Martineu, C. Lavigne, K. Juniper, A.F. Vézina, Univ. de Québec à Rimouski, Qué.

14. COMPARISON OF TWO METHODS FOR STUDYING THE STRUCTURE AND MICRO-DISTRIBUTION OF A GUILD OF DEEP-WATER BENTHIC POLYCHAETES IN THE LAURENTIAN TROUGH (RIMOUSKI EDDY)
B. Soucy, C. Brassard, G. Desrosiers, K. Juniper, Univ. de Québec à Rimouski, Qué.

15. PREMIERES OBSERVATIONS PHOTOGRAPHIQUES DE LA MEGAFAUNE ET DE LA BIOTURBATION DANS LE CHENAL LAURENTIEN (ZONE TOURBILLON DE RIMOUSKI)
A. Mauviel, C. Brassard, Univ. du Québec à Rimouski, Qué.

16. MODEL SIMULATIONS OF THE DRIFT AND SPREAD OF THE EXXON-VALDEZ OIL SPILL
S. Venkatesh, Atmos. Envir. Ser., Downsview, Ont.

17. RECENT DEVELOPMENTS IN THE CHEMICAL ANALYSIS OF MARINE TOXINS
R. Pocklington, Bedford Inst. Ocean., Dartmouth, N.S.
M.A. Quilliam, Atl. Res. Lab., Nat. Council Res., Halifax, N.S.

WEDNESDAY MAY 30/MERCREDI LE 30 MAI
CONCURRENT SESSIONS/SEANCES SIMULTANEES

FISHERIES OCEANOGRAPHY–3
OCEANOGRAPHIE DE LA PECHE–3
Room/Salle 331, Grant Block

Chair/Chef: F. Boyce, National Water Research Institute, Burlington, Ont.

0830 DOMINANCE OF BIOLOGICAL FACTORS IN DETERMINING THE ABUNDANCE AND DISTRIBUTION OF FISH STOCKS
T. Laevastu, Alaska Fish. Sci. Center, NMFS, Seattle, WA, U.S.A.

0850 THE IMPORTANCE OF OCEANOGRAPHIC CONDITIONS IN THE DYNAMICS OF THE CHUM AND COHO SALMON POPULATIONS OF A SMALL VANCOUVER ISLAND STREAM
L.B. Holtby, J.C. Scrivener, D.J. Blackbourn, B.C. Andersen, Pacific Biol. Stn., Nanaimo, B.C.

0910 THE LAKE ONTARIO SALMON FISHERY: HERE TO STAY? GONE TOMORROW?
F. Boyce, Nat. Water Res. Inst., Burlington, Ont.
W. Flint, State Univ. of New York at Buffalo, U.S.A.

0930 RELATIVE CONTRIBUTIONS OF INTERANNUAL CHANGE AND SEASONALITY TO VARIATIONS OF REPRODUCTION IN SOME CALIFORNIA CURRENT REGION PELAGIC, MESO-PELAGIC AND DEMERSAL FISHES
P.E. Smith, H.G. Moser, Southwest Fish. Center, NMFS, La Jolla, CA, U.S.A.

DISPERSION OF POLLUTANTS AND OIL SLICKS
DISPERSION DES POLLUANTS ET DEVERSEMENT D'HYDROCARBURES
Room/Salle 206, Grant Block

Chair/Chef: S. Venkatesh, Atmospheric Environment Service, Downsview, Ont.

0830 PASSIVE SCALAR TRANSPORT IN β-PLANE TURBULENCE
P. Bartello, Ser. de l'envir. atmos., Dorval, Qué.
G. Holloway, Inst. Ocean Sci., Sidney, B.C.

0850 MODELLING THE BEHAVIOUR OF OIL SPILLS IN ICE-INFESTED WATERS
S. Venkatesh, Atmos. Envir. Ser., Downsview, Ont.
H. El-Tahan, G. Comfort, R. Abdelnour, Fleet Technology Ltd., Kanata, Ont.

0910 DISPERSION OF POLLUTANTS IN THE SOUTHEASTERN SEA OF KOREA
Chang S. Kim, Tae Sung Jung, Jong Chan Lee, S.W. Kang, Korean Ocean R&D Inst., Ansan, Korea

0930 THE LOCAL METEOROLOGY OF A SEVERE AIR POLLUTION EPISODE IN THE LOWER FRASER VALLEY, B.C.
D.G. Steyn, A. Roberge, C. Jackson, Univ. of British Columbia, Vancouver, B.C.

OCEAN SURFACE WAVES-1 AND PROCESSES
VAGUES-1 ET PROCESSUS
Room/Salle 207, Grant Block

Chair/Chef: D. Masson, Institute of Ocean Sciences, Sidney, B.C.

0830 Invited Speaker: F. Dobson, Bedford Institute of Oceanography, Dartmouth, N.S.
OCEAN WAVES AND CLIMATE FORECASTING

0910 AN EXTREMES WIND AND WAVE CLIMATOLOGY OFF THE EAST COAST OF CANADA
V.R. Swail, Atmos. Envir. Ser., Downsview, Ont.
V.J. Cardone, Oceanweather Inc., Cos Cob, CT, U.S.A.
B. Eid, MacLaren Plansearch Ltd., Halifax, N.S.

0930 A FURTHER LOOK AT PARAMETERIZATION OF WIND-WAVE SPECTRA
P.C. Liu, NOAA/Great Lakes Envir. Res. Lab., Ann Arbor, MI, U.S.A.
N.E. Huang, NASA Goddard Space Flight Center, Greenbelt, MD, U.S.A.

0950 OPEN OCEAN BUBBLE SIZE DISTRIBUTIONS FROM MULTIFREQUENCY ACOUSTIC BACKSCATTER
S. Vagle, Inst. Ocean Sci., Sidney, B.C. and Univ. of Victoria, Victoria, B.C.

LARGE-SCALE OCEAN CIRCULATION 1
CIRCULATION OCEANIQUE A GRANDE ECHELLE-1
Room/Salle 205, Grant Block

Chair/Chef: G. Holloway, Institute of Ocean Sciences, Sidney, B.C.

0830 Invited Speaker: A.J. Semtner, Jr., Naval Postgraduate School, Monterey, CA, U.S.A.
R.M. Chervin, Nat. Center Atmos. Res., Boulder, CO, U.S.A.
OCEANIC CIRCULATION FROM A GLOBAL EDDY-RESOLVING MODEL

0910 PROGRESS IN CANADIAN WOCE PLANS
P.H. LeBlond, Univ. of British Columbia, Vancouver, B.C.

0930 ON THE IMPORTANCE OF VERTICAL RESOLUTION IN CERTAIN OCEAN GENERAL CIRCULATION MODELS
A.J. Weaver, McGill Univ., Montreal, Que.

0950 THE ASSIMILATION OF SEA SURFACE TEMPERATURE DATA INTO NUMERICAL OCEAN MODELS
A.T. Weaver, W.W. Hsieh, Univ. of British Columbia, Vancouver, B.C.

ICE AND SNOW RESEARCH-2
RECHERCHE DE LA GLACE ET DE LA NEIGE-2
Room/Salle 208, Grant Block

Chair/Chef: D.P. Krauel, Royal Roads Military College, Victoria, B.C.

0830 SMALL SCALE MELT PROCESSES AT THE ICE-WATER INTERFACE OF ANNUAL SEA ICE
E. Hudier, Univ. du Québec à Rimouski, Qué.
R.G. Ingram, McGill Univ., Montreal, Que.

0850 FEASIBILITY OF PREDICTING CLIMATE CHANGE; IMPACT ON EAST COAST ICE SEVERITY I: SCOPE OF PROBLEM AND EVALUATION OF IMPACTS ON ICEBERG CALVING RATES
J.R. Marko, Arctic Sciences Ltd., Sidney, B.C.
D.B. Fissel, Arctic Sciences Ltd., Dartmouth, N.S.
P.A. Wadhams, J.A. Dowdeswell, Univ. of Cambridge, Cambridge, England

0910 FEASIBILITY OF PREDICTING CLIMATE CHANGE; IMPACT ON EAST COAST ICE SEVERITY II: PRESENT MECHANISMS AND CONTROLLING FACTORS FOR ICEBERG TRANSPORT AND DETERIORATION
J.R. Marko, Arctic Sciences Ltd., Sidney, B.C.
D.B. Fissel, Arctic Sciences Ltd., Dartmouth, N.S.

0930 FEASIBILITY OF PREDICTING CLIMATE CHANGE; IMPACT ON EAST COAST ICE SEVERITY III: OBSTACLES TO CLIMATE CHANGE IMPACT FORECASTING AND FEASIBILITY OF SOLUTION
J.R. Marko, Arctic Sciences Ltd., Sidney, B.C.
D.B. Fissel, Arctic Sciences Ltd., Dartmouth, N.S.
P.A. Wadhams, Univ. of Cambridge, Cambridge, England
W.C. Thompson, Wm.C. Thompson & Associates Ltd, Calgary, Alta.
P.M. Kelly, Univ. of East Anglia, Norwich, England
R.D. Brown, Atmos. Envir. Ser. Ice Centre, Ottawa, Ont.

THE UPPER ATMOSPHERE RESEARCH SATELLITE PROGRAM
PROGRAMME DES SATELLITES DE RECHERCHE DANS L'ATMOSPHERE SUPERIEURE
Room/Salle 306, Grant Block

Chair/Chef: W.F.J. Evans, Atmospheric Environment Service, Downsview, Ont.

0830 THE UPPER ATMOSPHERE RESEARCH SATELLITE (UARS)
C.A. Reber, NASA/Goddard Space Flight Center, Greenbelt, MD, U.S.A.
J.R. Holton, Department of Meteorology, University of Washington, Seattle, Washington, U.S.A.

0850 THE HIGH RESOLUTION DOPPLER IMAGER
V.J. Abreu, Univ. of Michigan, Ann Arbor, MI, U.S.A.

0910 THE CRYOGENIC LIMB ARRAY SPECTROMETER
A.E. Roche, Lockheed Palo Alto Res. Lab., Palo Alto, CA, U.S.A.

0930 REMOTE SENSING OF ATMOSPHERIC STRUCTURE AND COMPOSITION BY PRESSURE MODULATOR RADIOMETRY FROM SPACE: THE ISAMS EXPERIMENT ON UARS
F.W. Taylor, Oxford Univ., Oxford, England

1010–1040
Health Break/Pause de santée, Quarter Deck

OCEAN SURFACE WAVES–2/VAGUES–2
Room/Salle 207, Grant Block

Chair/Chef: M.L. Khandekar, Atmospheric Environment Service, Downsview, Ont.

1040 AIR-SEA FLUXES BY THE DISSIPATION METHOD DURING THE OCEAN STORMS PROJECT
B.A. Proctor, Royal Roads Mil. Coll., Victoria, B.C.
G.A. McBean, Univ. of British Columbia, Vancouver, B.C.
R.F. Marsden, Royal Roads Mil. Coll., Victoria, B.C.

1100 FREQUENCY AND DIRECTIONAL EVALUATION OF THE ODGP WAVE SPECTRA AT HIBERNIA
B.-A. Jusżko, Jusżko Scientific Services, Victoria, B.C.
R. Graham, Def. Res. Est. Atl., Dartmouth, N.S.

1120 FETCH RELATIONS FOR WIND-GENERATED WAVES AS A FUNCTION OF WIND STRESS SCALING
W. Perrie, B. Toulany, Bedford Inst. Ocean., Dartmouth, N.S.

1140 EVIDENCE OF TEMPORAL CHANGES IN THE NORTH EUROPEAN SHELF WAVE CLIMATE
M. Reistad, J. Guddal, The Norwegian Meteor. Inst., Bergen, Norway

1200 LONG-TERM WAVE VARIABILITY ALONG THE SOUTHWEST COAST OF INDIA
N.P. Kurian, Centre for Earth Sci. Studies, Reg. Centre, Cochin, India

LARGE-SCALE OCEAN CIRCULATION–2
CIRCULATION OCEANIQUE A GRANDE ECHELLE–2
Room/Salle 205, Grant Block

Chair/Chef: L.A. Mysak, McGill University, Montreal, Que.

1040 Invited Speaker: P. Malanotte-Rizzoli, Massachusetts Institute of Technology, Cambridge, MA, U.S.A.
DATA ASSIMILATION IN OCEANOGRAPHY

1120 UNPREJUDICED OCEAN CIRCULATION
G. Holloway, Inst. Ocean Sci., Sidney, B.C.

1140 NPAL, AN UPPER-OCEAN MODEL OF THE NORTH PACIFIC: MODEL DESIGN AND INITIAL EXPERIMENTS
J. Cherniawsky, G. Holloway, Inst. Ocean Sci., Sidney, B.C.

THE CANADIAN WINDII PROGRAM–1
LE PROGRAMME CANADIEN WINDII–1
Room/Salle 206, Grant Block

Chair/Chef: B.L. Wetter, Canadian Space Agency, Ottawa, Ont.

1040 WIND IMAGING INTERFEROMETER (WINDII) FOR THE UPPER ATMOSPHERE SATELLITE MISSION
G.G. Shepherd, York Univ., North York, Ont.

1100 MEASURING THE MESOPAUSE TEMPERATURE WITH WINDII
R.P. Lowe, K.L. Gilbert, Univ. of Western Ontario, London, Ont.

1120 OXYGEN IN THE MIDDLE ATMOSPHERE
E.J. Llewellyn, Univ. of Saskatchewan, Saskatoon, Sask.

1140 THE WINDII INSTRUMENT AND ITS CALIBRATION
W.A. Gault, York Univ., North York, Ont.

WIND ANALYSIS AND MEASUREMENT
ANALYSE ET MESURE DES VENTS
Room/Salle 208, Grant Block

Chair/Chef: S.J. Cohen, Atmospheric Environment Service, Downsview, Ont.

1040 SATELLITE MEASUREMENT OF SURFACE WINDS IN THE NORTHEASTERN PACIFIC
N. Bepple, P. Austin, Univ. of British Columbia, Vancouver, B.C.

1100 MULTIPLE WINDBREAKS: AN AEOLIAN ENSEMBLE
K.J. McAneney, M.J. Judd, Min. Agric. Fish., Kerikeri, New Zealand

1120 A PRELIMINARY STUDY OF ORGANIZED MOTION IN WINDBREAK FLOW
Y. Zhuang, J. Wilson, Univ. of Alberta, Edmonton, Alta.

1140 WIND PROFILER NETWORKS – THE NEXT MAJOR ADVANCE IN OBSERVING THE UPPER WINDS
E. Hudson, Unisys Corp., Great Neck, NY, U.S.A.
J. Steranka, General Sciences Corp., Laurel, MD, U.S.A.

THE LAGRANGIAN OCEAN–1
L'OCEAN LAGRANGIEN–1
Room/Salle 331, Grant Block

Chair/Chef: C.R. Murthy, National Water Research Institute, Burlington, Ont.

1040 CURRENTS AND HORIZONTAL DIFFUSION ON GEORGES BANK AS MEASURED BY DRIFTING BUOYS
K. Drinkwater, J. Loder, F. Page, Bedford Inst. Ocean., Dartmouth, N.S.

1100 ANALYSIS OF DEEP-DROGUED SATELLITE-TRACKED DRIFTER MEASUREMENTS IN THE NORTHEAST PACIFIC
R.E. Thomson, Inst. Ocean Sci., Sidney, B.C.
P. LeBlond, Univ. of British Columbia, Vancouver, B.C.
W. Emery, Univ. of Colorado, CO, U.S.A.

1120 ESTIMATION OF EDDY-DIFFUSIVITIES, INTEGRAL LENGTH AND TIME SCALES FROM FRACTAL OCEANIC DRIFTER TRAJECTORIES
B. Sanderson, Memorial Univ. of Newfoundland, St. John's, Nfld.

1140 PARTICLE DISPERSION DUE TO TIDAL FLOW OVER TOPOGRAPHY
K.R. Thompson, Y. Shen, Dalhousie Univ., Halifax, N.S.

1200 THE FLOW OF A COASTAL CURRENT PAST A BLUNT HEADLAND
H.J. Freeland, Inst. Ocean Sci., Sidney, B.C.

ICE AND WAVES/GLACE ET VAGUES
Room/Salle 306, Grant Block

Chair/Chef: D.J. Schwab, NOAA Great Lakes Environmental Research Lab., Ann Arbor, MI, U.S.A.

1040 AIRBORNE SAR OBSERVATIONS OF WAVES IN ICE DURING LIMEX '89
P.W. Vachon, Can. Centre Remote Sensing, Ottawa, Ont.
A.S. Bhogal, Intera Technologies Ltd., Ottawa, Ont.

1100 WAVE-INDUCED DRIFT FORCE ON ICE FLOES
D. Masson, Inst. Ocean Sci., Sidney, B.C.

1120 FIELD DATA COLLECTION PROGRAMS AND THEIR IMPORTANCE TO SHIP ICING MODELLING
W.P. Zakrzewski, E.P. Lozowski, Univ. of Alberta, Edmonton, Alta.

1140 Floating Ice SIG Working Group Meeting
L. Lewis, D. Topham, Inst. Ocean Sci., Sidney, B.C.

1220–1350
Lunch/Déjeuner, Mess Decks

OCEANOGRAPHY–2/OCEANOGRAPHIE–2
Room/Salle 205, Grant Block

Chair/Chef: J.A. Stronach, Seaconsult Marine Research Ltd., Vancouver, B.C.

1350 PREDICTION OF CURRENTS IN THE WATERS OF NORTHERN BRITISH COLUMBIA
W.R. Crawford, K.S. Lee, Inst. Ocean Sci., Sidney, B.C.

1410 A THREE-DIMENSIONAL MODEL, GF8 FOR THE GEORGIA-FUCA SYSTEM
J.A. Stronach, Seaconsult Marine Research Ltd., Vancouver, B.C.
T.S. Murty, Inst. Ocean Sci., Sidney, B.C.

1430 ANALYSIS OF LONG-TERM SEALEVEL RECORDS FROM THE GEORGIA-FUCA-PUGET SOUND SYSTEM
D. Dunbar, Seaconsult Marine Research Ltd., Vancouver, B.C.

1450 IS THE LEEUWIN CURRENT DRIVEN BY PACIFIC HEATING AND WINDS?
A.J. Weaver, McGill Univ., Montreal, Que.
J.S. Godfrey, CSIRO Div. Ocean., Hobart, Tasmania, Australia

1510 CENTRIFUGAL UPWELLING OF COLD SALINE WATER AT THE ENDS OF LONG CAUSEWAYS IN THE SHALLOW BEAUFORT SEA
P. Greisman, Soliton Services, Vancouver, B.C.

HYDROLOGY–1/HYDROLOGIE–1
Room/Salle 207, Grant Block

Chair/Chef: R.G. Lawford, Environment Canada, Saskatoon, Sask.

1350 Invited Speaker: V. Klemeš, International Association of Hydrological Sciences, c/o Centre for Earth and Ocean Research, University of Victoria, Victoria, B.C.
HYDROLOGY IN THE CONTEXT OF CLIMATIC CHANGE

1430 SOME ASPECTS OF MODELLED SOIL MOISTURE FOR THE MONITORING OF DROUGHT/FLOODS IN THE CANADIAN PRAIRIES
L.O. Mapanao, Atmos. Envir. Ser., Downsview, Ont.

1450 A COMPARISON OF OPERATIONAL ESTIMATES OF OPEN-WATER EVAPORATION, AND 1990–91 FIELD STUDY PLANS
G.S. Strong, Nat. Hydrol. Res. Centre, Saskatoon, Sask.,
G.Z. Feng, Northwest. Agricultural Univ., Yangling, Shaanxi, China

1510 RECENT DROUGHTS IN SOUTHWESTERN MANITOBA: A MOISTURE DEFICIT ANALYSIS
R.A. McGinn, Brandon Univ., Brandon, Man.
B.T. Tolton, Univ. of Toronto, Toronto, Ont.

FISHERIES OCEANOGRAPHY–4
OCEANOGRAPHIE DE LA PECHE–4
Room/Salle 331, Grant Block

Chair/Chef: K.L. Denman, Institute of Ocean Sciences, Sidney, B.C.

1350 THE PROBABILITY DISTRIBUTION FOR THE ABUNDANCE OF FISH, AND ITS PATTERN IN SPACE
G. Evans, S. Akenhead, J. Rice, Dept. Fish. Oceans, Nfld. Region, St. John's, Nfld.

1410 CODAR REMOTE SENSING OF OCEAN CURRENTS OFF VANCOUVER ISLAND IN THE 1988 MASS PROGRAM
D. Hodgins, Seaconsult Marine Research Ltd., Vancouver, B.C.

1430 INTERANNUAL VARIABILITY OF SATELLITE-DERIVED SURFACE PIGMENT CONCENTRATION IN THE CALIFORNIA CURRENT
P.T. Strub, C. James, A.C. Thomas, Oregon State Univ., Corvallis, OR, U.S.A.

1450 TIME SCALES OF PATTERN EVOLUTION FROM CROSS-SPECTRUM ANALYSIS OF AVHRR AND CZCS IMAGERY
K.L. Denman, Inst. Ocean Sci., Sidney, B.C.
M.R. Abbott, Oregon State Univ., Corvallis, OR, U.S.A.

1510 RELATIONSHIPS BETWEEN WATER MASSES AND GROUNDFISH DISTRIBUTIONS ON THE SCOTIAN SHELF: AN INVESTIGATION OF INTERANNUAL VARIABILITY
R.I. Perry, R.J. Losier, Biological Stn., St. Andrews, N.B.

ATMOSPHERIC DYNAMICS–2
DYNAMIQUES ATMOSPHERIQUES–2
Room/Salle 208, Grant Block

Chair/Chef: J. Côté, Service de l'environnement atmosphérique, Dorval, Qué.

1350 THE HAMILTONIAN STRUCTURE OF GEOPHYSICAL FLUID DYNAMICS
T.G. Shepherd, Univ. of Toronto, Toronto, Ont.

1410 IMPROVING THE EFFICIENCY OF A FINITE-ELEMENT REGIONAL MODEL BY THE USE OF A TWO-TIME-LEVEL PSEUDO-STAGGERED SEMI-LAGRANGIAN SCHEME
S. Gravel, J. Côté, A. Staniforth, Ser. de l'envir. atmos., Dorval, Qué.

1430 A SEMI-IMPLICIT SEMI-LAGRANGIAN FULLY COMPRESSIBLE MODEL
M. Tanguay, Ser. de l'envir. atmos., Dorval, Qué.
A. Robert, R. Laprise, Univ. du Québec à Montréal, Qué.

1450 UN MODELE COLONNE DES ONDES INTERNES DANS L'ATMOSPHERE
K. Bouayad, R. Laprise, Univ. du Québec à Montréal, Qué.

1510 RECENT PROGRESS IN THE DEVELOPMENT OF A VARIABLE-RESOLUTION GLOBAL MODEL
J. Côté, A. Staniforth, Ser. de l'envir. atmos., Dorval, Qué.

SEDIMENT CHEMISTRY/CHEMIE DES SEDIMENTS
Room/Salle 306, Grant Block

Chair/Chef: S.E. Calvert, University of British Columbia, Vancouver, B.C.

1350 MODELLING pH-GRADIENTS NEAR O_2-H_2S INTERFACES IN SEDIMENTS
B.P. Boudreau, Dalhousie Univ., Halifax, N.S.

1410 EVALUATING THE UTILITY OF COMPLEX DIAGENETIC MODELS: THE SILICA/OPAL SYSTEMS AS AN EXAMPLE
B.P. Boudreau, Dalhousie Univ., Halifax, N.S.

1430 CONTAMINANT METAL ACCUMULATION IN SEDIMENTS OF HALIFAX HARBOUR AND IMPLICATIONS FOR FUTURE REMOBILIZATION
D.E. Buckley, Atl. Geosci. Centre, Dept. Energy, Mines Res., Darmouth, N.S.
B.D. Petrie, J.N. Smith, P.A. Yeats, Bedford Inst. Ocean., Dartmouth, N.S.

THE CANADIAN WINDII PROGRAM–2
LE PROGRAMME CANADIEN WINDII–2
Room/Salle 206, Grant Block

Chair/Chef: G.G. Shepherd, York University, North York, Ont.

1350 DERIVATION OF WINDII GEOPHYSICAL PARAMETERS
B. Solheim, York Univ., North York, Ont.

1410 MONITORING EFFECTS OF AURORAL OVAL ENERGY INPUT ON GLOBAL WIND PATTERNS WITH WINDII
R.L. Gattinger, Herzberg Inst. Astrophysics, Nat. Res. Council, Ottawa, Ont.
L.L. Cogger, Univ. of Calgary, Calgary, Alta.

1430 VALIDATION AND GROUND TRUTHING OR WINDII/UARS
W.F.J. Evans, York Univ., North York, Ont.
R.P. Lowe, Univ. of Western Ontario, London, Ont.

1450 MEASUREMENTS OF POLLUTION IN THE TROPOSPHERE (MOPITT)
J.R. Drummond, Univ. of Toronto, Toronto, Ont.
J.C. McConnell, York Univ., North York, Ont.
G.P. Brasseur, J.C. Gille, Nat. Center Atmos. Res., Boulder, CO, U.S.A.

1510 CHEMISTRY AND DYNAMICS OF THE TROPOSPHERE
J.C. McConnell, G. Klaassen, York Univ., North York, Ont.
H.-R. Cho, J.R. Drummond, Univ. of Toronto, Toronto, Ont.

1530–1600
Health Break/Pause de santée, Quarter Deck

OCEANOGRAPHY-3/OCEANOGRAPHIE-3
Room/Salle 205, Grant Block

Chair/Chef: H.J. Freeland, Institute of Ocean Sciences, Sidney, B.C.

1600 EXPERIMENTS WITH A THERMOCLINE MODEL FOR THE NORTH PACIFIC
M.G.G. Foreman, Inst. Ocean Sci., Sidney, B.C.
A.F. Bennett, Oregon State Univ., Corvallis, OR, U.S.A.

1620 ON THE MODELLING OF THE NORTH ATLANTIC INTERANNUAL VARIABILITY USING COADS FOR THE PERIOD 1950-79
R. Michaud, C.A. Lin, McGill Univ., Montreal, Que.

1640 THE GEORGES BANK FRONTAL STUDY
K. Drinkwater, E. Horne, J. Loder, N. Oakey, Bedford Inst. Ocean., Dartmouth, N.S.

1700 PARKSVILLE BAY - AN INVESTIGATION OF EROSION
B.J. Holden, Min. Envir., Victoria, B.C.

ATMOSPHERIC DYNAMICS-3
DYNAMIQUES ATMOSPHERIQUES-3
Room/Salle 208, Grant Block

Chair/Chef: G.J. Boer, Atmospheric Environment Service, Downsview, Ont.

1600 A CONVENIENT VERTICAL COORDINATE SYSTEM FOR INTEGRATING THE EULER EQUATIONS
B. Dugas, R. Laprise, Univ. du Québec à Montréal, Qué.

1620 VERTICAL WAVE PROPAGATION IN THE GFDL "SKYHI" MODEL
K. Hamilton, Princeton Univ., Princeton, NJ, U.S.A.

1640 THE DISTRIBUTION OF THE TIME SINCE (TILL) SURFACE CONTACT FOR A FLUID ELEMENT OBSERVED (RELEASED) IN THE CONVECTIVE BOUNDARY-LAYER
J.D. Wilson, G.E. Swaters, Univ. of Alberta, Edmonton, Alta.

1700 SOME ASPECTS OF EDDY-INDUCED MEAN MERIDIONAL CIRCULATIONS IN THE ATMOSPHERE
T.G. Shepherd, Univ. of Toronto, Toronto, Ont.

1720 DEVELOPMENT EQUATIONS FOR HYDROSTATIC METEOROLOGICAL SYSTEMS OF ALL SCALES
P. Zwack, M. Desgagné, Univ. du Québec à Montréal, Qué.
P. Smith, Purdue Univ., West Lafayette, IN, U.S.A.

MARINE CHEMISTRY–2
CHEMIE OCEANOGRAPHIQUE–2
Room/Salle 306, Grant Block

Chair/Chef: P.A. Yeats, Bedford Institute of Oceanography, Dartmouth, N.S.

1600 DISSOLVED INDIUM IN SEAWATER – AN ANALOGUE FOR ALUMINUM AND GALLIUM
K.J. Orians, Univ. of British Columbia, Vancouver, B.C.

1620 MEROMICTIC LAKES IN BRITISH COLUMBIA
K.A. Perry, T.F. Pedersen, Univ. of British Columbia, Vancouver, B.C.

1640 GEOCHEMICAL BEHAVIOUR OF A BURIED MARINE MINE TAILINGS DEPOSIT, HOWE SOUND, BRITISH COLUMBIA
K. Drysdale, Univ. of British Columbia, Vancouver, B.C.

OCEAN ACOUSTICS AND REMOTE SENSING
ACOUSTIQUE OCEANIQUE ET TELEDETECTION
Room/Salle 331, Grant Block

Chair/Chef: S.R. Waddell, Royal Roads Military College, Victoria, B.C.

1600 REMOTE MONITORING OF THERMAL STRUCTURE AND GROWTH OF LABRADOR SHELF ICE
I. Peterson, S.D. Smith, S. Prinsenberg, Bedford Inst. Ocean., Dartmouth, N.S.
R.H. Orton, MetOcean Data Systems, Dartmouth, N.S.

1620 ASSIMILATION OF SATELLITE SENSED WAVE DATA INTO AN OPERATIONAL WAVE PREDICTION MODEL – AN EVALUATION BASED ON SELECTED CANADIAN ATLANTIC STORMS
R. Lalbeharry, M.L. Khandekar, Atmos. Envir. Ser., Downsview, Ont.

1640 THE HORIZONTAL INTERPOLATION OF SOUND SPEED USING DENSITY SURFACES
K.L. Jones, S.R. Waddell, Royal Roads Mil. Coll., Victoria, B.C.

1700 THE SOUND FIELD DISTURBANCE CAUSED BY A MEDITERRANEAN SALT LENS
S.J. Newton, S.R. Waddell, Royal Roads Mil. Coll., Victoria, B.C.

1720 ACOUSTIC PROPAGATION AND ITS ANGLE-OF-ARRIVAL DISTRIBUTION IN A TURBULENT BOUNDARY LAYER
D. DiIorio, Inst. Ocean Sci., Sidney, B.C. and Univ. of Victoria, Victoria, B.C.

THE LAGRANGIAN OCEAN–2
L'OCEAN LAGRANGIEN–2
Room/Salle 206, Grant Block

Chair/Chef: W.R. Crawford, Institute of Ocean Sciences, Sidney, B.C.

1600 COMPUTERIZED RADAR TRACKING OF SURFACE DRIFTERS IN BARKLEY SOUND
J.R. Buckley, Royal Roads Mil. Coll., Victoria, B.C.

1620 LAGRANGIAN DRIFTER TRACKS IN A WIND-DRIVEN BAROTROPIC MODEL OF QUEEN CHARLOTTE SOUND AND HECATE STRAIT
C.G. Hannah, P.H. LeBlond, Univ. of British Columbia, Vancouver, B.C.
W.P. Budgell, W.R. Crawford, Inst. Ocean Sci., Sidney, B.C.

1640 COMPARISON OF MODELED AND OBSERVED DRIFTER TRAJECTORIES IN WESTERN LAKE ERIE
D.J. Schwab, G.S. Miller, NOAA Great Lakes Envir. Res. Lab., Ann Arbor, MI, U.S.A.
C.R. Murthy, K. Miners, Nat. Water Res. Inst., Burlington, Ont.

1700 PARTICLE DRIFT IN THE SURFACE LAYER OFF SOUTHWEST NOVA SCOTIA: EVALUATION OF A MODEL
P.C. Smith, Bedford Inst. Ocean., Dartmouth, N.S.
F.H. Page, Dalhousie Univ., Halifax, N.S.

1900
Bus transportation from Royal Roads to Royal B.C. Museum
Transport en autobus du Royal Roads au Musée royal de la Colombie Britannique

PUBLIC LECTURE/LECTURE PUBLIQUE
Newcombe Theatre, Royal British Columbia Museum
Théatre Newcombe, Musée royal de la Colombie Britannique
Victoria, B.C.

1930 D.F.W. Pollard, Forestry Canada, Pacific Forestry Centre, Victoria, British Columbia
CLIMATE CHANGE: CAN THE FOREST SECTOR RESPOND?

THURSDAY MAY 31/JEUDI LE 31 MAI

PLENARY–2/SEANCE PLENIERE–2
Gymnasium

Chair/Chef: P.H. LeBlond, University of British Columbia, Vancouver, B.C.

0830 J.C. Schaake, National Weather Service, Office of Hydrology, Silver Spring, MD, U.S.A.
MACROSCALE HYDROLOGICAL MODELS

0915 R.G. Fairbanks, Lamont-Doherty Geophysical Observatory of Columbia University, Palisades, NY, U.S.A.
INFLUENCE OF GLACIAL MELTING RATES ON OCEAN CIRCULATION AND ATMOSPHERIC CHEMISTRY OVER THE PAST 17,000 YEARS

1015–1030
Health Break/Pause de santée, Mess Decks

PLENARY–3/SEANCE PLENIERE–3
Gymnasium

Chair/Chef: M.I. El-Sabh, Université du Québec à Rimouski, Qué.

1030 W.R. Peltier, University of Toronto, Toronto, Ontario
GLOBAL SEA LEVEL RISE: AN OCEANOGRAPHIC INDICATOR OF GLOBAL CHANGE

1115 R.J. Reed, University of Washington, Seattle, WA, U.S.A.
RECENT ADVANCES IN UNDERSTANDING AND PREDICTION OF OCEAN STORMS

1200–1330
Lunch/Déjeuner, Mess Decks

CONCURRENT SESSIONS/SEANCES SIMULTANEES

HYDROLOGY–2/HYDROLOGIE–2
Room/Salle 207, Grant Block

Chair/Chef: G. Kite, Atmospheric Environment Service, Saskatoon, Sask.

1330 ANALYSIS OF LONG-TERM RIVERFLOW DATA IN ONTARIO
H. Goertz, Inland Waters Dir., Envir. Canada, Guelph, Ont.

1350 FEATURES OF A RUNOFF INDEX COMPARED TO MONTHLY STREAMFLOW AT SELECTED BASINS
L.O. Mapanao, Atmos. Envir. Ser., Downsview, Ont.

1410 AN ASSESSMENT OF THE RECORD OF PRECIPITATION AT OCEAN STATION "PAPA" (1953–1981)
J.L. Knox, Atmos. Envir. Ser., Downsview, Ont.

1430 THE USE OF HYDROGRAPH PARTIAL DURATION FREQUENCY TECHNIQUES TO IDENTIFY FLOOD GENERATING CLIMATOLOGICAL EVENTS
R.A. McGinn, Brandon Univ., Brandon, Man.
A.C. Giles, Atmos. Envir. Ser., Edmonton, Alta.

1450 FLOOD OF SEPTEMBER 1986 IN THE WATERSHEDS OF LODGE, BATTLE AND LYONS CREEKS, SOUTHWEST SASKATCHEWAN
L. Adrian, Envir. Canada, Regina, Sask.

1510 EFFECT OF LAND SURFACE TREATMENT ON GCM CLIMATE SIMULATIONS
D. Verseghy, Atmos. Envir. Ser., Downview, Ont.

PALEOCEANOGRAPHY/PALEOCEANOGAPHIE
Room/Salle 306, Grant Block

Chair/Chef: T.F. Pedersen, University of British Columbia, Vancouver, B.C.

1330 LATE QUATERNARY HISTORY OF HYDROGRAPHY, OXYGEN DEPLETION AND ORGANIC CARBON ACCUMULATION ON THE OMAN MARGIN
T.F. Pedersen, R. Zahn, Univ. of British Columbia, Vancouver, B.C.
G.B. Shimmield, Univ. of Edinburgh, Edinburgh, Scotland

1350 DEGLACIAL OCEAN CO_2-OUTGASSING: DOES IT LIMIT HIGH-RESOLUTION ^{14}C-AMS DATING OF THE LAST GLACIAL-INTERGLACIAL TRANSITION?
R. Zahn, Univ. of British Columbia, Vancouver, B.C.
L.D. Labeyrie, Lab. Faibles Radioact., CNRS, Gif-Sur-Yvette, France

1410 NEW PALEOCLIMATE INDICATORS IN REEF-BUILDING CORALS
G.T. Shen, Univ. of Washington, Seattle, WA, U.S.A.

1430 SEDIMENTARY GEOCHEMISTRY OF THE LATE PLEISTOCENE AND HOLOCENE SEDIMENTS OF THE BLACK SEA
S.E. Calvert, Univ. of British Columbia, Vancouver, B.C.
R. Karlin, Univ. of Nevada, Reno, NV, U.S.A.

OCEANOGRAPHY–4/OCEANOGRAPHIE–4
Room/Salle 205, Grant Block

Chair/Chef: W.J. Rapatz, Institute of Ocean Sciences, Sidney, B.C.

1330 SOME PECULIARITIES OF TSUNAMI RECURRENCE IN THE NORTHWEST PACIFIC
A.I. Ivashchenko, Inst. Mar. Geol. Geophys., Yuzhno-Sakhalinsk, U.S.S.R.

1350 INVESTIGATION OF INFRAGRAVITY WAVES ON THE SOUTHWESTERN SHELF OF KAMCHATKA
P.D. Kovalev, Inst. Marine Geology and Geophysics, Yuzhno-Sakhalinsk, U.S.S.R.
G.V. Shevchenko, U.S.S.R.
A.B. Rabinovich, Inst. Marine Geology and Geophysics, Yuzhno-Sakhalinsk, U.S.S.R.

1410 TIDAL MODULATION OF DEEP WATER REPLACEMENT IN THE STRAIT OF GEORGIA
H. Ma, P. LeBlond, S. Pond, Univ. of British Columbia, Vancouver, B.C.

1430 PROPAGATION OF COASTAL TRAPPED WAVES UNDER AN ICE COVER IN THE HUDSON BAY
T. Reynaud, R.G. Ingram, McGill Univ., Montreal, Que.

1450 COASTAL UPWELLING OFF THE WEST COAST OF VANCOUVER ISLAND
I. Jardine, P. LeBlond, Univ. of British Columbia, Vancouver, B.C.

1510 SEICHES IN THE KURIL BAYS: NUMERICAL CALCULATION BY RT-ALGORITHM AND OBSERVATIONS
A.S. Leviant, U.S.S.R.
A.B. Rabinovich, B.I. Rabinovich, Inst. Mar. Geol. Geophys., Yuzhno-Sakhalinsk, U.S.S.R.

FISHERIES OCEANOGRAPHY–5/OCEANOGRAPHIE DE LA PECHE–5
Room/Salle 331, Grant Block

Chair/Chef: G.S. Jamieson, Pacific Biological Station, Nanaimo, B.C.

1330 THE INTERTIDAL: PHYSICAL AND BIOLOGICAL INFLUENCES ON SPECIES COMPOSITION, ABUNDANCE AND RECRUITMENT PATTERNS
G.S. Jamieson, D. Noakes, Pacific Biol. Stn., Nanaimo, B.C.

1350 A POSSIBLE EDDY RETENTION MECHANISM FOR ICHTHYOPLANKTON IN HECATE STRAIT
W.R. Crawford, Inst. Ocean Sci., Sidney, B.C.
A.V. Tyler, Pacific Biol. Stn., Nanaimo, B.C.
R.E. Thomson, Inst. Ocean Sci., Sidney, B.C.

1410 THE DISTRIBUTION OF COMMERCIAL TROLL FISHING VESSELS OFF SOUTHWEST VANCOUVER ISLAND IN RELATION TO FISHING SUCCESS AND OCEANIC WATER PROPERTIES AND CIRCULATION
R.E. Thomson, Inst. Ocean Sci., Sidney, B.C.
M. Healey, J. Morris, Pacific Biol. Stn., Nanaimo, B.C.
G. Borstad, G.A. Borstad Associates Ltd., Sidney, B.C.

1430 CLIMATE, PREDATORS AND PREY: BEHAVIOUR OF A LINKED OSCILLATING SYSTEM
D.M. Ware, Pacific Biol. Stn., Nanaimo, B.C.

1450 ANALYZING CORRELATIONS BETWEEN MARINE SURVIVAL TRENDS IN NORTHEAST PACIFIC SALMON STOCKS AND ENVIRONMENTAL VARIABLES
R.D. Brodeur and R.C. Francis, Univ. of Washington, Seattle, WA, U.S.A.

1510 SEASONAL VARIATION IN EXPERIMENTALLY DERIVED GRAZING RATES OF THE MARINE COPEPODS, *Calanus pacificus* AND *Metridia pacifica*
K. Burns, Royal Roads Mil. Coll., Victoria, B.C.
L.A. Hobson, Univ. of Victoria, Victoria, B.C.

ATMOSPHERIC VARIABILITY–1
VARIABILITE ATMOSPHERIQUE–1
Room/Salle 208, Grant Block

Chair/Chef: G.A. McBean, University of British Columbia, Vancouver, B.C.

1330 CLIMATE CHANGE DUE TO INCREASED CO_2 SIMULATED WITH THE CCC GCM
G.J. Boer, Atmos. Envir. Ser., Downsview, Ont.

1350 A SKEPTICAL LOOK AT THE RECENTLY-PROPOSED SUN-QBO-WEATHER CONNECTION
K. Hamilton, Princeton Univ., Princeton, NJ, U.S.A.

1410 OBSERVED AND SIMULATED INTRASEASONAL ENERGETICS
S.J. Lambert, Can. Clim. Cent., Downsview, Ont.

1430 EFFECT OF ANNUAL VARIATION IN GROWING SEASON RAINFALL ON TREE GROWTH ON THE EAST COAST OF VANCOUVER ISLAND
D.L. Spittlehouse, B.C. Forest Ser., Min. Forests, Victoria, B.C.

1450 A COMPARISON OF THE METEOROLOGICAL CONDITIONS DURING THE DROUGHT OF THE 1930'S AND THE 1980'S FOR THE PRAIRIE PROVINCES
T.-A. Lang, K. Jones, Atmos. Envir. Ser., Regina, Sask.

1530–1600
Health Break/Pause de santée, Quarter Deck

FISHERIES OCEANOGRAPHY–6
OCEANOGRAPHIE DE LA PECHE–6
Room/Salle 206, Grant Block

Chair/Chef: D.L. Mackas, Institute of Ocean Sciences, Sidney, B.C.

1600 THE EFFECT OF TURBULENCE ON CHEMOSENSORY PERCEPTION USING THE LOW REYNOLDS NUMBER FEEDING CURRENT OF CALANOID COPEPODS
B. Sanderson, Memorial Univ. of Newfoundland, St. John's, Nfld.

1620 POPULATION GENETICS AND SPATIAL HETEROGENEITY IN THE NORTH PACIFIC KRILL *Euphausia pacifica*: A PRELIMINARY ASSESSMENT
C. Blanton, L.A. Hobson, Univ. of Victoria, Victoria, B.C.

1640 SEASONAL VARIATION IN THE CAROTENOID PIGMENT CONTENT AND COMPOSITION IN *Euphausia pacifica*
V.A. Funk, L.A. Hobson, Univ. of Victoria, Victoria, B.C.

1700 INTERANNUAL VARIABILITY OF OCEANOGRAPHIC CONDITIONS AND SPATIAL DISTRIBUTIONS OF DUNGENESS CRAB (*Cancer magister*) IN THE PACIFIC NORTHWEST
R.L. Hobbs, Univ. of California at Davis, CA, U.S.A.
A.C. Thomas, Oregon State Univ., Corvallis, OR, U.S.A.
L.W. Botsford, Univ. of California at Davis, CA, U.S.A.

1720 OCEANOGRAPHIC FACTORS AFFECTING THE CATCHABILITY OF PACIFIC OCEAN PERCH (*Sebastes alutus*)
B. Scott, Univ. of British Columbia, Vancouver, B.C.

HYDROLOGY–3/HYDROLOGIE–3
Room/Salle 207, Grant Block

Chair/Chef: S.T. Wong, Simon Fraser University, Burnaby, B.C.

1600 INTERANNUAL VARIABILITY OF PRECIPITATION IN WESTERN CANADA
R.G. Lawford, G.S. Lawrence, Envir. Canada, Saskatoon, Sask.

1620 ANALYSIS OF SELECTED HYDROMETEOROLOGICAL TIME SERIES
G. Kite, Atmos. Envir. Ser., Saskatoon, Sask.

1640 COMPARISON AND ANALYSIS OF DIFFERENCES BETWEEN THE CONCEPTUAL AND DISTRIBUTED RAINFALL-RUNOFF MODELS
E. Mekis, B.E. Goodison, Atmos. Envir. Ser., Downsview, Ont.

1700 DETERMINING THE REGIONAL HYDROLOGIC RESPONSE TO GLOBAL CLIMATE CHANGE: THE CASE OF BRITISH COLUMBIA
G. Thomas, Univ. of British Columbia, Vancouver, B.C.

OCEANOGRAPHY–5/OCEANOGRAPHIE–5
Room/Salle 205, Grant Block

Chair/Chef: J.F.R. Gower, Institute of Ocean Sciences, Sidney, B.C.

1600 TIDE REMOVAL FROM SHIP-MOUNTED ACOUSTIC DOPPLER MEASUREMENTS
M.G.G. Foreman, H.J. Freeland, Inst. Ocean Sci., Sidney, B.C.

1620 COMPARISON OF A NUMERICAL MODEL OF BURRARD INLET AND INDIAN ARM TO OBSERVATIONS OF SALINITY AND VELOCITY
A.N. Cameron, M.W. Stacey, Royal Roads Mil. Coll., Victoria, B.C.

1640 COMPARISON OF SHIP AND GEOSAT ALTIMETER OBSERVATIONS OF SEA-SURFACE HEIGHT ANOMALIES IN THE NORTHEAST PACIFIC
J.F.R. Gower, S. Tabata, Inst. Ocean Sci., Sidney, B.C.

1700 SEASONAL VARIABILITY OF OCEAN FEATURES AT THE ENTRANCE TO JUAN DE FUCA STRAIT
R.M. Zellerer, D.P. Kranel, Royal Roads Mil. Coll., Victoria, B.C.
R.E. Thomson, Inst. Ocean Sci., Sidney, B.C.

1720 NONLINEAR STABILITY OF FLOW OVER TOPOGRAPHY
J. Zou, W.W. Hseih, Univ. of British Columbia, Vancouver, B.C.
G. Holloway, Inst. Ocean Sci., Sidney, B.C.

ATMOSPHERIC VARIABILITY–2
VARIABILITE ATMOSPHERIQUE–2
Room/Salle 208, Grant Block

Chair/Chef: J.L. Knox, Atmospheric Environment Service, Downsview, Ont.

1600 SHORT-PERIOD CLIMATE FLUCTUATIONS IN THE FAR EAST REGION OF THE U.S.S.R. AND SEA SURFACE TEMPERATURE VARIATIONS IN THE KUROSHIO AREA
O.N. Likhacheva, A.B. Rabinovich, Inst. Marine Geol. Geophy., Far East Div., Yuzhno-Sakhalinsk

1620 TEMPORAL AND SPATIAL VARIABILITY OF THE TROPICAL RADIATION BUDGET FROM EARTH RADIATION BUDGET SATELLITE MEASUREMENTS
T.Y. Chang, R. Davies, McGill Univ., Montreal, Que.

1640 ON THE MEAN MERIDIONAL TRANSPORT OF ENERGY IN THE ATMOSPHERE AND OCEANS
R. Michaud, J. Derome, McGill Univ., Montreal, Que.

1700 THE BIG CHILL – AN INTENSE ARCTIC OUTBREAK IN SOUTHWESTERN BRITISH COLUMBIA
P.L. Jackson, Univ. of British Columbia, Vancouver, B.C.

1720 AN OBSERVATIONAL STUDY OF INTERACTIONS BETWEEN TRANSIENT EDDIES AND PERSISTENT CIRCULATION ANOMALIES
B. Dugas, J. Derome, McGill Univ., Montreal, Que.

1800
Bus transportation from Royal Roads to Banquet
Transport en autobus du Royal Roads au banquet

FRIDAY JUNE 1/VENDREDI LE 1 JUIN
CONCURRENT SESSIONS/SEANCES SIMULTANEES

OCEANOGRAPHY–6/OCEANOGRAPHIE–6
Room/Salle 205, Grant Block

Chair/Chef: M.G.G. Foreman, Institute of Ocean Sciences, Sidney, B.C.

0900 TIDAL CURRENTS IN A TWO-LAYERED STRATIFIED SEA WITH AN EXAMPLE FROM THE NORTH SEA
F.B. Pedersen, K. Bolding, Univ. of British Columbia, Vancouver, B.C.

0920 CAN A TWO-DIMENSIONAL VORTICITY CASCADE EXPLAIN THE DISTRIBUTION OF LENGTH SCALES SEEN IN LANGMUIR CELLS?
L. Zedel, Inst. Ocean Sci., Sidney, B.C. and Univ. of British Columbia, Vancouver, B.C.
D. Farmer, Inst. Ocean Sci., Sidney, B.C.

0940 ON THE EFFECT OF A BOTTOM BOUNDARY ON THE STABILITY OF A SALT-WEDGE, WITH APPLICATION TO ESTUARY-OCEAN MIXING
N. Yonemitsu, N. Rajarathnam, G.E. Swaters, Univ. of Alberta, Edmonton, Alta.

1000 PROGRESS TOWARDS A LONG TIME-SCALE, DENSITY-STRATIFIED SHELF CIRCULATION MODEL
R.J. Greatbatch, A. Goulding, Memorial Univ. of Newfoundland, St. John's, Nfld.

METEOROLOGICAL APPLICATIONS
APPLICATIONS METEOROLOGIQUES
Room/Salle 208, Grant Block

Chair/Chef: M.B. Danard, Atmospheric Dynamics Corp., Victoria, B.C.

0900 CURRENT PROCEDURES FOR TESTING THE HOMOGENEITY OF TEMPERATURE DATASETS FOR STATIONS IN THE CCC ARCHIVES
P.J.F. Sajecki, Atmos. Envir. Ser., Downsview, Ont.

0920 ON THE APPLICATION OF MICROCOMPUTERS TO THE ANALYSIS OF CLIMATE DATA BASES. PART 1: THE DETERMINATION OF USER REQUIREMENTS
A. Stuart, Weather Research House Inc., Downsview, Ont.

0940 ON THE APPLICATION OF MICROCOMPUTERS TO THE ANALYSIS OF CLIMATE DATA BASES. PART 2: THE DEVELOPMENT OF THE WEATHER INFORMATION DISPLAY SYSTEM
A. Stuart, Weather Research House Inc., Downsview, Ont.

1000 RADAR A POLARISATION CIRCULAIRE: UNE AMELIORATION DE LA METHODE DE CORRECTION DES EFFETS DE PROPAGATION
E. Torlaschi, Univ. du Québec à Montréal, Qué.

1020–1050
Health Break/Pause de santée, Quarter Deck

SIG HYDROLOGY/HYDROLOGIE GIS
Room/Salle 206, Grant Block

Chair/Chef: R.G. Lawford, Environment Canada, Saskatoon, Sask.

0900 Special Interest Group Hydrology Meeting

OCEANOGRAPHY–7/OCEANOGRAPHIE–7
Room/Salle 205, Grant Block

Chair/Chef: J.R. Buckley, Royal Roads Military College, Victoria, B.C.

1050 NUMERICAL TIDAL MODELLING STUDIES IN NORTHUMBERLAND STRAIT, CANADIAN EAST COAST
M.R. Tarbotton, C.S. Mihelcic, Triton Consultants Ltd., Vancouver, B.C.

1110 HEAT BUDGET FOR THE SCOTIAN SHELF: IMPLICATIONS FOR PREDICTION
J.U. Umoh, K.R. Thompson, Dalhousie Univ., Halifax, N.S.

1130 CIRCULATION OF THE NORTHEAST PACIFIC OCEAN INFERRED FROM TEMPERATURE AND SALINITY DATA
R.J. Matear, G. McBean, W.W. Hsieh, Univ. of British Columbia, B.C.

1150 VARIATIONS IN SURFACE LAYER MIXING EFFICIENCY ACROSS UPWELLED FRONTS
R.K. Dewey, J.N. Moum, Oregon State Univ., OR, U.S.A.

1210 SEASONAL VARIATIONS IN CONCEPTION BAY, NEWFOUNDLAND
B. DeYoung, Memorial Univ., St. John's, Nfld.

CLIMATE VARIATIONS/VARIATIONS CLIMATIQUE
Room/Salle 207, Grant Block

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

1050 MARINE CYCLONES AND GREENHOUSE WARMING: ANOTHER LOOK
O. Hertzman, Dalhousie Univ., Halifax, N.S.

1110 COMPENSATION OF SURFACE-FLUX ERRORS IN WEATHER/CLIMATE MODELS
J.D. Wilson, Univ. of Alberta, Edmonton, Alta.

1130 SIMULATION OF WATER AND KINETIC ENERGY BUDGETS OF CUMULUS CLOUDS
G.W. Reuter, McGill Univ., Montreal, Que.

1150 TEMPERATURE TRENDS IN CANADA
P. Kertland, Atmos. Envir. Ser., Downsview, Ont.

1210 MANIFESTATIONS OF THE EL NINO SOUTHERN OSCILLATION IN SOUTHEASTERN AUSTRALIAN WATERS
W.W. Hsieh, Univ. of British Columbia, Vancouver, B.C.
B.V. Hamon, Caringbah, New South Wales, Australia

1230
Lunch (No Host)/Déjeuner payant, Mess Decks

ABSTRACTS/RESUMES

PLENARY–1/SEANCE PLENIERE–1

Meteorological Aspects of Climate Variations

K.E. Trenberth, National Center for Atmospheric Research, Boulder, Colorado, U.S.A.

Because of man's activities leading to increased greenhouse gases in the atmosphere future climate change is deemed certain; indeed the climate system is not in equilibrium. But major questions remain concerning what form the climate changes will take and how rapidly they will occur. The 1988 North American drought evoked considerable publicity over whether it was caused by the greenhouse effect. Yet droughts are a natural phenomenon and have been documented throughout history. Nevertheless, their incidence and/or intensity may be influenced by climate change. When we examine recent temperature changes for possible "global warming", we find considerable spatial structure with largest warming over Alaska from 1977–86 but cooling over the North Pacific. Both are linked to circulation changes and a stronger Aleutian low pressure system in winter advecting warmer and moister air along the west coast of North America and into Alaska but colder air over the North Pacific. These changes appear to be linked to events in the tropics and the incidence of El Niños. Better understanding of these processes is essential if we are to detect the greenhouse gas-induced climate change.

El Niño, La Niña and the Southern Oscillation

G. Philander, Geophysical Fluid Dynamics Laboratory, Princeton University, Princeton, New Jersey, U.S.A

The Southern Oscillation, an irregular interannual fluctuation between warm, wet El Niño and cold, dry La Niña conditions has its largest amplitude in the tropical Pacific Ocean and influences meteorological conditions globally. From an oceanic point of view the changes in sea surface temperature patterns, from El Niño to La Niña, are caused by changes in the surface winds that drive the ocean. From a meteorological point of view the wind variations are part of the atmospheric response to the changing sea surface temperature patterns. This circular argument suggests that interactions between the ocean and atmosphere are at the heart of the matter. Stability analyses of these interactions in simple coupled models indicate that a broad spectrum of unstable ocean-atmospheric modes exists. The observed Southern Oscillation corresponds to the mode with the most rapid growth rate. Coupled General Circulation Models of the ocean and atmosphere succeed in capturing such a mode and reproduce a realistic Southern Oscillation. Seasonal variations in the solar radiation that the earth receives also excite one of these unstable ocean-atmosphere modes. This explains the remarkable similarity between the seasonal cycle in the tropics and the Southern Oscillation. Models for the prediction of El Niño have to take the seasonal cycle into account.

Comparison of Marine and Terrestrial Systems

J. Steele, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.

An understanding of the interactions of physical, chemical, and biological factors on the land, in the sea, and in the air is a practical societal necessity. Unfortunately, the possible nature and direction of biological changes are the most difficult aspect to predict and to relate to the other physical and chemical processes. Moreover, ecologists have treated terrestrial and marine environments separately. The organization of research, its funding, and the logistics of specific research programs exacerbates this dichotomy.

Should ecological theory and practice attempt to achieve a common basis in the oceans and on land? I argue that we must address the questions of generalizations capable of crossing the

land-to-sea boundary. Indeed, present changes at global and regional levels require that we must integrate the effects of these changes and especially their relevance to various societal, economic, and political questions.

FISHERIES OCEANOGRAPHY–1, PLANKTON
OCEANOGRAPHIE DE LA PECHE–1, PLANCTON

The Significance of Microalgal Blooms for Fisheries and for the Export of Particulate Organic Carbon in Oceans

L. Legendre, Département de Biologie, Université Laval à Québec, Québec

Microalgal blooms are rapid increases in biomass, caused by locally enhanced primary production and resulting in abnormally high cell concentrations. Hydrodynamical processes may control blooms through the agency of irradiance or nutrients. In the oceans, phytoplankton blooms governed by irradiance include the spring outburst, as well as the ice-edge, under-ice, winter and upwelling blooms. Those governed by nutrients comprise the tidal, summer, episodic and exceptional blooms. In addition, there are blooms of ice microalgae. Blooms reflect low recycling, and a large degree of uncoupling between increased primary production and grazing by zooplankton. As a consequence, they often result in high sedimentation of intact cells and faecal pellets. Microalgal blooms provide unique information on the potential fate (and not on the rate) of primary production in marine ecosystems. They have major effects on benthic and pelagic food webs, and are an essential condition for the great fisheries of temperate seas (Cushing, 1989). On the other hand, blooming systems have a high potential for exporting particulate organic matter from the euphotic layer, and thus provide unique information for the study of global fluxes of carbon in the marine environment.

Spatial and Temporal Variability of Zooplankton Biomass and Community Composition off Southern Vancouver Island

D.L. Mackas, Institute of Ocean Sciences, Biological Sciences Branch, Sidney, British Columbia

A five-year time series (1987–89) of zooplankton abundance estimates has been collected from the continental margin off southern Vancouver Island as part of the La Pérouse Project study of seasonal and interannual variability. Typical sampling density is 5–6 time periods per year, and 10–14 locations (selected from a standard list) per time period.

Although the eventual goal of the La Pérouse Project is to understand interannual variability, an essential first step is description of the "average" seasonal cycle and its spatial variability within the study area. Average zooplankton dryweight biomass ranges from a mid-winter low of about 1 g m^{-2} to an early summer high of about 7 g m^{-2}.

Both the seasonal and spatial variations of zooplankton community compostion are closely associated with the circulation pattern. "Warm water" taxa endemic to the Oregon and California coast are most abundant in winter following the fall transition to southeasterly mean winds. The cross-shore gradient in community compostion is concentrated along the shelf-break and across the shelf-break current.

Biological Studies on the Georges Bank Tidal Front: Zooplankton Distributions and Frontal Dynamics

R.I. Perry, Biological Station, St. Andrews, New Brunswick
G. Harding, K. Drinkwater, Bedford Institute of Oceanography, Dartmouth, Nova Scotia,
M.J. Tremblay, Department of Fisheries and Oceans, Halifax Laboratory, Halifax, Nova Scotia
C. Taggart, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

This study examines the role of the Georges Bank tidal front on the distributions of zooplankton at the northern edge of the Bank. Our objective was to investigate the interaction of zooplankton with the dynamic physical processes at the front. In particular, we assess whether cross-frontal convergent forces accumulate zooplankton at the front, and whether the front acts as a boundary or is transparent to the on-off Bank transport of various species of zooplankton and fish larvae.

Results of three surveys (July, August, October 1988) are presented. Zooplankton distributions can be classified into three basic patterns: species predominantly in the well mixed water on the Bank; species off the Bank in deep water below the thermocline; and species which occurred on both sides of the front. The effect of species-specific behavioural patterns interacting with the frontal dynamics to maintain such distributions will be discussed using current meter and drifter data from a concurrent physical oceanographic study of the frontal region.

Unusually Rapid Growth of Coastal 0^+ Dungeness Crab may Lead to Strong Fisheries

D. Armstrong, D. Gunderson, School of Fisheries WH-10, University of Washington, Seattle, Washington, U.S.A.

Since 1983 we have studied population dynamics of juvenile Dungeness crab *Cancer magister* along the southern Washington coast and in adjacent estuaries. Six of the worst fishing years on record occurred between 1980 and 1987 (3–4 $\times 10^6$ lb), but the third strongest year ($> 16 \times 10^6$ lb) occurred in 1988 and can be traced to the 1984 year class (YC). Estuarine production of 1^+ juveniles has been relatively constant during these years and varies only about two times, while coastal production has varied by over 14 times. In spring of 1984, '85 and '86, the estimated coastal 1^+ populations were 6.4, 29.0 and 2.0×10^6 crab, respectively. The strength of the 1984 YC (1^+ in 1985) may be traced to more rapid growth the previous summer along the coast than is typical in most years. By September of the 0^+ year (settlement in May–June), mean carapace widths of the 1983, '84 and '85 YCs along the coast were about 12, 25 and 14 mm, respectively. Attainment of substantially larger size by the end of summer may have protected the 1984 YC from continued, high predation that usually decimates a coastal YC by the following spring. Thus coastal fisheries of low or moderate yield may be largely based on relatively stable estuarine production of juveniles, but the very large fisheries peaks that characterize Dungeness crab could result from auspicious coastal conditions that, in this case, led to accelerated growth of the 0^+ age class in 1984.

ATMOSPHERIC CHEMISTRY
CHEMIE ATMOSPHERIQUE

High Elevation Fog and Precipitation Chemistry in Southwestern British Columbia

M.S. Kotturi, Environmental Protection Division, Ministry of Environment, Victoria, British Columbia

A preliminary fog chemistry program was conducted from January to March 1988 with passive collectors at elevations of 780 metres and 970 metres in southwestern British Columbia. The pH of the samples ranged from 3.63 to 4.98; the samples containing high sea salt content had pH values ranging from 5.25 to 7.26.

In 1989, a twelve month fog chemistry program was in operation at the same two sites. Precipitation samples were collected weekly near the lower fog monitoring site. Concentrations of anions – sulphate, nitrate, and chloride were significantly h gher in fogwater than in precipitation. The mean anion concentration in fogwater at 970 metres was 189.8 ± 186.2 μeq/L and at 780 metres was 221.9 ± 215.9 μeq/L. The mean anion concentration in precipitation samples was 57.6 ± 18.3 μeq/L. As noted by others, the variation of liquid water content seems to be the leading mechanism for the anion concentration changes in fog and precipitation with low

to moderate levels of pollution. A summary of available fog and precipitation chemistry and meteorological data is presented with discussion.

Simulation of Atmospheric Radon Distribution in a Diurnally-Varying Version of the GFDL "SKYHI" General Circulation Model

R.J. Wilson and K. Hamilton, Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, New Jersey, U.S.A.

A version of GFDL's 40-level troposphere-stratosphere-mesosphere general circulation model has been constructed that allows heat capacity in three soil layers. This model has been run with a diurnal cycle of radiation. A number of separate integrations have been performed with different formulations of the subgrid-scale transports between adjacent model atmospheric levels and between the lowest atmospheric level and the ground. A passive tracer meant to simulate atmospheric radon has also been included in the simulations. The vertical profile of the model tracer for each experiment can be compared with typical observations. This aids in evaluating the adequacy of the subgrid-scale mixing parameterizations. In this presentation the radon simulations and a number of other results related to the diurnal cycle will be discussed.

Monitoring of Stratospheric Ozone in Canada

J.B. Kerr, Atmospheric Environment Service, Downsview, Ontario

The goal of the Global Ozone Observing System is to detect changes in atmospheric ozone which may result from anthropogenic activity. The Canadian network, which is part of the Global System, has been upgraded during the 1980's by the Atmospheric Environment Service as a result of evidence indicating that depletion of stratospheric ozone is, in fact, occurring. Improvements to the network include expansion from five to seven stations and the installation of fully automated Brewer ozone spectrophotometers. Operation and calibration of the ozone monitoring network are discussed and results of measurements at some of the stations are presented.

Transport de Substances en Trace dans un Modèle Spectral de la Circulation Générale de l'Atmosphere

J. de Grandpré, R. Laprise, Département de Physique, Université du Québec à Montréal, Québec

Des tests ont été effectués avec le modèle de circulation générale (MCG) canadien afin d'étudier divers schémas numériques de transport de substances en trace. Les effets sur les simulations de corrections arbitraires fréquemment employées dans ce domaine pour palier à certaines propriétés non désirées des schémas numériques sont étudiés. Cette étude est une étape préliminaire s'inscrivant dans un effort à long terme visant la modélisation d'éléments photochimiques dans les MCG.

Effects of Foliage Wetness on the Deposition of Ozone

J.D. Fuentes, T.J. Gillespie, Department of Land Resource Science, University of Guelph, Guelph, Ontario

The effect of surface wetness on surface sink strengths of gaseous pollutants is largely unknown even though dew or intercepted raindrops may be present over large areas for many hours during long-range transport of pollutants. Experiments were conducted to understand the mechanisms governing the uptake of gaseous pollutants by vegetation, including the role of stomatal behaviour. A gas exchange system was developed for measuring the uptake of gaseous pollutants by whole leaves. Leaves of hypostomatous and amphistomatous plant species were exposed to known concentration of ozone (O_3) under controlled environments. Two different surface wetness

situations were studied: a film of distilled water similar to dew, and larger droplets which were placed on the adaxial surface of leaves to simulate raindrops. Initial results of O_3 fluxes to individual leaves indicate that leaf surface wetness substantially enhances the deposition of O_3. This observation is contrary to expectation, for O_3 is known to be quite insoluble in water. However, based on separate measurements of stomatal resistance to water vapour diffusion (r_{sv}) taken on the abaxial leaf surface, the marked increase in O_3 uptake appears to be controlled by stomatal behaviour. The r_{sv} measurements showed decreases in stomatal resistance shortly after water was sprayed on the adaxial surface of leaves. Our results suggest that dew or rainfall outdoors may be major meteorological factors affecting deposition of gaseous pollutants to vegetated surfaces.

ICE/SNOW RESEARCH–1
RECHERCHE DE LA GLACE ET DE LA NEIGE–1

Stability Enhancement of Sea Ice in the Greenland and Labrador Seas

R.F. Marsden, Department of Physics, Royal Roads Military College, Victoria, British Columbia
L.A. Mysak, Department of Meteorology, McGill University, Montreal, Quebec
R.A. Myers, Department of Fisheries and Oceans, St. John's, Newfoundland

Malmberg (1969) proposed that during the late 1960s anomalously low surface (upper 200 m) salinities in the Iceland Seas could increase the stability of the water column sufficiently to prevent deep convection. The increased stability would then enhance the formation of sea ice during winter in this region because even at the freezing point (−1.8°C), the surface water density is sufficiently low to prevent mixing with the water below. Hence, only a small portion of the water column need be cooled before freezing can occur and ice formation is enhanced. Here we explore this concept further by examining hydrographic data from three locations bordering Greenland and Iceland and then compare these with co-located sea ice concentrations. For the period 1953–1980, it is shown that the lag correlations between surface salinity and sea ice anomalies show a common structure for the case where salinity anomalies lead sea ice anomalies. It is shown that this correlation structure can be reproduced by a simple statistical feedback model using a non-stationary negative feedback coefficient to account for salinity forcing of ice anomalies. The data presented are all consistent with the concept of stability enhancement of sea ice formation.

Radiation and Energy Budgets of Alpine Tundra, British Columbia, Canada

I.R. Saunders, W.G. Bailey, Department of Geography, Simon Fraser University, Burnaby, British Columbia

Addressing the paucity of detailed knowledge of high mountain climatology, hourly and daily radiation and energy budget measurements were made at an alpine tundra site in the Cascade Mountains, southern British Columbia. Seasonal radiation regimes were strongly affected by the presence or absence of snow cover. The ephemerality of the thin, windblown snowpack in winter and early spring generated significant variability in the daily albedo, with consequences for other components of the radiation budget. In summer, the albedo was generally stable at about 0.17, and radiation budget variability was then largely controlled by cloud cover.

Energy budgets displayed a range of responses to the ambient surface and atmospheric conditions. In winter, sensible and latent heat exchanges were conservative, reflecting the general low-energy character of the season. In summer, convective energy tranfers were strongly governed by moisture availability, and in the absence of precipitation the tundra surface dessicated quickly. The range of mean daily Bowen ratios was 0.10 to 2.41, with a mean of 0.95. The controls affecting the evaporative water efflux were examined with respect to the surface resistance

considerations embodied by the Penman-Monteith combination model, the equilibrium approach of Priestley and Taylor, and the decoupling coefficient of McNaughton and Jarvis.

Labrador Sea Modeling with Ice Cover

M. Ikeda, Bedford Institute of Oceanography, Dartmouth, Nova Scotia

Southward advance of sea ice along Labrador is an indicator of cold climate. The sea ice can in turn affect weather and climate, and sometimes interferes with human activity. The southward extent of sea ice is controlled thermodynamically by the cold atmosphere associated with outbreaks from continents as well as dynamically by direct wind forcing and ocean currents. The ocean currents flow along fronts between cold fresh shelf water and warm salty offshore water, and are often regulated by the continental shelf break. Mechanisms to drive the ocean currents include basin-scale wind stress curl and buoyancy flux due to fresh water from the Arctic. In addition to these mechanisms, local alongshore wind stress induces coastal currents.

Southward advance takes place with a seasonal time scale and also differs from year to year. Over the Labrador Shelf, sea ice at least south of 55° is primarily advected from the north and melts on warmer water. Interannual variability of the ice extent is mostly attributable to air temperature, with secondary contribution from a wind stress. These two results suggest that, in colder winters, the atmosphere cools water more and reduces ice melting.

A six-level ocean model is coupled with Hibler's sea ice model to examine oceanic roles in seasonal ice advance off the east coast of the continent. The model has the straight coast to the west and the step-like shelf break, along with three open boundaries to the north, east and south. With dynamics simplified by a cross-shore geostrophic balance, the model describes processes such as wind-driven and buoyancy-driven flows, overturning, and planetary Rossby, topographic Rossby and internal Kelvin waves. Nonlinear (advection-diffusion) equations for temperature and salinity are solved for heat and salt balances. The model is driven by idealized forcing; for example, alongshore wind stress, inflow through the northern boundary and parameterized cooling.

Several individual physical mechanisms are examined by the model: when cooling is applied, convective overturning transfers oceanic heat stored in the lower ocean to the surface layer and tends to reduce ice formation. An intense inflow over the shelf break through the northern boundary tends to merge shoreward, constraining the cold and fresh shelf water over the shelf. This shoreward flow has a significant baroclinic component that is supported by interactions between an alongshore density gradient, which is maintained by upwelling due to the shoreward flow, and the shelf break. The shoreward flow brings significant heat to the shelf region, canceling negative heat flux due to a southward flow over the shelf. Ice cover is insensitive to northerly wind stresses, which contribute southward ice advection (and southward ocean currents also) and reduce ice formation by shoreward Ekman flow carrying the warm offshore water.

Evaluation of an Operational Version of the Sea Ice Dynamics Model over the Gulf of St. Lawrence during the Canadian Atlantic Storms Programme

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The Atmospheric Environment Service developed a regional scale sea ice motion model for obtaining short range, real time forecasts of ice conditions for operational use. The components of the model are the momentum balance, ice thickness redistribution, ice strength and constitutive law. The momentum equation describes the balance between air to ice stress, water to ice stress, Coriolis force, tilting force arising from varying sea surface height and forces due to internal ice stress. The ice thickness distribution accounts for changes in the compactness of different categories of ice due to mechanical and thermodynamic forcing. The ice strength is calculated in terms of ice distribution. The constitutive law relates internal ice stress to the strain rate and other material parameters. In addition to the other stresses in the momentum equation, internal

ice stress is modelled using a viscous-plastic rheology. The momentum equation is solved using a predictor-corrector technique in a finite difference Eulerian reference frame.

An operational version of the sea ice motion model is evaluated using compactness data over the Gulf of St. Lawrence area for a few selected cases from the Canadian Atlantic Storms Programme (CASP) conducted during January–March 1986. The evaluation is severely restricted due to the unavailability of observed data on ice drift and water currents. Model simulations are obtained using a grid distance of 42.33 km and a time step of 1 hr. Preliminary results suggest that the model is useful for operational ice forecasting work.

Determination of Wet Snow at Edmonton using Surface Weather Parameters

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The paper describes the derivation of a method for identifying wet snow at Edmonton using only the surface weather parameters. The difficulty is to identify upper air conditions which lead to melting, even when the surface temperature is below freezing.

The method, which is based on theoretical considerations, as well as empirical studies of thirty years of surface and upper air data from Edmonton Stony Plain, is as follows:

There is a 100% chance of wet snow at the surface when the following surface conditions are met (RH is the surface relative humidity in percent, and T is the surface temperature in degrees C):

$$T > 0$$

$$RH \geq 100 - 12.24T$$

There is a 50% chance of wet snow at the surface when:

$$-1.5 \leq T \leq 1$$
$$RH < 100 - 12.24T$$
$$RH \geq 90.1 - 5.3T$$

There is a 0% chance of wet snow when:

$$RH < 90.1 - 5.3T$$

We illustrate the application of the method to the surface records from a near-by station (Edmonton Municipal Airport), and show how the certainty of wet snow can be further improved when other, qualitative observations are taken into account.

TURBULENCE AND DIFFUSION IN THE OCEAN
TURBULENCE ET DIFFUSION DANS L'OCEAN

Isopycnal and Lateral Diffusion in a Box Ocean Circulation Model

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The Bryan-Cox ocean general circulation model is adapted to a box domain to examine the effects of lateral and isopycnal diffusive parameterizations on ocean circulation and tracer budgets. The geometry is an idealized box representation of the Atlantic Ocean between 20°–50°N, and 10°–60°W latitude/longitude horizontal resolution. There are 10 levels in the vertical covering 4000 m, with no bottom topography. The model is forced with seasonally varying surface wind stress and surface heat flux; it is initialized with 3-dimensional temperature and salinity fields interpolated

to the model grid. Isopycnal diffusion is parameterized using the rotated eddy diffusivity tensor. The numerical experiments consist of two 100-year spin-up-from-rest simulations using lateral and isopycnal diffusion. The diffusivities are chosen so that the two parameterizations become identical in the case of uniformly horizontal isopycnals. The effects of both forms of diffusion on the model dynamics, passive and active tracer distributions are presented. The tracer results from the 3-dimensional model are compared with those of a 1-dimensional advective-diffusive model. The role of ocean mixing on climate is also considered.

A Thermocline Ocean Model for Climate Studies

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A 3-dimensional 10-level mid-latitude (10°–60°N) box ocean general circulation model in spherical coordinates is formulated to examine the thermocline structure and thermohaline circulation of the North Atlantic Ocean. The model equations consist of full prognostic temperature and salinity equations, and diagnostic momentum equations with the nonlinear advective terms and horizontal mixing terms omitted. For a steady wind stress, the solution of the barotropic momentum equations leads to a Stommel gyre. Two formulations are used to treat the vertical diffusion for the baroclinic part. The first uses an eddy viscosity which is non-zero only in the uppermost level, so that geostrophic balance holds aside from the baroclinic wind stress contribution. This formulation is based on the ocean climate model developed in Germany. The second formulation parameterizes the vertical diffusion as linear damping at all levels. In both cases, the model is driven by idealized wind stress distributions and buoyancy fluxes. The diagnostic momentum equation formulation filters waves faster than long internal Rossby waves, thus allowing the use of long time steps for climate simulations.

The numerical experiments conducted include an examination of the model responses to wind and buoyancy forcing separately, as well as to both forcings. The thermocline structure and the thermohaline circulation are obtained by integrating to equilibrium, and a comparison of the results obtained using both treatments of the vertical diffusion is made.

Remote Measurement of Turbulent Velocity Fields in the Coastal Environment

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Strong turbulence is typical of many coastal areas. Although the associated mixing of water properties has important effects in areas such as nutrient supply to coastal ecosystems, pollutant dispersal, and aquaculture carrying capacity, to name but a few, direct measurements of the turbulent velocity field are almost non-existent to date. Such measurements are now possible, using a modified shipborne acoustic Doppler profiler. This paper will describe the necessary hardware and software modifications, and present examples of turbulent velocity fields produced by a variety of tidal flow structures in British Columbia coastal waters.

Upper Ocean Thermal Response to an Autumn Storm

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We have examined the short term (i.e. 1–2 days) ocean response to a specific storm observed during the Ocean Storms experiment. Three CASID buoys, with thermistor chains and pressure sensors, had been deployed before the storm of October 4, 1987 struck. Although the buoys were within a hundred kilometres of each other, the observed upper ocean response was quite different at the different locations. At one location, the mixed layer (ML) temperature dropped by 1.1°C in about 12 hours, corresponding to a ML heat loss rate estimated at 3700 W/m^2; at another

buoy, the heat loss rate was down to 1500 W/m^2. At all three buoys, most of the heat was mixed down into the thermocline. The measurements will be compared to similar observations of episodic cooling events made during STREX. We have been unable to reproduce the mixing and vertical redistribution of temperature observed using a simple one-dimensional dynamic instability model.

Evolution of Finestructure in a Tidal-Shear Flow

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The evolution of mixing layers is observed with a high resolution (in time and space) CTD data set with in which overturns are seen as inversions in the temperature, salinity and density profiles. The mixing layers are forced by the large amplitude internal tides which are generated at the head of the Laurentian channel in the St. Lawrence estuary. Shear associated with these waves destabilizes the water column, induces mixing overturns and this produces buoyancy flux and upward flux of nutrients.

Velocity profiles were also measured using an acoustic Doppler current profiler. These data combined with density profiles yield metre-scale Richardson numbers, providing a picture of the forcing field. Using this data set, the evolution of the water column from continuously stratified to layered can be studied and the overall buoyancy flux of the mixing can be evaluated. The further calculations of Available Potential Energy of the Fluctuations (*A.P.E.F.*) will allow the estimation of the rate if kinetic energy dissipation (ϵ) and when compared to the change in potential energy of the water column may also provide an estimate of the efficiency of mixing.

The use of Thorpe displacement profiles may contribute to the understanding of the evolution of not only overturn size and potential energy (using the related *A.P.E.F.*), but also of the structure of the overturns themselves, as a function of time and possibly *Ri*. It may be possible to use the reordering displacement pattern (Thorpe displacements) to say something about the state of the mixing overturn. These Thorpe displacement signatures may also be of help in distinguishing mixing overturns from intrusions.

CLOUD PHYSICS/PHYSIQUE DES NUAGES

Cloud Microphysics in Canadian Atlantic Storms

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During the Canadian Atlantic Storms Program (CASP) field project conducted from 15 January to 15 March 1986, cloud microphysical measurements were made using two instrumented aircraft: a Twin Otter and a DC-3. For 90% of the time in cloud, the aircraft were at temperatures between 0 and -12°C. Cloud droplet concentrations varied from low values to greater than 700 cm^{-3} with median values between 50 and 100 cm^{-3}. Ice crystals were usually present during cloud penetrations with the highest concentrations occurring at the warmest temperatures. Precipitation formation was through an ice crystal aggregation process. For both aircraft, severe icing conditions were encountered, and the microphysical character of these clouds have been documented.

Annual Variability in Hail Damage in Saskatchewan

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A time series of loss-to-risk ratio for crop-hail insurance in Saskatchewan from 1917 to the present is available. This paper examines the variation in this series in an effort to ascertain whether it is indicative of stability or change in climate over this period of almost a century. There

has been considerable speculation in the 1970s and 1980s that our climate is becoming stormier. The interpretation of the Saskatchewan hail-insurance data is subject to some constraints but it appears that the data do not support this contention.

The Saga of the Three-Peak Raindrop Size Distribution in Tropical Rain

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Laboratory-based numerical models on the evolution size of spectra in steady rainshafts produced (non-changing) equilibrium distributions with three distinct peaks in number concentration, 3PEDs. Measurements in Malaysia confirmed this conclusion for cases of steady rain in a general way, independent of the source clouds (convective or stratiform, cold or warm). A full proof is still not available due to the biases of the sampling device, the Joss disdrometer.

The observation of higher concentrations of drops in streaky rain at equilibrium peak sizes, led to the modeling of "pulsed" rain. Streaky packages, similar to those observed, were obtained using the model. Surprisingly, the resulting raindrops also developed a three peak distribution when integrated over the duration of the rainfall. While the peak positions are at about the same values as in 3PEDs, the relative heights however, varied with pulse duration and height in the shaft.

This study has important implications for tropical rain.

The Influence of Small Scale Rain Rate Variability on Radar Hydrology

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In assessing the importance of the factors affecting the precision of radar measurements of rain rate it is important to develop a theoretical framework that describes and predicts correctly the uncertainties involved.

A comparison of theoretical and observed errors due to interpolation and extrapolation of radar data as well as the discrepancies in radar-raingage comparison will be presented. The theoretical calculations take into account only the effects of the spatial and temporal variability of rain rate. The results show that the theory is adequate to describe the observations, and furthermore, the radar-raingage comparison indicates that the space-time variability is the most important factor in explaining the discrepancy between the two instruments.

Energy Budgets for Stratocumulus Clouds using Conserved Thermodynamic Variables

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The First International Satellite Cloud Climatology Program Regional Experiment (FIRE) provided an extensive set of satellite, aircraft, and groundbased measurements of marine stratocumulus clouds off the California coast. We have examined aircraft observations of radiative and thermodynamic variables for a nocturnal and a daytime FIRE case, using entropy and total water as conserved thermodynamic tracers. This technique provides consistent estimates of the surface and entrainment fluxes, as well as the convective velocity scale for the layer (Boers and Betts, 1988).

Layer mixing lines show the influence of sea-surface temperature changes on the boundary layer in the daytime case, and reveal a sharp ($\approx$ 5–10 km length scale) transition between two distinct thermodynamic regimes. For the nocturnal case, radiative cooling dominates the layer energy budget. The impact of radiative cooling on cloud droplets in the upper 50 m of the cloud is estimated using the circulation time scale given by the thermodynamic analysis; conditional samples of cloud drop-size distributions in descending air reveal that the cooling has some impact on droplet growth in this cloud.

References

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ATMOSPHERIC DYNAMICS–1
DYNAMIQUES ATMOSPHERIQUE–1

Application of the Semi-Lagrangian Method to a Multilevel Spectral Primitive Equations Model

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It has previously been shown that semi-Lagrangian schemes can be applied to spectral models of the shallow water equations using large time steps. The present study considers the extension of this work to a multilevel spectral primitive equations model.

As a first step, an Eulerian vorticity-divergence spectral model is converted to an Eulerian one based on a vector momentum form of the equation of motion. From the latter, several semi-Lagrangian ones are prepared: one using an interpolating semi-Lagrangian treatment of advection in the horizontal (referred to as 2DISL) while retaining Eulerian advection in the vertical, another using a three-dimensional interpolating semi-Lagrangian formulation (referred to as 3DISL), and another which combines the 2DISL scheme in the horizontal and a noninterpolating semi-Lagrangian treatment in the vertical (referred to as NISLV). Medium range intercomparison experiments are performed using models that include simple physical parameterizations. It is shown that the semi-Lagrangian semi-implicit approach can be applied accurately and stably to produce medium range (five day) forecasts using time steps that are far larger than those permitted by the Courant-Friedrichs-Lewy (CFL) stability criterion for the corresponding Eulerian model.

The NISLV version is found to be more accurate than the 3DISL one which apparently has excessive damping in the vicinity of the tropopause where all the model fields change abruptly in the vertical.

A Three-Dimensional Generalization of Eliassen's Balanced Vortex Equations

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A set of equations has been derived describing the motion of a fluid which is close to gradient balance in a circular vortex. For the case of axisymmetric flow, the balanced vortex equations reduce to the two-dimensional system described by Eliassen (1952, *Astrophys. Norv.*). which has been widely used in the study of tropical cyclones.

The equations are derived using the Hamiltonian method of Salmon (1985, *J. Fluid Mech.*). The primitive equations are expressed in variational form and approximations are made directly to the Lagrangian. This is done in such a way that time and particle-labelling symmetries are preserved, which ensures that the resulting equations conserve approximate forms of energy and potential vorticity. These correspond to the primitive equation quantities calculated using gradient wind.

Transformation to a potential radius coordinate R, where absolute angular momentum $M = R^2/2$, simplifies the system to a state which bears a formal resemblance to the quasi-geostrophic equations. This is analogous to the transformation to geostrophic coordinates in semigeostrophic theory, and has the effect of stretching regions where absolute vorticity is large.

Forecasting Polar Lows with Meso-scale Versions of the Canadian Regional Finite Element Model

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High-resolution versions of the present operational Regional Finite Element Model (RFE) have been developed to assess its potential in simulating these small scale, difficult-to-forecast and possibly-dangerous weather systems that are polar lows. The currently operational 100-km version and a 50-km version of the model have been run on three different polar low cases: two over Davis Strait and one over Hudson Bay. A 25-km version of the RFE was also run on the Hudson Bay event, together with further sensitivity experiments to ice cover. The reduction in spatial truncation errors provided by the increase in resolution does indeed result in a better simulation of the systems for two of the three cases. One of the possible explanations for the failure of the model to properly forecast the third event could be the absence of upper air support at initial time in the operational analysis for that case. The model has also shown a significant sensitivity to ice cover at high resolution, particularly for the surface wind structure. This set of experiments suggests that the improved forecast accurately obtained from increased resolution is limited not only by the quality of the standard upper air analysed variables supplied to the model, but is also significantly limited by the surface fields which act as a stationary forcing for the entire forecast period.

Experiments on Tropical Stratospheric Wind Variations in a High Vertical Resolution Spectral Model

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A 30 level version of the GFDL spectral climate model has been constructed with roughly 2 km resolution up to 60 km height. A simple drag parameterization has been added in the upper six levels to allow a reasonable simulation of the annual cycle in zonal stratospheric circulation. In common with other general circulation models, this model fails to produce a realistic quasi-biennial oscillation in the tropical stratosphere. A number of experiments are being conducted in an attempt to understand the dynamics of the tropical stratosphere in this model. The model has been initialized with the tropical zonal mean wind and temperature field strongly perturbed from those obtained in a standard run. Several interesting preliminary results have been obtained. It has been found that the relaxation back to equilibrium is much slower for easterly perturbations than for westerly perturbations. The relaxation in either case shows the downward phase propagation characteristic of actual QBO wind reversals. The vertical eddy momentum fluxes in the stratosphere are also affected systematically by the mean wind perturbations. Much more detailed analysis of these results is now underway.

Comparison of the Nonlinear Instability of Easterly and Westerly Jets in a Two-Layer β-plane Model

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The nonlinear evolution of unstable baroclinic Rossby waves (BRWs, hereafter) that emanate from a variety of different easterly and westerly jet profiles is examined with a two-layer quasi-geostrophic β-plane channel model. Significant differences are shown to arise between the solutions for easterly and westerly jets. For easterly jets, BRWs both grow and decay in a combined baroclinic/barotropic manner. The wave evolution is reversible and periodic. This contrasts with the results of Feldstein and Held (1989) for unstable westerly jets which find irreversible BRW life cycles consisting of baroclinic growth followed by barotropic decay.

The wave propagation characteristics of the easterly and westerly jets are examined in the context of linear WKB theory. It is found that the modes growing in the easterly jet are reflected at the walls of the channel, whereas the westerly jet's unstable modes are completely absorbed at critical latitudes. These reflections vs. absorption properties are used to explain the reversibility behaviour of the unstable BRWs.

Calculations are also performed for a variety of different jet widths. For unstable easterly jets, the ratio of barotropic to baroclinic energy conversion increases as the jet becomes narrower, but the general behaviour for all jet widths follows the same temporal behaviour described above. The unstable westerly jets display two distinctly different types of solutions. For westerly jets that have a width greater than one deformation radius, the BRWs undergo the irreversible life cycle described earlier. However, when the jet width is less than one deformation radius, reversible, periodic, life cycles consisting of barotropic growth followed by barotropic decay occur. These unstable, reversible, barotropic modes are shown to be reflected at turning points. In addition, it is found that when the wave evolution is reversible, the mean meridional circulation cell is fixed in latitudinal extent, whereas when the wave evolves in an irreversible manner, the cell broadens as the wave decays.

Lastly, the results from the easterly and westerly jet calculations are related to the instability of the African jet, the summer mesosphere easterly jet, narrow jets in the Southern Hemisphere, and the westerly jet of the winter stratosphere.

FISHERIES OCEANOGRAPHY–2
OCEAN-FISH CLIMATE AND CORRELATIONS
OCEANOGRAPHIE DE LA PECHE–2
OCEAN-PECHE, CLIMAT ET CORRELATIONS

Environmental Influences on Assessment and Management of West Coast Fish Populations

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Forecast of the maximum potential yield from a fish stock depends on accurate measurement of the abundance, growth and natural mortality of adult fish, and on determination of the rate at which recruitment decreases as the abundance of the spawning stock is reduced by the harvest. Variation in the ocean environment affects these factors directly, and indirectly through interference with our ability to measure appropriate quantities. The environmental phenomenon that has the most apparent influence on west coast fish stocks is the ENSO event. These anomalies are associated with decreased growth and with northward movement of the population's center of distribution. The change in fish distribution influences their availability to the fishery and our surveys, and complicates estimation of fish abundance. Observed inter-annual variation in recruitment confounds efforts to determine the dependence of recruitment on spawner abundance, and directly influences short-term forecasts of fish harvests. The ENSO events are not associated with most variation in recruitment. Upwelling and offshore transport have been invoked most often in efforts to hindcast variation in recruitment, but with little success. Simultaneous examination of environmental and biological factors may improve the success of these models. However, some environmental factor with broad teleconnection must be important because of the coherence of strong recruitment among diverse species over a wide geographic range in the NE Pacific Ocean.

Correlations between Fish Recruitment and Environmental Factors May Depend on the Natural Mortality Rate used to Reconstruct Fish Abundances

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One of the most common research approaches to the problem of recruitment variability in marine fish populations has been to correlate annual estimates of recruitment for a given stock with annual measures of an environmental variable. We show that when such correlations are based on recruitment abundances estimated by virtual population analysis (VPA), and when there are time trends in the fishing mortality rate and the oceanographic factor, the magnitude and statistical significance of correlations depends on the natural mortality rate (M) used in the VPA. We simulated an age-structured fish population with an assumed underlying "true" correlation between the abundance of recruits and an oceanographic factor and generated catch data and terminal fishing mortality rates for input to VPA. We then estimated recruits using VPA with a deliberately mis-specified M value (to reflect imprecise field estimates of M) and calculated the correlation that would be estimated between the estimated recruits and the observed oceanographic factor. When the model's true recruitment was significantly correlated with the oceanographic factor, certain ranges of incorrect M used in VPA masked the true correlation such that the estimated correlation was nonsignificant. When we assumed that true recruitment was independent of the oceanographic factor, other ranges of incorrect M created spurious correlations between recruitment and the oceanographic factor. To reduce the effects of time trends, we tried first-differencing the data prior to doing correlations. While first-differencing made correlations less sensitive to the choice of M used in VPA, estimated correlations were still quite different from true ones, regardless of the value of M used to reconstruct abundances. Because estimates of M are uncertain and trends in fishing mortality rates and oceanographic factors are common, existing correlations between recruitment and oceanographic variables (or lack thereof) may be artifacts. Thus, we recommend that analysts should generate several VPA estimates of recruitment time series using a plausible range of M values to demonstrate how conclusions are to the choice of M used in VPA.

An Empirical Simulation of Lagrangian Surface Currents: Part I – Interannual Changes in the Northeast Pacific Divergence

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Due to the complexity of measuring and monitoring ocean surface currents, numerical simulation models are an attractive alternative for estimating changes in the major features of ocean circulation. Also, satellite tracked drifter data have become available in the last decade to use for model calibration purposes.

An ocean-wide Ocean Surface Current Simulations (OSCURS) model was developed to examine the variability of circulation in areas of potential interest to fisheries in the North Pacific Ocean and Bering Sea north of 35°N from 1946 to 1986. Although currents intuitively affect the transport of young fish and even adult fish migrations, it is not possible to prove that ocean current fluctuations directly cause fluctuations in stock abundance due to inadequate fisheries data and predation effects. The purpose of the model is to describe more fully the patterns and changes that have occurred in ocean circulation.

This hindcast model used the FNOC gridded sea level pressure fields to calculate wind, then computed current speeds from the Witting (1909) formula. 4.8 times the square root of the wind speed. The angle of deflection, which averages about 25° to the right of the wind, was calculated from the Weber (1983) formula. The long-term mean geostrophic current (0/3000 db) was vectorially added to the wind current in each of the model's daily time steps.

Calibration of the Gulf of Alaska portion of OSCURS was performed by multiplying current speeds by 1.2 to make the best-fit visual agreement between model trajectories and daily positions of satellite tracked drifters which circulated around the Gulf of Alaska from July to December 1978 (Reed, 1980).

Year to year changes in the Great Divergence were examined by annual model runs which simulated the trajectories of drifters released at the same locations along 155°W in March. The eight-month drift subsequently traced out a characteristic pattern of eastward movement toward the U.S. and Canadian coastlines then a broad divergence toward the north and south near shore. Onshore flow was strongest in 1954 and weakest in 1970. Near the coast northward flow dominated in 1951, 58, 67, and 68 while the southward branch of the divergence was best developed in 1947, 48, 55, 60, and 61. At this stage the model has given descriptive insight into the variability problem that could not have been obtained by other means.

MARINE CHEMISTRY–1
CHEMIE OCEANOGRAPHIQUE–1

The Importance of Organic Complexation to the Oceanic Chemistry of Bioactive Trace Metals

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Recent advances in marine chemistry have demonstrated the paramount importance of complexation of trace metals such as Cu, Zn and Cd with natural organic ligands existing at low concentrations, and forming complexes with these bioactive trace metals having high conditional stability constants. Complexation of these metals by organic ligands is most pronounced in the surface euphotic zone where primary production is occurring. Organic complexation, combined with the variation in total dissolved metal concentrations, causes a 1000-fold variability in free ion activity of each of these trace metals between surface waters and intermediate depths of 600 metres. The importance of organic complexation to the dissolved speciation of these bioactive metals is being documented, providing strong justification for a closer examination of the role of organic complexation of trace metals to phytoplankton productivity and biogeochemical cycles.

On the Removal of Dissolved Aluminum in Seawater

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Recent field and mesocosm experiments have clearly demonstrated that dissolved Al is rapidly removed with increasing primary productivity associated with phytoplankton blooms (Moran and Moore, 1988a,b). Here, results from kinetic experiments conducted in order to study the adsorptive (passive) removal of dissolved Al by diatom particles in seawater are presented. Dissolved Al (initially ca. 50 nM) was monitored as a time series after addition of dead *Phaeodactylum tricornutum* diatom particles (1–10 mg/l) to seawater at 2°C in the dark. ^{234}Th tracer, a particle-reative element with a hydrolysis speciation ($Th(OH)_4^0$) similar to dissolved Al ($Al(OH)_3^0$, $Al(OH)_4^-$) in seawater, was also monitored during the experiments. An increase in the removal rate and the percentage of dissolved Al and ^{234}Th removed from solution was observed with increasing particle concentration (C_p) and hence particle surface area. Good agreement was found between Al kinetic data and a simple model which assumes reversible adsorption between dissolved Al and particle surfaces. A positive dependence of the model derived forward rate constants for Al and ^{234}Th on C_p was observed. A positive relationship between the reciprocal of oceanic residence times ($1/\tau$) of dissolved Al and C_p from a variety of oceanographic regions is taken as additional evidence that the removal of dissolved Al occurs at a rate proportional to C_p, further suggesting the primary importance of a passive adsorption mechanism in controlling the removal of dissolved Al on a global ocean scale.

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Metal Distributions and Transport on the Scotian Shelf

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Metal distributions measured on five sections across the Scotian Shelf in June 1985 are described in terms of their relationships to salinity and nutrients. Copper distributions can be described by a simple linear relationship with salinity. Manganese concentrations also decrease with increasing salinity but in this case the relationship is non-linear and different relationships apply for each section. Nickel and cadmium distributions are affected by relationships with both salinity and nutrients resulting in maxima in the metal salinity relationships. Lead does not show a clear relationship with salinity because of the existence of the highest lead concentrations in the surface waters but often in the offshore surface samples.

Observed metal and nutrient distributions are compared to those predicted by a model that uses S and T characteristics of the samples and known S, T, nutrient and metal concentrations in the source waters for the shelf. Deviations from predicted values are discussed in terms of biological uptake, inputs from sediments and chemical removal reactions. Metal and nutrient transports along and across the shelf are estimated by comparing the alongshore gradients in concentration to estimated transport at the shelf break.

MESOSCALE DYNAMICS AND CLIMATE
CLIMAT ET LA DYNAMIQUE DE L'ECHELLE MOYENNE

Mesoscale Vorticity Dynamics in a Weak Oceanic Cyclonic in ERICA

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In Intensive Operation Period 8 (Feb. 24–25, 1989) of ERICA, the Experiment on Rapidly Intensifying Cyclones over the Atlantic, a rapidly deepening cyclone did not occur as predicted. Wind, radar and thermodynamic data from aircraft and dropsondes are analyzed to investigate which of the necessary and sufficient conditions for a rapid deepening did not occur as predicted.

Preliminary analysis indicates that, despite strong low-level atmospheric baroclinicity across the north wall of the Gulf Stream, and an almost zeroth order low-level frontal surface, the Lagrangian vorticity budget in the frontal region was not positive enough to ensure rapid deepening. Vorticity production by stretching in the low levels, due to strong horizontal speed and direction convergence, approached 10^{-8} s^{-2} on scales of ~ 50 km. However, the storm was apparently unable to tap into the horizontal vorticity associated with the strong low-level shear of the horizontal wind near the front. This, combined with middle and upper level vorticity and convergence patterns which were poorly phased with lower level activity, effectively limited the strength of the storm. The role played by the very dry air aloft on the warm side of the front is still under investigation.

Impacts of Projected Global Warming: A Research Proposal for the Mackenzie Basin

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Recent experiments with atmospheric General Circulation Models (GCM) indicate that if concentrations of carbon dioxide and other trace gases continue to increase, the greenhouse effect would strengthen and global climate would experience unprecedented warming. In high latitude regions, such as the Mackenzie Basin, projected warming is expected to be double the global

average temperature change during the winter season. The Basin would certainly experience a number of physical and ecological changes, with subsequent impacts on the people who live there. At this time, however, only a rough qualitative picture of impacts can be provided.

This discussion includes a possible outline of a research program on the impacts of global warming scenarios in the Mackenzie Basin. These scenarios would include outputs from GCMs, such as the new one produced by the Canadian Climate Centre. Hydrology, permafrost and other first-order physical impacts would be investigated. These would be linked to second-order biological studies describing impacts on vegetation, fire potential, wildlife, etc. Third-order socio-economic studies would consider activities of the native and non-native communities. This effort would require several years to complete, and would be multidisciplinary, requiring the expertise and cooperation of many government and non-government entities. If this proposal is approved at the federal level, the next step would be to organize an interagency team which would identify participants, assign tasks and obtain resources. Any comments or suggestions regarding the proposed study would be welcome.

Finite-Time Thermodynamical Treatment of Water in Atmospheric Circulations

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Finite-time thermodynamics is an extension of the traditional equilibrium heat engine analysis (for example the Carnot cycle) by taking into account sources of irreversibility in transferring heat from thermal reservoirs to the working fluid and irreversibility due to the dynamics of the fluid itself. Dissipation rates, cycling times, improved estimates of efficiency and other predictions are possible depending on the applied constraints of the problem. This technique has already been applied to a simple closed cycle model of the global atmospheric circulation and it predicts average dissipation rates in excellent agreement with observations (about 2 W m^{-2}).

The calculations are being extended to explicitly include the effects of latent heat on the atmospheric circulation. Relationships between the speed of the atmospheric cycle, evaporation rates and the average humidity of the atmosphere are examined. Important insights into the role of the hydrological cycle can be obtained using this thermodynamic technique which can be used as guidance or perhaps even as a constraint in interpreting results from more complete dynamical models such as the GCM. The finite-time model will also be applied to regional circulations such as hurricanes, mesoscale convective systems and individual thunderstorms.

A Numerical Study of Rossby Wavebreaking: Where and When?

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A stationary Rossby wave, sinusoidal in longitude, is slowly switched on, and the meridional propagation of the resulting wave front through a shear flow is examined. Initially the flow is westerly everywhere and therefore free of critical layers. The transition from reversible to irreversible behaviour as the wave amplitude is increased is described. We first consider purely horizontal wave propagation (Fyfe and Held, 1990). It is shown that in an inviscid quasi-linear model, a steady state is obtained if and only if the mean flow is decelerated by less than approximately *two-fifths* of its initial value as a result of the passage of the wavefront. If this passage causes a larger mean flow reduction, a pile-up of wave activity in the shear layer culminates in the generation of a critical layer. Fully nonlinear calculations show that once the mean flow is decelerated by more than two-fifths of its initial value, rapid wave breaking and irreversible mixing also occurs but in this case in the absence of any critical layers. Finally, we conclude this study by allowing horizontal and vertical wave propagation, as well as, restoring forces on the mean flow. The relevance of these results to the atmosphere will be questioned in several ways.

Recent Anticyclonic Systems in Southeastern United States

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Droughts, freeze-drying weather, late-frosts, and similar events all came this past decade to the Southeast on rare, record-breaking occasions in conjunction with massive atmospheric high-pressures that recurred frequently.

More was involved than "ridges" of fair weather. Those ridges were patternistic, cyclic, persistent, and they had ill-defined electromagnetic properties. They were unique drought-inducing anticyclonic 'systems'.

In summertime, anticyclones of 1026 millibars often climbed to 5960 metres. The inductive radiation was oppressive, especially in the northeastern quadrant of each massive anticyclonic system. Droughty weather reappeared in a series of *paired periods*, 27 to 30 years apart, six times or more since the early 1800s. These were related to cyclic patterns that recurred at 7-year, 9-year, 11-year and other frequencies. Periodically these cycles did coincide, synergistically, inducing *climate droughts*.

In wintertime, freeze-drying anticyclones appeared as so-called 'arctic expresses'. These ranged from 1058 millibars upward. They originated ten days or so after the magnetic *aa-index* attained a value greater than 50. Several followed the full moon at apogee; others came behind prolonged emissions of M-class x-rays from solar flares. Also, late frosts came with a strange, yet historically unique, set of anticyclones that reappeared every 76 years, precisely. Again, frigid weather developed within massive anticyclonic systems, ten days or so after close proximity to Earth of Halley's comet. This pattern reappeared on each of four apparitions — 1759, 1835, 1910, 1986. *Frigid weather* was reported in the earliest times; new *late-frost* records were set in April on the latter occasions.

Further, all of the above occurred in conjunction with unique geophysical factors in the southeastern Piedmont. In wintertime, most of these southeast-bound anticyclonic systems followed a path generally along the line of zero magnetic declination; the big ones went into South America. In summertime, when cloud-bearing weather in the subtropical jetstream passed over the local lithosphere, wherein magnetite, iron, aluminum, etc. contribute electro-static and magneto-dynamic properties to the environment, the clouds appeared to levitate upward, dissipating temporarily, then reforming downwind over a different lithosphere.

Droughty weather persisted a decade because some astro-geomagnetic properties which seemed to govern them persisted also. Severe droughts came and went during that decade apparently because the magnetic properties related to them were modified by other astro-geophysical processes. All these interactions form better hypotheses for further cause-effect investigations.

ICE AND ARCTIC OCEANOGRAPHY
OCEANOGRAPHIE DE LES GLACONS ET DE L'ARCTIQUE

Acoustic Radiation of Ice Cracking Sound in the Arctic Ocean

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A few hundred ice cracking events have been analyzed for the central Arctic environment in the Spring when the air temperature is dropping. Aside from the fact that most of the events generated a dipole shape radiation pattern into the Arctic water, some of them showed an angularly dependent radiation character for different frequency components, i.e. the reflected signal from the sea floor carried a base band component of a higher frequency than that from the direct path. A simple theory based on plate vibration modes is introduced to offer a plausible explanation for this facinating phenomenon. Generally speaking, due to the mechanical properties of an ice cover, sound generated by upper surface failure of sea ice will produce a dipole radiation pattern with an angularly despersive character, and the sound is a relatively narrow band signal.

Greenland Sea Ice during 1901–1984 and their Relation to an Interdecadal Arctic Climate Cycle

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Two ice data sets from the Greenland and neighbouring seas have been analyzed to determine interannual and decadal time scale sea-ice extent anomalies during this century. Sea-ice concentration data on a $1° \times 1°$ grid for 1953–1984 revealed the presence of a large positive anomaly in the Greenland Sea during the 1960s which coincided with the "Great Salinity Anomaly", a low-salinity water mass that travelled cyclonically around the northern North Atlantic during 1968–1982. The two anomalies propagated into the Labrador Sea with a typical travel time of 3–5 y.

Spring and summer ice-limit data obtained from Danish Meteorological Institute charts for 1901–1956 indicated the presence of heavy ice conditions in the Greenland Sea during 1902–1920 and in the late 1940s, and generally light ice conditions during the 1920s and 1930s. Only limited evidence of propagation of Greenland Sea ice anomalies into the Labrador Sea was observed, however. On the other hand, several large ice anomalies in the Greenland Sea occurred 2–3 y after large runoffs from northern Canada into the western Arctic Ocean. Similarly, a large runoff into the Arctic preceded the large Greenland Sea ice anomaly of the 1960s. These facts, together with recent evidence of 'climatic jumps' in the Northern Hemisphere tropospheric circulation, suggest the existence of an interdecadal self-sustained climate cycle in the Arctic which is described in terms of a negative feedback loop. In the Greenland Sea this cycle is characterized by a state of large sea-ice extent overlaying a layer of cool fresh water that does not convectively overturn, which alternates with a state of small sea-ice extent and warm saline water that frequently overturns.

Plume Lift-off under a Complete Sea Ice Cover in Hudson Bay

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Measurements of the temperature and salinity fields immediately offshore of the sill at the mouth of the Great Whale River show the lift-off point to be 2–3 times deeper under sea ice than in open water for similar discharge. Comparison of field data for the under ice case and predictions based on recent laboratory and analystical studies show disagreement. Discussion of the processes at work, the importance of sea ice in reducing the level of turbulence, intrusions at the underside of the plume and evidence for supercooling under the plume immediately offshore of the lift-off point are presented.

Large Scale Variability of Ice Cover on Monthly and Seasonal Time Scales

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Ice cover is an important indicator of regional climate variability over weekly and monthly time scales because it acts as an integrator of temperature trends. It is also sensitive to temperature trends because of its high surface area-to-volume ratio. There is a general consensus amongst Global Circulation Models that any climate warming, due to the increased concentration of greenhouse gases, will be amplified in the Arctic about 2.5 times the global average during winter. As a result ice cover is an important variable for monitoring long term trends in climate.

Using Walsh's ice cover database for the northern hemisphere from 1953 to 1986, the distribution of regional ice anomalies around the polar regions is discussed in relation to atmospheric circulation anomalies during the El Niño years of 1982/83 and 1976/77. Walsh (1978) and others have demonstrated the strong relationship between temperature advection and ice cover and this study demonstrates it for two interesting cases.

The northern hemisphere temperature data from Jones (1982) is used to select anomalously

cold and warm hemisphere and arctic years. Differences in ice cover during these extreme years for eastern Canada, Hudson Bay, and the Beaufort Sea is used to develop analogues of ice cover changes which could be expected under a global warming scenario.

Some Aspects of Spray Icing Modelling of Ships

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A brief review of approaches to the problem of modelling the spray ice growth on ocean-going vessels is presented. The complexity of the physical mechanisms of ship icing, which create considerable difficulty for the modeller, is described. Some approaches to solving these difficulties are outlined, and the anatomy and performance of models, developed recently at the University of Alberta, are discussed.

THE RIMOUSKI EDDY EXPERIMENT
L'EXPERIENCE DU TOURBILLON DE RIMOUSKI

The Rimouski Eddy Experiment

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The Rimouski Eddy Experiment is a three-year multidisciplinary research program with the objective of studying the coupling between physical and biogeochemical processes in general, and in the lower St. Lawrence estuary in particular. Giving the hypothesis that mesoscale perturbations in the physical field have measurable consequences on biological and geochemical processes throughout the water column and at the benthic boundary layer, a two-year multidisciplinary, multi-ship sampling program was designed. Since all the processes found on the continental shelves are also found in the St. Lawrence estuary, we also hope to be able to export our findings regarding the formation, fate and transport of organic carbon to the continental shelf/slope region. The physical oceanography sampling program will be presented and preliminary results will be discussed.

Primary Production, New Production and Eddy Circulation in the Lower St. Lawrence Estuary

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Primary production is a major source of the organic matter flux to the deep waters and sediments of coastal systems. The proportion of the primary production that sinks out of the surface layer is termed new production since it must be replaced by new (external) supplies of carbon and nutrients to maintain productivity. In the open ocean, vertical exchange between surface and deep waters is assumed to supply the new nutrients; however, horizontal transport of nutrients may be important, especially in the coastal ocean. Furthermore, much of the circulation variability in coastal waters is associated with motions in the 3–15 days range of periods, or eddy motions. This leads to the hypothesis that the eddy circulation regulates nutrient supply, primary production and new production in coastal areas. An area of the lower St. Lawrence Estuary known for eddy activity (the Rimouski eddy) was surveyed continuously over 28 days to evaluate this hypothesis. A 35 × 70 km grid of 47 stations was visited at six (6) occasions. Vertical profiles of fluorescence and nitrate to 30 m were taken at each station concurrently with CTD casts. Light penetration, ammonium concentration, chlorophyll, particulate carbon, nitrogen and protein, carbon-14 productivity and incorporation of nitrate and ammonium were

measured at selected stations and depths. Discussion of the results will focus on the impact of the eddy circulation on new production and particulate flux at a deep-water station occupied for geochemical and microbiological studies of Laurentian Trough sediments.

Spatial and Temporal Patterns in the Vertical Flux of Particulate Matter in the Laurentian Trough

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Daily measurements of the sedimentation flux at the mid-water suspended particulate matter minimum in the central portion of the Laurentian Trough, Lower St. Lawrence Estuary were obtained using two free-drifting sediment traps, each of which provided subsamples from four 1/8 m^2 surface area collecting cylinders. Between June 25 and July 14, 1989, the daily mean flux of total settling particles and their mean carbon and nitrogen contents appear to have been related to the lunar tidal cycle, with the minimal particle flux and the maximal organic matter content occurring during spring tides.

During the 3-week period, the mean carbon content and particulate flux varied by factors of 3–4, almost as much as the annual range previously observed for samples obtained over a 5-year period. In this deep coastal environment, single-day sample collections during cruises of opportunity are thus not likely to reveal the true scale of events. The presence of abundant chain diatoms and the patterns of pigment concentration and hydrolyzable amino acids in the trap samples indicated a rapid tranfer of photic zone material to 150-m depths during two- to three-day bursts of intense phytoplankton production. Spatial variability was also very much present, being more marked during periods of increased total flux. The 1–2 km separation between the simultaneously deployed drifting traps was enough to occasionally cause radically different results for the mean carbon and nitrogen contents, as well as for total flux, indicative of the scale of patchiness in zooplankton feeding and fecal aggregate production. In spite of the integrating effect of the 3–6 km diameter tidal excursions of the drifting traps, factor of 2–5 differences in the weight of total collected particles and in the organic matter content were frequently observed between individual cylinders of the same trap. This suggests the existence in the water column of structural elements in the distribution of settling particles on the scale of metres.

Short-Term Variations of Geochemical Profiles in Pore Waters of Laurentian Trough Sediments

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Box cores were collected daily at a site in the Laurentian Trough to study the chemical responses of the sediments to short-term changes in the flux of fresh organic matter. Each of the 18 cores was finally subsampled under N_2 atmosphere and the pore waters separated and analysed for nitrate, ammonium, silicate and phosphate at sea within 12 hours.

Except for a few cores the concentration profiles over 40 cm depth were very similar from day to day. This allows us to assume that the variations we observe in the top 1.5 cm of the sediment reflect mainly the response to the most recent sedimentation events. Preliminary results indicate that nitrate appears to be most sensitive, the gradients being strongest during the period of highest carbon content in the sedimentation flux.

The concentrations of dissolved and particulate Mn were also determined in these cores. In addition, from companion cores which were very finely subdivided, dissolved O_2, carbon and Mn were also determined.

Bacterial Production in Deep-Water Sediments of the Lower St. Lawrence Estuary during the Early Summer Phytoplankton Bloom

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The response of sediment bacteria to a sudden influx of phytoplankton debris was studied during a multidisciplinary investigation of physical and biogeochemical processes in the lower St. Lawrence Estuary. Box cores were collected daily at a single station (350-m depth) near the centre of a suspected mesoscale eddy over a period of three weeks in June/July 1989. Bacterial productivity in the upper 8 mm of sediment was estimated from measures of ^{3}H-thymidine incorporation into DNA. Sediment bacterial numbers and cell volumes were determined by epifluorescence microscopy. Photosynthetic pigment, CHN, protein and carbohydrate measurements were made on all samples to reveal changes in sediment organic matte attributable to the bloom event. Results suggest a close short-term coupling between sediment bacterial productivity, sedimentation of phytoplankton debris and water column events. Sediment bacterial productivity increased by a factor of 2–3 during the phytoplankton bloom before falling off to intermediate levels. A similar pattern was noted in parallel studies of bacterial enzymatic activity and pore water nutrients in the same boxcores. Previously reported catabolism of exogenous thymidine by sediment bacteria was prevalent at the study site, such that activity of the ^{3}H label was greatest in the RNA fraction of bacterial cell extracts. This catabolic activity varied significantly during the study period but showed no clear relationship to nutrient availability or the rate of thymidine incorporation into bacterial DNA.

OCEANOGRAPHY–1 AND INTERNAL WAVES
OCEANOGRAPHIE–1 ET VAGUES INTERNES

Observations of Currents in the Northeast Pacific

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The first current measurements from the Alaska current were obtained from a current meter mooring deployed in 4000 m of water at 49°34′N and 138°40′W, near Station Papa. The mooring was in place from May to October 1989 and carried 5 current meters which spanned the depth of the water column. The current measurements are described and compared with results from a quasi-geostrophic numerical model of the northeast Pacific.

The flow in the upper layers of the water column is highly polarized in the north-south direction and is characterised by long-period (~100 days) time scales of variability. At abyssal depths, the flow displays shorter (~20 days) time scales of variability and without a preferred direction of motion. A modal decomposition shows that over 50% of the eddy kinetic energy is in the first internal mode. The model results suggest that the abyssal flows are due to a barotropic response to synoptic storm activity.

Low Frequency Subsurface Currents of the Northeast Pacific

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Twenty-four ARGOS-tracked buoys drogued between 100 and 150 m were deployed east of Ocean Weather Station P during the late spring (13 buoys) and fall (11 buoys) of 1987 and tracked for approximately one year. Under conditions of strong atmospheric forcing, currents at drogue depth are coherent with local geostrophic winds to the extent that they are valid predictors of the local surface winds. Buoys drogued slightly above the permanent pycnocline show more coherence than

those with drogues contained within this feature indicating reduced current/atmospheric coupling with depth. Spectral results show that winds and currents are generally more coherent in winter when the wind forcing is greater.

Several buoys became entrained in three long-duration mesoscale eddy-like features 550 km west of Vancouver Island. One cyclonic and two anticyclonic eddies are mapped for up to 10 months and are observed to rotate at frequencies of 0.1 to 0.05 cpd. Eddy radii are estimated to range from 20 to 60 km which is consistent with the internal Rossby radius of deformation, and angular speeds are seen to decrease with time. The meridional displacements of the eddy centres of curvature can be explained by conservation of potential vorticity.

The Nonlinear Critical Layer for Topographically Forced Internal Waves

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Nonlinear numerical simulations of stratified flow over two-dimensional topography for upstream conditions of uniform horizontal wind (U) and stability (N) have proven useful in the understanding of severe downslope windstorms. The essential result from such analyses is that "breaking" in the primary internal wave field launched by topography is the trigger which causes the subsequent evolution of the flow into the severe downslope windstorm state (Peltier and Clark, 1979). The sole non-dimensional governing parameter in such circumstances is the inverse Froude number $Fr = Nh/U$ (where h is maximum topographic height) which provides a measure of the nonlinearity of the internal waves that are launched by the topography.

In an effort to clarify and further understand the mechanism by which this transformation is nucleated, a critical level has been introduced into the imposed upstream flow. This has been achieved by employing a hyperbolic tangent profile of horizontal wind such that the shear is localized at some elevation Zc and aysmptotic to some value $-U$ above and $+U$ below this level. In this modified problem there now occur three non-dimensional governing parameters: the inverse Froude number Fr, the height of the imposed critical level Zc/λ_z (where $\lambda_z = 2\pi U/N$ is the hydrostatic vertical wavelength of the primary wave field), and the minimum gradient Richardson number $Ri(Z = Zc)$. To date, the long term characteristics of such flows have been considered only as a function of the height of the imposed critical level (Clark and Peltier, 1984) and of the inverse Froude number Fr (Durran, 1988; Bacmeister and Pierrehumbert, 1989). Results from the latter two investigations have led the authors to consider one layer hydraulic theory (Smith, 1985) to constitute the most viable explanation of the severe windstorm state.

Through a systematic investigation of the third and final parameter in this problem, we have found the temporal evolution of the flow to be strongly dependent on the minimum Ri imposed at the critical level in the initial flow. The sense of this dependence is such that, as Ri is decreased towards a value of $1/4$ in the background flow, the transition to the severe windstorm state is progressively delayed and can in fact be entirely prevented from occurring. Since the imposed value of Ri is crucial to the evolution of the flow into the fully developed storm and because such parameter is beyond the scope of hydraulic theory, these results serve to undermine rather than reinforce the validity of the hydraulic view.

Transition to Turbulence via Kelvin-Helmholtz and Holmboe Instabilities

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The occurrence of shear layers containing regions of stable density stratification is common in both the atmosphere and the oceans. The evolution of a stratified shear layer for which the bulk Richardson number J lies near the value $1/4$ is of particular interest for a number of reasons. If the depth of the stratified region is comparable to or greater than that of the shear layer, then the unstable Kelvin-Helmholtz (KH) mode which exists in conditions of weak stratification disappears when J exceeds the value $1/4$, at which point the flow becomes stable. If, however, the stratification is concentrated in a thin region surrounding the centre of the shear layer, the

stability characteristics of the flow are markedly different. In this case, when J exceeds a certain value, which is not less than 1/4, KH instability is replaced by Holmboe instability, an oscillatory disturbance having the appearance of a standing wave.

The linear analysis of disturbances to flows located near the KH-Holmboe transition has revealed that a sufficiently viscous stratified shear layer may bifurcate directly into a flow exhibiting dependence upon all three spatial coordinates without the need for an intervening two-dimensional state. This three-dimensional primary instability is probably responsible for the three-dimensional structures which are observed in laboratory realizations of Holmboe waves.

The evolution of finite-amplitude KH and Holmboe waves has been examined using a fully nonlinear, two-dimensional, time-dependent numerical model. We have also tested the stability of the resulting nonlinear waves to three-dimensional disturbances, and have found that strong secondary instability appears very early in the evolution of these waves. The growth of unstable modes is driven primarily by the shearing deformation which is present in the basic states and by convective activity due to overturning of the isentropes. As overturning is a more dominant feature in KH waves than it is in Holmboe waves, the former are in general more unstable to three-dimensional disturbances than are the latter. The dependence of growth rates upon the spanwise wavenumber exhibits no sign of a preferred spanwise length scale, but rather reveals a tendency for growth rates to increase monotonically with increasing wavenumber. This suggests that the instability of the nonlinear wave states is capable of injecting energy directly into the smallest scales of motion, i.e. that the two-dimensional waves evolve directly into a turbulent state.

Shelf Wave Scattering by Estuaries and Headlands

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Recent observations on the Scotian shelf (Canada) and in Bass Strait (Australia) have prompted new interest in how coastally trapped waves are influenced by strong topographic and coastal irregularities. A conceptual study addressing the questions of wave scattering is presented. The linear barotropic conservation equation of potential vorticity is solved on a straight, infinite shelf with exponential depth profile interrupted by a rectangular estuary or headland. Neglecting the barotropic Kelvin wave and assuming no flux through the shelf-ocean boundary allows the analytic calculation of the dispersion relation and the normal modes in the shelf and the estuary or headland region, respectively. Solutions are then obtained by mode matching.

Two cases are studied. In the shallow estuary region the cutoff frequency of shelf waves is larger than on the shelf. Hence, propagating modes exist in the estuary that are evanescent on the adjacent shelf. In particular, at least one trapped mode is present independent of the geometry and topography of the estuary. Wave motion is mainly in the estuary. For narrow estuaries this trapped mode is located around the estuary mouth with a large along-shelf decay scale and a frequency slightly larger than the shelf cutoff. Long shelf waves approaching the estuary are strongly scattered into a transmitted long wave and a backscattered short wave. At particular frequencies either complete transmission or reflection occurs. In the latter case the incident wave is in resonance, and shelf wave motion is well established in the estuary.

A headland is a less efficient scatterer. At no frequency does complete reflection occur. For large enough frequencies incident shelf waves cannot propagate abreast the headland and are evanescent there. Nonetheless, a portion of the wave energy always tunnels through this region and appears as an attenuated wave on the other side.

An outlook is given how the results can be applied to more general geometries.

POSTER SESSION
SEANCE DES AFFICHAGES

TRIGRID – An Interactive Graphical Software Package for Generation and Editing of Irregular Triangular Grids

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This poster describes recent progress in developing a set of portable interactive graphics programs for design of irregular triangular grids. The software was developed on a VAX computer, but has been ported recently to Sun and Apollo workstations and to personal computers. It is in use at several sites for development of grids suitable for finite element shallow water models. Compared with manual preparations of grids, this largely automated, interactive approach requires much less time and effort. It is also far less prone to bookkeeping errors.

The package provides irregular triangular grids which take the following conflicting design needs into account:

(a) accurate fitting of coastlines;
(b) maintenance of near-equilateral triangle shape so as to ensure accurate interpolation during subsequent model calculations;
(c) maintenance throughout the model domain of nearly uniform spatial sampling per wavelength, so as to minimize modelling computation time.

For shallow water models, condition (c) can be restated as a need to make triangle area proportional to mean water depth. In fact, the software permits element area to be geared to any scalar function defined over the model domain.

An important component of the package is an interactive graphical grid editor which facilitates modification of grids. For instance, extra nodes can be inserted where model results indicate more detail is needed, or nodes can be moved or deleted if required. The editor also permits visual checking of grid properties through a facility for colouring nodes or triangles according to various criteria. Other programs permit subdivision of a large grid into two or more small grids suitable for local models or the joining of separate, adjacent grids into a unified grid.

Relationship between Infrared AVHRR Satellite and Ship Temperature Data in the Gulf of St. Lawrence

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Sea-surface temperature using infrared AVHRR data from NOAA satellites are becoming of common use because of their ability to provide a synoptic view of the horizontal structure. Comparison with measurements at sea has been made in the open ocean. Comparison in coastal waters and inland seas remains to investigate in details. Influence of the land air-masses over the body of water add to the existing difficulty in calibration. The northern part of the Gulf of St. Lawrence has been investigated under the COHJAC program (Circulation, Oceanography and Hydrography of Jacques Cartier Strait). CTD casts as well as bulk surface temperature data have been gathered in 1896 to 1989 by ships' observations. The satellite temperature map is compared and merged with *in situ* temperature measurements. Regression between ship data temperature and the data from the 3 thermal channels of the satellite will be presented. Influence of atmospheric constituents in the area, mainly water vapour, is already under investigation. The presentation will focus on the day and night variation of this regression. Also of interest is the divergence of the regression coefficients as a function of the time difference between the ship

observation and the satellite measurement. Time scale of this divergence can be related to the time scale of oceanographic features in the area.

An Upper Layer Model for the St. Lawrence Estuary

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The numerical model GF4, was developed to describe the upper layer of the Strait of Georgia. Modifications have been made to GF4 in order to apply it to the St. Lawrence Estuary. The resulting model has been run under various conditions of river, tide and wind forcing.

The model results indicated that the lower estuary is capable of accommodating complex cross-channel modes of oscillation whose length scales are in accord with observations. Future improvements should include a baroclinic layer and a more rigorous treatment of the open boundary conditions.

The Influence of Fresh Water Forcing on the Low Frequency Dynamics of Coastal Waters

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The analysis of data collected during the Coastal Ocean Dynamics Experiment off Vancouver Island will be presented. Current meter data from mooring lines off Brooks Peninsula, Estevan Point and Carmanah Point are compared with simple analytical models, which are used to assess the influence of Juan de Fuca Strait on low frequency current fluctuations. Data from the summer period (May–September 1980) are analysed in order to reduce the effects of wind forcing and to concentrate on the influence of fresh water forcing from the strait.

Locally Generated Tsunamis in the Strait of Georgia

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The response of the Strait of Georgia to the local generation of tsunamis has been studied with the aid of a modified numerical model of the Georgia-Fuca-Puget Sound system. Four potential sources have been examined: vertical motion of the sea bottom resulting from a dip-slip earthquake along the Gulf Islands Fault; generation of a seiche from energy arriving from a distant great earthquake: submarine turbidity flows occurring at the heads of Howe Sound and Jervis Inlet: and a large turbidity flow originating off Robert's Bank in the Fraser River Delta. The latter source was found to result in the largest water levels. This study has included the development of a simple discrete particle model of turbidity flow that tracks the motion of individual mass elements responding to the force of reduced gravity, a quadratic friction law, and the local bottom slope. The depth change in each model grid cell (2×2 km) is calculated by differencing the contributions from all mass elements in each cell between successive 20s time steps.

Numerical Modelling and Benthic Boundary Layer

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Very powerful computers are needed to evolve models of the atmosphere that could, for research purposes, endeavour to understand atmospheric circulations better. The usefulness of such models of atmospheric circulations led to the idea of using them to model ocean circulations because

the ocean forms 70% of the bottom boundary of atmospheric models. Under simplifying assumptions, governing equations of motions were initially re-structured and analytically solved with closed solutions. However, discrepancies with observed values (either at laboratories or fields) were later noted and efforts were made to include non-linear terms in a more adequate fashion that led to the early numerical models. The present author intends to focus upon numerical simulation models based on finite differences with sophistication in quality (for accuracy in numerical calculations) by the "throw-back" technique of numerical mathematics while investigating the structural dynamics of the benthic boundary layer (Z_b: Prandtl, Ekman and Geostrophic layers) whose characteristics are still poorly known (Refs. 1,2,3).

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Canadian Forces Weather Services – 50 Years and Growing

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R.K. Cross, National Defence Headquarters, Ottawa, Ontario

The Canadian Forces Weather Services (CFWS) have provided meteorological and oceanographic services to the Department of National Defence for over 50 years. Originally formed in 1939, the CFWS now employs over 100 meteorologists and other professionals in an operational and administrative role. In addition, there are about 300 military meteorological technicians who provide administrative, briefing and observing functions. The CFWS has 17 operational offices across Canada, of which three are major weather centres. In addition there are two offices abroad serving Canada's NATO commitments in Europe.

A display of the various operational products and services of the CFWS will be presented. As the bulk of the CFWS resources are aimed at support of aviation activities, much of the display will be oriented towards aviation.

While efforts to support the air and land elements of the Canadian Forces continue to receive attention by the CFWS, maritime services are on the upswing. Tactical Environmental Support Teams (TEST's) have been recently developed; these mobile teams are capable of deploying operationally with Canada's Maritime Forces on major exercises. The display will also outline the TEST capabilities.

In honour of a half-century of providing weather and oceanographic services to DND, a History of the CFWS has been prepared which includes major highlights of the past 50 years. Copies of this booklet will be available at the display.

Oceanic Climatological Information from Special Sensor Microwave/Imager Data

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Sea surface and meteorological paramters over the oceans derived from Brightness Temperatures provided by the Special Sensor Microwave/Imager have been in use for research and experimental operational meteorology purposes for several years. In general the equations and procedures used give values of such parameters as wind speeds at several heights, rain rates, total water vapour and atmospheric liquid water at spacings of 25 km, in 14 swaths per day which are 1400 km wide. The values of the derived parameters, while suitable for operational purposes, tend to either exceed or fall short of the range of values found in conventional ship and buoy data, or as derived

from synoptic meteorological analyses. However, for climatological purposes, after-the-fact processing of the data using range correction procedures, preserves the high density of observation, with the detailed information it contains, as well as confirming to the distributions found in any selected calibrating data. Illustrations from the northeastern Pacific, the northwestern Atlantic, and the Gulf of Mexico will be used to demonstrate these ideas.

Field Intercomparison of Three Current Meters in an Environment Free from High Frequency Motion

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An intercomparison of three different types of current meter was performed in an Arctic environment where wave action was absent, permitting the evaluation of the instruments under natural conditions of weak currents and cold water. The instruments were an Aanderaa RCM4S, an Inter Ocean S4 and an EG&G-Neil Brown Smart Acoustic Current Meter (SACM). The S4 and the SACM both showed their ability to measure very small currents as opposed to the RCM4S which is limited by a mechanical rotor threshold. The agreement of the direction was better between the RCM4S and the SACM than between the RCM4S and the S4. Due to the misalignment of the Aanderaa vane in very weak currents, direction differences between the instruments of either pair can, however, reach 180°. The misalignment also shields the Aanderaa rotor leading to underestimation of current speed. The threshold for a good speed reading for the Aanderaa can be put conservatively at 5 cm s^{-1}. Above this value, the RCM4S overresponded compared to both the S4 and the SACM. The source of that problem seems to be related to different calibrations of the instruments. Finally a power spectrum analysis showed that the RCM4S, when not influenced by wave action, can produce a measure of energy as good as that of a vector averaging instrument.

The Role of Ice Phase Processes in Cyclonic Storms

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Considerable improvement in our understanding of mid-latitude cyclones has taken place over the last decade, due in large part to observational and numerical studies of cyclogenetic events. The problem of rapidly deepening storms, or "bombs", is of special interest due to their impact on man's activities. Added insight into cyclogenetic processes can be gained by studying this type of storm.

Instense cyclogenesis can be viewed as resulting from many physical processes which are interacting at a particular location in a manner which supports "self development". Diabatic processes such as surface heat fluxes and condensation are recognized as being important to storm development. Other diabatic effects which have not been fully examined are the phase change processes related to the ice phase. It is demonstrated that these effects are far from insignificant in determining storm structure and development and are a critical factor in explosive deepening events. A conceptual model of bombs which includes important ice phase effects is presented. The model is supported by climatological data as well as individual case studies.

Thermohaline Structure in the Rimouski Eddy Region: Summer of 1989

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Y. Gratton, Institut Maurice-Lamontagne, Mont-Joli, Québec

The first half of the physical oceanography field program of the Rimouski Eddy Experiment (see special session: "The Rimouski Eddy Experiment") was held in the summer of 1989. An area of the lower St. Lawrence estuary known for eddy activity was surveyed continuously for over 28 days (two neap-spring tidal cycles). A 35 × 70 km grid of 72 stations were visited on six

occasions yielding 398 CTD profiles. Twenty-five current meters distributed among six moorings were positioned in the eddy and south shore jet region. Preliminary results on the structure of the eddy and the general circulation are presented and discussed.

Variations Spatio-Temporelles dans l'Activité Enzymatique Bactérienne dans les Sédiments Profonds du Chenal Laurentien

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Des variations spatio-temporelles, à petite échelle, dans l'activité bactérienne, le nombre de bactéries et les concentrations en pigment photosynthétiques ont été étudiées simultanément à une même station (350 m), au centre du tourbillon de Rimouski. Afin d'étudier la variabilité temporelle, des carottes ont été prélevées quotidiennement à l'aide d'un carottier à boîte, pendent une période de 21 jours (25 juin au 14 juillet 1989). D'autres carottes ont été divisées, de façon aléatoire en sous-carottes et chaque sous-carotte a été divisée en six parties égales. Cette méthode d'échantillonnage nous a permis d'étudier la variabilité spatiale, à petite échelle, à trois niveaux différents. L'activité enzymatique bactérienne a été mesurée en dosant l'activité hydrolytique d'une glucosidase et d'une protéase à l'aide des substrats fluorogéniques MUF tels que 4-méthylumbelliféryl-B-D glucoside et L-leucine-4-méthylcoumarinyl-7-amide HCL. Le rapport entre les deux enzymes a été calculé. Le nombre de bactéries et la biomasse bactérienne ont été déterminés par microscopie à épifluorescence. On observe une augmentation du rapport entre les deux enzymes pendent la période échantillonnée ainsi que des changements dans le nombre total de bactéries dans les sédiments. Les concentrations en pigments photosynthétiques dans les sédiments fluctuent en fonction du cycle des marées.

Utilisation d'Indices Biochimiques dans l'Etude des Interactions Bentho-Pélagiques. Tourbillon de Rimouski (Rimouski Eddy)

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La sensibilité d'indicateurs biochimiques tels les protéines et les carbohydrates est testée dans l'étude des variations de la productivité hétéotrophe dans les sédiments sur une échelle spatio-temporelle en liason avec la production primaire en surface. L'échantillonnage de sédiments vaseux a été effectué au moyen d'un carottier à boîte à 350 m de fond dans le chenal laurentien (Québec) au début de l'été 1989, période recouvrant le bloom phytoplanctonique.

L'extraction et le dosage des protéines et des carbonhydrates sont réalisés selon les méthodes respectivement de Lowry (1951), Stein (1973), Dubois (1956), et Liu (1975), adaptées aux sédiments par Le Coz (1985). Les variations temporelles de ces paramètres biochimiques sont étudiées en relation avec des mesures de chlorophylle, de CHN effectuées parallélement dans les sédiments et la colonne d'eau.

Comparison of Two Methods for Studying the Structure and Micro-Disribution of a Guild of Deep-Water Benthic Polychaetes in the Laurentian Trough (Rimouski Eddy)

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The sediment infauna of the Laurentian Trough near the centre of the Rimouski Eddy was studied using a 0.25 m^2 USNEL boxcorer. The fauna is dominated by polychaete worms. The three principal species, in order of importance, are *Myriochele heeri* (Oweniidae), *Ampharete acutifrons* (Ampharetidae) and *Nereis pelagica* (Nereidae). All are surface deposit feeders. The standard technique of sieving sediments and identifying and enumerating organisms was compared with

identification and counting of worm tubes and burrows in photographs of the surface of intact boxcores prior to sieving. For the three dominant worm species, data yielded by the two methods were similar with respect to frequency coefficients. However, in some cases, absolute abundances were lower in the photos than for sieved samples of the same sediments. This is in part a result of disturbance of the core surface during sampling which obscured surface openings of tubes and burrows, and in part due to lighting deficiencies in photographs which were later corrected. It appears that these two techniques are complimentary. The first (sieving) permits correct identification of species and their respective tubes and burrows. The photographic method, based on the visual recognition of tubes and burrows, allows determination of the structure of the annelid population in less than 10% of the time required for sieving and sorting, thus permitting the treatment of a greater number of samples. In addition, the small-scale spatial distribution of the infauna can be determined more rapidly and with greater precision in digitized photographs than through sieving and sorting. This will be of particular interest to modelling studies of the effects of bioturbation and bioirrigation on sediment geochemical processes.

Premières Observations Photographiques de la Mégafaune et de la Bioturbation dans le Chenal Laurentien (Zone Tourbillon de Rimouski)

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En juillet 1989, 240 photographies du fond ont été prises dans la zone Tourbillon de Rimouski, (profondeur = 350 m). Ces photographies représentent une surface totale de 275 m^2. La mégafaune peu diversifiée est dominée par une ophiure épibenthique (*Ophiura sarsi*, densité = 9.2 individus/m^2) et par un polychète de la famille des Aphroditidae (densité = 5.3 individus/m^2). La bioturbation est liée à l'activité fouisseuse des échinodermes, d'une profondeur maximale de 5 cm dans les sédiments. Les traces dominantes sont trois types de terriers. Un de ces terriers (densité moyenne = 3.2 terriers/m^2) est construit par un décapode et peut atteindre un diamètre de 4 cm et une profondeur de 25 cm, pertubant intensivement les sédiments. La distribution spatiale de la mégafaune et des traces animales est hétérogène à l'intérieur de la zone étudiée (30 km^2) et doit être essentiellement influencée par les apports verticaux.

Model Simulations of the Drift and Spread of the Exxon-Valdez Oil Spill

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In this paper the drift and spread of the Exxon-Valdez oil spill that occurred on March 24, 1989 are simulated using a modified version of the Canadian Atmospheric Environment Service oil spill behaviour model. The model simulations show that the movement of the oil out of Prince William Sound and beyond is sensitive to the wind/ocean current combination. The net drift of the oil with wind and ocean currents taken into account is three to four times that with either wind or ocean currents only. While 12-day drift of the spill containing the higher concentrations of oil parcels is in very good agreement with observations, model simulations show the presence of oil farther to the south, albeit in lower concentrations. The lateral spread of the oil is also very well simulated by the model.

Recent Developments in the Chemical Analysis of Marine Toxins

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The standard method for detecting marine toxins in seafood is the mouse bioassay. Although adequate for protection of public health, this method gives little information on toxin composition. Instrumental methods of chemical analysis have the advantage of greater sensitivity and selectivity. This paper will review the recent application of high performance liquid chromatography

to the determination of amnesic shellfish toxins (domoic acid and related compounds) and paralytic shellfish toxins (saxitoxin and related compounds). Detection by a variety of "hyphenated" techniques (UV-DAD, FD-FMOC, and Ion-Spray MS) will be compared.

FISHERIES OCEANOGRAPHY–3
OCEANOGRAPHIE DE LA PECHE–3

Dominance of Biological Factors in Determining the Abundance and Distribution of Fish Stocks

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Past fisheries research has been searching predominantly "single-factor correlations" between environmental processes and anomalies on one hand and recruitment to and abundance of exploitable parts of fish stocks on the other hand. However, the fish ecosystem is affected concurrently by many environmental as well as biological factors and conditions, the influences of which vary in space and time. The influence of several biological rather than environmental factors usually dominate within the ecosystem.

It is shown that resource assessments can be, and often are, erroneous and consequently recruitment variations are misinterpreted, e.g. by not considering the changes in fishing patterns over time which affect the apparent age composition of exploitable stocks. It is also shown that recruitment at higher latitudes is largely controlled by predator and prey density-dependent predation. The effects of environmental anomalies on recruitment (such as the effects of wind-induced current anomalies in transport of larvae and changing predator-prey overlap of effect of temperature anomalies on delay of spawning) are very difficult, if not impossible, to demonstrate and verify and would have very little if any influence on recruitment variations if the latter is greatly affected by density-dependent predation.

The distribution of environmental parameters and anomalies cannot affect fish distribution "by choice" (i.e. fish searching for some "optimum environmental conditions") as is often assumed, as fish do not have any *a priori* knowledge of the distributions of environmental variables (nor does it have an oceanographic synoptic reporting and analysis system at hand, which even large nations seem to be unable to organize). However, most fish are in constant movement in search for food and/or their migrations are affected by innate seasonal and life-cycle requirements. Migration speed is affected by water temperature (physiological effects), abundance of food on migration routes (feeding behavioral aspects), as well as by depth (complex interactions with diurnal vertical migrations and presence of bottom, etc.). The interaction between fish migration and migration-affecting environmental factors can affect the distribution of species and even determine the plausible locations of fish aggregations. This is demonstrated with numerical simulation, in which it is shown that most known migration-affecting factors and processes must be included in such simulations to represent realistic conditions.

The Importance of Oceanographic Conditions in the Dynamics of Chum and Coho Salmon Populations of a Small Vancouver Island Stream

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After 1–5 yr in the ocean Pacific salmon return, with great precision, to their natal streams to spawn. This characteristic permits researchers to accurately measure survival and growth rates in the ocean by counting and sampling the fish entering the ocean and the survivors on their return. We have collected such data for two species of Pacific salmon as part of a 19-yr multidisciplinary study of the impacts of logging on a small salmon stream in a coastal rainforest. For both species, more than 50% of the total inter-annual variability in numbers can be ascribed

to variation in marine survivals, with the remainder ascribable to variation in stream conditions. Correlative models are presented which relate survival and growth to biological characteristics of the young fish entering the ocean and various oceanographic variables. For coho salmon, marine survivals were positively correlated with early ocean growth rates, which were in turn positively correlated with summertime sea-surface salinities off the northwest coast of Vancouver Island. Variation in the biological characteristics of coho salmon smolts had no detectable effects on marine survival or growth. The marine survival of chum salmon was also positively correlated with sea-surface salinities. Chum salmon survivals were also correlated with their numbers (+), size (+) and timing of peak emigration (early migration led to higher mortality). For both species, we suggest that interannual variability in survival was being driven primarily by changing ocean conditions affecting early ocean growth rates and consequently predation losses.

The Lake Ontario Salmon Fishery: Here to Stay? Gone Tomorrow?

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Pacific Salmon are among several exotic species introduced into the Great Lakes in the past century; they are now the mainstay of a basin-wide sport fishing industry valued at $2.6 billion annually. In the main body of the lake, thanks to both physical and biochemical attributes of the system, salmon are able to flourish. Salmon stocks are, however, maintained by a hatchery program; very few natural spawning tributaries that supported landlocked Atlantic Salmon in the last century remain suitable for salmon today. Parallel to the increase in Pacific Salmon, the phosphorus input to the Great Lakes has been reduced (mainly through secondary treatment of domestic sewage) in order to reverse a perceived trend to unacceptable eutrophication. Today it is thought that the productivity of fish in Lake Ontario is at an all time historic level but it is also thought by some investigators that the relatively low levels of primary productivity achieved by phosphorus control may not be sufficient to maintain the Pacific Salmon fishery. Other students of the Lake Ontario system argue for continued reductions in nutrient input in order to reestablish the earlier and presumably stable food web crowned by a naturally reproducing population of lake trout. Debates of this kind will be common if the concept of sustainable development is to be implemented. In addition to the debate concerning the stability of a put-and-take salmon fishery and a self-sustaining but possibly less productive lake trout fishery, there are widespread concerns with persistent contaminants in Great Lakes waters. It seems clear that contaminants are harming the fish-eating components of the non-human food web, including long-lived fish. There is little evidence from data averaged over the whole human population that contaminants in Lake Ontario water pose a threat to human health, but when the data is restricted to the subgroup that regularly consumes Great Lakes fish (salmon in particular), another story may be emerging.

Relative Contributions of Interannual Change and Seasonality to Variations of Reproduction in Some California Current Region Pelagic, Meso-Pelagic and Demersal Fishes

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The long-term (century) changes seen in scale deposition rates of pelagic fishes in varved sediment deposits can now be related to direct measurements of population parameters in the presence of significant oceanographic changes. In the intermediate term (decade), monthly records of seasonal reproductive output can be analyzed during an El Niño period for several species of pelagic, meso-pelagic and demersal fishes. In the short term (annual), many phases of the life cycle of the northern anchovy and Pacific sardine have been quantified and interannual variability in life table parameters have been monitored. Even though day length, temperature, and primary production

rates follow strong seasonal cycles, interannual and not seasonal changes dominate small plankton volume and the spawning of most fishes. The seasonal cycle of larval abundance accounts for less than 30% of the time series changes at the latitudes of 25 to 35°N and several fishes appear to have no seasonality at all. In contrast, demersal fishes of the continental slope at 1000 meters have strong seasonal reproductive cycles at depth with larval development in midwater (Dover sole) and at the surface (Sablefish). Monitoring of biomass and recruitment will require the implementation of new extensive programs to manage in the presence of environmental variability.

DISPERSION OF POLLUTANTS AND OIL SLICKS
DISPERSION DES POLLUANTS ET DEVERSEMENT D'HYDROCARBURES

Passive Scalar Transport in β-Plane Turbulence

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Evaluation of spectral closure theory and direct numerical simulation is used to examine the eddy transport of a passive scalar in barotropic β-plane flow. When a large-scale gradient of scalar concentration is imposed, the implied scale separation between fixed background gradient and eddies supports the concept of 'eddy diffusion'. The results can therefore be cast in terms of an eddy diffusion tensor **K**, whose behaviour as a function of mean vorticity gradient β is examined. Earlier theoretical work by Holloway and Kristmannsson (1984) is extended to include cases where strong vorticity-scalar correlations are observed, and corrected in order to restore random Galilean invariance.

The anisotropy of eddy energy and the direct influence of Rossby wave propagation contribute to the overall anisotropy of **K**. The resulting suppression of meridional diffusivity K_{yy}, and enhancement of zonal diffusivity K_{xx}, with increased β is examined. The variation in simulation K_{yy} is closely reproduced in the closure equations. However, the increased K_{xx} is the result of zonal jets whose persistence is not accounted for in the statistical theory.

Modelling the Behaviour of Oil Spills in Ice-Infested Waters

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This paper describes methodologies developed for predicting the drift and spread of oil spills in ice-infested waters. Particular emphasis is placed on oil spills in medium and high ice concentrations. For ice concentrations greater than about 30%, the oil is found to drift with the ice. Empirical methods are used to determine the spread of oil in ice of different concentrations. The study showed that the equilibrium oil thickness in slush or brash ice is nearly four times that on cold water which is itself very different from that on warm water. Comparisons with limited available data show good agreement.

Dispersion of Pollutants in the Southeastern Sea of Korea

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A prognostic model has been developed to predict the concentration of pollutants in coastal water off Korea. The study area covers the southeastern Sea of Korea where the Tsushima Current flows in through the western channel of the Korea Strait.

To understand the physical processes and variability, extensive field measurements were con-

ducted. The CTD surveys and current meter moorings at various transects were carried out in two typical seasons, summer and winter. The July survey shows strong gradients in water properties on the isobaric surface in the upper 50 m. Below the shallower isopycnal, the surface with σ_t values between 24.0 and 26.5 sloped steeply downward from the coastline toward open sea, indicating a signal of strong geostrophic current flowing northeastward. The currents measured from the moored arrays show the presence of those oceanic currents with velocity ranging from 10 cm/s to 40 cm/s. Strong signals of current fluctuations with periods of 2–4 days were observed due to the local wind effects. The current regimes in the area were changing in speed and direction with season with major forcings of tides, geostrophic pressure gradient as well as local winds.

To study the advection-diffusion of pollutants released at a coastal site in length and time scales longer than those of major tidal periods, a two-layer 'slab' model was applied. The observed hydrographic data were used to define the thickness of layers at each grid point. The currents at open boundaries were used for the flow boundary conditions. Using the Galerkin-based finite element methods, the flow field linearly combined with tidal, oceanic and wind-driven currents was simulated. The dispersion of pollutants was simulated with temporal and spatial evolution of concentration patterns under several cases of episodic wind conditions.

The Local Meteorology of a Severe Air Pollution Episode in the Lower Fraser Valley, B.C.

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The Lower Fraser Valley, B.C. is afflicted by seasonally poor air quality in the form of photochemical smog episodes. The episodes come about as a result of precursor emissions (largely from automobiles) in the city of Vancouver and its satellite communities. The photochemical transformations occur under atmospheric conditions characterised by slack synoptic pressure gradients and strong solar loading that occur during the anticyclonic situation that dominates the summer climatology of the B.C. coast. This synoptic condition also favours the development of a sea/land-breeze circulation and relatively depressed mixed-layer depths in the coastal zone. The spatial and temporal characteristics of the episodes are powerfully influenced by a combination of local meteorology and topography of the region.

This study concentrates on the local meteorology of a particularly severe recent episode that occurred on a weekend. Because of the generally lower automobile emissions during weekends, it is to be expected that the meteorological conditions during this episode will be representative of the conditions for worst-case episodes.

The study explores the temporal and spatial dimensions of the episode through network data on ambient ozone concentrations, and examines local fields of wind speed, direction and temperature. Acoustic sounder data provide a picture of the diurnal evolution of the mixed-layer depth, and spiral profiles from an instrumented aircraft probe the vertical structure of ozone concentrations.

OCEAN SURFACE WAVES–1 AND PROCESSES
VAGUES–1 ET PROCESSUS

Ocean Waves and Climate Forecasting

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It has long been supposed that ocean waves are the intermediary whereby momentum is passed from the winds to the sea, ending up in the global ocean circulation. The details of the passing have been ignored, perforce, since the processes by which waves are generated, grow and dissipate

are at best poorly understood. And for most purposes, (e.g. operational wave forecasting) our ignorance has had little effect on skill at predicting oceanographic processes from meteorological forcing.

The advent of the perception that climate may be predictable has changed the rules of the game. The coupling process by which momentum is transferred from air to sea must be more completely understood, if we are to make effective use of the global data sets offered by satellite-borne radars in our coupled ocean/atmosphere global climate models. Firstly, the radars sense the short-wavelength waves at the sea surface, which play a poorly-understood role in ocean wave development (What fraction of the momentum they receive goes into the wave field, or directly into currents?); secondly, the coupling constants in the climate models are themselves strong functions of the state of development of the wave field (How will such hitherto unaccounted-for couplings affect the (already strongly coupled) air-sea interchange equations?).

An Extremes Wind and Wave Climatology off the East Coast of Canada

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A method is described and results are presented of a wind and wave hindcast carried out for three areas off the east coast of Canada: the Grand Banks of Newfoundland, the Scotian shelf and Georges Bank.

In each area the 30 most severe wave-producing storms in the past 30 years were identified through objective and subjective storm selection procedures. These storm selection procedures differ somewhat from the procedures used in site-specific hindcast studies, since they cover a finite area. The storm selection procedures are considerably more complex and difficult than those where a continuous observational, or hindcast, record of waves (or winds) is available. In the present study, historical records of wind and wave observations from ships, drill rigs, land stations, previous hindcasts, previous studies and historical accounts were searched to produce a master list of all significant storms in east coast waters for the past 30 years. This amounted to more than 530 storms. This list was reduced in several stages, both objective and subjective, to final lists of the 30 most severe wave-producing storms in each of the three target areas. In addition, a separate population of tropical storms was identified for Georges Bank.

Once the storm population was identified, deep-water wind and wavehindcasts were carried out using conventional hindcast procedures, including isobaric analysis of historical storms, production of planetary boundary layer model winds, kinematic analysis of storm wind speeds and a first-generation spectral wave model. Modelling was carried out on a coarse-mesh grid 1.25° of latitude by 2.5° of longitude, with a nested fine-mesh grid at half that resolution.

Extremal analysis, using the Gumbel distribution, was performed on the hindcast wind speed, wave height and crest height values at a large number of locations to produce statistics required for the design of offshore structures, for example the 0.01 exceedance probability values for each parameter.

Analyses produced include geographical maps of the design (i.e. 100-year return period) values for significant wave height, and associated parameters such as the surface wind speed, maximum wave height and peak period. This illustrates the spatial variability of the wind and wave climate on the east coast of Canada. The temporal variability of east coast storms will also be addressed.

A Further Look at Parameterization of Wind-Wave Spectra

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The proper correlation for the equilibrium range constant α, used in developing spectral representations for wind waves, is presently still uncertain. Neither conventional approaches to correlating α with non-dimensional wind speed nor trying to readjust equilibrium range exponent have been fruitful. In this paper we established analytically a well-defined correlation of α in terms of the significant wave slope, spectral shape function, and the ratio of peak wave phase speed to friction velocity. This generalized α correlation has been empirically substantiated by over 2000 well-developed wave spectra recorded in the Great Lakes. With this approach spectral formulations using different equilibrium range exponents all led to sufficiently well-defined correlations. This suggests that the equilibrium range exponent is not unique and that a range of exponents can be used to provide satisfactory results. Thus the validity and choice of equilibrium range exponents cannot be readily confirmed by α correlations. Further applications of this approach also revealed that the shape function used in the JONSWAP formulation was inconsistent with general data. By making ancillary modifications to the form of the shape function, we were able to secure sufficiently consistent results.

Open Ocean Bubble Size Distributions from Multifrequency Acoustic Backscatter

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Gas bubbles occur in large numbers immediately below the sea surface, where they are produced by the breaking of waves, and play a major role in studies of air-sea interaction processes. In addition to the influence on sound propagation, recent studies indicate that the bubbles play a major role in gas exchange through the air-sea interface and can also be used as tracers to study the flow field in the upper ocean. In studies of the influence of bubbles on the physical processes in the upper ocean it is of fundamental importance to measure the size distribution of the bubbles in the water column. Here a multifrequency backscatter method for this purpose will be discussed and initial results from the SWAPP experiment, where six acoustic frequencies were used, will be presented. The acoustic method's ability to resolve bubble sizes down to a radius of 8 microns shows the presence of large numbers of the smaller bubbles as compared to previous optical measurements. The variability in the bubble size distributions is found to be coherent with time and depth giving valuable insight into the structure of the flow field in the upper ocean.

LARGE-SCALE OCEAN CIRCULATION–1
CIRCULATION OCEANIQUE A GRANDE ECHELLE

Oceanic Circulation from a Global Eddy-Resolving Model

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A global ocean model with $\frac{1}{2}^{\circ}$ horizontal grid spacing and 20 vertical levels has been integrated for a simulation time of thirty years, with seasonally varying forcing applied over the last seven years. Results of the simulation are presented.

A broad assortment of currents are well-represented in the model. In mid- and high-latitudes, these include the known unstable western boundary currents of the northern and southern hemispheres and the Antarctic Circumpolar Current. In the tropics, there are seasonally varying midocean flows such as the equatorial currents, countercurrents, and undercurrents. Seasonally

varying boundary currents in low- and mid-latitudes include the Somali Current, the North Brazil Current, the California Current, and the Leeuwin Current.

Most of the strong currents of the model are rich in instabilities. The nature of these instabilities is examined. Also, an analysis of the regional exchanges between different parts of the world ocean is conducted to give a picture of the general circulation, including aspects of heat transport.

Progress in Canadian WOCE Plans

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An update of progress towards the implementation of the WOCE program will be presented. Special emphasis will be placed on those sub-programs involving Canadian participation. Canadian plans and funding progress at government and university laboratories will also be reviewed. The WOCE mastodon is creaking into action! Come one and all and hear of its ponderous progress.

On the Importance of Vertical Resolution in Certain Ocean General Circulation Models

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In centred difference models of the ocean circulation, two grid point computational modes can be excited if grid Reynolds and Peclet numbers are greater than two. The Bryan-Cox General Circulation Model (GCM) is used to show the dramatic effect that this instability has on the equatorial thermohaline circulation. In many recent numerical calculations researchers have used 12 vertical levels. It is shown that this resolution produces an artificial cell at the equator when typical values of the vertical diffusivity and viscosity parameters are used. This artificial cell rotates counter to the primary cell driven by deep water formation at high latitudes, is driven by downwelling at the eastern boundary near the equator and is 40% the strength of the primary cell for the parameters used in the present study. When vertical resolution is increased the cell vanishes. It is suggested therefore that higher vertical resolution should be used in Bryan-Cox GCM deep ocean modelling studies when current values of the vertical diffusivity and viscosity parameters are used.

The Assimilation of Sea Surface Temperature Data into Numerical Ocean Models

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The ability of sea surface temperature (SST) data to improve the circulation in numerical ocean models is determined through a series of idealized numerical experiments, conducted using the GFDL Bryan-Cox primitive-equation OGCM set up as an eddy resolving, flat bottomed channel. The basic experiment consists of a control Run R representing the "real" world. The model is initially spun up diagnostically after which a small random perturbation is introduced into all fields of data and the model is allowed to evolve prognostically into a fully eddy active circulation. An additional model Run B is performed which is identical to Run R except for the introduction of a slightly different perturbation. Run B represents an imperfect numerical model trying to simulate the "real" ocean described by Run R. "Observed" SST data, taken as the temperature at the top level of model Run R, are then assimilated into Run B using a simple "nudging" scheme based on a surface heat flux Q, given by $Q = C(SST - T_{1B})$, is the temperature at the top level of Run B. The rate of data injection is controlled by adjusting the constant C to an optimal value. Tests are underway to determine if the velocity fields in Run B can be brought closer to those in Run R by this method.

ICE AND SNOW RESEARCH–2
RECHERCHE DE LA GLACE ET DE LA NEIGE–2

Small-scale Melt Processes at the Ice-Water Interface of Annual Sea Ice

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During the period of active melting, temperature, salinity and nutrient distribution have been sampled in the surface boundary layer of annual sea-ice. This has shown that melting occurred at both the underside of the ice with production of melt water and inside the ice sheet with rejection of brine. Melting at the interface has been correlated to solar radiation flux variations and to the eddy diffusivity in the surface layer. Moreover, the upward flux of salt has been shown to be the more restrictive variable for melt rate. These results combined with the spatial variability of pressure keel distribution suggests a spatial heterogeneity in the melt rate characteristics. In addition, our findings confirm that the ice-water interface dynamics is dominated by the fortnightly tidal variations. During neap tide, the development of a viscous sublayer combined with the production of fresh melt water creates conditions for the development of a stratified buoyant boundary layer. During spring tide, the vertical eddy diffusion increase creates an upward flux of salt and nutrients which erases the neap tide structure.

Feasibility of Predicting Climate Change; Impact on East Coast Ice Severity I: Scope of Problem and Evaluation of Impacts on Iceberg Calving Rates

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In response to a federal PERD (Panel on Energy Research & Development) requirement, multidisciplinary evaluation was carried out for the feasibility of predicting the impact of global-warming on iceberg and sea ice conditions off Eastern Canada. Primary focus was given to changes in iceberg severity. The work required assessment of the likely changes and accompanying uncertainties, which might occur in key atmospheric and oceanographic parameters together with estimation of present and attainable capabilities for quantitatively describing the effects of such changes on sea ice and icebergs.

Because of the current state of flux and controversy regarding the extent of the anticipated warming, our primary efforts were given to ascertaining the degree to which present knowledge of the sea ice/iceberg environment would be sufficient for the translation of various atmospheric and oceanographic warming scenarios into altered ice severities.

The first step in the process required a review of present understandings of berg production (calving). Assuming that warming occurs over a period of decades and allowing maintenance of quasi-equilibrium conditions, flux balance calculations were carried out to assess the likely extent of calving rate changes in the best documented West Greenland berg source, the Jakobhavns Isbrae. This approach yielded calculated calving rates in excellent agreement with recent field estimates. When the calculation was amended to allow for a universal 10% precipitation increase and higher coastal precipitation rates adjacent to oceanic areas cleared of sea ice, significant change in calving rate was only obtained for the most drastic tested warming scenario, equivalent to a 1000 m elevation of the equilibrium line. In the latter case a 30 to 40% decrease was obtained in the calving rates. Although relatively brief and local surges in iceberg production cannot be excluded as possible responses of the Greenland ice sheet and outlet glaciers, it was concluded that the overall impact of warming would be to either leave calving rates approximately at their present value or to produce a modest reduction in iceberg output.

Feasibility of Predicting Climate Change; Impact on East Coast Ice Severity II: Present Mechanisms and Controlling Factors for Iceberg Transport and Deterioration

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Review and analysis of existing iceberg, sea ice and oceanographic data were carried out to clarify the processes whereby bergs either move from their sources to impact areas south of 48°N or dissipate en route. Data support the proposition that, at most, a few percent of the originally calved total berg mass ever reaches the Labrador Sea north of the primary Grand Banks impact area. The loss of berg mass was attributable to a combination of the high probability of grounding and long term entrapment by sea ice on the shallow continental shelves of Baffin Bay and Davis Strait and to deterioration and melt during open water passages. The spatial and temporal characteristics of the observed berg flow were used to explain the "pulse" of bergs which is observed to appear in Davis Strait beginning, typically, in January.

A previous noted (Marko, Fissel and Birch, 1986) correspondence between the January Davis Strait ice extent and the numbers of bergs found south of 48°N in the following "iceberg season" was now found to be fully consistent with 28 years of ice and iceberg data. The mechanism whereby mid-winter Davis Strait ice determines subsequent downstream berg numbers was deduced from the close correspondence between the extent of this ice and later downstream ice extents. The ice pack of the Labrador Sea was found to be the key factor in determining the rate of mass loss for icebergs moving toward 48°N in the spring and summer months. Open water berg mass loss data and theoretical results for wave-induced erosion of berg mass were used to estimate minimum sizes required for the survival of Labrador bergs to the 48°N line as a function of seasonal ice extent. These results suggested that Labrador Sea ice extent controls the iceberg season severity by, in effect, setting a minimum limit for the size of an iceberg which could complete the journey to the Grand Banks.

Two noted deviations from the success of the Davis Strait ice extent "indicator", in 1975 and 1987, were shown to be consistent with this controlling mechanism and the effectiveness of easterly springtime wind components in reducing the spatial extent of the Labrador pack. Consistency of the mechanism with oceanographic data on the Grand Banks was also demonstrated.

References

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Feasibility of Predicting Climate Change; Impact on East Coast Ice Severity III: Obstacles to Climate Change Impact Forecasting and Feasibility of Solution

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Results obtained in assessing present knowledge relevant to predicting the impact of climate change in iceberg and sea ice severity were evaluated. The key conclusions from the extension of present knowledge of the sea ice and iceberg environments into the 50 to 100 year warming period of interest were:

a) the berg supply at the sources will either remain relatively unchanged or decrease by a few tens of percent; and

b) the likely changes in the numbers and masses of bergs reaching the impact areas can be deduced by determining, in turn, the effects of global/regional warming on upstream, mid-winter sea ice conditions.

Consequently, while further information is needed on almost all aspects of the problem, including overall global warming models and basic data on berg calving and deterioration rates and grounding/reflotation probabilities, further data and understanding pertinent to the present and future behaviour of the Baffin Bay and Davis Strait ice cover appear to be critical elements of any scheme to assess climate change impact. The requirements for a research program capable of achieving these understandings were identified and related to present and future technical capabilities.

THE UPPER ATMOSPHERE RESEARCH SATELLITE PROGRAM
PROGRAMME DES SATELLITES DE RECHERCHE DANS L'ATMOSPHERE SUPERIEURE

The Upper Atmosphere Research Satellite (UARS)

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The Upper Atmosphere Research Satellite (UARS), to be launched in late 1991, will provide a detailed look at the physical and chemical processes controlling ozone in the Earth's upper atmosphere. It will produce comprehensive state-of-the-art measurements of ozone and key members of the nitrogen, hydrogen, and chlorine chemical families, as well as energy inputs, temperature, and wind fields in the stratosphere, mesosphere, and lower thermosphere. The scientific payload includes one microwave and two infrared emission limb sounders for determining vertical profiles of trace species and temperature, an infrared solar occultation sensor for minor species, two high resolution interferometers for Doppler wind measurements, two full-disk solar spectrometers, and a high energy particle monitor. The UARS Science Team is composed of the nine investigator groups responsible for instruments, plus ten investigator groups providing additional capability in the areas of data analysis and interpretation. A dedicated distributed data system provides a powerful capability for data processing, storage, scientific analysis, and communictions. An extensive effort to utilize correlative measurements, both for instrument data validation and for complementary scientific studies, is expected to foster wide-spread cooperative efforts in the use and analysis of UARS data.

The High Resolution Doppler Imager

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The High Resolution Doppler Imager (HRDI) is a triple etalon Fabry-Perot interferometer designed to measure Doppler shifts of absorption and emission lines in the stratosphere and upper atmosphere. HRDI will be flown on board the Upper Atmosphere Research satellite in 1991. The vector winds will be determined in the stratosphere (10–40 km) and upper atmosphere (80–120 km) during the day and the upper atmosphere at night to an accuracy of 5 m/sec. The wind measurement concept and the operator scenario will be discussed.

The Cryogenic Limb Array Spectrometer

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Significant attention is focussed on the study of the upper atmosphere and potential effects of changes in the climate, weather, and protection provided by the ozone layer. The UARS will provide a global, continuous and comprehensive look at the upper atmosphere over an 18 month

period with the scheduled launch in the fall of 1991. The Cryogenic Limb Array Spectrometer (CLAES) will derive stratospheric temperatures and constituent number densities from the measurement of infrared spectral emissions. Overviews of the CLAES experiment and hardware will be given. The CLAES instrument is a solid CO_2 and neon cooled Fabry-Perot infrared spectrometer with the objective of obtaining measurements of a series of stratospheric minor species which are of significant interest to the photochemistry of the stratosphere and ozone layer.

Remote Sensing of Atmospheric Structure and Composition by Pressure Modulator Radiometry from Space: The ISAMS Experiment on UARS

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This paper describes the Improved Stratospheric and Mesospheric Sounder experiment on the Upper Atmosphere Research Satellite. ISAMS uses a technique called pressure modulator radiometry, which permits the measurement of selected atmospheric parameters with high precision and selectivity. Marriage of this technique with the objectives of the UARS programme is aimed at producing a radical improvement in current knowledge of the middle atmosphere. In particular, it is hoped to make significant progress in understanding the coupled behaviour of radiation, dynamics and photochemistry in the stratosphere and mesosphere.

The scientific objectives are discussed first, in the context of current knowledge of the middle atmosphere and of known problems which result from shortcomings in this knowledge. This is followed by a discussion of the instrument concept, its design, and its performance as calculated and measured in the laboratory. Finally, the implications of the instrumental capabilities and mission parameters for the achievement of specific objectives are discussed.

OCEAN SURFACE WAVES-2/VAGUES-2

Air-Sea Fluxes by the Dissipation Method during the Ocean Storms Project

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High frequency measurements of wind velocity and temperature fluctuations were made from the C.S.S. Parizeau in the fall of 1987. The dissipation method was applied on the resulting time series in order to determine friction velocities, u_* and characteristic temperature length scales, t_*. The time series of the u_* and t_* were then analysed using regression techniques to determine relationships for the drag coefficicent, c_d, and the Stanton number, c_h.

Least squares minimization on the u_* data yielded the following relation for the momentum flux: $c_d = 1.17 \times 10^{-3}$ for $4.0 < U_{\text{true}} < 10.0\,\text{m s}^{-1}$ and $c_d = 1.12 \times 10^{-3} + 5.06 \times 10^{-5} \cdot U_{\text{true}}$ for windspeeds over the range $10.0 \leq U_{\text{true}} \leq 18.1\,\text{m s}^{-1}$. This result is similar to that given by Large and Pond (1981), and Smith (1980). However, at high wind speeds, the regression relation gives lower values of c_d than the results given by Large and Pond and Smith. The deviation is attributed to low data quality and a sparseness of high wind speed measurements.

The results of the Stanton number, c_h were not as consistent as those for c_d. Because of data quality problems, the relationship obtained under neutral or positive static stability was not significant. Under conditions of negative static stability, c_h was found to be 2.17×10^{-3}. This compares to Large and Pond's (1982) result of 1.13×10^{-3} and 1.10×10^{-3} found by Smith (1980).

Frequency and Directional Evaluation of the ODGP Wave Spectra at Hibernia

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An evaluation of the ODGP (Offshore Data Gathering Program) hindcast winds and deep water wave spectra was performed. A coherence analysis between the "man-machine" mixed model winds and local winds, obtained from an offshore mobile drilling platform, showed acceptable inner coherences for frequencies below 0.75 cycles per day (cpd), and improvement over a purely geostrophic wind estimate which has a cut-off around 0.5 cpd. There was generally good agreement between the model and field spectral wave properties, particularly during storms. A coherence analysis using average wave spectral energy vectors, given by the significant wave height and vector mean direction, showed results similar to the winds. Qualitative assessment of the frequency dependent behaviour of the model, indicated generally good agreement between mid and high frequency portions of the wave spectra, a tendency for the model seas to develop faster than observed and no consistent agreement between observed and modelled swells. Coherence analysis results, using spectral energy vectors calculated over the selected frequency ranges, supported these observations with the low frequency swell being incoherent at all time scales while mid and high frequencies had acceptable coherence levels between 0.75 and 1.0 cpd.

Fetch Relations for Wind-Generated Waves as a Function of Wind Stress Scaling

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We present the variation that results when fetch relations in wind-generated wave spectra are scaled by the friction velocity component in the dominant wave direction rather than the magnitude of the friction velocity, using the data collected during the Canadian Atlantic Storms Program (CASP). The effects of three possible drag coefficients are considered: the usual constant drag coefficient, the open ocean long fetch drag coefficient, and finally, the wave age dependent drag coefficient for growing waves recently measured by Smith and Anderson (1989) in HEXOS.

Contributions to the correlation coefficient for dimensionless variables due to both the scaling variables and the dimensional variables are computed. We find that the friction velocity component in the dominant wave direction rather than the friction velocity magnitude should be used as the scaling variable. The self-correlation introduced to the correlation coefficient is then less than that resulting from the friction velocity magnitude.

Balance relations among physical fetch relations support this conclusion and imply that the wave age dependent drag coeffcient for growing waves is the appropriate drag coefficient to use in scaling variables. We generalize Snyder et al. (1981)'s parameterization of the wind input energy and derive a functional form for Phillips equilibrium range α function.

Evidence of Temporal Changes in the North European Shelf Wave Climate

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Temporal changes in the North European Shelf wave climate are indicated by analysing a continuous 35 year hindcast wave data base, residing at the Norwegian Institute. These changes are demonstrated both in terms of normal statistics, and in terms of extreme estimates based on limited sub-series within the 35 year series. The basic 35 year wave data series, generated by a discrete type spectral wave model, covers the NE Atlantic and adjacent waters, with a 75 km spatial resolution, 6 hourly intervals, from 1955 through 1989. The data base is partly validated against measurement data, and it has recently been used in storm selection procedures for the North European Shelf Study, NESS. The present study has relevance to such problems concerning extreme estimations, seasonal breakdown, storm threshold criteria and requested range of basic time series. In particular, we shall consider the statistical character of the 'warm decade'

of the 1980's.

Long-Term Wave Variability along the Southwest Coast of India

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The climate of India is dominated by the monsoons. The erratic behaviour of the monsoons leads to significant year to year variation in the climate. The long-term variation in the wave climate along the Indian coast has not been the subject of a study so far. This paper attempts to study the long-term variability in the wave climate along the southwest Indian coast in relation to the climatological factors. The wave climate along this coast shows considerable year to year variations. Recorded wave data from four locations along this coast shows that the lowest and highest wave intensity in the decade 1980–1989 occurred in 1982 and 1981 respectively. Correlation of the wave variability with winds along this coast and the influence of the long-travelled swells in bringing about year to year variations in the climate are studied. The lowest wave intensity during the decade corresponds to the strongest El Niño with an event intensity of 4, and the year of highest wave intensity preceded this. The observed long-term variability in the wave climate is discussed with reference to the global climatological events during this period.

LARGE-SCALE OCEAN CIRCULATION–2
CIRCULATION OCEANIQUE A GRANDE ECHELLE–2

Data Assimilation in Oceanography

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The forthcoming decade promises to be a most exciting one for oceanographers as for the first time measurements of dynamic variables will be available with global coverage. First and foremost, synoptic measurements of sea surface height will be provided by the TOPEX/POSEIDON mission and, hopefully, also the major surface forcing function of the ocean, the wind stress field, will be available through scatterometry. These datasets will be complemented by more traditional oceanographic measurements such as the classical hydrographic program with basin-wide sections of WOCE and some intensive field programs in localized basins and dynamically active regions.

This dataset of unprecedented size and quality has made the problem of data assimilation timely and important for oceanographers. Data assimilation was originated in the atmospheric sciences by the meteorological need of forecasting. The oceanographic problem of data assimilation however is motivated by the necessity of blending model-evaluated and actually measured variables through techniques of smoothing, filtering, dynamical interpolation and extrapolation so as to achieve a consistent rationalization and interpretation of all the available information. Thus, even though the existing literature already provides powerful methodologies for data assimilation, these must be interpreted and adapted to the oceanographic need and motivation.

A short review will first be given of the differences between the two fluids, atmosphere and ocean, and of the relative type of datasets, with their implications for oceanography. Important assimilation approaches will be described and their feasibility and practical use by existing numerical models of the ocean circulation will be discussed. Specific examples will be shown for the two categories of i.) simple models and sophisticated data assimilation techniques; ii.) complex models and simple techniques. Important physical questions will be addressed in the context of specific techniques such as how models can dynamically extrapolate the surface information provided by altimetry and hopefully reconstruct the abyssal circulation; whether localized arrays providing sparse clusters of measurements can still be effective and used especially in regional models and process studies.

Unprejudiced Ocean Circulation

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Least biased ('unprejudiced') ocean circulation is calculated over the global domain. Following information theory/statistical mechanics, one maximizes entropy $H = -\int d(\Phi)p(\Phi)\ln[p(\Phi)]$ where Φ is a state vector describing the ocean and $p(\Phi)d\Phi$ is the probability for the ocean to occur in region $d\Phi$ about any state Φ. Describing circulations on scales larger than first deformation radius by a quasigeostrophic streamfunction Ψ, the variation of H is carried out under constraints that advection conserves global integrals of energy $\int dA\frac{1}{2}|\nabla\Psi|^2$ and of enstrophy $\int dA^{\frac{1}{2}}\left(\nabla^2\Psi + f(1+h)\right)^2$ where f is the Coriolis parameter and h is the elevation of bottom relief as a fraction of reference ('mean') depth. This yields an expected streamfunction given by $(\gamma_1/\gamma_2 - \nabla^2) < \Psi \geq f(1+h)$, where γ_1 and γ_2 are Lagrange multipliers due to the energy and enstrophy constraints. In the equation for $< \Psi >$, only the ratio γ_1/γ_2 (with dimensions L^{-2}) occurs.

Maps of the flow field given by $< \Psi >$ already include a wealth of detailed current structure (due only to the relief of ocean basins), much of which appears to be quite realistic. However, calculation of $< \Psi >$ takes no account of the mean forcing fields (wind, sun, rain, etc.). Work in progress addresses ways that the statistical mechanical $< \Psi >$ can be combined with more conventional numerical models and/or data assimilation methods in order to realize some of the effects of ocean eddies without the computational burden of explicitly resolving eddies.

NPAL, an Upper-Ocean Model of the North Pacific: Model Design and Initial Experiments

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NPAL (North Pacific Active Layers) model was designed for process studies and for ocean climate sensitivity experiments on seasonal to decadal time-scales. It is a primitive-equations model, which presently consists of two active variable-depth layers: a Niiler and Kraus (1977) type mixed layer and a pycnocline layer over a semi-passive deep ocean. The model domain extends from equator to 62°N and from 123°E to 80°W. Horizontal resolution is 1° latitude by 1.5° longitude. The mixed layer is driven with Hellerman and Rosenstein (1983) monthly wind-stress and with heat and fresh-water fluxes derived from climatological surface monthly temperatures and seasonal salinities. The model is also driven from below with heat and fresh-water fluxes that are derived using climatological temperatures and salinities below its lower surface. We examine the sensitivity of the model-implied air-sea fluxes of heat and freshwater with respect to varying (a) surface and bottom boundary conditions, (b) southern (open) boundary conditions and (c) horizontal viscosity/diffusion.

THE CANADIAN WINDII PROGRAM–1
LE PROGRAMME CANADIEN WINDII–1

WIND Imaging Interferometer (WINDII) for the Upper Atmosphere Satellite Mission

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The WINDII instrument uses digital phase shifting interferometry to measure the shifts and widths of airglow emission lines. The use of a field-widened Michelson interferometer allows wind and temperature images to be obtained, using a CCD detector. By viewing different airglow emission wavelengths at the earth's limb, the altitude range 80 to 300 km can be covered, both in the daytime, and at night. The concept is described, and some pre-flight results presented.

Measuring the Mesopause Temperature with WINDII

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The hydroxyl airglow is emitted by a narrow region about 8 km thick centred near the mesopause. Two of the filters on WINDII isolate spectral features from the (8–3) band of this emission. In addition to providing information on the wind and the altitude profile of the emission, the measurements of the hydroxyl layer provided by these filters will allow a determination of the temperature in the emitting layer. The technique for determining the temperature will be outlined along with a discussion of the expected precision of the measurement and the requirements for ground truthing.

Oxygen in the Middle Atmosphere

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WINDII observations of airglow emissions that originate in the upper mesosphere can provide many parameters in addition to the wind and temperature profiles. The measured airglow emissions are in fact the result of a complex chain of atmospheric chemistry. In recent years our understanding of these processes has improved so that we can now use the observations to determine atmospheric constituent concentrations. The most notable among these is atomic oxygen which is formed through the solar dissociation of molecular oxygen in the thermosphere. In this paper some aspects of this atmosphere chemistry are described. It is also shown that photometric measurements with WINDII can provide significant information on some of the transport processes that control minor constituent concentrations in the middle atmosphere.

The WINDII Instrument and its Calibration

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The WINDII instrument consists of a CCD camera which views the horizon through a field-widened Michelson interferometer, two telescopes and a set of interference filters. One of the telescopes combines two orthogonal views into one, which appear simultaneously side by side on the CCD. Images of phase and visibility of the Michelson fringes (corresponding to wind and temperature) are produced in software by combining four CCD pictures taken at different phase steps. The phase steps are produced piezoelectrically by the motion of one of the interferometer's mirrors. This paper discusses optical, mechanical and thermal aspects of the instrument and methods used to characterize it.

WIND ANALYSIS AND MEASUREMENT
ANALYSE ET MESURE DES VENTS

Satellite Measurement of Surface Winds in the Northeastern Pacific

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The determination of wind speed and direction from the human interpretation of satellite images has become a standard operational procedure in forecast centres. Automating this process has proved more difficult, however. The assignment of cloud motion vectors to a specific height, the recognition of orographic, frontal, or other organized cloud systems, and the large amount of computer time needed to compute the cloud motion vectors has prevented, to a large degree,

the implementation of a computer-based cloud tracking scheme at the operational level.

We have designed and are testing a cloud tracking scheme for boundary layer clouds in the Northeastern Pacific. The scheme is based on the Sequential Similarity Detection Algorithm developed by Atkinson and Wilson (Swadley, 1988). This algorithm tracks clouds by identifying a template in an initial geostationary (GOES West) satellite image, and then searching for strong correlations between this template and portions of a subsequent image taken 30 to 60 minutes later. Initial tests for 9 days in December, 1989 show that the technique has skill at estimating boundary layer winds using low-level cumulus and stratocumulus clouds off the British Columbia coast, and can operate at acceptable speed on a desk-top workstation.

We have adapted a boundary layer model developed by Brown and Liu (1982) to relate the cloud motion vectors at the boundary layer top to the surface buoy winds. The model incorporates the effects of surface roughness, stratification, and thermal wind on the boundary layer wind profile. Wind data areavailable for six buoys located within the region of interest; we are currently comparing the surface wind estimates derived using the satellite cloud motion vectors and the boundary layer model with the buoy reports for each of the December cases. We plan to extend this study to marine boundary layers with a range of stabilities, and to implement measures of cloud texture to help in the identification of low-level stratocumulus and cumulus clouds best suited for automated tracking.

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Multiple Windbreaks: An Aeolian Ensemble

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Near-neutral measurements of the turbulent wind field within and above a sequence of 15 parallel windbreaks on a flat pastoral site are presented. The windbreak fences each had a porosity of 60% and were equally-spaced at 6 times their height ($h = 2$ m). The following conclusions seem justified for wind directions within 10° of the normal to the array:

(1) Above the windbreaks ($2h$), mean windspeeds first decreased and then increased asymptotically to a value in equilibrium with the new surface roughness. At $0.5h$, windspeeds exhibited a slow increase down the entire array.

(2) Reflecting the differences in approach flows, the drag on the initial fence was almost twice that on barriers farther downstream. This reduction in momentum extraction per windbreak was associated with an elevation in the zero-plane displacement to a level equal to $0.8h$.

(3) At positions well-removed from the initial fences, mean windspeeds were reduced throughout the entire region below shelter height. In this region, the flow became increasingly dominated by downward moving air with velocities much greater than the local average. The zone of reduced turbulence was small, extending only $2h$ downstream of a barrier at a height of $0.25h$. This corresponded with the region excluded from smoke trails released at the top of windbreaks.

(4) An approximate TKE budget mid-way between windbreaks 7 and 8 suggests that shear and wake production peak near $z = h$ and that production is balanced by dissipation and vertical transport components. Advective and inertial interaction terms are negligible at this midway position but are likely to be major sources of TKE closer to the windbreak. Local equilibrium is attained above $z = 1.5h$ implying the existence of a constant-stress layer.

The measurements show the practical difficulty of simultaneously reducing both mean windspeeds and turbulence levels with repeated windbreaks at conventional spacings for horticultural applications.

A Preliminary Study of Organized Motion in Windbreak Flow

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An experimental study of turbulence in the lee of a windbreak will be described. Recorded time series of velocity components have been analysed using spectral analysis, conditional sampling and the so-called orthogonal decomposition method to search for organized or coherent structures. The study provides some qualitative information on the role of coherent structures in the transport of mass and momentum in the disturbed flow. The implications of this study for models currently used to simulate turbulent flow are briefly discussed.

Wind Profiler Networks – The Next Major Advance in Observing the Upper Winds

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The National Oceanic and Atmospheric Administration of the U.S. Department of Commerce is in the process of establishing a 30-station Wind Profiler Demonstration Network in the central region of the United States. The network will cover an area of approximately 1500 × 1500 kilometres. Scheduled for completion in early 1991, this array will be used to assess the impact of wind profiler data in weather analysis and forecasting, and provide a foundation for planning a nationwide network for the 1990s.

The Wind Profiler is an unattended, highly sensitive Doppler radar that is designed to detect and process returns from the clear air. It makes an accurate, vertical profile of the speed and direction of the wind in increments of 250 metres from near the surface to an altitude of approximately 16 kilometres. It completes a wind profile every six minutes. The system also computes hourly consensus averages.

The data from each system in the network will be transmitted via satellite to a central processing facility in Boulder, Colorado. There, the data from the individual sensors will be integrated into hourly reports for dissemination to the U.S. National Weather Service and other meteorological users.

Where observations by rawinsonde stations and weather satellites are made only twice a day, Wind Profilers will monitor the upper winds on an almost continuous basis. This high sampling rate promises to allow a marked improvement in analyzing and predicting the winds aloft and in turn make weather forecasting more accurate. Other related benefits, such as making aviation operations safer and more economical, and making air pollution monitoring and control procedures more effective, are also expected to be realized.

THE LAGRANGIAN OCEAN–1
L'OCEAN LAGRANGIEN–1

Currents and Horizontal Diffusion on Georges Bank as Measured by Drifting Buoys

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Near-surface current measurements obtained with LORAN-C and ARGOS satellite-tracked buoys in the vicinity of a tidal front in the northeast corner of Georges Bank are described. Seventeen releases consisting of clusters of 2 to 13 buoys each were tracked for periods ranging from 1 to

6 d between June and October, 1988, and during July, 1989. The spatial variability of the mean and tidal flows are described. Time series of the divergence, vorticity, shearing deformation rate and stretching deformation rate are used to investigate the kinematic and dynamic properties of the flow. Of particular interest is the possibility of convergence zones near the front. The drift buoy measurements are compared to current meter data collected in the region during the time of the drifter deployments. Initial results from models of the Lagrangian flow will also be discussed.

Analysis of Deep-drogued Satellite-tracked Drifter Measurements in the Northeast Pacific

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We analyze the trajectories of 24 deep (120 m) drogued satellite-tracked drifters launched in the northeast Pacific during June and October 1987. Three aspects of the resulting Lagrangian velocity field are presented: (1) The spatial structure of the mean and variance fields; (2) The dispersion and eddy diffusion characteristics of the fluctuating motions; and (3) The properties of selected mesoscale eddies. The Lagrangian integral time scales of about 4 days for the motions are similar to those for the North Atlantic while the integral length scales are half those for the Atlantic. The observed dispersion is generally consistent with Taylor's (1921) theory for single-particle dispersion in homogeneous isotropic turbulence although many of the drifter tracks also indicate extensive periods for which the fractal dimension of the buoy dispersion is significantly less than that for random motions. The eddy diffusion for regions is estimated to have a steady state value of around 4×10^7 cm^2/s. Subsurface meanders and eddies were especially prevalent in the bifurcation region of the mean flow with mean rotation periods of 15 days and mean azimuthal speeds of 13 cm/s. Mesoscale eddies are predominantly clockwise rotary and propogate to the west at roughly 1.5 cm/s counter to the direction of the prevailing wind and background flow.

Estimation of Eddy-Diffusivities, Integral Length and Time Scales from Fractal Oceanic Drifter Trajectories

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Recent work (Osborne et al., 1989; Sanderson, 1990) indicates that single particle and two particle oceanic motion may be fractal. A fractional Brownian motion model seems most appropriate, although there is some evidence of multifractality. For such motion estimates of integral time, space scales and eddy-diffusivities become as much a function of the way in which the measurments are made as the phenomenon being measured. This dependence upon the measurement process is investigated within a fractal framework. Comparisons are made with estimates of eddy-diffusivities and integral scales obtained using conventional approaches.

The Flow of a Coastal Current past a Blunt Headland

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The effect of an abrupt headland on a barotropic oceanic boundary current with variable bottom topography is investigated. This study arose from a desire to understand how a coastal current system might interact with a severe obstacle like Brooks Peninsula off the north-west coast of Vancouver Island. It has been observed that squirts and jets are generated just to the south of Brooks Peninsula during the summer months only. These events are generated by the advection of some kind of tracer material, perhaps cold upwelled water, or high concentrations of chlorophyll, by a background current velocity field. It will be shown that the seasonal dependence of the large scale current field produces a strikingly different mode of response depending on whether the modelled forcing is appropriate to the summer or to the winter. The background flow is from the north in summer, and from the south in winter. In the former case the background flow field can support a train of topographic Rossby lee-waves. In the latter case no such waves are generated and this assymetry produces a dramatic assymetry in the response. Particles seeded in the velocity field appropriate to the lee wave case generate events strongly reminiscent of the squirts and jets observed in the field. No such jets are generated in the case that fits winter circulation conditions.

Particle Dispersion due to Tidal Flow over Topography

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It is well-known that particle trajectories in simple, time-dependent Eulerian flow fields can be surprisingly complex. In fact, even without genuine turbulence, particles can apparently disperse and this has led to the term "Lagrangian chaos" (e.g. Zimmerman, J., *Netherlands Journal of Sea Research*, **20**, pp. 133–154, 1986).

We examine particle trajectories associated with tidal flow over an isolated topographic feature: a cone with the top removed. Our goal is to parameterize the particle dispersion in terms of non-dimensional numbers such as tidal excursion to topographic length scale and the Rossby number. Our approach is to use simple analytical models wherever possible and then check the results with a fully non-linear, depth-integrated numerical model of the flow over the frustrum.

Although our study is highly-idealized, we note that it may be useful in classifying banks as "retentive" or "dispersive" given just their size and the strength of the background tidal flow.

ICE AND WAVES/GLACE ET VAGUES

Airborne SAR Observations of Waves in Ice during LIMEX '89

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The Canada Centre for Remote Sensing (CCRS) CV-580 aircraft, with its C- and X-band synthetic aperature radar (SAR) systems. collected imagery of the marginal ice zone off Newfoundland during the Labrador Ice Margin Experiment (LIMEX) in March, 1989. One component of the LIMEX '89 program was the observation, by SAR and other sensors, of ocean waves penetrating the marginal ice zone. These observations are being used to address two main research objectives:

1. to work towards a better understanding of the SAR imaging physics for ocean waves by studying the greatly simplified case of waves in ice;
2. to provide synoptic-scale information for the study of ocean wave evolution (attenuation and dispersion) in the marginal ice zone.

In this paper we review the LIMEX '89 SAR data collected for the ocean waves program, and provide some image spectral analysis results. We make observations concerning the role of the aircraft height-to-velocity ratio and the wave aspect angle, as well as temporal and spatial spectral evolution. At this stage, all observations are based upon the SAR imagery alone, and are referenced to velocity bunching and tilt cross-section modulation, the known dominant imaging mechanisms for waves in ice.

Wave-Induced Drift Force on Ice Floes

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Wind waves are commonly ignored when modelling the ice motion in the marginal ice zone. In order to estimate the importance of the wave forcing, an expression for the second order wave-induced drift force on a floe exposed to a full directional wave spectrum is obtained in terms of a quadratic transfer function. For a given floe shape, the transfer function generally augments with the incident wave frequency, with a sharp increase near the resonant frequency of the pitch motion. The short wave limit of this function is determined by the shape of the horizontal contour of the floe. The value corresponding to the truncated cylindrical floe used here is 2/3 of the value obtained by the two dimensional approximation. The total drift force is computed for two situations: an off-ice wind over a large polynya, and an on-ice wind at the extreme ice edge. In the first case, the drift force induced by the short fetch waves represents a significant fraction of the direct wind forcing and may be partly responsible for the formation of ice edge bands as previously suggested by Wadhams (1983). In the second case, the very large drift force on a floe exposed to the high frequency components of the open water spectrum rapidly decreases (in the first few hundred metres) as these short waves are efficiently attenuated by the ice. This rapid decrease of the force generates a large compressive stress which is important in compacting the ice at the extreme ice edge.

Field Data Collection Programs and their Importance to Ship Icing Modelling

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The structure of a modern ship icing model is discussed and an algorithm for model calibration is presented. Available data sets on (1) ship spray parameters, (2) ship icing-related parameters are critically reviewed.

The University of Alberta winter field surveys of 1987 and 1988 in the Labrador Sea are discussed along with the Cold Regions Research Engineering Laboratory icing survey of 1990 to the Bering Sea. The proposed objectives of a comprehensive winter ship field survey for collecting icing-related data are presented. The potential for international collaboration is assessed in the light of the need for involvement of specific types of vessels.

The need for specific and reliable ship icing data is demonstrated and model results based on currently available data are presented.

OCEANOGRAPHY–2/OCEANOGRAPHIE–2

Prediction of Currents in the Waters of Northern British Columbia

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It is the goal of the Canadian Hydrographic Service to predict the currents in coastal waters, for navigation, fisheries, and pollution control. These predictions are difficult for the scientist, because the dynamics of the currents change from one region to the next. We will present a

series of colour movies of observed currents in the waters of northern British Columbia, with the semi-diurnal and diurnal tidal currents, wind-driven, and average flow presented in separate segments. By presenting the flow in this manner, the overall complexity of the currents is reduced, the public can understand the currents more easily, and the scientist can evaluate the type of model required for each region and the degree of success expected from numerical models. In some regions such as Hecate Strait in winter, a barotropic wind-driven model can simulate the non-tidal currents. In Dixon Entrance, the two large gyres which fill this basin are not always present, and it is difficult to predict their presence and disappearance.

A Three-Dimensional Model, GF8 for the Georgia–Fuca System

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T.S. Murty, Institute of Ocean Sciences, Sidney, British Columbia

A three-dimensional hydrodynamical numerical model for the system consisting of the water bodies of the Strait of Georgia, Juan de Fuca Strait, and Puget Sound has been developed. The model has a horizontal resolution of 2 km and uses eight levels in the vertical direction. The model equations are numerically integrated using a semi-implicit scheme employing successive over-relaxation.

The vertical eddy viscosity is dependent upon the Richardson number for the baroclinic calculations, and upon the vertical shear for the barotropic computations. Barotropic tidal simulations agree well with observations. Prognostically calculated density from the baroclinic also agree well with the observed density field.

Analysis of Long-Term Sealevel Records from the Georgia-Fuca-Puget Sound System

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Hourly time-series of surface elevations were obtained from three tide gauges: Seattle (1900–1988), Victoria (1939–1988), and Point Atkinson (1963–1988). Initial harmonic analysis of the data revealed that the calculated amplitudes of the very low frequency tidal constituents (e.g., SA and SSA) are particularly sensitive to the presence of nontidal signals in the data (e.g., storm surges). A simple iterative procedure was developed for calculating the alternating portion of the tidal signal to within an estimated 1 cm of its true value. The value of mean sealevel was then calculated by fitting a smooth curve to a graph of yearly mean water levels. This graph suggests that the mean water level has been increasing from 1 to 2 mm per year during this century. Differing rates of increase between the stations indicate that at least part of this has been due to vertical crustal movements. In addition, several local sealevel maxima correspond closely to known El Niño events.

The results of the iterative harmonic analysis calculations were combined with the fitted sealevel curve to calculate the hourly tidal elevations for each station. These were then subtracted from the original time-series to yield the residual elevations. Subsequent analysis has isolated all major storm surge events that have occurred in this century. An intercomparison between storm surges at each of the three stations suggests a strong correlation between water levels at the three sites.

Is the Leeuwin Current Driven by Pacific Heating and Winds?

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J.S. Godfrey, CSIRO Division of Oceanography, Hobart, Tasmania, Australia

Warm west Pacific water can flow through the Indonesian channels to create a basin-scale buoyancy-driven circulation in the Indian Ocean, even in the absence of winds. The driving force for this circulation is the generation of meridional steric height gradients (and associated

zonal geostrophic flows) by the cooling of Pacific inflow water towards the latitude-dependent Haney equilibrium temperature. Eastern and western boundary currents must develop to feed this zonal flow; in particular, a Leeuwin Current-like flow develops at the eastern boundary.

To illustrate these ideas, we have run a numerical model of a rectangular "Indian Ocean", connected via a near-equatorial channel to the "Pacific" — which is treated simply as a reservoir of water with fixed vertical profiles of temperature and salinity. No wind stress curl is applied, so no Sverdrup circulation is produced; the flow is almost purely thermally-driven. The *total* mass flux from the Pacific to the Indian Ocean is identically zero in our model, but up to $9.6 \times 10^6\ m^3 s^{-1}$ flow in each direction between the basins. When our "Pacific" temperature and salinity profiles are as observed in the Indonesian region, cooling to the Haney equilibrium temperature produces a strong eastward flow at midlatitudes, fed by a western boundary current which is in turn fed by inflow from the Pacific. At the eastern boundary a Leeuwin Current develops, with deep mixed layers near Cape Leeuwin; the mixed water feeds a Leeuwin Undercurrent which eventually flows back to the "Pacific" through the western boundary current. The depth-integrated mass transport of the Current-Undercurrent system near Western Australia is near zero, as observed in the Leeuwin Current system. This pattern is hardly affected by the imposition of equatorward winds like those found off Western Australia.

When the "Indonesian" temperature profiles are replaced (in our model Pacific) by the much colder ones observed in the eastern equatorial Pacific, with no other change, none of these phenomena occur. Instead, a typical eastern boundary flow regime is obtained, with equatorward surface flow, upwelling and shallow surface mixed layers. A shallow layer is heated at low latitudes, but this effect does not penetrate deep enough to generate significant zonal flows in midlatitudes; the heated water mostly returns to the "Pacific" via the western boundary current and a zonal jet. The difference between the two flow regimes is due to Haney-induced convective overturning in the first case, and its absence in the second.

Quantitatively, the large difference between the specific volume anomaly profiles of the eastern and western equatorial Pacific Ocean can be explained (in a double depth-integrated sense) by the action of zonal winds, which cause a large gradient of pressure (and hence of specific volume anomaly and temperature) along the equatorial Pacific. Thus these winds may be the cause of the large difference between the Leeuwin Current flow regime and other eastern boundary flows — and of the large heat losses to the atmosphere in much of the Indian Ocean.

Centrifugal Upwelling of Cold Saline Water at the Ends of Long Causeways in the Shallow Beaufort Sea

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It is thought that the presence of anomalously cold and saline water may affect certain fish species' coastwise migration in the very shallow (< 5 m), highly stratified ($\Delta S > 10$ psu), nearshore region of the Beaufort Sea. Patches of cold, saline water have been observed near long (ca. 5 km) causeways which have been constructed generally perpendicular to the trend of the shoreline. Previous attempts have been made to attribute these patches to Ekman upwelling driven by easterly winds.

An alternative explanation is presented in which Coriolis effects are negligible compared with acceleration due to local flow curvature and friction.

"Centrifugal upwelling" may be present where a long, thin impermeable feature, such as a causeway, intercepts long-shore transport and concentrates the flow around its end. The wind component perpendicular to the causeway drives a downwind (in shallow water) transport against the causeway, balanced by a local downwind pressure gradient at the causeway. A landward pressure gradient is established against the shore and along the causeway which drives a jet seaward. At the end of the causeway and the termination of the downwind barrier, the flow rounds the structure and assumes the curvature of the artificial shoreline. Centrifugal acceleration is balanced by a radial pressure gradient, the interface rises near the structure and cold, saline water is brought to the surface.

Centrifugal upwelling can occur in response to winds from any direction which have a significant component perpendicular to the causeway.

HYDROLOGY–1/HYDROLOGIE–1

Hydrology in the Context of Climatic Change

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The talk will emphasize the need for the understanding of the underlying physical processes and mechanisms of their interactions before the effect of a climatic change on hydrology can be assessed. Examples will be given of possibly erroneous interpretations of the fluctuations observed in hydrologic and climatic records if they are not based on sound physics.

Nonstationarity will be discussed as the theoretical framework for climatic change and consequences from this drawn for the theory as well as the practice. Distinction will be drawn between the hydrological and water resource management aspects of climate change impact.

The problem of the use of the current generation of conceptual hydrolgical models for climate-change impact assessment will be discussed in relation to their structure and performance criteria.

New trends in hydrology, triggered by climate-change and other global-change issues will be outlined and the related activities of the International Association of Hydrological Sciences will be briefly described.

Some Aspects of Modelled Soil Moisture for the Monitoring of Drought/Floods in the Canadian Prairies

L.O. Mapanao, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

The Atmospheric Environment Service runs a simple water budget model in near real-time for climate monitoring. The model provides a number of derived components related to the soil moisture status of a location. In this study, model-generated soil moisture time series were analyzed to bring out patterns, structures and relationships which may be useful for drought/flood monitoring and assessment.

Certain aspects of the hydrological cycle and cumulative distribution functions of modelled soil moisture at six Canadian locations are discussed.

A Comparison of Operational Estimates of Open-Water Evaporation, and 1990–91 Field Study Plans

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G.Z. Feng, Department of Hydraulic Engineering, Northwestern Agricultural University, Yangling, Shaanxi, China

Water is the most critical resource on the Canadian Prairies, and evaporation of water is the most important variable in the hydrologic cycle. Summer-time evaporative losses from open water on the Prairies exceed rainfall by factors of 2–6. Despite its importance, evaporation from open water surfaces cannot be measured directly, while the absolute uncertainties of operational estimates using physically-based or semi-empirical techniques range from 25–200%, depending on the time and space scales of interest. This paper discusses these uncertainties using comparative results of evaporation estimates from several operational techniques.

The National Hydrology Research Centre (NHRC) plans to implement several field exper-

iments to study various aspects of evaporation on the Prairies. The first of these, a *Regional Evaporation Study* to be initiated during 1990, will investigate regional and diurnal changes in the moisture balance due to local evaporation, over areas ranging from 500 km down to 25 km horizontal scale. Other field experiments to follow will examine smaller-scale aspects of open-water evaporation and of evapotranspiration at horizontal scales of 1–50 km. These experiments are part of a larger Prairie Evaporation Study, which eventually will require controlled water-balance studies over lined reservoirs in order to develop measurement standards suitable to evaluate and improve operational techniques for estimating evaporation.

The field plans and rationale for NHRC evaporation studies are presented, with emphasis on the initial Regional Evaporation Study. Several other cooperative meteorological experiments with other agencies, to be coordinated with 1990–91 filed plans, will also be discussed. These include studies involving radar-rainfall calibrations, convective forecast tests, ground-truthing of remote sensing techniques, and field tests of new meteorological data systems.

Recent Droughts in Southwestern Manitoba: A Moisture Deficit

R.A. McGinn, Brandon University, Brandon, Manitoba
B.T. Tolton, University of Toronto, Toronto, Ontario

Agricultural drought and dry spells are extended periods of abnormally dry weather which result in severe moisture deficiencies. Southwestern Manitoba has experienced many agricultural droughts. During these drought periods, severe moisture deficiences have resulted in low crop yields and crop failures. The Palmer Moisture Index was used to identify seven severe agricultural droughts that have occurred in and around Brandon, Manitoba during the last thirty years. Weekly Climatological Water Balances were derived for each drought year and the magnitude and temporal nature of each specific moisture deficit examined.

Cumulative mass moisture deficit plots during the growing season indicate that droughts are associated with abnormally large moisture deficits and/or temporal shifts in the deficit period. A non-dimensional analysis supports these observations and provides an objective classification of prairie droughts and dry spells.

FISHERIES OCEANOGRAPHY–4
OCEANOGRAPHIE DE LA PECHE–4

The Probability Distribution for the Abundance of Fish, and its Pattern in Space

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Fish abundance at a given location is better described as a probability distribution than as a single number. The probability distribution has a changing pattern over space, which can be mapped. (Mapping the actual pattern of abundance at an instant is neither possible nor useful.) We describe some non-parametric techniques for estimating the probability distribution, discuss some of their properties and problems, and illustrate their use with catch data from a trawl survey.

This is a progress report. We have reached a plateau from which we can produce some interesting maps and numbers. People who respond now have a good chance of getting us to move in directions they can use.

CODAR Remote Sensing of Ocean Currents off Vancouver Island in the 1988 MASS Program

D.O. Hodgins, Seaconsult Marine Research Ltd., Vancouver, British Columbia

Ocean currents are notably variable in space and time: a few moorings of conventional current meters cannot provide enough resolution to describe surface current features that may influence fish distribution over the continental shelf. We describe two major observational programs undertaken in 1988 as part of the Marine Survival of Salmon study to measure surface currents off the mouth of Barkley Sound and over Swiftsure Bank using HF ground wave radar (CODAR). The results reveal, for the first time, the intricacies of the currents and their response to tide and wind forcing. Such surface features as convergence along fronts, areas of divergence, and eddies are clearly visible. The surface features over Swiftsure Bank, for example, show areas of upwelling and advection onto the bank during part of each tidal cycle. The implied supply of nutrients could be related to food abundance and ultimately to salmon aggregation in this area, in addition to hypotheses related to favourable energetics.

The basic principles of surface current measurement by HF radar are briefly discussed, and the 1988 observation program is described. The presentation focusses on current observations that seem particularly relevant to fish distribution, notably on Swiftsure Bank. Progress on the development of second-generation CODAR systems are discussed, along with applications to more extensive shelf circulation studies and their potential for fisheries research.

Interannual Variability of Satellite-Derived Surface Pigment Concentration in the California Current

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Monthly composites of satellite-derived (CZCS) surface pigment concentrations from the newly processed global data set over the California Current System (CCS) are used to examine interannual variability of surface pigment concentrations. Data coverage is best for the period November 1978 to the end of 1983, providing 4 years of data prior to the 1982–83 El Niño and a good look at the anomalous year. More sporadic data are available after that until June 1986. Spatial resolution of the composites is approximately 20 km. Errors caused by the new atmosphere algorithm used in the global processing are less severe than in the previous West Coast Time Series, but still produce suspiciously high values in winter (November–February) north of approximately 40°N. For the March–October period, we find the mean seasonal cycle and remove it to form the non-seasonal monthly anomalies. Similar fields are formed for anomalous alongshore wind stress, mixing power of the wind (proportional to the cube of the wind speed) and wind stress curl. The interannual variability of the fields is examined using EOF analysis and the relation between the wind and pigment is found using Canonical Correlation Analysis.

Time Scales of Pattern Evolution from Cross-Spectrum Analysis of AVHRR and CZCS Imagery

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We have selected square subareas (110 km on a side) from Coastal Zone Color Scanner (CZCS) and Advanced Very High Resolution (AVHRR) images for 1981 in the California Current region off northern California for which we could identify sequences of cloud free data over periods of days to weeks. We applied a two-dimensional Fast Fourier Transform to images after median filtering, (x, y) plane removal and cosine tapering. We formed autospectra and coherence spectra as functions of a scalar wavenumber. Coherence estimates between pairs of images were plotted against time separation between images for several wide wavenumber bands to provide a "spec-

tral lagged correlation coefficient". The temporal rate of loss of correlation in surface patterns provides a measure of the rate of pattern change or evolution as a function of spatial dimension. We found that patterns evolved (or lost correlation) approximately twice as rapidly in upwelling jets as in the "quieter" regions between jets. The rapid evolution of pigment patterns (lifetime about 1 week or less for scales of 50–100 km) ought to hinder biomass transfer to zooplankton predators compared with phytoplankton patches that persist for longer times.

We found no significant differences between the statistics of CZCS and AVHRR images (spectral shape or rate of decorrelation). In addition, the peak correlation between AVHRR and CZCS images from the same area occurred at zero lag, indicating that the patterns evolved simultaneously, although high pigment would be expected to lag low temperatures (and high nutrients) in recently upwelled water. We thus conclude that in such dynamic areas the phytoplankton cells (identified by pigment color patterns) behave as passive scalars at the mesoscale, and that growth, death and sinking of pigments collectively play an insignificant role in determining the spectral statisitics of the pigment patterns.

Relationships between Water Masses and Groundfish Distributions on the Scotian Shelf: An Investigation of Interannual Variability

R.I. Perry, R.J. Losier, Biological Station, St. Andrews, New Brunswick

Characteristic water masses on the Scotian Shelf during spring and summer can be identified by their temperature and salinity properties. In this presentation, seasonal research vessel survey catches of groundfish are compared with these characteristic water masses to determine if a small number of water masses account for the largest catches. Results suggest that large catches for several species occur in only a few water masses which are species-specific, and consistent between seasons. This technique provides a method of relating intra- and interannual changes in groundfish distribution and migration patterns to those oceanographic processes which alter water mass characteristics.

ATMOSPHERIC DYNAMICS–2
DYNAMIQUES ATMOSPHERIQUES–2

The Hamiltonian Structure of Geophysical Fluid Dynamics

T.G. Shepherd, Department of Physics, University of Toronto, Toronto, Ontario

It has only recently been realized that most of the fluid dynamical systems used in meteorology and oceanography are, at least in their inviscid form, examples of non-canonical Hamiltonian systems. Casting the equations into abstract form allows the application of general methods of analysis, and leads to a unified understanding of certain fundamental properties of the equations. Important examples include conservation laws, which are either linked to continuous symmetries of the governing equations by Noether's theorem, or are examples of "Casimir invariants"; and the concept of wave activity, with its implications for Arnold-type stability theorems. Furthermore, the Hamiltonian formalism provides a very convenient and, surprising though it may sound, *physically intuitive* way of approximating systems of equations. This enables one to find the common threads linking different fluid dynamical systems, and identify their most essential differences.

The concepts mentioned above will be elucidated by considering the following geophysical systems: the meteorological primitive equations; incompressible stratified flow; the shallow-water equations; and baroclinic quasi-geostrophic flow.

Improving the Efficiency of a Finite-Element Regional Model by the Use of a Two-Time-Level Pseudo-Staggered Semi-Lagrangian Scheme

S. Gravel, J. Côté, A. Staniforth, Recherche en prévision numérique, Service de l'environnement atmosphérique, Dorval, Québec

It is known that straighforward finite-difference and finite-element discretizations of the shallow-water equations, in their primitive (u-v) form, can lead to energy propagation in the wrong direction for the small scales. Two solutions to this problem have been proposed in the past. The first of these is to define the dependent variables on grids which are staggered with respect to one another, and the second is to use the governing equations in their differentiated (vorticity-divergence) form.

We propose a new scheme that works with the primitive form of the equations, uses an unstaggered grid, but doesn't propagate small-scale energy in the wrong direction, and is computationally efficient as staggered formulations using the primitive form of the equations. We refer to this approach as *pseudo-staggering*, since it achieves the benefits of a staggered formulation without a staggered placement of variables.

The proposed method has been tested using a regional finite-element barotropic model. We ran series of forecasts with different values of Δt. Their accuracy was measured by computing the r.m.s. differences (in the height and wind fields) from a control forecast run.

The new scheme yields acceptable accuracy with timesteps as long as three hours: the r.m.s. differences are smaller than or comparable to those of the scheme of Temperton and Staniforth (1987) as well as to those of the semi-implicit Eulerian scheme with a much smaller timestep.

A Semi-Implicit Semi-Lagrangian Fully Compressible Model

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The semi-implicit algorithm, originally developed for an efficient integration of the hydrostatic primitive equations, has been generalized to incorporate non-hydrostatic effects present in compressible atmospheres. It will be shown that a fully compressible model can thus be integrated at synoptic scales without any computational penalty over a similar integration of a hydrostatic model. With this important realization, it now seems feasible to develop a unique numerical model for simulating atmospheric phenomena taking place on a wide range of scales.

Un Modèle Colonne des Ondes Internes dans l'Atmosphère

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Une version colonne et linéaire qui a servi de prototype pour l'étude de Tanguay, Robert et Laprise (voir à ce congrès) a été utilisée pour étudier la propagation verticale des ondes internes dans une atmosphère où les inhomogénéités peuvent être importantes. Cette étude produit des résultats intéressants qui peuvent avoir des implications sur les paramétrages du transport de momentum dû au ressac des ondes de relief ("gravity wave drag") dans les modèles de prévision à grande échelle et les modèles de circulation générale.

Recent Progress in the Development of a Variable-Resolution Global Model

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As we go to higher resolution the cost of the spectral method, which has been the workhorse of global forecast models in recent years, becomes less competitive with respect to grid-point or finite-element methods because of the absence of a fast Legendre transform for the spectral

method. Furthermore the development of the semi-Lagrangian technique for advection has given rise to a new way of circumventing the so-called pole problem, which has plagued earlier grid-point models.

We will present the recent progress in the development of a two-time-level semi-Lagrangian model that uses a new unstaggered finite-element formulation for the horizontal discretization of the shallow-water equations in their primitive form. The use of an unstaggered grid allows us to have variable resolution. This model seems well suited for the design of a forecast system where the global (with reduced resolution in the southern hemisphere) and the regional (with highly focused resolution) forecasts would be produced using the same model, but running it in two different configurations.

The uniform resolution version of the model has been integrated successfully to 5 days with a timestep of 2 hours, producing forecasts that surpass the quality standards used in the development of our spectral Eulerian and semi-Lagrangian models.

SEDIMENT CHEMISTRY/CHEMIE DES SEDIMENTS

Modelling pH-Gradients Near O_2-H_2S Interfaces in Sediments

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The concentration of hydrogen ion is a determining variable in establishing the relative extent of the association/dissociation of common weak acids and bases (e.g. H_2CO_3, H_2S, NH_3) and the saturation state of porewaters with respect to carbonate, phosphate and sulfide minerals. The hydrogen ion concentration is itself influenced by the release of protolyic species from organic matter decay and various redox reactions, all of which leads to strong nonlinear couplings between these species. Particularly strong gradients in hydrogen ion (i.e. pH) occur in the vicinity of O_2-H_2S interfaces because of the reaction:

$$H_2S + HS^- + 4\,O_2 \rightarrow 3\,H^+ + 2\,SO_4^{=} \qquad (1)$$

This paper presents a diffusion-reaction (diagenetic) model for the dissolved species system O_2-H_2S-HS^--CO_2-HCO_3^--$CO_3^{=}$-OH^--H^+ that can predict hydrogen ion distributions near oxygen-sulfide intefaces where reaction (1) is the dominant sink for oxygen.

The model is applied to describe the pH data collected in algal mats (i.e. *Beggiatoa* ssp. and *Thiovulum* ssp.) from lagoons in Denmark and the Baja Peninsula, and the model results display remarkable agreement with the observations. The results also show that the calcite saturation state may fall dramatically in such mats, which can significantly influence the preservation of $CaCO_3$ in these sediments.

Evaluating the Utility of Complex Diagenetic Models: The Silica/Opal System as an Example

B.P. Boudreau, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

The past two decades have seen a dramatic rise in the use of mathematical models to answer questions in the fields of sedimentary geochemistry and diagenesis. The increased usage of these models has been matched by a marked increase in their sophistication. While the increased realism that accompanies these more complicated formulations may be laudable, there may be only a marginal increase in the accuracy of the solutions as compared to simpler forms.

As an example, early diagenesis in the coupled dissolved silica-opal system may be explained by one of three possible models of increasing mathematical complexity, i.e. the simple, but unused constant-opal model (abbreviated C.O.), the Schink et al. (1975) model (abbreviated SG&F) for which Wong and Grosch (1978) have supplied an analytical solution (designated as W&G), and

the "improved" but much more sophisticated model proposed by Schink and Guinasso (1980) that must be solved numerically (abbreviated as S&G). Scaling analysis and computational comparisons show that the C.O. model and the SG&F models, as calculated via the W&G solution, are asymptotically valid forms of more complete S&G model for the limits of "large" and "small" opal concentrations, respectively. It is also found that opal diagenesis in bioturbated shelf-like sediments appears to be accurately described by the C.O. model alone. Even in deep-sea-like sediments, the C.O. model, coupled where necessary to the W&G solution, constitutes an attractive alternative to the S&G model because relatively simple analytical methods of solution may be employed rather than advanced numerical techniques.

Contaminant Metal Accumulation in Sediments of Halifax Harbour and Implications for Future Remobilization

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Chemical contaminants have been deposited in the sediments of Halifax Harbour for at least 100 years from untreated sewage outfalls and other waste dumping. The result of this practice has been the accumulation of high concentrations of organic matter and metals such as Cu, Zn, Pb, Hg, Cd, and Cr in the upper 15 to 100 cm of sediment on the sea floor. Because of the high content of organic matter in the surface sediments (mean 4.2% organic carbon with maximum values to 12.5%) there is limited oxygen penetration into the sediment column. Oxygen uptake is more than $200\,\mu g\ O_2 \cdot g^{-1} \cdot h^{-1}$ in surface sediments from the inner harbour. These conditions result in sharp redox gradients within the top 1 cm in some areas. Core profiles show that sulfate reduction occurs within the top 10 cm, with total depletion at 60 cm in some cores. These sediments retain up to 800 ppm Pb, 3.3 ppm Hg and Cd, 700 ppm Zn, 200 ppm Cu, and 120 ppm Cr. According to information from ^{210}Pb dating techniques, the peak flux of Pb, and Hg contamination appears to have been reached in the 1960's. The accumulated reservoir of contaminant metals in the harbour sediments is estimated to be 600 tonnes for Pb, 5 tonnes for Hg, 500 tonnes for Zn, and 200 tonnes for Cu. Some of these contaminants may be remobilized under improved oxygenation conditions that could occur after establishment of sewage treatment facilities for the metropolitan area. Using a physical oceanographic box model and an assumed rate of remobilization of 1% per year from sediments, it has been estimated that concentrations of Pb, Hg, and Cd in the water column could rise by more than an order of magnitude, as compared to present concentrations.

THE CANADIAN WINDII PROGRAM-2
LE PROGRAMME CANADIEN WINDII-2

Derivation of WINDII Geophysical Parameters

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The Upper Atmosphere Research Satellite (UARS) provides near global coverage of both stratospheric and mesospheric regions. WINDII monitors the top side of the UARS altitude range providing temperature and wind between 80 and 300 km. These geophysical parameters are derived from intensity profiles of atmospheric airglow emissions. WINDII is an imaging instrument which views the limb of the atmosphere and provides images with a horizontal resolution of 25 km and a vertical resolution of less than 2 km. A single fringe of the interferogram is scanned for each emission line. From the phase of the fringe the wind speed is obtained and from the visibility of the fringe the temperature is obtained. The algorithms required to derive the wind and temperature data products are described. Results from simulations are also presented.

Monitoring Effects of Auroral Oval Energy Input on Global Wind Patterns with WINDII

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Canadian Space Scientists have developed considerable expertise in evaluating the energy inputs into the auroral oval using ground-based and satellite-borne instrumentation. The WIND Imaging Interferometer on UARS will provide a unique capability for monitoring global wind patterns at auroral altitudes. This will provide an excellent framework for investigating the coupling between the atmosphere and the aurora. Current mesosphere-thermosphere global circulation models require inputs of this type to verify their accuracy.

Validation and Ground Truthing for WINDII/UARS

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As part of the validation process of satellite remotely sensed data, correlative measurements and ground truthing measurements are required. The measurements which will be conducted in Canada as part of the WINDII/UARS project are described. Airglow emission profiles will be compared with rocket experiments and with measurements from other satellite instruments. Temperatures will be compared with LIDAR and Michelson ground based remote sensing measurements. Winds will be compared with meteorological rocket winds from Cold Lake Primrose range. Balloon-borne constituent profiles will be conducted from Saskatoon and Churchill for CLAES, HALOE and other instruments on UARS.

Measurements of Pollution in the Troposphere (MOPITT)

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MOPITT is a candidate instrument for the Earth Observing System Polar Orbiting Platforms to be flown by NASA at the end of this decade and beyond. The objective of the instrument is to measure carbon monoxide (CO) on a global scale with a resolution of about 22 km spatially and 4 km vertically. Measurements of carbon monoxide (CO) concentration in the lower atmosphere have been recognised as being important to our understanding of tropospheric chemistry as CO is involved in many natural and artificial chemical processes including biomass burning and hydroxyl reactions. The instrument is based on a new gas correlation technique known as a Length-Modulated Radiometer (LMR) and operates by sensing the upwelling infra-red radiation from the atmosphere in several wavelength regions. An overall description of the project will be given with specific discussion of the instrumentation and some of the anticipated scientific results.

Chemistry and Dynamics of the Troposphere

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H.-R. Cho, J. Drummond, Department of Physics, University of Toronto, Toronto, Ontario

A joint UT-York group has been funded for a 3-D modelling study of chemistry and dynamics in the troposphere. In addition, there will also be studies of inversion methods to be applied for IR sounding methods. The studies will concentrate on global, regional, and small scale modelling. The talk will outline the status of the current projects and plans for the future.

OCEANOGRAPHY–3/OCEANOGRAPHIE–3

Experiments with a Thermocline Model for the North Pacific

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A three dimensional model has been developed to simulate the circulation of heat and salt in the North Pacific Ocean. Although this model incorporates real bathymetry, real coastlines, and has a high resolution in the vertical, the horizontal resolution is coarse and the model physics have been simplified in order to facilitate data assimilation. A discussion of the model attributes and some experimental results will be presented.

On the Modelling of the North Atlantic Interannual Variability using COADS for the Period 1950–79

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The COADS data (merchant ship) for the period 1950–79 are used to reconstruct the interannual variability of the North Atlantic surface forcing fields. The latter are the available solar heat flux, the net long-wave heat flux, the sensible and latent heat fluxes and the zonal and meridional wind stresses. These forcing fields are used to drive a two-and-a-half layers primitive equation basin scale upper ocean model. We examine the interannual variability of the North Atlantic forcing fields and their impact on the various simulated fields of the model. In addition, the interannual variability of the model is compared to available oceanographic measurements.

The Georges Bank Frontal Study

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A physical oceanographic study of vertical and horizontal exchange processes in the vicinity of a tidal front on the northeastern side of Georges Bank is described. The field component was undertaken during June–October of 1988 with additional current information gathered in July of 1989. Eulerian observations included moored current meters at six sites in 1988 and one site in 1989. In 1989 velocity profiles were obtained from a ship-mounted acoustic Doppler current profiler. Lagrangian currents were measured by the repeated release and recovery of satellite-tracked surface buoys and LORAN-C drifters drogued at 10 m. Hydrographic data were collected from 6 CTD surveys, moored temperature chains, and detailed sections with the towed Batfish. Velocity and temperature microstructure measurements were taken at hourly intervals over the tidal cycle at the six current meter mooring sites. Some results from the field study will be presented. Of particular note was the identification of a tidally-forced internal hydraulic jump at the northern edge of the Bank. Enhanced turbulence levels and vertical mixing were measured within the hydraulic jump. The possible role of the internal waves in cross-bank exchange processes will be discussed.

Parksville Bay – An Investigation of Erosion

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Parksville Bay has an extensive flat foreshore, of very fine sand, which is a very important tourist resource for the City. Over the past few years, the city of Parksville has noticed an apparent erosion of the sandy beach area of Parksville Bay. It was also noticed that offshore bars, composed of gravel and cobble, were forming off the mouth of Parksville Bay.

The city of Parksville brought their concerns to the attention of the Ministry of Crown Lands and Ministry of Environment, and requested an investigation. Subsequent to this request, the

Ministry of Environment's coastal engineer made a presentation to the city of Parksville, describing the natural wave forces and beach processes which can be expected in the Parksville area. Following this presentation, the city of Parksville requested that the Ministry of Environment's coastal engineer carry out a more detailed study of the erosion question.

The study includes available data on geomorphology, ocean water levels and the wind and wave climate in the area off Parksville. The study also includes a description of the coastal processes along this coast and a discussion of some of the changes which have occurred over the last 40 years, with conclusions and recommendations. It was found that the natural sources of beach material for Parksville Bay are still available and that there are no structures on the coast near Parksville that disrupt the coastal processes. It is concluded that any changes, which may have occurred in recent years on the Parksville Bay beach, are probably natural processes, which occur from time to time. It is recommended that a detailed cross-sectional survey of the Parksville beach and foreshore be carried out, and that the City bylaws be amended with appropriate coastal setbacks.

ATMOSPHERIC DYNAMICS–3
DYNAMIQUES ATMOSPHERIQUES–3

A Convenient Vertical Coordinate System for Integrating the Euler Equations

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A novel vertical coordinate transformation has been developed that has some advantages for the numerical integration of a model based on the Euler field equations. Unlike the ubiquitous scaled height coordinate employed in non-hydrostatic models to date, the new "mass coordinate" has the advantage to revert exactly onto pressure when non-hydrostatic effects become negligible. Preliminary results obtained with the application of this coordinate system in a global spectral model of the atmosphere will be reported.

Vertical Wave Propagation in the GFDL "SKYHI" Model

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Both observations and numerical simulations show that the total wave activity flux decays rapidly with height in the middle atmosphere. This suggests that vertically-propagating waves are strongly dissipated in the stratosphere and mesosphere. The complexity of the spectrum of vertically-propagating waves makes a diagnostic determination of how the wave dissipation occurs very difficult, even in a general circulation model. In the present work a monochromatic equatorial Kelvin wave was introduced (via an arbitrary heat source) into the 40-level GFDL "SKYHI" grid point model. A number of experiments have been conducted in which the amplitude and phase speed of the imposed wave have been varied. The details of wave propagation and dissipation can be fairly readily diagnosed for the imposed simple monochromatic wave. The results suggest that a small-amplitude planetary-scale Kelvin wave can be described quite well by conventional linear theory, if the effective mechanical dissipation due to the presence of a broad spectrum of breaking waves is included. The finite-amplitude effects of the imposed wave on the zonal mean flow will also be discussed.

The Distribution of the Time (Till) Surface Contact for a Fluid Element Observed (Released) in the Convective Boundary-Layer

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If an observation is made at height h in the convective boundary-layer it may be of interest to

estimate the distribution of the time (and upstream distance) since the parcels observed last made contact with the surface (e.g., from the point of view of determining the source area contributing to a measured flux); by symmetry this equals the distribution of the time till surface contact for release from a source at h.

We will present analytical solutions for the distribution of time since contact by treating the CBL as consisting of two layers: an outer homogeneous layer with appropriate eddy diffusivity K_o and a surface layer which may be homogeneous (with arbitrary constant K_s) or inhomogeneous with $K_s \propto z$, where z is distance from the surface. It is found (not surprisingly) that the predicted distributions are very sensitive to the assumed eddy diffusivity at the most resistant part of the diffusional pathway, i.e., to the minimum value of K_s. If we pick $K_s = \text{const} = K(2|L|)$ (where $K(2|L|)$ is the "real world" eddy diffusivity at a height of twice the magnitude of the Monin-Obukhov length) we obtain an **underestimate** of the time since contact; even so, for a parcel tagged at $h = 100$ m in a CBL characterised by height $\delta = 2$ km, surface friction velocity $u_{*_o} = 0.3$ m/s, and Monin-Obukhov length $L = -12$ m, we find a 20% probability that the most recent contact with the surface occurred more than two hours ago.

Some Aspects of Eddy-Induced Mean Meridional Circulation in the Atmosphere

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As shown originally by Eliassen (1951), the instantaneous response of the zonal-averaged atmosphere to eddy forcing consists partly of a balanced tendency in the zonal wind and temperature fields, and partly of an eddy-induced mean meridional circulation. However, an effect that has been neglected in all studies from Eliassen onwards is the net meridional mass flux which is associated with a non-vanishing surface-pressure tendency, and which is an integral part of the response in the atmospheric angular momentum to an imposed torque. This "surface-pressure" effect will be elucidated through idealized examples; it turns out to be of major importance for planetary scales of motion.

The mean-flow response to eddy fluxes in a baroclinic life-cycle, calculated using the primitive equations on the sphere, will be described within the context of the above theory. The same picture will also be presented in terms of the "Eliassen-Palm" flux, and an explanation will be offered for Pfeffer's (1987) discovery that the horizontal momentum flux convergence seems, after all, to be a better predictor of zonal-wind acceleration in the troposphere than is the *internal* E-P flux convergence. Implications for transient-eddy parameterization (or "Rossby-wave drag") schemes will be discussed within this framework.

In the steady problem, a very simple constraint exists between the eddy forcing and the so-called "diabatic circulation", the latter being the best approximation to the tracer-bearing, mean Lagrangian circulation. It is argued that the strength of this circulation at any level is controlled by wave-breaking (and associated irreversible eddy fluxes) *above* that level, and that this fact has important diagnostic implications. The transition from the instantaneous response, which is elliptic in character, to the downward-controlled steady state, which is hyperbolic, is investigated through a study of the linearized initial-value problem in a radiatively-damped atmosphere.

Development Equations for Hydrostatic Meteorological Systems of All Scales

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The causes of the development rates of meteorological systems is currently a subject of widespread research, especially explosive development rates. Quasi-geostrophic development equations such as Petterssen's (1956) and Zwack and Okossi's (1986) provide a theoretical basis for understanding and diagnosing development rates having Rossby numbers of the order of 0.1. Unfortunately, observations and model simulations suggest that explosive developing systems are associated with

larger Rossby numbers. Tsou et al. (1987) attempted to diagnose the rapid development of an intense system using an "extended" (higher Rossby number) version of the height tendency equation found in Holton (1979). Their results suggest that the extended set of equations were appropriate for the system and diagnosed development rates of the right size. However, the causes of the intense development could not be directly deduced.

In order to overcome these problems, a development equation (in isobaric coordinates) has been derived that is valid for hydrostatic systems for all Rossby numbers. It combines the standard primitive equations (motion, continuity, hydrostatic, energy, and ideal gas) into one equation and makes use of the fact that the vertical motion goes to zero near the top of the atmosphere. The derivation of this general equation will be presented along with appropriately scaled vesions for various Rossby numbers between 1 and 0.1 which includes development equations corresponding to Krishnamurti's (1968) "balanced omega" equation and Tsou et al.'s (1987) "extended" tendency equation.

MARINE CHEMISTRY–2
CHEMIE OCEANOGRAPHIQUE–2

Dissolved Indium in Seawater – an Analogue for Aluminum and Gallium

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A preliminary look at the marine geochemistry of dissolved indium shows features similar to those found for dissolved aluminum, with a surface maximum and lower concentrations in the deep waters. Dissolved gallium, in contrast, shows low values in the surface waters, a subsurface maximum, and concentrations increasing from a minimum in the intermediate waters to a maximum at depth. Differences in the distributions of indium, gallium and aluminum, in the same column of the periodic table, are indications of the biogeochemical controls on trace elements in seawater. Aluminum and gallium have an eolian surface source, a deep (pore water?) source and rapid removal from the water column via adsorption onto particle surfaces ("scavenging"). The gallium distribution indicates a longer residence time (less particle-reactive), a more involved internal cycle of uptake, regeneration, and re-scavenging in the upper water column – creating a subsurface maximum, and a more pronounced deep water source. The relative reactivity of Al and Ga is proposed to be controlled primarily by the hydrolysis speciation, with the anionic $Ga(OH)4^-$ species being less reactive with anionic particle surfaces than the predominantly neutral Al(OH)3 species (Orians & Bruland, 1988a).

Indium, predicted to exist as the neutral In(OH)3 species, is expected to be more like aluminum in its seawater reactivity than gallium, consistent with the data presented here. In addition, the anomalous subsurface maximum observed for gallium indicates that certain biogeochemical cycles are affecting dissolved gallium which do not have a significant effect on aluminum and indium, above and below gallium in the periodic table. Dissolved gallium may have a greater involvement in biological cycling, due to the similar charge and radius of Fe(III) and Ga(III). Gallium may be inadvertently taken up into soft tissue in the surface waters and regenerated at shallow depth along with iron and other nutrients. Gallium would then be scavenged onto particle surfaces at depth, departing from nutrient-type behavior and returning to the behavior typical of the group three elements, exemplified by Al and In.

Meromictic Lakes in British Columbia

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Powell and Sakinaw lakes are stably stratified ex-fjords, which became isolated from the Strait of Georgia approximately 12,000 years ago by emerged sills due to post-glacial isostatic rebound.

Although both lakes contain highly sulphidic relict seawater (PL 3.0 mM; SL 5.5 mM), they have distinct chemical differences, which may in part be due to SL receiving occasional inputs of seawater over the barely-emerged sill when strong onshore winds are coincident with spring tides. PL, now 50 m above sea level, has not had seawater input since the sill originally emerged. SL has a very sharp chemocline located just below the oxic/anoxic interface, whereas in PL, the interface is spread out over 200 m of the water column. One of the more startling differences between the lakes is seen in their nutrient chemistry. Both lakes tend to serve as nutrient traps as the stratification prevents upward mixing of nutrients released at depth from remineralization of organic matter. Ammonia concentrations are 4 mM and nearly 8 mM in PL and SL respectively. Silicate is also present at very high levels (PL 300 μM, SL 1000 μM). However, although a large amount of dissolved phosphate is released at depth in SL (300 μM), concentrations never get above 0.7 μM in PL, resulting in inorganic dissolved N/P ratios of > 7000, over 400 times that predicted by the Redfield ratio. This is in spite of both lakes having relatively similar particulate organic N/P ratios in the upper oxic waters, which vary from the Redfield ratio by a factor of 8 at the most. Hence, some mechanism for phosphorus removal is present in PL, although geochemical conditions are not conducive to phosphorus mineral precipitation.

Geochemical Behaviour of a Buried Marine Mine Tailings Deposit, Howe Sound, British Columbia

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The Anaconda Mine at Britannia Beach, B.C. operated for 75 years, dumping a tailings slurry enriched in copper, zinc, and lead into the restricted inner basin of nearby Howe Sound. A study began in 1987 to determine the extent of metal contamination still evident in the surface sediments of the sound (despite roughly 15 years of dilution by natural sediments) and the current reactivity of those tailings. Analysis of 150 surface and core samples from throughout the sound show that copper, zinc and lead are still enriched in sediments near the original mine outfall, though metal levels are considerably diluted relative to concentrations found shortly after the mine shut down. With distance from the mine site, metal levels rapidly decrease in surface sediments in both basins, approaching normal background levels for the area. Porewater analysis of two cores was undertaken to determine the redox conditions within the sediments, which in turn can detemine the reactivity, or mobility, of trace metals. The inner basin, which has periodic hypoxia events due to restricted deep water circulation, has a compressed redox profile, becoming anoxic very close to the sediment/seawater inteface. This, plus the absence of dissolved sulphides in porewaters, presumably due to pyrite precipitation suggests that the metals of interest are largely contained within insoluble sulphides, and therefore are effectively prevented from diffusing into the overlying water.

OCEAN ACOUSTICS AND REMOTE SENSING
ACOUSTIQUE OCEANIQUE ET TELEDETECTION

Remote Monitoring of Thermal Structure and Growth of Labrador Shelf Ice

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A prototype Ice Monitoring Platform, designed to measure air temperature and the temperature profile of sea ice and to transmit the data via satellite, was deployed in shore-fast ice along the Labrador coast, giving information on ice thickness and growth through the 1988 ice season (January–May). The rate of release of heat of fusion due to growth of new ice at the lower surface

was found to be nearly equal to the upward conductive heat flux through the ice, indicating that the oceanic heat flux was negligible. Ice growth rates are compared to those predicted by "freezing degree day" formulas.

Assimilation of Satellite Sensed Wave Data into an Operational Wave Model – An Evaluation based on Selected Canadian Atlantic Storms

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With the expected availability of wind and wave data in real time from the European Space Agency ERS-1 satellite scheduled to be launched in late 1990, there is a growing interest in the problem of data assimilation in ocean wave prediction models. The assimilation of wind and wave data in wave models is expected to create more accurate initial sea states, which may lead to improved wave nowcasting and forecasting.

This paper examines the impact of integrating wave data in the specification of the initial wave energy for an operational wave model. The wave model grid covers the northwest Atlantic and is driven by winds produced by the weather prediction model of the Canadian Meteorological Centre (CMC) at Montreal. The integration of wave data is made over two storm periods selected from the Canadian Atlantic Storms Program (CASP) field project conducted from January to March 1986. The hindcast initial wave field is considered to be the first guess field which is then modified using the GEOSAT satellite and buoy wave data and the Cressman successive correction method.

The incorporation of wave data to initialize a spectral ocean wave model provides a definite improvement of the wave forecast, in particular, the nowcast and the "day-one" forecast. The two storms examined in deep waters in the Canadian Atlantic suggest the potential impact of a wave data assimilation system for wave prediction in coastal and deep waters.

The Horizontal Interpolation of Sound Speed using Density Surfaces

K.L. Jones, S.R. Waddell, Department of Phsyics, Royal Roads Military College, Victoria, British Columbia

An interpolation algorithm to determine sound speed from limited CTD measurements has been developed. The algorithm constructs linear density surfaces, using observed CTD data from two or three stations, at various depths throughout the water column. Temperature and salinity are calculated at an intermediate position using linear interpolation along these density surfaces. Sound speed profiles at the intermediate position are then constructed. The interpolated profiles are tested by comparison with measured profiles at the same location. Initial test results indicate that this method produces reliable sound speed profiles for possible use in range dependent propagation studies.

The Sound Field Disturbance Caused by a Mediterranean Salt Lens

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Sub-mesoscale coherent vortices of Mediterranean water called meddies can be found in the main sound channel of the Canary Basin. Their positive temperature and salinity anomalies create a $+16\ \mathrm{m\,s^{-1}}$ sound speed aberration at 30°N. The meddy splits the sound channel into a thermal sound channel and a deeper hydrostatic channel. Examination of historical data reveals that the sound speed anomaly caused by the meddy is never large enough to exceed the limiting sound speed of the background main channel.

The sound field generated by sources at 1000 Hz and 4Hz were examined for seasonal and geometric variation in both non-perturbed (meddy absent), and perturbed environments. The

presence of a meddy had negligible effect on a shallow source in summer and only weak effect in winter. Sound fields generated by sources at 500, 1000 and 2500 m experienced large (up to 12 dB) variations in transmission loss. It was found that the meddy removed energy from the convergence zones and redistributed it into the shadow zones within the SOFAR channel. Strong modal coupling caused by large horizontal sound speed gradients at the meddy edge for frequencies above 6 Hz caused by ray path instability created a complex arrival pattern.

Acoustic Propagation and its Angle-of-Arrival Distribiution in a Turbulent Boundary Layer

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Measurements of acoustic propagation at a frequency of 67.6 kHz have been obtained over a wholly refracted path of length 0.7 km in a shallow tidal channel (Cordova Channel) where the water is actively mixing due to the presence of a bottom boundary layer that has spread throughout the water column. The use of a 2-dimensional transducer array and the availability of a signal-to-noise ratio sufficient to resolve phase ambiguity, permit calculation of both horizontal and vertical components of the angle-of-arrival distribution. The properties of this distribution depend on the soundspeed fluctuations (evident both in the acoustic propagation direction and in the vertical plane), current flow, and the anisotropy of the refractive index variability of the intervening medium.

THE LAGRANGIAN OCEAN–2
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Computerized Radar Tracking of Surface Drifters in Barkley Sound

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The practice of estimating surface circulation through the successive positioning of surface-keyed drifting buoys using standard marine radar is well established. A major practical problem of the technique has been that recording techniques of radar data (either photographic or manual) have required that target position determination and identification take place after the field work has been completed.

To alleviate this problem, an inexpensive and portable system has been designed in which a small marine radar is directly connected to an MS-DOS computer. Software provides automatic digital recording and display or radar data, semi-automatic target identification and tracking, and real-time data processing. The result is a system which simplifies the operation of a surface current measurement study and reduces the post-field phase of data processing to negligible amounts.

The system was successfully tested in Barkley Sound on the west coast of Vancouver Island as part of the Marine Survival of Salmon (MASS) field program in the summer of 1988. Twelve days of useful data were collected in late May and early June from a small vessel at anchor. These data provided a time-dependent picture of surface circulation within a two mile radius of the measurement site and showed that flow through the archipelagos that divide the Sound into three regions was driven more by tide than by wind.

Lagrangian Drifter Tracks in a Wind-Driven Barotropic Model of Queen Charlotte Sound and Hecate Strait

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Knowledge of the exchange processes between the Pacific Ocean and the coastal waters between the Queen Charlotte Islands and the mainland is important for fisheries management and petroleum exploration. A barotropic model of Queen Charlotte Sound and Hecate Strait was developed to provide preliminary information on this exchange. When forced by idealized summer winds, the model simulates many of the features of the summer currents evident in current meter observations. Drifter tracks were computed for two scenarios: a summer storm and a period of relatively light winds. These simulated tracks will be used to determine the placement and expected trajectories of surface drifters during a two-month observation program in the summer of 1990.

Comparison of Modeled and Observed Drifter Trajectories in Western Lake Erie

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The western basin of Lake Erie is a shallow (8 m average depth) semi-enclosed area separated from the main body of the Lake by a chain of islands. A large tributary (Detroit River, average flow 5700 cubic metres per second) flows into the northwestern part of the basin. Because the size of the basin (2900 square km), circulation patterns are sometimes dominated by the hydraulic flow and sometimes dominated by wind-induced currents. The shallow depths in the basin make a measurement program from fixed moorings impractical. Therefore in 1986, three deployments of eight satellite-tracked Lagrangian drifters were carried out to investigate the relative importance of wind-induced versus hydraulically-induced currents and to determine mean flow patterns. Each deployment lasted about two weeks. Drifter trajectories reveal a tendency of the hydraulic flow to cling to the north shore, but on some occassions the flow is more uniformly distributed throughout the basin. Two-dimensional and three-dimensional lake circulation models are used to simulate currents in the western basin during the deployments. A particle trajectory model with a variable windage parameter is used to simulate observed drifter trajectories. Optimal values of the windage parameter for each of the deployments are compared and differences between modeled and observed trajectories are discussed.

Particle Drift in the Surface Layer off Southwest Nova Scotia: Evaluation of a Model

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A two-dimensional, nonlinear barotropic model, driven by quasi-steady wind and M_2 tide, is used to investigate particle dispersion in the surface layer off southwest Nova Scotia. Particle trajectories are influenced by 1) tidal phase at the time of release and 2) the relative strengths of the residual current components driven by mean surface wind stress and by tidal rectification. Low-frequency periodic winds have little effect on the net particle displacements. Comparisons between modelled and observed trajectories of satellite-tracked drogues indicate that the model consistently underestimates the magnitudes of the observed displacements and occasionally gives the wrong direction as well. These discrepancies are probably related to a) unmodelled baroclinic components of the circulation, and/or b) poor model resolution of strong topographic gradients resulting in weak model currents. A sensitivity analysis explores the influence of residual current strength on model displacements.

PUBLIC LECTURE/LECTURE PUBLIQUE

Climate Change: Can the Forest Sector Respond?

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Foresters are caught in a dilemma: they implement plans for our future forests that are quite irreversible, but they must do so amid many uncertainties. Along with a predicted shortfall in timber supply, emerging competition offshore, and a rapidly developing public involvement in decision making, the forester must now cope with the threat of disturbance in the most critical factor of all, climate. At the heart of the issue is the possibility that forest ecosystems, both natural and managed, old and new, will gradually become less adapted to prevailing conditions as climatic regions shift position during the course of a single life cycle of the dominant trees. Some technological solutions will undoubtedly ensue, but the impact of a mismatch between forests and climate will ultimately depend on the resilience in the genetic composition of key species. In worst case senarios, forests will become stressed by soil moisture deficits induced by climate change, and rendered increasingly vulnerable to pests that may in turn be favoured by the same changes. Offsetting such calamitous prospects is the possibility that forest growth will be enhanced by warmer longer seasons and by an assured increase in available carbon dioxide; the latter offers the intriguing potential for improved efficiency in the use of water, even under drought. In the meantime, forests are being perceived as instruments for conserving carbon. The concept of forests as sinks for excess carbon has been promulgated by local residents and international agencies alike. Great care must be exercised in drawing upon the forest resource for this task, for only certain strategies can be effective, and even these must be on a massive scale. There is potential for ineffective action that could seriously compromise options open to forest managers. It is conceivable that forest nations will be called upon in the future to assist in slowing the greenhouse effect. But the ultimate solution must lie in curbing emissions, not absorbing them.

PLENARY-2/SEANCE PLENIERE-2

Macroscale Hydrologic Models

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One of the most important research areas to improve our understanding of the climate changes that might occur from increases in Greenhouse gases in the atmosphere is the hydrologic cycle of the earth. The ICSU/WMO World Climate Research Program is planning a Global Water and Energy Cycle Experiment (GEWEX) to contribute to this research need.

Hydrologic models that would be appropriate to use at the scale of a Global Climate Model (GCM) grid square (e.g. 10^5 km^2) and that could accept atmospheric model data as input are "macroscale" hydrologic models. During the past three decades, hydrologists developed a large number of hydrologic models ranging in sophistication and complexity. Essentially all this work applies to geographical areas smaller than the area represented by a typical GCM grid square, although some basin-scale hydrologic models have been applied to areas as large as 10^4 km^2.

Preparing macroscale hydrological models for GEWEX is a major undertaking that will require a cooperative effort of hydrologists and other geoscientists throughout the world. The challenge is to extend existing knowledge of hydrologic processes, as they occur at a point location and on the scale of small basins or catchments, to the macroscale. Macroscale hydrologic models for GEWEX must be able to exchange information with atmospheric models. Processes that occur at subgrid scale must be accounted for internally in the hydrologic models. Ultimately, it must be possible to apply the model globally. Sufficient data do not exist to calibrate macroscale

hydrologic models in the same way that hydrologists usually calibrate catchment models. Therefore, the required macroscale models must account for the water balance of "ungaged areas", and model parameters must be estimated *a priori* using limited climate, soils and vegetation data.

To help define the work to be done and to stimulate some of the required collaboration, a joint working group on GEWEX was formed by IAHS and WMO. It was agreed at the first meeting of the IAHS/WMO Working Group for GEWEX at Baltimore, U.S.A., 15 May, 1989 that a "Pilot study of large-scale hydrological modelling" be undertaken. This project would support the broad objective of development, validation and use of large-scale hydrological models spanning a hierarchy of scales, possibly coupled with GCM's, and making use of data from space observing systems. The working group established an *ad hoc* steering group to develop a detailed proposal.

A proposal was developed by the steering group and presented to the second meeting of the IAHS/WMO Working Group for GEWEX at St. Moritz, 12 December, 1989. It was proposed the project should draw on the expertise of several national groups already involved in this area. The IAHS/WMO Working Group requested the steering group to identify specific groups and contributions they are prepared to make during the interim period of GEWEX.

At the second planning meeting of the Scientific Steering Group for GEWEX, at Paris, January, 1990, it was agreed to undertake a Continental Scale Hydrological Pilot Study. Because enough historical data should be readily available for the Mississippi River Basin, it was decided to focus the pilot study on that basin. The study is proposed to begin immediately and continue for 5 years.

Several areas of work are needed to prepare macroscale hydrologic models for use in GEWEX. These are:

(i) Develop alternative macroscale hydrologic models.

(ii) Intercompare and evaluate alternative models through large scale hydrologic experiments.

(iii) Assess data requirements.

(iv) Develop data assimilation system and databases.

(v) Estimate model parameters on a global scale.

(vi) Incorporate macroscale hydrologic models in GCM's and evaluate results.

This paper presents a brief description of these areas of work.

Influence of Glacial Melting Rates on Ocean Circulation and Atmospheric Chemistry over the Past 17,000 Years

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Coral reefs drilled offshore Barbados provide the first continuous and detailed record of sea level change during the last deglaciation. The sea level curve is not monotonic; rather, it is marked by two pulses of rapid rise centered at $12,000 \pm 200$ and $9,500 \pm 200$ radiocarbon years before present (BP) which are separated by an interval of relatively slow sea level rise centered at 11,000 yrs. BP. The rates of sea level rise reached levels as high as 40 and 25 millimetres per year during these two pulses.

The oxygen isotopic composition of melting glacial ice is extremely low (approximately $-42‰$ $\delta^{18}O$) compared to sea water. The rapid injection of low $\delta^{18}O$ melt water (primarily into the North Atlantic) can be radiocarbon dated and traced throughout the world's oceans via $\delta^{18}O$ measurements of deep sea cores. The $\delta^{18}O$ spikes are also propagated through the atmosphere via evaporation of North Atlantic surface waters low in $\delta^{18}O$ and can be measured in precipitation records preserved in Greenland ice cores. This natural tracer experiment documents the rapid reorganization of the ocean circulation and the ocean and atmospheric chemistry during the deglaciation. In addition, the $\delta^{18}O$ spikes allow stratigraphic correlation of well dated

deep sea cores and poorly dated ice cores, thereby permitting comparison of atmospheric gas chemistry preserved in Greenland ice cores and deep sea circulation reconstructions.

Varying glacial discharge rates dramatically affected North Atlantic Deep Water (NADW) production. NADW production reached minimum flow during the two melt water pulses, marking two periods when Norwegian ice sheets briefly readvanced to the North Sea. Coincident with the melt water pulse at 12,000 years BP, North Atlantic intermediate water ceased production and was replaced by high pCO_2 Antarctic Intermediate Water which flooded the North Atlantic and possibly other oceans for the first time since the last interglacial period. This interval is coincident with the rapid increase in atmospheric CO_2 measured in the Dye III ice core from south Greenland. These results suggest that efforts to understand the causes of the lower atmospheric CO_2 concentration during the glacial period might be redirected from current emphasis on the polar sink region to studies of the tropical source region.

PLENARY–3/SEANCE PLENIERE–3

Global Sea Level Rise: An Oceanographic Indicator of Global Change

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Modern tide gauge records of secular sea level change are strongly contaminated by the ongoing influence of glacial isostatic adjustment. An accurate high resolution model has been developed that may be employed to filter this signal from the raw data, however, and this has been employed to reduce the time series of monthly mean heights from over 500 tide gauge records from which data are available over time spans longer than 10 years. These records are all contained in the archive of the Permanent Service for Mean Sea Level (PSMSL) at Bidston in the United Kingdom. Prior to removal of the isostatic adjustment contamination from these records the secular sea level signal is seen to exhibit both rising and falling levels depending upon geographic location, with regions of falling level corresponding to those that were ice covered during the last glaciation event of the present ice age. After filtering, the geographic heterogeneity in rates is considerably reduced, so much so that a globally coherent component consisting of a rise of sea level at a rate of $2.4 \pm 0.9 \mathrm{mm\,yr}^{-1}$ is revealed. This could conceivably be driven by the enhanced "greenhouse effect" although no particular mechanism has been unambiguously identified by our analysis. We investigate the impact of a number of different variants of the analysis procedures upon the inferred global signal and find it to be sensitive to such variations.

Recent Advances in Understanding and Prediction of Ocean Storms

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Ocean storms have been the object of much attention since Sanders and Gyakum in 1980 raised the question of the cause of explosive marine cyclogenesis and speculated on the reason for the poor performance of the operational numerical models of that day in predicting storm intensification. In the intervening years a number of field programs have been carried out to study ocean storms: The Storm Transfer and Response Experiment (STREX), the Genesis of Atlantic Lows Experiment (GALE) and its companion project the Canadian Atlantic Storm Program (CASP), the Alaskan and Ocean Storms Programs of NOAA, and the Experiment on Rapid Intensification of Cyclones in the Atlantic (ERICA). At the same time mesoscale regional models have been used increasingly to examine the physical mechanisms involved in notable cases of marine cyclogenesis and to investigate the cause of forecast failures. Ironically, the forecast performance of operation models has vastly improved in the past few years with many spectacular successes now on record. Although this achievement has reduced the urgency of research in rapid cyclogenesis, it has provided an unparalleled opportunity for diagnostic studies aimed at enhanced understanding of cyclone development. This talk will highlight some of the important findings

that have emerged from recent observational and modelling studies.

On the observational side, the main finding is the "T-bone" frontal arrangement and secluded warm core observed by Shapiro in a number of major oceanic cyclones. Although the structure has features in common with those shown in the early Norwegian cyclone model, its genesis does not fit the polar front description well. Rather it conforms remarkably well to recent idealized model simulations of cyclone development by Hoskins and West, Takayabu, Peltier, Moore and Palawarapu, and Schäre. In each case the investigators started the simulations from an initial state characterized by a jet stream with enhanced baroclinity below it but not a thermal discontinuity. It is possible that this finding will lead to a much-needed replacement of the polar front model as the basic cyclone model.

On the numerical modelling side, simulations with real data have shed much light on the nature of rapid cyclogenesis. Sensitivity tests reveal that baroclinity and latent heat release are always major factors in rapid deepening. The role of surface energy fluxes is quite variable, ranging from moderately positive to slightly negative during the 24-h period of most rapid deepening. The surface fluxes, however, sometimes play a crucial role during the early stages of storms that form over or near the Gulf Stream. All cases studied to date involve interaction between upper-level short waves jet streaks and low-level baroclinity in conformity with the Petterssen type B description and the IPV (Isentropic Potential Vorticity) scenario for cyclone development of Hoskins, McIntyre and Roberston. Another recent finding of interest concerns the mechanism of rapid spin-up of low-level vorticity in the intense ocean storms. The mechanism involves strong frontogenesis acting on symmetrically unstable or neutral air in the warm frontal region ahead of the cyclone, associated strong frontal ascent and vortex-tube stretching, and flow of the vorticity-rich air into the storm center.

HYDROLOGY–2/HYDROLOGIE–2

Analysis of Long-Term Riverflow Data in Ontario

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The hydrometric network in Ontario includes approximately 430 active riverflow stations. Of this group 30 have more than 65 years of record. This study involves the review of the data of the long-term stations with regard to trends and patterns.

Trend analysis has been of concern in many hydrotechnical investigations and has become of increased concern due to climate change questions. Trends in hydrologic data series can be of simple or complex composition. The trends may be due to various interventions and/or may be increasing, decreasing, changes in mean value, increases or decreases in variability, or combination of these. Several exploratory data analysis techniques are applied in this study to trends in the selected riverflow series.

Patterns in the data sets may be of various kinds. Several exploratory techniques were applied to review and gain insight to the individual riverflow series and gain an improved measure of the similarity of the series under investigation.

The hydrologic data sets investigated include stations with data beginning as early as 1860. The drainage areas of the stations varies in size from 200 to 700,000 square kilometres.

The parameters investigated include: mean annual flow series, annual maximum-daily flow series, annual maximum-instantaneous flow series and annual minimum-daily flow series. Various parameters could be selected for investigation of trends and patterns. The above four parameters were selected since these provide a characterization of long-term variability regarding average flows (and annual volumes), high flows and low flows.

The study indicates the complexity of riverflow time series over a relatively long period of time and also over a large area such as the Province of Ontario. The study also confirms the value of applying exploratory data techniques in gaining an improved understanding of hydrologic data.

Features of Runoff Index Compared to Monthly Streamflow at Selected Basins

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Runoff as exemplified by the customary precipitation minus evaporation equation is approximated by a moisture-heat balance index.

How well the runoff index can faithfully represent monthly streamflows are presented with our results for selected Canadian basins.

An Assessment of the Record of Precipitation at Ocean Station "Papa" (1953–1981)

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Because of the almost total absence of ground-truth measurements, published charts of the precipitation climatology of the world's oceanic mid-latitudes show widely varying estimates, and nowhere is the disagreement more evident than over the North Pacific Ocean. There have been relatively recent attempts to produce more accurate estimates, e.g. Dorman and Bourke (1979) by statistically relating present weather observations to rate of precipitation. Singularly absent in all investigations to date, however, is the use of a unique (for the high seas) 28-year record of precipitation amount at Ocean Weather Station "P" (50°N 145°W). This paper examines this record's credibility, from the point of view of instrumentation, exposure, data quality control, and consistency with contemporaneous synoptic conditions.

The Use of Hydrographic Partial Duration Frequency Techniques to Identify Flood Generating Climatological Events

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Twenty-six watersheds located on the scarp face of the Manitoba Escarpment are or have been monitored by Water Survey Canada. Each watershed is considered to be "flashy" since it drains an area less than 400 km^2 and responds to flow generating inputs (snowmelt and/or rainfall events) within sixty hours. The daily discharge records (1961–1989) were examined and the annual hydrographs plotted.

At least two peak flow events were identified for each watershed each calendar year. Daily climatic variables and in many cases, the synoptic conditions associated with specific peak flow events were studied.

At least once a year, a peak flow is associated with snowmelt climatic conditions. Occasionally a "rain-on-snow" event generates an enhanced snowmelt freshet. In some instances, peak flows are the direct result of local thunderstorms while in others a sequence of baroclinic disturbances have generated a flood. However, some of the most significant flood events appear to be associated with orographically reinforced frontal storms.

Flood of September 1986 in the Watersheds of Lodge, Battle and Lyons Creeks, Southwest Saskatchewan

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In September, 1986 a strong storm system developed over Montana, generating high winds and heavy rainfall. On September 24 the storm event moved cyclonically in a northwest direction across southwestern Saskatchewan and into eastern Alberta.

Culminating from a combination of factors, including former hurricane Newton and former tropical storm Madeline, the storm deposited up to 175 mm of rain in Saskatchewan during the 48 hour period of September 24–26. Following in the wake of above normal precipitation which fell during the earlier part of September, the storm created extreme flows and considerable flooding in the Milk River tributary drainage basins of Lodge, Battle and Lyons creeks. Structural

damages were limited due to the sparsely populated nature of the region. Storm formation and movement is detailed within this report.

September 1988 precipitation at six climatological stations in the area ranged from 342% to 960% above September values. Frequency analysis on September rainfall yielded storm return periods ranging from 1 in 173 years to 1 in 4800 years.

Data from sixteen hydrometric stations in the immediate area have been analyzed. The time of occurrence of peak flows during the flood event at stations in the area shows that the storm moved up the drainage basins, and that peak flows were predominantly due to localized precipitation rather than the culmination of runoff from the upper reaches. The maximum instantaneous recorded flow in the region was 280 m^3/s (19:00 CST September 25) at station Lodge Creek below McRae Creek at International Boundary (11AB083), which was an increase in flow of 279.95 m^3/s over an eighteen hour period.

Frequency analysis has been conducted using annual maximum instantaneous flows at those stations for which streamflow regulation is negligible. As recorded annual peaks in the area are almost solely the result of meltwater runoff in the spring, the resulting return periods obtained during the analysis represent the likelihood of a similar event occurring at any time of the year, and not the likelihood of a similar occurrence in September. The probability of occurrence of a similar flow ranges from 1 in 1 year to 1 in 200 years at the stations analyzed.

Effect of Land Surface Treatment on GCM Climate Simulations

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The results of seasonal climate simulations using the CCC GCM and two widely differing land surface models are compared and contrasted. The first, or "old" model incorporates the force-restore method for the calculation of ground temperatures and the so-called bucket model for ground hydrology. "CLASS" (Canadian Land Surface Scheme) features a three layer soil model with an explicitly modelled snow cover, an iterative solution for surface temperature and physically-based calculations of heat and moisture transfer between layers. The ensuing differences in global circulation patterns, surface fluxes and heat and moisture budgets are examined.

PALEOCEANOGRAPHY/PALEOCEANOGRAPHIE

Late Quaternary History of Hydrography, Oxygen Depletion and Organic Carbon Accumulation on the Oman Margin

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Measurements of the sedimentary organic carbon, nitrogen, and minor element concentrations are used along with stable isotope records obtained from planktonic and benthic foraminifera to interpret hydrographic history at mid-depth (600 m) on the central Oman Margin (ODP Site 724) over the past half million years. Both *C. wuellerstorfi* data and iodine/Corg ratio information indicate that the oxygen minimum on the margin has been continuously present over the period examined. Glacial-interglacial $\delta^{18}O$ amplitudes recorded by benthic foraminifera are reduced when compared to the estimated mean ocean changes of $\delta^{18}O_{seawater}$. This implies that Red Sea outflow waters (which are enriched in $\delta^{18}O$ and $\delta^{13}C$) were replaced during glacial periods by intermediate waters still enriched in $\delta^{13}C$ but relatively depleted in $\delta^{18}O$. Glacial-interglacial amplitudes of the planktonic $\delta^{18}O$ record exceed those of the mean ocean $\delta^{18}O$ variation and imply decreased surface water temperatures at this site during glacial times. This might reflect the influence of colder outflow winds from the Tibetan Plateau during these periods, or increased upwelling. These alternatives will be assessed in view of the organic carbon and nitrogen data.

Deglacial Ocean CO_2-Outgassing: Does it Limit High-Resolution ^{14}C-AMS Dating of the Last Glacial-Interglacial Transition?

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The use of tandem accelerator mass-spectrometry for radiocarbon determination has greatly improved our ability to obtain accurate age data from micro-quantities of foraminiferal carbonate samples. Paired ^{14}C determinations on samples of coexisting planktonic and benthonic foraminifera, for instance, have shown that deep waters in the North Atlantic and Pacific oceans were older at the Last Glacial Maximum by respectively 200 and 500 years relative to modern deep-water ages. These increased glacial-maximum ages are believed to document reduced rates of deep-sea ventilation which have resulted in longer residence times of the deep-waters. As revealed by ice core CO_2 records obtained from polar ice caps and Tibetan mountain glaciers, about 70 p.p.m.v. of CO_2 were injected into the atmosphere at the end of the last glacial period. As most of the carbon available to drive these changes lies in the ocean, this process has conceivably spiked the atmosphere with "old" CO_2 which has previously been stored in the deep ocean. Re-equilibrium of this old CO_2 with the ocean waters has the potential to alter the $^{14}C/^{12}C$ inventory of the ocean and thus to shift foraminiferal ^{14}C ages towards fictitiously older ages. This would artificially steepen the age-depth relationship within sediment cores and hence mimic fluctuations of the rate of climatic change which in reality did not occur. We compare continuous planktic ^{14}C-AMS profiles from three sediment cores with the glacial-interglacial CO_2 record obtained from the Antarctic Vostok ice core. The data show periods of increased foraminiferal ^{14}C exist in the marine record which correlate with the deglacial ocean CO_2 outburst recorded in the Vostok ice core profile. Depending on the rate of CO_2 release from the ocean to the atmosphere and on the rate of air-sea re-equilibrium, the age-equivalent of the low-$^{14}C/^{12}C$ CO_2-overshoot could have been up to 700–800 years.

New Paleoclimate Indicators in Reef-Building Corals

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Trace element distributions in corals from the Equatorial Pacific Ocean and Caribbean Sea reveal temporal variability associated with diverse climatological phenomena. Near the Galapagos Islands, seasonal and interannual changes in Cd/Ca and Mn/Ca ratios are caused by upwelling and vertical displacement of the thermocline associated with El Niño. A sixty-year calibration of these proxy indices against intrumental records has been completed.

In the western Equatorial Pacific, hydrographic changes in the upper ocean are generally too subtle to cause variations in dissolved metals. Curiously, however, Mn/Ca ratios measured in a coral from Tarawa Atoll (1°N, 173°E) are highly perturbed during three El Niño–Southern Oscillation events (1965, 1972, 1976) which occurred within the lifespan of the coral (1960–1977). These Mn enrichments coincide with the appearance of westerly wind anomalies at Tarawa which frequently signal the onset of ENSO. Particularly strong wind anomalies (5–10 m/sec) during the above years (Harrison, 1987) may have generated wind waves of sufficient strength to create an aura of diagenetically remobilized Mn from within the shallow westward facing lagoon of Tarawa.

At Barbados in the Caribbean Sea, seasonal cycling of Cd, Cu, Fe, and Ba in a 15-yr coral section are neither associated with upwelling nor wind-induced resuspension. The cause of the observed variation is likely to be long-range surface advection of Amazon, and to a lesser extent, Orinoco River discharge. Inputs of metals via Saharan dust fluxes are probably small in comparison, but increased transport during Sahelian droughts may be superimposed in the coral record.

Sedimentary Geochemistry of the Late Pleistocene and Holocene Sediments of the Black Sea

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The geochemical record of changing oceanographic conditions during the late Pleistocene and Holocene evolution of the Black Sea has been examined with a new suite of box and gravity cores collected in 1988. High resolution records have been obtained through the modern facies (laminated coccolith marls), the sapropel (organic-rich mud) and the upper part of the Pleistocene lake sediments (laminated calcareous muds).

The surface sediments in the deep basin of the Black Sea have organic carbon contents of around 10%, decreasing to around 6% below 5 cm depth. They have chemical compositions consistent with accumulation under fully anoxic conditions (high Mo, low I and Mn). The sapropel unit has much higher concentrations of C, I, Mn, Mo, Ni and V, indicating an exceptionally high organic matter flux in an oxygenated basin. The base of the sapropel in each core examined contains a turbidite; this may signify a major basin-wide disturbance which was followed by a period of enhanced primary production caused by the overturn of the deep waters.

The sediments below the sapropel unit were deposited under fully oxygenated conditions when glacially-lowered sea level isolated the Black Sea basin from the Mediterranean. They contain significant amounts of authigenic calcite occurring as < 1–10 μm euhedral rhombs. These were produced during seasonal CO_2 depletion in a stratified lake which led to inorganic carbonate precipitation in the epilimnion.

The complex stratigraphy of the sediments of the Black Sea provides an unusual opportunity to unravel the geochemical and mineralogical indices of sediment accumulation under marine oxic and anoxic conditions, variable organic matter supplies, and low salinity or freshwater conditions.

OCEANOGRAPHY–4/OCEANOGRAPHIE–4

Some Peculiarties of Tsunami Recurrence in the Northwest Pacific

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The occurrence of historical tsunamis in space and time for the northwestern Pacific was investigated using the data, published in the well known catalogues by S.L. Soloviev and Ch.N. Go (1974, 1978, 1986). The recurrence function for the largest tsunamigenic earthquakes deviates noticeably from the Poisson distribution. An auto-oscillating regime with dominant periods of about 5.5 and 30 years and relaxation is exposed in the space and time interval under study. An attempt was undertaken to reveal the possible relations of these peculiarities with manifestation of other know geophysical phenomena, such as solar activity, climate fluctuations and Earth rotation disturbances.

Investigation of Infragravity Waves on the Southwestern Shelf of Kamchatka

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During the 1987–1990 years several experiments on long wave observations were made on the southwestern shelf of Kamchatka (Okhotsk Sea). Two cable stations were installed there in 1987 and three more in 1988. Microfluctuations of atmospheric pressure were recorded simultaneously.

The data of these stations were used to investigate ocean and atmospheric waves with frequencies 0.5–0.02 cpm. It was discovered that: 1) atmospheric spectra are very stable and monotonic in this frequency range and correspond to the power law $\omega^{-2.3}$; 2) direct influence of atmospheric pressure on the generation of ocean waves is mostly negligible but there is definite correlation between these waves and sea surface activity (wind waves and swell); 3) a structure of wave field offshore (maxima and minima of spectra) is in good agreement with theoretical estimates of standing waves for a linear sloping shelf.

Tidal Modulation of Deep Water Replacement in the Strait of Georgia

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Observations of currents, salinity and temperature at an array of moorings in the central Strait of Georgia show strong monthly and semi-monthly flow pulses and pronounced changes in scalar properties near the bottom during summer months. The timing of the pulses is closely correlated with periods of neap tides and minimum tidal currents in Boundary Passage. Calculations of travel time are consistent with flow pulses originating in Boundary Passage; reasonable mixing ratios of Juan de Fuca water and Strait of Georgia surface water yield observed water properties in the pulses. The fortnightly pulsations in deep currents in the Strait of Georgia are postulated to occur because of weak mixing conditions in a manner similar and simultaneous to the modulation of fresh water export at the surface towards Juan de Fuca Strait.

Propagation of Coastal Trapped Waves under an Ice Cover in Hudson Bay

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Since the beginning of the sixties, coastal trapped waves have been one of the most popular subjects in physical oceanography. Initially, we discuss their characteristics in southeast Hudson Bay, using the Brink and Chapman model. Then we compare the normal modes obtained with current observations made in Kuujjuarapik (Hudson Bay) in 1986 using Freeland techniques. This area is difficult to model because of rapid changes of stratification in the water column during the ice break-up period. The best fit was found for two topographic waves both having a period of three days with phase speeds of 70 cm/s and 13 cm/s. In this work it has been shown that the response function of the system due to atmospheric pressure gradients has a maximum at a period corresponding to the period of the topographic waves.

Coastal Upwelling off the West Coast of Vancouver Island

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Wind-driven upwelling events near the Brooks Peninsula off the west coast of Vancouver Island have been identified during the summers of 1988 and 1989 from sea surface NOAA AVHRR thermal imagery obtained at the U.B.C. Laboratory for Satellite Oceanography. Software has been developed to characterize the strength and extent of the surface cooling associated with upwelling. A two-dimensional 2-layer finite difference model with 1 km resolution has been formulated to examine the small-scale dynamics of the upwelling events. The model uses local wind and includes realistic coastline and bathymetry. The results of the model are compared to the observed sea surface temperature field.

Seiches in the Kuril Bays: Numerical Calculation by RT-Algorithm and Observations

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A new method of seiche calculation is suggested. This method is based on numerical conformal mapping of the complicated region onto a simpler one by means of the RT-algorithm and following the use of Ritz's procedure. It was tested for some relatively simple regions and showed its high effectiveness both for nonrotational and rotational cases. The method was used to compute eigenmodes in some bays of the South Kuril Islands. The theoretical results agreed quite well with observational data and enable us to explain some peculiarities of spectra of tide gage records in the region under study.

FISHERIES OCEANOGRAPHY–5
OCEANOGRAPHIE DE LA PECHE–5

The Intertidal: Physical and Biological Influences on Species Composition, Abundance and Recruitment Patterns

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The intertidal environment is unique in that it is exposed to both meteorological and oceanographic climate events, with typically wide temperature and salinity fluctuations over relatively short time durations. Intertidal species high in the subtidal have to primarily cope with terrestrial competitors or predators while those low in the subtidal have to primarily cope with marine examples. This interaction of the physical and biological environment has tended to result in marine species which either move in and out of this zone with the tides or if sedentary, have a hard, sealable exoskeleton or burying behaviour to allow them to avoid both predation and adverse physical conditions. Nevertheless, a pronounced zonation of species occurs and because of the relatively short geographic distances involved, this marine environment is likely to be the first obviously impacted by any pronounced pattern of climatic change. Physical and biological events and their probable consequences on the distribution and recruitment of commercial species inhabiting the intertidal are discussed, with consideration of the magnitude of change and data time series required to produce statistically significant effects.

A Possible Eddy Retention Mechanism for Ichthyoplankton in Hecate Strait

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The cause of the high rate of production of groundfish in Hecate Strait is uncertain. It is likely that the large, shallow areas of the Strait contribute to the high productivity because of their suitability as juvenile habitat, but, in winter when many groundfish species spawn, a strong current which flows northward through the Strait into Dixon Entrance likely carries many of the larvae out of the Strait. A recent study shows that the recruitment rate of Pacific cod varies inversely with this current, which is to be expected if the larvae are swept out of the Strait by the flow. We examine current and wind data from a variety of field programs in Hecate Strait, and find evidence for a return flow toward the southwest in Hecate Strait, counter to the wind-driven transport. This return flow is driven by the setup of sea level along the Strait by the wind, and its strength increases with the intensity of southeast storm winds. We believe this return flow will recirculate a significant fraction of the larvae in the Strait, increasing their residence time sufficiently to allow settling out, and thereby enhance recruitment to populations of these species occurring in the Strait.

The Distribution of Commercial Troll Fishing Vessels off Southwest Vancouver Island in Relation to Fishing Success and Oceanic Water Properties and Circulation

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Radar-derived distribution patterns of salmon troll fishing vessels off southwestern British Columbia have been obtained for April to September 1982 and 1983 and for July 1988. Vessel distributions are related to capture success in the fishery and to persistent features in the water property structure and circulation on the continental shelf. Especially dense concentrations of vessels occurs in regions of locally intensified upwelling associated with: (1) topographically-induced rectification of tidal flow at the margins of shallow fishing banks; (2) a mesoscale quasi-permanent cyclonic eddy off Juan de Fuca Strait; and (3) the transition zone between the poleward flowing Vancouver Island Coastal Current and the equatorward flowing shelf-break current. The aggregation of fishing vessels illustrates a response of the salmon to local features of their environment. This response is probably mediated through the food supply with food organisms aggregating in the vicinity of local upwelling.

Climate, Predators and Prey: Behaviour of a Linked Oscillating System

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Over the last 50 years the dominant oscillations in ocean climate in southern British Columbia have occurred on average at periods of 5 and 10 yrs. This pattern tends to be caused by moderate to strong El Niño-Southen Oscillation (ENSO) episodes originating in the equatorial Pacific. Ten time series were analysed to identify a model of Pacific herring growth and recruitment. The results indicate that herring growth rates are forced primarily by variations in oceanic conditions (and presumably the associated zooplankton biomass) at the ENSO period of 5 yrs, and by interannual variations in herring year-class size. The resulting changes in herring size-at-age cause measurable changes in stock biomass and egg production, and possibly a weak recruitment oscillation. Most of the variation in herring recruitment can be linked to changes in predator (Pacific hake) abundance, zooplankton biomass, and the particular pattern of moderate and strong ENSO events that have occurred since the late 1930s. This paper is being published in the proceedings of the "Long-term variability of pelagic fish populations and their environment" symposium.

Analyzing Correlations between Marine Survival Trends in Northeast Pacific Salmon Stocks and Environmental Variables

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Time series of survivals of Washington and Oregon coho salmon stocks and Columbia River spring chinook stocks show substantial variations over the last 25 yrs. Time series of environmental variables that may influence these survivals were assembled and utilized as independent variables in univariate and multivariate time series analysis. These variables included meteorological (Northeast Pacific Index and Pacific Northwest Index), oceanographic (Bakun Upwelling Index, sea surface temperature, and spring transition date) and lotic (river flow in the Columbia River Estuary) series measured during the year of smolt outmigration. Our results are discussed in terms of the relevant spatial and temporal scales of oceanographic variation which affect salmon survival.

Seasonal Variation in Experimentally Derived Grazing Rates of the Marine Copepods, *Calanus pacificus* and *Metridia pacifica*

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Superimposed on the diurnal variation in grazing rates of herbivorous marine copepods is a strong seasonal component which has not previously been described. In order to understand the cumulative effects of *in situ* grazing by the dominant hebivorous copepods in Saanich Inlet on a seasonal cycle, the *in vitro* grazing rates were experimentally derived once a month for a year using the gut fluorescence method. Gut pigment concentrations were measured for animals feeding at a constant temperature and food concentration. For both species, maximum *in vitro* grazing rates occurred in April and July. *Calanus pacificus* did not feed in experimental aquaria from December to March, while *Metridia pacifica* maintained a reduced grazing rate during this time period. Weight specific grazing rates were always significantly higher in *Metridia* compared to *Calanus*. The higher rate suggests that *Metridia* is able to utilize periods of low food availability more effectively than *Calanus*.

ATMOSPHERIC VARIABILITY–1
VARIABILITE ATMOSPHERIQUE–1

Climate Change due to Increased CO_2 Simulated with the CCC GCM

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In this experiment a three-dimensional atmospheric general circulation model coupled to a "slab" ocean and a thermodynamic sea-ice model is used. The climate equilibrium of the system consistent with twice the current amount of atmospheric CO_2 (the $2\times CO_2$ case) is compared with the current climate (the $1\times CO_2$ case).

Because of the long integration times required, rather low resolutions have heretofore been used for this experiment. Grid sizes ranging from 8×10 degrees to 4×5 degrees in latitude and longitude and vertical resolutions from 2 to 11 levels have been used. Although not "high" by forecast model standards, the current experiment is carried out with a T32L10 model, i.e. with 10 levels in the vertical and a transform grid of 3.75×3.75 degrees.

Additional features of the CCC model are: (1) a full diurnal and annual cycle, (2) ocean and ice treatment involving specification of ocean transports so as to permit a good simulation of $1\times CO_2$ ocean temperatures and ice boundaries, (3) a modified treatment of land surface processes and hydrology which attempts to be more sophisticated than the usual "bucket" treatment, (4) a parameterization of cloud optical properties feedbacks and (5) the retention of special application data sets containing surface parameters for North America and Europe.

After describing some of the features of the model and its $1\times CO_2$ climate, the simulated change in climate due to a doubling of CO_2 including aspects of the hydrological cycle will be discussed.

A Skeptical Look at the Recently-Proposed Sun-QBO-Weather Connection

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The search for clear indications of solar cycle effects on the terrestrial lower atmosphere has been a long and frustrating endeavour. Recently H. van Loon and K. Labitzke (vLL) have adopted a novel approach that has produced surprising results. vLL stratified various seasonal mean meteorological variables by the phase of the quasi-biennial oscillation (QBO) of the tropical

stratosphere, and then computed correlations with an index of solar activity. In many instances, they find apparently significant correlations when only years with westerly QBO phase are considered. In other cases the significant results are obtained only for easterly QBO phases.

vLL's analysis is restricted to the period since about 1952 when regular direct stratospheric wind observations are available to determine the phase of the QBO. The present work tried to see whether earlier meteorological and solar activity data could be reconciled with vLL's results. The approach adopted was to generate over 25 million plausible series of QBO phases for two 40-year periods, 1875–1914 and 1897–1936. vLL's analysis was repeated for each of the 25 million possibilities. It was found to be impossible to find even a single plausible QBO series that allowed vLL's "modern" results to be reproduced in the older data. Thus one is forced to conclude that either vLL's correlations are not a stable feature of the atmospheric data, or the QBO itself must have behaved very differently in the 1875–1936 period than in the modern era.

Observed and Simulated Intraseasonal Energetics

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The observed intraseasonal rotational and divergent kinetic energy budgets in terms of the two-dimensional wavenumber are computed based on five years of ECMWF/WMO operational analyses.

Corresponding calculations are presented based on a five-year integration of the Canadian Climate Centre General Circulation Model.

Effect of Annual Variation in Growing Season Rainfall on Tree Growth on the East Coast of Vancouver Island

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Plant moisture stress limits tree growth during the summer on the east coast of Vancouver Island. The reduction in water availability results from the low summer rainfall, and, in some areas, shallow soil. Year-to-year variations and within year variations in growing season rainfall are large. Summer water balances for the period 1951 to 1985 for a site near Cowichan Lake, and for 1959 to 1985 for a site near Courtenay will be presented. Four patterns of summer water depletion can be identified. There is a high correlation between annual water deficit and tree growth. This information is used to assess how forest productivity may change with changes in climate.

A Comparison of the Meteorolgical Conditions during the Drought of the 1930's and the 1980's for the Prairie Provinces

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Lower rainfalls and higher than normal temperatures across the prairie provinces in the spring of 1988 caused considerable problems for the agricultural community and water resource managers. The dry hot spring of 1988, however, was not an isolated drought incident but rather the continuation of a series of very dry years which resulted in a significant tax on water resources for the Prairies. The 1980's have rivaled the 1930's for lack of precipitation but the 1980's have been much warmer especially in the last three years 1986–88 than the 1930's. Evaporation was greater in the 1980's especially in 1988 when most stations in Saskatchewan reported the hottest June on record.

FISHERIES OCEANOGRAPHY–6
OCEANOGRAPHIE DE LA PECHE–6

The Effect of Turbulence of Chemosensory Perception using the Low Reynolds Number Feeding Current of Calanoid Copepods

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The active space is the zone around an alga where chemical exudates are sufficiently concentrated and regularly distributed, to promote an effective behavioral response in a grazing zooplankton. We find that interaction of molecular diffusion with turbulence in the viscous-diffusive subrange is important for defining the dimension of the undeformed active space. Simple dimensional arguments are then used to show the following. (a) An alga that is entrained into the centre (or slightly off centre) of a copepod feeding current will have its active zone elongated by an order of magnitude in the direction of the flow. (b) For weak turbulence the dimension of the undeformed active zone is comparable to the lateral dimension of the feeding current. (c) For strong turbulence the dimension of the active zone is an order of magnitude less than the lateral dimension of the feeding current, and an alga entrained at the edge of the feeding current will have its active zone deformed equally by the feeding current and turbulence.

We also propose that a copepod might use chemosensory perception to track down prey, in much the same manner a dog might. This is made possible by the speed of feeding currents compared to the slow distortion of the exudate cloud by Kolmogorov scale eddies.

Population Genetics and Spatial Heterogeneity in the North Pacific Krill *Euphausia pacifica*: A Preliminary Report

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An electrophoretic study of the planktonic crustacean *E. pacifica* using five enzyme-specific stains to visualize the gene products of seven loci detected no statistically significant differentiation among the five sites sampled in the coastal waters of British Columbia, Canada. Euphausiids from the Coastal Shelf of Vancouver Island had the same types and frequencies of electrophoretic protein polymorphism as those taken from fjords in the semi-enclosed Strait of Georgia region. The results suggest extensive gene flow occurs between subpopulations of euphausiids in the straits and inlets surrounding Vancouver Island and the lower B.C. mainland. *E. pacifica* appears able to exploit the local movement of water masses for transportation from one favourable habitat to another; anecdotal evidence, however, suggests migration rates are insufficient to allow immediate recovery of over-exploited subpopulations (as has been observed in Jervis Inlet). This study demonstrates the necessity for synoptic biomass surveys to correlate migratory patterns with the dynamics of secondary production in euphausiid subpopulations.

Seasonal Variation in the Carotenoid Pigment Content and Composition in *Euphausia pacifica*

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The carotenoid pigment content and composition of *Euphausia pacifica*, a preferential herbivore, was determined at monthly intervals from March, 1988 to May, 1989 to determine whether or not season and/or sexual maturity affected the carotenoid content and composition. The total weight specific carotenoid content varied from 306–536 μg/g dry weight over the 15 month period. The maximum occurred in February and March, just prior to sexual maturity and spawning, and the minimum occurred in October, 1988. The weight specific carotenoid content remained relatively constant throughout the summer and early fall (June–November, 1988) and

then increased over the winter as the average dry weight of the euphausiid population decreased. The data suggested that *E. pacifica* utilized energy stores such as lipid and protein preferentially to carotenoid pigments during times when the food supply was limited. *E. pacifica* also appeared to accumulate carotenoid pigments on an individual basis during early spring (February–April, 1989) in preparation for spawning. Results from two-dimensional silica TLC and RP-HPLC suggest that 90% of the carotenoid pigments present in *E. pacifica* consit of astaxanthin, its mono- and diesters each contributing 5, 49. and 40%. The astaxanthin molecules appear to be esterified to only two different fatty acids: the combinations producing two monoesters and three diesters. The relative contribution of all the carotenoid fractions isolated from *E. pacifica* remained remarkably constant throughout the study period suggesting functional importance.

Interannual Variability of Oceanographic Conditions and Spatial Distributions of Dungeness Crab (*Cancer magister*) in the Pacific Northwest

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Spatial distributions of Dungeness crab megalopae are compared with temporal and spatial patterns of large-scale wind forcing and satellite measured patterns of near-surface chlorophyll to characterize the interannual variability of megalopal distributions and oceanographic conditions. Megalopae concentrations are determined from neuston and bongo samples collected by the cooperative U.S./U.S.S.R. ichthyoplankton surveys off Washington, Oregon and Northern California. The data are from 5 cruises in the springs of 1981, 1982, 1983, and 1985, a time series which includes the major El Niño of 1983 and its associated large oceanographic anomalies. Crab abundance data are corrected for vertical migratory behavior using time of day and cloud cover. Total observed crab larvae in each year is strongly inversely related to the Julian sampling date within the year, reflecting a constant larval mortality rate, independent of year. This regression is used to correct data within each cruise for presumed mortality to approximate synoptic samples. The resulting patterns are compared to local surface conditions from cruise data (temperature, salinity, dissolved oxygen) and satellite measured near-surface chlorophyll patterns. These patterns are related to wind forcing calculated from the Fleet Numerical Oceanographic Center (FNOC) wind product and derived Ekman transport. The results are discussed in terms of upwelling, offshore transport, wind mixing, and larval food availability.

Oceanographic Factors Affecting the Catchability of Pacific Ocean Perch (*Sebastes alutus*)

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Fish and their movement patterns are greatly influenced by the surrounding physical environment. It follows that their catchability (availability to the fishery) depends upon the characteristics of the water and bathymetry over which one is fishing. This study investigated the ability to define Pacific Ocean Perch (*Sebastes alutus*) habitat and assess catchability using physical oceanographic variables. Pacific Ocean Perch were found to prefer a temperature range from 6.7 to at least 4.8°C and their movement patterns were linked to the movement of these temperatures by coastal scale upwelling processes. The fish concentrate at predictably higher quantities at the lower temperatures. Pacific Ocean Perch prefer areas with steep, rocky bathymetry and these areas may give rise to frontal activities due to interactions between the local bathymetry and currents. Therefore Pacific Ocean Perch habitat is definable using temperature and bathymetry preferences and their catchability can be linked to these physical oceanographic variables.

HYDROLOGY-3/HYDROLOGIE-3

Interannual Variability of Precipitation in Western Canada

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The interannual variability of precipitation for the period from 1921 to 1985 inclusive is examined for stations in western Canada using accumulated surplus/deficit curves. The results indicate that trends over large areas are quite similar although several significant discontinuities exist. One discontinuity appears to be associated with the eastern slopes of the Rocky Mountains. The nature and possible causes of these discontinuities and their implications for spatial variations in precipitation trends are discussed.

Rescaled range analysis, Hurst coefficients and cross-correlations are used to examine possible non-random fluctuations in the time series of annual precipitation amounts. The timing of broad-scale reversals in precipitation trends are also examined. Below average precipitation across the prairies occurred during the late 1930's and 1940's while a shift to higher precipitation amounts occurred in the early 1950's. The implications of these findings for the predictability of annual precipitation amounts and trends are discussed.

Analysis of Selected Hydrometeorological Time Series

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Practical analyses of hydrometeorological time series, for example to aid in the design of reservoirs for hydroelectric power generation, have generally assumed stationarity. Similarly, climatologists have related their analyses to 30-year climate 'normals'. The most obvious exception to this general assumption has occurred when the effects of man on a watershed are so large as to force attention; for example, the various diversions into and out of the Great Lakes.

Recently, attention has concentrated on a much larger scale anthropogenic effect, the green-house warming and it's anticipated change in climate and, hence, in water resources. Projections have forecast decreases in runoff of up to 50% resulting from increases of 1°C in temperature. It is obviously important to know if such a climatic change is occurring.

If the induced changes are so large, then, by detecting the resultant trends in runoff time series, it should be possible to work backwards and identify the causative climatic change. This paper looks at long-term runoff records across Canada as well as some of the associated climatic records and analyses them for such trends.

Comparison and Analysis of Differences between the Conceptual and Distributed Rainfall-Runoff Models

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Conceptual rainfall-runoff modelling has a long history, and several models have been developed in different countries. Initially, the whole catchment was handled as a unit; later, the models were able to define different sub-basins and elevation zones (for example TANK, HBV, UBC models). Now with satellite data being available on a more regular basis, there is a demand to include those data among the inputs of rainfall-runoff models. In Canada, INRS-Eau is developing the HYDROTEL distributed rainfall-runoff model, one capable of using spatially distributed inputs, including remotely sensed data. This work has been supported by the Government of Canada as an unsolicited proposal. The authors of this paper have been involved in the testing of the model and its application to the Upper Grand River Basin in Southern Ontario. The Swedish HBV

model (Bergström, 1976) was chosen as the conceptual model for the purpose of comparison; it is used operationally in many countries in northern Europe and mid South America. The study area is the same in order to be able to compare the results from the point of view of data requirements and outputs. The question which must eventually be addressed is what are the benefits of acquiring and including remotely sensed data for running the distributed model on a daily basis? Do the additional data inputs of the distributed model automatically result in a higher accuracy?

This paper will provide an initial comparison of the performance of the two models for selected periods. It will compare the differences in the model structure and in the required inputs. For example, the distributed model takes into consideration the precipitation for each square, and also uses image data for the determination of the land use classes. In the case of the HBV model, it is possible to define more sub-basins and different elevation zones. Calibration of the unknown parameters was done primarily using manual methods because of the large number of parameters. The time-lag of both models is one day. Comparison of the model output (runoff) will be carried out in two different ways: by the use of standard statistical tools (efficiency coefficient, accumulated difference of volume) and by the comparison of the main characteristics of the peaks (time of peak, peak volume). This assessment will provide insight into required model development for Canadian conditions.

Determining the Regional Hydrologic Response to Global Climate Change: The Case of British Columbia

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The contemporary view of the Earth's climate as variable on timescales significant to human economic development has prompted numerous studies which seek to estimate the possible impacts of climate change on biophysical and socioeconomic systems. A number of such studies incorporate the results from global numerical models in an attempt to provide a linkage between the global-scale estimates of climate change and the regional impacts.

The appropriateness of such an approach is explored by considering the classic 'GCM' approach to determining the hydrological response to an alteration in boundary conditions, i.e. a change in atmospheric CO_2 content. The results of the GCM study are contrasted with the methodology appropriate for studying the inherently regional nature of the climate impacts on streamflow (and thus water resources). The contrast is illustrated by considering recent changes in the hydrological regime of streams in British Columbia. An intermediate linkage between the GCM scale and the regional scale is the use of a regional climate model. Some preliminary results are presented of an integration of such a regional model with focus on the surface hydrological component.

OCEANOGRAPHY-5/OCEANOGRAPHIE-5

Tide Removal from Ship-Mounted Acoustic Doppler Measurements

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Tidal currents predicted by i) a barotropic finite element model of the southwest coast of Vancouver Island, and ii) an enhanced model that has been adjusted in accordance with previous current meter observations, are removed from ship-mounted acoustic Doppler measurements. The resultant residual currents are compared with geopotential fields and clearly show the Juan de Fuca Eddy.

Comparison of a Numerical Model of Burrard Inlet and Indian Arm to Observations of Salinity and Velocity

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A laterally-integrated, two-dimensional, time-dependent numerical model of the tidally forced circulation in Burrard Inlet and Indian Arm is compared to time series of velocity and salinity obtained from cyclesonde moorings. The data were collected over two winters, 1983–84 and 1984–85, and include one episode (during 1984–85) of deep water renewal. Analysis includes harmonic analysis of the simulated and measured velocity and salinity time series, concentrating on the K_1 and M_2 tides. The simulated and measured residual currents are also compared. The simulations show that fresh-water input has a significant influence on the stratification of the inlet, even at depth. Preliminary indications are that the model predicts the K_1 tide better than the M_2 tide. Agreement between the model and data was better during periods when deep water renewal was not occurring. The model tends to overestimate the intensity during renewal events.

Seasonal Variability of Ocean Features at the Entrance to Juan de Fuca Strait

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Data from 38 CTD surveys at the entrance to Juan de Fuca Strait (48°N–49°N, 124°30′W–127°00′W) from 1984 to 1989, inclusive, were mapped using objective analysis techniques and analyzed. The data were combined seasonally to produce averaged objective analysis plots and the variances were calculated to give indications of seasonal and interannual variability. The averaged distributions retain the features observed in individual cruise plots and documented in previous studies (Freeland and Denman, 1984). The winter regime is dominated in the surface layer by the northward flowing coastal current and is relatively featureless below the mixed layer. The spring transition is marked by a "confused" deep layer, as flow on the shelf break reverses to flow southward. The summer regime is dominated by the Juan de Fuca eddy along with a frontal feature to the north and indications of a smaller feature on the La Pérouse Bank. The autumn cruises show a return to a featureless winter regime.

Comparison of Ship and GEOSAT Altimeter Observations of Sea-Surface Height Anomalies in the Northeast Pacific

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Consistent sea-surface height anomalies with space scales of order 100–300 km, are observed at 17-day intervals in GEOSAT altimetry data of the northeast Pacific. Anomaly amplitudes are in the range of 10 to 30 cm, with anomaly displacement velocities of about 1 cm/s. We compare the altimetry results with the more precise, but less frequent data from hydrographic and CTD measurements along lines P and R, extending from the B.C. coast (Juan de Fuca Strait and Cape St. James, respectively) to Ocean Station Papa.

Nonlinear Stability of Flow over Topography

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W.W. Hsieh, Department of Oceanography, University of British Columbia, Vancouver, British Columbia

We applied the energy method from the stabilty theory (Joseph, 1976) to a forced-dissipative, barotropic quasi-geostrophic flow within a β-plane channel (periodic in the east-west direction)

for nonlinear analysis of global stability of flow over topography. In particular, we formulated the stability problem as an initial value problem for which an energy inequality for disturbances was established. General sufficient condition for global stability (GS) was then inferred.

We applied the general condition to the problem of flow over topography and analyzed the GS with regard to the zonal velocity and the relative height of the topography. Three global stability regions (GSR) were identified, one for westward subresonant flows and the remaining two for eastward superresonant and subresonant flows. We also examined how the horizontal topographic scale, the dissipation coefficient and β affect these GSRs.

ATMOSPHERIC VARIABILITY–2
VARIABILITE ATMOSPHERIQUE–2

Short-Period Climatic Fluctuations in the Far East Region of the U.S.S.R. and Sea Surface Tempeatures

O.N. Likhacheva, A.B. Rabinovich, Institute of Marine Geology and Geophysics, Far East Division, U.S.S.R. Academy of Sciences, Yuzhno-Sakhalinsk, U.S.S.R.

Twenty-year series of sea surface temperature (SST) at three points in the Kuroshio area were investigated together with climatic characteristics (air temperature, atmospheric pressure and precipitation) in Vladivostok, Petropavlovsk and Yuzhno-Sakhalinsk. Annual (Sa) and semiannual (Ssa) harmonics and their temporal variations for different parameters were analysed and corresponding relations were looked for as well as relations between residual series. It was found that: 1) seasonal harmonics are strongly dominated in air and water temperatures (94–98%) and in atmospheric pressure in Vladivostok (77%), play an important role in Petropavlovsk pressure and Vladivostok precipitation (50%) and are much weaker in Yuzhno-Sakhalinsk pressure, precipitation, and Petropavlovsk precipitation (17–23%); 2) there is a definite negative correlation between south SST points and air temperatures (residual) in Petropavlovsk and Yuzhno-Sakhalinsk ($R_{xy} \sim -0.37$ and -0.48, respectively) but no correlation with Vladivostok temperature; 3) the north SST point has no similar relations to air temperature in any station but there is a noticeable correlation with Vladivostok pressure ($R_{xy} \sim 0.45$); 4) there are definite variations of SST at the north point with periods 8.3, 2.7 and 1.4 years. These periods are much weaker at other points and in othe climatic parameters.

Correlation between the Sun activity and climatic fluctuations were also studied and some relations were found as well as some correlations with sea level oscillations in the Kuril-Kamchatka region.

Temporal and Spatial Variability of the Tropical Radiation Budget from Earth Radiation Budget Satellite Measurements

Chang Tin Yee and R. Davies, Department of Meteorology, McGill University, Montreal, Quebec

Temporal, spatial, and cloud-forced variations in the planetary radiation budget are important features of the climate system, particularly in the tropics. In an effort to attain a quantitative understanding of the temporal and spatial variability of tropical radiation budgets, we have analyzed a complete annual cycle of measurements by the ERBS scanning radiometer (from March, 1985 to February, 1986).

Results show the existence of strong diurnal variation in the longwave emission to space over clear land scenes (especially deserts), and in the reflected shortwave radiation for all scenes. Substantial east-west variation is also evident in the time-averaged radiation budgets within given latitude zones. Seasonally, the main changes in the tropical radiation budget are associated with the Asian summer monsoon and the migration of the Inter Tropical Convergence Zone.

Overall, a positive radiation budget of about 44 W m^{-2} is obtained for the annual mean tropical radiation budget.

On the Mean Meridional Transport of Energy in the Atmosphere and Oceans

R. Michaud, J. Derome, Department of Meteorology, McGill University, Montreal, Quebec

The global ECMWF analyses for the period 1981-86 are used to compute the mean meridional transport of moist static energy in the atmosphere. The contributions to the transport effected by the mean meridional circulation, the transient eddies and the standing waves are examined separately. In addition, the moist static energy is separated into its component parts, namely, the sensible and latent heats and the potential energy. The recurring changes made to the analysis procedure over the years have resulted in such a significant increase in the transport due to the mean meridional circulation in the tropics that in that region it is not meaningful to average the six years of results. The maximum poleward transport of the total energy amounts to about 4 PW near 45° of latitude in both hemispheres during the winter season. The subtraction of the annual mean atmospheric transport from the total ocean-atmosphere transport implied by the observed net radiation flux at the top of the atmosphere leads to a maximum northward heat transport of 3.2 PW at 25°N in the oceans. This value exceeds by 1 PW or more the values obtained using surface marine data and bulk aerodynamic formulae in previous studies.

The Big Chill — An Intense Arctic Outbreak in Southwestern British Columbia

P.L. Jackson, Atmospheric Science Programme, Department of Geography, University of British Columbia Vancouver, British Columbia

Early January of 1989 will be remembered as one of the coldest on record in much of western North America. Accompanying the extreme cold and record high pressure over the Yukon and Alaska, were very strong *gap* or *outflow* winds which occurred through the fjords and valleys dissecting the coastal mountain barrier which separates the coast from the interior plateau. The meso- and synoptic-scale setting for the temperatures and winds which occurred in southwest British Columbia will be presented and described. Models, which have been applied to describe the winds in the fjords and valleys under these meteorological conditions, will be discussed, and the results presented and compared to observations.

An Observational Study of Interactions between Transient Eddies and Persistent Circulation Anomalies

B. Dugas, J. Derome, Department of Meteorology, McGill University, Montreal, Quebec

Several years of observations are first used to identify periods during which large-amplitude persistent anticyclonic circulation anomalies are present in the data. An empirical orthogonal function analysis is then performed to obtain the characteristic structures of North Atlantic anomalies. The interaction between the fast transients and the anomalous highs is computed by means of the E vector formulation for one of the characteristic patterns. The results show that the baroclinic effects dominate the interaction during the onset of the anomalous circulation, providing an anticyclonic forcing upstream of the incipient ridge. During the mature stage of the mean high, the transient eddies provide their forcing through the barotropic component of the flow.

OCEANOGRAPHY–6/OCEANOGRAPHIE–6

Tidal Currents in a Two-Layered Stratified Sea with an Example from the North Sea

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During summertime a distinct two-layer temperature stratification is encountered in the North Sea. At the end of a period with extreme calm weather conditions, ADCP measurements in the central part of the North Sea revealed a significant difference in the upper and lower velocities. By setting up a simple two-layer model with friction subject to a harmonic pressure field, the observed velocity variations are fully explained by the phase-lag between upper and lower layer, caused by the difference in the bottom friction (relatively high) and the interfacial friction (relatively low).

Can a Two-Dimensional Vorticity Cascade Explain the Distribution of Length Scales Seen in Langmuir Cells?

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D.M. Farmer, Institute of Ocean Sciences, Sidney, British Columbia

Langmuir circulation is a frequently occurring process in both lakes and the oceans. When present it provides an important mechanism for mixing near surface water yet it remains a poorly understood process. One characteristic that has emerged in our acoustic observations (and in many previous reports) is the simultaneous presence of many scales of Langmuir cells.

Our mid-ocean observations show Langmuir circulation with scales from 1 to 20 m with the mean value depending on wind speed: mean spacings of 5 m occurred when winds were < 5 m/s, and this increased to about 8 m with winds of approximately 12 m/s. The multiplicity of scales occurring in these observations suggests the possibility of a vorticity cascade from smaller to larger scales. We investigate the dynamics of such a cascade numerically using a two-dimensional Lagrangian vorticity model. Through such an approach we hope to provide parameterizations of mixing (by Langmuir circulation) that can be used in the study of air-sea interaction.

On the Effect of a Bottom Boundary on the Stability of a Salt-Wedge, with Application to Estuary-Ocean Mixing

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

Numerical and experimental results on the effect of a bottom boundary on the stability characteristics of a salt-wedge are presented. Our numerical work shows that the presence of a bottom boundary stabilizes high wavenumber and de-stabilizes low wavenumber perturbations, similar to the effect observed in atmospheric shear layers. The spatial and temporal characteristics of these modes are described. As well, we present a comparison between our numerical work and data taken from field experiments and laboratory simulations. The agreement between the two is very good.

Progress towards a Long-Time Scale, Density-Stratified Shelf Circulation Model

R.J. Greatbatch, A. Goulding, Department of Physics, Memorial University of Newfoundland, St. John's, Newfoundland

We describe a finite-difference numerical model in which the density field is calculated using a time-stepping technique with the corresponding velocity field being diagnosed at each time step. The method relies on neglecting the local time derivative, non-linear and horizontal mixing terms in the momentum equations and is suitable for modelling circulation and variability in a stratified, wide shelf region with time scales longer than a few weeks (by "wide" we mean "shelf width much greater than the internal Rossby radius of deformation", an example being the Newfoundland and Labrador Shelf). The model uses a linear parameterization of bottom friction in terms of bottom geostrophic velocity and can accommodate any formulation for the vertical eddy viscosity and also the diffusion coefficients in the density equation.

METEOROLOGICAL APPLICATIONS
APPLICATIONS METEOROLOGIQUES

Current Procedures for Testing the Homogeneity of Temperature Datasets for Stations in the CCC Archives

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In studies of climatic change it is not of great importance that the times series used be free of unknown inhomogeneities which can be ascribed to human causes such as changes in the observing site, local environment, and instrumentation. Comparisons with climatic records from neighbouring stations are also necessary, so that apparent climatic changes are not mistakenly attributed to regional climate or that undue significance is attached to unimportant changes at the climate station under study.

Maximum and minimum temperature series are tested by statistical methods such as the Student's T distribution and F test in conjunction with regional temperature series from auxiliary stations in order to identify potential inhomogeneities. These tests are done by seasons and annually. Temperature series from the base station and combined auxiliary networks are graphed. Statistical and graphic output along with station history files are examined and analysed. A report is then prepared describing the homogeneity and completeness of the station's temperature datasets.

Examples will be taken from a number of stations across Canada.

On the Application of Microcomputers to the Analysis of Climate Data Bases Part 1: The Determination of User Requirements

A. Stuart, Weather Research House, Downsview, Ontario

Any detailed analysis of climate variability and its impact requires a variety of climate statistics for the relevant geographical area. These statistics - which may include frequency distributions, extreme values, return periods and the like - are in turn derived from several decades of hourly or daily weather observations. The exact statistics required for any particular application depend on the nature of the climate impact being studied, and will vary greatly from one part of Canada to another. Accordingly, there is considerable value in having local climate archives and analysis capability as close as possible to specialists concerned with any particular climate impact.

In the past, the size of the data bases containing several thousands of weather observations and the cost of mainframe computers necessary for the derivation of climatological statistics, dictated that only one centralized facility in Canada could be justified in financial terms. However,

the dramatic improvements in desk-top microcomputers in the past few yeaers combined with their ever decreasing costs, have removed any financial impediments to a greater decentralization of the distribution system of climate data in Canada. Computers which are powerful enough to store and analyze climate archives now exist in the offices of most climate sensitive organizations across the country.

Before the capabilities of desk-top microcomputers could be realized, it was necessary to develop appropriate software to process large climate data bases, and return statistical products that would be of use to the potential users of such systems.

Studies on the use of climate information in Alberta and Saskatchewan were carried out in attempt to study user requirements for such statistics in considerable detail. A seventeen page questionnaire on how users currently obtain information, how often and which products are required, the necessary turnaround times and how the information is eventually used were distributed to over 400 individuals and organizations in the two provinces. Almost 200 of these were returned and subsequently analyzed. Follow-up interviews were carried out with approximately 20 per cent of the questionnaire respondents. An analysis of survey responses and interview comments strongly suggested that different types of information were required in different formats, and that information was required faster and from a local data source. Temperature, wind speed and direction and precipitation amount and precipitation occurrence were most often cited by users as important weather elements, while humidity, the occurrence of frost, soil temperature and soil moisture were also regarded as important by many respondents. A summary of these and other findings from the questionnaire responses and interviews will be presented.

On the Application of Microcomputers to the Analysis of Climate Data Bases Part 2: The Development of the Weather Information Display System

A. Stuart, Weather Research House, Downsview, Ontario

Information on user requirements for climate data products was used to develop the specifications for a series of new software packages to analyse large climate data bases and display resultant statistics. It was clear that the package must be capable of delivering a tremendous variety of statistics, that the selection process to determine which products at any time be easily and quickly carried out, and that the results be presented in both numerical and graphical formats which could be easily understood by nonspecialists.

User surveys indicated very clearly that most users would be unwilling to pay more than a few hundred dollars for climatological analysis software. In an attempt to reduce costs and development time, it was decided at the outset to examine the large number of programmable, analysis products currently available for MS-DOS based microcomputers to determine if these products could be adapted to meet our specifications. It was found that integrated spreadsheet programs with macro facilities could be successfully adapted to produce the climate data products required.

As is the case with most microcomputer software, a menu system is used to accept input during the running of the program. Flow charts that describe the menu systems for two current products will be shown along with an overview of the tasks completed by the computer as each selection is made. Important spreadsheet functions and routines will be discussed as they apply to the analysis of large climate data sets. Examples of output products in both numerical and graphical formats will be given, and the application of more sophisticated graphics software will also be discussed.

This presentation will demonstrate that many of the spreadsheet programs now running on MS-DOS compatible microcomputers have within their internal function options, data base handling capabilities, and output graphics features, the necessary capabilities to derive a variety of time series plots, histograms, duration statistics, percentiles and probability distributions. Procedures from current research projects will be used to illustrate the power and flexibility of hardware and software that currently exists in most scientific institutions.

Radar à Polarisation Circulaire: une Amélioration de la Méthode de Correction des Effets de Propagation

E. Torlaschi, Département de Physique, Université du Québec à Montréal, Québec

Lorsqu'il pénètre la précipitation, un faiceau radar polarisé circulairement change son état de polarisation de circulaire à elliptique. Ce changement est attribué à l'atténuation différentielle et au déphasage différential des composantes circulaires de l'onde dans le milieu de propagation. Les mesures de radar se trouvent contaminées par ces effets, par conséquent, leur interprétation en termes des caractéristiques de polarisation propres à la précipitation ciblée est quelque peu compromise.

Dans le but de produire une méthode visant à interpréter les observations d'un radar à polarisation circulaires de l'onde reçue sont décrites en termes des paramètres radars usuels: le facteur de réfectivité équivalent, $\tilde{Z}_e$, le rapport de dépolarisation circulaire, $\tilde{\text{CDR}}$, et la corrélation complexe entre les deux composantes, $\tilde{\rho}\exp(j\tilde{\Phi})$. Ces paramètres mesurés sont reliés aux paramètres de polarisation de la cible Z_e, CDR, $\rho\exp(j\Phi)$, au moyen du terme de propagation $p\exp(j\chi)$. Il en résulte un système de quatre équations non-fermé. Pour résoudre le problème de fermeture l'atténuation différentielle et l'atténuation moyenne sont estimées des mesures par l'entremise de relations empiriques. A défaut d'équations supplémentaires, nous posons des hypothèses simplificatrices: i) le déphasage différentiel de diffusion en polarisation circulaire prend, pour la pluie à 3 GHz, une valeur constant voisine de π, et ii) l'axe de symétrie des diffuseurs est aligné avec la verticale locale. L'introduction de ces hypothèses dans les équations nous permet d'estimer les paramètres radar en termes de valeurs mesurées. Dans le but de valider cette nouvelle méthode de correction, les mesures de radar à polarisation circulaire provenant d'un modèle de pluie seront simulées numériquement. Les valeurs intrinsèques des paramètres seront comparées aux valeurs corrigées.

OCEANOGRAPHY–7/OCEANOGRAPHIE–7

Numerical Tidal Modelling Studies in Northumberland Strait, Canadian East Coast

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The concept of a fixed crossing in the form of a bridge or causeway linking New Brunswick and Prince Edward Island on the Canadian east coast has been studied for at least 50 years.

Recent proposals by Public Works Canada for a bridge between Cape Tormentine (N.B.) and Port Borden (P.E.I.) have sparked renewed interest in the possible impact that such a structure might have on the tidal dynamics in Northumberland Strait.

This paper describes the results of numerical tidal modelling studies undertaken for Public Works Canada to assess the probable impact of the bridge piers, which would induce a flow blockage of about 10%, on the tidal elevations, tidal currents, and tidal residual currents in the Strait.

Northumberland Strait is approximately 300 km long and, being open to the Gulf of St. Lawrence at both its east and west ends, exhibits unusually complex tidal behaviour. Semi-diurnal tides dominate the eastern section of the Strait and diurnal tides predominate in the west. Although the quantity of field data collected since 1958 is considerable, the tidal records for the same location, often for three different years, show a spread of up to 40% for a parameter such as M_2 tidal elevation. These differences in the recorded data (some are clearly in error) are as yet not fully explained although some mechanisms are tentatively suggested in this paper.

The tidal model used for these studies uses a two-dimensional depth-averaged finite difference solution to the hydrodynamic equations with a quadratic friction formulation and the non-linear convective acceleration term retained. The latter non-linear term proved to be a major source of tidal residual currents in the Strait.

Two numerical model grids were set up for these studies, one with a 3000 m spacing covering the whole of the Strait and a "smaller" model with a spacing of 1000 m for the Central Strait Region.

This paper details the difficulties experienced with calibration of the model to field data, the results of a resonance evaluation of the Strait, and the estimated impacts of the bridge on the tidal dynamics. Results of an analysis of surge water levels and currents is also discussed. In addition, vector plots of the calculated semi-diurnal tidal and tidal residual currents in the Strait are presented. This latter data is of particular interest to marine biologists.

Heat Budget for the Scotian Shelf: Implictions for Prediction

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Seasonal changes in the heat content of the upper layer of the Scotian Shelf are driven primarily by direct air-sea exchange. This leads us to a one dimensional diffusion model to the observed changes in water temperature, as a function of both depth and time. As part of the fit we estimate the vertical eddy diffusivity $K_v(z,t)$ and find, as expected, that K_v changes with the background water density. In particular, we find that K_v varies approximately as N^{-1}, consistent with the result of Gargett (1984).

Thompson et al. (1988) showed that winter sea surface temperature anomalies on the Scotian Shelf sometimes reappear the following summer. They hypothesized this was due to the entrainment, into the shallow summer mixed layer, of deep water that was cooled the previous winter. We use our model to specifically test this hypothesis and, more generally, explore the possibility of predicting the vertical distribution of temperature on the Scotian Shelf.

Circulation of the Northeast Pacific Ocean inferred from Temperature and Salinity Data

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The temperature, salinity, and pressure (STP) data were collected during two cruises, one in early October and the other in early December of 1987, as part of the Ocean Storms experiment . These hydrographic data were analyzed to determine the circulation of the northeast Pacific Ocean and to calculate the factors influencing the heat and salt content of the upper ocean. To determine the circulation, an inverse model was developed, assuming that the flow was geostrophic and that the vertical velocity satisfied a linear β-plane vorticity equation. This inverse model calculated the vertical and horizontal velocities at a reference level of 1000 dbars, and the horizontal and vertical mixing terms by conserving mass, salt, and heat. These conservation constraints were applied to large boxes defined by four hydrographic stations and two pressure surfaces.

The circulation determined using the model showed well-defined flow features. Comparison of the absolute geostrophic flow with the seven-day averaged current meter observations showed much similarity, despite complications from an incident storm. Correlation between the geostrophic flow at the surface and the total flow field inferred from drifter data was also high. An estimate of the ageostrophic flow suggested that acceleration and nonlinear terms played an important role in affecting the flow field during the first cruise.

The observed change in the salt content of the upper 150 m of the ocean was 0.004 ppt for the sixty days between the two cruises. The net transport of salt into the study area by the calculated flow field was −0.016 ppt. Therefore, to balance the salt budget would require E − P = 9 cm. The upper ocean lost 92 W m^{-2} of heat during the sixty days between the two cruises. As the vertical and horizontal transport of heat accounted for 40 W m^{-2} loss of heat, the remainder of heat lost, 52 W m^{-2}, was attributed to air-sea boundary processes.

Variations in Surface Layer Mixing Efficiency across Upwelled Fronts

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Microstructure observations near upwelled fronts indicate considerable variation in the structure of vertical mixing across the frontal region. Observations of cool filaments off Northern California indicate that, within the cool (dense) core of filaments, the raised pycnocline inhibits the penetration to mid-depths of surface-generated mixing. The microstructure profiles are used to estimate the available wind energy for mixing as a function of pycnocline, or mixed layer depth. A greater portion of energy input at the surface is available for entrainment of dense fluid through the pycnocline and into the surface mixed layer where the pycnocline is shallow. Hence, surface-forced mixing may cause a more rapid increase in mixed layer density within the cool filament than outside the filament, resulting in an enhanced horizontal density gradient in the mixed layer. Assuming the flow adjusts towards geostrophy, the enhanced horizontal density gradient at the front could result in an accelerated mixed layer in the direction of the pre-existing geostrophic flow. Proportions relating the gain in potential energy to the wind energy ($m_o = J_1/E_o$) vary inversely with pycnocline depth and differ by as much as an order of magnitude from the findings of Denman and Miyake (1973) and Davis *et al.* (1981). Horizontal variability of pycnocline erosion may not be properly taken into account in some models and should more realistically be parameterized by including dependence on pycnocline depth.

Seasonal Variations in Conception Bay, Newfoundland

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Results are presented from an intensive study of a large coastal embayment. Current meter and CTD data cover the period from the spring development of stratification to strong mixing events which occur in the late fall. Tidal currents are weak in the bay so wind and buoyancy forcing dominate. Current measurements are compared with dynamic height computations to determine circulation characteristics of the bay. Regular deepwater exchange controls the bottom water properties of the bay. The effects of buoyancy forcing on the development of the seasonal cycle is discussed.

CLIMATE VARIATIONS/VARIATIONS CLIMATIQUE

Marine Cyclones and Greenhouse Warming: Another Look

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Recent statements from primarily European sources indicate that there is a widespread assumption that one of the consequences of an anthropogenic "Greenhouse Warming" is an increase in mid- and high-latitude cyclonic storm intensity.

It is proposed here that the above assertion *may* be true for some regions of the mid- and high-latitudes, but that is not true in general. The fundamental question is how the spatial distribution of temperature change in the "warmed" climate will affect the synoptic scale baroclinity in the regions where storms are spawned and/or intensified.

Most of the doubled CO_2 GCM scenarios indicate several degrees Kelvin more warming near the poles than near the equator. Now, a sizeable portion of this warming will affect ocean areas. As this warmed water is mixed equatorward it will necessarily increase the mean zonally averaged ocean temperatures in the upper mid-latitudes. This water's temperature is often seen as the warm side lower boundary condition for the atmospheric baroclinic zones in the primary cyclonic storm generation zones southeast of the Canadian Maritimes, Greenland and Siberia.

The fundamental hypothesis here is that warming will *strengthen* storm development in

regions where large areas of glacier ice lie on the poleward side of the mean tropospheric jet (and baroclinic zone), but will *weaken* storm development where the mean tropospheric jet (and primary baroclinic zone) are at or near the coast of a non-glaciated land region. The former situation applies to many of the storms in western Europe and Antarctica, while the latter situation applies to most of the storms of eastern North America and eastern Asia.

In the North Atlantic it is possible that these changes may be reinforcing because of the interplay, via surface fluxes of latent and sensible heat, between the lower atmosphere and the Gulf Stream.

Compensation of Surface-Flux Errors in Weather/Climate Models

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A numerical study has been initiated to quantify the tendency for an overestimation (say) of the sensible heat flux over a given grid cell to result in a compensatingly reduced sensible heat flux in subsequent time-steps over that and downstream cells: I would like to determine whether there exists a spatial scale over which areal-average estimates of the heat and vapour fluxes by weather/climate models are accurate despite local (single-cell) errors due to oversimplified boundary treatment. Preliminary results of an examination of compensation on the **microscale** (i.e., an error-swath width of order 10 m) indicate that a very long downstream O[100 km] is required for even 80% compensation of the injected error.

Simulation of Water and Kinetic Energy Budgets of Cumulus Clouds

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A three-dimensional numerical model developed by Steiner (JAS 1973), Yau (JAS 1980), and Yau and Michaud (JAS 1982) is used to simulate convective storms. The model results are analyzed to investigate time evolution of the water and kinetic energy budgets. The model is based on the deep anelastic system of equations. Subgrid scale turbulent processes are modeled using a first order closure scheme with the eddy exchange coefficient depending on deformation shear and local buoyancy. Precipitation processes are parameterized using the Kessler scheme for warm rain. The ice-phase microphysics is given in Yau and Macpherson (1984, Volume of extended abstracts, 9th Int. Cloud Physics Conf., Tallin, p. 585–588).

The initial conditions for the cloud simulations are taken from sounding data collected at the Bethlehem Precipitation Research Project. Comparison between simulated and observed radar reflectivities indicate a good agreement in maximum heights of radar reflectivity. The agreement in peak reflectivity is fair. The volume-integrated water budget of the simulated clouds indicates the importance of the collision-coalescence process in initiating and intensifying the rain formation. Deposition and riming yield about the same overall contribution to the growth of the ice content. Our analysis of the kinetic energy budgets reveal that the simulated storms obtain their kinetic energy from conversion of potential energy released during condensation. In addition, the storm motion also abstracts a large fraction of its kinetic energy from feeding on the shear of the ambient flow field.

Temperature Trends in Canada

P. Kertland, Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario

Ninety year records of temperature at 10 stations across southern Canada were analyzed to assess annual and seasonal temperature trends. A general warming trend was evident at all stations during the first half of the record, peaking in the mid-40's in western Canada and in the early 50's in eastern Canada. The trends are much more complex and seasonally dependent for the

last 40 years, with only western Canada showing annual temperatures currently warmer than the mid-record peak. As well, an analysis of regional patterns of temperature across Canada for the past 30 years was undertaken. This analysis shows a strong zone of warming in western Canada during most seasons and areas of cooling in eastern Canada, particularly in autumn. These results, their implications and the supporting methodologies will be discussed in detail.

Manifestations of the El Niño Southern Oscillation in Southeastern Australian Waters

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B.V. Hamon, Caringbah, New South Wales, Australia

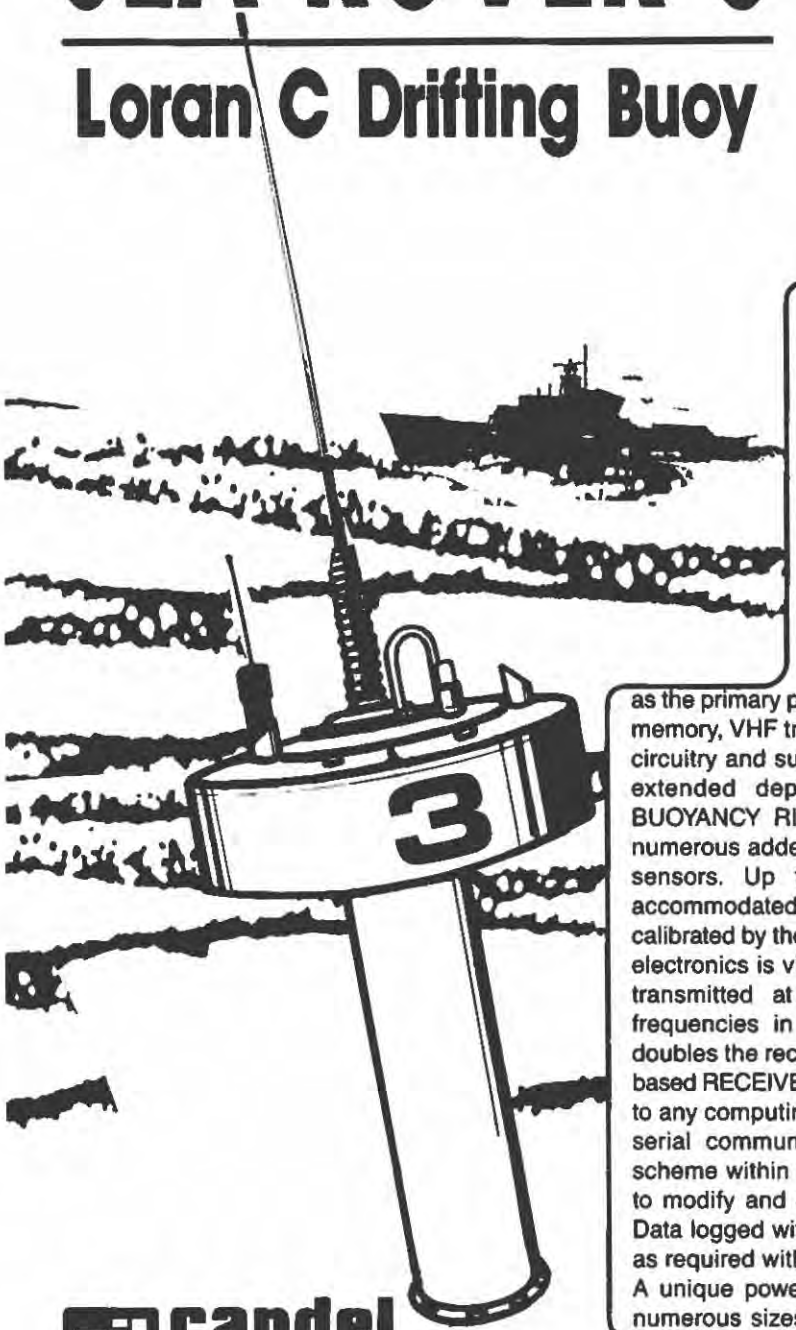
Using four decades of hydrographic data collected off the coast near Sydney, New South Wales, and the sea level data at Sydney, we studied the interannual variability in southeastern Australian shelf waters. The first three empirical orthogonal function (EOF) modes of the band-pass filtered 50 m depth hydrographic data (temperature T, salinity S, nitrate N, phosphate P and oxygen O), sea level (SL) and adjusted sea level (ASL) data accounted respectively for 51, 27 and 10% of the total variance. The first two modes were significantly correlated with the Southern Oscillation Index (SOI). The first mode, with T, S, O and ASL varying in opposition to N and P, represented the internal or baroclinic response associated with vertical displacements of the isopycnals. The second mode, with large in-phase fluctuations in SL and ASL but small changes in the hydrographic variables, represented mainly the external or barotropic response during ENSO.

Three-year composites centred around seven ENSO warm episodes revealed that T, S, O and ASL were generally low while N, P, SL and SOI were high in the year before the ENSO warm episode, but the former group rose while the latter group dropped in the year of the warm episode. The changes in the hydrographic variables at 50 m were consistent with relatively shallow isopycnals in the year before the ENSO warm episode, followed by a deepening of the isopycnals during the warm episode. Estimates of this downward displacement of isopycnals using T, N, P and O were in the range 7–10 m.

The geostrophic wind arising from the pressure fluctuations during ENSO is proposed as a probable cause for the vertical displacement of the isopycnals. In the year before the warm episode, the low pressure centre near Darwin would produce a clockwise geostrophic wind around the southern half of Australia, generating offshore Ekman transport and upwelling off southeastern Australia. During the warm episode, the air pressure near Darwin rises, the geostrophic wind reverses, and downward movement of the isopycnals would occur.

SEA ROVER 3

Loran C Drifting Buoy



The SEA ROVER 3 Drifting Buoy employs advanced telemetry technology to acquire real-time Lagrangian open ocean and near shore current data. The SEA ROVER 3 has been severely tested in sea states exceeding 10 meters with transmit ranges approaching 50 nautical miles. A series of Drogue Systems enable measurement of currents at any depth.

Each SEA ROVER 3 employs Loran-C as the primary positioning system. Internal control logic, memory, VHF transmission circuitry, power conversion circuitry and sufficient battery power are provided for extended deployments. A series of removable BUOYANCY RINGS provide sufficient buoyancy for numerous added drogue systems or optional external sensors. Up to six additional sensors may be accommodated and transmitted, each defined and calibrated by the user. All communications with internal electronics is via a top mounted RS 232 port. Data is transmitted at user definable periods over VHF frequencies in a unique scheme which effectively doubles the reception range. A shore, ship or airborne based RECEIVER 2 provides access and display of data to any computing or printing device capable of simple serial communications. A unique internal software scheme within the buoy and receiver permit the user to modify and customize the presented data format. Data logged within memory can be retrieved as often as required without effecting the integrity of that data. A unique power conversion circuitry enables use of numerous sizes and types of batteries.

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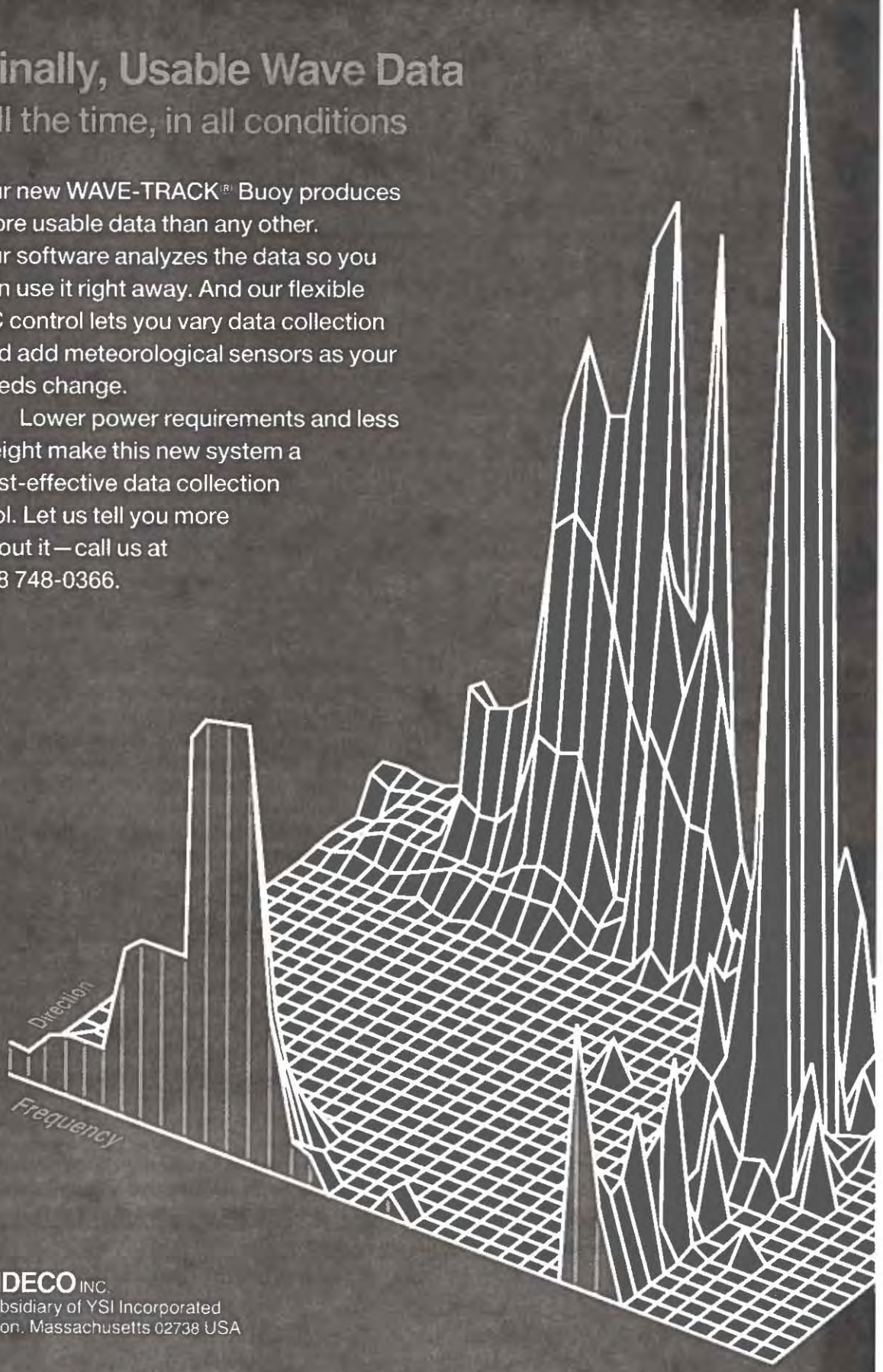
Finally, Usable Wave Data

All the time, in all conditions

Our new WAVE-TRACK® Buoy produces more usable data than any other. Our software analyzes the data so you can use it right away. And our flexible PC control lets you vary data collection and add meteorological sensors as your needs change.

Lower power requirements and less weight make this new system a cost-effective data collection tool. Let us tell you more about it—call us at 508 748-0366.



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