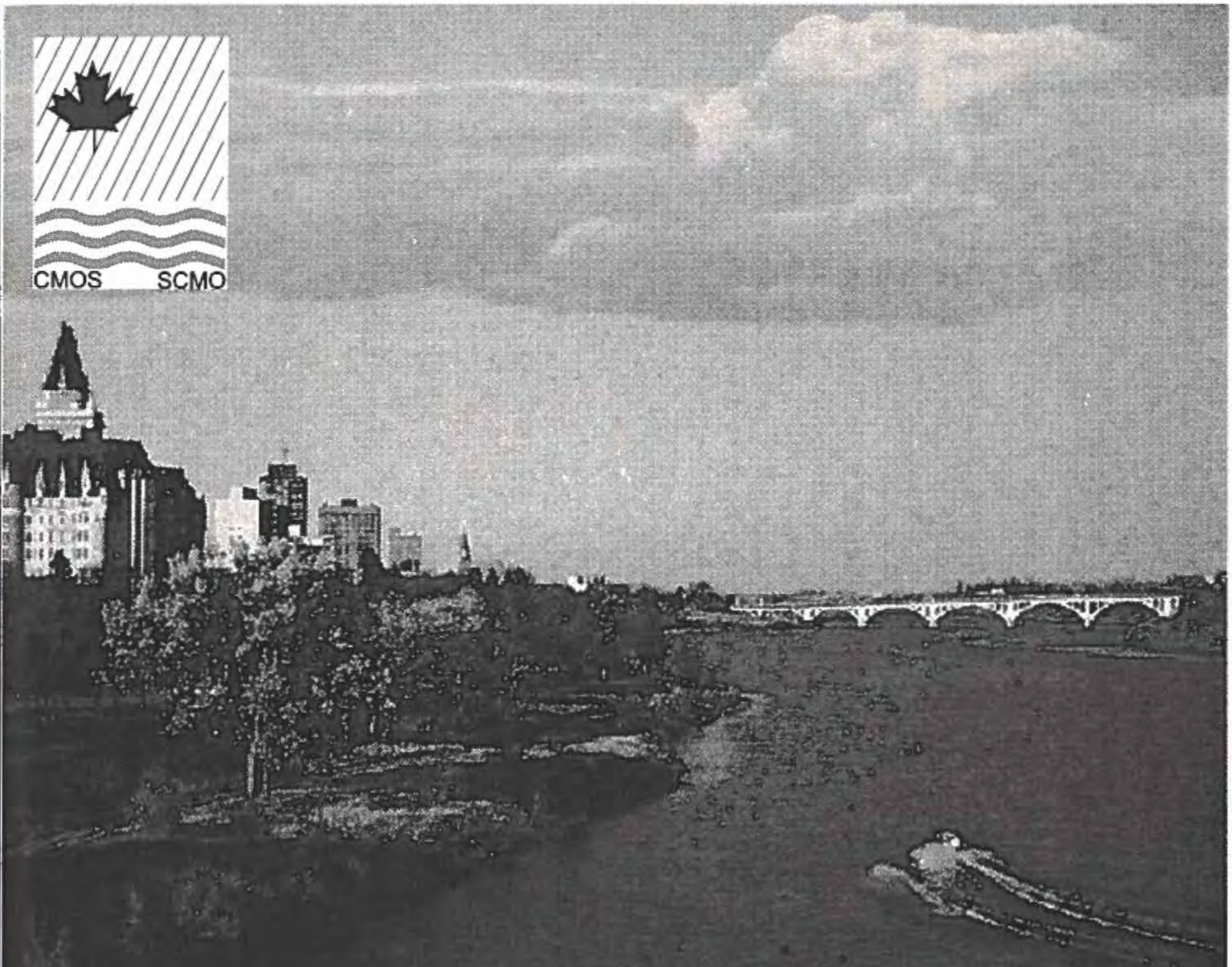
PROGRAM AND ABSTRACTS

31 st CMOS Congress
31 ième Congrès SCMO



Design: Bruce Cole

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Calgary AB.

SASKATOON, SASKATCHEWAN
1-5 JUNE/JUIN 1997

Welcome to the 31st CMOS Congress...
Bienvenue à la 31ième SCMO Congrès...

The organizing committees of the 31st Annual Congress of the Canadian Meteorological and Oceanographic Society are pleased to present to you this program and abstracts book.

Registrants to Congress are invited to attend any sessions or committee meetings, and please feel free to move between sessions if you wish to hear specific papers in coincident sessions. In fairness to speakers, we ask that you do this with a minimum amount of disturbance; *i.e.,* during the break between presentations if possible.

AUTHORS are reminded that the time alotted for most presentations is **15 minutes + 5 minutes** for discussion, **20 minutes total**, except for plenary and invited presentations as noted. Chairpersons have been instructed to adhere closely to this schedule, so that all registrants can keep to their own schedule.

There are several social events throughout the week which we hope you will take the time to enjoy. We specifically invite you to participate in Campbell Scientific's "*Calendar Art*" presentation on Monday at 5:30 PM; Ed Verkaik's "*Severe Weather photo-art display*" on Tuesday at 8:30 PM, the commercial exhibits, and especially your banquet on Wednesday evening. Above all, enjoy 'your' Congress, the beautiful University of Saskatchwan campus, and Saskatoon.

Geoff Strong
Chair Scientific Program Committee

Joe Eley
Chair Local Arrangements Committee

31st CMOS Congress
University of Saskatchewan
Saskatoon, Saskatchewan

01-05 June, 1997

PROGRAM AND ABSTRACTS

31st CMOS Congress/ 31ième Congrès

"Energy and Water Cycles"
"Les Cycles de l'Eau et de l'Énergie"

Canadian Meteorological and Oceanographic Society/
La Société Canadienne de Météorologie et d'Océanographie
University of/Université du Saskatchewan
Saskatoon, SK, Canada
1-5 June/juin 1997

Co-Editors/Co-éditeurs — G.S. (Geoff) Strong, F.J. (Joe) Eley

Editorial Assistant/Assistant éditeur: — Yvonne ML. Wilkinson

ISBN 0-9698414-J-4

Table of Contents
Table des Matières

Canadian Meteorological and Oceanographic Society
La Société Canadienne de Météorologie et d'Océanographie

***About the Society...**la Sociétée...*

The Canadian Meteorological Society was formed in 1967 from a branch of the Royal Meteorological Society. After the oceanographic community joined, the name of the society was changed to the Canadian Meteorological and Oceanographic Society [CMOS] in 1984. CMOS is a national society of individuals and organizations dedicated to advancing all aspects of atmospheric science, oceanography and related disciplines in Canada. The society also offers accreditation of meteorological consultants.

Fourteen Society centres and chapters located across Canada serve as focal points for local and regional activities. Special interest groups [SIGs] in the Society consider issues of operational meteorology, hydrology, agriculture/forestry meteorology, mesoscale meteorology, floating ice, and fisheries oceanography.

The main publications of CMOS are the bimonthly "CMOS Bulletin SCMO", which features articles of general interest and Society news, and "Atmosphere-Ocean" [A-O], a quarterly refereed journal for the publication of results from original research. The society also maintains an electronic Web Site, with information on the society and its activities, and on meteorological and oceanographic science and education across Canada. Detailed information on CMOS can be found on this web site at **http://192.139.141.69/cmos/**

La Société canadienne de météorologie et d'océanographie [SCMO], fut formée en 1967 comme la Société canadienne de météorologie, à laquelle se joignirent les océanographes en 1977. C'est une organisation nationale regroupant des individus et des organismes voués à la promotion, au Canada, de la météorologie et de l'océanographie, ainsi que des disciplines environnementales connexes, sous tous leurs aspects.

En 14 endroits au Canada, des centres locaux ou sections tiennent des réunions pour entendre des conférenciers et discuter de sujets météorologiques et océanographiques. Plusieurs groupes s'intéressant à des sujets d'intérêts spéciaux tels l'hydrologie, la météorologie d'exploitation, la pollution de l'air, la météorologie agricole et forestière, les glaces flottantes, la mésométéorologie et l'océanographie des pêches ont été constitués par la Société. Ces groupes se concentrent sur des sujets précis et servent de groupe-expert ad hoc pour la Société.

ATMOSPHÈRE-OCÉAN est la revue scientifique principale que la Société publie sur une base trimestrielle. Elle sert à présenter des articles, préalablement soumis à la critique, sur les résultats de recherches originales, ou des revues. CMOS BULLETIN SCMO est une publication bi-mensuelle qui vise à renseigner les membres de la SCMO sur les événements et sujets courants ou historiques. INTERNET- La SCMO publie aussi une page d'accueil - on y trouve de l'information générale sur la SCMO, ses centres ou sections, ses publications. Une section spéciale est dévouée aux universités canadiennes qui offrent des études post-graduées en météorologie ou en océanographie. Venez nous voire à **http://192.139.141.69/cmos/**

A word from our President
Un mot de notre Président

I would like to welcome you to the 31st Annual Canadian Meteorological and Oceanographic Society [CMOS] Congress. As you know, the Congress is our opportunity to get together to discuss CMOS business and to exchange ideas in the areas of scientific, educational, and professional activities in meteorology and oceanography, and related fields. With this latter point in mind, I would like to especially welcome the acitve participation at this Congress of a number of distinguished hydrologists. I wish you all a fruitful week and would like to thank the Saskatoon Centre for hosting this Congress.

Je vous souhaite la bienvenue au 31ième Congrès annuel de la Sociétée Canadienne de Métérologie et d'Océanogrphie *[SCMO]*. Come vous le savez, le Congrès nous donne l'opportunité de se rencontrer afin de discuter des dossiers de la SCMO et d'échanger des idées dans les domaines de la science, de l'éducation, et des activités professionnelles en métérologie, en océanographie, et dans des domaines connexes. A ce sujet, j'aimerais tout particulièrement souligner la participation active a ce congrès de plusieurs hydrologistes renommés. Je vous souhaite donc a tous et a toutes une semaine fructueuse et remercie le Centre Saskatoon en tant qu'hote de ce Congrès.

Peter Zwack
President, CMOS
Président, SCMO

Welcome to Saskatoon
Bienvenue a Saskatoon

Welcome to the 31st Annual Congress of the Canadian Meteorological and Oceanographic Society.
***Bienvenue** au 31ième congrès annuel de la Sociétée Canadienne de Météorologie de Océanographie.*

Congress Location/*emplacement de Congres*
The congress will be held in the Arts Building of the University of Saskatchewan, located at: 9 Campus Drive. This location is off Wiggins Avenue, immediately behind the Royal University Hospital.
La Congrès sera situé dans la batîment d'Arts de l'Université de Saskatchewan, 9 rue Campus, nord de l'avenue Wiggins, en arrière de l'hôpital Université Royale.

Campus Parking/*stationnement*
All day parking in **Lot Z** across College Drive from the University is included with University Accommodations. For those staying elsewhere, all-day parking is available in either the **Agriculture Building Parkade, Parking Lot M, or Place Riel Parking Lot** at rates ranging from $0.75/hr to $2.00 and $3.00/day. Numerous metered locations also exist on the Campus, as well as on street parking off campus (the streets nearest the Campus have a 2-hr limit). Free all-day street parking south of the Campus can be accessed by a 15 minute walk. (see Campus map on back cover)
Stationnement de journée en Garage Z, en travers de la rue College, est compris avec l'hébergement de l'Université. Pour ceux qui reste d'ailleurs, les garages d'Agriculture, Garage M, et Place Riel sont disponibles pour un droit d'entrée de $.75/heure ou bien de $2.00 et $3.00/journée. Stationnement libre et gratuit est aussi accessible - une courte marche de 15 minutes. (voyez la carte a fin du livre)

Registration Desk/*Bureau d'enregistrement*
The registration desk will be located in the central lobby of the Arts Building on Monday (June 2) then in the 2nd floor Student Lounge (Room 239.1) for the remainder of the Congress. Marquis Hall lunch tickets, as well as tickets for the banquet and the Patterson Lunch will be available at the registration desk.
Pour lundi (2 juin), le bureau d'enregistrement, sera situé dans le couloir centre de la batîment d'Arts; et pour le reste du congres, au Centre d'Études (Salle 239.1). Billets pour diner a Marquis Hall, billets de banquet et de diner en l'honneur de Patterson seront ici disponible.

Lunches/*repas diner*
Lunches will be available daily at Marquis Hall (with pre-paid tickets @ $8.25). Marquis Hall is out the front door of the Arts Building, the second building on the right side of the central Campus 'Bowl'. There are many fine restaurants in Saskatoon, but of course it will be easier to keep to our schedules if you lunch closer to the action.
La cafétéria d'étudiants, situé a Marquis Hall, sera accessible (avec billets afranchi) pour diner chaque journée du Congrès. Marquis Hall est la deuxieme batîment a la droite de Campus Bowl. Bien que Saskatoon a beaucoups de restaurants, vous êtes encourager de partagés de diner au centre d'action.

Questions/*questions*?
If you have any questions, or require some assistance, please contact the registration desk and a Congress official will try to help you.
Le bureau d'enregistrement, ou bien un officiel de Congrès, seront disponibles pour vous aider pendant la durée du Congrès.

Congress '97 Organizing Committees
Congrès '97 Comités Organisateurs

Scientific Program Committee

Geoff Strong (Chair), Atmospheric Environment Service [AES], Saskatoon, SK
Kirk Dawson, Canadian Institute for Climate Studies, Victoria, BC
Howard Freeland, Institute of Ocean Sciences, Sidney, BC
Steve Lambert, AES, Canadian Centre for Climate Modelling & Analysis, Victoria, BC
Ed Lozowski, Dept. of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB
Alan Manson, ISAS, University of Saskatchewen, Saskatoon, SK
Phil Marsh, National Hydrology Research Institute [NHRI], Saskatoon, SK
Carr McLeod, AES, Downsview, ON
John Pomeroy, NHRI, Saskatoon, SK
Hal Ritchie, Recherche en Prevision Numerique/AES, Dorval, QU
Peter Schuepp, Dept. of Natural Resource Sciences, McGill University, Montreal, QU
Ron Stewart, AES, Downsview, ON
Ambury Stuart, Weather Research House, Willowdale, ON
Peter Summers, Retired, Richmond Hill, ON

Local Arrangements Committee

Joe Eley (Chair), AES, Climate Processes & Earth Observation Division, Saskatoon, SK
Dwight Clarke (Registrar), Sask Environmental Services Centre, Saskatoon, SK
Ron Hopkinson, Environment Canada, Regina, SK
Oscar Koren (Commercial Exhibits), Retired Meteorologist, Concord, ON
Alec Paul, University of Regina, Regina, SK
Brian Proctor (Computer Systems), CCRP, Saskatoon
Craig Smith, Climatologist, Saskatoon, SK
Geoff Strong (Chair, Scientific Program), AES, Saskatoon, SK
Virginia Wittrock (Treasurer), Saskatchewan Research Council, Saskatoon, SK

Acknowledgements
Remerciements

The organizing committee would like to thank the following people who graciously offered their time and expertise to ensure the success of this Congress:

Neil Campbell (Executive Director, Canadian Meteorological and Oceanographic Society, Ottawa, ON)

Bruce Cole and ***Steve Enns*** (Atmospheric Environment Service, Saskatoon, SK) for the Congress poster and cover design.

Jim Drummond (University of Toronto), and *William Hsieh* (University of British Columbia) for providing the initial software and support for the Congress web site.

Ron Garnett (Birds Eye View, Calgary, AB) for the use of his photo on our poster and cover.

Charmaine Hrynkiw (Atmospheric Environment Service, Saskatoon, SK) for correspondence.

Uri Schwarz (Executive Director 'Emeritus', Canadian Meteorological and Oceanographic Society, Ottawa, ON)

We would also like to acknowledge the efforts of the following paid helpers:

Annick Blanc (CAP Office, Ottawa, ON) for French translations.

Bob Crawford, WEB page work (under contract to AES, but did this for us on his own time!)

Craig Smith, general arrangements.

Yvonne Wilkinson, Technical Editor of the Program & Abstracts book.

CMOS also acknowledges the *Atmospheric Environment Service* for enabling several staff members to participate in the Scientific Program and Local Arrangements Committee for the 31st Congress, as well as providing the use of its facilities. *Environment Canada SENSC Office* and the *Saskatchewan Research Council* also provided staff on the Local Arrangements Committee. We would also like to thank *Environment Canada's National Hydrology Research Centre* for providing use of their meeting rooms for Congress committee meetings.

We acknowledge, with thanks, the cooperation and support of the *University of Saskatchewan* and its *Conference and Catering Staff* for their hospitality and for the use of several classrooms and theatres for Congress sessions.

Our corporate sponsors are also graciously acknowledged for their financial assistance.

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E-mail: altek@agt.net
Attn: Alan Hutton

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SCI-TEC Instruments
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Saskatchewan, Canada
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E-mail:scitec@eagle.wbm.ca
Attn: André Roberge

World Weatherwatch
Forecasting Services
401 Bentley Street, Unit #4, Markham, Ontario
L3R 9T2 Canada
Tel: 905-477-4120/Fax: 905-477-0824
Attn: Mory Hirt

Commercial Exhibitors
Exposants Commerciaux

American Meteorological Society [AMS]
Campbell Scientific (Canada) Corp.
Canadian Institute for Climate Studies
Canadian Meteorological & Oceanographic Society [CMOS]
NASA/Goddard Space Flight Centre DAAC
Saskatchewan Research Council
Sci-Tec Instruments Inc.

Exhibitors' Abstracts
Résumés d'Exposants

The American Meteorological Society - Project ATMOSPHERE

The American Meteorological Society [AMS], founded in 1919, is a scientific and professional society. Interdisciplinary in scope, the Society actively promotes the development and dissemination of information on the atmospheric and related oceanic and hydrologic sciences. AMS has more than 10,000 professional members from more than 100 countries, and over 135 corporate and institutional members representing 40 countries.

Project ATMOSPHERE is the educational initiative of the American Meteorological Society to foster the teaching of atmospheric topics across the curriculum in grades K-12. It is a unique partnership between scientists and teachers, with the ultimate goal of attracting young people to further studies in science, mathematics, and technology. Project ATMOSPHERE has two major components. A national network of Atmospheric Education Resource Agents [AERAs] has been established and has representation in nearly every state. AERAs are primarily master precollege teachers who have been trained to engage in special leadership roles in their local and state educational systems and teacher associations. The other major component is the development and dissemination of scientifically accurate, up-to-date, and instructionally sound resource materials for teachers and students.

For further information on the AMS or its affiliations, contact: The American Meteorological Society, 45 Beacon Street, Boston, MA 02108-3693 (PH: 617-227-2425; Fax: 617-742-8718)
For questions about membership applications, dues statements, member address changes, and book orders: Kathy Benson (PH: 617-227-2426, ext. 209; e-mail:kbenson@ametsoc.org). For questions about Project ATMOSPHERE (PH: 202-682-9337; e-mail:amsedu@dc.ametsoc.org)

Campbell Scientific (Canada) Corp.

Campbell Scientific (Canada) Corp. has introduced several new products to its line of Data Acquisition Systems. Our main stay, the CR10, has been redesigned as the CR10X, incorporating battery backed-up clock, program and data. The standard memory has been increased from 64K to 128K with the option to increase the size to 1 or 2 Meg. The CR500 with two differential and two pulse channels is the newest addition to Campbell Scientific's family of loggers. Designed for reliable unattended monitoring in harsh environments, the CR500 is simple to set up through Short Cut, our point-and-click program generator. PC208 has a new face as PC208W (2.0), our full Windows Datalogger Support Software which was released in April 1997. The R.M. Young Company has released a series of new indicators and displays. The 26700 Programmable Translator is a microprocessor-based display and data collection device featuring a high degree of flexibility to perform many monitoring tasks. The Tracker series of displays with alarms include the 06201 Wind Tracker, the 06206 Wind Tracker Marine with special features for shipboard including Serial NMEA output, and the 46203 Temp Tracker for displaying Temperature and Relative Humidity. For further information on Campbell Scientific, call: 403-454-2505.

Canadian Institute for Climate Studies

Created as a means of promoting industry, academia and government collaboration in the understanding and application of the climate system knowledge, the Canadian Institute for Climate Studies fosters scientific research, invests in climate system prediction, and develops opportunities for the industrial application of climate science and information in decision-making.

The Institute fosters research through the Climate Research Network, a Canadian network of university and government researchers which has been developed to manage research in a structured way. It is focused on modelling of global climate change and improving the modelling of climate processes involving energy and water, aerosols and land surfaces as well as enhanced understanding of climate variability.

The Institute is also placing an increasing emphasis on working with businesses and organizations of all types to assist them in addressing climate-related problems. The Institute currently counts amongst it members a number of large Canadian corporations in water resources, energy, agriculture and industry, as well as individuals from across the country. The Institute assists its members in the use of climate information, climate predictions and other applications where they are affected by climate variability and or change on a seasonal, annual or decadal timescale.

Further information on the Institute and how it can work with you can be found at our website http://www.cics.uvic.ca or by contacting the Institute at 1-250-721-8800. Dr. D. Kirk Dawson (Executive Director), Dr. Ian Rutherford (Research Manager), or Rick Lee (Manager, Product Development) will be pleased to assist you.

NASA/Goddard Space Flight Center Distributed Active Archive Center

NASA/Goddard Space Flight Center Distributed Active Archive Center [DAAC] is a data repository created as a part of NASA's Earth Observing System [EOS] to make data and information about Earth's environment and climate available to research, education, and information communities. Goddard DAAC products reflect a variety of data sets covering a range of disciplines. All products are available FREE through the World Wide Web. The DAAC also publishes and distributes data set collections on CD. These collections target specific Earth science topics of interest to the scientific, educational, and interdisciplinary Earth Science communities. Where to find us: Tel: 1-800-257-6151 WWW: http://gcmd.gsfc.nasa.gov/

Saskatchewan Research Council

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- design, development, and fabrication of industrial, scientific, manufacturing instruments
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- design & develop instrumentation devices for automation (*e.g.*, control software development; automated evaporation pan)

Where to find us: Tel: 306-933-5400/http://www.innovplace.saskatoon.sk.ca/src

SCI-TEC Instruments Inc.

SCI-TEC INSTRUMENTS
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SCI-TEC Instruments Inc. provides state-of-the-art environmental monitoring equipment to global markets. In conjunction with its subsidiary, the Dutch firm of Kipp & Zonen B.V., and distribution agreements with other corporations, SCI-TEC has developed, marketed, and sold sophisticated instrumentation to customers in over thirty-three countries on all seven continents.

The head office of SCI-TEC is located in Saskatoon, Saskatchewan, Canada and has over thirty-five employees encompassing a wide range of disciplines. A strong commitment to research and development has brought national awards for two of its products, the Brewer Spectrophotometer and the Petro Tag Tank Gauging System. Currently, activity is focused on the introduction of the PerspectUV ambient air gas monitors, utilizing electro-optic technology obtained through the purchase of the Russian firm, ENO.

Instruments on display at the CMOS Congress will include a mainstay of the SCI-TEC product line, the 2AP Two-Axis Tracker/Positioner. These rugged, reliable and affordable tracking/ positioning instruments are used to accurately point small and medium-sized payloads at terrestrial and celestial objects. Also on display will be radiation-measurement instruments from Kipp & Zonen, which can be combined with the 2AP Tracker to obtain an economical, fully equipped solar monitoring station. For further information on SCI-TEC, call 306-934-0101.

Plenary Speakers
Conférenciers des Plénières

GEWEX — **Session 1-A**
Dr. G. McBean (Atmospheric Environment Service, Downsview, ON)
"A Research Focus on Water and Energy Cycles: the Mackenzie GEWEX Study"
Monday, June 2
09:05
Lecture Theatre 143

BOREAS — **Session 2-A**
Dr. Alan K. Betts (Atmospheric Research, Pittsford, VM)
"A Review of Some Results From BOREAS: 1994-1996"
Tuesday, June 3
09:05
Lecture Theatre 143

HYDROLOGY — **Session 3-A**
Prof. M.K. Woo (McMaster University, Hamilton, ON)
Dr. Philip Marsh (National Hydrology Research Centre, Saskatoon, SK)
"Cold Regions Hydrological Research"
Wednesday, June 4
09:05
Lecture Theatre 143

WOCE/CLIVAR — **Session 4-A**
Dr. John Lazier (Bedford Institute of Oceanography, Dartmouth, NS)
"WOCE/CLIVAR and Interannual Variability in the North Atlantic"
Thursday, June 5
08:35
Lecture Theatre 143

Invited Speakers
Conférenciers Invités

A.J. Weaver (School of Earth and Ocean Sciences, University of Victoria, Victoria, BC)
"Global Ocean Modelling Within the Canadian Climate Research Network"
Session1-C3
Monday, June 2
Lecture Theatre 146

Inez Fung (School of Earth and Ocean Sciences, University of Victoria, Victoria, BC)
"The Canadian Climate Research Network on Integrative Carbon Studies"
Session 1-C3
Monday, June 2
Lecture Theatre 146

L.A. Barrie, J.P. Blanchet, & R. Leaitch (Atmospheric Environment Service, Downsview, ON)
"The Northern Aerosol Regional Climate Model [NARCM] Project"
Session 1-C3
Monday, June 2
Lecture Theatre 146

R.G. Lawford (NOAA Office of Global Programs, Silver Spring, MD)
"Challenges in Closing Water Budgets on Continental Scales: Lessons From the GCIP Experience"
Session 1-D1
Monday, June 2
Lecture Theatre 143

J. Arnold (NASA Headquarters, Washington, DC, USA)
C.A. Nobre (CPTEC/INPE, Cachoeira Paulista, SP, Brazil)
"The Large-Scale Biosphere-Atmosphere Experiment in Amazonia [LBA]"
Session 1-D1
Monday, June 2
Lecture Theatre 143

J. Derome (McGill University, Montreal, QU)
"Some Research Activities in Climate Variability"
Session 1-D3
Monday, June 2
Lecture Theatre 146

Daniel G. Wright (Bedford Institute of Oceanography, Dartmouth, NS)
"Modelling the North Atlantic as a Contribution to the Climate Research Network"
Session 1-D3
Monday, June 2
Lecture Theatre 146

W.R. Peltier (University of Toronto, Toronto, ON, Canada)
"Climate System History and Dynamics: A Canadian National Programme in Paleoclimatology"
Session 1-D3
Monday, June 2
Lecture Theatre 146

Dr. Madhav Khandekar (Atmospheric Environment Service, Downsview, ON)
"An Overview and Present Status of Long-Range/Seasonal Forecasting"
Session 4-A
Thursday, June 5
Lecture Theatre 143

P.L. Smith (South Dakota School of Mines and Technology, Rapid City, SD, USA)
L.R. Lemon (Lockheed Martin Tactical Defense Systems, Independence, MO, USA)
"Characteristics of Radar Echoes From Hailstorms"
Session 4-B4
Thursday, June 5
Lecture Theatre 146

D.M. (Don) McKay (Vice-President, Alberta Severe Weather, Calgary, AB)
"Hail: An Insurance Industry Perspective"
Session 4-B4
Thursday, June 5
Lecture Theatre 146

Committee Meetings & Social Events
Réunions de Comités et Activités Sociales

Day	Time	Meeting/Event	Chair/Contact	Room #
SUNDAY 01 June	09:00-16:00	National Climate Network Meeting	Jaques Derome	NHRC
	10:00-12:00	Scientific Committee Meeting	John Reid	NHRC
	10:00-16:00	Scientific Committee on Oceanic Research [SCOR]	Brian Nicholls	NHRC
	12:00-13:00	LUNCH (hosted by Congress /97)		NHRC, Front Foyer
	13:00-16:00	National Climate Network (continued)	Jaques Derome	NHRC
		SCOR (continued)	Brian Nicholls	NHRC
	13:00-15:00	➢ CMOS 'Centre Chairs' Meeting	John Reid	NHRC
		➢ Education Committee	Gerhard Reuter	NHRC
		➢ Publications Committee and A-O Board	Richard Asselin	NHRC
		➢ Accreditation Committee	Jim Salmon	NHRC
		➢ Private Sector Committee	Ambury Stuart	NHRC
	15:00-15:30	COFFEE		
	15:30-18:00	➢ CMOS Council Meeting ➢ CNC/IUGG Meeting	Peter Zwack Ron Stewart	NHRC NHRC
	19:00-21:00	★ **AEP *"Alternative Service Delivery"* (Open Meeting)**	**Gordon McBean**	**NHRC**
MONDAY 02 June	17:30-18:30	Icebreaker Reception *"Campbell Scientific Calendar Art"*	Claude Labine	Marquis Hall
	20:00-22:00	CMOS Annual General Meeting	Peter Zwack	Lecture Theatre 146
TUESDAY 03 June	12:10-13:40	Patterson Luncheon		Marquis Hall
	13:40-17:00	Open Forum *"Canadian Climate Program"*	Gordon McBean	Lecture Theatre 146
	17:30-18:30	Open GEWEX/MAGS Information Meeting	Ron Stewart	Marquis Hall
	19:30-20:30	Reception & Cash Bar		Marquis Hall
	20:30-21:30	'Entertaining' *Severe Weather* Photo-Art Display	the 'Verkaiks'	Marquis Hall
WEDNESDAY 04 June	07:15-08:15	GEWEX/MAGS Science Committee (Breakfast Meeting)	Ron Stewart	Bessborough Hotel
	10:30-17:00	Marine Icing Workshop (3 sessions)	Ed Lozowski	Arts 206
	13:40-17:00	Environment Canada's Severe Weather Program Presentation & Panel	Carr McLeod	Lecture Theatre 146
	18:00-19:00	Cash Bar		Marquis Hall
	19:00	CMOS Awards Banquet		Marquis Hall
THURSDAY 05 June	12:10-13:40	MT/Course-23 30th Anniversary Reunion Lunch		TBA
	18:00	Alberta Hail Projects (ALHAS/ALHAP) 40th Anniversary Reunion Dinner		TBA

CMOS 31st Congress Week-at-a-Glance
31ième Congrès - Aperçu de Semaine

Sunday 01 June	Monday 02 June	Tuesday 03 June	Wednesday 04 June	Thursday 05 June
09:00-12:00 **Committee Mtgs** NHRC 11 Innovation Blvd.	08:30-9:50 Introductions Exhibitor Presentations **GEWEX Plenary**	08:30-9:50 Introductions Poster Summaries **BOREAS Plenary**	07:15 **GEWEX/MAGS Science Committee Mtg** 09:00-9:50 **Hydrology Plenary**	08:30-10:10 **WOCE/CLIVAR Plenary** and Invited Talk
	09:50-10:10 Health Break	09:50-10:10 Health Break	09:50-10:10 Health Break	09:50-10:10 Health Break
	10:10-12:10 **GEWEX-1** Regional Climate Modelling Data Assimilation Aviation Meteorology	10:10-12:10 **BOREAS-1** Atmospheric Modelling Cloud & Precipiation Physics-1 Ocean Circulation & Modelling	10:10-12:10 Cold Climate Hydrology Climate/Interanual Variability-1 Mesoscale Processes & Severe Weather-2 Marine Icing Workshop-1	10:10-12:10 WOCE/CLIVAR Long-Range Seasonal Forecasting-1 HAIL-1
12:00-13:00 Lunch	12:10-13:40 Lunch	12:10-13:40 Patterson Lunch Marquis Hall	12:10-13:40 Lunch	12:10-13:40 Lunch
13:00-15:00 **Committee Mtgs** NHRC 11 Innovation Blvd.	13:40-15:00 **GEWEX-2** Paleoclimate Climate Research Network-1 Weather Forecasting-1	13:40-15:00 **BOREAS-2** Coastal Oceanography Cloud & Precipitation Physics-2 Climate Program Board Open Forum-1	13:40-15:00 Boundary Layer Meteorology Climate/Interanual Variability-2 Environment Canada's Severe Weather Program-1 Marine Icing Workshop-2	13:40-15:00 Middle Atmosphere Dynamics-1 Long-Range Seasonal Forecasting-2 HAIL-2
15:00-15:30 Health Break	15:00-15:20 Health Break	15:00-15:20 Health Break	15:00-15:20 Health Break	15:00-15:20 Health Break
15:30-18:00 **CMOS Council Mtg** **CNC/IUGG Mtg** NHRC 11 Innovation Blvd.	15:20-17:00 **GEWEX-3** Air Quality Climate Research Network-2 Weather Forecasting-2	15:20-17:00 POSTER Session Mesoscale Processes & Severe Weather-1 Climate Program Board Open Forum-2	15:20-15:70 **GEWEX-4** Agriculture/Forest Meteorology/Hydrology Environment Canada's Severe Weather Program-2 Marine Icing Workshop-3	15:20-17:00 Middle Atmosphere Dynamics-2 HAIL-3
17:30-18:00 Cocktails	Icebreaker Reception (Campbell Scientific Social)	17:30-18:30 **GEWEX/MAGS Open Mtg** Marquis Hall	18:00 Cocktails followed by CMOS Awards Banquet	18:00 ALHAS/ALHAP 40th Ann. Dinner
19:00-21:00 **AEP Open Mtg** NHRC 11 Innovation Blvd.	20:00-22:00 **CMOS AGM** Lecture Theatre 146	19:30-20:30 Cocktails Marquis Hall 20:30-21:30 **Severe Weather Photo Art Display** Marquis Hall		

TUESDAY, 03 June (AM)

	PLENARY SESSION 2-A: BOREAS (Lecture Theatre 143)
08:30-08:35	Welcoming Remarks & Introductions ***(Geoff Strong, Chair)***
08:35-09:05	Poster Paper Summaries ***(Oscar Koren, Chair)*** (15 posters, 2 min/each)
09:05-09:50	***Dr. Alan K. Betts***, Private Meteorologist, Pittsford, VT **"A Review of Some Results from BOREAS: 1994-1996"**
09:50-10:10	**HEALTH BREAK & EXHIBITS**

SESSIONS 2-B

10:10-12:10 start times only	**Session 2-B1 (Lect. Th. 143)** **BOREAS -1** ***Chair: Peter Schuepp***	**Session 2-B2 (Room 217)** **Atmospheric Modelling** ***Chair: Hal Ritchie***	**Session 2-B3 (Room 200)** **Cloud and Precipitation Physics - 1** ***Chair: John Reid***	**Session 2-B4 (Room 206)** **Ocean Circulation & Modelling** ***Chair: Peter Smith***
10:10	The Climatology of the BOREAS Years of 1994, 1995, and 1996 at a Select BOREAS/SRC Mesonet Site ***(S.R. Shewchuk)***	EuroMET: Teaching Meteorology Internationally Using Internet *(P. Zwack & **C. Page**)*	The Effect of Cumulus Clouds on the Sub-Grid Scale Distribution of Quasi-Conserved Variables in a Statistical Layer Cloud Scheme *(**N. McFarlane**, K. Abdella, & U. Lohmann)*	A Second Order Turbulence Closure Scheme for the Upper Ocean *(**S.J.D. D'Alessio**, N. McFarlane, & K. Abdella)*
10:30	Atmosphere-Surface Coupling Over the Boreal Forest Determined from Aircraft-Based Flux Relationships and Surface Conditions During BOREAS 1994 *(**C.M. Mitic**, P.H. Schuepp, R. Desjardins, & I. MacPherson)*	Experiments with a Two-Time-Level Version of the Canadian Global Spectral Forecast Model *(**H. Ritchie** & C.Beaudoin)*	Comparing Different Cloud Schemes of a Single Column Model by Using Mesoscale Forcing and Nudging Technique *(**U. Lohmann**, N. McFarlane, L. Levkov, & K. Abdella)*	A General Pressure Gradient Scheme and its Applications to North Atlantic Modelling *(Y. Song & **D.G. Wright**)*
10:50	Lessons from BOREAS *(**P.H. Schuepp**, S.O. Ogunjemiyo, B. Abareshi, R.L. Desjardins, & J.I. MacPherson)*	Diagnosing the Motion of a Hurricane in the Canadian Global Forecast Model ***(P. Zwack)***	Influence of Temperature on the Droplet Spectra Formation ***(F. Celik)***	Seasonal Hydrographic and Baroclinic Circulation on the Newfoundland Shelf *(**Z. Xu**, J. Loder, C. Hannah, & B. Petrie)*
11:10	Effects of Turbulence and Climatic Variability on the Annual Carbon Sequestration by a Boreal Aspen Forest *(**W.J. Chen**,T.A. Black, P.C. Yang, A.G. Barr, H.H. Nenmann, P.D. Blacken, Z. Nesic, J. Eley, & M.D. Novak)*	Matching Numerical Methods to Atmospheric Dynamics as a Function of Scale *(**P. Bartello** & S.J. Thomas)*	Radar Observations of Snow Formation *(**G. Reuter** & R. Beaubien)*	Experiments with a Comprehensive Finite Element Model Examining the Scotian Shelf Region *(**D.A. Greenberg**, C.G. Hannah, J.W. Loder, & J.A. Shore)*
11:30		The Response of a Simple Nonlinear Model Atmosphere to Sea Surface Temperature Anomalies in the North Pacific *(**Z. Xing**, J. Derome, H. Lin, & C.A. Lin)*	Determination of Hail Storm Cloud Structure From Satellite Microwave Measurements ***(I.G. Rubinstein)***	A Semi-Lagrangian Finite Element Barotropic Ocean Model *(**D.Y. Le Roux**, C.A. Lin, & A. Staniforth)*
11:50		The Canadian MC2 Modelling System - Massively Parallel Implementation & Other Recent Developments *(**M. Desgagne**, S. Thomas, R. Benoit, & P. Pellerin)*		
12:10-13:40	**PATTERSON LUNCHEON** (Marquis Hall)			

*Speakers noted in **bold** text   *Start times are approximate, unless noted otherwise in title box

SESSIONS 2-C

13:40-15:00 start times only	Session 2-C1 (Lect. Th. 143) BOREAS - 2 *Chair: Peter Schuepp*	Session 2-C2 (Room 206) Coastal Oceanography *Chair: Denis Lefaivre*	Session 2-C3 (Room 200) Cloud and Precipitation Physics - 2 *Chair: George Isaac*	Session 2-C4 (Lect. Th. 146) Climate Program Board Open Forum - 1 *Chair: Gordon McBean*
13:40	A Simulation Study on the Enhancement of Nocturnal Inversion and the Formation of Low Level Jet [LLJ] Over the Boreal Forest *(**H. Wang**, A.K. Lo, & Y. Li)*	Seasonal Mean Circulation in the Laurentian Channel Region *(G. Han, P.C. Smith, & J.W. Loder)*	Ground-Based Measurements of the Near-Infrared Anomalous Cloud Absorption Effect *(W.F.J. Evans)*	*"New Partnerships for The Canadian Climate Program"* "OPEN FORUM"
14:00	Mixed Boundary-Layer Evolution Above Boreal Forest *(A.G. Barr & A.K. Betts)*	Coastal Applications of Finite Element Models *(**D.A. Greenberg** & J.D. Chaffey)*	Cloud Vertical Inhomogeneity and Cloud Anomalous Absorption *(L. Jiangnan)*	
14:20	Hypotheses on Feedbacks of Trembling Aspen Forests on Regional Weather and Climate in the Southern Boreal Forest of Western Canada *(**E.H. Hogg**, P.A. Hurdle, T.A. Black, P.D. Blanken, A. Wu, W. Chen, & A. Barr)*	Daily Forecast of an Oil Spill Trajectory and Forecasted Bottom Contamination by PCBs During the 1996 Salvage of the Irving Whale Barge *(**D. Lefaivre**, F.J. Saucier, J. Chasse, & A. Gosselin)*	New Insights into Freezing Drizzle Formation Mechanisms *(**G.A. Isaac**, A. Korolev, S.G. Cober, J.W. Strapp, A. Tremblay, & R.A. Stuart)*	
14:40	BOREAS Mesoscale Evapotranspiration Modelling Project *(C. Pion, **R. Leconte**, E.D. Soulis, & N. Kouwen)*	Improving Search and Rescue Forecasts with Data Assimilative Models for Surface Drift *(**J. Sheng**, P.C. Smith, K.R. Thompson, & D.J. Lawrence)*	Formation of Bi-Modal Droplet Spectra in Stratiform Clouds *(**F. Celik** & J.D. Marwitz)*	
15:00-15:20	**HEALTH BREAK, EXHIBITS, & POSTERS**			

SESSIONS 2-D

15:20-17:00 start times only	Session 2-D1 (Room 202, 203, 214) POSTERS** *Chair: Oscar Koren*		Session 2-D3 (Room 200) Mesoscale Processes & Severe Weather - 1 *Chair: Paul Joe*	Session 2-D4 (Lect. Th. 146) Climate Program Board Open Forum - 2 *Chair: Gordon McBean*
15:20	*Data Systems & Data Assimilation* - 3 posters		High Resolution Simulation of the Severe Precipitation Events *(**W.Yu**, C.A. Lin, & R. Benoit)*	*"New Partnerships for The Canadian Climate Program"* "OPEN FORUM"
15:40	*Diagnostic & Mesoscale Studies* - 3 posters		Multi-Model High-Resolution Ensemble Mesoscale Forecast Research for Western Canada *(**R. Stull**, H. Modzelewski, & J. Hacker)*	
16:00	*Remote Sensing Applications* - 2 posters		The Severe Weather Soundings and Radar Storm Classification *(**L. Xin**, N. Donaldson, & P. Joe)*	
16:20	*Atmospheric/Climate Models* - 2 posters		*Lake Breeze Triggered Thunderstorms: Do They Pose a Significant Severe Weather Threat? (D.M.L. Sills)*	
16:40	*Climate Change & Impacts* - 3 posters		*An Experiment to Study the Effects of Lake Breezes on Convective Weather (P.W.S. King)*	

*Speakers noted in bold text *Start times are approximate, unless noted otherwise in title box **All poster presenters are available througout

WEDNESDAY, 04 June (AM)

	PLENARY SESSION 3-A: Hydrology (Lecture Theatre 143)
09:00-09:05	Morning Introductions ***(Geoff Strong, Chair)***
09:05-09:50	***Prof. M.K. Woo*** (McMaster University, Hamilton, ON) and ***Dr. P. Marsh*** (National Hydrology Research Institute, Saskatoon, SK) **"Cold Regions Hydrological Research"**
09:50-10:10	**HEALTH BREAK & EXHIBITS**

SESSIONS 3-B

10:10-12:10 start times only	**Session 3-B1 (Room 217)** **Cold Climate Hydrology** ***Chair: John Pomeroy***	**Session 3-B2 (Lect. Th. 143)** **Climate/Interannual Variability - 1** ***Chair: Madhav Khandekar***	**Session 3-B3 (Room 200)** **Mesoscale Processes & Severe Weather - 2** ***Chair: Geoff Strong***	**Session 3-B4 (Room 206)** **MARINE ICING WORKSHOP - 1** **Presentations** ***Chair: Chuck Ryerson***
10:10	Probability of Blowing Snow Occurrence by Wind *(**L. Li** & J.W. Pomeroy)*	Climatic Connections in Inter-annual Variability for the Marine and Land Environment *(**B.J. Topliss**, J.M. Potts, R.S. Shiel, & Y.A. Papadopoulous)*	Descending Reflectivity Cores and the Onset of Severe Weather *(**L. Li** & P. Joe)*	Some Recent Developments in Marine Icing Research *(**E.P. Lozowski**)*
10:30	Snow Interception and Sublimation in a Boreal Forest *(**J.W. Pomeroy**, N.R. Hedstrom, J. Parviainen, & D.M. Gray)*	On the ENSO-Related Atmospheric Teleconnection Patterns in the Northern Hemisphere *(**R. Mo**, J.C. Fyfe, & J. Derome)*	Some Aspects of Tornado Climatology in Southern Ontario *(**P.W.S. King** & D.M.L. Sills)*	Operational Practices and Their Applicability to Forecast Freezing Spray in Arctic Waters *(**A. Nowak**)*
10:50	Energetics of Boreal Forest Snowmelt *(**D.A. Faria** & J.W. Pomeroy)*	A Comparison of Inter-Annual Statistics Derived From NCEP/NCAR Reanalyses and NMC/NCEP Operational Analyses *(**S.J. Lambert**)*	Tornado Tracks and Damaging Downburst Areas of the 4 July 1996 Saskatoon-Maymont-Osler Thunderstorm Outbreak *(**S. Knott** & D. Clarke)*	An Experimental Study of Spongy Ice Growth *(**Z. Shi** & E. Lozowski)*
11:10	Modelling Surface Energy Fluxes Over a Melting Arctic Snowcover *(**N.N. Neumann**, P. Marsh, & R.L.H. Essery)*	The PNA Pattern, Transient Eddies and SST Anomalies in the Tropical and Northern Pacific *(**Jian Sheng**)*	The April 20th, 1996 Tornadoes in Southern Ontario *(**A. Verkaik**)*	Progress in De-Icing Technology Applied to Overhead Cables *(**J.-L. Laforte** & M.L. Allaire)*
11:30	Hydrological Modelling of Snowmelt Dominated Streamflow *(**B.L. Li** & G.K. Kite)*	Inter-Annual Variability of Precipitation in an Ensemble of AMIP Climate Simulations Conducted with the CCC GCM2 *(X.L. Wang & **F.W. Zwiers**)*	The Open-Ended Interview in Tornado Research: Treasure Chest or Pandora's Box? *(**J. Verkaik**)*	A Theoretical Investigation of the Distribution of Freshwater Spongy Spray Icing on a Vertical Cylinder *(**R.Z. Blackmore** & E.P. Lozowski)*
11:50		Climate Variability in the South Atlantic: a Singular Value Decomposition Analysis *(**S.A. Venegas**, L.A. Mysak, & D.N. Straub)*		
12:10-13:40	**LUNCH**			

*Speakers noted in **bold text**

*Start times are approximate, unless noted otherwise in title box

WEDNESDAY, 04 June (PM)

SESSIONS 3-C

13:40-15:00 start times only	**Session 3-C1 (Room 200)** **Boundary Layer Meteorology** ***Chair: Stan Shewchuk***	**Session 3-C2 (Lect. Th. 143)** **Climate/Interannual Variability - 2** ***Chair: Madhav Khandekar***	**Session 3-C3 (Lect. Th. 146)** **Environment Canada's Severe Weather Program - 1** ***Chair: Carr McLeod***	**Session 3-C4 (Room 206)** **MARINE ICING WORKSHOP - 2** ***Chair: Ryan Blackmore***
13:40	Modelling Boundary Layer Clouds Using a Statistical Cloud Scheme *(**K. Abdella** & N. McFarlane)*	Impact of a Warming Climate on Evapotranspiration on the Eastern Prairies *(**R.L. Raddatz** & C.F. Shaykewich)*	Environment Canada's Severe Weather Program Overview - Past, Present, and Future ***(N. Cutler)***	Dynamic Effects of Marine Icing on Vessel Stability *(**K.K. Chung** & E.P. Lozowski)*
14:00	Convective Boundary Layer Wind and Temperature Profiles *(E. Santoso & **R. Stull**)*	Changes in the Extremes of the Climate Simulated by CCC GCM2 Under CO_2 Doubling *(F.W. Zwiers & **V.V. Kharin**)*	The National Weather Radar Project *(**B. Greer**, G. Pearson, & P. Ford)*	Using Adaptive Logic Neural Networks to Predict Ship Icing ***(J.M.D. Bullas)***
14:20	Size Distributions of Boundary-Layer Cumulus Clouds *(**L.K. Berg** & R.B. Stull)*	Spatial-Temporal Structures of Trend and Oscillatory Variabilities of Precipitation Over Northern Eurasia *(X.L. Wang & **H.-R. Cho**)*	The Canadian Lightning Detection Network - An Overview *(**G. Fournier**, C. McLeod, & R. Pyle)* *- 30 min*	A New Instrument for Measuring Marine Icing on Offshore Structures *(T.W. Forest, B. Faulkner, M. Chekhar, & **E.P. Lozowski**)*
14:40	Extraction of the Refractive Index Field Near the Surface by Radar Using Ground Targets *(**F. Fabry**, C. Frush, I. Zawadzki, & A. Kilambi)*	Hydrologic Sensitivity of Wascana Creek to Climate Variability *(**R.F. Hopkinson** & L.H. Wiens)*	**14:50** Discussion	Structure and Properties of Superstructure Spray Ice on a Coast Guard Cutter ***(C.C. Ryerson)***
15:00-15:20	**HEALTH BREAK & EXHIBITS**			

SESSIONS 3-D

15:20-17:00 start times only	**Session 3-D1 (Lect. Th. 143)** **GEWEX-4: Basin-Scale Experiments, II** ***Chair: Terry Krauss***	**Session 3-D2 (Room 200)** **Agriculture/Forest Meteorology/Hydrology** ***Chair: Alan Barr***	**Session 3-D3 (Lect. Th. 146)** **Environment Canada's Severe Weather Program - 2** ***Chair: Carr McLeod***	**Session 3-D4 (Room 206)** **MARINE ICING WORKSHOP - 3** ***Chair: Ed Lozowski***
15:20	The Upper Missouri River Basin Hydrology Project *(**P.L. Smith** & S.O. Farwell)*	Association Between Circulation Anomalies in the Mid-Troposphere and Area Burned by Forest Fires in Canada *(**W.R. Skinner**, B.J. Stocks, & D.L. Martell)*	Mesoscale Modelling in Support of Severe Weather Prediction ***(Pierre Dubreuil)***	**ROUNDTABLE DISCUSSION OF FUTURE DIRECTIONS FOR MARINE ICING RESEARCH**
15:40	The Mackenzie GEWEX Study [MAGS] Observational Strategy *(**B. Kochtubajda**, G.S. Strong, G.W.K. Moore, R.E. Stewart, P. Marsh, H.G. Leighton, H. Ritchie, W.R. Rouse, E.D. Soulis, & R.W. Crawford)*	An example of the Potential Value of Numerical WindFlow Models *(**J.D. Wilson** & T.K. Flesch)*	WeatherAlert - Delivering the Message in Time to Make a Difference! ***(E.R. Adamson)***	
16:00	Atmospheric Sciences and Other Related Activities of SRC Within the Southeastern Part of the MAGS Project Area ***(S.R. Shewchuk)***	Partitioning of Energy and Water in Boreal Forest Ecosystems *(**R. Granger** & J.W. Pomeroy)*	**PANEL DISCUSSION**	
16:20	Data Management for the Mackenzie GEWEX Study [MAGS] ***(R.W. Crawford)***	Rainfall Interception in a Subhumid Forest: Implications for Water and Energy Cycles *(**B. Toth**, J.W. Pomeroy, & R.J. Granger)*		
16:40	Statistical Relationships between Topography and Regional Finite Element Model Quantitative Precipitation Forecasts in the Mackenzie Basin of Canada *(**B.A. Proctor** & C. Smith)*	Accurate Monitoring of Soil Moisture on a Scale of Hectares Using Deep Ground Water Piezometers *(**G. van der Kamp** & R. Schmidt)*		

*Speakers noted in bold text   *Start times are approximate, unless noted otherwise in title box

Daily Session Schedule
Programme Journalier

MONDAY, 02 June (AM)

PLENARY SESSION 1-A: GEWEX *(Geoff Strong, Chair)* (Lecture Theatre 143)

08:30-09:00	Welcoming Remarks & Introductions ***(Geoff Strong)***
08:35-08:40	Welcome from University of Saskatchewan (***Dr. Dennis Johnson***, Associate Vice-President, Research)
08:40-08:45	Welcome from City of Saskatoon
08:45-09:05	Exhibitors' Presentations ***(Oscar Koren)*** (2 min/each)
09:05-09:50	***Dr. G. McBean***, ADM Atmospheric Environment Service, Downsview, ON **"A Research Focus on Water and Energy Cycles: The Mackenzie GEWEX Study"** ***Chair: Ron Stewart***
09:50-10:10	**HEALTH BREAK & EXHIBITS**

SESSIONS 1-B

10:10-12:10 start times only	**Session 1-B1 (Lect. Th. 143)** **GEWEX-1:** **Surface Water & Energy Cycles** ***Chair: Ron Stewart***	**Session 1-B2 (Room 217)** **Regional Climate Modelling** ***Chair: Norm McFarlane***	**Session 1-B3 (Room 200)** **Data Assimilation** ***Chair: Ambury Stuart***	**Session1-B4 (Room 206)** **Aviation Meteorology** ***Chair: John Bullas***
10:10	Water and Energy Fluxes at the Forest-Tundra Transition in Northern Canada *(**P. Marsh**, J. Pomeroy, W. Rouse, & W. Quinton)*	Sensitivity of the One-Dimensional Kain-Fritsch Convection Scheme *(**D. Paquin** & R. Laprise)*	Decision Support System as a Useful Tool for Observational Network Rationalization *(P. Ford, **T. Yip**, & G. Grieco)*	Aviation Impact Variables and the CMC Aviation Weather Database *(M.-F. Turcotte, D. Beauchamp, & **R. Verret**)*
10:30	The Influence of the Near-Stream Area on Streamflow in an Arctic Tundra Basin *(**W.L. Quinton** & P. Marsh)*	A Modelling Assessment of the Impacts of Historical Wetland Drainage and Other Land Use Changes on the Regional Climate of the Canadian Prairies *(**C.D. Smith**, R. Lawford, & A. Barr)*	Adjoint Data Assimilation in Coupled Atmosphere-Ocean Models - Determining Model Initial Conditions in a Simple Equatorial Model *(J. Lu & **W. Hsieh**)*	Using A Column Boundary Layer Model to Provide Meteorological Support to the US Aircraft Vortex Spacing System *(**R. Tardif** & P. Zwack)*
10:50	Application of a Radiation-Temperature Index Snowmelt Models to the Lower Liard River Valley *(**A. Pietroniro**, L. Hamlin, T.D. Prowse, E.D. Soulis, & N. Kouwen)*	Climate of Western Canada Under Current and Enhanced Greenhouse Gases Concentration as Simulated by the Canadian Regional Climate Model *(**H. Coté**, R. Laprise, M. Giguere, & G. Bergeron)*	Moving Towards the Implementation of a 3-D Variational Assimilation System at the Canadian Meteorological Centre *(**P. Koclas**, P. Gauthier, C. Charette, & S. Laroche)*	A Nowcasting System for Ground De-icing *(**P. Joe**, B. Sheppard, & N. Donaldson)*
11:10	Hydrometeorological Complexities Affecting Flooding of the Peace-Athabasca Delta *(**T.D. Prowse** & M.F. Conly)*	Application of the Canadian Regional Climate Model to Eastern Canada and the Laurentian Great Lakes *(**S.G. Goyette**, N.A.M. McFarlane, & G.M.F. Flato)*	A Comparison of the BOREAS and Atmospheric Environment Service Humidity Sensor at Meadow Lake, Saskatchewan *(**S.R. Shewchuk**, B.J. Smith, & A.K. Betts)*	Using Forecast Production Assistant to Produce a Shared Graphical Aviation Area Forecast *(**D. Kania** & M.Van Olst)*
11:30	Regional Variations in Water Balance Regime in the Continental Arctic Using Isotopic Tracers *(**J.J. Gibson** & T.D. Prowse)*		Can We Estimate Net Radiation From Solar Radiation Measurements? *(**J. Eley** & A. Barr)*	Quantitative Glace Accretion Measurements From the U.S. National Weather Service ASOS *(**C.C. Ryerson** & A.C. Ramsay)*
11:50	Basin-Scale Surface Energy and Water Balance for GCIP From the ECMWF Reanalysis *(**A.K. Betts** & P. Viterbo)*			
12:10-13:40	**LUNCH**			

SESSIONS 1-C

13:40-15:00 start times only	Session 1-C1 (Lect. Th. 143) GEWEX - 2: Atmospheric Water & Energy Cycles *Chair: Phil Marsh*	Session 1-C2 (Room 200) PaleoClimate *Chair: Jeff Whiting*	Session 1-C3 (Lect. Th. 146) Climate Research Network - 1 *Chair: John Stone*	Session 1-C4 (Room 206) Weather Forecasting - 1 *Chair: Ron Hopkinson*
13:40	Atmospheric Moisture Flux Convergence Over the Mackenzie Basin *(**A.G. Barr**, M. Wang, G.S. Strong, & B. Proctor)*	Paleoclimatic Response of the Closure of the Isthmus of Panama in a Coupled Ocean-Atmosphere Model *(**T.Q. Murdock**, A.J. Weaver, & A.F. Fanning)*	Global Ocean Modelling Within the Canadian Climate Research Network *(**A.J. Weaver**)* *- 30 min*	Operational Models and Analysis Systems at the Canadian Meteorological Centre *(**R. Hogue**)*
14:00	RFE Model Validation of MAGS Moisture Sources and Sinks *(**G.S. Strong**, B. Proctor, A.G. Barr, & M. Wang)*	Do Epsiodic Glacier Surges Explain Rapid Climatic Variability During the Last Glaciation? *(**H. Bjornsson** & L.A. Mysak)*	14:10 The Canadian Climate Research Network on Integrative Carbon Studies *(**Inez Fung**)* *- 25 min*	Kalman Filters to Forecast Statistical Surface Temperature *(M.-F. Turcotte, **R. Verret**, & G. Desautels)*
14:20	Monthly Rainfall Estimates Over the Mackenzie Basin Using GOES-9 (VIS,IR) Data *(**A. Bellon**, I. Zawadzki, & S. Gagnon)*	Precipitation Variability in Southwestern Saskatchewan and Southeastern Alberta: A 300-Year Proxy Record From the Cypress Hills *(**D.J. Sauchyn**)*	14:35 The Northern Aerosol Regional Climate Model [NARCM] Project *(L.A. Barrie, **J.P. Blanchet**, & R. Leaitch)* *- 25 min*	Use of Regional Model Grid Point Data in Cold Season Quantitative Precipitation Forecasting *(**B.P. Murphy**)*
14:40	Atmospheric Warming During the Cold Season Over the Mackenzie Basin *(**Z. Cao**, R.E. Stewart, & W. Hogg)*			A Product Generator *(**R. Verret**, D. Vigneux, J. Marcoux, F. Petrucci, C. Landry, L. Pelletier, G. Hardy, and R. Parent)*
15:00-15:20	HEALTH BREAK & EXHIBITS			

SESSIONS 1-D

15:20-17:00 start times only	Session 1-D1 (Lect. Th. 143) GEWEX-3: Basin-Scale Experiments - I *Chair: Geoff Strong* (15:20)	Session 1-D2 (Room 217) Air Quality *Chair: John Maybank*	Session 1-D3 (Lect. Th. 146) Climate Research Network - 2 *Chair: John Stone*	Session 1-D4 (Room 206) Weather Forecasting - 2 *Chair: Fraser Hunter*
15:20	15:20 Challenges in Closing Water Budgets on Continental Scales: Lessons From the GCIP Experience *(**R.G. Lawford**)* *- 25 min*	Modelling Pollutant Emissions From a Road Network *(**J.A. Salmond** & D.R. Middleton)*	Some Research Activities in Climate Variability *(**J. Derome**)* *- 30 min*	Effects of Atmospheric Refraction on Sunrise and Sunset *(**R.D. Sampson** & E.P. Lozowski)*
15:40	15:50 The Large-Scale Biosphere-Atmosphere Experiment in Amazonia [LBA] *(**C.A. Nobre** & **J. Arnold**)* *- 30 min*	CANFIS: A Procedure to Build Statistical Air-quality Forecast Models Based on CART and Neuro-Fuzzy Inference Systems *(**W.R. Burrows** & **J. Montpetit**)*	15:50 Modelling the North Atlantic as a Contribution to the Climate Research Network *(**D.G. Wright**)* *- 30 min*	Public Forecast Verification *(**R. Verret**)*
16:00		Developing Wind Data for Dispersion Modelling in Complex Terrain *(**R.G. Humphries**, S. O'Kane, A. Schutte, & J. Mitchel)*		Performance Measurement Based on Client's Needs *(**J.M. Paola** & J.E. Shaykewich)*
16:20	Modelling the Hydrological Cycle in the Mackenzie River Basin *(**M.D. MacKay**, R.E. Stewart, & G. Bergeron)*	Application of the Canadian Regional Climate Model to Tropospheric Ozone Climatology *(**V.S. Bouchet**, E. Torlaschi, R. Laprise, & J.C. McConnell)*	Climate System History and Dynamics: A Canadian National Programme in Paleoclimatology *(**W.R. Peltier**)* *- 30 min*	Rethinking Our Weather Forecast Service: Moving Beyond "Partly Cloudy with a 20 Percent Chance of a Shower" *(**S. Ricketts**)*
16:40	The Impact of the Canadian Land Surface Scheme on Monthly Simulations of Hydrological Parameters over the Mackenzie River Basin *(**E. Radeva** & H. Ritchie)*		16:50 Discussion	

*Speakers noted in bold text *Start times are approximate unless otherwise noted in title box

THURSDAY, 05 June (AM)

PLENARY SESSION 4-A: WOCE/CLIVAR and Invited Talk *(Dan Wright, Chair)* (Lecture Theatre 143)	
08:30-08:35	Morning Introductions ***(Geoff Strong)***
08:35-09:20	***Dr. John Lazier***, BIO, Dartmouth, NS **"WOCE/CLIVAR and Interannual Variability in the North Atlantic"** ***Chair: Dan Wright***
09:20-09:50	***Dr. Madhav Khandekar***, AES, Downsview, ON **"An Overview and Present Status of Long-Range/Seasonal Forecasting"**
09:50-10:10	**HEALTH BREAK, EXHIBITS, & POSTERS**

SESSIONS 4-B

10:10-12:10 start times only	**Session 4-B1 (Room 206)** **WOCE/CLIVAR** ***Chair: Dan Wright***	**Session 4-B2 (Room 200)** **Long-Range/Seasonal Forecasting-1** ***Chair: Steve Lambert***		**Session 4-B4 (Lect. Th. 146)** **HAIL-1 Presentations** ***Chair: Peter Summers***
10:10	A Coupled Ocean General Circulation and Marine Foodweb Model of the Subarctic Pacific *(S. Haigh, K.L. Denman, & **W.W. Hsieh**)*	ENSO Related Precipitation Responses Over Canada *(A. Shabbar, **B.R. Bonsal**, & M.L. Khandekar)*		Alberta Hail Research Retrospective - Part I, The Alberta Hail Studies Project 1957-1973 ***(P.W. Summers)***
10:30	The Influence of the Mean State on Interdecadal Variability in Flat-Bottomed Ocean Models *(**K.A. Peterson** & R.J. Greatbatch)*	Long-Range Forecasting at the Canadian Meteorological Centre *(A. Plante, N. Gagnon, & **L. Lefaivre**)*		Alberta Hail Research Retrospective - Part II, The Alberta Hail Project 1974-1986 ***(J.H. Renick)***
10:50	North Atlantic Current Transport From Moored Array Measurements *(**R.M. Hendry**, R.A. Clarke, & D.R. Watts)*	Ensemble Prediction System Applications at the Canadian Meteorological Centre *(A. Bergeron, P.L. Houtekamer, **L. Lefaivre**, & R. Verret)*		Characteristics of Radar Echoes From Hailstorms *(**P.L. Smith** & L.R. Lemon)* *- 30 min*
11:10	Sensitivity Experiments of the Influence of Sea Ice Distribution on Cyclone Behaviour *(**P. Gachon** & P. Zwack)*	A Phase Space Approach to Seasonal Prediction *(**R. Wang & G. Brunet**, R. Vautard, G. Plaut, & H. Van den Dool)*		**11:20** Hail: An Insurance Industry Perspective ***(D.M. McKay)*** *- 30 min*
11:30	The Interactions Between Sea Ice and the Thermohaline Circulation *(**Z. Wang** & L.A. Mysak)*	Long-Range Forecasting for the Canadian Prairies: A Cost/Benefit Analysis *(**E. Ray Garnett** & Madhav L. Khandekar)*		
11:50				The New Alberta Hail Suppression Project *(**T.W. Krauss** & J. Renick)*
12:10-13:40	**MT/Course-23**	**LUNCH**		

*Speakers noted in **bold** text

*Start times are approximate, unless noted otherwise in title box

	SESSIONS 4-C			
13:40-15:00	**Session 4-C1 (Room 206)** **Middle Atmosphere: Dynamics, Chemistry, & Middle Atmosphere Modelling -1** ***Chair: Alan Manson***	**Session 4-C2 (Room 200)** **Long-Range/Seasonal Forecasting - 2** ***Chair: Steve Lambert***		**Session 4-C4 (Lect. Th. 146)** **HAIL - 2, presentations** ***Chair: Peter Summers***
13:40	Improving Stratospheric Circulations with a Hybrid Vertical Coordinate Version of the Canadian Global Spectral Forecast Model *(**H. Ritchie** & N.R. Ek)*	Construction of a 3-D State Space for the ENSO System Using Neural Networks and Ensemble Forecasting with Neural Networks *(B. Tang & **W.W. Hsieh**)*		The Greek National Hail Suppression Program Revisited *(**C.M. Sackiw**)*
14:00	Diagnostic Study of a Stratospheric Sudden Warming During the Winter of 1994/95 *(**H. Sheng** & H. Ritchie)*	Forecasting Tropical Pacific Sea Surface Temperatures with Neural Network Models *(F.T. Tangang, **W.W. Hsieh**, B. Tank, & A.H. Monahan)*		Hail Measurement Re-Visited *(**G.S. Strong**)*
14:20	Momentum Flux Measurements With a VHF Windprofiler Radar in Eastern Canada *(**R. Belu** & W.K. Hocking)*	Results from the Historical Forecasting Project *(**A. Plante**, N. Gagnon, & L. Lefaivre)*		Overview of Some Feeder-cloud Transport and Dispersion Experiments Using a Gaseous Tracer and Radar Chaff *(**P.L. Smith**, T.E. Bowen, A.G. Detwiler, & J.L. Stith)*
14:40	Discussion	The Genesis of the PNA Pattern and its Predictability in a Simple Model *(**H. Lin**, J. Derome, & C.A. Lin)*		Polarization Radar Study of Chaff in an Alberta Hailstorm *(**P.I. Joe**, A. Holt, & B. Kochtubajda)*
15:00-15:20	**HEALTH BREAK**			
	SESSION 4-D			
15:20-17:00 start times only	**Session 4-D1 (Room 206)** **Middle Atmosphere: Dynamics, Chemistry, & Middle Atmosphere Modelling - 2** ***Chair: Alan Manson***			**Session 4-D4 (Lect. Th. 146)** **HAIL - 3** **Presentations and Discussion** ***Chair: Peter Summers***
15:20	The Development of the Canadian Middle Atmosphere Model: A Status Report *(S.R. Beagley, J. de Grandpre, J.N. Koshyk, N.A. McFarlane, & **T.G. Shepherd**)*			The Alberta Hail Project Digital Data Archive: One Year on the World Wide Web *(**B. Kochtubajda**, C. Humphrey, E.P. Lozowski, & M.R. Johnson)*
15:40	Transport and Chemistry of Constituents in the Middle Atmosphere Using CMAM *(**J. de Grandpre**, J.C. McConnell, S.R. Beagley, & P.C. Croteau)*			Hailstorm Forecasting Re-Visited *(**G.S. Strong**)*
16:00	Impact of the Doppler Spread Gravity Wave Drag Parameterization on the Middle Atmosphere of a General Circulation Model: Effects on the Zonal Mean Flow and Tides *(C. McLandress, **N. McFarlane**, & S. Beagley)*			Hail Damaged Shingles *(**R. Charlton** & B. Kachman)*
16:20	Gravity Wave Spectra, Direction Statistics and Wave Interactions as Observed by MF Radars in Canada and Global MLT Network *(**A.H. Manson** & C.E. Meek)*			The Episodic Occurrence of Hail in Central Alberta *(**G. Reuter**, & S. Smith)*
16:40	Discussion			The Edmonton Tornado...Ten Years After *(**G. Vickers** & S. Ricketts)*

*Speakers noted in **bold** text

*Start times are approximate, unless noted otherwise in title box


METEOROLOGICAL INSTRUMENTS
SENSORS TO MEASURE
• Wind Speed
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• Precipitation
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YOUNG

Abstracts
Presentations

Session 1-A

GEWEX Plenary
Chair: Geoff Strong

Monday, June 2 09:05-09:50 Lecture Theatre 143

1-A.1 A Research Focus on Water and Energy Cycles: the Mackenzie GEWEX Study

(Plenary paper, 45 min)

Dr. G. McBean (Atmospheric Environment Service, Downsview, ON, Canada)

Canada has long been a major participant in the World Climate Research Programme [WCRP] and it has in particular been active within the Global Energy and Water Cycle Experiment [GEWEX]. One of the main objectives of GEWEX is to improve the capability for predicting seasonal to annual water resources and much of this effort is being carried out within continental-scale river basins over several regions of the world. Canada=s major contribution to GEWEX is through the Mackenzie GEWEX Study [MAGS] that is focusing on our largest northern-flowing river. The goals of MAGS are to understand, quantify, and model the critical processes that control the climate of this region and to work with other WCRP initiatives to realize our predictive capability goals. MAGS is then concerned with the flow of water and energy into and through the Basin, including the critical fresh water discharge into the Arctic Ocean. MAGS, therefore, is concentrating on the many processes involving the atmosphere, surface, and hydrology that collectively result in about 40% of the water vapour entering the Basin ending up as fresh water inflow into the Arctic Ocean. Although MAGS is directly associated with GEWEX, it is also contributing to other WCRP projects such as ACSYS and CLIVAR and it will greatly benefit IGBP as well. MAGS involves many researchers from both the university and government communities in Canada and close connections with clients are being developed.

Session 1-B1

GEWEX-1: Surface Water & Energy Cycles
Chair: Ron Stewart

Monday, June 2 10:10-12:10 Lecture Theatre 143

1-B1.1 Water and Energy Fluxes at the Forest-Tundra Transition in Northern Canada

P. Marsh[1] (speaker), *J. Pomeroy*[1], *W. Rouse*[2], *and W. Quinton*[1] ([1]National Hydrology Research Institute, Environment Canada, Saskatoon, SK, Canada; [2]McMaster University, Hamilton, ON)

Research on the processes controlling water and energy fluxes during an entire annual cycle are ongoing at NHRI/MAGS research sites near Inuvik, an area typical of the northern and western portions of the Mackenzie Basin. Details of some of this work have been presented in accompanying papers. These results will be applied to explain various aspects of both the

variations in fluxes over critical periods of the year and the runoff regime at the forest-tundra transition zone in the Inuvik area. Such results are critical for the development and validation of larger scale models required for the Mackenzie GEWEX Study. The important processes and fluxes to be considered in this paper include: the role of blowing snow in redistribution and sublimation of winter snow, the effect of local advection in controlling snowmelt timing and magnitude, the flux of melt water through the snowcover, the lateral transfer of water through organic flow paths with gradually deepening active layer and orders of magnitude differences in hydraulic conductivity, limited soil moisture storage due to a thin active layer, and evaporation from snow free surfaces. This paper will quantify each of these to demonstrate their relative importance to the annual and daily water balance of a typical area at the arctic forest-tundra transition.

1-B1.2 The Influence of the Near-Stream Area on Streamflow in an Arctic Tundra Basin

W.L. Quinton (speaker) *and P. Marsh* (National Hydrology Research Institute, Environment Canada Saskatoon, SK, Canada)

Streamflow and hillslope runoff processes within a 95 ha catchment (Siksik Creek) in the tundra region of the Canadian western Arctic were studied for three years (1992-1994). Measurements over this period included all hydrological inputs, continuous gauging of the main stream channel, monitoring of active layer and water table depths, and detailed mapping of the soil types on hillslopes. The area of tundra close to the stream has hydrological properties that distinguish it from the surrounding tundra. The near-stream area is composed of relatively deep peat accumulations, and the water table is maintained above the mineral substrate for all or most of the thaw season. The transition from the upland to the near-stream area is marked by a change in the vegetation community to one dominated by mosses. The near-stream area extends for a distance of approximately 10 to 40 m upslope from the stream channel, depending upon hillslope gradient. Although the near-stream area represents less than 10% of the basin, it is of great importance to basin runoff since it occupies the boundary between the hillslopes and the stream channel, and therefore acts as the hydrological linkage between the two. The level of discharge in the stream was found to be strongly dependant upon the elevation of the saturated layer on the adjacent hillslopes owing to unique physical and hydraulic properties of peat, and the influence of the near-stream area on the expansion of runoff source areas. As a result basin runoff response depends upon the runoff-transmission ability of the near-stream area. An understanding of the impact of the near-stream area on the level of discharge in channels will improve our ability to model runoff in Arctic-tundra environments.

1-B1.3 Application of a Radiation-Temperature Index Snowmelt Models to the Lower Liard River Valley

A. Pietroniro[1] (speaker), *L. Hamlin*[1], *T.D. Prowse*[1], *E.D. Soulis*[2], *and N. Kouwen*[2] ([1]National Hydrology Research Institute, Environment Canada, Saskatoon, SK, Canada; [2]Department of Civil Engineering, University of Waterloo, Waterloo, ON, Canada)

Applications of snowmelt models are often limited to energy-balance models concentrating on micro-scale studies or lumped-model applications at the macro-scale. The latter modelling scale typically requires basin-wide optimised parameters which often neglect some of the major physical processes controlling melt production. These lumped models often over-simplify the physical processes and fail to reveal subtle differences between land-cover types and their specific response to meteorological inputs. At the other extreme of the micro-scale, physically realistic models can be implemented. However, the data requirements are often too numerous to make these types of models practical to apply within the framework of meso- or macro-scale hydrologic simulation models. This work examines the use of indexed snowmelt algorithms derived for individual land-cover component characteristics of the wetland-dominated region of the lower Liard River valley, NWT, Canada. The algorithm presented uses an hourly temperature-radiation index approach to estimate snowmelt within the different land-cover types. The algorithms developed are incorporated into a fully distributed hydrologic model

(SPL7) that uses the Grouped Response Unit [GRU] method for basin discritization. Internal energy terms used in the simulation occurring within the snowpack are described in detail. Since these terms are conceptual, attempts at providing a physical basis to these terms are discussed. Results show that the radiation-temperature algorithm provided slightly improved calibration results, however both algorithms validated equally well. Results also show a need for a better understanding of the energetics of the snowpack, as simulated by these conceptual index approaches.

1-B1.4 Hydrometeorological Complexities Affecting Flooding of the Peace-Athabasca Delta

Terry D. Prowse[1] (speaker) and *Malcolm F. Conly*[2] ([1]National Hydrology Research Institute, Environment Canada, Saskatoon, SK, Canada; [2]Prairie and Northern Wildlife Research Centre, Environment Canada, Saskatoon, SK, Canada)

A common perception during the 1970s and 1980s was that regulated lower flows on the Peace River minimized the probability of large open-water floods capable of inundating the perched basins of the Peace Athabasca Delta [PAD], one of the world's largest freshwater deltas. Analysis of hydrometric data in conjunction with various historical and local-knowledge sources has established, however, that ice-jam backwater has been responsible for the major flooding of the elevated perched basins within the PAD. Although ice breakup events dominate the flooding regime of the PAD, there has been a marked decline in their occurrence. This reduction in large-order flood events seems to be related to a combined effect of flow regulation and the vagaries of climate.

A reduction in ice-jam flooding can be related, in part, to flow regulation, but it is not a reduction in flows that is the contributing factor. Flow contributions from the point of regulation are higher, on average, at the time of breakup near the PAD in the post-regulation period than prior to regulation. The major ice-jam floods that occurred prior to and since regulation were associated with large snowmelt runoff from downstream tributaries. Temporal trends of winter snowpack accumulation for one tributary basin suggests that there has been a shift to lower than average values beginning in the mid-1970s.

The major effect of regulation on breakup ice jamming results from sustained higher winter flows and related, increased freeze-up elevations. Along the lower portions of the Peace River, flow regulation seems to have produced only minor changes in related ice-jam factors, such as ice thickness and strength. Temporal analysis of these factors, however, also detected a climate signal suggesting that since approximately the mid-1970s the period of ice cover may have become slightly warmer and the pre-breakup melt period more intense and/or more protracted.

1-B1.5 Regional Variations in Water Balance Regime in the Continental Arctic Using Isotopic Tracers

J.J. Gibson (speaker) and *T.D. Prowse* (National Hydrology Research Institute, Environment Canada, Saskatoon, SK, Canada)

One principal unknown in the hydroclimatology of the Mackenzie Basin is the hydrologic response of permafrost basins situated in remote, northeastern areas of the catchment where climatic and hydrometric networks are sparse. To gain a better understanding of the hydrologic regime and to evaluate the role of lakes in the regional runoff, a GEWEX-MAGS component was undertaken using isotopic tracers to predict lake water balance trends across a 200,000 km^2 area that straddles the drainage divide between the Mackenzie Basin and Arctic Coastal Plain. The study, which has relied on isotopic analysis of water samples collected during a 1993 water quality survey and spatially extends over three NHRI/University of Waterloo isotope hydrology field sites, has examined patterns of evaporative isotopic enrichment as a mass tracer of the fraction of lake water lost by evaporation (evaporation/inflow or E/I). While data reduction and assimilation are still in the preliminary stages, systematic isotopic enrichment by evaporation has been identified across the study region, and isotope mass balance techniques are now being applied to interpret the spatial isotopic fields. Of interest, preliminary results suggest that E/I ranges from about 10-15% in tundra regions draining into the Arctic Ocean to 50-60% in the Great Bear Lake-Great Slave Lake corridor. Results will be presented and compared with available hydrometric and climatic data in surrounding regions. Planned future studies will endeavour to improve linkage between 'point' process studies and meso- to macro-scale modelling activities in the Mackenzie Basin by examining source-areas and components of the hydrograph at selected river discharge nodes. These activities will also aid hydrologic modelling where specific sub-regime response is unknown or poorly understood.

1-B1.6 Basin-Scale Surface Energy and Water Balance for GCIP From the ECMWF Reanalysis

A.K. Betts[1] (speaker) and *P. Viterbo*[2] ([1]Atmospheric Research, Pittsford, VM, USA; [2]ECMWF, Reading, England)

Average surface energy and water budgets, subsurface variables and atmospheric profiles were computed on-line with an hourly timescale from the ECMWF reanalysis for five sub-basins of the Mississippi river from 1985-1993. The results for the Arkansas Red River basin will be discussed on diurnal, seasonal and interannual time-scales.

Session 1-B2

Regional Climate Modelling

Chair: Norm McFarlane

Monday, June 2 10:10-12:10 Room 217

1-B2.1 Sensitivity of the One-Dimensional Kain-Fritsch Convection Scheme

Dominique Paquin (speaker) *and Rene Laprise* (Dep. des Sciences de la Terre, Université du Québec a Montréal, QU, Canada)

The Kain-Fritsch scheme is a mesoscale parameterization of cumulus convection. Specially designed for grids ranging from 10 km^2 to 30 km^2, it is generally used in short simulations, where it performs very well. It is contemplated as a candidate scheme for use in high-resolution Canadian Regional Climate Model. To better understand the scheme's behaviour, we decided to investigate the sensitivity of temperature and moisture tendancies to some model's parameters (vertical resolution, timestep, grid size, or vertical wind). An efficient approach to conduct such an experiment is to use a one-dimensional version of the scheme. Such an approach reduces the computation costs associated with the study and simplifies the identification of convection impacts. Results from these sensitivity tests will be presented.

1-B2.2 A Modelling Assessment of the Impacts of Historical Wetland Drainage and Other Land Use Changes on the Regional Climate of the Canadian Prairies

C.D. Smith[1] (speaker), *R. Lawford*[2], *and A. Barr*[3] ([1]National Hydrology Research Centre, Saskatoon, SK, Canada; [2]GCIP Project Office-NOAA/OGP, Silver Spring, MD; [3]CPEOD, Environment Canada, Saskatoon, SK, Canada)

Historical land use changes may have modified the regional climate of the Canadian prairies. This study uses a regional atmospheric model to examine the potential impact of surface modification on the regional climate of the Yorkton region in south-eastern Saskatchewan. Simulations are designed to represent both historical surface conditions and present surface conditions in the region with an emphasis on wetland drainage. Potential impacts of vegetation alteration and soil moisture variability are also examined. Modelling results indicate that a 3% historical surface area change from water to dry land has little impact on accumulated precipitation or temperature during the 72-hour simulations but does influence the timing of the precipitation events. The simulation with 10% surface water by area has a positive influence on precipitation while the removal of vegetation has a negative influence. Analysis of the local climate statistics shows no clear impact of agricultural expansion on precipitation. The temperature trends are consistent with larger scale variability in both agricultural and non-agricultural regions.

1-B2.3 Climate of Western Canada Under Current and Enhanced Greenhouse Gases Concentration as Simulated by the Canadian Regional Climate Model

Hélène Côté (speaker), *René Laprise, Michel Giguere, and Guy Bergeron* (Dep. des Sciences de la Terre, Université du Québec, Montréal, C.P., Montréal, QU, Canada)

The first climate simulations ever performed with the novel Canadian Regional Climate Model [CRCM] will be presented. CRCM is based on fully elastic non-hydrostatic field equations solved with the very efficient semi-implicit semi-Lagrangian [SISL] marching algorithm of the MC2 kernel and the physical parameterization package of the second-generation Canadian Global Climate Model [GCMII]. Two 5-year integrations of CRCM nested with GCMII simulated data were made for conditions corresponding to current and doubled greenhouse gases [GHG] concentration scenarios. CRCM used a grid size of 45 km on a polar-stereographic projection, 20 scaled-height levels and a timestep of 15 min, while its nesting GCMII used a spectral truncation of T32 (about 650 km), 10 hybrid pressure levels and a timestep of 20 min. We will compare climatological fields simulated by both CRCM and GCMII under two greenhouse gases scenarios. These comparisons will give some insights about the behaviour of the CGMII physics package at much higher resolutions than the ones for which it was initially designed for.

1-B2.4 Application of the Canadian Regional Climate Model to Eastern Canada and the Laurentian Great Lakes

S.G. Goyette (speaker), *N.A.M. McFarlane, and G.M.F. Flato* (Canadian Centre for Climate Modelling and Analysis, Atmospheric Environment Service, University of Victoria, Victoria, BC, Canada)

Nested regional climate models [RCM] are becoming valuable tools for downscaling general circulation model [GCM] climate projections to finer scales. The RCM used for the present application emerged from the coupling of the semi-Lagrangian semi-implicit MC2 dynamical model with the second generation Canadian general circulation model [GCMII] physics parameterization package. The nesting procedure consists of driving the RCM with a given time series of GCMII atmospheric fields at the external lateral boundaries of the region of interest. The present application aims at the downscaling of GCMII results over Eastern Canada including the Laurentian Great Lakes basin. The lakes are sufficiently large so that we can use a "mixed layer" model to simulate the lake surface temperature, and a thermodynamic ice model to

simulate lake ice. These are based on the ocean and sea-ice submodels used in GCMII, but adapted for freshwater bodies. Therefore, we simulate lake surface temperature and ice over the seasons. The lake mean mixed layer depths are derived empirically and parameterization of lake ice coverage is based on observations. These submodels require a flux correction procedure in order to keep the surface water temperature and surface ice close to observed climatology. We are currently integrating the RCM over Eastern Canada with prescribed seasonally varying surface water temperature and ice in order to evaluate the monthly heat fluxes needed for the flux correction procedure. We performed some sensitivity experiments to assess the effects of the Laurentian Great Lakes on regional climate. We will show some of the "well known" lake effects that have been identified and simulated.

Session 1-B3

Data Assimilation

Chair: Ambury Stuart

Monday, June 2 10:10-12:10 Room 200

1-B3.1 Decision Support System as a Useful Tool for Observational Network Rationalization

Paul Ford, Tsoi Yip (speaker), *and Gary Grieco* (Atmospheric Environment Service, Downsview, ON, Canada)

In recent years, the amount of capital available for systematic observation has been significantly reduced. It is important to rationalize the Atmospheric Environment Program's observational networks carefully to ensure that they will meet Environment Canada's evolving operational and research requirements in a cost effective manner. In the radar modernization plan, Monitoring and Technology Strategies Division used a Decision Support System [DSS] to assist designer to locate new and to relocate a few existing radars. Radar is an important tool for the monitoring of summer severe weather, freezing precipitation, snow squalls, wind shear lines, precipitation amounts, *etc*. We would like to locate radars to cover populated areas where these weather hazards occur most frequently. Observations from strategically located radars can help weather forecasters to issue advance warning to the public to minimize loss of lives and damage to property. To eliminate duplication of effort, we take advantage of other sources of data such as the US radars, research radars, and other Government Department radars. These put considerable constraints on the distribution of radars in the new network. The DSS that we developed enables us to combine all the above weather hazards and constraints together objectively. A set of recommendations is formulated to help decision makers derive the desired radar network.

1-B3.2 Adjoint Data Assimilation in Coupled Atmosphere-Ocean Models - Determining Model Initial Conditions in a Simple Equatorial Model

Jingxi Lu and William W. Hsieh (speaker) (Oceanography, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, BC, Canada)

Simple equatorial coupled atmosphere-ocean models have been successfully used to predict the El Nino phenomenon. We explore the possibility of determining the initial conditions in these coupled models by the adjoint data assimilation method, since accurate initialization of the

ocean model will greatly improve the forecast capability of these coupled models. Identical twin experiments were conducted to determine the initial conditions of three oceanic fields (the sea level height, SLH, and the two horizontal current components) in a simple coupled model, where the atmosphere and the ocean were each represented by a single-layer linear shallow water model. Wind and SLH data, generated from a 90-day unstable local-growth simulation of a warm event, were assimilated to test the effects of (i) data type and sparsity, (ii) initial guess, and (iii) noisy data on retrieving the oceanic initial conditions. SLH data were found to be more efficient in retrieving the oceanic initial conditions than wind data, and the initial SLH field was more accurately retrieved than the initial currents. The current fields were sensitive to the temporal density of data, especially with wind data, where once a day would be the minimum density needed for satisfactory retrieval. The initial guess of the oceanic state could contain errors in the magnitude and in the phase of the warm event anomaly. Data assimilation readily corrected the error in the magnitude of the initial guess, but not the error in the phase. Assimilation of noisy data showed that the retrieval of the initial conditions was more sensitive to noise in the SLH data than in the wind data.

1-B3.3 Moving Towards the Implementation of a 3-D Variational Assimilation System at the Canadian Meteorological Centre

P. Koclas (speaker), *P. Gauthier, C. Charette, and S. Laroche* (Environment Canada, Dorval, QU, Canada)

A global spectral 3-D variational analysis (3-Dvar) is currently being tested for implementation at the Canadian Meteorological Centre to replace the operational analysis based on optimal interpolation (Mitchell *et al.*, 1996). The 3-Dvar has been built as close as possible to the operational system which has permitted the study of the impact of data selection on the analysis. Results from the parallel run show that the two systems perform quite similarly on average. However, slight differences have been observed especially in the upper levels(above the tropopause). This can be partly explained by the fact that the 3-Dvar spreads the bias error of the model over a deeper layer than OI that filters part of this effect through data selection. Following the implementation of the 3-Dvar, we intend to cycle it in "spinup" mode with the GEM model now replacing the RFE model. Future implementations will lead to the direct assimilation of TOVS radiances and SSMI moisture data.

1-B3.4 A Comparison of the BOREAS and Atmospheric Environment Service Humidity Sensor at Meadow Lake, Saskatchewan

S.R. Shewchuk[1] (speaker), *B.J. Smith*[1], *and A.K. Betts*[2] (Saskatchewan Research Council, Saskatoon, SK, Canada; Atmospheric Research, Pittsford, VM, USA)

During the collection of BOREAS surface meteorological data, one site located at Meadow Lake, Saskatchewan, has a co-located set of sensor arrays with the Atmospheric Environment Service. While the majority of the parameters agreed quite closely during a routine data intercomparison, relative humidity did not. After comparison of the RH sensors, it was noticed that while both sensors adsorb water at the same rate during the day, the two sensors do not desorb at the same rate. This rate difference could provide quite different values of mixing rate at certain times during the day to standard operational mesoscale models.

1-B3.5 Can We Estimate Net Radiation From Solar Radiation Measurements?

Joe Eley (speaker) *and Alan Barr* (Environment Canada, Saskatoon, SK, Canada)

During the past year, a four-way radiometer array has been operated at the BOREAS mature aspen site in Prince Albert National Park, along with a net radiometer. Our intent was both to measure the capability of the net radiometer to estimate net radiation, and to have a record of each component separately for a more thorough understanding of the radiation budget of this ecosystem. One of the questions that can be dealt with using 4-way radiation data, is the

estimated precision of an estimate of net radiation using downward solar radiation only. Our initial trial correlated the attenuation of solar radiation (due to cloud) compared to the enhancement of sky long-wave radiation due to cloud. The long-wave radiation enhancement was relative to an estimate of sky long-wave radiation modelled using near-surface temperature and humidity. We found there is a clear relationship, although with some degree of spread. This net estimate would be very useful when averaged over time scales of several days or longer, but would be misleading on time scales of an hour or less.

Session 1-B4

Aviation Meteorology

Chair: John Bullas

Monday, June 2 10:10-12:10 Room 206

1-B4.1 Aviation Impact Variables and the CMC Aviation Weather Database

M.-F. Turcotte, D. Beauchamp, and R. Verret (speaker) (Canadian Meteorological Centre, Dorval, QU, Canada)

Current aviation weather observations and forecast products demand that the users integrate the information from a variety of alphanumeric and graphic sources, in order to obtain a mental picture of the prevailing and forecast weather for a specific area or route of flight. Little progress has been made so far to present the weather information in a more friendly manner to users in spite of many technological and scientific progresses in analysing and forecasting atmospheric conditions. The capability of numerical weather prediction models to ingest an ever-increasing amount of data from various sources and to produce high-quality gridded forecasts in relatively short periods of time and at an always improving spatial resolution, has prompted initiatives on the automated production of a new generation of aviation weather products. Other related initiatives include the development of user-friendly interactive systems to generate those products in graphic formats tailored to users needs allowing a quick and intuitive understanding of actual and forecast aviation weather conditions.

The Canadian Meteorological Centre is developing a gridded interactive aviation weather database [AWeD] designed to be the core component of a future aviation weather display system to be used as a self-briefing tool. Development work has resulted so far in the creation of a database of aviation-impact variables [AIV], updated in real time at each model run, that can be interactively queried at the Canadian Meteorological Centre by using locally developed utility applications. The driving model is the operational Canadian Regional model. The gridded meteorological variables are computed at the model resolution on the high resolution window of the model's grid which covers all of Canada, adjacent waters and a significant portion of the United States. The variables are computed at 40 flight levels (every 1000 feet, from the surface up to 40 000 feet) and the time resolution of the database is three hours, from zero- to 48-h projection time. The database includes temperatures, winds (speed and direction), relative humidity, clouds, vertical motion, total cloud cover, surface precipitation rate, freezing level, icing, turbulence, tropopause height pressure and temperature. The database also includes surface aviation observations [METAR] and aviation terminal forecasts [TAF] in decoded format.

Plan views and vertical cross-sections of the variables included in the database can be generated. Applications have been developed to present TAFs in graphical format. Two algorithms are used to forecast icing. One is the Appleman criteria which looks at the air temperature, dew point depression and vertical motion to assess the occurrence or non-occurrence of icing. A new algorithm has also been developed and implemented in the database, based on the super-cooled liquid water content as forecast by the driving model. Case studies have been carried, showing the superiority of the super-cooled liquid water algorithm. It has the advantage of forecasting occurrence of icing over smaller areas, thus reducing the rate of false alarm. The algorithm used to forecast clear air turbulence is based on the vertical shear deformation index. It has been compared in case studies with two other forecast approaches, one based on the Richardson number and the other one based on the turbulent kinetic energy. The vertical shear deformation index appears to be superior to the latter two techniques.

A verification system has been designed and is under development to verify forecasts of icing and turbulence. The main source of observations is currently the aircraft reports, but other sources of observations, mainly remote observations, will be added in later versions. The lack of reliable observations makes the aviation impact variables forecasts verification difficult, and the problem is even made more complex due to the lack of observations of non-occurrences of events, which makes the calculation of false alarm impossible. It is proposed to go around the problem by inversely weighting the probability of detection of the forecasts with the area covered by the forecasts. Examples of graphical products that are possible to generate from the database will be presented. The super-cooled liquid water algorithm for icing and the results of the case studies done on icing and turbulence will also be presented. And finally the progress done on the development of the verification system will be presented.

1-B4.2 Using A Column Boundary Layer Model to Provide Meteorological Support to the US Aircraft Vortex Spacing System

Robert Tardif (speaker) *and Peter Zwack* (Université du Québec a Montréal, Dep. des Sciences de la Terre, Montréal, QU, Canada)

The behaviour of wake vortices in the vicinity of runways dictate to a certain extent the minimal separation allowed in between landing aircrafts. Changes in atmospheric stability, wind speed/direction and turbulence intensity can result in important changes in wake vortex behavior and decay rate, and thus affect an airport acceptance rate. The use of the COBEL column model is being investigated for the representation of the local atmospheric boundary layer environment in which wake vortices evolve. The most recent configuration of the model, developed at the Université du Québec a Montréal, will be reviewed. It consists of the originally published model (Bergot and Guedalia, MWR, 1994), along with the addition of mesoscale pressure tendencies and vertical motion as external forcings, a more sophisticated soil model and data assimilation capabilities. Several morning and evening boundary layer transitions observed during the Memphis and Dallas-Fort Worth Wake Vortex field measurement programs are used as a basis for assessing COBEL's performance.

1-B4.3 A Nowcasting System for Ground De-icing

P. Joe (speaker)*, B. Sheppard, and N. Donaldson* (Cloud Physics Research Division, Atmospheric Environment Service, Downsview, ON, Canada)

Ground anti/de-icing operations require the accurate nowcasts of temperature, precipitation type and rate. Key elements of the nowcast is the accurate measurement and prediction of prediction amount and type. A test site was established at the Pearson International Airport that evaluated various optical and microwave sensors for the high temporal measurement of these quantities. Prediction of the movement of radar echoes in this winter scenario requires the development of a different extrapolation or advection algorithm than in summer situations. The nowcasting system will be described. Results of the sensor evaluation for the high temporal measurement of precipitation amount and type and the advection technique will be described.

1-B4.4 Using Forecast Production Assistant to Produce a Shared Graphical Aviation Area Forecast

D. Kania (speaker) *and M.Van Olst* (Environment Canada, Saskatoon Environmental Services Centre, Saskatoon, SK, Canada)

Since its inception in the 1940s, the format of the alphanumeric Area Forecast [FA] has changed very little. With the explosion in desktop computer technology it has become possible to provide more useful and accurate information using a graphical approach. By utilizing the increasing communications capacity of wide area networks it is possible for meteorologists to work in a virtual office. The main goal of this study was to use advances in technology and telecommunications to allow four forecast offices to supply input into a regionally produced "stand alone" Graphical Aviation Area Forecast.

1-B4.5 Quantitative Glace Accretion Measurements From the U.S. National Weather Service ASOS

C.C. Ryerson[1] (speaker) *and A.C. Ramsay*[2] ([1]Cold Regions Research and Engineering Laboratory, Hanover, NH, USA; [2]Hughes STX Corporation, Sterling, VA, USA)

Evaluations of the ASOS freezing-rain sensor have indicated that it may be able to provide reliable quantitative measurements of freezing rain, drizzle, rime and hoarfrost. If it can be shown that the ASOS ice detector provides accurate quantitative estimates of ice accretion on "standard" surfaces, it should be possible to develop transfer functions from the standard surfaces for such purposes as assisting determinations of highway and runway slipperyness, aircraft de-icing scheduling, or design of communications towers and power lines. In 1995, CRREL, the National Weather Service's Eastern Region and the ASOS Program Office partnered to perform a limited evaluation at six sites. Standardized ice-accretion rods and plates were installed near freezing-rain sensors at Binghamton, NY; Cleveland OH; Johnstown, PA; Sterling VA; Mt. Washington Observatory, and Hanover, NH. Personnel at these locations provided detailed observations of glaze ice thickness on horizontal plates and of glaze ice mass on 3-cm diameter by 1-m long aluminum rods. The test has been limited by a lack of significant freezing precipitation the last two winters in the northeastern United States, but results obtained with the limited data are positive. Correlations between cumulative frequency drop of the freezing-rain sensor through storms and ice accretions are greater than 0.76 for ice thickness, and 0.96 for ice mass. These results are sufficiently encouraging that the project will continue for several years. This presentation describes measurement procedures, analysis of the measurements, and a case study from the winter of 1995-1996.

Session 1-C1

GEWEX-2: Atmospheric Water & Energy Cycles

Chair: Phil Marsh

Monday, June 2 13:40-15:00 Lecture Theatre 143

1-C1.1 Atmospheric Moisture Flux Convergence Over the Mackenzie Basin

A.G. Barr (speaker), *M. Wang, G.S. Strong, and B. Proctor* (Atmospheric Environment Service, National Hydrology Research Centre, Saskatoon, SK, Canada)

Atmospheric moisture flux convergence is a major source of water to the MacKenzie Basin. In this study, we evaluate the atmospheric moisture budget over the MacKenzie Basin for the hydrologic year Oct 1995 to Sept 1996. The analysis is based on run zero analyses of the Canadian Regional Finite Element Model, computed on a 35 km grid and 29 sigma vertical levels. We also calculate the atmospheric moisture budget of the six principal sub-basins of the Mackenzie Basin. An anomaly between the atmospheric moisture budget estimate of (precipitation minus evapotranspiration) and long-term mean measured river discharge is identified and discussed. We also identify the primary zones of moisture influx and efflux from the basin over the annual cycle.

1-C1.2 RFE Model Validation of MAGS Moisture Sources and Sinks

G.S. Strong[1] (speaker), *B. Proctor*[1]*, A.G. Barr,*[1] *and M. Wang*[2] ([1]Atmospheric Environment Service, National Hydrology Research Centre, Saskatoon, SK, Canada; [2]Atmospheric Science Program, Department of Physics, Dalhousie University, Halifax, NS, Canada)

One of the main goals of the Mackenzie Basin GEWEX Study [MAGS] is to quantify the hydrologic water cycle of the Mackenzie Basin. This basin, which terminates with the Mackenzie

River flowing into the Beaufort Sea, is comparable in size to the Mississippi Basin. However, due to the larger impact of climate warming in the north, the Mackenzie is thought to have a more significant influence over global climate change than the Mississippi. An essential part of MAGS therefore is to quantify the annual cycle of the atmospheric moisture budget while identifying moisture sources and sinks.

Radiosondes are the main data source for atmospheric moisture budget studies. However, there are currently only four sites within the larger basin, and another three in the immediate vicinity in a representative area of approximately 3 million km^2, for an average spacing of 700 km. The Mackenzie is fed by a number of sub-basins, ranging in size from 100,000 to 300,000 km^2, so that the identification of sources and sinks at the sub-basin scale is a rather formidable task at best. Therefore, MAGS is depending on 35-km grid output from the value-added capability of the CMC RFE model-initialized (Run-0) fields to increase the accuracy of moisture budget analyses.

This presentation addresses uncertainties in RFE moisture analyses by: (1) comparing measured and modelled vertically-integrated totals of vapour mass at the seven sounding sites indicated above; (2) comparing coincidental moisture budget analyses using synoptic scale upper air data at 600-km resolution with analyses using a limited mesoscale upper air data set at 60-km resolution over a small region just south of the Mackenzie Basin. The results are then used to critically examine monthly RFE outputs of moisture sources and sinks.

1-C1.3 Monthly Rainfall Estimates Over the Mackenzie Basin Using GOES-9 (VIS,IR) Data

Aldo Bellon[1] (speaker), *Isztar Zawadzki*[2], *and Stephane Gagnon*[3] ([1, 2]McGill Weather Radar, Ste-Anne-de-Bellevue, QU, Canada; [3]St-Laurent, QU, Canada)

GOES-9 visible and infrared radiances have been calibrated with Carvel radar data to derive a rainfall rate relationship appropriate for the region. Monthly and 5-day rainfall accumulations have been obtained over the entire Mackenzie Basin for May to August 1996. The monthly estimates are compared with CMC rainfall analyses derived from a combination of surface observations and of model output. They show coincident minima and maxima features, but their absolute difference may be large.

1-C1.4 Atmospheric Warming During the Cold Season Over the Mackenzie Basin

Z. Cao (speaker), *R.E. Stewart, and W. Hogg* (Atmospheric Environment Service, Downsview, ON, Canada)

Climate models generally predict that global warming should be very pronounced during the cold season over high latitudes. Observations over the last 30 years have also indicated that surface air temperature has increased over high-latitude northern regions during the winter and spring, and an especially strong warming signal has appeared over the Mackenzie Basin. It is suggested that atmospheric circulation anomalies over the basin are important factors leading to the warming during the cold season. There are at least two types of dynamically induced circulation anomalies that can significantly affect the temperature field. Firstly, persistent anomalies of high pressure systems over the basin during the winter associated with the low-level inversion can lead to the warming of surface air temperature through adiabatic compression and thermal advection. Secondly, a chinook process can cause the increase of surface air temperature in the lee of the western mountain barrier through moist processes including intensified Gulf of Alaska circulation. These two possible explanations are the subject of the present diagnostic study using radiosonde observations and analysis data.

Session 1-C2 Paleoclimate

Chair: Jeff Whiting

Monday, June 2 | 13:40-15:00 | Room 200

1-C2.1 Paleoclimatic Response of the Closure of the Isthmus of Panama in a Coupled Ocean-Atmosphere Model

T.Q. Murdock (speaker), *A.J. Weaver, and A.F. Fanning* (School of Earth and Ocean Sciences, University of Victoria, Victoria, BC, Canada)

The paleoclimatic effects of the closure of the Isthmus of Panama at 3 Ma are investigated using a coupled atmosphere-ocean model. Consistent with earlier ocean-only modelling studies, it is shown that prior to closure there is an absence of deep water formation in the North Atlantic. Hence there is a reduction in oceanic heat transport. This is largely compensated for by the atmosphere such that only small changes in total planetary heat transport occur. The model climate of the North Atlantic is significantly warmer after Isthmus closure. In addition, the regions surrounding the Pacific Ocean and South Atlantic are generally cooler while the Indian Ocean is generally warmer in the model present-day climate. Possible relationships of this event to glaciation and initiation of northern hemisphere glacial cycles are investigated.

1-C2.2 Do Epsiodic Glacier Surges Explain Rapid Climatic Variability During the Last Glaciation?

H. Bjornsson (speaker) and *L.A. Mysak* (Department of Atmospheric and Oceanic Sciences, McGill University, Montréal, QU, Canada)

There is ample evidence to show that during the last glaciation there were episodic ice surges from the Laurentide Ice Sheet into the Northern Atlantic. Using a coupled zonally averaged atmosphere-ocean-sea ice model, we try to answer the following two questions: What were the climatic consequences of these ice surges? How was the "signal" transmitted throughout the globe? We investigate the response of the thermohaline or thermocline circulation to ice surges of varying magnitude and length. We also examine how the changes in the thermohaline circulation impacted on climate, and how long it took for the changes in circulation to propagate to other ocean basins.

1-C2.3 Precipitation Variability in Southwestern Saskatchewan and Southeastern Alberta: A 300-Year Proxy Record From the Cypress Hills

D.J. Sauchyn (Department of Geography, University of Regina, Regina, SK, Canada)

The best pre-instrumental records of climatic variability are derived from the characteristics of tree rings. These data are lacking for the subhumid Canadian prairies, and thus climatic variability has been inferred from the dendroclimatology of the adjacent montane and boreal forests. However, near the geographic centre of the driest part of the Canadian plains (*i.e.,* the Palliser Triangle), the western Cypress Hills support an extensive white spruce, lodgepole pine forest. Trees at the drier sites preserve a strong signal of summer precipitation. As a result of pre-settlement fire and post-settlement demand for wood, the age of the oldest living trees is less than 200 years. On the other hand, some of the timber that was harvested by the North West Mounted Police and the early settlers has remained in the region. During November, 1997, we collected 21 disks and 39 cores from log buildings. By cross dating growth rings from living trees and the older logs, we have established a ring-width chronology exceeding 300 years. Tree ring width correlates with summer precipitation measured in the Cypress Hills and at various meteorological stations on the surrounding plains. This relationship enables us to reconstruct precipitation variability since the late 17th century. This dendroclimatic record reveals severe pre-settlement droughts, for example during the 1790s, and

other periods of anomalous summer climate that would have influenced the regional ecology (*e.g.,* plant and animal populations, sand dune activity) and perhaps early EuroCanadian perceptions of the Canadian plains.

Session 1-C3

Climate Research Network - 1

Chair: John Stone

Monday, June 2 13:40-15:00 Room 146

1-C3.1 Global Ocean Modelling Within the Canadian Climate Research Network

(Invited paper, 30 min)

A.J. Weaver (School of Earth and Ocean Sciences, University of Victoria, Victoria, BC, Canada)

An Energy/Moisture Balance Atmosphere Model [EMBM] has recently been developed by Fanning and Weaver (1996) and coupled to a Thermodynamic Ice Model and an Ocean General Circulation Model. This fully coupled model now serves as the basis for our analysis of the ocean's role in climate and climate variability. In this talk the climatology of the coupled model is presented and some preliminary experiments and future directions are discussed. In addition, some recent results are shown from ocean model experiments conducted with isopycnal and isopycnal thickness diffusion parameterizations for subgrid scale mixing associated with mesoscale eddies. It is shown that when the mixing tensor is rotated, so that mixing is primarily along isopycnals, numerical problems may occur and non-monotonic solutions which violate the second law of thermodynamics may arise. These numerical problems can be reduced or eliminated if sufficient explicit background horizontal diffusion is added to the mixing scheme. A more appropriate solution is the use of more sophisticated numerical advection algorithms, such as the flux-corrected transport algorithm. This choice of advection scheme adds additional mixing only where it is needed to preserve montonicity and so retains the physically-desirable aspects of the isopycnal and isopycnal thickness diffusion parameterizations, while removing the undesirable numerical noise. The price for this improvement is a computational increase.

1-C3.2 The Canadian Climate Research Network on Integrative Carbon Studies

(Invited paper, 25 min)

Inez Fung (School of Earth and Ocean Sciences, University of Victoria, Victoria, BC, Canada)

The new Carbon network, established in December 1996, is a joint research program at the University of Victoria, McGill University, University of Ottawa, Institute of Ocean Sciences [IOS], Atmosheric Environment Service [AES]/Victoria, and AES/Toronto. The focus is the analysis and modelling of the variations of atmospheric CO_2 in the last 50 years in order to gain predictive understanding of likely climate-carbon feedbacks in the next 50 years. The research will link together analysis of the available atmospheric and oceanic CO_2 data, global modelling of the terrestrial and oceanic carbon cycles as well as the transport of carbon by atmospheric and oceanic circulation. This paper presents the scientific challenges and opportunities in carbon cycle research.

1-C3.3 The Northern Aerosol Regional Climate Model [NARCM] Project

(Invited paper, 25 min)
L.A. Barrie, J.P. Blanchet, and R. Leaitch (speaker) (Atmospheric Environment Service, Downsview, ON, Canada)

A very recent addition to the Canadian Climate Research Network projects is this three-year, twenty person government and university cooperative effort to model the effects of aerosols on climate using the regional climate model [UQAM] on a north pole centred northern hemispheric domain and the global GCM/MAM (AES/Victoria). Anthropogenic sulphates, black carbon as well as natural biogenic sulphur, sea salt, and soil dust are carried prognostically and allowed to interact with solar radiation directly as well as indirectly through cloud albedo effects. Emissions to the atmosphere of aerosol constituents are simulated using either global emissions inventories for anthropogenic substances or wind driven air surface exchange flux parameterizations for the other constituents. Aerosol mass and composition are calculated using a discrete 12 size-bin representation of the size distribution covering the 0.01 to 25 micrometer radius size-range. Nucleation, coagulation, gas-to-particle conversion, and removal by dry deposition and precipitation are simulated. Cloud albedo effects are linked to aerosol number, composition and vertical velocity indices. The parameterizations currently used for these processes are described followed by the results of the model applied to sea salt using a column 1-D, a 3-D RCM, and the global GCM. Projects that are underway that are designed to evaluate model performance include the use of satellite optical depth data, LITE-shuttle LIDAR vertical profiles obtained in September 1994, and climatologies of aerosol composition obtained at Canadian and other remote baseline air chemistry observatories.

Session 1-C4

Weather Forecasting - 1

Chair: Ron Hopkinson

Monday, June 2 13:40-15:00 Room 206

1-C4.1 Operational Models and Analysis Systems at the Canadian Meteorological Centre

R. Hogue (Environment Canada, Dorval, QU, Canada)

The Operations Branch of the Canadian Meteorological Center [CMC] is responsible for running the operational models and analysis systems that have been developed by the R&D Divisions of CMC and RPN (Recherche en Prevision Numerique). Major changes to these operational systems have been implemented in the past months and more changes are planned during the next year. A description of these current and future systems will be presented. One of these significant changes was the replacement in February 1997 of the RFE regional model by the regional version of the Global Environment Multi-Scale [GEM] model. As well, a significant change in the data assimilation system has been running in test mode for the past year. This new system, called the 3D-Variational [3D-VAR] analysis will replace the current Optimum Interpolation [OI] analysis scheme. A brief description of these changes as well as corresponding changes to the operational run schedule at CMC will be presented. The question of availability as well as transmission of analysis and model outputs to various CMC users will also be discussed. Also, a brief description of the CMC Operations archive database will be presented.

1-C4.2 Kalman Filters to Forecast Statistical Surface Temperature

M.-F. Turcotte, R. Verret (speaker), *and G. Desautels* (Canadian Meteorological Centre, Dorval, QU, Canada)

Several techniques are available to objectively forecast surface temperatures. The first one that come to mind is based on the extraction of direct model output temperatures. However, it is well known that most numerical models show systematic errors that can be attributed partly to their horizontal resolution responsible for an inadequate representation of topography and to deficiencies in the physical parameterization. Statistical techniques have been developed to alleviate some of these problems as much as possible. Perfect Prog [PP] multiple linear regression is well suited to forecast surface temperatures. The PP approach implies that the statistical relationships between the predictand and the predictors are developed using a long historical database of observed and analysed data. The operational surface temperature guidance generated at the Canadian Meteorological Centre and disseminated to the Regions is based on that technique.

The Model Output Statistics [MOS] is also another interesting approach which can make use efficiently of sophisticated model predictors that are not normally available in the PP systems. MOS implies that the database used to generate the statistical relationships includes observations of the predictand but the predictors are provided by the driving model. The main disadvantage of the MOS approach is that it is model dependant, thus rendering the statistical relationships obsolete whenever a significant model change is brought operational. However, it is possible to partly process new data at each model run in such a way that the updates of the MOS equations is easier to do when a new model is implemented, thus making MOS still a viable approach.

On top of these statistical systems, error-feedback mechanisms, such as the Kalman filtering technique, can be developed and applied to the statistical forecasts or to the direct model output forecasts. Kalman filtering continuously and automatically updates the statistical relationships between the predictand and the predictors in a recursive manner at each model run taking into account the recent performance of the forecasts. Once a new observation of the predictand becomes available, the forecasts generated in the previous runs are verified and the errors are fed back into the system in generating the new forecasts in the current run. The main advantage of the Kalman filtering approach is that it will adapt itself quickly to a model change and it will always try to find the best fit between the predictand and the predictors. It is not computer intensive and does not require a long historical database to develop the statistical relationships. In theory, Kalman filtering will remove all biases imbedded in the forecasts. However, it has the disadvantage of being reactive rather than dynamic, in assuming that the past errors always persist. The Canadian Meteorological Centre has developed two versions of the Kalman filters to post-process surface temperatures. The first version includes two predictors: direct model output surface temperatures and the model mean temperature between 925 and 700 hPa as calculated with the hypsometric equation. The second version of the Kalman filters includes a third predictor which is the PP statistical surface temperature. The first version is used to filter the model surface temperatures and the latter to filter the statistical PP temperatures. It is important to recognize that the Kalman filtering technique is generally used to forecast the forecast error and feed-back the error into the forecasts. The version described here recursively forecasts the predictand directly. Kalman filtered surface temperature forecasts have been generated at approximately 200 Canadian stations for several months and verified. The Kalman filtered temperatures are compared against the direct model output temperatures and the PP statistical temperature forecasts. Results indicate that the two-predictor version of the Kalman filters improve the direct model output temperatures in such a way that they become quite comparable to the PP statistical temperatures with similar biases and root mean square errors. The three-predictor version of the Kalman filters generally improve the PP statistical temperature forecasts. However the improvement varies largely from stations to stations. Results will be presented and the advantages and disadvantages of the Kalman filtering technique will be highlighted.

1-C4.3 Use of Regional Model Grid Point Data in Cold Season Quantitative Precipitation Forecasting

B.P. Murphy (Thunder Bay Regional Weather Centre, Thunder Bay, ON, Canada)

With the continual advancement in computing power and technology, high resolution numerical model grid point [GRIB] data has become readily available to meteorologists. The advancement in the prediction of quantitative precipitation however, has not kept pace with the technological gains as the Quantitative Precipitation Forecast [QPF] remains one of the most difficult tasks a forcaster has to undertake, especially during the cold season. A software platform MAX (Meteorological Applications in X-windows) was recently developed at the Canadian Meteorological Centre [CMC] for the display and manipulation of GRIB data. The author has written several macros for the MAX platform. Some of these pertaining to cold season QPF will be presented along with some case study examples. The results will be compared with some of the more traditional QPF methods.

1-C4.4 A Product Generator

R. Verret (speaker), *D. Vigneux, J. Marcoux, F. Petrucci, C. Landry, L. Pelletier, G. Hardy, and R. Parent* (Canadian Meteorological Centre, Dorval, QU, Canada)

The Canadian Meteorological Centre has developed SCRIBE, an interactive expert system for composition of meteorological forecast products from weather element matrices available at an ensemble of stations or sample points. The matrices are produced at approximately 600 points across Canada and include statistical and direct model output parameters at a 3-h time resolution. Upon reception of the matrices, the SCRIBE Knowledge Base System processes the data to extract the events or meteorological concepts that are the results of a semantic numerical analysis of the weather element matrices content. The concepts can be displayed on a graphical user interface for editing if needed and then the Knowledge Base System is called once more to generate the forecast products. It is possible to generate from the same data a multitude of products tailored to the needs of specific clients under a variety of formats.

SCRIBE version 3.0, a Product Generator, is based on the same approach and has been designed to have an improved flexibility, to be easier to manage and maintained, and to give to the users the capabilities of defining the desired products, generating, managing and modifying them on site and as needed without relying on experts. The products to be generated are defined in Product Description Files and thus the product generation is driven by external directive files. The main component of the Product Generator is the Blackboard which gets its instructions from the Product Description Files. Depending on the products to be generated, the Blackboard issues requests to the relational Database Management System that has been developed to manage the static data, and also issues objectives to the Knowledge Base System which works on the dynamic meteorological data in the concepts file.

The objectives are the goals that the Knowledge Base System must achieve to generate a particular forecast product and the results of the Knowledge Base System's work is returned to the Blackboard. An objective could be for example the clouds and weather part of a regular public forecast bulletin in plain language, or the forecasts surface temperature and relative humidity at noon local time. The results of the objectives can be in textual and/or numerical formats. The Blackboard can also run external scripts and programs than can use as inputs results of objectives. Once all the requests have been fulfilled and the results are made available, the Blackboard assembles the data and generates the products in the format specified in the Product Description Files. The outputs of the Blackboard can be sent to other specialized applications for final formatting and/or graphical packaging. In its current stage, the Blackboard has access only to the static database and to the dynamic meteorological data in the concepts file. However, it is planned to create links with other databases to have access to different kinds of data such as observations, climatological parameters and model fields, thus expanding the variety of products that can be generated.

Work has begun to update the concepts file with real time observations to make use of the latest observations collected between the time the guidance is prepared and the time the forecast products are generated. The weather element matrices are expanded and interpolated in time to a one-hour time resolution in the first 12 to 18 hours. Hourly observations are then introduced in the expanded matrices and a relaxation system meshes the observations with the objective guidance. Once the task is completed, the expanded matrices are processed in SCRIBE to generate the concepts file that can be accessed by the Product Generator.

The development of the Product Generator has necessitated a complete redesign of the Knowledge Base System to make it modular and more flexible in order to be in a position of generating results from objectives without having to go through the complete ensemble of rules. The main advantage of the Product Generator is the capability of generating all the desired forecast products from a single weather element database by writing simple Product Description Files. The flexibility of the Product Generator will be demonstrated and examples of Product Description Files and final forecast products will be given.

Session 1-D1

GEWEX-3: Basin-Scale Experiments - Part I

Chair: Geoff Strong

Monday, June 2 | 15:20-17:00 | Lecture Theatre 143

1-D1.1 Challenges in Closing Water Budgets on Continental Scales: Lessons From the GCIP Experience
(Invited paper, 30 min)
R.G. Lawford (NOAA Office of Global Programs, Silver Spring, MD)

Through its Global and Energy Water Cycle Experiment [GEWEX], the World Climate Research Program [WCRP] has initiated five Continental Scale Experiments [CSEs] to study regional energy and water budgets over large land areas. By 2005, the research results from these experiments will be combined with the modelling capabilities developed in other WCRP initiatives to demonstrate skill in predicting changes in water resources on time scales up to seasonal, annual and inter-annual. To achieve this mission these CSEs are developing an understanding of the atmospheric moisture and surface water fluxes into and out of continental scale areas as well as the cycling of water within those areas. Furthermore, to adequately model land-atmosphere-hydrology interactions over the entire globe, it is necessary to develop a comprehensive understanding of the relevant physical processes that can have application in all climate regimes over a range of spatial and temporal scales.

The GEWEX Continental-scale International Project [GCIP] is arguably the most advanced CSE in terms of its research on water cycling over a continental scale area. GCIP has been underway in the Mississippi River Basin for the past two years. In addition, some earlier pilot projects in the southwestern part of the basin have also been carried out. This experience has provided useful insights regarding the extent to which accurate water budgets can be computed for the most extensively instrumented continental scale river basin in the world. This presentation begins with a description of the importance of understanding water budgets in the areas being considered by the different CSEs. It will then focus on the GCIP initiative and its role in contributing to the goals of the WCRP and NOAA (GCIP's principal funding agency). As part of this overview the project structure and philosophy will be briefly described.

The majority of this presentation will deal with some of the successes and difficulties GCIP has encountered in attempting to quantify individual water budget components and in closing the overall water balance for the Mississippi River Basin. It is evident from these results that large uncertainties exist in the quantification of the water budget, particularly for warm season atmospheric moisture budgets computed from data. Cold season measurement uncertainties are also a source of error in these budgets. There is growing recognition that coupled land atmosphere models at appropriate scales must be used in conjunction with data to effectively quantify the water cycle and its seasonal and inter-annual variability.

Even though its end goal of demonstrating skill in seasonal prediction will only be realized after a number of years of research, it will be shown that GCIP's quest for this goal has already resulted in benefits for hydrometeorological services and water resource assessments. The presentation will conclude with a brief review of some of the scientific issues facing GCIP and the other GEWEX CSEs.

1-D1.2 The Large-Scale Biosphere-Atmosphere Experiment in Amazonia [LBA]

(Invited paper, 30 min)

C.A. Nobre[1] *and J. Arnold*[2] (speaker) ([1]CPTEC/INPE, Cachoeira Paulista, SP, Brazil; [2]NASA Headquarters, Washington, DC, USA)

The Large-Scale Biosphere Atmosphere Experiment in Amazonia [LBA] is an international research initiative lead by Brazil. LBA is designed to create the new knowledge needed to understand the climatological, ecological, biogeochemical, and hydrological functioning of Amazonia, the impact of land use change on these functions, and the interactions between Amazonia and the Earth system. LBA is centred around two key questions that will be addressed through multi disciplinary research, integrating studies in the physical, chemical, biological, and human sciences: (1) How does Amazonia currently function as a regional entity? (2) How will changes in land use and climate affect the biological, chemical, and physical functions of Amazonia, including the sustainability of development in the region and the influence of Amazonia on global climate? The two components of LBA mostly directly related to GEWEX are Physical Climate and Hydrology. The Physical Climate component will study the movement of energy and water into, out of, and through the atmospheric phase of their respective cycles, and how the interactions between the vegetation and the atmosphere feed back to influence these cycles. Meteorological and hydrological studies will be conducted for nested spatial scales, from plots to the entire Amazonia, with focus on determining and understanding the spatial and temporal variations of energy and water fluxes. Variations of climate, and the responses of the Amazonian system to these variations, will be determined on daily to seasonal to interannual time scales. The Hydrology component will consider issues related to both the quantity and the chemistry of water in the Amazon Basin. The stores and fluxes of water, and the controls on movement of water in soils and in streams, and the associated transport of constituents, will be determined for a nested suite of catchments representing a range of land use intensities. The data will be used to improve the capability of hydrometeorological models to assess the response of flows of the Amazon and its tributaries to changes in climate and changes in land use.

1-D1.3 Modelling the Hydrological Cycle in the Mackenzie River Basin

M.D. MacKay[1] (speaker), *R.E. Stewart*[1], *and G. Bergeron*[2] ([1]Climate Processes and Earth Observation Division, Atmospheric Environment Service, Downsview, ON, Canada; [2]Dep. des Sciences de la Terre, Université du Québec, Montréal, QU, Canada)

One of the major goals of the Mackenzie GEWEX Study [MAGS] is to understand, quantify, and model critical components of the hydrological cycle that affect the climate of the Mackenzie Basin. It is generally believed that current GCMs are incapable of adequately resolving hydrological processes at the regional level, and attention has recently turned to Regional Climate Models [RCMs] to address this issue. RCMs are high resolution, limited area models that are nested (usually 1-way) within either a GCM (*e.g.,* for climate scenario studies) or analysed fields (*e.g.,* for climate process studies). A number of studies have shown that RCMs can successfully downscale large scale (GCM or analysis) flow fields to the regional level. In this paper, the Canadian Regional Climate Model is nested within the CCCMA GCM (version II) AMIP experiment, and run for the water year 1987-88 over the Mackenzie Basin. Results from both models will be compared with data from the International Satellite Land Surface Climatology Project (ISLSCP Initiative I) in order to assess whether the current version of the RCM can plausibly downscale the large-scale flow fields of the GCM and successfully simulate the hydrological cycle of the Mackenzie Basin, and in particular, integrated hydrological quantities such as runoff.

1-D1.4 The Impact of the Canadian Land Surface Scheme on Monthly Simulations of Hydrological Parameters over the Mackenzie River Basin

Ekaterina Radeva (speaker) *and Harold Ritchie* (Trans-Canada Research, Dorval, QU, Canada)

As part of the Mackenzie GEWEX Study [MAGS], Canadian global spectral forecast model simulations of surface water and energy budgets over the Mackenzie River basin are examined. The focus of this work is to gauge the impact of the Canadian Land Surface Scheme [CLASS], on the predictability of some hydrological variables. We also compare the performance of the currently operational version of the model with that of a previous one used during a similar study. The model, connected successively to the current operational force-restore land surface scheme and to CLASS, generates nine-member ensemble simulations of one month duration from analyses perturbed with the bred-mode technique, for spring, summer, fall and winter cases. The perturbations are comparable in magnitude to observational errors. As diagnostics we use the spatial averages, over the basin, of the forecast accumulated surface energy and water fluxes. The ensemble statistics of these area-averages are based on the set of simulations. We estimate the forecast sensitivity to initial conditions from the ensemble standard deviation of the area-averages. Time series of the ensemble statistics of the area-averages are constructed in order to track the evolution of the estimated error. Some preliminary results show that the surface energy and water budget fields exhibit moderate variability that increases with time. The ensemble standard deviations observed in the spring and summer cases are generally smaller than the ones produced by the study conducted with the earlier version of the model. Similar to the previous study, we notice an abrupt increase of the ensemble standard deviation of area-averaged precipitation and run-off, but its occurence is delayed by five to seven days. This investigation suggests that, currently, spectral model forecast of hydrological parameters on the basin scale have definite value out to about twenty days. Later results with the CLASS scheme will be presented at the Congress.

Air Quality – Session D2

Chair: John Maybank

Monday, June 2 15:20 - 17:00 Room 217

1-D2.1 An Aerosol Module for the MC2-CALGRID Photochemical Modelling System

M.A. Hedley (speaker), *W. Jiang, and D.L. Singleton* (Institute for Chemical Process and Environmental Technology, Ottawa, ON, Canada)

An aerosol module for the MC2-CALGRID photochemical modelling system is proposed. The model is to be applied to the Lower Fraser Valley of British Columbia, and our intention is to use measurements from the REVEAL and Pacific 93 field studies that took place during July-August 1993 to validate the performance of the model. Results for a preliminary test run for a case in July 1985 will be shown.

1-D2.2 Modelling Pollutant Emissions From a Road Network

J.A. Salmond[1] (speaker) *and D.R. Middleton*[2] ([1]Department of Geography, University of British Columbia, Vancouver, BC, Canada; [2]The UK Meteorological Office, Bracknell, Berks, UK)

The development of air quality models is an integral part of understanding and managing atmospheric pollution in urban areas. Vehicle exhaust emissions are recognised as the predominant source of air pollution in European cities. This paper explores the potential of 'Spaglink', a Gaussian plume model, to facilitate the identification of the spatial distribution of pollution 'hotspots'. Spaglink was designed to estimate the ambient concentrations of the oxides of nitrogen emitted from the Birmingham (UK) road network. The model uses data from the new West Midlands Atmospheric Emissions Inventory to calculate air quality and to map the hourly concentrations of pollutants at a 10 m resolution. Model validation is an integral part of the process whereby planning decisions might be justified in a public fora. An important objective of this study was to identify the problems associated with air quality modelling and validation at the urban scale. A range of statistical measures were used to assess the performance of the model against pollutant time series recorded at three sites in Birmingham during 1995. The broad spatial and temporal characteristics of the data sets were well represented by the model. The best modelling results were achieved during periods of the day when emissions from traffic sources were high. The results highlight the importance of an accurate emissions inventory to air quality modelling at the urban scale. This study serves as a test case to illustrate the potential value of models such as Spaglink in the development of air quality management schemes.

1-D2.3 CANFIS: A Procedure to Build Statistical Air-quality Forecast Models Based on CART and Neuro-Fuzzy Inference Systems

W.R. Burrows and J. Montpetit (speaker) (Numerical Prediction Research Division, Meteorological Research Branch, Atmospheric Environment Service, Downsview, ON, Canada)

Statistical forecast models provide a low-cost solution to the problem of producing forecasts of environmental variables, and can give a good trade-off between significance and precision in return for substantially lower computer resource requirements. Most environmental variables have non-linear dependency on predictors in part or all of their distribution. Recent data-modelling techniques allow for a significant increase in accuracy of statistical models. Two are Classification and Regression Trees [CART] and the Neuro-Fuzzy Inference System [NFIS]. Both can model complex predictand distributions, including the tails. Given learning data of matched

predictand and predictors, CART produces a non-linear piecewise-continuous model of the predictand data. It optimizes the task of predictor selection, often greatly reducing initial data dimensionality. NFIS reduces dimensionality by subtractive clustering, but does not eliminate predictors. Over-lapping coverage in predictor-space is enhanced in NFIS with a Gaussian membership function for each cluster component. Coefficients for a continuous-response model based on the fuzzified cluster centres are obtained by least-squares estimation. The CANFIS procedure combines the strengths of both methods. A CANFIS model requires negligible CPU time to run. Models for ground-level ozone and particulates are being produced for about 100 Canadian sites. They will run in forecast mode twice daily at the Canadian Meteorological Centre using a small number of predictors selected at each site from a large pool of potential predictors. Predictors are derived from meteorology and pollutant emissions along a 72-hour back-trajectory calculated by the operational weather prediction model at CMC. The models begin operational use in New Brunswick in May 1997.

1-D2.4 Developing Wind Data for Dispersion Modelling in Complex Terrain

R.G. Humphries (speaker), *S. O'Kane, A. Schutte, and J. Mitchel* (Richmond, BC, Canada)

Northern British Columbia is rich in forest and energy resources which has resulted in many environmental impact assessments for construction projects related to these sectors of the economy. Unfortunately for the dispersion modeller, this area is noted for its complex terrain and scarcity of meteorological data. Typically the nearest meteorological station is 100 km away located in terrain that is not similar to that of the plant site. To address this problem, surface observations from Environment Canada stations were statistically compared with surface observations from stations associated with three gas plants in northern BC. The aim of the statistical analysis was to obtain a correlation function that will adjust the wind direction from the Environment Canada observations to represent the wind direction at the plant site. The results show that it is possible to derive a wind rose that is more representative of the plant site than using the Environment Canada data only. This suggests that for sites were the wind data is incomplete or only available for a short period of time, say two or three months, it is possible to establish an adjustment so that long term data from the nearest weather station can be used with better confidence in a dispersion model.

1-D2.5 Application of the Canadian Regional Climate Model to Tropospheric Ozone Climatology

V.S. Bouchet[1] (speaker), *E. Torlaschi*[1], *R. Laprise*[1], *and J.C. McConnell*[2] ([1]Dept des sciences de la Terre, Université du Québec, Montréal, QU, Canada; [2]Department of Earth and Space Sciences, York University, North York, ON, Canada)

Photochemical pollution in the Windsor-Québec Corridor [WQC] is a topic of concern as it is the region of Canada where ozone excursions above the maximum acceptable level (82 ppb) occur with the highest frequency. Long range transport has been estimated to account for as much as 60% of the high levels of ozone in southern Ontario. However, the extent of the long range transport contribution within the WQC is still an open question that we wish to investigate. Our approach consists in studying the climatology of ozone given by a regional climate model for the north-eastern part of the WQC. Thus, we are in the process of adapting the Canadian Regional Climate Model [CRCM] by adding a photochemical mechanism, derived from the Acid Deposition and Oxidant Model [ADOM], as well as emission and dry deposition parameterizations. The RCM is a three dimensional model resulting from the coupling of the subgrid parameterization of the Canadian General Circulation Model [CGCM] with a semi-Langrangian and semi-implicit advection scheme and driven by the CGCM through a one-way nesting procedure. As our application of the model will involve either long or numerous runs, it has been chosen to introduce the chemical module on-line. The ability of the model to simulate tropospheric ozone formation and accumulation over summertime periods will be discussed.

Session 1-D3

Climate Research Network - 2

Chair: John Stone

Monday, June 2 15:20-17:00 Lecture Theatre 146

1-D3.1 Some Research Activities in Climate Variability
(Invited paper, 30 min)
J. Derome (Department of Atmospheric and Oceanic Sciences and Centre for Climate and Global Change Research, McGill University, Montréal, QU, Canada)

One of the main goals of climate research is to better understand the nature and causes of climate variability, and to determine the extent to which this variability is predictable. To help coordinate Canadian climate research activities dealing with variability on a broad range of time scales, from the interannual to the century time scale, and to increase the interaction among researchers, a coast-to-coast research group has been formed. The group brings together atmospheric and oceanic scientists from Canadian universities as well as from the AES. The presentation will give an overview of the range of climate variability problems that are being investigated by members of the group, and of the main results obtained so far. Projects include the analysis of the relationship between Pacific SST and mid-latitude atmospheric anomalies, the dynamics of the Pacific North American pattern, the development of coupled atmosphere-ocean models and the predictability of mean-seasonal states.

1-D3.2 Modelling the North Atlantic as a Contribution to the Climate Research Network
(Invited paper, 30 min)
Daniel G. Wright (Ocean Circulation Division, Bedford Institute of Oceanography, Dartmouth, NS, Canada)

The North Atlantic basin has been identified as both a sensitive and a critically important element of the global climate system. As such, it has been singled out for special attention by the Atmospheric Environment Service's Climate Research Initiative. Canadian researchers have contributed greatly to our present knowledge of the North Atlantic, primarily through the collection, analysis and interpretation of field observations. We are now entering a phase of the World Ocean Circulation Experiment in which an intensive observational program will be undertaken in the Atlantic Ocean, with very substantial emphasis being placed on the North Atlantic Basin, and Canadian scientists are actively participating in this project. The consolidation of previous results and the integration of new information into our understanding of the North Atlantic, including improved understanding of how it participates in the climate system, will require intensive modelling efforts. This project aims to contribute Canadian expertise to this international effort. The main goals are (1) to develop a realistic model of the North Atlantic, (2) to use the model to motivate and test conceptual ideas regarding the nature of the present ocean circulation and how it may change in the future, (3) to compare the model results with observations to identify and understand model weaknesses, and correct such weaknesses when possible, (4) use the model to develop improved interpretations of available data sets and to assist in the development of future field programs, and (5) to encourage collaborations within the oceanographic and climate research communities. At present we are just obtaining our first model results for the North Atlantic and looking forward to the exciting

phase of analysis, interpretation and evaluation. Specific goals and progress towards these goals will be discussed in this presentation.

1-D3.3 <u>Climate System History and Dynamics: A Canadian National Programme in Paleoclimatology</u>

(Invited paper, 30 min)

W.R. Peltier (University of Toronto, Toronto, ON, Canada)

The CSHD Programme of the CRN is a scientific collaboration funded jointly by the AES and NSERC that involves ten research groups located in both Government laboratories and Universities. The goal of the research programme is to test the Atmospheric GCM of the CCCMA by confronting it with the constraints provided by paleoclimatological observations. Initial analyses have been performed which focus upon the time slices centred on 6,000, 12,000 and 21,000 years before present. The results obtained to date from this sequence of climate system simulations will be summarized.

Session 1-D4

Weather Forecasting - 2

Chair: Fraser Hunter

Monday, June 2 — 15:20-17:00 — Room 206

1-D4.1 <u>Effects of Atmospheric Refraction on Sunrise and Sunset</u>

R.D. Sampson (speaker) *and E.P. Lozowski* (Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB, Canada)

Public weather forecasts frequently include the times of sunrise and sunset. Variations in the vertical temperature gradient of the atmosphere produce changes in the amount of refraction which can result in variations in the time of sunrise and sunset. In this statistical study, observed timings of 244 sunrises and 125 sunsets from the city of Edmonton were used to determine the refraction of the Sun's upper limb at the moment of sunrise and sunset on a zero horizon. The observed values of refraction are compared with accepted predictive formulae and suggestions for possible improvements are provided. Anomalously large refraction events (greater than 1 degree), also known as the Novaya Zemlya Solar Mirage, are discussed with respect to their frequency and relationship with surface meteorological conditions.

1-D4.2 <u>Public Forecast Verification</u>

R. Verret (Canadian Meteorological Centre, Dorval, QU, Canada)

The Canadian Meteorological Centre has developed a verification system to verify public forecasts based on the following framework. All available observations, synoptic, hourly, and supplementary aviation observations are used to create a truth file at a set of stations. The truth file is basically a matrix which includes all observed weather elements with a one-hour time resolution, taking into account the special observations produced at non standard times. The weather elements are cross-checked between themselves to validate the observations and create the truth assumed to be the actual representation of the weather that really occurred. The truth files are generated once a day at each station for the past twenty four hours. Similar matrices are generated for the forecasts. The forecasts and observations can then be compared and the validity and skill of the forecasts assessed. The most important weather elements can be verified, mainly maximum and minimum temperatures, probability of precipitation, precipitation amounts, precipitation types, winds speed, wind direction and sky cover. The verification can be done for Today, Tonight, and Tomorrow for the early morning issue of the forecasts and for Tonight, Tomorrow, and the following day for the afternoon issue. Several verification scores are calculated for each weather element, and contingency tables constructed. The advantage of contingency tables is that they give an insight into the joint frequency distributions of observations and forecasts. The Signal Detection Theory [SDT] is applied on the verification of the probability of precipitation forecasts. The technique tries to take into account the utility as well as accuracy in evaluating the skill of the forecasts. SDT is nicely applicable in verification of probabilistic forecasts for dichotomous variables, such as the occurrence or non-occurrence of precipitation events. It tries to model a decision making process where a precipitation event is expected when the forecast probability of precipitation exceeds some user defined threshold value that is normally unknown to those in charge of verification. However, SDT does not provide an absolute measure of the utility of the forecasts, but is rather applicable in comparing two forecast systems. Similarly, the Baysian Correlation Score [BCS] is computed for the maximum and minimum temperature forecasts. BCS is another measure of the skill of the forecasts that takes into account the utility of the forecasts up to some point. It is based on the assumption that the users of temperature forecasts will recognize the systematic biases of the forecasts and base their decision accordingly. It takes into account the variance of the forecasts that is not explained by the least square linear regression of the forecasts on the observations. The objective (machine forecasts) public forecasts based on the operational Regional and Global models at the Canadian Meteorological Centre that have been produced since December 1994 have been verified. The verification results have been stratified into three-month seasons. Verification results will be presented and the usefulness and flexibility of the verification system demonstrated.

1-D4.3 <u>Performance Measurement Based on Client's Needs</u>

J.M. Paola (speaker) *and J.E. Shaykewich* (APBC/PPID, Downsview, ON, Canada)

Historically, the performance measurement emphasis of the national meteorological services has been on technical performance, such as forecast accuracy, model accuracy, *etc.* This scientific scrutiny is a natural bias of the people involved in this physical science discipline. Typically, less than 10% of the resources spent on such scientific scrutiny are spent on evaluating the needs and utility of the client or end-user. An overall performance measurement system must by necessity adopt a more balanced scorecard approach. In a national meteorological service setting, a balanced performance measurement system can be thought of as encompassing the dimensions of external clients (and users), employees (the suppliers), and internal clients (policy & planning groups, for use in public accountability) as well as that of technical performance. The focus of this paper is that of the external clients while keeping in mind the other three dimensions. This paper will define the constituent parts of the external client dimensions (awareness, satisfaction, needs, expectations, utility, and effectiveness) and outline past, current, and planned endeavors of developing performance indicators and at measuring performances for this critical dimension. Through the investigation of how a program is being delivered, by the client=s expectations and what the critical needs are of the client, a utility factor can be determined. The realization of the "gap" of current level of service and this utility factor, will allow sound program adjustments to be made by the program managers to better serve the client.

1-D4.4 <u>Rethinking Our Weather Forecast Service: Moving Beyond "Partly Cloudy with a 20 Percent Chance of a Shower"</u>

S. Ricketts (Environment Canada, Edmonton, AB, Canada)

Despite significant advances over the past 20 to 30 years (in information, in data, in technology, in the science, in communication systems), Environment Canada=s basic weather services (*e.g.,* the public forecast bulletins and weather warnings) have not changed much. Using our traditional products and dissemination systems, we are unable to tell the public all that we know about the weather, especially in the short-term and when it can matter the most. Even with our move into providing commercial services, we still have an obligation to supply Canadians, our number 1 client, with good weather information. We have a role to play in encouraging Canadians to make informed and responsible decisions regarding their daily activities; *e.g.,* to incorporate weather into their decision-making processes. We need to look at better products and into better ways to distribute them to Canadians, including strengthening our partnership with the media. We need to get more information directly into the hands of people, and show them how to better understand and apply it. This session will explore some possibilities along these lines.

1-D4.5 The Canadian MC2 Modelling System - Massively Parallel Implementation and Other Recent Developments

M. Desgagne (speaker), *S. Thomas, R. Benoit, and P. Pellerin* (Recherche en Prevision Numerique - Atmospheric Environment Service, Dorval, QU, Canada)

Since its delivery to the scientific community in 1991, the MC2 model has been used in many research projects. Many of those have led some research groups to modify existing code or develop entirely new code in order to meet their research targets. One of the important roles of the MC2 central support team at RPN is to gather all this incoming code and produce new and improved versions of the model. We will focus on recent additions/modifications to the MC2 modelling system which have significantly contributed to improve the model performances. We will discuss the new semi-Lagrangian interpolator and the new massively parallel elliptic solver based on Krylov sub-space. We will describe the new MC2-MPP dynamic kernel; a distributed memory MPI based version of MC2 which makes it one of the fastest atmospheric models in the world. We will also discuss the introduction of 2 new microphysics schemes in the CMC/RPN physics package: one from Kong and Yau (McGill University) and another one from Tremblay (AES).

Session 2-A1

BOREAS Plenary

Chair: Peter Schuepp

Tuesday, June 3 | 09:05-09:50 | Lecture Theatre 143

2-A1.1 A Review of Some Results From BOREAS: 1994-1996

(Plenary paper, 45 min)

Alan K. Betts (Atmospheric Research, Pittsford, VM, USA)

This paper will review the results to date of the 1994-96 BOREAS Field Campaigns. The primary emphasis will be on the role of the boreal forest in weather and climate models and the regional hydrology. I shall also review progress in the modelling of the energy/water/carbon cycles on both short and long time-scales, based on the results of many other researchers.

Session 2-B1

BOREAS - 1
Chair: Peter Schuepp

Tuesday, June 3 10:10-12:10 Lecture Theatre 143

2-B1.1 The Climatology of the BOREAS Years of 1994, 1995, and 1996 at a Select BOREAS/SRC Mesonet Site

S.R. Shewchuk (Saskatchewan Research Council, Saskatoon, SK, Canada)

The Saskatchewan Research Council [SRC] has operated a Climate Reference Station [CRS] for over 30 years. SRC has established its own series of normals at this site. This station has been used to design the surface mesonet for BOREAS with NASA. The climatology of the SRC-CRS during BOREAS years is considered in the paper. The BOREAS mesonet was primarily an above the canopy array of sensors; however, the SRC-CRS is located away from main tower flux sites and references the entire data field to the agricultural lands to the south. The sensor arrays were completely homogeneous and the mesonet sensors were laboratory calibrated prior to field installation. Both 1994 and 1995 had warmer than normal mean annual temperatures for the south fringe of the BOREAS region; however, year 1996 was considerably cooler than normal. One of the surprising features of this mesonet was that it revealed strong shortwave albedo gradient across various biomes within the Boreal forest. These conditions broadly represented the climate of the southern fringe of the BOREAS project.

2-B1.2 Atmosphere-Surface Coupling Over the Boreal Forest Determined from Aircraft-Based Flux Relationships and Surface Conditions During BOREAS 1994

C.M. Mitic[1] (speaker), *P.H. Schuepp*[1], *R. Desjardins*[2], *and J.I. MacPherson*[3] ([1]Department of Natural Resource Sciences, McGill University, Montréal, QU, Canada; [2]Agriculture and Agri-Food Canada, Ottawa, ON, Canada; [3]Institute of Aerospace Research, National Research Council, Ottawa, ON, Canada)

The ability to link surface characteristics to atmospheric processes has been established by a number of studies for different ecosystems. Our study however goes a step further in establishing the surface-atmosphere link by examining the flux composition and scales of coherent structures dominating transport and their link to conditions at the surface by way of their spatial locations. Grid flight observations made by the Twin Otter aircraft of the National Research Council of Canada during the 1994 BOREAS intensive field campaigns (May 24 - Sept 19) for both the southern and northern sites are used to examine the relationships between the characteristics of coherent structures and the those of the underlying surfaces. The distributions, compositions, and scales of these structures indicate the degree of coupling between the underlying surface and the atmosphere. This is particularly interesting for the different forest types such as the black spruce and aspen stands. The flux intensities and associations of CO_2, H_2O, and heat within the coherent structures is partially a function of the surface controls as well as the atmospheric conditions. Questions such as, the relationship between CO_2, H_2O, and heat fluxes, and conditions such as surface wetness, surface temperature, radiation, forest stand characteristics are addressed.

2-B1.3 Lessons from BOREAS

P.H. Schuepp[1] (speaker), *S.O. Ogunjemiyo*[1], *B. Abareshi*[1], *R.L. Desjardins*[2], *and J.I. MacPherson*[3] ([1]Department of Natural Resources Sciences, McGill University, Ste-Anne-De-

Bellevue, QU, Canada; [2]Agriculture and Agri-Food Canada, Ottawa, ON, Canada; [3]Institute for Aerospace Research, National Research Council of Canada, Ottawa, ON, Canada)

The boreal ecosystem-atmosphere study [BOREAS] provided a unique opportunity for the development and testing of sampling and analysis procedures in airborne observations over heterogeneous northern landscapes. These landscapes are not only characterized by patchiness in surface conditions (temperature, moisture, vegetation cover), but also by very dynamic boundary layers, which pose a challenge for flux observation by aircraft. Our paper is based on analysis and interpretation of flux observations (of momentum, sensible heat, moisture and CO_2) made by the Canadian Twin Otter research aircraft in BOREAS 1994 and 1996, over two 16 km x 16 km areas in the southern and northern study areas. Of particular interest are the effects of short-term variability introduced by boundary layer dynamics and changing radiation conditions on flux maps (spatial distributions of sources and sinks for the above-mentioned fluxes). Only if this variability is properly accounted for can the resulting flux maps be meaningfully related to surface characteristics (such as detected from radiometric remote sensing) or to predictions from regional climate models. We will review the current state of progress on these latter questions, and how they might relate to GEWEX objectives.

2-B1.4 Effects of Turbulence and Climatic Variability on the Annual Carbon Sequestration by a Boreal Aspen Forest

W.J. Chen[1] (speaker), *T.A. Black*[1], *P.C. Yang*[1], *A.G. Barr*[2], *H.H. Nenmann*[2], *P.D. Blacken*[1], *Z. Nesic*[2], *J. Eley*[2], *and M.D. Novak*[1] ([1]University of British Columbia, Vancouver, BC, Canada; [2]Atmospheric Environment Service, Saskatoon, SK, Canada)

Net terrestrial ecosystem productivity [NEP] plays a key role in global carbon budget and global climate change. At present, eddy correlation is the only reliable technique which provides undisturbed and continuous measurement of NEP. Uncertainty in annual NEP estimates using the eddy correlation technique, however, may arise from the lack of full-year measurements and the treatment of general low and variable CO_2 fluxes on calm nights. The first problem will be addressed by long-term flux measurements at various sites of the international CO_2 flux networks (Ameriflux Network in North America, Euroflux Network in Europe and Ozzflux network in Australian and New Zealand). Approaches to deal with the second problem will be addressed in detail using data from the Old Aspen site, which is one of the Boreal Ecosystem-Atmosphere Study [BOREAS] sites. Preliminary analysis shows that the growing-season NEP of the OA stand in 1994 is about 30% higher than that in 1996. Climatic and biological causes of the difference will be also examined in this presentation.

Session 2-B2

Atmospheric Modelling

Chair: Hal Ritchie

Tuesday, June 3 10:10-12:10 Room 217

2-B2.1 EuroMET: Teaching Meteorology Internationally Using Internet

Peter Zwack and Christian Page (speaker) (Université du Québec, Montréal, QU, Canada)

Project EuroMet is a cooperative project of 20 training establishments in Meteorology in Europe and Canada. Its goal is to address the education and training needs of professional meteorologists employed by the national meteorological services and students in universities. This service will provide open and distance learning for this group in a way which can be customise to fit local needs. Two highly interactive courses of 120 modules each will be available on-line for early 1998 : Numerical Weather Prediction and Satellite Meteorology. The courses will be delivered in any of four languages using World Wide Web (WWW) tools and will employ a variety of media including text with mathematics, images, video, sound, and animations. The WWW clients will be enhanced to include a high degree of interaction. WWW servers with a high-compute capacity will provide image processing and simulation services more powerful than can be delivered on a standard workstation. In support of this learning environment communication facilities for one-to-one and one-to-many are included. These communication facilities support all media elements and both symmetric and asymmetric communication. An overview of the course will be given along with an example of a completed EuroMET module in the NWP course.

2-B2.2 Experiments with a Two-Time-Level Version of the Canadian Global Spectral Forecast Model

Harold Ritchie (speaker) *and Christiane Beaudoin* (Transcanadian Hwy, Dorval, QU, Canada)

The Canadian global spectral forecast model that is used for global data assimilation and medium- and long-range forecasts at the Canadian Meteorological Centre currently uses a three-time-level [3TL] semi-implicit semi-Lagrangian time integration scheme (Ritchie,1991). Recently Temperton (1996) showed that a two-time-level [2TL] scheme with a two-term extrapolation of the nonlinear terms could readily be incorporated in the ECMWF spectral model. Here we follow a similar approach except that we use an extension of the Cote and Staniforth (1988) implicit treatment of the Coriolis terms, which avoids some subtleties for the "advective treatment" of the Coriolis terms as described by Temperton. As a control model, we integrated the model using a triangular truncation at 199 waves in the horizontal spectral representation, 27 hybrid levels in the vertical finite-element discretization and the 3TL scheme with a 30 minute time step. This model has a split-implicit coupling of the dynamics and physical processes in such a way that the parameterizations adjust the fields over an interval of two time steps, or 60 minutes in this case. This version was compared with the 2TL experimental model using a 60 minute step, with the physical parameterizations adjusting the fields over an interval of one step, *i.e.,* still 60 minutes. A comparison of these models was performed on five day forecasts for eight test cases that span the seasons of the year. The average (over the 8 cases) root-mean-square [RMS] errors and biases, compared to radiosonde observations over the Northern Hemisphere, will be presented for the geopotential height and temperature forecasts at 120 hours. The results are very similar. The main advantage of the 2TL scheme is that it is almost twice as efficient as the 3TL one (the relatively expensive radiation calculations are performed every three hours in both versions).

2-B2.3 Diagnosing the Motion of a Hurricane in the Canadian Global Forecast Model

Peter Zwack (Department of Earth and Atmospheric Sciences Université du Québec, Montréal, QU, Canada)

It is well know that hurricanes are driven by diabatic effects. However, their motion often follows a "steering current" which is related to the winds in the middle and upper troposphere. Numerical forecasts of hurricane motion and intensification are improving slowly with the improvements in physical parameterizations and model resolution. However, there can be large discrepancies between forecasts from different models. An example of such situation will be presented along with a diagnosis of hurricane motion in the operational Canadian Global Forecast Model. The diagnostics are from a enhanced version of the diagnostic package DIONYSOS, which is currently becoming operational in the French and Canadian Meteorological Centres as well as being implemented in WFO-advance. The presentation will first describe the improvements in

DIONYSOS necessary to diagnose tropical cyclones as simulated in forecast models. This will be followed by the diagnostics which show that, for one hurricane in the model, the vorticity tendency at all levels in the hurricane were indeed dominated by latent heating but that as much as 25% was produced by vorticity advection, which also very much helped to determine the hurricane motion. Comparison diagnostics will also be shown from two different forecast models for another hurricane.

2-B2.4 Matching Numerical Methods to Atmospheric Dynamics as a Function of Scale

P. Bartello (speaker) *and S.J. Thomas* (Recherche en Prevision Numerique/AES, Dorval, QU, Canada)

Increasingly, attention has been focused on ever diminishing length scales in numerical weather prediction. In the past decade, for example, spatial truncation scales have evolved from on the order of 100 km to order 10 km, while a variety of mesoscale applications employ even finer grids. Over the range from large-scale quasigeostrophic flow to boundary-layer turbulence, the nature of the fluid dynamics of the atmosphere changes a great deal. Such issues as the breakdown of balance and the interaction between vortical motions and the gravity-inertial wave field are clearly not completely understood. After introducing a numerical grid in space and time, one selects numerical approximations to the dynamics for the range of length scales of interest, which maximize the accuracy for a given expenditure of computational effort. In addition, it is necessary to represent spatial and temporal subgridscale processes. Optimal numerical representation of both the resolved and unresolved dynamics clearly depends on the size of the grid, which determines the nature of the true atmospheric dynamics. It will be argued that in this context the concept of a "universal" model, employing any one particular numerical scheme, is to be avoided. For example, it will be shown that semi-Lagrangian advection schemes, which can be very efficient for quasigeostrophic dynamics in the absence of topography are not at all efficient below approximately 300 km, where the mesoscale $k^{-5/3}$ spectral range begins.

2-B2.5 The Response of a Simple Nonlinear Model Atmosphere to Sea Surface Temperature Anomalies in the North Pacific

Z. Xing (speaker), *J. Derome, H. Lin, and C.A. Lin* (Department of Atmospheric and Oceanic Sciences and Centre for Climate and Global Change Research, McGill University, Montréal, QU, Canada)

The responses to positive and negative sea surface temperature [SST] anomalies in the North Pacific are computed with a time-dependent, quasi-geostrophic, global spectral model with a T21 horizontal resolution and three levels in the vertical. The simplicity of the model allows a large number of cases to be run. The model produces a ridge (low) downstream of the warm (cold) SST anomaly, but the response to the warm anomaly is much weaker and statistically less significant than that to the cold anomaly. In the case of the warm SST anomaly, the storm track is displaced northward into the high-pressure atmospheric anomaly, whereas in the case of the cold SST anomaly the storm track is moved southward, away from the atmospheric low-pressure anomaly. The higher level of atmospheric nonlinearity in the warm case leads to more case-to-case variability in the model response to the SST anomaly than for the cold SST anomaly. The results are compared with those of previous GCM studies based on fewer cases.

Session 2-B3
Cloud and Precipitation Physics - 1

Chair: John Reid

Tuesday, June 3 10:10-12:10 Room 200

2-B3.1 The Effect of Cumulus Clouds on the Sub-Grid Scale Distribution of Quasi-Conserved Variables in a Statistical Layer Cloud Scheme

N. McFarlane (speaker), *K. Abdella, and U. Lohmann* (Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada)

A scheme for predicting the evolution of layer clouds and their condensed water content has recently been developed for use in atmospheric general circulation models. This scheme relies on a statistical approach to modelling the sub-grid scale features of layer clouds. Implementation of the scheme requires evaluation of both first and second moments of the distributions of quasi-conserved variables within a given GCM grid volume. In this paper ways of accounting for the separate contributions due to smale scale turbulence and cumulus convection are discussed. Results of experiments using a single column model will be presented to illustrate the coupling between parameterized cumulus convection and predicted layer clouds.

2-B3.2 Comparing Different Cloud Schemes of a Single Column Model by Using Mesoscale Forcing and Nudging Technique

U. Lohmann[2] (speaker), *N. McFarlane*[2], *L. Levkov*[2], *and K. Abdella*[1] ([1]Canadian Centre for Climate Modelling and Analyses, University of Victoria, Victoria, BC, Canada; [2]GKSS-Forschungszentrum Geesthacht, Germany)

Different cloud schemes using the single column model [SCM] version of the general circulation model [GCM] of the Canadian Centre for Climate Modelling and Analysis are compared. Emphasis is placed on the differences between a statistical cloud scheme and an explicit one, both commonly used in GCMs. Two case studies, one day during the European Cloud and Radiation Experiment [EUCREX] and one day during the North Atlantic Regional Experiment [NARE], which both took place in September 1993 were chosen. During the EUCREX case study the SCM is forced by advection from the mesoscale model GESIMA. One major difference between GESIMA and the explicit cloud scheme is the slower development in the latter of maximum liquid and ice water contents in all clouds. In the statistical cloud scheme the fast development of clouds is captured as in GESIMA, if a minimum standard deviation of the total water distribution in higher layers is considered. During the NARE case study four subsequent vertical profiles are available so that wind, temperature and moisture of the SCM can be nudged towards their observed values. The cloud is able to lift as observed only when the statistical scheme is used and not only temperature and wind, but moisture as well, are adjusted towards observations.

2-B3.3 Influence of Temperature on the Droplet Spectra Formation

F. Celik (University of Wyoming, Department of Atmospheric Sciences, Laramie, Wyoming, USA)

A droplet spectrum containing droplets with different salinity and size is an unstable system. Droplet spectra change with time spontaneously in a cloud. Changes in the droplet spectrum take place such that the spectrum broadens toward large and small sizes due to transfer of water vapor from ripening smaller droplets to larger droplets (Ostwald ripening). Kinetics of this process is a function of temperature. Influence of temperature on the droplet spectra broadening and formation of large droplets in a shallow stratiform cloud is numerically analysed. It is shown that rate of droplet spectra broadening and formation of large droplets increases with increasing temperature. However, droplet concentration decreases with increasing temperature. Due to ripening droplet concentration decreases continuously with time.

2-B3.4 Radar Observations of Snow Formation

Gerhard Reuter[1] (speaker) *and Raymond Beaubien*[2] ([1]University of Alberta, Edmonton, AB, Canada; [2]Prairie and Northern Region, Environment Canada, Edmonton, AB, Canada)

Snowfall production is analysed for a long-lasting snowband that formed in advance of a warm front moving across Alberta. Radar reflectivity fields were used to estimate the evolution of total snow content and outflow rate. The snowfall rate averaged across the cloud base was about 0.8 cm/h. The characteristic time defined as the ratio of total snow content over mass outflow rate was about 30 minutes. The precipitation efficiency of the snowband, defined as the ratio of snow mass outflow to water vapour inflow, was estimated to be 14%.

2-B3.5 Determination of Hail Storm Cloud Structure From Satellite Microwave Measurements

I.G. Rubinstein (Earth Obs. Lab., North York, ON, Canada)

Special Scanning Microwave Imager data were used to analyze cloud structure for several severe hail storm events in Alberta and Ontario. A technique that combined theoretical models with the statistical properties of microwave radiances was used to derive the cloud ice indices and precipitation rates. The vertical and horizontal structure information was determined using weighting functions derived for each one of the SSM/I seven channels. The high sensitivity of the 85 GHz channels to volume scattering by precipitation, especially ice, was the basis for derivation of the cloud ice index. The liquid precipitation distribution was retrieved using 37 GHz and 19 GHz radiances. At the present time there are several SSM/I sensors in orbit providing two to six looks per day of the same target area. The results of this research suggest that the historical and currently available SSM/I data can be used for the analysis and monitoring of the cloud structure characteristic for severe precipitation events.

Session 2-B4

Ocean Circulation & Modelling

Chair: Peter Smith

Tuesday, June 3 10:10-12:10 Room 206

2-B4.1 A Second Order Turbulence Closure Scheme for the Upper Ocean

S.J.D. D'Alessio (speaker), *N. McFarlane, and K. Abdella* (Canadian Centre for Climate Modelling & Analysis, University of Victoria, Victoria, BC, Canada)

In climate modelling it is imperative to include the exchange processes such as heat, momentum and water vapour between the atmosphere and the ocean. The mixed layer refers to the upper portion of the ocean that is in direct contact with the atmosphere and is usually observed to be thoroughly mixed. It plays an important role in communicating and negotiating fluxes with the atmosphere. A means of investigating the response of the upper ocean to atmospheric forcing is through the implementation of one-dimensional column models which account for vertical variations. Horizontal variations can be significant under certain conditions and in specific regions; however, their influence is omitted in these models. In column models a set of conservation equations governing the mean horizontal velocity components [U, V], temperature [T], and salinity [S] are driven by fluxes of heat, wind stress, and solar radiation imposed by the atmosphere at the ocean surface. The mixed layer then responds to such a forcing through deepening or shallowing and heating or cooling. The resulting sea-surface temperature [SST] has a great influence on the climate and also on the local biological environment.

Over the years numerous models have been proposed to simulate the mixed layer. There are generally two common approaches taken in solving the set of equations. In bulk models the equations are integrated across the mixed layer on the assumption that the mean quantities are nearly uniform throughout it. In these models the advance and retreat of the mixed layer depends on the parameterizations of the fluxes at its base. Another approach, known as turbulence closure schemes, attempt to model the various turbulent fluxes appearing in the equations. Here, the equations are dealt with in a differential form rather than an integral form. One is then faced with the task of prescribing the various turbulent fluxes in terms of the computed quantities.

To be presented in this talk is a second-order turbulence closure scheme for the upper ocean. In second-order closure schemes, the equations dictating the turbulent fluxes are closed at the

second-moment level and thus require the specification of unknown third-moment turbulence quantities. Unless simplifications are made, substantial computational demands can be required by turbulence closure schemes since they introduce additional equations for the various second moments that must be solved in conjunction with the usual set for U, V, T and S. In this scheme the only additional equation required is that for the turbulent kinetic energy [TKE] as in a Mellor-Yamada level 2.5 scheme. By making certain assumptions about the turbulence, the remaining second moments can be determined algebraically.

The model was tested against several bulk and turbulence closure schemes for various idealized forcings including wind driven, heating and cooling cases. Also, the model was tested against observational data taken from ocean weathership stations [OWS] Papa and November (located at 50 N, 145 W and 30 N, 140 W, respectively) for the year 1961 and does reasonably well in reproducing the observed SST and mixed-layer depth.

2-B4.2 A General Pressure Gradient Scheme and its Applications to North Atlantic Modelling

Yuhe Song and D.G. Wright (speaker) (Fisheries & Oceans Canada, Bedford Institute of Oceanography, Dartmouth, NS, Canada)

A new formulation of the pressure gradient force for use in models with topography-following coordinates is proposed. It is based on a Jacobian formulation, it can be used in conjunction with any vertical coordinate system, and it is easily implemented. Two discrete schemes are derived: the first using standard centered differencing in the computational vertical coordinate and the second using vertical weighting such that the hydrostatic inconsistency is eliminated for density perturbation fields which vary quadratically. Both schemes achieve second order accuracy for any vertical coordinate and are significantly more accurate than the conventional scheme based on applying finite differencing directly to the pressure field. The new schemes are numerically consistent, energetically consistent and accurately represent the bottom pressure torque. Their performances in a large-scale wind-driven basin are tested prognostically for both numerical accuracy and long-term integral stability, based on a model with and without topography. The integrations are carried out for 10 years in each case and results show that the schemes are stable, and the steep topography causes no obvious problems. A realistic meandering western boundary current is well developed with detached cold cyclonic and warm anticyclonic eddies as it extends across the basin. In addition, the results with topography show earlier separation and enhanced transport in the western boundary currents due to the bottom pressure torque. A North Atlantic model with the new pressure gradient schemes has been developed for the Canadian Community Modelling Effort. The model domain is from 7N to 71N and from 98W to 15E with 1/3 degree resolution.

2-B4.3 Seasonal Hydrographic and Baroclinic Circulation on the Newfoundland Shelf

Xu, Zhigang[1] (speaker), *John Loder*[1], *Charles Hannah*[2], *and Brian Petrie*[1] ([1]Coastal Circulation, Bedford Institute of Oceanography, Dartmouth, NS, Canada; [2]Oceandyne Environment Consultants, Bedford, NS, Canada)

The climatological seasonal variations of hydrography and baroclinic circulation in the Newfoundland Shelf region are investigated using archived hydrographic and current data, and a 3-D diagnostic circulation model. Optimal linear interpolation is used to estimate seasonal-mean temperature, salinity, and density fields for four periods (early spring, late spring, summer, and fall) on the model grid. The circulation associated with specified baroclinic pressure gradients in the model interior and specified barotropic pressure (elevation) gradients on the model boundaries is then obtained from the linear harmonic finite-element model FUNDY5. The boundary elevations are specified using steric heights calculated from the density data, and additional barotropic pressure gradients estimated from moored near-bottom current measurements along the upstream (Bonavista section) boundary. The model flow fields are dominated by the equatorward transport of the Labrador Current along the the shelf edge, with important barotropic and baroclinic components. Although there are pronounced seasonal changes in hydrographic properties, the baroclinic flow component has a persistent structure in the various seasons examined. Evaluation of the model flow fields against observed currents from moored measurements and surface drifters indicates good overall agreement for transports and horizontal structure, and resolution of both the vertical and horizontal structure of the Labrador Current in some (but not all) local areas.

2-B4.4 Experiments with a Comprehensive Finite Element Model Examining the Scotian Shelf Region

D.A. Greenberg[1] (speaker), *C.G. Hannah*[2], *J.W. Loder*[1], *and J.A. Shore*[1] ([1]Coastal Ocean Science, Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, NS, Canada; [2]Oceandyne Environmental Consultants, Bedford, NS, Canada)

A quantitative representation of the 3-D seasonal-mean circulation in the Scotian Shelf region has recently been obtained using a nonlinear diagnostic model (Han, *et al.*, JGR 102, 1011-1025, 1997). To obtain an improved representation and increase our understanding of the important processes, we are using a fully nonlinear time-stepping model, prognostic in temperature and salinity and incorporating Mellor-Yamada level 2.5 turbulence closure (Lynch *et al.*, CSR 16, 875-906, 1966). In this paper we will concentrate on aspects of the spring circulation, using historical data to optimally estimate temperature and salinity fields centered on April 1st. To increase confidence in the model computations, we will be examining various aspects of the forcing and using an idealized density field to determine important time and space scales.

2-B4.5 A Semi-Lagrangian Finite Element Barotropic Ocean Model

D.Y. Le Roux[1] (speaker), *C.A. Lin*[1], *and A. Staniforth*[2] ([1]Department of Atmospheric and Oceanic Sciences, McGill University, Montréal, QU, Canada; [2]Recherche en Prevision Numerique, Environnement Canada, Dorval, QU, Canada)

We present a new model combining for the first time in ocean modelling the finite element and semi-Lagrangian methods on unstructured meshes. A barotropic two dimensional flow is simulated by discretizing the inviscid shallow water equations. The treatmentof Rossby waves is at least fourth order accurate, through the use of a kriging interpolation scheme. We show that the choice of an appropriate low order finite element is crucial for the noise-free simulation of geostrophic balance. Experiments are performed with a wind-driven test problem and eddy-shelf interaction in a basin.

Session 2-C1

BOREAS - 2

Chair: Peter Schuepp

Tuesday, June 3 13:40-15:00 Lecture Theatre 143

2-C1.1 A Simulation Study on the Enhancement of Nocturnal Inversion and the Formation of Low Level Jet [LLJ] Over the Boreal Forest

Hanjie Wang (speaker), *Aloysius K. Lo, and Yi-Fan Li* (Atmospheric Environment Service, Environment Canada, Toronto, ON, Canada)

Based on the Intensive Field Campaign [IFC] BOREAS data, the profiles of wind and temperature in the low level atmosphere (below 1500 m) are analysed to reveal the relationship between the enhanced inversion layer and the formation of low level jet [LLJ] in the boreal region. It has been fund that during the clear nights in earlier summer (IFC-1 was from May 24 to June 16, 1994), the forested area intensifies both intensity and thickness of the inversion layer due to the long wave radiation cooling of the canopy, which consequently form or enhance the low level jet. The 3-D meso-scale primitive equation model that incorporates boreal forest developed recently by Wang *et. al.* (1995, 1996) is used to simulate the causality of LLJ and temperature inversion. The simulation study shows that the more intense the inversion, the stronger the

LLJ. The height of LLJ in this region appears frequently at 200-300 m and the corresponding inversion intensity is about 2.5-3.0EC/100 m. The formation or development of LLJ in the atmosphere boundary layer is important, not only because it affets the turbulent transfer process, but also interferes the stability of meso-scale model that simulates the 3-dimensional meteorological fields. *Keywords:* BOREAS, low level jet, temperature inversion, meso-scale modelling.

2-C1.2 Mixed Boundary-Layer Evolution Above Boreal Forest

A.G. Barr[1] (speaker) *and A.K. Betts*[2] ([1]Atmospheric Environment Service, National Hydrology Research Centre, Saskatoon, SK, Canada; [2]Atmospheric Research, Pittsford, VT, USA)

The 1994 and 1996 Boreal Ecosystem-Atmosphere Experiment [BOREAS] included an upper-air sounding network which spanned the north-to-south geographic extent of the Canadian boreal forest and the seasons of spring to fall. We analyse the diurnal and seasonal cycles of the daytime mixed boundary layer, and explore the role of external forcings on mixed-layer development. We also contrast the boreal forest's daytime mixed layer with that of the crop- and grassland to the south.

2-C1.3 Hypotheses on Feedbacks of Trembling Aspen Forests on Regional Weather and Climate in the Southern Boreal Forest of Western Canada

E.H. (Ted) Hogg[1], *P.A. Hurdle*[1], *T.A. Black*[2], *P.D. Blacken*[2], *A. Wu*[2], *W. Chen*[2], *and Alan Barr*[3] ([1]Canadian Forest Service, Edmonton, AB, Canada; [2]University of British Columbia, Vancouver, BC, Canada; [3]Atmospheric Environment Service, Saskatoon, SK, Canada)

The Boreal-Ecosystem Atmosphere Study [BOREAS] is a large international field experiment that has made a major contribution to understanding the interactions between the boreal forest and the atmosphere. One of the most significant results from the recent BOREAS field campaigns was that during the peak growing season, evapotranspiration rates measured from forests of trembling aspen (Populus tremuloides) were about twice as great as those from boreal conifer forests. This resulted in correspondingly much lower rates of upward sensible heat flux density from aspen forests than from conifer forests. However, this pattern applies only when aspen forests are in full leaf-out (early June to mid-September): during spring and fall when leaves are absent, evapotranspiration rates are very low, while sensible heat flux densities are much higher. Because aspen forests predominate over a ca. 300 km wide zone extending from northern Alberta to southern Manitoba, significant feedbacks of aspen on seasonal patterns of weather and climate might be expected.

In the present analysis, seasonal changes in monthly mean temperature were examined from the long-term climate normals at stations across western Canada. Seasonal temperature changes were found to show the greatest deviation from an annual cosine function in a geographic zone coinciding with the greatest abundance of aspen. In this zone, mean temperatures are 2-3EC warmer in April and October, but nearly 2EC cooler in June and July, relative to that expected from a best-fitting cosine function. We postulate that seasonal leafing and leaf-fall in aspen could be a contributor to this pattern. Furthermore, feedbacks on regional weather conditions might be expected during years when large (up to 300 x 500 km) areas of aspen are defoliated by the forest tent caterpillar. Recent periods with widespread defoliation in the region include the early 1960s and the 1980s, notably 1980-82 and 1988.

2-C1.4 BOREAS Mesoscale Evapotranspiration Modelling Project

C. Pion[1], R. Leconte[1] (speaker), *E.D. Soulis[2], and N. Kouwen[2]* ([1]Groupe de recherche DRAME, Ecole de Technologie Superieure, Department of Construction Engineering, Montréal, QU, Canada; [2]Department of Civil Engineering, University of Waterloo, Waterloo, ON, Canada)

Evapotranspiration [ET] is a major component of the hydrological cycle in boreal ecosystems. It is known that ET varies both spatially and temporally, and is affected at the mesoscale by such factors as topography, soil properties, vegetation and climate. A physically based approach which takes into account these factors must therefore be used in order to better understand and accurately represent the variability of actual ET. A distributed hydrological model called WATFLOOD, which can simulate actual ET based on the Priestley-Taylor approach, was used to model the hydrologic cycle in a boreal ecosystem. The watersheds under study, which are located within the limits of the BOREAS region, cover a total area of approximately 100 000 sq. km. They encompass the Southern and Northern Study Areas [SSA and NSA], as well as the transect connecting these two areas. The objective of this research being to model spatially distributed evapotranspiration at the mesoscale, special care was taken to represent as accurately as possible the spatial and temporal variations of the radiative fluxes, a variable required by the Priestley-Taylor model. To that end, the short- and long-wave incident and reflected radiative fluxes were computed using a radiative-convective climate model developed at UQAM. The model was successfully calibrated against radiative fluxes measured at the BOREAS tower flux sites. The required atmospheric forcing data for this model, which included air and soil temperature, air pressure and relative humidity, were obtained from Environment Canada's operational Regional Finite Element model archive at 50-km resolution. Precipitation, streamflow, land cover data including elevation, soil and vegetation types were gathered from various sources (BORIS data base, NOAA AVHRR land cover map, HYDAT data base) and further processed. At the time this was written, preliminary simulations were being carried out to calibrate the hydrological model. Results of the simulations runs, which will include computed streamflow and actual ET, will be presented and discussed at the conference.

Session 2-C2

Coastal Oceanography

Chair: Denis Lefaivre

Tuesday, June 3 — 13:40-15:00 — Room 206

2-C2.1 Seasonal Mean Circulation in the Laurentian Channel Region

G. Han, P.C. Smith (speaker), *and J.W. Loder* (Coastal Ocean Science, Bedford Institute of Oceanography, Dartmouth, NS, Canada)

The climatological seasonal-mean circulation in the Laurentian Channel region (Gulf of St. Lawrence, the eastern Scotian and southern Newfoundland shelves) are studied by numerically computing four bi-monthly (January-February, April-May, July-August, and October-November) circulation fields using a three-dimensional (3-D) diagnostic model. The model is forced by baroclinic and associated barotropic pressure gradients (estimated from bi-monthly hydrographic fields based on a historical hydrographic database), surface wind stresses (calculated from a meteorological dataset for Sable Island), and remotely forced barotropic inflows through the Strait of Belle Isle (based on tide-gauge observations). The four bi-monthly numerical solutions, together with the hydrographic fields, support the conventional understanding, *i.e.,* seasonally varying seaward (in the Gulf) and southwestward (on the shelf) flows of lighter near-surface

waters and seasonally-steady on-shelf penetration of Slope Water at depth. They also point to close gulf-shelf connections, significant regional regimes, pronounced topographic-scale features, and strong seasonal variability. The circulation is generally cyclonic in the Gulf, reinforced by the inflow of Labrador Shelf water through the Strait of the Belle Isle; while the circulation over the Scotian Shelf is dominated by the southwestward nearshore and shelf-break flows of water from the Gulf and the Newfoundland Shelf. The model solutions are in approximate agreement with observed currents at selected sites, but with significant quantitative differences.

2-C2.2 Coastal Applications of Finite Element Models

D.A. Greenberg (speaker) *and J.D. Chaffey* (Coastal Ocean Science, Bedford Institute of Oceanography, Dartmouth NS, Canada)

Finite element models of increasing complexity have been used to study many aspects of continental shelf circulation. The models range from linear harmonic with tides and diagnostic density computations, to fully nonlinear time stepping prognostic in temperature and salinity using Mellor-Yamada level 2.5 turbulence closure. The ability to resolve many length scales makes the models attractive for applications in complex nearshore areas. Two such cases are presented here. A model of Halifax Harbour is being developed to give tidal elevations and currents as well as wind driven currents for use in the new electronic charts [ECDIS] and in a simulator to be used by pilots for guiding large ships into port. Problems related to aquaculture have lead to the development of a high resolution model of Passamaquoddy Bay. The high tides in the area have required experimentation with including drying tidal flats in the model. In this presentation we will describe some of the aspects of setting up these models and give some preliminary results.

2-C2.3 Daily Forecast of an Oil Spill Trajectory and Forecasted Bottom Contamination by PCBs During the 1996 Salvage of the Irving Whale Barge

D. Lefaivre (speaker)*, F.J. Saucier, J. Chasse, and A. Gosselin* (Maurice Lamontagne Institute, Mont-Joli, QU, Canada)

The decision to raise the Irving Whale Barge from the sea floor of the Gulf of St. Lawrence led to a series of actions in order to identify coastline at risk in the event of an oil spill. An on-line daily forecast of a trajectory that an oil-spill would take was finally proposed. A joint effort of teams from AEB, CCG and DFO produced the following: A moored surface meteorological buoy provided on-line winds; A surface drifter with internal GPS and ARGOS transmitter provided on-line surface currents; A numerical model of circulation provided the tidal and residual surface currents. Subtracting the drift due to tidal and residual currents as well as due to the wind, from the observed surface drift provided an estimate of the surface inertial current. This inertial current was added to the effects of the currents from the circulation model and of the forecasted winds to produce a forecasted trajectory. During the whole month of July 1996, these daily forecasts made possible the quick deployment of ships for remediation in case of an oil-spill. It occurred on the final days and successful remediation took place. Specific forecasts were issued using the observed positions of the slick and made available to the on-scene commander of the CCG as well as the daily ones. The model was also able to rule out the assertion that oil reported on the shore of PEI being a result of the salvage operations. Finally, with the use of a Doppler currrentmeter on the salvage ship, a forecasted contamination of the bottom sediment by a spill of PCBs (heavier than sea-water) on-board the Irving Whale barge was issued. These forecasts allowed both to guide the bottom sampling and to evaluate the quantity that would have been spilled. Analysis of the bottom contamination is still on-going.

2-C2.4 Improving Search and Rescue Forecasts with Data Assimilative Models for Surface Drift

J. Sheng[1], P.C. Smith[2] (speaker), *K.R. Thompson[1], and D.J. Lawrence[2]* ([1]Department of Oceanography, Dalhousie University, Halifax, NS, Canada; [2]Coastal Ocean Science, Bedford Institute of Oceanography, Dartmouth, NS, Canada)

In an effort to improve the Canadian Search And Rescue Planning tool [CANSARP], a surface drift experiment was conducted on the Scotian Shelf during February, 1996. The experiment consisted of four consecutive weekly deployments of clusters of calibrated drift buoys and other objects (including a life raft and dory), supplemented by moored current meter and hydrographic measurements. System components tested include high-resolution AES forecast winds and a new ocean circulation model capable of assimilating coastal sea level and other types of oceanographic data. In addition to data assimilation, the model uses new formulations for the surface drift layer and leeway for the drift objects. Results indicate that the circulation model explains about 65% of the observed near-surface current variance and has root mean square error in predicted displacement of about 19 km after 5 days. Results will be compared against the predictive skill of the CANSARP system.

Session 2-C3

Cloud and Precipitation Physics - 2

Chair: George Isaac

Tuesday, June 3 13:40-15:00 Room 200

2-C3.1 Ground-Based Measurements of the Near-Infrared Anomalous Cloud Absorption Effect

W.F.J. Evans (Environmental Resource Studies, Trent University, Peterborough, ON, Canada)

Ground based measurements of the near infrared solar flux using a set of 3 pyranometers have yielded important statistical information concerning the anomalous cloud absorption effect. Pyranometers with bandpasses from 0.3 to 1.0 micrometers, from 0.8 to 3 micrometers and from 0.3 to 3 micrometers were operated to monitor the visible, the NIR and the full short wave band. The ratio of NIR to visible was usually 40% on clear days, but decreased to below 10% on some cloudy days. This ratio usually was around 20% on cloudy days. Histograms of the ratio will be shown for numerous days. A comparison of solar fluxes for clear and cloudy sky conditions for many days in summer 1996 at Peterborough, a mid-latitude location demonstrates that 50 to 100 W/m2 of the solar radiation in the NIR from 1 to 3 micrometers can be absorbed preferentially by cumulus clouds. It has been assumed previously in climate models that clouds maily scatter solar radiation while absorbing about 40% of the extraterrestrial insolation; our measurements indicate that this absorption may reach over 12% in cumulus clouds. The absorption of the NIR solar radiation by the cloud may be dominated by the absorption due to liquid water rather than by water vapour as in teh clear atmosphere.

2-C3.2 Cloud Vertical Inhomogeneity and Cloud Anomalous Absorption

Jiangnan, Li Li (CCCMA, University of Victoria, Victoria, BC, Canada)

Using a detailed line-by-line, multiple-scattering solar radiative transfer model, the influences due to cloud internal inhomogeneity upon the solar radiative transfer are investigated. In particular, the consequences due to nonuniform vertical profiles of liquid water and droplet sizes within cloud are explored in a systematic manner. The fine structure of the spectral overlap between the water droplet and water vapor optical properties, and its effects upon the radiation absorbed within cloud layer, and that reflected at the top of cloud are discussed. The existence of water vapor can partly offset the enhancement of cloud absorption due to the vertical inhomogeneity of cloud microphysics properties. The vertical distribution of cloud heating rate is changed drastically due to inhomogeneities. In the top region of the cloud, the heating rate is nearly doubled in the vertically inhomogeneous case compared to its homogeneous counterpart. The vertical inhomogeneity has little influence on the broadband albedo, but can cause cloud albedo decreases significantly in the near infrared region with wavelength larger than 1 micrometer.

2-C3.3 New Insights into Freezing Drizzle Formation Mechanisms

G.A. Isaac[1] (speaker), *A. Korolev*[1], *S.G. Cober*[1], *J.W. Strapp*[1], *A. Tremblay*[1], *and R.A. Stuart*[2]
([1]Cloud Physics Research Division, Atmospheric Environment Service, Downsview, ON, Canada; [2]Weather Research House, Willowdale, ON, Canada)

Freezing drizzle can form through either a classical or a non-classical mechanism. The classical mechanism has ice crystals melting in a warm layer aloft, and the resulting drops usually supercooling in a cold layer near the surface, before freezing as they strike an object. The non-classical mechanism involves the drops forming entirely *via* condensation and/or coalescence. Studies in eastern Canada have shown that freezing drizzle forms over 60% of the time via the non-classical mechanism. The frequency of occurrence of freezing drizzle is also closely tied to topography, being highest near coastlines when the winds are off the water/ice surface. Climatological studies for St. John's, Newfoundland, in March, indicate that over 5% of the hours have freezing precipitation (freezing drizzle and freezing rain), while at Stephenville, 250 km to the west, only 0.5% of the hours have recorded freezing precipitation. In the Ottawa-Montréal area, freezing drizzle occurs more often when winds are from the north and northeast. The climate data clearly shows the mesoscale character of freezing precipitation.

Field projects out of St. John's, Newfoundland in 1992 and 1995, and a new project out of Ottawa in 1996/97, using instrumented aircraft, have provided a very large data set to help understand the microphysical mechanisms responsible for freezing drizzle formation. Classical freezing drizzle formation is relatively easy to explain. However, non-classical mechanisms are much more complicated. Large droplets are often found near cloud top which suggests wind shear, gravity waves, entrainment, *etc.*, may be key factors in the formation of such droplets. Spectra are sometimes bimodal with both peaks being very narrow in number concentration, which also suggests that these large droplets may be forming primarily through condensation. No one mechanism can easily explain all the different cases observed. This paper will examine possible drizzle formation mechanisms, using climatological data and data collected onboard project aircraft. The difficulties of producing a numerical scheme to predict non-classical drizzle formation in weather forecasting models will also be discussed.

2-C3.4 Formation of Bi-Modal Droplet Spectra in Stratiform Clouds

F. Celik (speaker) *and J.D. Marwitz* (University of Wyoming, Department of Atmospheric Sciences, Laramie, Wyoming, USA)

Responses of droplet size spectrum to vertical oscillations with different amplitudes and frequencies are numerically examined for a shallow stratiform cloud. It is shown that droplet spectra broadening and formation of large droplets are independent of vertical oscillations or turbulent fluctuations in a closed cloud parcel. Bi-modal droplet spectrum forms by activation of haze particles or fresh cloud condensation nuclei [CCN] during updrafts. It is shown that formation of bi-modality in a droplet size spectrum related to age of cloud, strength of updrafts, amplitude and frequency of wave oscillations or turbulent fluctuations.

Session 2-C4

Climate Program Board Open Forum - 1

Chair: Gordon McBean

Tuesday, June 3 — 13:40-15:00 — Lecture Theatre 146

Session 2-D1

Posters

Chair: Oscar Koren

Tuesday, June 3 — 15:20-17:00 — Room 202, 205, 214

DATA SYSTEMS & DATA ASSIMILATION

2-D1.1 <u>NASA/Man TopEOSDIS Presents the Earth Science Information Management System [IMS]</u>

John Scialdone (speaker), *James Closs, Lisa McLerran, and Sara Spivey* (NASA/Goddard Space Flight Centre, Upper Marlboro, MD, USA)

NASA's Earth Observing System Data and Information System [EOSDIS] Earth Science Information Management System [IMS] is a cooperative effort between various data centers around the United States and the Goddard Space Flight Center [GSFC] Earth Science Data Information System [ESDIS] project. The goals of the EOSDIS IMS system are to facilitate Earth science research through improved access to existing data. The IMS will be the operational search and order tool for the EOSDIS Core System [ECS]. The ECS is being built to accommodate the huge amounts of data expected from the EOS instruments to be launched beginning in 1998. The EOSDIS IMS provides a consistent view of data sets held at ESDIS data centers, allowing users, without specific prior knowledge of the data, to search science data holdings, retrieve high level descriptions of data sets and detailed descriptions of the data inventory, view browse images, and place orders for data.
The system is accessible over the Internet, using a World Wide Web, or a graphical user interface. Access information is available from the EOSDIS IMS Homepage at the following URL: http://eos.nasa.gov/v0ims. The following search types are provided in the IMS: Directory provides high-level information about EOSDIS data sets. A directory search will access the Global Change Master Directory, a multidisciplinary database of information about Earth and space science data. Guide provides detailed descriptions about data sets, platforms, sensors,

projects, and data centers. This includes algorithm descriptions, calibration information, and truth in usage. Inventory Search function provides descriptions of specific observations or collection of observations of data (granules) that are available for request from a data center. The following additional functions are provided by the IMS: Coverage Map is a two-dimensional graphical representation of the geographic coverage of selected inventory granules. It displays the earth in an orthographic projection. Order Data function allows users to order data, selecting the media desired. Much of the data is available free of charge. The order request is sent to the appropriate data center for processing. Browse function allows a user to locate and retrieve reduced resolution images as an aid to data selection. The user may view the image in the IMS interface or have it staged for FTP pickup.

2-D1.2 Atmospheric Dynamics Data from Assimilation and Retrievals at the Goddard Distributed Active Archive Center [DAAC]

G.N. Serafino (speaker), *J. Qin, and Q. Yang* (NASA/Goddard Space Flight Center, Greenbelt, MD, USA)

In cooperation with the Data Assimilation Office [DAO] and the Satellite Data Utilization Office [SDUO] at the Goddard Space Flight Center, we have participated in producing and archiving a complete set of data products describing the dynamics of the global atmospheric system with temporal coverage currently from 1985-1994, and planned coverage from 1980 - present for both systems. The DAO data are obtained from the DAO's GEOS-1 system which assimilates data from real-time *in situ* observations, TOVS (Tiros data Operational Vertical Sounder) satellite retrievals, and satellite cloud-tracked winds. The products in the full time series include 80 physical quantities ranging from wind, temperature, and humidity profiles, to boundary fluxes, soil moisture and precipitation estimates useful for hydrological studies. Coverage is global at a spatial of 2.5 deg x 2.0 deg, a vertical resolution of 18 pressure levels, and a temporal resolution of 3Z or 6Z (depending on the quantity).

The DAAC also produces: A 22 parameter subset of the assimilation data at the same temporal and spatial resolution; Monthly mean derived products at the same spatial resolution; A subset of 26 of the 80 parameters of the monthly mean data, that have been regridded to 2.0 deg x 2.0 deg horizontal resolution; Immediate on-line subsetting of the DAO data by parameter, spatial location, temporal location, or pressure level through the DAAC's WWW-based user interface. To complement these products the DAAC also offers physically based retrievals for vertical temperature and moisture profiles, total ozone, cloud fraction, and other products using a system developed by the SDOU, with input data from the TOVS instruments. These products have been gridded to a spatial resolution of 1 deg x 1 deg, and 12 vertical levels for daily, five day and monthly averages for ascending (AM) and descending (PM) orbits. Also available are AM/PM averaged five day and monthly subsets of these data at the same spatial resolution.

All these data together with documentation, educational applications, online images, and animations are available for free through the WWW at: http://daac.gsfc.nasa.gov/atmospheric_dynamics/

2-D1.3 CMC Model Archives and Activities in Support to GEWEX and GCIP

R. Hogue (speaker) *and M. Beauchemin* (Recherche en Prevision Numerique, Dorval, QU, Canada)

The Operations Branch of the Canadian Meteorological Center [CMC] has been running an archiving project for model output data for GEWEX since October 1995. The main focus of this archive is to provide high resolution model outputs to the research community for their work on the study of water and energy budgets. An extensive number of output fields are archived in a gridded format as well as in a location time series format at more than 200 sites. This special archive is also used to exchange model outputs within the GCIP project for intercomparaison studies between NCEP's ETA model, NCAR's MAPS model, CMC's regional model, and the GEM

(Global Environmental Multiscale) model (which replaced the RFE model in February 1997). A detailed description of this special archive will be presented as well as a description of the different ways to access the database.

DIAGNOSTIC & MESOSCALE STUDIES

2-D1.4 A Study of Meso-Cyclone Detection in Québec/Étude de Detection des Meso-Cyclones au Québec

P. Vaillancourt (speaker), *A. Bellon, and I. Zawadzki* (Marshall Radar Observatory, McGill University, Montréal, QU, Canada)

The wind field in a severe thunderstorm is not uniform. Divergence, convergence, shear, rotational and deformation zones are visible on a Doppler Radar. Many algorithms have been developped to analyse automatically these data. Such an algorithm is in use for detection of meso-cyclonic circulations at the Marshall Radar Observatory (McGill University, Montréal) since 1993. Meso-cyclones are usually associated with severe thunderstorms, especially with tornadoes, and their detection is thus of great importance. After three summers (1994,95,96) of use, a study of the statistics of detection of meso-cyclones has been done last fall. This poster will show the results and propose an optimization of the algorithm parameters. Some interesting cases of severe weather will be shown too, with an analysis of their stucture and their evolution.

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Le champ de vitesse dans un orage n'est pas uniforme. Des zones de déformation, de cisaillement et de rotation sont visibles sur une image de radar Doppler. Divers algorithmes ont été developpés pour essayer d'en faire une analyse automatique. Depuis 1993, un tel algorithme est en fonction à l'observatoire Marshall de l'Université McGill à Montréal afin de detecter les meso-cyclones. Ceux-ci sont le plus souvent associés avec des orages violents et particulièrement avec les tornades. Les données de detection de ces meso-cyclones durant les étés 1994 a 1996 ont été analysées et nous présentons les resultats tout en proposant un ajustement des parametres qu'utilise l'algorithme. En plus, des cas intéressants de temps violent avec meso-cyclones seront présentés.

2-D1.5 Tornado Tracks and Damaging Downburst Areas of the 4 July 1996 Saskatoon-Maymont-Osler Thunderstorm Outbreak

Stephen Knott (speaker) *and Dwight Clarke* (poster session) (Environment Canada, Saskatoon, SK, Canada)

The thunderstorm outbreak of 4 July 1996 was a major event for the area bounded by Saskatoon, Maymont, and Osler. An estimated 10 documented tornadoes occurred in addition to an approximate area of 950 km^2 of near F1 strength or greater downburst winds. Of the eleven tornadoes three are estimated to have tracks greater than 10 km. The parent thunderstorm initiated 60 km south of North Battleford and moved eastnortheastwards. The tornadic activity began as the storm moved across to the north side of the North Saskatchewan River Basin. An F2 tornado tracked 10 km moving just southeast of Maymont. It is hypothesized that a new mesocyclone reformed 10 km further south resulting in an F3 tornado which tracked 20 km and had a maximum width of 1.5 km. As the thunderstorm approached the Osler and Saskatoon area it became more downdraft dominated, however 7 more tornadoes have been documented. Six of these tornadoes were likely F1 or weaker, however an F2 developed just west of Rheinland and tracked 15 km southeastwards with a maximum width of near 1 km. This tornado caused extensive damage along its path. The majority of the residents in the Saskatoon-Osler area were affected by downburst winds with an areal coverage of at least 790 km^2.

2-D1.6 Water Vapour Bugdet: Explicit *vs.* Diagnostic Methods

Guy Bergeron (speaker), *Anne Frigon, and Rene Laprise* (Dept Sciences de la Terre, Université du Québec a Montréal, QU, Canada)

Two methods have been developed to do atmospheric water budget in CRCM. In the first method (called explicit), vertically integrated and time averaged horizontal moisture fluxes are computed within the model, at each time steps of 15 min., and stored at archival periods. In the second method (called diagnostic), moisture fluxes are calculated from archived samples of winds and humidity profiles, after their interpolation to pressure surfaces. Clearly, time and vertical discretization differences will exist between the 2 methods. Each of these error components is studied separately.

REMOTE SENSING APPLICATIONS

2-D1.7 Mise en Operation du Systeme Rainsat Pour la Region du Québec

Stephane Gagnon[1] (speaker) *and Aldo Bellon*[2] ([1]Environnement Canada, Saint-Laurent, QU, Canada; [2]J.S. Marshall Radar Observatory, Ste-Anne-de-Bellevue, QU, Canada)

RAINSAT est une technique qui utilise les images visible et infrarouge des satellites geostationnaires pour deriver des accumulations de precipitations. Cette technique a ete developpee dans les annees 80 a l'Université McGill. Avec la venue d'une nouvelle generation de satellite geostationnaire, une nouvelle version du systeme RAINSAT a ete entreprise par l'Université McGill. Recemment, le groupe de recherche du MRO (Marshall Radar Observatory) a derive des accumulations de precipitations mensuelles (ete 1996) pour la region du bassin du fleuve Mackenzie. Ces resultats ont ete compares avec les donnees du radar de Carvel et avec les accumulations de precipitations mensuelles analysees du Centre Meteorologique Canadien. Suite a ces resultats, les Bureaux de Services Meteorologiques Environnementaux du Québec mettront le systeme RAINSAT en operation pour l'ete 1997. RAINSAT produira des taux et des accumulations de precipitations sur la region du Québec.

2-D1.8 A Bistatic Radar System at McGill

A. Kilambi[1], *A. Singh*[1], *J. Wurman*[2], *and I. Zawadzki*[1] (speaker) ([1]J.S. Marshall Radar Observatory, McGill University, Montréal, QU, Canada; [2]University of Oklahoma, Norman, OK)

In cooperation with the University of Oklahoma (Norman), a bistatic receiver developed by Wurman was installed 40 km south-east of the radar, with a second unit to be set up 30 km to the north-east. This system designed at NCAR allows the direct measurement of 2-D or 3-D winds in real-time by the use of additional receivers at remote locations. The geometry of the main radar site and the additional receiver allows us to get accurate dual-Doppler winds in the vicinity of Montréal's airport (Dorval). The bistatic system was set up to support our retrieval work, both as a verification of single radar wind retrievals or linear wind approximations as well as an additional constraint for future real-time thermodynamic retrievals. In this presentation, examples of wind measurements will be shown and compared with data from the McGill wind profiler. Future plans for the use of this system will also be presented.

ATMOSPHERIC/CLIMATE MODELS

2-D1.9 Sensitivity of Second-order Tubulence Closure Models to Their Closure Constants

B.P. Crenna (Department of Earth and Atmospheric sciences, University of Alberta, Edmonton, AB, Canada)

In formulating a simple turbulence scheme (*e.g.,* Mellor-Yamada), a set of unknown closure constants is unavoidably introduced. To determine these constants, the model is applied to neutral, horizontally-homogeneous, steady-state turbulent flows, and the constants are tuned to match experimental observations of the same flows. However, there is some uncertainty associated with the empirical data, and with the manner in which the scheme is matched to them. An investigation of a generalized second-order closure model, which incorporates features of many of the popular schemes, reveals that its properties (*e.g.,* realizability, onset of turbulence, and intensity of predicted turbulent kinetic energy for non-neutral flows) are highly sensitive to adjustments of its closure constants. In particular, the model can display markedly different behaviour even when the constants are varied in a manner which retains consistency with the neutral flow data. Therefore, it appears that there is some arbitrariness in the choice of constants and in the predictions made by the resulting model.

2-D1.10 The Influence of Lateral Boundary Conditions on the Fine Scale Features in CRCM

Dominique Paquin (speaker), *Daniel Caya, Sebastien Biner, and Rene Laprise* (Dept. de Sciences de la Terre, Université du Québec a Montréal, QU, Canada)

The sensitivity of CRCM simulations to initial and lateral boundary conditions is investigated. The dependence on initial condition is very different in global and regional models. In global models, slight perturbations in initial conditions will lead to totally different scenario in long simulations. In regional models however, the lateral boundary conditions exert a strong control on the simulation and the influence of initial conditions vanishes after 10 to 15 days of simulation. This control by lateral boundary conditions on regional models was first investigated by Anthes *et al.* (1989). They showed that the growth of simulation error was limited by the use of observed lateral boundary conditions and that the dependence on initial conditions was very weak after a couple of days. This suggests that the high resolution features in a regional model are independent of initial conditions if the simulation is carried out for a sufficiently long period.

In the work of Anthes *et al.,* (1989) the investigation is mainly oriented toward the limitation in error growth when a high resolution initial state is projected forward in time. In our study, we mainly investigate the development of high resolution features from low resolution initial state and the sensitivity of these high resolution features on initial conditions. It has been observed that the high resolution features are essentially independent of initial conditions and that their evolution is very similar for a given set of lateral boundary conditions.

A number of CRCM simulations have been carried out for different initial conditions while sharing the same time dependent lateral boundary conditions. All the simulations evolve from a GCMII low-resolution initial state toward a high resolution scenario steered by the lateral boundary conditions. RMS differences of temperature, winds, geopotential and specific humidity between simulations are computed over the grid and their evolution in time is investigated. For all fields, RMS differences between simulations decrease in time following what seems to be an exponential curve. There is a strong dependence on the e folding time with altitude, adjustment being much faster at higher altitude.

CLIMATE CHANGE & IMPACTS

2-D1.11 Climate Change and Interannual Variability at Cold Lake, Alberta

S.R. Macpherson (Cold Lake, AB, Canada)

This study examines climate change and interannual variability at Cold Lake, Alberta, located at the northern edge of the Canadian prairies. Simple statistical methods and subjective visual inspection of plotted data were used to determine trends and cycles. An attempt was made to correlate interannual variability with ENSO events. Standard climate data (temperature, precipitation) from 1953-1996 were examined as well as flying weather (ceiling, visibility, aviation hazards) from 1974-1996. Although the period of record is short by climate study standards, some interesting results were obtained. A warming trend is evident for the spring and winter seasons, which contributed to an increase in annual mean temperature of about one degree Celsius over the entire 44 year period. In contrast, the last few years have shown a cooling trend, with 1996 being the coldest year on record. Some of the marked interannual variability in annual mean temperature can be related to ENSO events, although the correlation is far from perfect or consistent. Cycles in fall season precipitation were evident. Summer rainfall shows a decreasing trend over the period of record. There were no obvious long-term trends in annual flying weather. The last four years have had poorer than normal summer flying weather. "Quiet" and "active" periods for hazardous aviation weather were evident. Cold Lake seems to be in a quiet (below-normal) phase for freezing precipitation and an active (above-normal) phase for dense summer fog.

2-D1.12 1993 Summer Rainfall on the Canadian Prairies - An Extreme Year or a Sign of Things to Come?

James Cummine (Environment Canada, Winnipeg, MB, Canada)

The summer of 1993 will be remembered by many as the wettest summer ever on the Canadian Prairies. 1993 was an extreme year for rainfall in some locations on the Canadian Prairies, but was it a rare event that is attributable to natural climate variability or was it a signal of what to expect with climate change? The three summer months of June, July, and August are normally the wettest period on the Prairies. In 1993, rainfall amounts exceeded 100-year old records in several locations. Copious amounts of rain fell across much of the three prairie provinces with many areas receiving more than twice their usual precipitation amounts. Winnipeg, Regina, Swift Current, and Lethbridge all had the wettest summer in over 100 years. Rainfall in Winnipeg exceeded 460 mm and was so severe that there was over 200 million dollars in flood damage. The wet conditions were not confined to small areas; rainfall amounts across the southern Prairies were generally 150 to 200 percent of normal summer precipitation on the Canadian Prairies usually comes from convective storms, although these thunderstorms are driven by the synoptic scale cyclones that track across the region. In 1993, the upper flow was dominated by a trough of low pressure over the upper Mississippi valley and southern Canadian Prairies. Single day rainfalls exceeded 100 mm numerous times across the region, with over 200-mm rainfalls occurring on a couple of occasions. Very few single rainfall events set records, but it was the cumulative and persistent nature of the rains combined with the antecedent conditions and other related factors that caused the economic and social impact to the region. There were a few more days with rain than normal in most areas, but not an exceptionally high number. There were however more days than normal with moderate to heavy rainfall totals. For example in Winnipeg, three events accounted for a whole summers worth of rainfall. Three storms tracked over Winnipeg between July 24 and August 14 and gave a total of 239 mm; normal summer rainfall is 231 mm in Winnipeg. The return period for most events was in the order of 10 to 25 years, although there were a few events that exceeded 100-year return period. The summer rainfall total for Winnipeg has a return period of over

500 years. Rainfall and stream flow data from sites on the Canadian prairies indicate that during the summer of 1993, there were extreme events. By examining the summer of 1993, we can understand the impact that extreme precipitation events have on the Prairie ecozone.

2-D1.13 Regional Scale Variability of the Western Canada Climate Simulated by the Canadian Regional Climate Model Under Current and Enhanced Greenhouse Gases Scenarios

Helene, Côté (speaker), *René Laprise, Michel Giguere, and Guy Bergeron* (Dépt des Sciences de la Terre, Université du Québec, Montréal, QU, Canada)

Canadian Regional Climate Model [CRCM] is based on the MC2 dynamical kernel and the physical parameterization package of the second-generation Canadian Global Climate Model [GCMII]. Two 5-year CRCM integrations have been nested with GCMII simulated data and were made for conditions corresponding to current and doubled greenhouse gases [GHG] concentration scenarios. CRCM used a grid size of 45 km on a polar-stereographic projection, 20 scaled-height levels and a timestep of 15 min, while its nesting GCMII used a spectral truncation of T32 (about 650 km), 10 hybrid pressure levels and a timestep of 20 min. We will compare the variability of the screen level temperatures during winter as simulated by CRCM and GCMII under both greenhouse gases scenarios. Climatological means for each simulations will be shown. In addition, we will focus on the climatological, interannual and intraseasonnal standard-deviations of the screen level temperature field. These results will show the ability of CRCM to provide additional information on the spatial and temporal climate variability.

Session 2-D3

Mesoscale Processes & Severe Weather - 1

Chair: Paul Joe

Tuesday, June 3 15:20-17:00 Room 200

2-D3.1 High Resolution Simulation of the Severe Precipitation Events

W.Yu[1] (speaker), *C.A. Lin*[2], *and R. Benoit*[3] ([1]CERCA, Montréal, QU, Canada; [2]CERCA/McGill University, Montréal, QU, Canada; [3]Recherche en Prevision Numerique/Atmospheric Environment Service, Trans-Canadian Highway, Dorval, QU, Canada)

A high resolution regional simulation of the severe precipitation episode which gave rise to the floods in the Saguenay, Québec region during July 19-21, 1996 was performed using the Mesoscale Compressible Community (MC2) model. The model is first calibrated by comparing the simulated precipitation field with radar observations for an earlier precipitation event. The model is then applied without further tuning to the Saguenay episode. This simulation is initialized with the Canadian Meteorological Center [CMC] analyses at a resolution of 35 km. A nested integration is next performed with a resolution of 10 km. The simulated precipitation field compares well with available station observations. The efficiency and accuracy of the model demonstrate its ability to simulate severe precipitation events and its potential application for flash flood warning.

2-D3.2 Multi-Model High-Resolution Ensemble Mesoscale Forecast Research for Western Canada

R. Stull (speaker), *H. Modzelewski, and J. Hacker* (Department of Geography, University of British Columbia, Vancouver, BC, Canada)

Two factors make weather forecasting difficult for Western Canada: (1) the "Pacific data void" just upstream, and (2) the complex topography of mountains and shorelines. To address the first factor, we have developed an ensemble forecast technique using multiple numerical models (Canadian MC2 and Wisconsin UW-NMS) with multiple initial conditions. For the second factor,

we are running nested medium mesh (30 km resolution) and fine mesh (10 km resolution) domains along the west coast of Canada. To avoid biasing our research to any few "golden days" or case studies, we are running these research forecasts realtime, every day in true forecast mode. Ensemble perturbation techniques, "picket-fence" validation methods, and storm and precipitation forecasts will be discussed with validation statistics.

2-D3.3 The Severe Weather Soundings and Radar Storm Classification

L. Xin (speaker), *N. Donaldson, and P. Joe* (Cloud Physics Research Division, King City, ON, Canada)

Severe weather can occur with any type of convective storm, but certain storms are more likely than others to produce severe weather. Knowing what type of convective storm can evolve in a given environment and by what physical mechanism it is apt to evolve can be invaluable to forecasters. Convective storms producing severe weather in southern Ontario region during seven-year period (1989-1996) are studied. Systematic analyses are first performed to classify the type of convective storms using Doppler radar data. Then, sounding data and some modeling results are employed to examine the environmental conditions for the occurrence of the severe weather. How the storm type changes for different combination of wind hodograph and buoyancy is investigated.

2-D3.4 Lake Breeze Triggered Thunderstorms: Do They Pose a Significant Severe Weather Threat?

D.M.L. Sills (York University, North York, ON, Canada)

Atmospheric conditions suitable for the development of thunderstorms are present on many summer days in southwestern Ontario. However, a mesoscale 'trigger mechanism' is often required to initiate deep convection. On days when lake breezes are active, convergence and uplift at a lake breeze front can act as that trigger. Thunderstorms produced in such a way have historically been regarded as relatively benign due to their short lifetimes and isolated nature. However, lake breezes on several days during the SOMOS field campaign of summer 1993 triggered deep convection that resulted in thunderstorms approaching or meeting severe storm criteria. The types of severe weather produced included damaging outflow winds, heavy rainfall and even weak tornadoes. Various meteorological data including satellite images, radar images and surface mesonet observations will be used to illustrate the development of these storms. The Mesoscale Compressible Community (MC2) model was used to simulate lake breeze circulations on these days and model output will be examined for evidence of the well-developed lake breeze convergence lines that preceded these storms. The output will also be examined for highly localized vertical vorticity maxima embedded within the convergence lines that likely preceded the tornadic storms. Regions of enhanced convective development and convective suppression in southwestern Ontario will be discussed within the context of lake breeze climatology.

2-D3.5 An Experiment to Study the Effects of Lake Breezes on Convective Weather

P.W.S. King (Environment Canada, Downsview, ON, Canada)

An experiment to study the Effects of Lake Breezes On convective Weather [ELBOW] is planned for southern Ontario for the summer of 1997. The purpose will be to gather evidence concerning the effect which lake breezes have on convective weather and eventually to assess their role as a trigger for severe convection. The experiment will be a cooperative effort involving Environment Canada (Meteorological Research Branch and the Toronto Regional Weather Centre), York University and possibly other groups. Two two-week intensive observing periods are planned: one in late spring when temperature differences between the lakes and inland regions are large and one in mid-summer when temperature differences are smaller. Doppler Radar and satellite imagery will be used to coordinate spotter teams who will deploy portable weather stations in key locations. Using data from the AES surface network, data from provincial and regional networks, and the special data collected by the spotters we will determine whether the radar and satellite data can be used to predict regions of enhanced convection. It is hoped that some preliminary results can be presented at the Congress.

Session 2-D4

Climate Program Board Open Forum - 2

Chair: Gordon McBean

Tuesday, June 3 15:20-17:00 Lecture Theatre 146

Session 3-A1

PLENARY SESSION - Hydrology

Chair: Phil Marsh

Wednesday, June 4 09:05-09:50 Lecture Theatre 143

3-A1.1 <u>Cold Regions Hydrological Research</u>

(Plenary paper, 45 min)

Prof. M.K. Woo[1] (speaker) *and Dr. Philip Marsh*[2] ([1]Geography Department, Hamilton College, McMaster University, Hamilton, ON, Canada; [2]National Hydrology Research Institute, Saskatoon, SK, Canada)

Snow, ice and frozen soil affect the activities of most Canadians and their roles are magnified in the polar regions. Recurrence of snowmelt floods has long prompted the studies of snow accumulation, redistribution and melt processes and the delivery of meltwater from the snow cover. Research has been conducted in both tundra and forested environments, with particular emphases on the very cold, polar snow. Spring floods are amplified by snow and ice jams on rivers and lakes. Much has been learnt about the freeze-up and breakup processes and their hydrological consequences. Glacier melt is an important source of summer flow in glacierized catchments of Eastern Arctic and the Western Cordilleras. Although mass balance studies, glacier melt and runoff have received attention in the past this aspect of research is regrettably declining in Canada, even though it is of great importance to climatic change considerations. Research on the hydrology of frozen soil, be it seasonal frost or permafrost, has applications to northern energy (fossil fuel and hydroelectric) development, mining and environmental protection; and the results have implications to the populace south of the Arctic and the subarctic. In the past decades, progress has been made on the effects of frost on surface runoff and ground water flow, infiltration, ground ice storage, streamflow and basin responses to climatic forcing.

In addition to the necessity of furthering our understanding on the cold regions hydrological processes, several major aspects call for attention: (1) There is a need to develop hydrological models that explicitly reflect the snow, ice and frozen soil processes central to northern Canada. Available models incorporate equations adapted to the temperate latitudes, supplemented by empiricism based on limited data, and produce outputs that are seldom verified (or verifiable). (2) Upscaling of hydrological information is required for parameter ion, spatial representation of input data and physically reconcilable simplifications of equations for use in regional scale models. Field surveys, remote sensing and modelling have to be integrated, through spatial statistics, to ensure appropriate usage of information for various scales of hydrological investigations. This is a particular challenge to the North where ground data are sparse. (3) Cross-disciplinary studies continue to be important, to address issues larger than hydrology.

Inter-basin water transfer, climatic change, atmospheric-terrestrial-oceanic moisture and energy exchanges are a few examples.

Session 3-B1

Cold Climate Hydrology

Chair: John Pomeroy

Wednesday, June 4 10:10-12:10 Room 217

3-B1.1 Probability of Blowing Snow Occurrence by Wind

L. Li[1] (speaker) *and J.W. Pomeroy*[2] ([1]Division of Hydrology, University of Saskatchewan, Saskatoon, SK, Canada; [2]National Hydrology Research Institute, Saskatoon, SK, Canada)

Blowing snow (snow transport) affects snow cover distribution and snowmelt runoff patterns in cold, wind-swept regions. A statistical method is used to examine snow transport occurrence and the meteorological conditions recorded for 16 stations on the Prairies of western Canada over six winters. The results show that the occurrence probability is highly related to wind speed, air temperature and snow age. For the same air temperature and snow age, the occurrence probability increases with increasing wind speed. The probability distribution of occurrence with respect to wind speed approximates a cumulative normal probability distribution, depending on the mean and variance of wind speed: the location and scale parameters of the normal distribution. It was found that these two statistical parameters essentially indicate snow resistance and sensitivity to wind transport. Analysis of blowing snow occurrence probability distributions for different classes of air temperature and snow age reveals that the mean wind speed of the normal distribution generally increases with increasing air temperature and snow age, and the variance of wind speed increases with increasing air temperature. This leads to the development of a model which first estimates the two parameters of the normal distribution using air temperature and snow age, and then estimates the probability of snow transport occurrence using wind speed and the two parameters with the cumulative normal probability function. Comparison of hours snow transport occurrence, and fluxes of snow transport and sublimation estimated using the model to those determined using observations of snow transport occurrence shows good agreement. The results of this study can be used to estimate the frequency of snow transport events using standard meteorological data, determine the snow transport and snow sublimation fluxes, and examine the effect of meteorological conditions on snow transport processes.

3-B1.2 Snow Interception and Sublimation in a Boreal Forest

J.W. Pomeroy[1] (speaker), *N.R. Hedstrom*[1], *J. Parviainen*[2], *and D.M. Gray*[2] ([1]National Hydrology Research Institute, Saskatoon, SK, Canada; [2]Division of Hydrology, College of Engineering, University of Saskatchewan, Saskatoon, SK, Canada)

Coniferous canopies in the boreal forest have high winter leaf areas and consequently intercept a large proportion of the annual snowfall. This intercepted snow is stored in the canopy for as long as several months, where it is well-exposed to the atmosphere and subject to relatively high sublimation rates compared to snow surfaces on the ground. A GEWEX/Model Forest experiment in the southern boreal forest of western Canada has detailed the intercepted snow load in coniferous canopies, snow mass balance and energy balance over three winters. The field

results show that: i) 28% to 65% of cumulative seasonal snowfall can be intercepted and stored in coniferous canopies in mid-winter, and ii) 30% to 45% of annual snowfall sublimates due to its exposure as intercepted snow. A series of algorithms has been developed to describe the accumulation and storage of intercepted snow in northern canopies. These algorithms are unique in that they account for features of interception in cold climates such as declining interception efficiency with increasing snow load and temperature. Leaf area index, canopy closure and tree species are used to relate interception efficiency to quantitative stand characteristics. Sublimation routines described by Pomeroy and Gray (1995) have been applied to the calculated snow loads in order to model a sequence of canopy snow storage and sublimation events in the winter of 1995-96. The coupled model of snow storage and sublimation from the canopy is physically accurate, uncalibrated and reasonably successful in estimating snow sublimation loss. It can thus aid in the development of land surface process schemes and hydrometeorological models that are suitable for operation in the boreal forest.

3-B1.3 Energetics of Boreal Forest Snowmelt

D.A. Faria[1] (speaker) *and J.W. Pomeroy*[2] ([1]Division of Hydrology, College of Engineering, University of Saskatchewan, Saskatoon, SK, Canada; [2]National Hydrology Research Institute, Saskatoon, SK, Canada)

The energetics of snowmelt under boreal forest canopies in central Saskatchewan are examined with respect to the influence of forest canopy structure and the spatial variability of snowcover on the snowmelt rate. Coniferous canopies influence the spatial variability of snow water equivalent, through interception and subsequent sublimation of snowfall, making the snowpack deeper in the openings between trees. Canopies also resist turbulent transfer of sensible and latent heat, attenuate short-wave radiation and emit long-wave radiation. Therefore, particular attention is given to the role of sub-canopy radiation in the melt process. Extinction of shortwave radiation in canopies is significant and decreases with increasing solar angle above the horizon. Canopy extinction of shortwave radiation and the high albedo of the snowpack reduce net shortwave radiation under the canopy in the premelt period. As melt progresses, the forest floor becomes exposed first around tree trunks and under low branches where the snow is shallow and longwave fluxes are large. The exposure of bare ground and shrubs reduces the overall albedo of the forest floor. Reduced albedo and canopy extinction during the spring period increase net radiation at the forest floor, providing energy for snowmelt. Measured radiation fluxes above and below the canopy are shown for a variety of canopy types, pine, mixed-wood and spruce. Relationships are examined between the spatial distribution of canopy elements (branches, trunks), coefficient of variation of snow water equivalent, albedo decay and subsequent melt rates.

3-B1.4 Modelling Surface Energy Fluxes Over a Melting Arctic Snowcover

N.N. Neumann[1] (speaker), *P. Marsh*[1], *and R.L.H. Essery*[2] ([1]National Hydrology Research Institute, Saskatoon, SK, Canada; [2]Hadley Centre Meteorological Office, Bracknell, Berks., UK)

The spring landscape of the Arctic tundra is characterised by a snowcover which is highly variable in depth. Shallow areas melt early in the spring, and the melt landscape becomes dominated by a patchy snowcover. The low albedo snow-free areas absorb greater solar radiation and rapidly rise in temperature, while the adjacent snow patches are limited to a maximum temperature of zero degrees Celsius. This heterogeneous landcover results in horizontal temperature gradients, and a resultant transfer of energy from bare areas to snow patches, a process often termed local advection.

The magnitude of local advection is poorly documented, and many studies in recent years have attempted to develop methods for measuring areally-averaged energy balance components over heterogeneous terrain by either ignoring or parameterising horizontal advection at a small scale. Further, these studies tend to lack reliable field measurements against which results may be compared. For this study, field measurements were collected at an Arctic research site for the purpose of providing reliable comparison data for a boundary layer model adapted to calculate snowmelt. Meteorological stations were established over a persistent snowcovered site and a bare ground patch and their individual energy balances were calculated. In addition, eddy correlation measurements of sensible and latent heat fluxes were obtained over a larger, heterogeneous area.

A UK Meteorological Office boundary layer model [BLM] is a two-dimensional model which calculates the energy fluxes over a heterogeneous surface, and has been used by Essery in recent studies to determine the influence of bare areas on the snowmelt profiles of downwind snow patches, using theoretical landscape patterns. This study will use snowcover patterns from SPOT satellite images collected during the 1996 spring melt season as input for the BLM, and compare the results of the model with the calculated energy fluxes from measurements at the field sites.

3-B1.5 Hydrological Modelling of Snowmelt Dominated Streamflow

B.L. Li (speaker) *and G.K. Kite* (National Hydrology Research Institute, Saskatoon, SK, Canada)

For scientific research for the north with high latitudes a hydrological model which can adequately take account of such cold-regions hydrologic processes as snowmelt, permafrost interactions, and evapotranspiration becomes necessary. This study describes an approach of modeling the effects of snowmelt contribution on a mountainous sub-arctic streamflow of Wolf Creek Basin. The basin occupies a 220 km^2 areas, located at approximately 61 degrees north latitude and 135 degrees west longitude with elevations ranging from 800 to 2250 metres. As a research basin, the Wolf Creek basin has been equipped with instruments to measure the snow depth and density. For this study, the basin was divided into 19 Aggregated Simulation Areas or ASAs based on the expected hydrological similarity, and each of these was further subdivided by land cover classification using Landsat images. A daily distributed hydrological model, SLURP, was calibrated and applied separately to each land cover class in each ASA, and the resulting hydrographs were routed through lower ASAs to the basin outlet. The model includes a snow component, therefore it is able to estimate both rainfall and snowmelt generated streamflow. A procedure to convert snow data time series into precipitation required by SLURP was developed. Different model runs with and without snow data were carried out. The effectiveness of snow data for simulating streamflow is then discussed.

Session 3-B2

Climate/Interannual Variability - 1

Chair: Madhav Khandekar

Wednesday, June 4 | 10:10-12:10 | Lecture Theatre 143

3-B2.1 Climatic Connections in Inter-annual Variability for the Marine and Land Environment

B.J. Topliss[1] (speaker), J.M. Potts[2], R.S. Shiel[3], and Y.A. Papadopoulous[4] ([1]Ocean Sciences Division, Fisheries & Oceans Canada, Bedford Institute of Oceanography, Dartmouth, NS, Canada; [2]AFRC Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Herts, UK; [3]Department of Agriculture & Environmental Science, University of Newcastle upon Tyne, Newcastle upon Tyne, UK; [4]Agriculture & Agri-Food Canada, Research Farm Nappan, NS, Canada)

Apart from meteorological data there are very few sources of long term environmental records. This study is currently exploring how agricultural time series may complement oceanographic data by establishing where seasonal and temporal climatological influences may occur. These extended data analyses have involved data access from the marine UK/SAHFOS and DFO databases, the land UK/AFRC and Agriculture Canada databases and the climate NOAA/NCDC web sites and CDIAC databases. Numerous publications have shown an apparent relationship between the North Atlantic Oscillation [NAO] and both atmosphere, ocean and ice-related parameters. The influence and workings of such a climatological pressure system over the North Atlantic can be clearly seen in the patterns of air temperatures and rainfall along the land masses bordering the northern north Atlantic. At certain times during the last century the typical NAO climate pattern may have either broken down or have been superseded by other, unspecified systems. In the early 1990s large anomalies occurred in both long term oceanographic and agricultural records on both sides of the Atlantic. This study will discuss how those anomalies might be linked to each other and explore potential spatial patterns which could link those widespread anomalies.

3-B2.2 On the ENSO-Related Atmospheric Teleconnection Patterns in the Northern Hemisphere

R. Mo[1] (speaker), J.C. Fyfe[2], and J. Derome[1] ([1]Centre for Climate and Global Change Research and Department of Atmospheric and Oceanic Sciences, McGill University, Montréal, QU, Canada; [2]Canadian Centre for Climate Modelling and Analysis, Atmospheric Environment Service, University of Victoria, Victoria, BC, Canada)

In this study, teleconnections between the Pacific SST anomalies and the dominant patterns of winter Northern Hemisphere 500 hPa height are examined by applying statistical techniques such as rotated principal component analysis. It is found that the PNA or PNA-like pattern appears as an important mode of the atmospheric circulation in the cold season from November through April, while the western Pacific [WP] pattern is significant only in December, January, and February, when the east Asian jet moves to its most southeastern position. The PNA pattern in November through March is correlated most significantly with the ENSO-related SST anomalies in the previous October, while the WP pattern is more sensitive to the ENSO forcing in December (or January). The typical response of the 500 hPa height to the ENSO forcing is a combination of PNA and WP patterns. In addition, the PNA response to the ENSO forcing during La Nina events is more significant than that during El Nino events, while the WP response is stronger during El Nino events than during La Nina events. Possible dynamical explanations of the above results are provided. The available evidence suggests that the WP pattern is linked to regions of anomalous convection in the central equatorial Pacific via advection of vorticity by the upper-tropospheric divergent outflow (or convergent inflow). This mechanism depends crucially on the presence of large gradients of vorticity, which are always associated with a strong east Asian jet. There exists a positive (negative) feedback between the WP pattern and the east Asian jet during El Nino (La Nina) events, leading to a strong (weak) WP response to the ENSO forcing. The PNA pattern cannot benefit very much from advection of vorticity by the divergent (convergent) flow, because of the weak gradients of vorticity over the PNA region. A direct linkage between the PNA pattern and SST anomalies over the tropical Pacific can be

provided by the localized Hadley circulation. However, this mechanism cannot fully account for the observed PNA response. It is suggested that the western boundary current in the ocean may function as a complementary "bridge", by means of which tropical SST anomalies associated with ENSO induce extratropical SST anomalies which in turn trigger a further atmosphere-ocean interaction over the North Pacific. This mechanism highlights possible reasons for the asymmetric nature of the PNA response to ENSO-related SST anomalies of opposite signs. Observational evidence for this hypothesis is also discussed.

3-B2.3 A Comparison of Inter-Annual Statistics Derived From NCEP/NCAR Reanalyses and NMC/NCEP Operational Analyses

S.J. Lambert (Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada)

The analyses produced by Data Assimilation Systems are an especially convenient source of data for climate research. In an "operational" configuation, such analyses are produced to provide the initial conditional for numerical forecats. In general, the analyses are produced by a sophisticated statistical techniques which combine observations and a model-produced first-guess field. Data assimilation methods are constantly being changed and improved with the result that the character of the analyses changes with time. These changes result in artificial trends and artificially enhanced long-term variability. Reanalysis projects attempt to address this problem by assimiating data over a long period using an invariant data assimilation system which removes much of the artificial variance and trends contained in operational analyses. In an attempt to quantify the spurious trends and variability present in operational analyses, a comparison between selected statistics derived from ten years of operational-based analyses and those derived from ten years of reanalysis-based analyses is presented and discussed.

3-B2.4 The PNA Pattern, Transient Eddies and SST Anomalies in the Tropical and Northern Pacific

Jian Sheng (Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada)

The relationship between the PNA pattern and the tropical and extratropical SST anomalies is investigated using historical height [NCEP] and SST [GISST] data sets. The lag correlation between the PNA index and SST anomalies in the tropical and northern is calculated. It is shown that the PNA pattern is associated with north Pacific SST anomalies that propagate eastward along 35N. The strongest correlation occurs near (160W, 35N) when the PNA pattern leads extratropical SST by one month. On the other hand, tropical SST leads the PNA pattern by 2-3 months but the correlation is much weaker. Partial correlation is also calculated to evaluate the relationship among the north Pacific SST, the PNA pattern, and the transient eddies excluding the correlation with the tropical SST anomalies.

3-B2.5 Inter-Annual Variability of Precipitation in an Ensemble of AMIP Climate Simulations Conducted with the CCC GCM2

X.L. Wang and F.W. Zwiers (speaker) (Canadian Centre for Climate Modelling and Analysis, Atmospheric Environment Service, University of Victoria, Victoria, BC, Canada)

Log-linear analysis and analysis of variance approaches are used to analyse the inter-annual variability and potential predictability of precipitation as it is simulated in the CCCMA ensemble of AMIP climate simulations. The issue of how the variability in the frequency, intensity and seasonal total of precipitation is affected by anomalous boundary (SSTs/sea-ice) conditions is addressed. The CCC GCM2 AMIP ensemble consists of six 10-year simulations which were forced with observed 1979-1988 sea-surface temperature and sea ice extent. Generally, the specified

SST/sea-ice forcing was found to have significant effects on both the frequency and the intensity of precipitation, particularly in the tropics, but also in the temperate latitudes. For instance, the model suggests that 10-40% of the total inter-annual variability of seasonal total precipitation over western and southern North America and over South China to India, may be predictable from the lower boundary conditions, especially in DJF and MAM. Precipitation frequency is found to be more sensitive to the effects of the prescribed boundary conditions than intensity, especially over land areas. Potential predictability from internal sources (*e.g.,* soil moisture and snow cover) is generally small.

3-B2.6 Climate Variability in the South Atlantic: a Singular Value Decomposition Analysis

S.A. Venegas (speaker), *L.A. Mysak, and D.N. Straub* (Centre for Climate and Global Change Research and Department of Atmospheric and Oceanic Sciences, McGill University, Montréal, QU, Canada)

A singular value decomposition [SVD] analysis is used to examine the coupled modes of variability of monthly sea surface temperature [SST] and sea level pressure [SLP] data from the South Atlantic region, for the period 1953-1992. The three leading SVD modes respectively account for 63%, 20% and 6% of the total square covariance. The first mode represents an approximately 15-year period oscillation in the strength of the subtropical anticyclone, accompanied by fluctuations of a north-south dipole structure in the SST. It appears to be linked to the global-scale inter-decadal (15-year) joint mode in SST and SLP recently studied by Mann and Park. The second mode is characterized by east-west displacements of the anticyclone centre, in association with strong 6 to 7-year period fluctuations of SST off the coast of Africa. Finally, the third mode is characterized by north-south displacements of the anticyclone and 4-year period fluctuations in the SST in a broad band across the central South Atlantic. This mode is strongly correlated with ENSO.

Session 3-B3

Mesoscale Processes & Severe Weather - 2

Chair: Geoff Strong

Wednesday, June 4 10:10-12:10 Room 200

3-B3.1 Descending Reflectivity Cores and the Onset of Severe Weather

L. Li (speaker) *and P. Joe* (Cloud Physics Research Division, King City, ON, Canada)

Two years of severe weather-producing storms from southern Ontario were examined using radar. The purpose of this study is to identify radar signatures that may indicate the onset of severe weather. About 86 % of surface damage events reported in the severe weather log were coincident with the descent of a maximum reflectivity core. The descent period (the time for a core to drop from its maximum height to surface) varied from 10 min to 40 min. Doppler radar data revealed that convergence at different altitudes within a storm cell were associated with different patterns of descending reflectivity cores. The increase of convergence with height indicated a sharp drop of the precipitation core (implying short lead time), whereas roughly equal values or small values indicated a slow descent of the reflectivity core (meaning long lead time). This technique provides a method to predict the onset of severe weather with a 10 ~ 30 min lead time with greater precision than before.

3-B3.2 Some Aspects of Tornado Climatology in Southern Ontario

P.W.S. King[1] (speaker) *and D.M.L. Sills*[2] ([1]Environment Canada, Downsview, ON, Canada; [2]York University, North York, ON, Canada)

Southern Ontario has the reputation as being the most tornado prone region in Canada. In this presentation we use the Canadian tornado data base (1918-1992) to discuss regional and temporal variations in the tornado climatology of southern Ontario. We find what appears to be a strong

effect of the Great Lakes in both suppression and enhancement of tornadoes. In particular, early in the season (April-May) tornadoes are confined mainly to a central corridor running northeast from Sarnia toward Lake Simcoe. Later in the season, as the lakes become warmer, activity spreads closer to the Lakes. There is a strong regional variation in tornado tracks. Most long track storms have occurred in the corridor between Sarnia and Lake Simcoe. In regions near the lakeshores most tornadoes occur in mid-summer and are short-tracked. Comparison with neighbouring American states indicates slightly lower numbers which may be attributed to a general suppression of severe convective activity and/or differences in tornado assessment. We hypothesize that the Great Lakes have two effects on the tornado climatology of southern Ontario: (1) A general suppression of activity in areas directly downwind of the lakes; (2) A local increase in activity on convergence lines induced by lake breezes and their interactions with other phenomena (cold fronts, storm outflows, *etc.*). Animated loops of satellite imagery will be shown to support the hypotheses.

3-B3.3 Tornado Tracks and Damaging Downburst Areas of the 4 July 1996 Saskatoon-Maymont-Osler Thunderstorm Outbreak

Stephen Knott (speaker) *and Dwight Clarke* (poster session) (Environment Canada, Saskatoon, SK, Canada)

The thunderstorm outbreak of 4 July 1996 was a major event for the area bounded by Saskatoon, Maymont, and Osler. An estimated 10 documented tornadoes occurred in addition to an approximate area of 950 km^2 of near F1 strength or greater downburst winds. Of the eleven tornadoes three are estimated to have tracks greater than 10 km. The parent thunderstorm initiated 60 km south of North Battleford and moved eastnortheastwards. The tornadic activity began as the storm moved across to the north side of the North Saskatchewan River Basin. An F2 tornado tracked 10 km moving just southeast of Maymont. It is hypothesized that a new mesocyclone reformed 10 km further south resulting in an F3 tornado which tracked 20 km and had a maximum width of 1.5 km. As the thunderstorm approached the Osler and Saskatoon area it became more downdraft dominated, however 7 more tornadoes have been documented. Six of these tornadoes were likely F1 or weaker, however an F2 developed just west of Rheinland and tracked 15 km southeastwards with a maximum width of near 1 km. This tornado caused extensive damage along its path. The majority of the residents in the Saskatoon-Osler area were affected by downburst winds with an areal coverage of atleast 790 km^2.

3-B3.4 The April 20th, 1996 Tornadoes in Southern Ontario

Arjen Verkaik (SkyArt Productions, Elmwood, ON, Canada)

Two F2/F3 tornadoes crossed south-central Ontario during the late-afternoon of April 20th, 1996 as part of a near-classic severe outbreak situation. Despite extensive damage, no one was killed. Both tornadoes had many characteristics in common (long-track, highly visible, multiple-vortex, *etc.*) and the two storms evolved and looked quite similar too. However, the northern one, the Williamsford tornado, was a complete shock and surprise to the residents of Grey County, who still had snow on the ground in places, and hadn't seen this intense and early an event for almost a century. By comparison, the southern, Arthur tornado, sailed in plain sight across the same region that suffered through the infamous Barrie tornado outbreak eleven years earlier. The author will discuss the evolution of these storms and tornadoes and point out a few of the more intriguing findings, using slides of tornado photographs gathered from observers along both tracks. The highly-sheared, relatively dry air mass produced remarkable visibilities and storm details not normally seen in Ontario, and more like the conditions experienced in the Prairies or western Kansas. Both storms were supercells similar to those found along a dryline. The tornadoes changed size, structure and strength over their lifetimes, and the author will walk you through these changes, comparing them to the wind and cloud features of the parent thunderstorms. These two tornadoes presented us with a very wide range of features and characteristics in one event. A few of these confirmed present theory and thinking about tornadoes, but a few other discoveries were surprises, and provided the basis for a fresh look at some of the currently-held ideas about them. Although this event doesn't rank high on the list of worst or killer tornadoes, it may have been the most visible, most watched and documented tornado event we've ever known in Ontario. Tornado research is far from complete yet, and a tornado is one of the few natural phenomena we can't measure or study easily. Every event, therefore, gives everyone involved (scientists and the public) an opportunity to contribute to uncovering its secrets.

3-B3.5 The Open-Ended Interview in Tornado Research: Treasure Chest or Pandora's Box?

Jerrine Verkaik (SkyArt Productions, Elmwood, ON, Canada)

Anecdotal accounts of tornado experiences are too often limited to the "here today, gone tomorrow" sensationalizing media reporter. As a result, a wealth of data often remains unplumbed. The larger context of this paper is an examination of the issues and misconceptions (on the part of both meteorologists and the public) that contribute to failures in understanding and communication about severe weather. The author conducted more than 500 intensive interviews with victims and witnesses of the April 20th, 1996 tornadoes in Ontario, and offers insight into ways to structure interviews to achieve the fullest possible accounting of both observational data and public awareness and misconceptions vis a vis severe weather. Attention will be given to interview methodology, assessing and organizing the data, and a review of some of the more intriguing findings of this in-depth study of the naive observer's experience of the April 20th event.

Session 3-B4

Marine Icing Workshop - 1, presentations

Chair: Chuck Ryerson

Wednesday, June 4 10:10-12:10 Room 206

3-B4.1 Some Recent Developments In Marine Icing Research

E.P. Lozowski (Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB, Canada)

The serious effects of marine icing on ships have been documented in the scientific and popular literature back to the 19th Century. The freezing of wave-impact spray and supercooled fog can lead to heavy ice loads with grave consequences for vessel and crew. Attempts to mitigate its effects beginning in the 1950s, have led to the development of forecasting procedures and design regulations, as well as anti-icing and de-icing methods. Japanese, British, Russian and Canadian research programs during the 1960s and 70s focused on the icing of fishing vessels, and important advances were made in the understanding of the problem and how to deal with it. Nevertheless ice-laden ships continued to sink.

In the 1980s, attention turned to the possibility of icing in connexion with offshore hydrocarbon exploration activities, especially along the coast of Northern Norway and offshore Eastern Canada. Research programs in these two countries led to the development of marine icing climatologies and icing models for offshore platforms. While the experience of icing for offshore platforms is not nearly as extensive as that for fishing fleets, current evidence suggests that icing is not a serious safety hazard or even an important operational problem, most of the time. There are indications, however, that extreme icing events on floating platforms can impact both operations and safety. Plans for future offshore hydrocarbon production using floating platforms are already well-developed for the East Coast and Northern Russia. However, it isn't clear what preparations need to be made (if any) to allow for marine icing.

The past decade has seen the development of three-dimensional, time-dependent models of vessel and platform icing, the construction of marine icing wind tunnels in which the phenomenon can be reproducibly simulated, the invention of instruments to measure spray flux and icing rates, and the improvement of freezing spray forecasting algorithms. Does this mean that we have succeeded in taming this natural hazard, and that marine icing has ceased to be a concern? By reviewing some of these developments, we will endeavour to answer this question, and to chart an appropriate course into the next millennium.

3-B4.2 Operational Practices and Their Applicability to Forecast Freezing Spray in Arctic Waters

A. Nowak (Arctic Weather Centre, Edmonton, AB, Canada)

Arctic Weather Centre meteorologists issue marine forecasts for Canadian Arctic waters spanning Hudson Bay, Davis Strait, Baffin Bay, waterways between the islands of Arctic archipelago, and the Beaufort. Freezing spray can occur on these Arctic waters during most of the marine forecasting season and is an important component of the Arctic Weather Centre marine forecasts. A simple, not qualitative nor quantitative, method for forecasting freezing spray is used at the Arctic Weather Centre. This method is also implemented into the production of an automated marine forecast. Operational practices used at the Arctic Weather Centre to forecast freezing spray will be discussed with a focus on their applicability to the Arctic Environment. Additionally, the results of a users survey regarding the usefulness of the forecast will be presented.

3-B4.3 An Experimental Study of Spongy Ice Growth

Shi, Zhigang (speaker) *and Edward Lozowski* (Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB, Canada)

Spongy accretions consisting of pure ice and unfrozen liquid can more than double the icing load on a vessel. With this in mind, a wind tunnel investigation was conducted to stimulate the growth of spongy ice on a fixed disc and a rotating cylinder, which were immersed in a cold airstream with either freshwater or saline spray. An extensive set of experiments was performed to measure the sponginess (liquid water fraction) and the growth rate of these accretions as a function of a wide range of environmental parameters, including air temperature, spray liquid water content, spray salinity and accretion time.

The data reveal that within an intermediate range of air temperature, the sponginess of the ice accretions is close to 50%, and almost independent of the environmental conditions. Beyond this range (that is for temperatures nearing the freezing point and for very low temperatures), the sponginess falls rapidly towards zero, yielding solid ice growth. The sponginess of saline ice accretions is significantly greater than that for freshwater accretions grown under the same conditions. In contrast to some previous results, we find that the growth rate is essentially

constant for the accretions growing on both the cylinder and the disk. These results have been used to verify the performance of a numerical spongy icing model.

3-B4.4 Progress in De-Icing Technology Applied to Overhead Cables

J.-L. Laforte (speaker) *and M.L. Allaire* (Dep. Sciences Appliquees, Université du Québec Chicoutimi [UQAC], Chicoutimi, QU, Canada)

More than thirty different de-icing techniques are reported in literature. These include thermal, mechanical, passive and miscellaneous methods more or less capable of removing ice and assuring anti-icing protection. Although many of these techniques have not yet made it beyond the concept stage, some of them are used in several areas such as air and rail transport, electrical networks, telecommunications, *etc.* During the last two years, important progress has been achieved in the de-icing field with the development of a innovative system using electromagnetic impulses to de-ice stranded wires and cables. In this system, the electro-impulse de-icing technology, which was first developed for aircraft de-icing, have been adapted to stranded cables and successfully tested in a recent research and development work conducted during the winters of 1996 and 1997. After reviewing the main existing de-icing techniques, especially the electro-impulsive de-icing technology, this paper presents the results of the experiments showing the feasibility of the electro-impulse de-icing technology applied to cables. First tests have been successfully performed in the winter of 1996 with 56 meter long guy wires of the mast of a real telecommunication tower, and others, in the winter of 1997, using a 257 meters long Optical Fibre Ground Cable [OFGC]. In addition to the demonstration of the efficiency of the new technology, these tests show that de-icing cable system requires very low power, is environmentally safe and does not cause disturbing interference within telecommunication bands. The developed de-icing technology could be adapted to all types of existing overhead wires and cables. This new de-icing application looks very promising as a solution to marine icing problems.

A device giving early warning of ice formation during icing storms should be very useful for the airports operators, which have to applied de-icing and anti-icing products on ground aircraft especially under frost and icing fog conditions. This function is achieved by the new measurement system recently set up in UQAC laboratory. The system consists of the ground rime-meter used since fifteen years by Hydro-Québec for monitoring its power network, and a user friendly control program capable of real time data recording, the latter being developed in UQAC. This system has been experimented in laboratory and outdoor tests during 1994-95 and 1995-96 winter seasons, which reveal the great sensibility of the sensor to detect and measure in real time the intensity of all types of ground atmospheric icing: sublimation or condensation frost, freezing fog, freezing drizzle, freezing rain, and wet snow. The objective of this paper is to present an exhaustive analysis of the numerous icing data recorded by four units of this system which were operated during the two last winter seasons. The information transfer and the access to daily files of each site, both during and after icing episodes, were made using a phone line through a modem. From this analysis, it is possible to point out the two main features of the developed system: real time ice detection and intensity measurement even under very light frost condition, and determination of the time at which all types of atmospheric icing start and end. The latter should be very useful for the airport ground aircraft deicing operations, thus telling them when there is active riming and to apply de-icing or anti-icing products as soon as frost or other ice deposit have been detected. It would be possible to develop in a very near future an improved version of the system with an interface for identification of the type of icing, distinguishing then between freezing drizzle and freezing rain.

Keywords: De-icing, anti-icing, thermal, mechanical, marine icing, overhead cables, guy wires.

3-B4.5 A Theoretical Investigation of the Distribution of Freshwater Spongy Spray Icing on a Vertical Cylinder

R.Z. Blackmore (speaker) *and E.P. Lozowski* (Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB, Canada)

A theoretical steady-state model of freshwater spray icing for a vertical cylinder gives insight into the icing of ship components such as masts or rigging. Even though salinity effects are neglected, a falling film of excess liquid and a surficial layer of growing dendritic ice called the freezing zone are included. The microphysics of the icing surface result in a nearly constant predicted sponginess. The model's prediction of icing rate agrees well with data. Depending on the spray temperature and the distribution of spray, the icing rate may increase or decrease with elevation.

Session 3-C1

Boundary Layer Meteorology

Chair: Stan Shewchuk

Wednesday, June 4 13:40-15:00 Room 200

3-C1.1 Modelling Boundary Layer Clouds Using a Statistical Cloud Scheme

K. Abdella (speaker) *and N. McFarlane* (Canadian Centre for Climate Modelling and Analysis, Sydney, BC, Canada)

We present a second order turbulence model for the planetary boundary layer [PBL] which is extended for application of a statistical scheme of the subgrid-scale condensation. The model contains a prognostic equation for the turbulent kinetic energy. The other second order moments modelled through the parameterization of the third order moments which are obtained through a convective mass-flux argument. For the heat flux this leads to a formulation with the usual down-gradient term and a counter-gradient term. The effect of the turbulence scheme on the partial cloudiness scheme will be discussed and the performance of the model is tested by considering different cloudy PBL conditions and comparing the results with observed reference cases. The model produces the mean as well as the turbulent quantities that are in a reasonable agreement with the observational data.

3-C1.2 Convective Boundary Layer Wind and Temperature Profiles

E. Santoso and R. Stull (speaker) (Department of Geography, University of British Columbia, Vancouver, BC, Canada)

During conditions of free convection, traditional Monin-Obukhov similarity theory does not work well in the bottom third of the mixed layer. This is because turbulence is generated by buoyant thermals rather than the shear-driven eddies for which surface-layer theory was designed. We have identified a "radix layer" in the bottom third of the mixed layer where wind speed and potential temperature vary from their near-surface values to their uniform values in the middle of the mixed layer. The traditional surface layer occupies the bottom portion of the radix layer. A similarity profile equation is presented for this radix layer domain, and is shown to fit observed data better over a wider range of heights than traditional similarity theory. New field results from the 1996 Boundary Layer Experiment (BLX96) are also presented

and used to validate the profile equations. Potential applications include weather and climate modelling where near-surface conditions must be estimated from mid-boundary-layer values, and wind turbines and air pollution where wind profiles are critical.

3-C1.3 Size Distributions of Boundary-Layer Cumulus Clouds

L.K. Berg (speaker) *and R.B. Stull* (Department of Geography, University of British Columbia, Atmospheric Science Programme, Vancouver, BC, Canada)

Joint Frequency Distributions [JFD] of virtual potential temperature and moisture can be used to describe the thermodynamic state of the convective boundary layer. These JFD can be related to cumulus cloud cover and cloud onset time. Conceptually, the JFD represents the likelihood that a parcel will rise and the likelihood that condensation will occur. The virtual potential temperature for each point of the JFD can be compared to the mean virtual potential temperature of the mixed layer. If the parcel has a virtual potential temperature less than that of the mixed layer the parcel will not rise. If the parcel has a virtual potential temperature greater than the mixed layer the parcel will rise dry adiabatically. A subset of the these rising parcels will reach their saturation level and form clouds. These parcels will continue to rise, moist adiabatically, until they reach the stable layer above the convective mixed layer. Other rising parcels will not condense but will continue to rise, dry adiabatically, as clear air parcels until they reach the stable layer. It has been shown that JFD computed from time seriesо measured by surface instruments do not provide adequate cloud forecasts. New data for JFD were collected during Boundary Layer Experiment 1996 (BLX96) over Oklahoma and Kansas USA. Each of the three flight tracks were flown over different land use types to quantify the relationship between the JFD and surface type. Data were gathered at five different heights in the convective boundary layer to examine how JFD change with height. These JFD were used to estimate fair-weather cumulus onset time and population characteristics for the BLX96 case study days.

3-C1.4 Extraction of the Refractive Index Field Near the Surface by Radar Using Ground Targets

F. Fabry[1] (speaker), *C. Frush*[2], *I. Zawadzki*[1], *and A. Kilambi*[1] ([1]J.S. Marshall Radar Observatory, McGill University, Montréal, QU, Canada; [2]National Center for Atmospheric Research, Boulder, CO)

Changes in the travel time of EM waves between a radar and fixed targets are caused by changes in the index of refraction in the atmosphere between them. Using the time evolution of the phase information from ground targets as a proxy for the travel time of radar waves, a procedure for measuring the near-surface index of refraction field around the radar (20-45 km range) is demonstrated and implemented. Because of the close link between index of refraction and temperature and moisture, this measurement may allow the extraction of information about the temperature and moisture fields in the surface layer. The theory behind the measurement, an implementation of the theory, and early measurements of the index of refraction field in various weather conditions will be shown. Some of the possibilities offered by this new radar-measured variable will also be presented.

Session 3-C2

Climate/Interannual Variability - 2 *Chair: Madhav Khandekar*		
Wednesday, June 4	13:40-15:00	Lecture Theatre 143

3-C2.1 Impact of a Warming Climate on Evapotranspiration on the Eastern Prairies

R.L. Raddatz[1] (speaker) *and C.F. Shaykewich*[2] ([1]Prairie and Northern Region, Environment Canada, Winnipeg, MB, Canada; [2]Department of Soil Science, University of Manitoba, Winnipeg, MB, Canada)

Will increasing levels of atmospheric carbon dioxide and rising temperatures enhance or suppress total seasonal evapotranspiration? The answer depends on the relative magnitudes of these opposing effects which are influenced by several factors including the type of vegetation and the character of the climate, in particular its aridity. This study focused on the eastern portion of the Canadian Prairies grassland ecoclimatic zone, a semi-arid region where over 60% of the land is being cultivated. The dominant crop is spring wheat - a cool-season C3 annual grass. A comparison of areal-average growth-period evapotranspiration totals for spring wheat, from 1988 to 1996, demonstrates that a warm (cool) summer reduces (increases) evapotranspiration as above (below) normal temperatures hasten (slow-down) crop maturity. This impact is greater than the cumulative effect of higher (lower) daily evapotranspiration rates with warmer (cooler) temperatures. By analogy, this suggests that climate warming will reduce the average growing-season evapotranspiration on the eastern Canadian Prairies. The consequence for agriculture may be a reduction in average yields for C3 crops as yield is primarily a function of growth-period evapotranspiration. In addition, anecdotal evidence suggests that evapotranspiration from crops plays an essential role in the occurrence of summer severe local storms as it is an incremental regional source of atmospheric moisture. Thus, as the crop growth-period shortens so may the period of severe convective storms.

3-C2.2 Changes in the Extremes of the Climate Simulated by CCC GCM2 Under CO_2 Doubling

F.W. Zwiers and V.V. Kharin (speaker) (Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada)

Changes due to CO_2 doubling in the extremes of the surface climate as simulated by the second generation circulation model of the Canadian Centre for Climate Modelling and Analysis are studied in two 20-year equilibrium simulations. Extreme values of screen temperature, precipitation and near surface wind in the control, or $1xCO_2$ climate are compared to those estimated from 17 years of the NCEP/NCAR reanalysis data and from the available Canadian station data. The extremes of screen temperature are reasonably well reproduced in the control climate. Their changes under CO_2 doubling can be connected with different physical processes such as surface albedo changes due to the reduction of the snow and sea ice cover as well as a decrease of soil moisture in the warmer world. The signal in the extremes of daily precipitation and near surface wind speed due to CO_2 doubling is less obvious. The extreme precipitation has increased almost everywhere over the globe, with the strongest change over northwest of India which is related to the intensification of the summer monsoon in this region. The modest reduction of wind extremes in tropics and middle latitudes is consistent with the reduction of the meridional temperature gradient in the $2xCO_2$ climate. The wind extremes are increased in the areas where sea ice has been retreated.

3-C2.3 Spatial-Temporal Structures of Trend and Oscillatory Variabilities of Precipitation Over Northern Eurasia

X.L. Wang[1] *and H.-R. Cho*[2] (speaker) ([1]Canadian Centre for Climate Modelling and Analysis, Atmospheric Environment Service, University of Victoria, Victoria, BC, Canada; [2]Department of Physics, University of Toronto, Toronto, ON, Canada)

Combinations of statistical analyses including principal component analysis, and uni- and multi-variate singular spectrum analyses, were carried out to characterize the spatial-temporal structures of trend and inter-annual oscillatory variabilities of precipitation over the major north-flowing river basins in the former USSR. The series of monthly precipitation were corrected for the biases of precipitation measurement due to the gauge type change and changes in observing procedures. An upward trend was found in the monthly precipitation series for the last half century. This upward trend was stronger in the North Dvina and Pechora River basins, and in the Ob-Irtysh River basins, but much weaker (still upward, though) in the Yenisey-Lena River basins. The notable increases of precipitation over the southwestern part - the Volga and Ural River basins were found to be due at least in part to the upward phase of some quasi-century periodicity. Generally speaking, the precipitation increases appeared to be more apparent during the cold seasons in the western half of the sector, while in the eastern part, it appeared to be equally or more notable during summer. On the inter-annual time scales, signals of 4-5 year and quasi-biennial oscillations were found in the space-time dependent precipitation series. The 4-5 year oscillation was quite apparent over the entire Northern Eurasian sector, being stronger over the southeastern and western parts. This oscillation appeared to propagate eastward. The quasi-biennial oscillation was generally weaker; and it was very weak during the 1955-1965 period. This oscillation was relatively stronger in the western half of the sector, and weaker over the eastern half.

3-C2.4 Hydrologic Sensitivity of Wascana Creek to Climate Variability

R.F. Hopkinson (speaker) *and L.H. Wiens* (Environment Canada, Regina, SK, Canada)

Statistical and simulation model analysis techniques were applied as part of a sensitivity study of a small prairie drainage basin, in an attempt to determine the hydrologic response to climate forcing. The specific purpose of the work was to develop a scientifically based technique for the adjustment of hydrometric records to realistically reflect the influence of climate change scenarios produced by general circulation models [GCMs]. From such an understanding, planners and decision makers can develop water resource management strategies to adapt to a range of future climate scenarios. A number of streams in the prairie or boreal ecosystems were identified as having reasonably long records of both stream flow and climatology. Wascana Creek was selected as one such basin meeting the basic screening criteria and it was subjected to statistical and modelling analyses. The statistical approach, using multiple non-linear regression analysis, yielded a good relationship between antecedent moisture conditions, precipitation and stream flow volume. This relationship was used to determine the sensitivity of stream flow to changes in precipitation. Results of sensitivity tests using SLURP (Single Lumped Reservoir Parametric model) will be presented from the simulation of selected years. Although, the model produced similar sensitivity to changes in precipitation in years with average to above average flow, the failure of SLURP to simulate flows in low flow years and through the dry summer period limited its application with respect to a complete sensitivity analysis.

Session 3-C3

Environment Canada's Severe Weather Program - 1

Chair: Carr McLeod

Wednesday, June 4 13:40-15:00 Lecture Theatre 146

3-C3.1 Environment Canada's Severe Weather Program Overview - Past, Present, and Future

N. Cutler (Environment Canada, Downsview, ON, Canada)

Minister Marchi, Minister of the Environment, said in announcing the Doppler radar extension, "the safety and security of Canadians is our number one priority". Severe weather, both summer and winter, threaten the lives and well-being of Candians at an alarmingly increasing rate. The paper will review a brief history of severe weather events in Canada including the Barrie and Edmonton tornadoes and how they have shaped our current program. The paper will examine four cornerstones of the severe weather program as we move into the 21st Century. Doppler radar expansion plans have been announced and will be reviewed here. The new Canadian Lightning Detection Network which extends our severe summer weather watch capacity will be presented. Advances in numerical modeling capability and capacity will be examined with an eye on impacts on both severe summer and winter weather. Lastly, new dissemination methods will be briefly looked at that will enable weather warnings in all seasosns to reach Canadians in a timely and efficient manner.

3-C3.2 The National Weather Radar Project

Barry Greer (speaker), *Gary Pearson, and Paul Ford* (Atmospheric Environment Service [AES], Downsview, ON)

A major upgrade to the National Weather Radar Network is to be implemented over the next six years. Ten new radars will be added to the current network of 19 radars. All 29 radars will have Doppler capability as compared to only three at present. Radar data will be processed and presented to users by systems developed from those currently used with the King and Carvel Doppler Radars. This project will significantly enhance severe weather identification and warning capabilities for over 90% of Canada's population and will also support other meteorological, hydrological, and environmental programs, as well as providing various commercial opportunities.

3-C3.3 The Canadian Lightning Detection Network - An Overview

Gilles Fournier[1] (speaker, 30 min), *Carr McLeod*[2], *and Richard Pyle*[3] ([1]Atmospheric Environment Service, Ottawa, ON, Canada; [2]Atmospheric Environment Service, Downsview, ON, Canada; [3]Global Atmospherics, Inc., Tucson, Arizona, USA)

Thunderstorms are one of the most severe forms of weather. Lightning kills more people in North America than any other meteorological hazard. Lightning also causes millions of dollars in damage to property, most notably to Canada's forests, and disruptions to electrical power transmission, causing inconvenience to the public and economic loss to the power utility. A lightning detection network is a series of sensors that allows the detection, location and characterisation of lightning strikes. Lightning detection provides the best time/space resolution of thunderstorm activity. From these data, forecasts of lightning and other forms of severe weather are prepared. A lightning detection network also provides increased research and revenue generation opportunities. Environment Canada has let a contract to Global Atmospherics Inc. [GAI] of Tucson, Arizona, for the implementation of the Canadian Lightning Detection Network [CLDN]. The CLDN will be composed of 81 sensors mixing Time-Of-Arrival [TOA] and Magnetic

Direction Finding [MDF] methodologies, in a configuration which allows for detection efficiency over 90% and accuracy better than 500 meters over the area of interest. The CLDN will help Environment Canada fulfil its responsibility for more timely and accurate weather predictions. It is the first national network of its kind for Canada, and an extension of the American network. These integrated networks will form the first ever North America Lightning Detection Network [NALDN]. This presentation will provide an overview of the Canadian Lightning Detection Network, the lightning detection systems composing it, and the implementation schedule.

Session 3-C4

Marine Icing Workshop - 2, presentations

Chair: Ryan Blackmore

Wednesday, June 4 13:40-15:00 Room 206

3-C4.1 Dynamic Effects of Marine Icing on Vessel Stability

K.K. Chung (speaker) *and E.P. Lozowski* (Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB, Canada)

A three-dimensional ship icing model has been developed for the stern trawler MT Zandberg. The numerical model consists of of two subprograms. The first is a spraying model which is empirically based on data from model-scale experiments. This model calculates the local spray flux to each cell of a grid mesh which is superimposed upon the surface of the vessel. The second subprogram calculates the spray thermodynamics, the brine film dynamics and the icing rate. These work together to determine the ice accretion growth rate on each grid cell. The disappearance of the side trawler Blue Mist II off Newfoundland in 1956 is used as a case study to demonstrate the performance of the icing model, and to examine the influence of the ice load on the static and dynamic stability of the Zandberg. With beam winds 15 degrees off the bow, a heavy, asymmetrical ice load accumulates very rapidly. This load causes the vessel to trim and list significantly and to become statically unstable within 10 hours. This ice load is superimposed on the vessel and the resulting iced ship is input to NRC's Ship Dynamics Simulation Package, in order to examine its dynamic response to the icing. This analysis shows that under the Blue Mist II conditions, the asymmetrical ice distribution on the Zandberg, after only three hours, would have been sufficient to induce large rolling motions leading to its capsize and eventual sinking.

3-C4.2 Using Adaptive Logic Neural Networks to Predict Ship Icing

J.M.D. Bullas (Department of Computing Science, Unversity of Alberta, Edmonton, AB, Canada)

Ships travelling in the northern seas encounter a problem that their compatriots in the south do not - ship icing. Ice forming on ships can cause severe imbalancing and, in several cases, can lead to the capsizing and sinking of vessels caught in severe storms. Some attempts have been made to build a model that will allow scientists to predict the rate at which icing occurs, but these models are still in the development stage and are not terribly accurate. This paper will investigate the use of an Adaptive Logic Neural Network to predict the rate of icing aboard a ship. Initial results obtained in this paper are encouraging, and the prospect of finding cleaner data leaves this author with the hope that improvements can be found.

3-C4.3 A New Instrument for Measuring Marine Icing on Offshore Structures

T.W. Forest[1], B. Faulkner[1], M. Chekhar, and E.P. Lozowski[2] (speaker) ([1]Department of Mechanical Engineering, University of Alberta, Edmonton, AB; [2]Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB)

Offshore structures in the marine environment are subject to ice accretion during winter conditions when the air temperature fall below about -2EC, and sea-spray is generated by wave-structure interaction. Several cases have been reported where an estimated 200 to 500 tonnes of ice accreted on semi-submersible platforms, causing problems with draft and stability. In order to establish a reliable icing data base for offshore operations, and to verify existing or improved rig icing models, there is a need for robust, automatic methods to measure spray ice load and thickness on offshore platforms. This paper describes the design, construction and testing of a new ice thickness sensor, which has been designed for use on an offshore oil production platform. The icing load sensor consists of a hollow cylindrical shell 0.4 m in diameter and 1 m in length. The shell is segmented circumferentially into five individual plates, approximately 0.25 m wide by 1 m long. Each of the five plates is attached to a 0.15 m diameter steel pipe, using a series of linkages, two of which are instrumented with strain gauges to measure the weight and moment of the ice which has accreted on the surface of the plate. From these measurements, the total load and mean thickness of the ice on each plate can be readily determined. The sensor is mounted to a platform leg. A data logger inside the sensor samples the signal from each of the ten load cells at regular intervals, and sends the data to a dedicated computer on board the platform. The sensor's operation was tested in a cold room at -10EC, where marine icing conditions were simulated by manually spraying brine at 0EC, unidirectional onto the ventilated surface of the sensor with an intermittent cycle. The test lasted 40 hours, during which an average ice thickness of 10 cm was accumulated. A comparison between the measured ice thickness on the plate and the ice thickness inferred from the strain gauge measurements (with an assumed accretion density of 1000 kg/cubic metre) shows a mean error of between 1 to 2 cm. This is reasonably good for this type of measurement.

3-C4.4 Structure and Properties of Superstructure Spray Ice on a Coast Guard Cutter

C.C. Ryerson (Cold Regions Research and Engineering Laboratory, Hanover, NH, USA)

In February and March 1990 CRREL made measurements of bow spray and superstructure ice on a U.S. Coast Guard cutter in the Bering Sea. Few have measured superstructure ice structure and properties outside of Russia, and these are the first known measurements from a large ship. Twenty- three ice samples were removed from bulkheads, decks, lifelines, and icicles during two icing events. Ice property measurements included salinity, density and temperature, with computed estimates of air and brine volume and total porosity. Samples were taken during and immediately after icing events to minimize brine drainage. Most measurements were made in cold rooms after ice was shipped to CRREL. This presentation describes measurements made and their relationship to weather and position on the ship. Ice crystals were universally small and isotropic on bulkheads, and larger and elongated on decks. Crystals on decks often exhibited development parallel to the deck near the deck surface, and orthogonal to the deck near the air/ice interface. Ice on horizontal surfaces produced fewer and smaller brine pockets than on vertical surfaces, with some brine channels on vertical surfaces nearly paralles to, but curving down and away from the bulkhead. Ice salinity was greater on decks than on bulkheads, and decreased with time on all surfaces. Salinity averaged about 12 ppt on bulkheads and about 21 ppt on decks. Ice densities ranged from 0.72 g/cm^{-3} to 0.92 g/cm^{-3}. Densities were generally,

but not consistently, larger on decks. Air and brine volumes, and total porosity, were computed using algrithms from Cox and Weeks (1983). Bulkhead ice had larger computed total porosity and air volume, and lower brine volume than deck ice. Of the samples taken, lifeline and icicle samples were most unique. Samples taken from decks and bulkheads generally compared well with Russian measurements.

Session 3-D1

GEWEX-4: Basin-Scale Experiments - Part II

Chair: Terry Krauss

Wednesday, June 4 15:20-17:00 Lecture Theatre 143

3-D1.1 The Upper Missouri River Basin Hydrology Project

P.L. Smith (speaker) *and S.O. Farwell* (South Dakota School of Mines and Technology, Rapid City, SD, USA)

A collaborative research project on the atmospheric/surface/subsurface hydrology of the Upper Missouri River Basin is being organized as part of NASA's Mission to Planet Earth. This project is closely related to the studies planned in the GCIP Large-scale Area Northwest [LSA-NW], which is roughly congruent with the Upper Missouri River Basin. Major topics of scientific study include: (1) the effects of orography on precipitation and its distribution, and on snow accumulation and snowmelt under conditions of varying altitude, slope and solar aspect; (2) the effects of land cover variations in a region where natural C3 photosynthetic systems have been dominant and the boundary between rangeland and productive tilled agriculture is sensitive to moisture and temperature variations; and (3) the multi-scale characterization of coupled atmospheric, hydrospheric, land-surface and biospheric processes. Work on coupled atmosphere/surface/subsurface models applicable at regional (GCIP Small-scale Area, SSA, or Intermediate-scale Area, ISA) scales and on the use of remote sensing to establish land-cover characteristics is featured. Efforts to clarify the issues of water vapor fluxes on SSA and ISA scales and to observe and model the surface fluxes of heat, water vapor and carbon are included. The more than fifty scientific participants come from ten universities in the Basin or other areas as well as from the U.S. Geological Survey's EROS Data Center and Water Resources Division along with other federal and state agencies. This paper will provide an overview of the project structure and the research activities planned for the next five years.

3-D1.2 The Mackenzie GEWEX Study [MAGS] Observational Strategy

B. Kochtubajda[1] (speaker), *G.S. Strong*[2], *G.W.K. Moore*[3], *R.E. Stewart*[2], *P. Marsh*[5], *H.G. Leighton*[6], *H. Ritchie*[7], *W.R. Rouse*[8], *E.D. Soulis*[9], *and R.W. Crawford*[4] ([1]Environment Canada, Edmonton, AB, Canada; [2]Environment Canada, Saskatoon, SK, Canada; [3]University of Toronto, Toronto, ON, Canada; [4]Environment Canada, Downsview, ON, Canada; [5]National Hydrology Research Institute, Saskatoon, SK, Canada; [6]McGill University, Montréal, QU, Canada; [7]Environment Canada, Dorval, QU, Canada; [8]McMaster University, Hamilton, ON, Canada; [9]University of Waterloo, Waterloo, ON, Canada)

The Mackenzie GEWEX Study [MAGS] represents the Canadian contribution to the international GEWEX hydrometeorology effort, and involves a coordinated series of process, remote sensing, and modeling studies within the Mackenzie River Basin. MAGS reflects a collaborative partnership involving teams of scientists from federal government laboratories and universities. It is the only continental scale experiment that is concentrating on a high latitude, northward

flowing river. Results from MAGS will provide an improved understanding of cold region, high latitude hydrological and meteorological processes, and the role that they play in the global climate system. To satisfy the scientific objectives of MAGS, proper observations are required for climatological studies, for model initialization and validation, and for process studies. A critical issue facing MAGS concerns the lack of adequate surface observations ov er the entire Basin. The MAGS observational strategy proposes to use existing data sets (numerical model outputs, weather, hydrometric and upper air observations), to enhance long-term observations, and to take additional measurements, during the 1997-99 time period, on time scales from hourly to monthly, in order to resolve the relevant hydrological and related atmospheric and land-atmosphere processes. Some observations will be made over an entire annual cycle, but the major effort will be focused on gathering enhanced measurements over critical periods of the year. Additional streamflow measurements at existing hydrometric sites, evaporation studies on Great Slave Lake, and the deployment of weather radars coupled with strategically placed remote surface meteorological sites are proposed to enhance existing surface observations. Supplementary radiosonde sites are proposed together with additional soundings at existing operational sites to adequately resolve the atmospheric moisture budget. Access to the numerical model data, the observations from the enhanced measurement periods and the hydrometric data will be made available through the archive centres located in Montréal, Downsview, and Saskatoon.

3-D1.3 Atmospheric Sciences and Other Related Activities of SRC Within the Southeastern Part of the MAGS Project Area

S.R. Shewchuk (Saskatchewan Research Council, Saskatoon, SK, Canada)

For several years now SRC has maintained a meteorological tower with the MAGS area at Uranium City. Data is retrieved from this site by GOES satellite technology. While the data collected from the site is primarily focused on the uranium industry, some component of the results may be applied to the MAGS project. The basic climatology of our site will be described along with the industry's requirements for surface radiation data. Within the data collection protocols established in this region, SRC would like to establish a surface mesonet for MAGS covering several important biomes of the project using the same infrastructure technology applied to BOREAS.

3-D1.4 Data Management for the Mackenzie GEWEX Study [MAGS]

R.W. Crawford (Environment Canada, Downsview, ON, Canada)

The Mackenzie GEWEX Study [MAGS] requires a common dataset to meet its objectives and there is a responsibility to maintain such a database in order to help meet the global objectives of GEWEX. This database required a distributed dta management system that allows open exchange of all relevant information, codes, and algorithms respecting the rights of individual scientists and agencies respected. The WWW was chosen as the primary method for disseminating common MAGS data due to its low cost, wide access and ease of use.

A brief description of the history of the MAGS homepage and other data management activities will be presented, along with a look at what to expect in the future.

3-D1.5 Statistical Relationships between Topography and Regional Finite Element Model Quantitative Precipitation Forecasts in the Mackenzie Basin of Canada

B.A. Proctor (speaker) *and C. Smith* (Climate Research Branch, Environment Canada, Saskatoon, SK, Canada)

One of the goals of the Mackenzie GEWEX study is to try to better refine current understanding of the hydrologic cycle in high latitude areas. One problem with working in such locations is the sparseness and lack of representative climate stations. This is especially true at higher elevations which are the source regions for much of the runoff occurring in the basin. Datasets that avoid these limitations are derived from operational meteorologic models. These models produce forecasts of precipitation at a variety of grid points over the model domain. Precipitation forecasts were accumulated over week, month, and season long intervals at each grid point for a two year study period. A mean 70.0 kPa wind velocity was also calculated for each time period. These fields were then ingested into a GIS and precipitation-elevation, aspect and slope relationships calculated. The objective of this paper is to present preliminary results of this work.

Agriculture/Forest Meteorology/Hydrology
Session 3-D2

Chair: Alan Barr

Wednesday, June 4 15:20-17:00 Room 200

3-D2.1 Association Between Circulation Anomalies in the Mid-Troposphere and Area Burned by Forest Fires in Canada

W.R. Skinner[1] (speaker), *B.J. Stocks*[2], *and D.L. Martel*[3] ([1]Atmospheric Environment Service, Climate Research Branch [CCRM], Downsview, ON, Canada; [2]Great Lakes Forestry Centre, Canadian Forestry Service, Sault Ste. Marie, ON, Canada; [3]Faculty of Forestry, University of Toronto, Toronto, ON, Canada)

The area burned by forest fires in Canada has shown a detectable increase in recent decades. One of the many possible causes for this change includes variability in mid-tropospheric circulation over Canada and the Northern Hemisphere. This study analyses composites of Northern Hemisphere circulation anomalies during extreme and benign forest fire months. The physical link between anomalous upper atmospheric flow over western and central Canada and forest fire severity is discussed. Analysis of monthly and seasonal area burned for the period 1953 to 1995 indicates a bimodal distribution consisting of distinct low and extreme area burned years. These coincide with negative and positive 50 kPa height anomalies, respectively, over the central and western Canadian target area. Two sample comparison tests show statistically significant differences in both the means and variances of the fire data populations during negative and positive phases of upper atmospheric flow.

Regression models are developed for individual months, and for the May through August fire season, both provincially and nationally. They show statistically significant relationships between positive circulation anomalies and area burned, indicating that anomalous upper atmospheric ridging is directly related to increases in area burned. No significant relationships are found between negative circulation anomalies and area burned. Time series analysis of the area burned and 50 kPa height anomaly data show detectable increases in magnitude, especially after the mid-1970s. Two sample (1953-75 and 1976-95) comparison tests show statistically significant increases in provincial and national mean area burned, as well as marginally significant increases in mean 50 kPa heights over the central and western Canadian target area.

3-D2.2 An Example of the Potential Value of Numerical WindFlow Models

J.D. Wilson (speaker) *and T.K. Flesch* (Department of Earth & Atmospheric Sciences, Unversity of Alberta, Edmonton, AB, Canada)

The numerical flow model is our means to integrate information, accumulated from micrometeorological experiments, into a "whole" picture. And when we undertake numerical studies of "agro-meteorological flows" it is with the hope that eventually we shall converge on a tool that satisfactorily "describes reality," and proves a trustworthy design aid. But considering the enterprise cynically, the tangible output of a model is usually no more than a curve on a graph in a journal paper, hopefully accompanied by experimental data! And the cynic may further argue that the model curve shown is only the best of about a hundred actually produced, and has been selected by fiddling with constants. There is undoubtedly an element of truth in that perspective. Then, what is the value of trying to "model" the infinity of disturbed flows near ground?

As one argument for the essential role and ultimate potential of windflow models, this talk will describe our attempt to use a flow model to interpret the spatial pattern of tree windthrow, as observed in field trials of alternative harvesting practises for the Canadian boreal forest. The

trials involve an alternation of clearings (width Xc) in which the Aspen have been harvested but the Spruce left standing, and intervening uncut shelter strips (width Xf). What are optimal values of (Xc, Xf) as regards windthrow of the isolated remnant spruce? The crucial role of flow modelling follows from the fact that, according to our own wind and sway measurements, the variance of tree sway angle (for the remnant Spruce) can be inferred from windspeed statistics nearby, which statistics vary dramatically across the cutblock. If a flow model could be demonstrated to give the variation of those statistics across the landscape, one would have a basis for extrapolation to arbitrary cutblock designs (Xc, Xf).

3-D2.3 Partitioning of Energy and Water in Boreal Forest Ecosystems

Raoul Granger (speaker) *and John W. Pomeroy* (National Hydrology Research Institute, Saskatoon, SK, Canada)

In Canada, the western boreal forest represents the transition between semi-arid (water-limited) prairies to the south and sub-arctic (temperature-limited) regions to the north. This forest ecosystem has sustained itself through its ability to act as a water, climate and nutrient regulation system, interacting with the atmosphere and soils to produce the specific conditions of water retention and flow, nutrient status and surface climate required for its development. The western boreal forest is very sensitive to disturbances, both natural and man-induced; it is also located in that area of the Northern Hemisphere which, according to recent climate change predictions, will encounter the greatest warming due to the accumulation of greenhouse gases in the atmosphere. The role of water and energy use in the sustainability of the boreal is the subject of a special study. Research sites have been established in undisturbed and disturbed stands within and near Prince Albert National Park and in the Wolf Creek Research Basin near Whitehorse. Continuous measurements of the energy and water balance components, including evapotranspiration, interception and infiltration, are being carried out.

The partitioning of water and energy at these natural and disturbed stands is presented, with particular emphasis on the evapotranspiration, which is the common term in the water and energy balances. Its effect on surface heating and the local climate is demonstrated. Differences between southern (water-limited) and northern (temperature-limited) sites are also presented.

3-D2.4 Rainfall Interception in a Subhumid Forest: Implications for Water and Energy Cycles

B. Toth (speaker), *J.W. Pomeroy, and R.J. Ganger* (National Hydrology Research Institute, Saskatoon, SK, Canada)

Interception is significant in the water cycle of forested surfaces as it partitions rainfall into that which is stored, evaporated or delivered to the surface. Interception, storage and evaporation of rainfall plays an important role not only in the water balance, but also in the energy balance of a forest. The discrimination of evapotranspiration into a) evaporation from wet surfaces in the canopy, and b) the sum of transpiration and vapour flux from the soil is important for process-based modelling of energy and water exchanges between the atmosphere and land surfaces.

Rainfall and associated within and above-canopy hydrometeorological measurements were made in three different forest stands at a GEWEX site in the Prince Albert Model Forest. The forest stands examined are typical of the southern boreal environment: a mixed wood of aspen and spruce, a mature pine stand, and a previously harvested and now regenerating pine stand. Above and below canopy precipitation was measured at locations of varying canopy density within each stand to provide information necessary to apply a physically based rainfall interception simulation for the forest. For each stand the relationships between canopy architecture, rainfall interception, storage, and drainage from the canopy were quantified and interception and net precipitation delivery were successfully modelled.

Interception efficiencies (interception/gross rainfall) showed significant variability ranging from 3% to 58%, with efficiency increasing as the canopy density increases. The between stand and within stand variability of intercepted precipitation is shown as a function of stand type and canopy density. The influence of rainfall interception on the separation of direct wet canopy evaporation from total evapotranspiration will be examined.

3-D2.5 Accurate Monitoring of Soil Moisture on a Scale of Hectares Using Deep Ground Water Piezometers

G. van der Kamp (speaker) *and R. Schmidt* (National Hydrology Research Institute, Saskatoon, SK, Canada)

A method has been developed for continuous measurement of total soil moisture on a scale of hectares. The method is based on accurate measurement of groundwater pressures in thick clay formations and depends on the principle that changes of mechanical load result in changes of groundwater pressure. The resulting data are similar to those obtained by conventional weighing lysimeters, but on a much larger scale and with no significant hydrologic disturbance of the site. Precipitation, snow accumulation and actual evapotranspiration can be measured to within a millimeter and with little cumulative error. Surface runoff can be measured in real time if independent measurements of precipitation are available. The method meets a need in hydrology for water balance measurements at scales intermediate between point measurements and river basins. Numerous applications can be envisioned in topics such as validation of hydrologic models, flood forecasting, irrigation scheduling, and forest hydrology.

Several years of field testing have showed the method to be practicable. Once an installation is operating properly it requires little maintenance or data processing effort. Small erratic pressure fluctuations do occur at times, mostly in winter. These may be related to changes of lateral stress resulting from uneven cooling and freezing near the ground surface. In its present form, the method is restricted to locations underlain by thick clay-rich formations, but extension to more general conditions is possible in principle.

Session 3-D3

Environment Canada=s Severe Weather Program - 2

Chair: Carr McLeod

Wednesday, June 4 15:20-17:00 Lecture Theatre 146

3-D3.1 Mesoscale Modelling in Support of Severe Weather Prediction

Pierre Dubreuil

*Abstract not available.

3-D3.2 WeatherAlert - Delivering the Message in Time to Make a Difference!

E.R. Adamson (Environment Canada, Toronto, ON, Canada)

Warnings are often issued with only a 15-20 minute lead time particularly in the case of summer severe weather. Environment Canada relies on a number of different systems to distribute these warnings to Canadians including the electronic media, Weatheradio and Weathercopy (the digital version of Weatheradio). The speed of delivery varies greatly with the nature of each system. Weathercopy can deliver the message in less than a minute while some television stations will hesitate to deliver the information.

WeatherAlert is a made for television system that is designed to alert the television viewer of impending severe weather in time to make a difference. Two technologies are being tested in the Toronto area. The first is designed to take advantage of the cable television system. The second is designed for use by local broadcasters. Both systems can deliver alert messages in

the form of a message "crawled" along the bottom of the television screen within minutes of the issue of a weather warning.

The paper will outline the design of the systems, provide examples of messages being transmitted and present initial reactions to the testing.

3-D3.3 Panel Discussion (*Chair: Carr McLeod*)

Session 3-D4
Marine Icing Workshop - 3
Roundtable Discussion of Future Directions for Marine Icing Research

Chair: Ed Lozowski

Wednesday, June 4 | 15:20-17:00 | Room 206

Session 4-A1

WOCE/CLIVAR - Plenary and Invited Talk

Chair: Dan Wright

Thursday, June 5 | 08:35-09:50 | Lecture Theatre 143

4-A1.1 WOCE/CLIVAR and Interannual Variability in the North Atlantic

(Plenary paper, 45 min)

John Lazier (speaker) *and Allyn Clarke* (Bedford Institute of Oceanography, Dartmouth, NS, Canada)

The World Ocean Circulation Experiment [WOCE] was established in 1990 to improve our ability to describe and model the ocean's role within the global climate system. Its successor program, CLIVAR, will focus on climate variability and predictability. A major Canadian contribution to WOCE has been the investigation of the interannual variability of the waters of the Labrador Sea. Labrador Sea Water [LSW] is a water mass that forms in winter in the Labrador Sea. This water spreads throughout the northern North Atlantic and along the western boundary of the entire North Atlantic at depths of 1400 to 2200 metres. The temperature and salinity of this water have decreased by 0.6 and 0.06 over the past 35 years. These changes result from interannual changes in the winter cooling of the Labrador Sea and in the supply of fresh water to the surface of the Labrador Sea from run off and ice melt. The North Atlantic Oscillation appears to play a role in these changes and this phenomena is to be a focus of the developing CLIVAR program in the North Atlantic sector.

4-A1.2 An Overview and Present Status of Long-range/Seasonal Forecasting

(Invited paper, 30 min)

Madhav L. Khandekar (Atmospheric Environment Service, Downsview, ON, Canada)

Predicting weather on a time scale of one season (3 months) or longer has been a long-standing problem in Meteorology. This paper will present a brief overview of the development of seasonal weather forecasting beginning with the pioneering work of Sir Gilbert Walker on correlation analysis between the Indian monsoon rainfall and world-wide weather elements. Recent seasonal forecasting methods using statistical techniques (*e.g.,* Canonical Correlation Analysis) as well as using coupled atmosphere-ocean general circulation models will be reviewed. Finally, the forecasting skill associated with various techniques will be assessed with particular reference to North America and Canada.

WOCE/OGL IV-BR

Chair: Dan Wright

Thursday, June 5 10:10-12:10 Room 206

4-B1.1 A Coupled Ocean General Circulation and Marine Foodweb Model of the Subarctic Pacific

Susan Haigh[1], *Ken L. Denman*[1], *and William W. Hsieh*[2] (speaker) ([1]Institute of Ocean Sciences, Sidney, BC, Canada; [2]Oceanography, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, BC, Canada)

As part of GLOBEC Canada (Global Ocean Ecosystems Dynamics), we are using MICOM (Miami Isopycnal Coordinate Model) to model the North Pacific Ocean and are coupling it to an ecosystem model. One goal of this project is to investigate how the structure and parameters of the physical model affect the biological components. The ecosystem model being implemented is a four component model (nitrogen, phytoplankton, zooplankton and detritus). Since an ecosystem model requires high resolution in the vertical near the ocean's surface, the splitting algorithms of Drange (1994) are used to divide the physical layers near the surface into several ecosystem sublayers. Various aspects of both the physical and ecosystem model are discussed and preliminary results are presented.

4-B1.2 The Influence of the Mean State on Interdecadal Variability in Flat-Bottomed Ocean Models

K.A. Peterson (speaker) *and R.J. Greatbatch* (Department of Physics and Physical Oceanography, St. John's, NF, Canada)

It has been well demonstrated that many flat-bottomed ocean models possess interdecadal oscillatory solutions. Recently, propagation of viscous Kelvin waves around the boundary has been implicated in the oscillations. In this talk, we examine how the mean state affects the character of the oscillation. We show that the stratification along the northern boundary has a large effect upon the oscillation. Mean states with an essentially unstratified north-east corner, lead to long period oscillations as the viscous boundary wave slowly crosses the northern boundary. Conversely, mean states with a stratified north-east corner, but unstratified north-west corner lead to short period, but larger amplitude oscillations since boundary wave propagation is arrested only in the north-west corner. We demonstate that the different character of oscillations under different zonal redistributions of a diagnosed flux are a consequence of the different mean states induced by the redistribution.

4-B1.3 North Atlantic Current Transport From Moored Array Measurements

R.M. Hendry[1] (speaker), *R.A. Clarke*[1], *and D.R. Watts*[2] ([1]Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, NS, Canada; [2]Graduate School of Oceanography, University of Rhode Island, Kingston, RI, USA)

An array of moored current meters was deployed across the path of the North Atlantic Current [NAC] near latitude 43 N during the period August 1993 to June 1995 to gauge the volume and heat transport of this northward extension of the Gulf Stream and of the southward flowing Deep Western Boundary Current [DWBC] and intermediate depth flows inshore of the NAC. This array was designated Atlantic Current Meter Mooring Array 6 [ACM6] in the World Ocean Circulation Experiment [WOCE] Science Plan, and formed part of a collaborative 1993-1995 Newfoundland Basin Experiment by the Bedford Institute of Oceanography and the University of Rhode Island. A preliminary estimate of the mean volume transport of the NAC and other

northward flowing currents crossing the moored array is 125 million cubic metres per second, but this includes a significant contribution from an anticyclonic recirculation cell offshore of the NAC that was not completely spanned by the moored array. Sea level measurements from the TOPEX/POSEIDON altimetric mission provide coverage of the Newfoundland Basin during this time period and should be helpful in interpreting the moored transport measurements.

4-B1.4 Sensitivity Experiments of the Influence of Sea Ice Distribution on Cyclone Behaviour

P. Gachon (speaker) *and P. Zwack* (Dep. des Sciences de la Terre, Université du Québec, Montréal, QU, Canada)

In northern regions, the distribution of seasonal sea ice cover changes strongly on the regional and interannual scale. This spatial variability in the sea ice cover modifies synoptic activity because of local heat sources when the sea is free of ice. Using the Canadian RCM (Regional Climate Model), developed at UQAM (Montréal), we study various scenarios of monthly sea ice distribution and the effects of variable surface conditions on the synoptic circulation, specifically in the Labrador sea and Hudson Bay. In these regions, we prescribe differents sea ice conditions in december in the RCM. One experiment run with "full" sea ice is compared to another experiment with the Hudson and Baffin Bay free of ice. The initial conditions in the two simulations are identical. The lateral boundary conditions are derive from 1xCO_2 Canadian GCMII simulation. We use also NMC (National Meteorological Center) analyses of the year 1988 for RCM initialisation. For the ice free condition versus full sea ice, cyclones are more intense and more permanent in this region. However, changes of theatmospheric circulation appear to be sensitive to the RCM grid size. In order to understanding the reasons of the differences, we apply a diagnostic package DIONYSOS, developed at UQAM, on the RCM model results. DIONYSOS diagnoses the effect of local heat source on the atmosphere, and calculates the direct influence of the sensible heat flux repartition (Laplacian of sensible heat flux) on the model tendencies. This upward sensible heat flux in open northern waters is of the order of 300-400 W m^{-2} and is as important as temperature advection and tourbillon advection in cyclone development. For certain cases, this diabatic forcing has a same order of amplitude as thermal or dynamic forcings, and induces cyclonicity and vertical movement in the region free of sea ice. Apart from this direct effect on the local cyclonic development, the sensible heat flux due to sea ice free can change the distribution of temperature and tourbillon advection in the lower part of the troposphere. These indirect effect are also important for evolution of cyclones in this region.

4-B1.5 The Interactions Between Sea Ice and the Thermohaline Circulation

Z. Wang (speaker) *and L.A. Mysak* (Department of Atmospheric and Oceanic Sciences, McGill University, Montréal, QU, Canada)

A thermodynamic sea ice model is coupled to a zonally averaged ocean model and an energy-moisture balance model [EMBM] of the atmosphere. The seasonal cycle is not included. In the sea ice model, the ice thickness and surface temperature are calculated by using energy budget equations. The variation of ice concentration is considered and predicted by the method used by Hibler (1981). Sea ice has a very strong insulating effect and the variation of ice concentration can significantly affect the heat exchange between ocean and atmosphere. First, we run the coupled sea ice-ocean model under the mixed boundary conditions. The prescribing of equivalent atmospheric temperature excludes the feedback from the atmosphere. For different restoring times for heat and different intensities of salt rejection, there exist chaotic, multi-periodic, periodic oscillations and steady state. The oscillations are of interannual or decadal time scale. In the upwelling region, there are no oscillations. These results show that the response of the model system is very sensitive to the heat flux and fresh water flux.

Using a time scale analysis, we find that only deep convection can match interannual or decadal time scales. Therefore, there exist strong interactions between sea ice and deep convection. The EMBM is then coupled to the sea ice-ocean model. Due to the feedback of atmosphere, all the oscillations disappear. When ice retreats, the ocean becomes cooler, which is a negative feedback for the variation of sea ice. But the atmosphere becomes warmer, and hence, the sea ice surface temperature increases, which is a positive feedback.

4-B2 Long-Range/Seasonal Forecasting - 1

Chair: Steve Lambert

Thursday, June 5 | 10:10-12:10 | Room 200

4-B2.1 ENSO Related Precipitation Responses Over Canada

A. Shabbar, B.R. Bonsal (speaker), *and M.L. Khandekar* (Atmospheric Environment Service, Environment Canada, Downsview, ON, Canada)

Precipitation responses over Canada associated with the two extreme phases of ENSO (El Niño and La Niña) are identified. Using the best available precipitation data from 1911 to 1994, both the spatial and temporal behaviour of the responses are analysed from the ENSO onset, to several seasons afterwards. Composite and correlation analyses indicate that precipitation over a large region of southern Canada extending from British Columbia, through the Prairies, and into the Great Lakes region is significantly influenced by the ENSO phenomenon. The results show a distinct pattern of negative (positive) precipitation anomalies in this region during the first winter following the onset of El Niño (La Niña) events. Two other smaller regions have significant precipitation responses only during El Niño events. They include positive anomalies over the northern Prairies and south-eastern Northwest Territories during the winter following the onset, and positive anomalies over southern British Columbia and western Alberta during the second spring following the onset. All of the significant precipitation anomalies can be explained by the associated upper atmospheric flow patterns which during the first winter following the onset of El Niño (La Niña) events, resemble the positive (negative) phase of the PNA pattern. Results also indicate a build-up of negative (positive) SOI values prior to the observed precipitation anomalies during the winter following the onset of El Niño (La Niña) events. This suggests the possibility of developing a long-range forecasting technique for Canadian precipitation based on the occurrence and evolution of the various phases of ENSO.

4-B2.2 Long-Range Forecasting at the Canadian Meteorological Centre

A. Plante[1], N. Gagnon[2], and L. Lefaivre[1] (speaker) ([1]CMC, Atmospheric Environment Centre, Dorval, QU, Canada; [2]Department of Atmospheric and Oceanic Sciences, McGill University, Montréal, QU, Canada)

The Canadian Meteorological Centre has been involved in long-range forecasts for many years. Over the last 2 years, considerable changes have been introduced to these products, which are now mostly deduced from numerical outputs. A brief description of the products will be presented, followed by verifications of the 10-day, 15-day and monthly forecasts. Verifications of seasonal forecasts have little significance yet, since they are only done four times a year. To obtain a statistical idea of the skill of forecasts at that time scale, a large effort has been invested to redo 15 years of seasonal forecasts, using the NCEP reanalyses (1979-1995). Preliminary verifications of those seasonal forecasts will be shown and skill presented as a function of time and space.

4-B2.3 Ensemble Prediction System Applications at the Canadian Meteorological Centre

A. Bergeron[1], P.L. Houtekamer[2], L. Lefaivre[1] (speaker), *and R. Verret[1]* ([1]CMC, Atmospheric Environment Centre, Dorval, QU, Canada; [2]Department of Atmospheric and Oceanic Sciences, McGill University, Montréal, QU, Canada)

An experimental ensemble cycle has been running in quasi-real time since January 1996 to produce an 8 member ensemble analyses. This cycle uses different sets of observations and is driven by different models. The observations are perturbed by the addition of random values, of the order of their observational errors. Driving models have either T63 or T95 resolution and use different convection schemes or different parameters of physics options. The 8 perturbed analyses and a control run (unperturbed observations and a "mean" driving model) produce 10

day forecasts every day from 00Z analyses. All the forecasts are produced using the same driving model as the one used in the assimilation cycle. The root mean square (RMS) scores at 500 hPa, performed against radiosondes both for the operational model and the ensemble mean, show that ensemble mean forecasts over Northern Hemisphere improve upon the operational model as early as day 3. Since the Summer of 1996, ensemble outputs have been used to feed the statistical package to forecast precipitations, winds and temperatures (max and min). Examples of variety of products will be shown. Verifications of ensemble forecasts will be presented with examples of the usefulness of the technique.

4-B2.4 A Phase Space Approach to Seasonal Prediction

R. Wang[1] *and G. Brunet*[1] (speakers), *R. Vautard*[2], *G. Plaut*[2], *and H. Van den Dool*[3]
([1]Recherche en Prevision Numerique [RPN], Service de l'Environnement Atmospherique, Dorval, QU, Canada; [2]Laboratoire de Meteorologie Dynamique, CNRS, Paris, France; [3]Climate Prediction Center, National Centers for Environmental Prediction, National Centers for Environmental Prediction [NWS/NOAA], Camp Springs, MD)

The atmospheric dynamics is typically a complex of regularity and randomness that unfolds on a broad spectrum of space-time scales; its predictability, defined in terms of the rate at which two initially close states diverge with time, changes with scales. The effectiveness of seasonal prediction based on empirical models depends crucially on whether the relevant components (with respect to space and time scales) to be used as predictors are suitably embedded into the prediction scheme and whether the relations between the predictors and predictands (which may not necessarily be linear) are properly reconstructed. The predictive skills can be derived either from the internal atmospheric dynamics, *i.e.,* the low frequency variability [LFV], or from the "external" forcing field, in particular, tropical SST associated with ENSO. For middle latitude atmosphere, the interplay between the two may be important, particularly when considering that the atmosphere responses differently to the SST forcing for different initial background states. It is argued in this study that the seasonal prediction should be considered as the estimate of the future predictand, such as the seasonal surface air temperature [SAT], under an observed forcing field [SST] and a specific current "background" state of the atmosphere. It is concluded that the leading space-time extended principal components [ST-PCs] of the predictand field (SAT), when the time window is much larger than three months, are able the provide the initial background information about the current state, and that the essential part of the variability relevant to seasonal scales can be embedded into a low dimensional phase space, allowing a nonlinear prediction of the seasonal climate which otherwise is difficult when using a standard analogue approach.

4-B2.5 Long-Range Forecasting for the Canadian Prairies: A Cost/Benefit Analysis

E. Ray Garnett[1] (speaker) *and Madhav L. Khandekar*[2] ([1]The Canadian Wheat Board, Weather & Crop Surveillance Department, Winnipeg, MB, Canada; [2]Atmospheric Environment Service, Downsview, ON, Canada)

The Canadian prairie provinces constitute one of the world's major agricultural regions, producing on an average 25 million tonnes of spring wheat per year. Interannual climatic variability contributes to large deviations in production and poses a threat to the agrosystem and rural livelihood. Availability of skillful Long-Range weather and crop forecasting over the Canadian prairies would be economically beneficial to Western Canadian agriculture including the input, marketing and transportation sectors. In this paper, a simple cost benefit analysis of the potential value of Long-Range forecasting for the marketing of prairie crops and the prairie economy in general is made. Further, the impact of the level of skill associated with long range-forecasting techniques is assessed in terms of its potential benefits to users such as the Wheat Board and to prairie agriculture in general. Several examples of the cost benefit analysis based on past data will be presented and discussed.

Session 4-B4

Hail - 1, presentations
Chair: Peter Summers

Thursday, June 5 10:10-12:10 Lecture Theatre 146

4-B4.1 Alberta Hail Research Retrospective - Part I, The Alberta Hail Studies Project 1957-1973

P.W. Summers (Richmond Hill, ON, Canada)

In response to increasing crop losses due to hail damage, farmers in central Alberta approached the government for funds to operate a commercial hail suppression program. Because of the scientific controversy and uncertainty surrounding the effectiveness of such a program the Alberta Research Council persuaded the Canadian Meteorological Service and the National Research Council to join them sponsoring a research project. The Stormy Weather Group at McGill University was asked to carry out a research program aimed at understanding the nature and behaviour of hailstorms with the eventual goal of providing a sound scientific basis for hail suppression. After some exploratory trials in the summer of 1956, a full observational field program began 40 years ago in the summer of 1957. From the outset the program relied heavily on the use of weather radar and on ground observations of hailfall characteristics provided by co-operating farmers. By combining these observations with time-lapse cloud photography, descriptive models of hailstorm growth and decay were developed. Project Hailstop was initiated in 1970 using a system of droppable pyrotechnic flares test the hypothesis of suppressing hail growth by seeding the newly formed Afeeder clouds". Evaluation of physical parameters was emphasized, rather than using statistical techniques. These tests continued for 4 years and laid the groundwork for the much larger program of both operational and research activities that followed. This paper will give a chronology of the project evolution indicating; the major participants; some of the scientific achievements, and finally some lessons learned.

4-B4.2 Alberta Hail Research Retrospective - Part II, The Alberta Hail Project 1974-1986

J.H. Renick (Alberta Severe Weather Management Society, Red Deer, AB, Canada)

Following the cloud seeding experiments of 1968-72, the farmers of central Alberta continued to pressure the provincial government to move more rapidly into hail suppression operations. In response, the Alberta Weather Modification Board was established in 1973 under the Minister of Agriculture with a five-year mandate to conduct both an operational and a research hail suppression program in central Alberta. While the operational program appeared forefront to many, research into storm genesis, radar storm microstructure and hailfall characteristics expanded the understanding of hailstorms, their mechanisms for hailstone growth, and provided the basis for evaluation of the cloud seeding effects. Crop damages during the period were lower than historical, but corroborating statistics and physical evidence was lacking. Crucial questions however, had now been formulated. The project was reorganized in 1980 under the Alberta Research Council with a new five-year mandate to continue the cloud seeding operations and carry out physical studies of storms. These studies combined observations from a cloud physics research aircraft with surface, radar and numerical modeling to clarify the links in the precipitation chain and how they might be modified. This paper will continue the chronology

began in Part I summarizing the various aspects of the program, the research results obtained, and finally, some more lessons learned.

4-B4.3 Characteristics of Radar Echoes From Hailstorms

(Invited paper, 30 min)

P.L. Smith[1] (speaker) *and L.R. Lemon*[2] ([1]South Dakota School of Mines and Technology, Rapid City, SD, USA; [2]Lockheed Martin Tactical Defense Systems, Independence, MO)

Developments leading to our current knowledge of the characteristics of radar echoes from hailstorms are reviewed, with particular reference to the contributions made by the Alberta Hail Project. Simple quantities like maximum echo height and maximum echo intensity, and "signatures" like the hook echo, were initially established as useful hail indicators, and remain important today. On the other hand some features ("hail fingers") once thought to be significant have disappeared from our liturgy. Further studies in Alberta and elsewhere established characteristic features such as the weak-echo vault, indicating the region of strong updraft containing only small hydrometeors, lines of "feeder clouds" flanking the main cell, and the echo overhang indicative of divergence in the upper part of the storm. The presence of high reflectivities aloft (to which the Soviet "accumulation zone" concept is related), high values of the "Vertically-Integrated Liquid Water content" [VIL], or "flare echoes" representing three-body scattering, were found to be useful hail indicators. Doppler radar observations allow characterization of storm kinematics and measurement of the divergence at storm top. Polarimetric measurements, a focus of the Alberta work, permit some inferences about storm microphysics. The way some of these characteristics are incorporated into the current NEXRAD hail algorithm is illustrated.

4-B4.4 Hail: An Insurance Industry Perspective

(Invited paper, 30 min)
D.M. (Don) McKay (Vice-President, Alberta Severe Weather, Calgary, AB, Canada)

Last June (1996), the insurance industry in Alberta started an urban hail suppression program in the Calgary-Red Deer region of the province. This presentation will discuss the history, changes and work within the insurance industry that brought about the establishment of the Alberta Severe Weather Management Society and the re-creation of a hail suppression program in Alberta.

4-B4.5 The New Alberta Hail Suppression Project

T.W. Krauss[1] (speaker) *and J. Renick*[2] ([1]Weather Modification Inc., Red Deer, AB, Canada; [2]Alberta Severe Weather Management Society, Red Deer, AB, Canada)

A new hail suppression project was started in Alberta in 1996. Weather Modification Inc. [WMI] of Fargo, North Dakota was awarded a five year contract by the Alberta Severe Weather Management Society [ASWMS] of Calgary, Alberta to conduct cloud seeding to reduce urban property damage from hail, particularly for the Calgary and Red Deer areas. The operational program runs from June 15th to September 15th each year for five years. This project is rather unique because it is funded entirely by private insurance companies with the sole intent to mitigate the damage to property by hail storms. The seeding program is based upon the hailstorm conceptual model, seeding methods, and storm forecasting techniques of the previous long-term hail research project conducted by the Alberta Research Council from the late 1960's through 1985.

In 1996, a C-band weather radar with computer recording and communications systems and three cloud seeding aircraft were dedicated to the project. The aircraft and radar crews provided 24 hr coverage, seven days a week throughout the period. Sixty-five cloud seeding flights took place on thirty storm days. The total number of silver-iodide flares dispensed was 3817 ejectables (76.3 kg AgI) and 542 end-burners (81.3 kg AgI). A total of 80.42 gallons of AgI-acetone solution was dispensed (5.5 kg AgI). The 10 most active days were July 3, 4, 9, 15, 16, 24, 26 and August 6, 15 and 17. Hail was reported within the project area on 22 days. Walnut or larger sized hail was observed on 5 days. Severe storms struck the city of Calgary on July 16 and 24.

The program has rekindled much interest in cloud seeding and received considerable positive public and media attention, including numerous newspaper stories, local television coverage, National CTV news coverage, as well as a special Discovery Channel TV program. The ASWMS will asses the benefits of the project using insurance information. Future physical assessments will be conducted primarily using radar data.

Session 4-C1

Middle Atmosphere: Dynamics, Chemistry, and Middle Atmosphere Modelling - 1

Chair: Alan Manson

Thursday, June 5 13:40-15:00 Room 206

4-C1.1 Improving Stratospheric Circulations with a Hybrid Vertical Coordinate Version of the Canadian Global Spectral Forecast Model

Harold Ritchie (speaker) *and Nils R. Ek* (Recherche en Prevision Numerique, Dorval, QU, Canada)

The current operational version of the Canadian global spectral forecast model uses a conventional sigma vertical coordinate on a regular (unstaggered) grid. Presently the representation of the stratosphere is rather coarse, with the uppermost model sigma levels being .010, .045, .090., .140, .190. The forecast range for this global system has recently been increased to monthly and seasonal scales, and work is in progress to also do stratospheric data assimilation and prediction. For this purpose, modifications have been made to introduce a hybrid vertical coordinate and to raise the model top to approximately the stratopause with an associated increase in the number of vertical levels. In the new hybrid version all linear (semi-implicit) vertical operators keep the same form as in the sigma version. Here we present results for a series of experiments that have been performed to assess the incremental impact of the sequence of steps in improving the model. Various versions have been compared using five day forecasts for eight test cases that span the seasons of the year. In all cases the horizontal spectral representation uses a triangular truncation at 199 waves. Our control model corresponds to the operational model with its 21 sigma levels and a three-time-level semi-Lagrangian scheme using a 30-minute time-step. A second version has 27 sigma levels with a finer stratospheric resolution and a top at 0.05, the third one uses additionally the hybrid coordinate, and the fourth version takes advantage of a two-time-level formulation with a 60-minute time step, described in a companion (Ritchie and Beaudoin). We compare the root-mean-square temperature errors of the forecasts with respect to radiosonde observations. In progressing from one version to the next, we note an improvement, particularly in the stratosphere, with the total impact from the control to the fourth version being very significant. We are currently diagnosing the quality of our physical parameterizations in the stratosphere to see if further improvements are possible.

4-C1.2 Diagnostic Study of a Stratospheric Sudden Warming During the Winter of 1994/95

Hua Sheng (speaker) *and Harold Ritchie* (Recherche en Prevision Numerique/Atmospheric Environment Service, Dorval, QU, Canada)

The two stratospheric sudden warming occurred in the 1994/1995 northern hemisphere winter. Inspecting the development in time and space of the planetary height (10MB) wave 1 and 2, the first anomalous amplification of height wave 1 took place at the late December and early January during the minor warming. The second anomalous amplification of height wave 1 occurred at the middle of January, concurrently with a minimum of height wave 2, which is precursor of major warming (late January). Terms in the transformed Eulerian equation are computed for the stratospheric during the winter, together with cross section showing Eliassen-Palm [EP] flux and divergence, and residual mean meridional circulation with total dynamical temperature tendency. The intense convergence of EP flux which embodies the wave forcing on the mean flow bring about intense deceleration of the mean zonal wind and a poleward and downward residual mean meridional flow in the stratosphere, leading to sudden warming. The zero wind line is of key interesting and like the wall of wave propagation. During the warming, the maximum of refractive index which are located at high latitude and polar stratosphere guide the planetary wave poleward from stratosphere at low latitude and upperward from troposphere. The maps of potential vorticity [IPV] on the isentropic surface of

850K are presented. During the stratospheric sudden warming, a long tongue of high IPV air have been polled out from the main vortex, mixed quasi-horizontally and irreversibly into the surrounding region of weaker gradient, and formed a gigantic surf zone, in some part of which the planetary wave are breaking. The smallest area of main vortex is the precondition of the major warming.

4-C1.3 Momentum Flux Measurements With a VHF Windprofiler Radar In Eastern Canada

R. Belu (speaker) *and W.K. Hocking* (Department of Physics and Astronomy, University of Western Ontario, London, ON, Canada)

Gravity waves generated by various sources, especially in the troposphere, can transport significant momentum and energy into the upper atmosphere. Windprofiler radars offer excellent capabilities in measurement of these fluxes close to their source. We have been using the CLOVAR (Canadian London, Ontario VHF Atmospheric Radar) instrument to measure these fluxes in southern Ontario. Our radar works at a frequency of 40.68 MHz, and has a peak power of 10 kW. It is situated in flat terrain. We have been using several methods to make our measurements, all involving tilted radar beams, and have been collecting data for over a full year. In this presentation, we will discuss our techniques, intercompare several different methods, and finally show our results. Seasonal variations as well as results obtained under different meteorological conditions will be presented. The relevance of our data to middle atmosphere models and studies will be presented. This work is supported in part by the Institute for Space and Terrestrial Science of Ontario.

4-C1.4 Discussion Period

Session 4-C2 Long-Range/Seasonal Forecasting - 2

Chair: Steve Lambert

Thursday, June 5 13:40-15:00 Room 200

4-C2.1 Construction of a 3-D State Space for the ENSO System Using Neural Networks and Ensemble Forecasting with Neural Networks

Benyang Tang and William W. Hsieh (speaker) (Oceanography, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, BC, Canada)

In this study, we used neural networks to extract three variables important to the evolution of the ENSO system. The input of the neural network were the first 10 extended EOF of the tropical Pacific wind stress, and the output were the same variables one month later. The neural network had three hidden units, each feeding one activation value to the output layer. After training the neural network with the wind stress EEOF, we obtained a transformation from the network input to the three activation values of the hidden units. By tracing the trajectory of the three activation values in a 3-D space, we identified a subspace for warm events, and a subspace for cold events. All warm events (or all cold events) followed a similar trajectory of development, and precursor subspaces were identified. We have also developed ensemble models with neural networks. The ensemble models improve the stability of the our previous neural network models. The ensemble models were applied to the prediction of the North Pacific Ocean SST, to be issued on our web site and in the NOAA Long-Lead Forecast Bulletin.

4-C2.2 Forecasting Tropical Pacific Sea Surface Temperatures with Neural Network Models

Fredolin T. Tangang, William W. Hsieh (speaker), *Benyang Tang, and Adam H. Monahan* (Oceanography, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, BC, Canada)

Using neural network models, we compared the wind stress and the sea level pressure [SLP] EOFs as predictors for the sea surface temperature anomalies [SSTA] in various regions of the tropical Pacific. While at short lead times, the wind stress tended to be the better predictor, at long lead times of 6 months and beyond, the SLP came out superior. We then used the SLP Extended EOFs [EEOF] (instead of the EOFs) as predictors, which resulted in a drastic reduction in the size of the network. By network pruning and spectral analysis, we identified four important inputs: modes 1, 2 and 6 of the SLP EEOFs and the SSTA persistence. Mode 1 characterized the low frequency oscillation (LFO, with 4-5 years period), while mode 2 characterized the quasi-biennial oscillation [QBO] plus the LFO. Mode 6 was dominated by decadal and interdecadal variations. The nonlinearity of the networks tended to increase with lead time, and to become stronger for the eastern regions of the equatorial Pacific Ocean.

4-C2.3 Results from the Historical Forecasting Project

A. Plante[1] (speaker), *N. Gagnon*[2], *and L. Lefaivre*[1] ([1]CMC, Atmospheric Environment Centre, Dorval, QU, Canada; [2]Department of Atmospheric and Oceanic Sciences, McGill University, Montréal, QU, Canada)

Recently, a number of seasonal simulations has been initiated with the SEF and GCMII models. This project, the Historical Forecasting Project [HFP], is a joint effort of Canadian Meteorological Centre [CMC], Canadian Center for Climate Modelling and Analysis [CCCMA], Recherche en prevision numerique [RPN] and McGill university. The goal of this project is to evaluate the skill of the models to predict the atmospheric seasonal mean properties. Also, it will provide a validation of the CMC seasonal forecast operational setup. The models are run for 3 months, corresponding to the CMC seasonal forecast season (December-January-February, March-April-May, June-July-August and September-October-November). For each season, 2 ensembles of 6 members are produced with the models. The members differ by their atmospheric initial

conditions, which are taken from the National Centers for Environmental Prediction [NCEP] reanalysis data 6 hours apart. The forcing of the experiment comes from the sea surface temperature [SST] field, the sea ice extent [ICE] and the snow line [SNOW]. The SST initial anomaly, calculated with the Global sea Ice and Sea Surface Temperature [GISST] dataset is persisted throughout the 3 month integrations. The ICE field is set to the climatological value. The snow line is a mix of climatology (southern hemisphere) and of NCEP observations (northern hemisphere). The simulated seasonal fields are compared with the NCEP reanalysis seasonal data. Results for the northern winter indicate that, the case for major ENSO events the models give good anomaly correlation (geopotential height at 500 hPa). The models give different responses to the same forcing, which reinforces the idea of using 2 models to produce the seasonal forecast. Results for the winter, as well as for the other seasons, will be presented and commented.

4-C2.4 The Genesis of the PNA Pattern and its Predictability in a Simple Model

Hai Lin (speaker), *Jacques Derome, and Charles A. Lin* (Department of Atmospheric & Oceanic Sciences and Centre for Climate and Global Change Research, McGill University, Montréal, QU, Canada)

The setup process of the Pacific/North American [PNA] pattern and the role played by synoptic-scale transients are investigated using a T21 three-level quasi-geostrophic model. The low-frequency PNA anomalies are related only to the atmospheric internal dynamics. From a 300-winter integration, 100 cases of positive PNA and 118 cases of negative PNA lasting at least 10 days are identified. The PNA composites reveal that 5 days before the setup of a positive (negative) PNA there is a negative (positive) height anomaly over Canada. This anomaly moves westward and stops over the North Pacific. It then intensifies and a wave train develops downstream. To assess the contribution from the instability of the mean flow, the linear version of the model is used. With the 300-winter climatology as its basic state and the height anomaly at day -5 as the initial perturbation, the linear model is able to simulate the setup process of both positive and negative PNAs. The amplitudes of the anomaly centres after 5 days integration are only about one third of those in the nonlinear model. This suggests that the instability of the mean flow is important in determining the position of the PNA anomalies, while the feedback from transient activity appears to amplify the anomalies. The role of the synoptic-scale transients is further explored through prediction experiments that either include or exclude the synoptic-scale transients in the initial conditions.

Session 4-C4

Hail - 2, presentations

Chair: Peter Summers

Thursday, June 5 13:40-15:00 Lecture Theatre 146

4-C4.1 The Greek National Hail Suppression Program Revisited

C.M. Sackiw (EC/DOE/AES/CFWS/CFFC CFB Trenton, previously with INTERA Technologies Ltd.)

Established in 1984, the Greek National Hail Suppression Project had two main objectives. These were to reduce crop damage in in northern Greece from hail and to evaluate the program through a randomized cross-over experiment. The project areas consisted of three agriculturally sensitive areas: Emathia-Pella (Area 1), Serrae-Drama (Area 2) and Karditsa-Larisa

(Area 3). Each area had a weather radar to provide coverage for cloud seeding operations. Five aircraft equipped for cloud top and cloud base seeding conducted the seeding operations. A hailpad network within Area 1 provided an objective means to determine hailfall. This area was subdivided into a northern and a southern portion based on climatological storm motion. The hailpad data base was collected from 1984 to 1988 inclusive. Statistical results of this five year period indicate a significant reduction in hailfall in the target versus the control areas. A summary of these results will be presented.

4-C4.2 Hail Measurement Re-Visited

G.S. Strong (Atmospheric Environment Service, Saskatoon, SK, Canada)

The measurement of hailfall during the Alberta Hail Studies [ALHAS] and Alberta Hail Project [ALHAP] programs is re-visited, including subjective estimates from the farming community, and particularly the use of and degree of success with simple "hailpads". Hailpads provided the first and probably only view of the surprising degree of oranization of hailfall on the ground. The theory and calibration behind these simple but effective sensors is reviewed, together with verification data. Areal hailfall analyses from networks of hailpads at horizontal spacings of 1-5 km are reviewed. Some little-known hailfall parameters available from hailpads, including wind direction and speed, are also discussed.

4-C4.3 Overview of Some Feeder-cloud Transport and Dispersion Experiments Using a Gaseous Tracer and Radar Chaff

P.L. Smith[1] (speaker), *T.E. Bowen*[1], *A.G. Detwiler*[1], *and J.L. Stith*[2] ([1]South Dakota School of Mines and Technology, Rapid City, SD, USA; [2]University of North Dakota, Grand Forks, ND, USA)

Studies of in-cloud transport and dispersion processes have been carried out using two tracer techniques. One involves the release of gaseous SF6 from an aircraft at selected points in or near a cloud and sampling passes through the cloud by other aircraft equipped with fast-response SF6 analysers. The other involves release of radar chaff in similar (often coincident) locations, and observations with a radar that uses circular polarization to distinguish between chaff and precipitation echoes. This paper analyses a group of such experiments conducted on thunderstorm feeder clouds in the summers of 1989 and 1993. A total of 22 experiments involved tracer releases at mid-levels in feeder clouds associated with nearby mature thunderstorms. Half of the cases involved chaff and SF6 together, and the remainder had SF6 only. The experimental objective was to investigate dispersion through the upper part of the feeder cell and possible transport from it to the adjacent mature cell. The former was observed in many of the cases, but on only a few occasions was evidence found of transport to the mature cell. Experimental difficulties may be a factor here, but these results also raise questions about the importance of such inter-cell transport processes within multi-cell storms.

4-C4.4 Polarization Radar Study of Chaff in an Alberta Hailstorm

P.I. Joe[1] (speaker), *A. Holt*[2], *and B. Kochtubajda*[3] ([1]Cloud Physics Research Division, Atmospheric Environment Service, Downsview, ON, Canada; [2]Department of Mathematics, University of Essex, Colchester, UK; [3] Atmospheric Environment Service, Edmonton, AB, Canada)

Chaff consists of foil strips and is a highly reflective and polarizing material. During the Alberta Hail Project, chaff was used experimentally to examine the air flow through hail storms. On Aug 3, 1983, following an aborted seeding experiment, chaff was released into the centre at low levels of a mature hail storm. The ARC S Band polarization radar collected three minute volume scans on this storm. The polarization radar data showed that chaff was initially carried upwards to the storm top and downwind. Subsequently, as the chaff dispersed within the storm, some of it was caught in the rear flank downdraft of the storm and was carried to the

back of the storm and eventually wrapping around to the southern edge. The polarization radar view of the chaff signatures can be used to infer the three dimensional internal storm motions with consequences for seeding scenarios. The study also shows the high quality of the ARCS Band polarization radar for meteorological studies.

Session 4-D1

Middle Atmosphere: Dynamics, Chemistry, and Middle Atmosphere Modelling - 2

Chair: Alan Manson

Thursday, June 5 15:20-17:00 Room 206

4-D1.1 The Development of the Canadian Middle Atmosphere Model: A Status Report

S.R. Beagley[1], *J. de Grandpre*[1], *J.N. Koshyk*[2], *N.A. McFarlane*[3], *and T.G. Shepherd*[2] (speaker) ([1]Department of Earth & Atmospheric Science, York University, North York, ON, Canada; [2]Department of Physics, University of Toronto, Toronto, ON, Canada; [3]CCCMA, Atmospheric Environment Service, University of Victoria, Victoria, BC, Canada)

The Canadian Middle Atmosphere Model [CMAM] is a comprehensive general circulation model of the troposphere-stratosphere-mesosphere system, including a prognostic representation of middle atmosphere chemistry. The CMAM has been under development for about four years. Latest progress with the CMAM will be presented, reporting on its radiative-dynamical climate, and emphasizing new developments over the past year. The CMAM has recently been run in several formulations using varied forcing conditions including the use of developing gravity wave drag parameterization schemes. Results will be presented on these simulations as part of an overview of the latest state of the model.

4-D1.2 Transport and Chemistry of Constituents in the Middle Atmosphere Using CMAM

Jean de Grandpre (speaker), *J.C. McConnell, S.R. Beagley, and P.C. Croteau* (Department of Earth & Atmospheric Science, York University, North York, ON, Canada)

The Canadian Middle Atmosphere Model (0-95 km) has been used to investigate the annual variability of chemical constituents in the Middle Atmosphere and lower thermosphere. Several years of integration with an on-line chemical module have been performed to obtain and analyse a climatology of the distribution and variability of ozone and several long lived species such as H_2O, CH_4 and CO. The chemistry module includes a relatively complete set of constituents to solve ozone photo-chemistry including odd-hydrogen, nitrogen, chlorine, bromine families and methane related species. Some comparisons of model results with ground based and satellite observations will be presented to illustrate the model capability to represent middle atmosphere photochemistry throughout the disparate conditions of the stratosphere, mesosphere, and lower thermosphere regions. This chemistry package forms the basis of a comprehensive gas phase and heterogeneous chemistry package to be used in an interactive mode in CMAM.

4-D1.3 Impact of the Doppler Spread Gravity Wave Drag Parameterization on the Middle Atmosphere of A General Circulation Model: Effects on the Zonal Mean Flow and Tides

C. McLandress[1], *N. McFarlane*[2] (speaker), *and S. Beagley*[3] ([1]Department of Atmospheric Sciences, University of Washington, Seattle, Washington, USA; [2]Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada; [3]Dept of Earth and Atmospheric Science, York University, North York, ON, Canada)

The parameterization of vertically propagating gravity waves is one of the most difficult and important problems facing middle atmosphere modelling. Over the past few years several gravity wave drag parameterizations have been developed which treat the gravity waves as a continuous and interacting spectrum. One of these, the Doppler spread parameterization [DSP] of Hines (1997), has recently been implemented in the Canadian Middle Atmosphere Model, a fully 3-dimensional general circulation model that extends from the ground to 96 km. Results are presented of two simulations, one using the DSP and one without. The distinctive features of the simulation with the parameterized gravity wave drag are the reversal of the mesospheric zonal mean winds and the enhancement of the semi-annual oscillation in the zonal mean winds in the tropics. The structure of the migrating diurnal tide is also compared. The tidal amplitudes of both simulations exhibit a strong seasonal variation with amplitude maxima occurring at the equinoxes. This is in qualitative agreement with observations from the Upper Atmosphere Research Satellite [UARS], which show a strong semiannual oscillation in the diurnal tide amplitudes.

4-D1.4 Gravity Wave Spectra, Direction Statistics and Wave Interactions as Observed by MF Radars in Canada and the Global MLT Network

A.H. Manson (speaker) *and C.E. Meek* (ISAS, University of Saskatchewen, Saskatoon, SK, Canada)

Observations of winds and gravity waves [GW] by MF radars in Canada and those part of the global mesosphere-lower thermosphere [MLT] network, are used to provide frequency spectra, information on azimuthal directions of propagation and wave interactions (planetary, tidal) of the GW. The variations of the monthly spectra show strong universality of slope throughout the year at all locations, with slopes near -5/3 at upper heights in winter months, but increasingly smaller slopes at higher frequencies (periods less than 2 hrs.) in summer months. At lower heights smaller slopes are observed. Spectral variances and propagation directions for bands (10-100min, 1.5-6 hrs.) show distinctive changes with season, latitude and location, consistent with changes of background zonal winds and gravity wave sources. Strong evidence for Doppler shifting is presented. Modulation of GW by the tides and PW is a complex process, and the nature of these modulations are studied by statistical and case-study methods.

Session 4-D4

Hail - 3, presentations and discussion

Chair: Peter Summers

Thursday, June 5 | 15:20-17:00 | Lecture Theatre 146

4-D1.5 Discussion Period

4-D4.1 The Alberta Hail Project Digital Data Archive: One Year on the World Wide Web

B. *Kochtubajda*[1] (speaker), *C. Humphrey*[2], *E.P. Lozowski*[3], *and M.R. Johnson*[4] ([1]Environment Canada, Edmonton, AB, Canada; [2]University of Alberta, Data Library, Edmonton, AB, Canada; [3]University of Alberta, Earth and Atmospheric Sciences Department, Edmonton, AB, Canada; [4]InfoHarvest Inc., Edmonton, AB, Canada)

The Alberta Hail Studies Project was established to study hailstorm physics and dynamics and to design and test means for suppressing hail. During its 30-year existence, an extensive archive of data was collected to conduct research into precipitation mechanisms, severe storm development, hail suppression, hydrology, and microwave propagation.

A documented digital archive of radar, aircraft, upper-air, and surface precipitation data along with supporting calibrations and documentation was preserved on a series of 62 compact disks. A set of World Wide Web pages was developed and made available on the Internet in late 1995. The archive can be accessed through network services provided by the Data Library (University of Alberta) by opening the URL: http://datalib.library.ualberta.ca/AHParchive/

Data can be accessed in one of three ways. Researchers can obtain hail and rain files directly from an anonymous file transfer protocol [FTP] site. For selected case studies, the set of hourly aircraft files or the daily radar directory can be transferred from the CD library and made available on the anonymous FTP site for subsequent retrieval. Requests for larger amounts of data are shipped to the researcher on customized CDs. User access patterns and an update on the status of the archive will be presented.

4-D4.2 Hailstorm Forecasting Re-Visited

G.S. Strong (Atmospheric Environment Service, Saskatoon, SK, Canada)

The success of predicting hail/no-hail, hail size, and "where and when" storms would form over Alberta Hail Project [ALHAP] operations area during 1976-85 is reviewed. The development of an objective and very successful predictive index called the Synoptic Index of Convection is discussed. ALHAP forecasting during this period is reviewed and evaluated, including the use of synoptic scale patterns and data, versus traditional instability parameters. The success of using the Synoptic Index in other areas, including integration with artificial intelligence systems, is also discussed.

4-D4.3 Hail Damaged Shingles

R. Charlton (speaker) *and B. Kachman* (Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB, Canada)

Shingle damage caused by Alberta hailstorms was the primary factor in several phenomenal homeowner-insurance losses: approximately $60 million from the hail accompanying the 1987 Edmonton tornado and, in Calgary, $200 million in September 1991 and another $100 million in July 1996. Weathering reduces the ability of asphalt shingles to withstand the impacts of hailstones. Engineering studies suggest that new shingles are fractured by 5.1 cm (2 inch) spherical hailstones, and within 10 years, 3.5 cm (1.25 to 1.5 inch) spheres will cause fracturing. At 15 years, 1.9 cm (0.75 inch) will suffice. For equal kinetic energy these three sizes were adjusted to account for the average shape of large hailstones determined during the Alberta Hail Project, the shapes of near record-sized stones collected after the Edmonton tornado, and the higher fall velocities at Edmonton's altitude. Thereby, it was determined that the three sizes represent real hailstones with maximum dimensions of 6.4 cm (actual tennis balls), 4.4 cm (actual golfballs), and 2.3 cm (small walnuts), respectively. Our studies of reshinglings in Edmonton suggest that shingles retain their resilience for approximately their first five years, and that beyond 15 years, they may tolerate the impacts of walnut sized stones. For Edmonton's three airports, hail days averaged 2.0 per year during the 1980s and 1990s. Calgary's airport had more hail days. The relative frequencies of occurrence of the various hail-size categories in central Alberta were determined from 47,000 farmer reports made during the Alberta Hail Project. The foregoing sources suggest that the average lifetime of asphalt shingles exposed to Edmonton hailstorms is 14 years. If old shingles could resist fracturing by golfball sized hailstones, the expected life would rise to 27 years and, by inference, the insurance losses would fall in half. Calgary, with 4.1 hail days per year, has an average shingle lifetime of 11 years and, with improved "golfball" shingles, the lifetime would be 17 years.

4-D4.4 The Episodic Occurrence of Hail in Central Alberta

Gerhard Reuter[1] (speaker), *and Stephan Smith*[2] ([1]University of Alberta, Edmonton, AB, Canada; [2]TDL, National Weather Service, Silver Spring, Maryland, USA)

The frequency and duration of hail day episodes were analyzed based on 29 summers of hail data. A hail episode consists of one or more consecutive days with at least one hail report. A severe hail episode is defined as an episode that has at least one day of severe hail. Severe and non-severe hail episodes are found to occur on average 4.2 and 13.7 times, with mean durations of 4.6 and 2.4 days.

4-D4.5 The Edmonton Tornado...Ten Years After

G. Vickers (speaker) *and S. Ricketts* (Environment Canada, Edmonton, AB, Canada)

On July 31, 1987, a severe tornado ripped through Edmonton, killing 27 people and causing $250M in damage. This disaster created a lot of attention and spawned a total review of Environment Canada's weather warning procedures and disaster planning in the city.

Ten years later, it is timely to look back to see what has been learned from this event. While the likelihood of another tornado hitting Edmonton - or any other major metropolitan area in the Prairies - is small, it is not zero. Significant strides have been taken, through a combination of technology and people, in order to minimize the impact of another tornado.

Improved satellite imagery and a Doppler weather radar system have improved our ability to detect and track tornado-producing storms. A network of volunteer weather watchers has been set up to alert us to the touch-down of tornadoes. We have developed software systems to enable us to evaluate the potential of storms, and then to produce and transmit weather warnings very efficiently. Finally, there is a Emergency Public Warning System [EPWS] that allows forecasters to cut into the programming of all Edmonton-area media and directly broadcast warnings. We have worked with the media to increase public awareness of these threats, and what to do should something happen.

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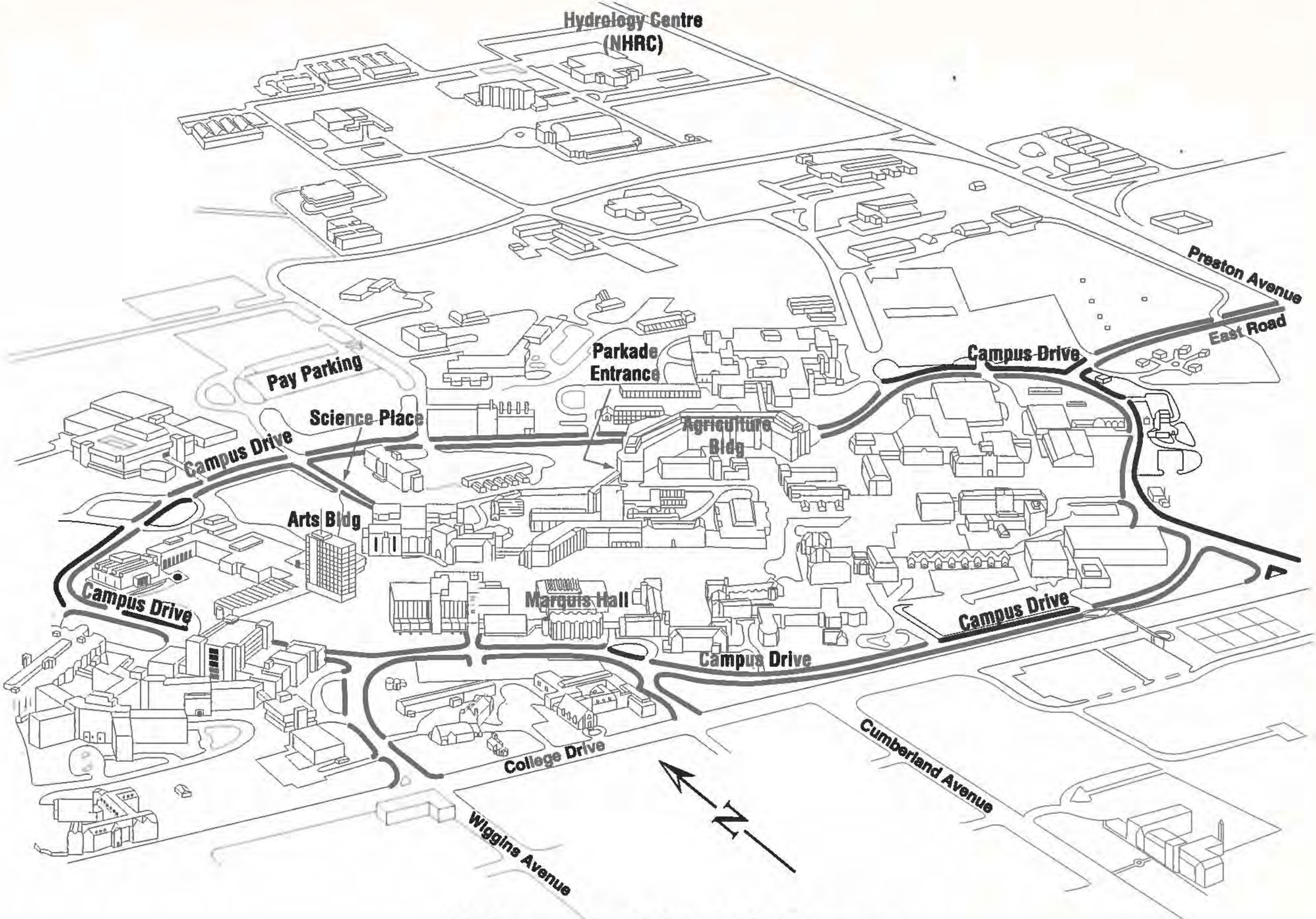
Index of Authors
Index des Auteurs



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