Proceedings of the 2\textsuperscript{nd} Scientific Workshop for the Mackenzie GEWEX Study (MAGS)

held at the National Hydrology Research Centre
Saskatoon, Saskatchewan
23-26 March, 1997

Attendees at the 2\textsuperscript{nd} GEWEX/MAGS Workshop, Saskatoon, 23-26 March, 1997
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Technical Editors:
G.S. Strong and C. Hrynkiw
Atmospheric Environment Service
11 Innovation Boulevard
Saskatoon, Sask., Canada  S7N 3H5

Address e-mail correspondence to: Geoff.Strong@ec.gc.ca

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GEWEX/MAGS Web Site:

These proceedings are also available on the MAGS web site at:
http://www.tor.ec.gc.ca/GEWEX/MAGS.html
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Participants in the 2\textsuperscript{nd} GEWEX/MAGS Workshop, Saskatoon, Saskatchewan, 23-25 March, 1997

\textbf{Left-to-right:} Anthony Maxfield (NHRI), Ron Hopkinson (EC), Alan Barr (AES), John Pomeroy (NHRI), Peter Schuepp (McGill Univ.), Geoff Kite (NHRI), Rob Nissen (AES), Chris Spence (EC), John Gibson (NHRI), Terry Prowse (NHRI), Jean Stein (U of Quebec), Aldo Bellon (McGill Univ.), Ian McPherson (McGill Univ.), Joe Eley (AES), Ken Snelgrove (U of Waterloo), Raoul Granger (NHRI), Ron Stewart (AES), Phil Marsh (NHRI), Bob Kotchubajda (AES), Frank Seglenieks (U of Waterloo), Peter Taylor (York Univ.), Peter Yau (McGill Univ.), Uwe Haberlandt (NHRI), Muyin Wang (Dalhousie Univ.), Henry Leighton (McGill Univ.), Maryse Beauchemin (CMC), Hal Ritchie (RPN), Louis Garand (AES), Brian Proctor (AES), Richard Petrone (McMaster Univ.), Al Pietroniro (NHRI), Stan Shewchuk (Sask. Research Council), Ric Soulis (U of Waterloo), Geoff Strong (AES)
OBJECTIVES of MAGS:

The Mackenzie GEWEX Study (MAGS) is a major Canadian contribution to the global Energy and Water Cycle Experiment (GEWEX). MAGS is a comprehensive study of the hydrologic cycle and energy fluxes of the Mackenzie River Basin. The Mackenzie River is the largest North American source of fresh water for the Arctic Ocean, and this region has experienced one of the most pronounced warming trends in the world over the last few decades. An improved understanding of the this climate system will contribute significantly to coupled atmospheric-hydrologic-land surface models capable of predicting the climate for many decades into the future. The objectives of MAGS are therefore to:

1) quantify the hydrologic cycle and energy fluxes of the Mackenzie Basin;
2) accurately model the hydrological cycle and its impact on the atmosphere, land surface, and the oceans;
3) develop abilities to predict climate change-induced variations in hydrological processes and water resources;
4) foster development of observational and data management systems that allow us to monitor such changes.

OBJECTIVES of WORKSHOP #2:

One approach being used to realize our objectives is to conduct regular workshops in order to bring together most of the principal investigators and other participants to review research progress, and to review and revise as necessary future research plans for the Mackenzie basin. The first workshop was held in Toronto in November, 1995. The objectives of this second workshop held in Saskatoon in March, 1997 are:

1) to review progress on MAGS process research results of the past year in terms of overall MAGS objectives;
2) review progress on hydrologic and atmospheric modeling results of the past year in terms of overall MAGS objectives;
3) identify any gaps in our Science and Implementation Plan;
4) identify any gaps in data necessary to 1 - 3;
5) to modify MAGS (CAGES) data collection plans according to 3 and 4.

Most of the participants in this workshop are shown and identified in the photograph on the adjacent page. These proceedings contain the extended abstracts for this second workshop, summaries of the sessions, and statements from the working groups.
1. AGENDA

Mackenzie Basin GEWEX Study (MAGS)

2nd Annual Workshop -- 23-26 March, 1997

Seminar Room
National Hydrology Research Centre
11 Innovation Boulevard, Saskatoon, Sask.

A. Introduction:

0.1 MAGS Observational Strategy – Strong/Kochtubajda

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B. MAGS Reports:

1. Climatology of the Mackenzie Basin:  (Chair: Barry Goodison)
   1.1 Improved precipitation measurement methodologies – Louie (presented by Goodison)
   1.2 MAGS precipitation patterns – Proctor
   1.3 Surface moisture, evaluation of precipitation modeling – Hogg (presented by Hopkinson)
   1.4 Variability of Precipitation in major northward flowing rivers – Cho

2. Atmospheric Moisture (and Energy) Budget Studies:  (Chair: Kent Moore)
   2.1 Surface-Atmosphere Energy Exchange – Schuepp
   2.2 Moisture Budgets:  Model validation, sources & sinks – Strong/Wang
   2.3 Cyclones and role in high latitude vapour transport (a) –  Gyakum

3. Land Surface Process Studies:  (Chair: Phil Marsh)
   3.1 MAGS Evaporation – Rouse (presented by Marsh/Petrone)
   3.2 Snow Cover Development, Ablation in Boreal/Tundra Ecosystems – Pomeroy
   3.3 Hydrologic processes in cold regions – Gray (presented by Pomeroy)
   3.4 Water and energy fluxes during snowmelt period – Marsh
   3.5 Effects of frost & permafrost on MAGS hydrology – Woo (presented by Marsh)
   3.6 Surface radiation budgets in the Mackenzie Basin – Leighton
   3.7 Isotopic Tracing of Water Balance in the Mackenzie - Prowse

4. Remote Sensing Studies:  (Chair: Henry Leighton)
   4.1 AVHRR-Based clear-sky Evapotranspiration for the Mackenzie Basin – Bussieres
   4.2 Clouds, radiation, and humidity from satellite observations – Garand
   4.3 Cryospheric elements from passive microwave satellite data – Walker
   4.4 Snowmelt in northern watersheds from radar satellite – Maxfield
   4.5 Radar & aircraft observations – Hudak
   4.6 Satellite rainfall estimates – Zawadski (presented by Bellon)
4.7 Cloud profiling from IPIX radar – Haykin (presented by Pasika)
4.8 Parameterization of evapotranspiration using remotely sensed data – Granger

5a. Modelling Studies (Hydrologic): (Chair: Ric Soulis)
5.1 Simulation of mainstream and delta systems – Kerr (presented by Spence)
5.2 Integrated hydrologic modelling – Soulis (presented by Seglenieks)
5.3 Part 1: Development of a distributed hydrological model – Kite
   Part 2: Using TOPEX/POSEIDON data to estimate elev. and areas of lakes – Kite
5.4 Application of GRU hydrologic model in discontinuous permafrost – Pietroniro

5b. Modelling Studies (Atmospheric): (Chair: Hal Ritchie)
5.5 Climate Modeling over the Mackenzie Basin, and Cloud Fields – Stewart
5.6 Global NWP system for MAGS – Ritchie
5.7 High resolution simulations of MAGS mesoscale precipitation systems – Yau/Zhang
5.8 Northern boundary layer modelling – Taylor
5.9 VSAS2 Model results: links to Regional Model – Stein/Martz

6. MAGS Support and Operational Inputs: (Chair: Geoff Strong)
6.1 Data Management Update – Crawford
6.2 Operational Meteorology perspective – Schram (presented by Kochtubajda)
6.3 Operational Hydrology perspective – Weddell (presented by Spence)
6.4 CMC Model Archives and Activities in Support of GEWEX – Hogue (presented by Beauchemin)

==================================
2. Extended Abstracts of Workshop
0.1 MAGS OPERATIONAL STRATEGY

*Geoff Strong¹ and Bob Kochtabajda²*

¹Environment Canada, Saskatoon, SK, ²Environment Canada, Edmonton, AB

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.

**Rationale for Sub-Basin Studies:**

Figure 1 is a schematic comparison of spatial versus temporal scales of select hydrometeorological processes, many of which must be incorporated into the Mackenzie Basin:

- **Weather Systems**
  - Scale Dimensions Mack. Basin (2Mkm² ~ 1500km)
- **Mesoscale Systems**
  - Hurricanes
- **Mesoscale Systems**
  - Major Sub-basins (250,000km² ~ 500km)
- **Convection Clouds**
  - Small Basin Studies (2500km² ~ 50km)
- **Rain Bands**
- **Ice Jams Spring Breakup**
- **Transpiration/Evaporation Estimates**

**Figure 1:** Schematic comparison of spatial versus temporal scales of atmospheric and hydrological processes.
Basin GEWEX Study (MAGS), though obviously not hurricanes or tornadoes. For the meteorologist, these processes range from microscale evapotranspiration to mesoscale convective systems, to synoptic-scale weather systems, to atmospheric long waves, and all the way up through longer time-scale climate change patterns. The meteorologist has one advantage over the hydrologist, in that there is only one discontinuity to be concerned about, the land/ocean surface, so that the atmosphere itself can be considered a continuum, for which reason large-scale atmospheric models must necessarily have a ‘global’ domain; that is, individual atmospheric waves cannot be modeled in isolation. On the other hand, the hydrologist must deal with discontinuities in three dimensions. Hydrologic processes and model domains are therefore based on the smallest ‘river basin’ scale, which in turn can be modeled in isolation.

Thus, we find that ‘links’ between scales for hydrologic processes are not ‘as neat’ and well-connected as for atmospheric processes. While ‘scaling-up’ for the meteorologist is not generally a problem (as it is for ‘scaling-down’), the discontinuities between ‘basins’ does not easily allow scaling-up of hydrologic processes. Land surface cover and terrain elevations become a more complicated problem for hydrologic processes. Figure 1 suggests furthermore that ‘links’ between hydrologic and atmospheric processes must be made laterally rather than simply scaling-up or down. Furthermore, since most hydrologic research must be conducted at the small ‘basin’ scale, it makes sense to incorporate these processes into hydrologic models prior to transferring to the larger scale of MAGS. This is an important consideration in the design and implementation of CAGES.

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 over 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. All research sites have been established in four areas in and around the basin. These sites provide ongoing information on a variety of parameters within regions that represent conditions found across the entire Mackenzie Basin. 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. Figure 2 shows the locations of the research basins and locations where enhanced observations are proposed. 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 Montreal, Downsview, and Saskatoon.

Figure 2: Mackenzie Basin and proposed sites for enhanced observations for MAGS
1.1 IMPLEMENTATION OF IMPROVED PRECIPITATION MEASUREMENT METHODOLOGIES

P.Y.T. Louie, Barry E. Goodison, J.R. Metcalf, and R. Brown
(Presented by Barry Goodison)
DOE/Climate Research Branch, Downsview, ON

Goal

To provide more accurate estimates of actual point precipitation amounts in Canada by defining the accuracy of precipitation measurements and implementing appropriate corrections for the systematic errors of measurement.

Objectives

- Complete the assessment of errors in Canadian precipitation measurements;
- Develop and document methods for adjusting Canadian and other national gauge data base on the WMO Solid Precipitation Measurement Intercomparison Study;
- Develop and document methods for adjusting ruler measurement of snowfall;
- Develop and document methods for adjusting autostation measurement of precipitation;
- Establish operational procedures for adjusting point precipitation measurements in Canada applicable to research, operational and historical data users; and
- Create a "adjusted precipitation archive" for Arctic and MacKenzie Basin stations in the GEWEX study areas and make it readily available to researchers.

CANADIAN PRECIPITATION MEASUREMENT METHODS: Currently in Canada, precipitation is measured at more than 2,400 AES co-operative climate stations, resulting in an average precipitation station density of 2.5 stations per 10,000 km². In the Arctic and Mackenzie basin, however, the density is closer to 1 station per 50,000 km². Most stations still use non-recording or manual methods of measurement, with an observer making the measurements. The Type B rain gauge is currently used to measure rainfall at all of these stations; the Canadian Nipher Shielded Snow Gauge System is the standard AES instrument for measuring fresh snowfall water equivalent at about 350 of these stations. The remaining stations estimate snowfall precipitation from ruler measurements of the depth of freshly fallen snow and by assuming the density of fresh snow to be 100 kg m⁻³.
PRECIPITATION MEASUREMENT ERRORS: Gauge measurements of rainfall are affected by systematic errors due to losses from the adhesion of water to the gauge surface (wetting loss), evaporation between measurement periods, splash out, and reduced catch efficiency by wind. These systematic errors for Canadian rain gauges have changed significantly over time with the introduction of new methodologies, however, they can now be quantified.

Gauge measurement of snowfall is done using the Canadian Nipher gauge, a non-recording gauge requiring the melted contents to be poured out into a measuring graduate. The significant systematic errors are wetting loss, the affect of wind and loss from “trace amounts”. Previous studies and the more recent results from the WMO Intercomparison experiment have quantified the systematic errors due to wetting loss and the affect of wind for the Canadian Nipher gauge. The measurement of "trace amounts" of precipitation (<0.2 mm) using the Nipher gauge is a concern. Some Arctic stations have reported over 80% of all precipitation observations as trace amounts. A trace is assigned a value of zero in the AES digital archive. Using techniques similar to those described above for resolving wetting loss, it was determined that a trace could be an actual measurable amount, the value of which lies between 0.0 mm and 0.15 mm. For correction purposes a trace reported in any 6-hour period is assigned a value of 0.07 mm. In the Arctic, where there is a high incidence of ice crystals reported, each trace is assigned an even lower value of 0.03 mm.

Ruler measurement of snowfall was used by all AES stations prior to 1960 to estimate fresh snowfall precipitation. Where snow has fallen since the last observation, the snow depth is measured using a ruler. The snowfall water equivalent is then estimated assuming the density of fresh snow to be 100 kg m\(^{-3}\). This method can be subject to substantial error. For an individual event the error depends on the magnitude of the deviation of the true density from 100 kg m\(^{-3}\), on the representativeness of both the site and the depth measurements and the time of the observation during the storm.

ADJUSTING AES PRECIPITATION ARCHIVE DATA: Precipitation data in the AES archive are stored as many separate elements. These include: each 6 hour precipitation measurement; 24 hour rainfall (i.e. millimetres of rainfall from rain gauge measurement); 24 hour snowfall (i.e. centimetres of fresh snowfall depth from ruler measurement); and 24 hour precipitation total (i.e. millimetres of water equivalent from either or both rain gauge and Nipher gauge measurement). A set of procedures have been developed to adjust these archived data. The procedures were complicated by several factors: the type of precipitation for each six hour amount is not identified; wind is not measured at gauge height; and it is impossible to determine accurately the gauge used to make measurements when mixed precipitation (i.e. rain and snow) occurs. In order to adjust snow ruler measurements at stations for periods prior to Nipher gauge measurements, a mean density is calculated based on the ratio of snowfall measurements to adjusted Nipher gauge measurements for storms of 5.0 mm or greater during the period when ruler and gauge measurements were made coincidentally. This new density is then used to go back and adjust 24 hour precipitation total amounts prior to gauge measurements. To adjust stations which have only snow ruler
measurements, a map of average regional snow densities based on the above procedure was used to interpolate average snow density at a particular station.

PROGRESS REPORT: Development and testing on an improved version of the procedures for adjusting the 6-hourly precipitation archive was completed. This Version 2.0 shown in Figures 1 and 2 includes the final results from the WMO Solid Precipitation Measurement Intercomparison Study and an improved algorithm to distinguish between rain and snow events in the archived total precipitation data. Figure 3 shows the adjustment applied to precipitation data for Yellowknife, NWT. Version 2.0 of the procedures will be the operational version and will be applied to all climate stations in the network collecting 6-hourly precipitation. It will also be used as the standard basis for developing and comparing adjustment procedures for the daily precipitation archive.

Publications and Conference Reports for 95/96


FIGURE 1 -- CANADIAN PRECIPITATION ARCHIVE CORRECTION PROCEDURE FOR NIPHER GAUGE MEASUREMENTS -- VERSION 2.0

If Trace

Add 0.17 mm (copper) or 0.14 mm (plastic)

Wetting Loss

Add 0.17 mm (copper) or 0.14 mm (plastic)

Wind Correction

Copper Gauge: +4%
Type B Gauge: +2%

Figure 3. Yellowknife, NWT precipitation after Version 2.0 adjustment
1.2 AN EVALUATION OF THE SPATIAL DISTRIBUTION OF REGIONAL FINITE ELEMENT QPF DATA OVER THE MACKENZIE BASIN

Brian A. Proctor and Craig Smith
Climate Research Branch, Environment Canada,
National Hydrology Research Centre, 11 Innovation Boulevard Saskatoon, SK

Precipitation Climatology

The precipitation distributions differ markedly east and west of the divide. West of the Rocky Mountains the precipitation tends to peak in the summer months but continues at high levels through the fall as defined from 1961-1990 normals. Further north in the basin, the precipitation decreases in the fall months. East of the continental divide the precipitation peaks again in summer months with stations near the southern edge of the basin recording ~50% of the annual precipitation in the summer months. This emphasises the importance of summer precipitation events on the annual hydrologic cycle and the need for a summer study period in CAGES.

Study Methodology

One of the largest problems associated with studying precipitation in mountainous terrain is the lack of representative climate stations at elevation. Walsh et al., (1994) identified that within the basin station observations under-estimated precipitation during winter months by amounts equivalent to several centimetres per year. This under-estimation can be likely attributed to instrument under-catch (Metcalfe et al., 1994) and a lack of observing locations at higher elevations (Krauss, 1996). Given the limitations with existing observational data sets, a decision was made investigate model output. Data was readily available from the Regional Finite Element model for two hydrologic years, October 1994 to September, 1995 and October 1995 through September 1996. For the first year, the RFE was run on a 50km grid. In the second year, the model was run with a 50km grid spacing for ~3 months (subsequently interpolated to 35km), and with a 35 km grid spacing for the remainder of the period.

Methodology

6hr quantitative precipitation forecasts based on the 00utc model runs were accumulated into daily, weekly, monthly, and seasonal amounts at every grid point over the basin. The resulting quantitative precipitation forecasts were then compared with seven observing stations within the basin which had Nipher shields on the precipitation gauges. The stations chosen were
Measured Precipitation was compared to that resulting from the model over month long periods. Figure 1 shows the residual between measured -model data on a monthly basis in the second hydrologic year. The largest deviations occurred at Fort Simpson A and Fort Smith A during the months of August and September of 1996 respectively. A preliminary examination of the hourly observations at each location indicates that convective precipitation events are likely largely responsible for the error.

![Figure 1: Residuals Between observed and model monthly total precipitation(mm) for 7 principle stations within the Mackenzie Basin](image)

**Figure 1: Residuals Between observed and model monthly total precipitation(mm) for 7 principle stations within the Mackenzie Basin**
The quantitative precipitation forecasts data was subsequently ingested into a GIS for development of relationships between precipitation and slope, elevation and aspect. Both linear and multiple linear regression techniques were applied on monthly and seasonal bases for the whole basin. The results indicated that elevation was statistically significant in all seasons with correlation coefficients ranging from 0.42 to 0.88. In general the correlations were highest in spring and lowest in the fall. The slope was found to be more important than he aspect. The results obtained from multiple regression methods improved the correlations slightly. However, the improvement was not marked. Some additional improvement was found when the data was stratified for a wind from the southwest to west.

The results are detailed in the following tables:

### Linear Regression Summary precipitation vs elevation (correlation coefficients)

<table>
<thead>
<tr>
<th>Year</th>
<th>Fall</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994-95</td>
<td>0.42</td>
<td>0.58</td>
<td>0.88</td>
<td>0.81</td>
</tr>
<tr>
<td>1995-96</td>
<td>0.61</td>
<td>0.71</td>
<td>0.79</td>
<td>0.70</td>
</tr>
</tbody>
</table>

### Seasonal Multiple Regression Summary

<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>Fall</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple r</td>
<td>1994-95</td>
<td>0.46</td>
<td>0.59</td>
<td>0.88</td>
<td>0.81</td>
</tr>
<tr>
<td>Elevation (beta)</td>
<td>1994-95</td>
<td>0.35*</td>
<td>0.51*</td>
<td>0.85*</td>
<td>0.80*</td>
</tr>
<tr>
<td>Aspect (beta)</td>
<td>1994-95</td>
<td>0.16*</td>
<td>0.03</td>
<td>-0.08*</td>
<td>-4.0x10^-4</td>
</tr>
<tr>
<td>Slope (beta)</td>
<td>1994-95</td>
<td>0.15*</td>
<td>0.13*</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>Multiple r</td>
<td>1995-96</td>
<td>0.61</td>
<td>0.72</td>
<td>0.81</td>
<td>0.70</td>
</tr>
<tr>
<td>Elevation (beta)</td>
<td>1995-96</td>
<td>0.59*</td>
<td>0.64*</td>
<td>0.77*</td>
<td>0.69*</td>
</tr>
<tr>
<td>Aspect (beta)</td>
<td>1995-96</td>
<td>0.03</td>
<td>-0.07*</td>
<td>-0.12*</td>
<td>-0.07*</td>
</tr>
<tr>
<td>Slope (beta)</td>
<td>1995-96</td>
<td>0.04</td>
<td>0.10*</td>
<td>0.02</td>
<td>-0.01</td>
</tr>
</tbody>
</table>

* significant at least to the 95% confidence level

### Discussion

The model placed the highest precipitation in winter over the elevation band between 2000 and 2200 m. Over higher elevations, the precipitation decreased slightly. The average precipitation in the basin was found to occur where the slope was steepest. In the summer season, the precipitation maximum was found to occur between 1800 and 2000 m but significantly more precipitation occurred at lower elevations. See Figure 2. The model also did a reasonable job of placing the majority of precipitation on windward slopes.
Figure 2: Average seasonal precipitation (mm) vs elevation band (200 m intervals)

Future Work

Analysis is to extend for one more hydrologic year and the regression relationships will be re-examined on a sub-basin scale.
1.3 GRIDDED WATER BALANCE CLIMATOLOGY FOR THE MACKENZIE BASIN

W.D. Hogg\textsuperscript{1}, P.Y.T. Louie\textsuperscript{1}, A. Niitsoo\textsuperscript{1}, E. Milewska\textsuperscript{1} and B. Routledge\textsuperscript{1}

(Presented by R. Hopkinson\textsuperscript{2})

\textsuperscript{1}Climate Research Branch, Environment Canada
4905 Dufferin St., Downsview, Ontario, Canada M3H 5T4

\textsuperscript{2}Environment Canada, Regina, SK

The goal of this project was to provide a baseline climatology for the Mackenzie River Basin by mapping its surface water balance parameters using optimal spatial interpolation techniques. A spatial resolution of 50 km on a polar stereographic projection grid which is congruent to the Canadian Meteorological Centre numerical model output grid was selected. The ability to incorporate conventional measurements, modeling output and remote sensing was considered important because of the data sparse nature of the Mackenzie Basin. To properly identify climate variability and trends within the limits of data availability, monthly maps for the period 1950-present and 1-10 years of daily or weekly maps were considered reasonable objectives. For the work carried out to date, monthly maps of the grids of water balance parameters (1950-94) have been completed involving six steps:

1) precipitation data were adjusted for all known measurement errors and changes in observing program using procedures developed in the Climate Research Branch.
2) using the adjusted precipitation data, grids of monthly normals of precipitation and temperature were derived from a modified square grid regression approach (Soulis et al., 1994);
3) departures from station normals were determined for each station, for each month of the time series for both temperature and precipitation;
4) these departures from normal were interpolated to the grid using optimal interpolation (Figure 1);
5) monthly grids or maps of temperature and precipitation were calculated for each month in the time series by combining the normals grid with the departures grid;
6) these parameters then served as input to a simple Thornthwaite climatic water balance model which was run independently on each grid point producing values of evapotranspiration and water surplus for each month of the time series.

A sample of nine years of the monthly grids is shown in Figure 2. Colour images of the full period (1950-1994) are contained on the MAGS Website at: http://www.tor.ec.gc.ca/GEWEX/projects/temp_precip/mags_anomalies.html. The gridded data are available from the investigators.

This study has demonstrated a method for providing improved distributed precipitation fields for the Mackenzie Basin GEWEX study area and created a data set for temporal
and spatial analyses of temperature and precipitation in the Mackenzie Basin. Additional work to improve the evapotranspiration computation is required before historical trends and variability of the other water balance parameters can be analysed satisfactorily.

Figure 1

Mackenzie Basin Precipitation 1981 Normalized Departures

Figure 2
Figure 3: Enlarged example of thumbnail sketch from Figure 2.

Reference

1.4 VARIABILITY OF PRECIPITATION IN MAJOR NORTHWARD FLOWING RIVERS

H.-R. Cho
University of Toronto

During the past year we are continuing our research on the variability of precipitation in the basins of major north-flowing rivers. In particular we have completed our studies of precipitation over the Eurasia continent. A paper on this subject is in press in the Journal of Climate. At the moment we are continuing our studies of the Eurasia continent with the winter snow cover field. In the next year we will carry out similar analysis for the Mackenzie River Basin.

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.

Studies in progress include the variability of snow cover over the Eurasian continent, and wavelet analysis for Mackenzie River Basin stations.
2.1 AIRBORNE OBSERVATIONS PLANNED FOR MARGS: WHAT ARE WE LEARNING?

P.H. Schuepp\textsuperscript{1}, B. Abareshi\textsuperscript{1}, S.O. Ogunjemiyo\textsuperscript{1}, C.M. Mitic\textsuperscript{1},
J.I. MacPherson\textsuperscript{2}, R.L. Desjardins\textsuperscript{3} and N. Bussieres\textsuperscript{4}

\textsuperscript{1}Dept. of Natural Resource Sciences, Macdonald Campus of McGill University;
\textsuperscript{2}Institute for Aerospace Research, National Research Council of Canada; \textsuperscript{3}Eastern Cereal and Oilseed Research Centre, Agriculture Canada. \textsuperscript{4}Atmospheric Environment Service, Environment Canada.

Airborne sampling of fluxes have become an integral part of large-scale land surface climatology projects. In GEWEX-MARGS, as in earlier applications of airborne observations, the Twin Otter aircraft will be used to provide information on spatial distributions of sources and sinks for surface atmosphere exchange of heat and moisture that is not available from fixed tower observations, and at scales that can be related to remote sensing observations of the surface. Of particular interest will be energy partitioning (between sensible and latent heat flux) over surfaces with complex surface moisture distributions. A number of studies on analysis and interpretation of airborne observations currently underway or planned to be completed before the end of 1996, by three Ph.D. students, are relevant to MARGS objectives. They are briefly described below.

(i) Sampling criteria for airborne flux observation over heterogeneous surfaces: We are currently refining our ability to define the resolution (in terms of amplitude and scale of variations in source/sink distributions) obtainable from single and multiple transects and grid flights, based on observations over the BOREAS landscape. This will enhance our ability to define limits of confidence for any distribution patterns of moisture and energy sources within the target area which we will provide to MARGS.

(ii) Structural analysis of energy and moisture transport from heterogeneous surfaces: We are continuing efforts to characterize the size, spacing and content of 'coherent' turbulent structures that dominate the exchange of sensible and latent heat between the surface and the atmosphere. This is done through 'quadrant analysis', which divides transporting structures into the four quadrants of excess up/down and deficit up/down. Analysis of structure size and spacing helps us to refine the sampling criteria (see above), while analysis of content elucidates the driving force behind moisture exchange (shear vs. buoyancy). So far, only data obtained over partly irrigated agricultural land in California (from CODE 1991) has been interpreted in this way. We are currently applying the technique to BOREAS data and plan to revisit data obtained over northern wetlands (NOWES 1990), characterized by patchiness in surface moisture at a variety of scale, not unlike that envisaged for MARGS. The vertically stacked flight trajectories in NOWES will permit evaluation of the role of local advection over patchy surfaces, a problem of great concern in MARGS.
(iii) Modeling of energy and moisture exchange over heterogeneous surfaces: We are currently exploring the use of airborne observations to calibrate microclimate models as a tool to generalize localized (in space and time) observations. This is of particular interest over target areas such as the MacKenzie delta, where direct observations of the local energy balance will always be limited. We are collaborating with J.-P. Blanchet (UQAM) in this area, using the LCM model. We anticipate significant progress in this area to result from our invited participation in the 1997 surface moisture project in Oklahoma (SGP97), which specifically targets the response of boundary layer structure to changes in surface moisture.

(iv) Relating spatial distributions of sources and sinks for heat and moisture to those of remotely sensed surface characteristics: The BOREAS observations have shown much more complex links between radiometric surface temperature and energy exchange than has been observed by us and other researchers over simpler ecosystems. For this reason, aircraft-observed maps of sensible and latent heat flux differed significantly from those inverted from satellite-based radiometric remote sensing (on the basis of an assumed linear or non-linear relationship between sensible heat flux and excess of radiometric surface temperature over air temperature, with latent heat as a residual in the energy balance). The preliminary studies, which showed good agreement between aircraft and satellite-observed surface temperature patterns were done in collaboration with N. Bussieres (AES), based on two days within the BOREAS 1994 data set where coincident NOAA AVHRR data were available to complement the grid flights. These observations, which will be further pursued, suggest that in areas with forest cover a multi-layer approach may have to be employed to account for shifts in source/sink height within canopies, if the surface energy balance is to be inferred from satellite-based remote sensing.
2.2 ATMOSPHERIC MOISTURE BUDGETS AND MODEL VALIDATION

Geoff Strong¹, Muyin Wang², Alan Barr¹ and Brian Proctor¹
¹Environment Canada, Saskatoon, SK, ²Dalhousie University, Halifax, NS

1. OBJECTIVES

1996/97 was the first year of this planned three year study. The overall objectives are:
1) to evaluate the atmospheric moisture budget of the MacKenzie Basin and its principal subbasins over entire annual cycles, using both observed radiosonde data and the outputs from high-resolution analysis and forecast models;
2) to assess the reliability of the budget estimates; identify deficiencies in the observations and model analyses; and validate the budget estimates of atmospheric moisture convergence using observed streamflow and modelled precipitation minus evaporation.

In addition, this study was tasked with preparing recommendations regarding supplemental upper-air sites for CAGES. Significant progress has been made in all areas, and in some cases, the milestones established for 1996/97 have been exceeded.

2. PRELIMINARY RESULTS

The atmospheric moisture budget.

Analysis of RFE model output for the period October 1996 to September 1997 showed a net positive moisture flux convergence of 1.6 x 10⁷ kg s⁻¹ over the MacKenzie basin. This is equivalent to an annual total P-E of 279 mm over the basin’s area of 1.77 x 10⁶ km² (Figure 1). The mean monthly moisture flux convergence over the entire basin was positive for each month between Oct/95 and Sept/96. It reached a minimum in June, peaked in Aug-Sept., and remained high throughout fall and winter. The regions of atmospheric moisture influx and efflux varied strongly with season. October to May was dominated by atmospheric moisture influx from the SW and efflux to the SE, with other sectors relatively inactive. In contrast, June to September analyses suggest moisture influx from all directions (SW and NW were strongest), so that the MacKenzie Basin was a significant atmospheric moisture source to regions east during this period.

Roughly 50% of the annual precipitation occurs during the summer period, most likely due to relatively high rates of evapotranspiration and significant convective activity over the Mackenzie basin. This compares favourably with the climatological annual average of 249 mm/yr obtained by Walsh et al. However, estimates in the literature using streamflow and precipitation data have been 25-50% lower, suggesting some sort of systematic error in one or both approaches.
Analyses at 00, 06, 12 and 1800 UTC also showed a significant diurnal variation in mean monthly moisture flux convergence, peaking at 0000 UTC, and reaching a minimum at 1800 UTC.

Model biases.

Comparisons of atmospheric vapour mass using observed and (RFE) model data yield a slight negative bias on vertically-integrated vapour mass compared with measured values. Only minor differences were noted between vapour mass computations for observed and modelled data at the available spatial scale of radiosonde data (approximately 700 km mean spacing). As expected, larger differences occur between the two sets of computed vapour mass at point radiosonde locations, partly because of the resolution of terrain elevations in the RFE model. Month-to-month continuity of mean monthly analyses suggests that the RFE does provide value-added resolution at the 35-km grid scale.

However, a measureable diurnal cycle in integrated vapour mass during summer, anticipated because of indications of significant evapotranspiration, was not evident in either the observed or modelled data, possibly because only two soundings per day (1200
and 0000 UTC) are available. If there is a significant summertime diurnal signal (as other indicators suggest) which is not being observed with only two soundings per day (1200 and 0000 UTC), then this has important implications for CAGES. A negative bias in vapour mass computations produced by this scenario would be cumulative, and could possibly explain the differences in P-E computations between the moisture budget and streamflow approaches.

3. FUTURE WORK

During the next few months, computations of moisture flux convergence will be repeated using better-defined boundaries around the basin. The moisture budget will also be investigated over the sub-basins. Longer time series of MAGS analyses are important to consolidate current conclusions, as well as more detailed analyses of temporal and spatial resolution problems. If funding permits, sequential soundings may be carried out at an appropriate site in the basin this summer to try and detect the diurnal signature in vapour mass.

4. PUBLICATIONS and PAPERS

2.3 CYCLONES AND THEIR ROLE IN HIGH LATITUDE WATER VAPOR TRANSPORT

John Gyakum
McGill University, Montreal, Quebec

I. A statement of the science

We are continuing to study the role of synoptic- and planetary-scale circulation systems in the transport of water vapor into the Mackenzie River Basin. This study is based upon a combination of regional climatology research for the Basin and high resolution numerical simulations of particularly important precipitating events. Specific accomplishments include:

A. A seasonal database of cyclone occurrence for the Mackenzie Basin based upon a 1962-89 historical analysis from the National Centers for Environmental Prediction (NCEP).

B. We have used a 1962-89 record of precipitation data at 16 Mackenzie Basin stations to document significant precipitating events.

C. Composite Northern Hemispheric meteorological fields have been generated for significant precipitating events of varying intensities and structures for all four seasons.

D. Dynamical fields associated with these composites have been presented at the GEWEX workshop in Downsview, Ontario (November 1995).

E. These composite results have been published in the December 1996 issue of ATMOSPHERE-OCEAN (Lackmann and Gyakum 1996).

F. We have simulated a significant Mackenzie Basin precipitation event of 10-12 January 1996 with the MC2 model. This case has substantial similarity to the cold-season composite documented by Lackmann and Gyakum (1996).

G. This model simulation has been validated with respect to both the gridded CMC analyses and the raw observations.

H. Considering that the MC2 produced a credible simulation of this major precipitating event, we have diagnosed the case using the high resolution detail of the MC2. The dynamical understanding of this case is achieved with a quasi-geostrophic potential vorticity inversion technique that is designed to isolate specific flow anomalies responsible for the moisture transport over the Rocky Mountains in the Mackenzie River Basin. This work has been conditionally accepted for publication in the MONTHLY
WEATHER REVIEW (Lackmann, Gyakum, and Benoit 1997). The research has also been presented at the CMOS Congress of May 1996 in Toronto.

I. We have contributed to the NSERC site review presentation (June 1996) by providing color overhead transparencies, and a color poster.

J. We have initiated work on dynamics relating to Mackenzie Basin precipitation with an investigation of lower-tropospheric frontogenesis and vorticity-generation mechanisms.

II. How the research relates to MAGS objectives:

A. To understand, quantify, and model the critical components of water and energy cycles that affect the climate of the Mackenzie Basin

B. To improve our capability to predict changes to the water resources of the Mackenzie Basin that are influenced by natural climate variability and that may be altered by anthropogenic climate change.

Our research directly addresses objective A by quantifying the contributions of specific circulation anomalies to the water vapour transport into the Mackenzie Basin during important precipitation events (Lackmann, Gyakum and Benoit 1997). These precipitation events constitute the bulk of the precipitation that falls into the region. We address objective B by identifying specific circulation anomalies that contribute to changes in the water resources of the Mackenzie Basin (Lackmann and Gyakum 1996). These anomalies, being capably produced by global general circulation models will help to predict the discharge of the Mackenzie River into the Arctic Ocean. Continuing studies of water vapour transport mechanisms will focus on longer historical records and on more detailed atmospheric diagnoses, such as will be available on the NCEP reanalyses back to 1957.

III. How the research interacts with other MAGS projects

The study will complement the precipitation structure study of Cho. The data collected during CAGES will allow us to study in more detail the structure and evolution of cyclonic systems affecting the Mackenzie Basin. Use will be made of the data supplied by Zawadzki. Continuing interactions are taking place with Yau and Zhang regarding modelling and parameterization aspects of the MC2. We expect that interactions with the hydrological community will result during the planning stages for CAGES.

IV. MAGS data
Our research uses the historical data provided by the University of Washington on compact disk, the MC2 provided to the university community, and the NCEP reanalyses currently being processed at the National Climatic Data Center.

Publications directly related to GEWEX:

A case of slow growth/rapid cyclogenesis during CASP II. Atmos.-Ocean, 34, 17-50.

Presentations:
3.1 LANDSCAPE MODELLING OF EVAPORATION FROM THE MACKENZIE BASIN

Wayne R. Rouse1 and Richard M. Petrone1
(Presented by P. Marsh2 and M. Petrone1)
1Program in Earth and Environmental Research
School of Geography and Geology, McMaster University
2NHRI

Evaporation is the largest component of the Mackenzie Basin’s annual water balance during the snow-free period. Consequently, evaporation could prove to be significant within a changing climate scenario, responding strongly to changes in temperature. In addition, as a major component of the surface energy balance, it should interact strongly with the permafrost regime. Thus, to model the basin scale atmospheric/hydrologic cycle of the Mackenzie Basin will require accurate representation of evaporation.

Many years of research in the Hudson Bay Lowland have illustrated that it is difficult to model evaporation in highly heterogeneous regions. Thus, to model the evaporation from a natural surface we must obtain accurate measurements of evaporation from the various terrain types representative of that particular region. Boudreau and Rouse (1995) have shown that the partitioning of the surface energy balance varies strongly for different terrain types. The latent heat flux was seen to account for 50% to 83% of the net radiation, for upland lichen-heath and shallow lake sites respectively, and 71% for a sedge wetland. This variation with terrain types indicates that evaporation responds to three major components: (1) radiative and temperature forcing, (2) water availability, and (3) the vegetation comprising the terrain unit.

Drawing from measurement and modelling results and techniques in Churchill, Manitoba, energy balance sites are being established in the Lower Mackenzie treeline and tundra zone. An energy balance site is currently in operation in the Trail Valley Creek (TVC) area, northeast of Inuvik, NWT, representing a lowland moist-sedge tundra. The site has been in operation since May, 1996 and is operating year round. Figure 1 illustrates the seasonal energy balance terms for this TVC site. The focus of this work will be on the summer energy balance which will then be incorporated with the winter work of other MAGS investigators. It is clear from Figure 1 that by the end of September, well into freeze-back, the net radiation (Q* ) and most terms become negative and are suppressed. The curve of the latent heat flux (QE) suggests that there is some evidence of sublimation after freeze-back. The ground heat flux (QG) demonstrates that the ground is gaining significant amounts of heat during the summer season as the active layer develops and then loses large amounts of heat during freeze-back. Of greater significance, Figure 1 shows that during the summer months, QE is the dominant surface energy flux.
Figure 1  Daily Energy Balance Terms,
Trail Valley Creek, NWT,
Spring, 1996 - Winter, 1997

- Net Radiation
- Latent Heat Flux
- Sensible Heat
- Ground Heat Flux

May 23  July 12  Aug 31  Oct 20  Dec 9  Jan 26

Date
Figure 2 shows the thermal regime, ground heat flux and Bowen ratio ($\beta$) for the TVC site. The air temperature is consistent with historical mean values, suggesting an average season for the area. The surface temperature was measured on both hummocks and hollows and is seen to be approximately the same for both over the course of the season. $Q_G$ was also measured on both
hummocks and hollows. \( Q_G \) for the hollows is greater than that for the hummocks during the summer months, but less than the hummocks during the fall and winter. This difference in \( Q_G \) between the hummocks and hollows is likely due to surface ponding in the hollows over the course of the season. As expected, the Bowen ratio is very small and positive during the summer months (Ohmura, 1982; Rouse, 1990). Bowen ratio values are not shown for the fall and winter months due to the unreliability of the sensible and latent heat flux calculations at this point in the analysis.

**Figure 3  Seasonal Patterns of Evaporation, Precipitation**

**Cumulative Water Loss, TVC, NWT, 1996.**

Figure 3 demonstrates the seasonal patterns of precipitation, evaporation and cumulative water loss for the TVC site. The largest precipitation event observed over the season was \( \sim 8.5 \) mm and
occurred mid-August. The early summer period was fairly dry with the bulk of precipitation occurring in the late summer and early fall. The evaporation is highest during the middle of June, and decreases steadily over the course of the season. These high evaporation values, despite the lack of precipitation over the same period, suggest the importance of surface water remaining after the melt period has ended. The cumulative water loss increased over the course of the season, with slight decreases corresponding with precipitation events and wet periods seen in the late summer and early fall.

Research in the TVC area is well underway and the project is poised for its next steps. Over the course of the following year, snow-free season data collected at this site will be integrated with the winter snow studies of Pomeroy and Marsh. On the modelling side of the project, TVC work will be integrated with long-term projects for similar terrain types in the Hudson Bay Lowlands. Further field plans in preparation for CAGES involve the installation of an upland dwarf birch tundra site in the TVC area, and the initiation of an evaporation/energy balance study at Great Slave Lake this coming spring.

References


3.2 BIOME-SCALE REPRESENTATION OF SNOW COVER DEVELOPMENT IN BOREAL AND TUNDRA ECOSYSTEMS

J.W. Pomeroy\textsuperscript{1}, R.J. Granger\textsuperscript{1}, A. Pietroniro\textsuperscript{1}, G. Kite\textsuperscript{1} and J.R. Janowicz\textsuperscript{2}

\textsuperscript{1}National Hydrology Research Institute, Environment Canada, Saskatoon, SK
\textsuperscript{2}DIAND, Whitehorse, YT

Associated University GEWEX Studies:
D.M. Gray, M-K. Woo, P. Taylor

The storage and transformations of water as snow and water vapour are largely overlooked in the winter period by present hydrological and global circulation models, yet at high latitudes and altitudes the annual magnitude of the fluxes are large and quite sensitive to climate, vegetation and terrain. The primary processes that influence accumulation are interception of snow in coniferous forests and wind redistribution of snow in open areas. Sublimation is concomitant with these processes and presents a notable annual flux of water vapour to the atmosphere. Snow fluxes have been examined in recent campaigns conducted at four Canadian GEWEX "observatories" in the MAGS "domain" -

1) Southern boreal forest: Waskesiu, Sask. with pine, mixed-wood, burned, clear-cut and regenerating clear-cut sites,
2) Boreal-alpine transition: Whitehorse, Yukon with alpine, shrub-tundra, and forest sites in Wolf Creek,
3) Subarctic forest-tundra: Havikpak Creek, Inuvik, NWT and
4) Arctic tundra: Trail Valley Creek, north of Inuvik, NWT.

The measurements have been complemented by modelling of blowing snow and intercepted snow processes and initial linkages with land-surface models and GCMs. Recent results are highlighted by:

i) \textit{Interception storage function}. Up to 60\% of snowfall can be intercepted in mid-winter by conifers. A process-based model has been developed that represents snow accumulation in boreal forest canopies. Weighed conifers and comparative snow surveys validate the results.

ii) \textit{Exposure parameterisation of intercepted snow}. Fractal geometry indexes the exposure of snow in the forest canopy for use in sublimation rate calculations. An exposure coefficient model has been developed for intercepted snow that in conjunction with the interception storage algorithms can provide the amount and degree of exposure of intercepted snow for use in energy balance evaporation/sublimation schemes.

iii) \textit{Sublimation from intercepted snow}. Snow exposure, intercepted snow mass and within-canopy energy balance are used to determine snow sublimation from coniferous canopies using a single particle energy and mass balance scaled up to the forest stand canopy scale. Sublimation losses are 30-35\% of annual snowfall for conifers in the southern boreal forest, less in more northerly forests.

iv) \textit{Energy balance of the winter boreal forest}. The latent heat flux can be notable and variable, its direction governed by conifer coverage and the load of intercepted snow. Radiation is extinguished and emitted by the coniferous canopy, affecting the energetics of snow beneath
and the atmosphere above. A canopy radiation model has been developed and its implications for snow ablation explored. Early results show that canopy alteration of the radiation regime extends the length of the snowmelt period 3 fold under dense canopies compared to adjacent open areas.

v) **Blowing snow transport threshold condition.** Two new algorithms predict the threshold wind speed for transport and the probability of occurrence of blowing snow. The algorithms permits application of physically-complete blowing snow algorithms to a variety of environments and data sets and solve the problem of scaling from point representations to larger snowfields.

vi) **Distributed Blowing Snow Model (DBSM).** Landscape classifications, a regional snow budget and blowing snow flux routines calculate blowing snow fluxes over complex land surfaces. The DBSM has been applied and tested in an Arctic and subarctic catchment. It realistically represents the distribution of snow water equivalent and matched basin snow accumulation within 6%. Sublimation losses were small for the subarctic basin, about 21% over the arctic basin and 30% from tundra surfaces.

vii) **Blowing snow in alpine terrain.** Fluxes of latent heat and snow particles along a northern alpine ridge crest suggest that small-scale advection of energy plays an important role in driving sublimation fluxes in mountain basins. Mass and energy balances are being calculated for alpine blowing snow and provision is being made for an implementation in SLURP of blowing snow routines for this environment.

The field and modelling results show that winter snow transformations are critical elements of the global cycle of water and energy in cold environments. Many of these transformation have been unrecognised before this study. As the field datasets mature, robust algorithms describing these processes are being developed for implementation in hydrological and land surface models that will contribute to GEWEX modelling efforts.

**GEWEX Refereed Publications** (numerous conference presentations and non-refereed publications are supplemental to this list)


Marsh, P., J.W. Pomeroy and N. Neumann 1996. Sensible heat flux and local advection over a
heterogeneous landscape at an arctic tundra site during snowmelt. *Annals of Glaciology*. In press.


**GEWEX BOOK**

3.3 HYDROLOGICAL PROCESSES IN COLD REGIONS

D.M. Gray¹, D.H. Male¹, C.P. Maule¹, J. Pomeroy² and P. Marsh²
(Presented by J. Pomeroy)
¹University of Saskatchewan, ²NHRI

Ablation of Seasonal Snowcovers

1. Field monitoring of point and areal albedo, radiative and turbulent fluxes and other components of the energy budget during snowcover ablation at Saskatoon, SK and Trail Valley Creek near Inuvik, NWT in spring of 1995/96. Micrometeorological instrumentation installed, soil moisture and snow survey data collected at Prince Albert National Forest, Waskesiu, SK, Wolf Creek Basin, Whitehorse, YT, and Trail Valley Creek near Inuvik, 1996/97.

2. Development of:
   (a) first-generation model for simulating the areal depletion of shallow seasonal snowcovers during ablation based on the melt flux and spatial frequency distribution of the snow water equivalent.
   (b) combined energy balance-aerodynamic approach for estimating the flux of sensible energy to complete snowcovers during large-scale advection.
   (c) methodologies for classifying and stratifying landscapes according to their snow retention properties based on terrain and vegetative variables. Correlations between snow depth density, and water equivalent.
   (d) methodologies for synthesizing and scaling the spatial distribution of snow water.

3. Evaluation of a two-dimensional model for estimating small-scale advection of a patchy snowcover.


Coupled Heat and Mass Flow in Frozen Ground

1. Field monitoring of snowcover properties and soil temperature and moisture distributions during fall, winter and spring in forested and cleared sites in boreal forest at Prince Albert National Forest, Waskesiu, SK and Whitehorse, YT.

2. Development of a physically-based, numerical simulation of coupled heat and moisture flow during snowmelt infiltration into frozen soils.

3. Development of first generation parametric equations describing snowmelt infiltration into frozen silty clay and sandy loam soils from measurable soil physical properties.

4. Initial assessment of the role and importance of infiltration into frozen soils on snowmelt runoff from the Wolf Creek Basin, Whitehorse, YT.

5. Initiation of studies directed to the development expressions for snowmelt infiltration in Boreal Forest (Waskesiu, SK; Whitehorse, YT) and Arctic tundra (Inuvik) ecoregions.
Wind Transport of Snow

1. Field monitoring of snowcover accumulation, micrometeorological variables and blowing snow fluxes at Waskesiu, SK, Whitehorse, YT and Inuvik, NWT.

2. Development and initial testing of:
   (a) monthly time-step, distributed, blowing-snow model for an Arctic environment using a landscape classification derived from LANDSAT imagery and a digital elevation model.
   (b) algorithms for PBSM to estimate the threshold wind speed for snow transport as a function of air temperature and snow wetness and to estimate the probability of blowing snow occurrence as a function of wind speed, air temperature, snowpack age and snow wetness. The routine also includes new features that include a correction for snowfall under measurement at high wind speeds, a mid-winter snowmelt routine, improved snow density estimates and improved estimation of the effect of exposed vegetation on aerodynamic roughness height during blowing snow.

3. Initial development and testing of a snow interception model for Boreal forest canopies.
3.4 WATER AND ENERGY FLUXES DURING SNOWMELT PERIOD

P. Marsh
National Hydrology Research Institute, Saskatoon, SK

The long term goal of this work is to develop improved predictive algorithms of the energy and water fluxes during the spring melt and summer periods, and to incorporate and test them in distributed-hydrologic models applicable to forested and tundra areas in the zone of continuous permafrost.

During the previous four years, field studies have been conducted at NHRI research basins in the Inuvik area. Due to logistical, personnel, and financial limitations, each field season has concentrated on a separate component of the overall long-term program. For example: 1993 - surface energy balance measurements and hill slope runoff; 1994 - snow percolation studies and hillslope runoff; 1995 - stream discharge measurement system (this field season was very limited due to the exceptionally early melt period); 1996. - the role of local advection in surface fluxes and streamflow measurement system.

Details of our work during 1996/97 are as follows:

1. Measurement program: The measurement systems at Trail Valley (TVC) and Havipak Creek (HPC) sites have been upgraded with new radiometers, radiometer aspirators designed to limit snow/frost accumulation on domes, anemometers, humidity sensors, and power supply (wind generator, larger solar panels, larger batteries) being installed. This has helped improve the quality of the data collected. However, the aspirators have not worked as well as expected and therefore the winter radiation data is still of extremely poor quality. The winter wind record has improved, but continued power problems continue to result in loss of record during calm periods during the period of limited solar radiation.

2. Surface energy fluxes during the melt period: During the melt period in arctic regions, the snowpack is typically patchy, with snowcovered and snow-free areas. As a result, local scale advection plays an important role in the surface energy balance. A simple parameterization technique to estimate the magnitude of local advection was tested at the Trail Valley Creek research site (Marsh et al., 1996). This paper suggested that the energy advected from the bare area to the snowpatches was a simple function of the snowcovered area. During spring 1997 a detailed experiment, with multiple level eddy correlation measurements and energy balance measurements over individual terrain types, and extensive remote sensing images, was carried out at the Trail Valley Ck. area to test various parameterization techniques. In addition, collaborative work with the Hadley Centre was initiated to use their 2D Atmospheric Boundary Layer Model to carry out simulations of the role of local scale advection under various snow cover and atmospheric conditions. This work is currently being carried out as part of an M.Sc. Thesis at the UofS and is expected to be completed by the fall of 1997.

3. Runoff pathways - Ph.D. thesis by W.L. Quinton has been completed. This work has shown that the near stream zone (up to 50 m in width) plays an important, and very dynamic, role in transferring meltwater from the upland areas to the stream channels. This near stream area is
dominated by mineral earth hummocks, with organic flow paths in the zones between the hummocks. These features are the most extensive surface feature in the permafrost regions of the world, and they greatly impact the timing and magnitude of runoff by promoting preferential flow through the inter-hummock zone which is highly permeable near the surface, but has a hydraulic conductivity that decreases exponentially with depth. Both the timing and magnitude of runoff is controlled by the location of the active layer within this area, the soil moisture, and the distribution of hummocks. A conceptual model was developed to outline the interconnections between various processes. This work will play an important role in improving hydrologic models to properly model runoff from these environments.

(4) Improved method for measuring runoff during spring melt: a major limitation in understanding the hydrological cycle in northern basins is the difficulty in measuring runoff during spring peak flow period when the stream channels are blocked by snow and ice. To date, the only reliable discharge measurements have been obtained by specialized research teams/projects. Operational estimates of discharge provide reasonably accurate estimates during the open water season, but are of very poor quality during the melt period when the peak flow occurs and the total flow may represent one half of the annual total. To overcome this problem for small research basins, we developed and tested a continuous injection dilution gauging system during the spring melt of 1995 and 1996. The results from this test were very encouraging. Comparisons with standard stream gauging techniques were within approximately +/-5%, but has the added advantage of being able to provide estimates of average hourly discharge throughout the melt period, and require a minimum of manpower. Final analysis of the 1996 data are underway by a student from the UofS and modification of the system are underway for final testing in 1997.

(5) Data management: Data has been provided to a number of University and Government GEWEX investigators, including: A. Maxfield, J. Pomeroy, W. Rouse, D. Gray on a request basis. In addition, data from the Inuvik research sites has been provided to the BASE program. A WWW site describing the Inuvik field sites and containing data used in publications is underdevelopment at NHRI. The longer term goal of having a wider selection of data available on CD is ongoing. However, the highest priority is to prepare data required for ongoing research studies and since sufficient resources required for the large task of checking and documenting data are not available, the task of providing a more general data base will be delayed. This problem can only be overcome if further funds are provided to hire the skilled personnel required for this job.

1996 Publications directly funded by GEWEX:

Peer-reviewed journals

Ph.D. Thesis

Conference abstracts/presentation and Reports
3.5 EFFECTS OF SEASONAL FROST AND PERMAFROST ON THE HYDROLOGY OF SUBALPINE SLOPES AND DRAINAGE BASINS

Ming-ko Woo¹ and Sean Carey¹
(Presented by P. Marsh²)
¹McMaster University, ²NHRI

This report pertains only to the field study portion of our activities. The modelling and parameterization aspects are reported separately by J. Stein and L. Martz. Two slopes in Wolf Creek basin, Yukon, were studied during the summer of 1996 to determine the effects of frost on their hydrologic and thermal conditions. The north-facing slope is underlain by permafrost. Above the mineral soil (glacial deposits) is a layer of organic soil of varying depths up to 0.30 m, topped by lichen, moss and sedges. White and black spruce occur sporadically, about 20 m apart and brush growth covers most of the slope. The south-facing slope is steeper (gradient of 0.65) than the north slope (gradient 0.25). It is covered by 11 m high aspen forest, below which is a thin layer of leaf litter covering a homogeneous silty soil. Only seasonal frost underlies this slope.

Instrumentation

The north-facing slope is instrumented with two 6-m meteorological towers, 30 m apart. The lower tower is located approximately 6 m up from the slope base. The lower tower is instrumented with short wave and net radiometers, an air temperature and humidity probe and an anemometer. The upper tower has a net radiometer, an anemometer and five wet and dry bulb thermocouples at five heights, approximately 1 m apart, to provide data for evaporation calculation using the Bowen ratio method (an eddy-correlation devise would be added in 1997 to compare the evaporation calculated using both methods). There are 15 groundwater wells on the slope, 5 each along three lines approximately 7.5 m apart spanning the distance between the two towers. Three wells along the centre line have automatic water level recorders. For soil moisture measurements, TDR probes are located at the upper and lower towers, and adjacent to the well between the towers at the mid point of the study area. Two flumes with water level recorders are located at the base of the slope in two rills. A third one is located upslope in a rill 8 m to the left of the top tower. Thermocouple rods with junctions at several depths, down to a maximum of 1.5 m, are emplaced at seven points on the slope to bracket both the up and down slope conditions.

The south facing slope has one 17-m tower erected in an aspen forest at the centre of the slope. The tower carries both net and short wave radiometers, a temperature and humidity sensor, an anemometer, and four wet and dry bulb thermocouples placed at four heights, 1.5 m apart, all being above the canopy. Four wells are dug on this slope: at the top, middle, lower and flat area beyond the base of the slope. TDR probes are located at the top and base of the slope down to a depth of 1 m. Ground temperature profiles are measured at the top, middle and lower slope locations.
A tower in the flat valley bottom between the slopes measures net radiation, short wave radiation and windspeed. Adjacent to this tower, a tipping-bucket rain gauge is located on a stand just above the buckbrush canopy. Ground temperature and a groundwater well are also located near the tower.

**Results**

There were no major differences in the air temperature above the north and south-facing slopes. Net radiation was significantly higher on the south than the north slope in April and May because the snow on the south slope melted earlier. Afterwards, net radiation on both slopes became similar.

Rainfall for the period April to August was 110 mm while the Whitehorse climatic normal is 300-400 mm per year, with approximately 60% falling as rain. Most of the events were of low magnitude, but rainfall often persisted for several days.

Evaporation, calculated by Bowen ratio method, was higher on the south-facing forest compared with the north-facing slope which was underlain by permafrost. The lower value over the north-facing slope was probably due to the non-vascular organic material which inhibited evaporation during the dry period.

Hydrologically, the upper and lower sites on the north-facing slope are distinct. Several features emerged:
1. The organic layer often had higher moisture contents than the underlying mineral soils. The break in the moisture profile corresponded with the organic-mineral interface and produced a water table that was perched.
2. At the upper slope, the moisture content increased gradually over the summer as the ground thawed.
3. For the upper slope, moisture changes became more prominent as the frost table declined. At the lower site, all ground ice melts by July 13 and moisture changes were less variable with depth.

The upper and lower sites on the south slope also had dissimilar soil moisture profiles.
1. The lower site is subject to direct beam incidence which produced a drier surface earlier in the summer.
2. At the upper site beneath the forest, the soil was wetter at the mid-profile and much drier at depth than the lower site.
3. Water loss in the 1 m soil column was greater at the upper site due to moisture uptake by plant roots.
4. Total soil moisture was similar between the two sites.

Ground heat flux decreased during July and August as the soil warmed. Ground heat flux beneath the south-facing forest was greater in both magnitude and as a percentage of net radiation for July and most of August. By mid-August, heat was lost from the warm south-facing surface as air temperatures began to cool the ground, causing a reversal in the ground heat flux. The cooler
permafrost soils of the north-facing slope did not experience such a reversal because the ground remained cooler than the air to maintain the downward flux.
3.6 SURFACE RADIATION BUDGETS IN THE MACKENZIE BASIN

H. Leighton

Abstract not available.
3.7 ISOTOPIC TRACING OF WATER BALANCE IN THE MACKENZIE BASIN AND CENTRAL ARCTIC

T. Prowse\(^1\), J. Gibson\(^1\) and T. Edwards\(^2\)
\(^1\)National Hydrology Research Institute, Saskatoon, SK
\(^2\)University of Waterloo

Rationale

This study was initiated in response to a request by the GEWEX Secretariat (T. Krauss) to acquire a better understanding of the role of lakes in runoff from remote permafrost regions of the northeast Mackenzie Basin where climate data including precipitation and evaporation are limited. To accommodate the broad scale of the investigation and to minimize field work expenses, an isotope tracer approach was applied which relied on an existing archive of water samples from a distributed network of several hundred lakes. These preliminary studies were largely successful in predicting regional water balance variability as outlined below. The second phase of isotope hydrology studies will involve further integration with hydrologic modelling at the macroscale (G. Kite) and mesoscale (A. Pietroniro). Planned activities will examine source-areas and components of the hydrograph at selected river discharge nodes to aid hydrologic modelling where specific sub-regime response is unknown or poorly understood.

Background

Variations in the stable isotope composition of lakes and inferred water balance trends were examined across a 200,000 km\(^2\) area of the central Arctic 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 DIAND water quality survey \[1\] and is spatially tied-in to 3 NHRI/University of Waterloo isotope hydrology field sites, has examined patterns of isotopic enrichment as a mass tracer of the fraction of lakewater lost by evaporation (evaporation/inflow or E/I).

The basis for isotopic tracing of E/I in lakes has been previously established \[2-4\] and recent studies have applied and validated the method in Arctic Canada \[5-8\]. In brief, surface waters exposed to evaporation are isotopically enriched due to retarded rates of diffusion of the species \(^1\)H\(^1\)H\(^{18}\)O and \(^1\)H\(^2\)H\(^{16}\)O relative to \(^1\)H\(^1\)H\(^{16}\)O above the air-water interface \[9,10\]. Isotopic enrichment levels in natural lakes, above background concentrations observed in precipitation/groundwater input, are controlled by both water balance and atmospheric parameters, the latter of which has been reasonably well-constrained from field studies conducted in the region \[5\].

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. Details of activities and preliminary results are presented below.
Summary of Results

The observed regional isotopic variability is largely the result of evaporative modification of surface waters. As shown on a plot of $\delta^{18}$O versus $\delta^2$H (Fig. 1) lakewaters lie consistently below the meteoric water line (MWL), representing the mean trend of global precipitation, along a well-defined local evaporation line (LEL), and display differential evaporative isotopic enrichment. An estimate of the regional mean isotopic composition of precipitation input of $-22.9 \%e$ in $\delta^{18}$O and $-173\%e$ in $\delta^2$H is predicted by the intersection of the LEL and MWL, which is consistent with detailed studies conducted at sites across the region. Maximum displacement along the LEL from the MWL in the most evaporative lakes is about 10 $\%e$ in $\delta^{18}$O and 40$\%e$ in $\delta^2$H or 100 and 40 times larger than the analytical uncertainty of each tracer, respectively.

Spatial variation in lakewater $\delta^{18}$O is pronounced (Fig. 2a), although systematic regional trends in enrichment are not immediately apparent due to volume effects, which have been shown to be a critical factor controlling levels of isotopic enrichment in shallow lakes but have negligible influence on deep lakes [5]. Data were stratified according to lake depth (as measured using depth-sounding equipment) to eliminate the influence of lake volume on isotopic enrichment. As shown for $\delta^{18}$O in Fig. 2b (page 4) for lakes greater than 20 m-depth, an overall regional shift in lakewater isotopic composition becomes evident (decreasing $\delta^{18}$O [increasing enrichment] from northeast to southwest). Similar regional trends, which are attributed to regional shifts in water balance regime, are found to be robust for lakes greater than 25, 30 and 35 m-depth and in the case where isotopic data are detrended to account for a 50-day sampling time lag (not shown).

A steady-state isotope mass balance model was used to calculate E/I for lakes greater than 20m depth (where seasonal fluctuations are minor, and lake volume and volumetric changes could be considered negligible over the residence time of water in each lake, V/I . 20+ years). As shown in Fig. 2c (page 5) for a first-approximation modelling scenario, E/I ranges from about 10% in some tundra regions to greater than 60% in the region south of Great Bear Lake. While modelling and sensitivity analysis are still in progress, the significance of the results are being considered in view of available hydrometric and climatic data. Results are consistent with estimates from detailed isotope hydrology studies at a tundra site (Lupin NWT; E/I .13, see Fig. 2c), but the areal coverage...
is insufficient to compare with studies at forest-tundra transition and forested sites (Salmita and Yellowknife, respectively). Proposed activities include supplementary sampling, as outlined in the Research Proposal, to extend observations southward to permit these comparisons.

**Related activities**

Several presentations, publications, and reviews have also been completed, and a related conference is in preparation. In response to national and international interest in isotope hydrology we have undertaken to form a Canadian Geophysical Union-Hydrology Section (CGU-HS) Committee on Isotope Techniques in Hydrology and a Subcommittee on Canadian Network of Isotopes in Precipitation (to be sanctioned at the CGU annual meeting in May 1997). Of interest, the subcommittee will examine a formal Canadian contribution to GNIP (Global Network of Isotopes in Precipitation) in collaboration with the International Atomic Energy Agency, WMO, IAHS, IGBP and PAGES.

In support of application of isotopes in large-scale studies such as GEWEX-MAGS and BALTEX, we have arranged ISOBALANCE, an international workshop on application of stable isotopes in water balance studies to be hosted by NHRI in July 1997, and co-sponsored by GEWEX-MAGS, CGU-HS, DIAND (Water Resources Division, Yellowknife), Sustainable Forest Management-Network of Centres of Excellence, AECL, and the Waterloo Centre for Groundwater Research. A state-of-the-science book to be published by Wiley & Sons involving 11 international isotope experts participating in ISOBALANCE and a special issue of *Hydrological Processes* will allow for critical assessment of isotope strategies in large-scale studies and will provide international exposure for MAGS.

Preliminary results of lake studies will also be presented at an IAEA/UNESCO symposium in Vienna in April 1997 at which time we also have been invited to discuss possible collaboration in a formal isotope hydrology contribution to BALTEX. A research update will also be given at the CMOS Congress in Saskatoon in June 1997.

Comprehensive literature searches and reviews on isotope hydrograph separation, including comparisons with conventional methods have also been undertaken using government research funds in preparation for 1997/98 when emphasis will shift from study of lakes to river discharge.

**List of Publications/Presentations and Reviews**


Figure 2 a) Spatial distribution of δ\(^{18}\)O for lakes sampled across the central Arctic during late-July to mid-September 1993. Solid circles denote sampling nodes. Variations in δ\(^{18}\)O reflect variations in water balance conditions (E/I) weighted over the residence time of water in each lake (V/I). Less negative (more enriched) δ\(^{18}\)O values are found to the south of Great Bear Lake and in isolated areas where lakes are characteristically shallow with short residence times. Similar trends were found for δ\(^{2}\)H (not shown).
Figure 2 b) Spatial distribution of $\delta^{18}O$ for lakes greater than 20 m-depth sampled across the central Arctic during late-July to mid-September 1993. Solid circles denote sampling nodes. Regional shifts in $\delta^{18}O$ are attributed primarily to changes in water balance conditions (E/I) as weighted over the residence time of water in each lake (V/I, 20+ years). Less negative (more enriched) $\delta^{18}O$ values are found to the south of Great Bear Lake.
Figure 2 c) Derived evaporation/inflow (E/I) (first-approximation) based on $\delta^{18}O$ distribution in lakes greater than 20 m depth (Fig. 2b). Solid circles denote lake sampling nodes. Green triangles indicate approximate position of northern treeline. Boxed values indicate E/I estimates for deep lakes (>20m-depth) at NHRI/University of Waterloo field sites where multi-year time-series sampling has been conducted.

E/I trends suggest that runoff is the dominant sink for precipitation in most areas, but may be equal or subordinate to evaporation losses in forested catchments to the extreme west of the study area. In general, E/I decreases from northeast (Coronation Gulf/Bathurst Inlet area) to southwest (south of Great Bear Lake) across northern treeline. Unexpectedly low E/I values are found in the area above the North Arm of Great Slave Lake.
4.1 APPLICATION OF SATELLITE EVAPOTRANSPIRATION ALGORITHMS

Normand Bussières\(^1\), Raoul Granger\(^2\) and Kalifa Goïta\(^1\)

\(^1\)AES/CCRD/CCRP, \(^2\)NHRI

Outline Of Research Project:

Satellite ET algorithms are being developed to yield estimates of evapotranspiration during the warm season over the Mackenzie basin. This is important when considering that ET and intermediate variables like land-surface temperature and surface radiation balance are not well known by conventional methods in enough spatial detail and extent for a complete four-dimensional diagnostic representation of the basin's energy and water cycle. Difficulties exist however because of the frequency of the cloud cover and in the design of a useful energy budget inversion satellite algorithm for MAGS. Solutions proposed by the investigators are being implemented and tested over the whole basin. A separate project is conducted by Granger and Pomeroy, providing research site data for the continuing development of Granger's feedback algorithm using remotely-sensed data.

Progress Report

Since 1993, the project investigators developed and used an infrastructure to develop satellite ET algorithms for MAGS. They generated remote sensing scenes and derived products for 17 days of Summer 1994 at 1-km resolution on an area of approximately 2000 x 2000 km centered over the Mackenzie basin. This model validation data, which is a critical component of the MAGS data management strategy, are kept on a HP workstation at AES. The data were used as follows:

- basin-wide land surface temperatures estimates (see virtual CD on MAGS WWW site)
- validation of LST estimates at local observations sites (paper: Granger, 1996)
- development of land surface emissivity maps in the AVHRR thermal bands (papers: Goïta et al., 1996-97)
- undertaking of a draft paper for J. of Climate on basin's thermal regime (draft paper by Bussières, Goïta and Granger available on request)
- linkage with McGill - Dr. P. Schuepp in validation of fluxes over southern BOREAS site (paper: Ogunjemyo et al., 1996)
- intercomparison with RFE weather model and passive microwave data (paper: Bussières and Goïta, 1996)
- strategy to deal with cloudy situations (paper: Bussières and Goïta, 1996)
- linkage with McGill U. - Dr. H. Leighton / F. Jian for development of radiation balance
- detailed exploration of remote unpopulated areas of the Mackenzie basin and illustration of the need for measurements to characterize these regions (paper: Bussières, 1995).
Bussières and Goïta (1996) confirmed the limitations of the satellite ET algorithms related to cloud cover. Over a portion of the western Mackenzie basin, useable clear-sky conditions occur for satellite purposes, only 10% of the time. Solutions were examined. A maximum value compositing technique (Bussières, 1995) was found to be useful for intercomparison with model data over the whole basin; the blending of microwave channels to infer land surface temperature required more research than initially expected. The assimilation of radiances directly into atmospheric models appears the most likely option on the long term.

The original project involved two algorithms to estimate evapotranspiration using satellite data: a modified energy budget inversion (EBI) algorithm (Bussières) and a feedback algorithm proposed by Granger (1995). Recent experimental work (BOREAS) indicates that flux estimation by the simple EBI algorithm is not satisfactory over the boreal forest. The EBI was originally developed for rapid monitoring purposes. For model validation, the EBI complexity would have to be increased to that of RCM/CLASS. It was decided to put more effort on the feedback algorithm, in the light of Granger's successful validations, while continuing the development of the Energy Budget components.

Data obtained from field observations by Granger above various forest cover types (coniferous and mixed-wood stands) in the southern boreal forest were used to develop relationships and the feedback algorithm. AVHRR albedo was used to develop a simple algorithm for the broadband surface albedo which, in conjunction with easily-calculated values of the clear sky solar radiation, is used to provide reliable estimates of the daily net radiation at the surface.

A split-window technique was shown to be useful to obtain reliable estimates of the land surface temperatures for conditions where atmospheric corrections using standard atmospheric models are not feasible because of a lack of data (i.e. from atmospheric soundings). A feedback relationship was used in conjunction with remotely-sensed surface temperature observations to provide a useful estimate of the vapour pressure deficit in the air layer overlying the surface. An algorithm based on this feedback relationship was shown to be applicable to a variety of forest land cover types, as well as for the agricultural surfaces for which it was originally developed.

The satellite-derived estimates of net radiation and vapour pressure deficit can be used as input data to a conventional evapotranspiration model, allowing for evapotranspiration estimates derived using only the information provided by the satellite-mounted sensors. These satellite-derived evapotranspiration estimates compare favorably with estimates obtained with a conventional evapotranspiration model using data from a network of field stations.
Recent Publications In Refered Journals:


Recent Conference Papers:


4.2 SATELLITE OBSERVATIONS OF CLOUDS, RADIATION AND HUMIDITY DURING BASE: METHODS, TRENDS AND ASSIMILATION

Louis Garand and Serge Nadon
AES, Dorval, Quebec

The project was funded for this third year by a Canadian GEWEX grant of $20,000. The grant was used entirely to give an additional 7 months contract to Serge Nadon. The contract covered the period ranging from April to December 1996 with a 2-month break during summer. This report marks the end of the project. A new proposal which is in fact a continuation of item “b” below, has been submitted for GEWEX funding under MAGS.

A) Clouds and Radiation

The project on clouds and radiation (L. Garand supervision) was completed in December 1996 and a substantial article has been submitted to the Journal of Climate. The paper describes:

a) a cloud detection algorithm working both day and night, adapted for Arctic regions
b) results on model (MC2) validation of clouds and radiation during BASE. The most fundamental result there is that the model has a relatively large positive bias in outgoing radiation caused by clouds which are too low on average by 800 m, being trapped in the boundary layer. Efforts have been initiated with other MRB researchers to solve this major problem in the physics of our models.

c) a method to obtain the physical height of the clouds based on the observed equivalent height and the observed 11u brightness temperatures.

d) cirrus trends through the BASE period

e) the diurnal cycle of clouds and radiation during BASE

B) Detection of Precipitation Using AVHRR

This activity was undertaken as opposed to that on assimilation using TOVS (C. Chouinard) in the last months of 1996. We (Chouinard, Garand) planned to delay the TOVS study to January 1997, but S. Nadon announced that he would be leaving at the end of 1996 to work in Ottawa. Serge did an outstanding work as a researcher assistant; unfortunately he had to leave for family reasons. Therefore, we decided to further
postpone TOVS work for MAGS and to formally end the current project. The activity on precipitation was quite successful and consisted in the following:

1) to develop clustering algorithms to detect rain rate both for snow and water based on AVHRR measures; these are the difference between channels 4 and 5, the cloud fraction and the cloud equivalent height. In addition topography and temperature profiles were used as ancillary information. The algorithm was trained from model output of rainfall along with model measures that are equivalent to those observable by satellite (just mentioned).

A few examples of figures taken from the Garand and Nadon article submitted to the Journal of Climate are here briefly presented:

![Figure 9a](image1.png)

![Figure 9b](image2.png)

Fig. 9 a and b compare model and observed histograms of the outgoing infrared brightness temperature (BT) for 6-h and 18-h forecasts based on 31 consecutive forecasts fun each day of BASE. Differences at 6 UTC and 18UTC are minor. There is a clear
warm bias (seen on maps not shown here) in the model which can be appreciated by the warm model shift at low BTs of about 5 K.

Fig. 9c and 9f show the corresponding equivalent height distributions. Clearly the model has a too many low cloud tops (bin 0-1000 m) at the expense of mid level clouds bins 2000 to 4000 ). This is the most significant problem in terms of clouds and radiation identified in the current physics of MC2 and regional model.
Fig. 12 a and b intercompare cloud cover distributions observed at ground stations, observed by satellite and predicted by the model at 15 km resolution. Satellite and ground station observations are quite similar, showing that the satellite retrieval is quite good. Model distributions are also quite realistic, but underestimate overcast cloud cover cases at the expense of broken situations. This study also showed that human observers tend to underestimate cloud cover at night (6 UTC is night, 18 UTC is mid afternoon).

Fig. 15 shows a plot of the true physical height of clouds as a function of the equivalent height seen by satellite by matching the observed brightness temperature with analyzed temperature profile. The relationship varies as a function of the difference between channel 4 (11u) and 5 (12u) brightness temperature with ranges indicated in the figure. The higher the difference CH-4 minus CH-5, the more high is the true height above the apparent height. In fact when the difference is above 1.5K, clouds are almost always above 7km regardless of the measured equivalent height.
Fig. 16 shows trends through the month of the CH-4 minus CH-5 difference, of the equivalent height HE and the cloud fraction CF. There is a clear trend towards lower values of the CH-4 minus CH-5 difference interpreted as trend towards less currus clouds, itself perhaps linked to a drop by about 5 K of upper tropospheric temperatures. The model has captured this trend. The trend is not strongly linked with total cloud fraction which is dominated by low clouds. Each point on the graphs represent a one-day average using 3-hourly model output (8 model frames) and between 5-11 AVHRR scenes. Verification shown for closest point to Norman Wells.
4.3 DETERMINATION OF CRYOSPHERIC ELEMENTS IN WESTERN CANADA USING PASSIVE MICROWAVE SATELLITE DATA: SNOW COVER AND LAKE ICE

Anne Walker, B.E. Goodison, K. Goita, R. Brown, A. Silis, J.R. Metcalfe and M.R. Davey
DOE/Climate Research Branch, Downsview, ON

Snow Cover

The snow cover component of this investigation has the ultimate objective of producing a representative snow water equivalent (SWE) map product (digital map and gridded data set) for the MAGS study area using SSM/I passive microwave satellite data. In order to achieve this goal, algorithms have to be developed that take into account the effects of land cover, including spatial variability. For the Mackenzie basin, boreal forest and open (or sparsely vegetated) areas are dominant land cover types, thus any algorithms that are applied to this region must account for the effects of different forest types and other characteristics, such as density.

During FY 96/97, progress was made in the development of boreal forest SWE algorithms using airborne microwave radiometer data and conventional SWE measurements acquired during the BOREAS February 1994 winter campaign conducted at the BOREAS study sites in central Saskatchewan and northern Manitoba. Three algorithms were developed which take into account the effects of coniferous, deciduous and sparse forest. A combined algorithm incorporating the three forest algorithms and the previously developed prairie algorithm is undergoing testing and validation using SSM/I satellite data for the BOREAS region. Initial results indicate that the new combined algorithm provides more representative SWE values for the boreal forest region than the prairie SWE algorithm on its own. Although this algorithm development work is being conducted within the context of the investigators’ BOREAS science investigation, the algorithms developed will also be tested for the Mackenzie basin region as a FY 97/98 science objective within this MAGS investigation. Thus the BOREAS SWE algorithm development achieves an important milestone within the context of this MAGS investigation.

Critical to the application of passive microwave SWE algorithms for the MAGS study area is the availability of a representative land cover classification for use in deriving land cover statistics for the SSM/I grid cells (EASE-Grid product). An evaluation of national and international satellite-derived land cover data sets for the BOREAS study region was initiated during FY 96/97 within the investigators’ EOS CRYSYS research program. The results of this effort will be used as the basis for a similar evaluation that is planned for the Mackenzie basin as a 97/98 science objective within our MAGS investigation.
Lake ice

The lake ice component of this MAGS science investigation focuses on assembling a time series of Great Slave and Great Bear lake ice freeze-up and break-up using historical SSM/I 85 GHz data (1987 to present). The time series will consist of digital images and gridded data sets for each lake ice freeze-up and break-up season during the period, and will provide information on the spatial and temporal variability of ice formation and decay over the lakes. In order to achieve the lake ice objectives of this investigation, a student was hired using the 96/97 funds awarded to help in satellite data processing and analysis.

An evaluation of three possible sources of SSM/I data was completed during 96/97. The three data sources were (1) orbital swath data, (2) gridded, daily averaged data from the NSIDC CD-ROM product: DMSP SSM/I Brightness Temperature Grids for the Northern Hemisphere, and (3) the new NSIDC CD-ROM product: EASE-Grid (Equal Area SSM/I Earth Grid) Brightness Temperatures. The results of this evaluation determined that the EASE-Grid data set was the most suitable for the time series generation for the following reasons: (i) the brightness temperatures are archived on a fixed grid (an advantage over using the swath data), and (ii) the brightness temperatures from ascending and descending orbits are archived separately (an advantage over the gridded, daily-averaged data set).

The availability of EASE-Grid SSM/I data during FY 96/97 was limited to the period August 1987 to December 1988. Using SSM/I 85 GHz brightness temperatures extracted from this data set, images depicting Great Slave and Great Bear lake ice conditions were created for the 1988 break-up season. Based on these images, the ice break-up process for Great Slave Lake can be observed over the period June 5-15, while for Great Slave Lake the ice break-up period is several weeks later, from June 29 to July 4.

The need for separate archiving of ascending and descending orbital brightness temperatures was reinforced in producing the 1988 lake ice break-up images. Since clouds are a dominant feature in the MAGS area, especially during the spring and fall seasons, clouds may be present during either or both of the ascending and descending orbit passes. The 85 GHz channels are affected by the presence of cloud liquid water, thus the separate orbit passes are necessary to maximize ice cover detection. Preliminary methods to discriminate the presence of ice during cloud cover conditions are the focus of ongoing investigation.

Related Publications:

4.4 SNOWMELT IN NORTHERN WATERSHEDS FROM RADAR SATELLITE

A. Maxfield
National Hydrology Research Institute, Saskatoon, SK

Multi temporal radar-satellite techniques were developed for snow and soil moisture monitoring of Arctic tundras, at Trail Valley Creek near Inuvik. The spatial radar patterns were examined by using power-ratio images. Theory was developed for application of power ratio images, from which radarbeam topographic effects are largely removed by ratioing to a standard winter scene. The radar sequences show changing patterns of both very low and intense backscatter, which respectively resemble changes in the snowcover and resultant soil moisture distribution. They also show large areas of intermediate-backscatter levels, indicating either unresolved partial-snowcover in mixed-pixels or less-wet, snow-free pixels. Methods of both single-image and multi temporal analysis were examined. Single-image snow/no-snow discrimination was found to occur at a power-ratio threshold of 1.5, for the Trail Valley area. Although the radar and visible snowcovers are very similar in appearance, single-image radar snow mapping was found to underestimate snow cover by 23% of total area, due to confusion with less-wet pixels. To overcome this problem, multi temporal radar was tested; it was found to unambiguously separate the effects of partial-snowcover from those of soil moisture. An interpretation key was developed for a multi-temporal colour-composite of radar images for the snowmelt period. The key is an application of a dual-variable five-level classification scheme. The radar classification scheme was specifically developed for snow and soil moisture interpretation, in areas of thin snowpack and very-wet soil. It was found that multi temporal radar gives interpretations consistent with expected topographic effects in the Trail Valley Creek area.

Radar satellite soil moisture monitoring was extended from the snowmelt period, to cover the whole annual soil moisture cycle at Trail Valley Creek. Twenty-two ERS-1 satellite images were coregistered and compared with eleven visible band observations. The seasonal backscatter changes were shown to illustrate radar response to the dominant watershed processes occurring within the basin: spring snowmelt, general summer drying with rainfall events; early-winter soil freezing and the relatively constant late-winter levels. For targets 140 metres across, the number of significantly different levels of soil moisture was determined. This number was found to be six classes of soil moisture for single images, and three classes for multi temporal images. Multi temporal sequences are affected by limitations of radar system stability, as was shown by examining backscatter from the runway at Inuvik Airport.

Radar backscatter during the snow-free period, was compared with measured basin streamflow during the summer. The latter were used as a surrogate for active layer soil moisture. The backscatter-streamflow correlation was found to be significant at the 1% level, with a regression coefficient, R equal to +0.93. This shows that radar satellite
observations provide information on soil moisture distribution that cannot be obtained from any other satellite sensor.

Publications


Conference Presentations

4.5 DOPPLER RADAR TECHNIQUES/OBSERVATIONS DURING BASE

D. Hudak, R. Nissen and P. Rodriguez
Cloud Physics Research Division, AES, King City, ON

Summary of Results:

Preliminary analyses from BASE strongly suggest that there are fundamental differences in the nature of the cloud systems between storms originating in the Pacific and those originating in the Arctic. The first two objectives were designed to examine the basic character of these different storms from the perspective of precipitation formation and evolution.

**Objective 1: To describe the microphysical characteristics of the cloud systems associated with Beaufort Sea storms.**

Innovative analysis techniques were developed to combine the Doppler radar data with aircraft, PMS 2-D ground probe, microwave radiometer, and LANDSAT observations.
(Hudak et al., 1996, Gulitepe et al., 1997). One particularly insightful field was the vertical precipitation flux (VPF). This parameter was also used by Drummond et al. (1996) to examine precipitation formation processes with the McGill radar. Adding a 3-D wind field analysis (Laroche and Zawadzki, 1994) using Doppler radar data taken at Inuvik and Tuktoyaktuk enabled a determination to be made of the mesoscale influences affecting the various precipitation formation mechanisms. Figure 1 is an example of this analysis taken from IOP 7. For the layer from 250 m to 500 m, derived vertical speeds are

![figure](image)

**Figure 2a and b**
shown and give a maximum upward speed of 0.6 m s$^{-1}$. Superimposed are mean horizontal wind velocities at a spatial resolution of 500 m at the same height. Three volume scans at 10 min intervals were used as input. In this case, there was a good correlation between upward vertical velocities and higher cloud tops.

When considering all the information available, conceptual models of storm scale precipitation evolution can be made. Figure 2a shows the time height history of the VPF and Figure 2b the associated upper air temperatures and winds for IOP 3. Gradients in Figure 2a indicate regions of precipitation formation or dissipation. In this case, diffusional growth initiated precipitation at the -15°C level (at about 8/1600 UTC), aggregation occurred in the mid-levels near the low centre, and melting was active further below (8/1800 UTC). This gave way to a dissipating cloud deck and sublimation (8/2100 UTC). Finally, accretion became active in the northerly flow off the Beaufort Sea behind the disturbance (8/2300 UTC).

Findings to date include: accretion in Arctic disturbances is much more significant than was previously thought; for Pacific disturbances, sublimation below the cloud layers plays a key role in the moisture budget; and the wind field at the -15°C level is a critical factor in the initiation of precipitation.

**Objective 2: To identify the critical processes involved in precipitation formation in these systems and assess their relative importance.**

The high resolution Doppler spectrum information from the radar at Inuvik was used to examine the microphysical processes in greater detail. The work in progress will deduce the rate of sublimation of ice crystals below cloud and the rate of accretional growth in low level flow off the Beaufort Sea. Figure 3, a terminal velocity vs height depiction of a vertically pointing radar scan with shaded contours in radar reflectivity intervals, indicates the nature of the data upon which the analysis is based. Note the decrease in echo intensity and fall speed with decreasing height for sublimation (Figure 3a). Cloud base in this case was 2.0 km. By 0.8 km, the precipitation was no longer detectable. The reverse situation is occurring during accretion (Figure 3b). In this case, there is a steady increase in terminal velocity and echo intensity downwards from echo top.

**Objective 3: To investigate the quantitative measurement of snowfall by Doppler radar.**

Sources of error with this remote sensing technology were identified. The nature of the snowfall strongly influenced the quality of the measurements. Periods when accretion was the dominant mechanism had the most promising results for snowfall determination by radar. The higher terminal velocities and the steadier wind flow during periods of accretion were key factors in the higher correlations. In addition, low level influences (below the lowest level sampled by the radar) had a profound effect on limiting the usefulness of the radar measurements. The siting problems for Doppler radars to make sub-basin wide measurements of low intensity solid precipitation were highlighted.
Although a function of beamwidth, the general conclusion was that the lowest elevation angle used in PPI scanning must be at least as low as 0.5°.

Figure 3a
References:


4.6 SATELLITE RAINFALL ESTIMATE OVER THE MACKENZIE BASIN

I. Zawadzki

Presented by Aldo Bellon

J.S. Marshall Radar Observatory, McGill University, Montreal, Quebec

GOES - 8 and AVHRR data sets during daylight hours from the summer of 1995 over the Carvel radar were use to develop the methodology of work and to evaluate the relative contribution of GOES, AVHRR and model output to the quality of the estimates of precipitation from satellite data. Results showed that precipitation estimates from AVHRR information alone, with time interpolation using cloud motion from numerical model outputs or from cloud tracking by cross-correlation, are not as good as those from GOES-8 alone. Since the field of upward motion from model output is very weak in this region in the summertime and is not representative of actual vertical motions, it was not used. It has been incorporated instead in an analysis of winter data over Montreal that is described in a companion report. However, the vertical motions derived from the RFE model do not necessarily delineate regions where precipitation actually occurs, (mainly due to phase errors in the model), and consequently, regions of multi-layered non precipitating clouds cannot be automatically identified. It was concluded that with the present techniques we are unable to estimate precipitation amounts from satellite data in winter situations. It may well be that the more detailed microphysics in the MC2 model could better delineate regions of precipitation. A collaboration with Prof. Charles Lin of our Department to validate with radar data the precipitation derived from MC2 is currently ongoing.

Another approach we are exploring is the potential of Neural Networks techniques to develop an advanced RAINSAT algorithm. We will continue with this work during the current year until it can be decided whether it is a useful approach. However, preliminary results are not too encouraging and the success of this technique is far from certain.

From the experience gained so far in this project and considering the reliance on atmospheric modeling of a good part of the Canadian GEWEX program, I believe that validation and tuning of atmospheric numerical models should be of high priority. This is crucial for our project, and the same can be said in general of the other aspects of the Canadian GEWEX program. I thus propose to redirect some of our efforts towards this goal. The idea has already been discussed with Prof. Re’ne’ Laprise of UQAM and we agreed on a joint supervision of a Ph. D. student working in this area.

Consequently, the scope of the RAINSAT contribution to GEWEX has been reduced to estimates of precipitation amounts during only the summer months. Towards this goal, histograms giving the satellite rainfall rate as a function of (VID,IR) pairs have been derived for four separate months, (May to August 1996), using as ground truth half-hourly rainfall accumulation maps from the Carvel radar at a height of 1.5 km and at a resolution of 2 km. (It should be noted that GOES-8 was replaced by GOES-9 at the
beginning of 1996 and, consequently, the 1995 calibration of satellite data in terms of precipitation had to be repeated. Moreover, the ‘96 satellite data we received had an error in the way raw IR data were converted to a byte level which necessitated a recalibration.) The “VIS-IR” and “IR only” rainfall rate relationships for each month have been applied to half-hourly visible and IR (1024x1024) images at 2 km resolution to estimate daily accumulations over the Mackenzie Basin and surrounding regions. Typically, images for 40 to 45 half-hourly time intervals were available per day, although the last two weeks August contained a 10-hour had between 04.00 and 14.00 GMT. Of course, for approximately 2/3 of the time, the “IR. only” relationship had to be used when the visible data became contaminated by low sun angle effects and then is unavailable at night. “Five-day” and monthly accumulations were then derived over the same area at 16 km resolution and made available to other GEWEX users. (A monthly estimate for May was not attempted because of a data gap of 14 days that is considered too large).

The Satellite accumulations for June, July and August, ‘96 have been recently compared with the CMC monthly analyses of surface rainfall. The latter employ a combination of point gauge rainfall measurements and of made forecasts to derive distributed rainfall amounts from which monthly totals are computed. A compensating factor has been applied to the June and July satellite estimates in order to account for the 4 and 6 missing days respectively. Considering the heavy reliance on “IR. only” data, the remoteness of the Carvel training region from the area of application, the simple correction for the missing days and the significant data gaps on many days, the satellite estimates appear qualitatively adequate, with coinciding maxima and minima, although the quantitative estimates from both sources may differ appreciably. Given the scarcity of gauge measurements in our area on interest, any comparison with this “ground truth” should be viewed as a “difference” rather than as an “error”. Comparisons have thus been performed in terms of the cross-correlation coefficient, y, the mean absolute difference, MAD, and of the RMS difference. Even though the satellite estimates are computed over a (128x128) array at 16 km resolution that includes a portion of the Pacific Ocean and much of BC, a quantitative comparison has been made only over the Mackenzie Basin, since the RAINSAT algorithm is not expected to adequately reproduce the intensity of the orographic rain along the BC coast. In the table that follows, statistics have been derived for (16x16) km2 areas. However, given the relatively smooth nature of both fields, very little improvement has been observed when comparisons were also performed at 48 km resolution. The bias, defined as the ratio of the mean “RAINSAT” and of the “CMC” estimates, is intended as an indication of an overall overestimation or underestimation over the entire basin. The average rainfall R in mm over the basin is also provided and is used to express the MAD and RMS statistics as percentages.

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<td>64.1</td>
<td>66.7</td>
</tr>
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<td>0.64</td>
<td>0.51</td>
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<td>[y]</td>
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<tr>
<td>[MAD]</td>
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<td>[1.25]</td>
<td>[1.61]</td>
</tr>
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<tr>
<td>[R (MAD)]</td>
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<td>[36]</td>
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67
The Scores in () brackets are derived after removing observed bias from the satellite estimates. To identify any improvement in skill provided by the visible data, the statistics derived from comparisons of “IR. only” estimates are included in [] brackets. Finally, in {} brackets are the scores obtained when the bias from the “IR. only” estimates is likewise removed. Even though the visible data can be used for only approximately 1/3 of the time, these comparisons reveal that they generally produce rainfall fields with higher correlations and lower “errors” than those generated with only IR. data. However, compensation for the bias renders the “IR. only” MAD and RMS statistics almost as good as those of the “bias corrected” VIS-IR method. The overall assessment of this monthly satellite estimates can only be made by the potential users. It may be considered positive if MAD scores in the 30% to 40% range and a correlation coefficient of at least 0.5 are judged sufficiently accurate. Further improvement can be expected if a radar data training set can be made available in the more northerly section of the Mackenzie Basin.

**Reports:**
4.7 CLOUD PROFILING FROM IPIX RADAR

S. Haykin
(Presented by H. Pasika)

Abstract not available.
4.8  PARAMETERIZATION OF EVAPOTRANSPIRATION USING REMOTELY-SENSED DATA

\textit{1Raoul Granger, 1John Pomeroy, 2Ric Janowicz and 3Normand Bussières}

\textit{1National Hydrology Research Institute, 2Indian and Northern Affairs Canada, 3AES/CCRD/CCRP}

During the 1994, 1995 and 1996 snow-free seasons, data collection was continued at the Prince Albert and Whitehorse research sites. At the Prince Albert site, four instrument towers are maintained (at Jackpine, mixed wood, a recent clearcut and a regenerating cut site). At the Wolf Creek Watershed (Whitehorse), three instrument towers are maintained (at jackpine forest, highbush taiga and alpine sites). Energy balance estimates are being prepared using the data from these sites; the evapotranspiration estimates will be used for the verification of the remote sensing procedures, and the observed surface temperature and net radiation values will be used for the calibration of the remote sensing algorithms used to estimate these parameters. Eddy-correlation equipment was deployed at various sites during special observation periods; the data collected allowed for the direct determination of the roughness parameters for these sites as well as for the establishment of relationships between the daily vapour transfer coefficient and the roughness of the surface cover. These relationships are essential for use in the daily evapotranspiration model used in conjunction with remotely-sensed data.

Data obtained from field observations above various forest cover types (coniferous and mixed-wood stands) in the southern boreal forest were used to develop relationships and algorithms for use in the estimate of areal evapotranspiration with remote sensing. The AVHRR channel 2 albedo (normalized using the cosine of the solar zenith angle) was used to develop a simple algorithm for the broadband surface albedo which, in conjunction with daily net radiation at a surface.

A split-window technique was shown to be useful to obtain reliable estimates of the land surface temperatures for conditions where atmospheric corrections using standard atmospheric models are not feasible because of a lack of data (ie. from atmospheric soundings). A feedback relationship was used in conjunction with remotely-sensed surface temperature observations to provide a useful estimate of the vapour pressure deficit in the air layer overlying the surface. An algorithm based on this feedback relationship was shown to be applicable to a variety of forest land cover types, as well as for the agricultural surfaces for which it was originally developed.

The satellite-derived estimates of net radiation and vapour pressure deficit can be used as input data to a conventional evapotranspiration model, allowing for evapotranspiration estimates derived using only the information provided by the satellite-mounted sensors. These satellite-derived evapotranspiration estimates compare favourably with estimates obtained with a conventional evapotranspiration model using data from a network of field stations.
Work will continue toward the production of evapotranspiration maps using remotely-sensed data. A separate project, conducted by Normand Bussières (co-investigators are R. Granger and K. Goïta), deals specifically with the application of satellite evapotranspiration algorithms.

**Publications and Conferences:**


Granger, R.J., 1997. Comparison of surface and satellite-derived estimates of evapotranspiration using a feedback algorithm. Third international workshop on the application of remote sensing in hydrology, in press.


5.1 WATER LEVEL AND FLOW PROJECTIONS FOR LARGER NWT LAKES, MAINSTEM MACKENZIE RIVER, AND THE MACKENZIE DELTA

J.A. Kerr and J N. Jasper
(Presented by C. Spence)
Atmospheric & Hydrologic Sciences Division
PO Box 2970, Yellowknife
Environment Canada, Yellowknife, NT X1A 2R2

General:

The goal of Environment Canada’s NWT GEWEX project is to derive estimates of future flows and water levels throughout the NWT portion of the Mackenzie Basin, by utilizing climate change and hydrologic study results for the Mackenzie Basin as inputs to departmental water balance and flow routing models.

Use of output from Global Circulation Model and hydrologic models for prediction of impacts of climate change in the Mackenzie Basin requires application of hydrologic and hydraulic engineering models. Runoff from headwater areas must be routed through large lakes, other inflows must be added, and all flows must be routed down the Mackenzie River and through the Mackenzie Delta using hydraulic engineering techniques. The following Environment Canada tools are being used:

1. Lake water balance and routing model - applied to G Slave and G Bear lakes (from 1973)
2. Operational Mackenzie River/NWT water level and flow forecast system, adapted to study downstream impacts of climate change on Mackenzie River mainstem reaches (from 1973)
3. 1-D Mackenzie Delta Model - applied to 85-channel Mackenzie Delta system between the delta head and the Arctic Ocean (from 1982)
4. Auxiliary tools, including water level and flow void completion, establishing input and output data sets, computing ungauged tributary inflows, defining stage-outflow curves for large lakes, analysis of lake evaporation by the water balance method, etc.

Milestones and Upcoming Tasks:

1. Historic and climate-change water level, flow and climate datasets with voids completed were prepared in 1996-97 for the period 1973-92, and are being updated to include data from 19794-96 (with documentation on how voids were completed, including a three-character “footnote” in the database after each completed void). These datasets are being prepared for access by other researchers. Copies of many of the datasets will be sent to the GEWEX Data Center at Downsview in 1997-98.
2. Ungauged tributary inflows (for the NWT portion of the Mackenzie Basin) were computed for the period 1973-92, and are being refined and updated to include 1994-96 data.

3. Stage-outflow curves were derived for Great Slave and Great Bear lakes in 1996-97, and will be refined. For Great Slave Lake, the latter work includes routing from Great Slave Lake to Mills Lake using the cross sections and model (US Army Corps of Engineers HEC-2) prepared by Dr. Faye Hicks, University of Alberta for NWT Ferries studies (and to Fort Simpson using the EC SIMMAC Streamflow Routing Model).

4. Great Slave and Great Bear water levels for the period 1973-92 were analyzed in detail in 1996-97, including corrections for effects from beginning-of-month winds and lake water temperatures on lake water volumes and levels. This work will be updated to include the period 1994-96 in 1997-98.

5. Estimates of inflow-available-for outflow (net basin supply) and evaporation by the water balance method were made for Great Slave and Great Bear lakes in 1995-96 and 1996-97 for the period 1973-92. Refined estimates are underway for the periods 1973-94, using updated ungauged tributary inflows and outflows and corrected precipitation and lake water levels. In 1997-98, evaporation computed by the water balance method will be compared with evaporation computed by formulas by NHRI/Saskatoon, and collaboration with these and other researchers is planned to assess the impacts of climate change on lake meteorology, evaporation and sub-basin flows.

6. Historic flows routed through the two lakes and down the Mackenzie River for the period 1972-93 in 1995-96 were updated in 1996-97, using corrected precipitation over the two lakes and refined routing model coefficients. Historic flows for 1973-92 were also routed through the Mackenzie Delta in 1995-96. Rerouting of historic flows through the two lakes and down the Mackenzie River system will be updated to include 1994-96 data during 1997-98, after further refining input data as noted above.

7. Climate-change flows have been routed through Great Slave and Great Bear lakes and down the Mackenzie River system for the period 1973-92, and will be updated to include 1992-96 data during 1997-98, when improved climate-change flows from hydrologic input models become available and the refinements listed above have been completed.

**Reporting:**

1. Progress reports in form of papers summarizing work were distributed at May/95 GEWEX Banff and at May/96 MBIS Yellowknife workshops - the latter paper was subsequently updated to include additional work, and is being published in the MBIS Workshop Proceedings in March 1997 (copy of paper attached).
2. This 1996-97 GEWEX Progress Report, an accompanying GEWEX FUNDING REQUEST for 1997-98, and the MBIS paper, document work done and planned.

3. Additional papers and reports scheduled for the period April 1, 1997 to March 31, 1998, including information on historic and void-completed water level and flow databases, documentation on the lower Mackenzie Basin flow routing model, analysis of lake water balance and evaporation, and results of routing model recalibration (ungauged NWT inflows) and revised tributary basin flows by others based on GCM model outputs.
5.2 DEVELOPMENT OF AN INTEGRATED HYDROLOGIC MODELLING SCHEME FOR GEWEX

E.D. Soulis and N. Kouwen
(Presented by F. Seglenieks)
Dept. of Civil Engineering, University of Waterloo

This year’s work has focused on:

- establishing the land surface data base for the MAGS area
- implementation of the current version of WATFLOOD on the Mackenzie River Basin
- development of the code for WATFLOOD/CLASS
- completion of Phase II of the distributed monthly water balance for the Basin

The starting point for the land surface data base was the 5’ by 5’ raster data base developed for the Mackenzie Basin Impact Study (MBIS) but this has been replaced by a data base using the USGS 30 arc second Digital Terrain Model for North America. This new high resolution data set has enabled us to develop and verify techniques for the automatic establishment of pixel-to-pixel drainage direction in the data base and to define watershed structure in the Basin. Basin delineation for over 200 WSC basins have been checked for accuracy by using WSC reported drainage areas and NAIS digital blue line maps. Errors to date are acceptable. Estimated areas are generally within 5% of the reported areas and the computed blue lines match the map blue lines satisfactorily at scales of over 10km.

Techniques have been developed to build the required watershed files for simulation of streamflow throughout the Basin. Files have been generated for both a lat/lon projection (12.5’x25’) for nesting within the CCC GCM grid and a 35 km polar stereographic projection for use with the numerical weather prediction models.

Land cover data in the original data base has been replaced by the recently released USGS 1km AVHRR based land cover characteristics data base for North America.

Initial tests of the files are complete. WATFLOOD was successfully implemented for the Basin and trail runs were completed using forcing data interpolated from CCC GCM 1xCO2 output. The timing of the hydrographs is satisfactory at Arctic Red and at 7 modelled sub-basins, although flows are generally too high due to high precipitation in the GCM output. Data from April 1996 to March 1997 are being extracted by GCM from the 35 km RFE archive for more detailed tests.

Code for WATFLOOD/CLASS is complete. Conceptual issues between the models have been resolved and parameter estimation for the combined model is in progress using a southwestern Ontario 01Jan93 - 30Jun93 dataset over 4 watersheds. The rainfall...
response is satisfactory but snowmelt peak flows are too high and too early. This is under investigation. The model is also being tested using BOREAS transact data.

Code for CLASS/WATFLOOD has been designed but not implemented.

Phase II of the distribution monthly water balance task is complete. The hydrometric data has been assembled from 1950 to 1993 and cross-correlation work has been conducted to extend the records using a new seasonally-based approach. Mean monthly flows have been generated for about 200 stations in the basin, which is about double the number available for Phase I. Corrected station precipitation data, received from Bill Hogg - AES Downsview, have been used in place of the recorded data. The standard errors of the interpolation equations have been reduced by a factor of 2 using the improved data set. Phase III, which involves joint mapping of the new runoff and precipitation fields, is in progress.

RESEARCH PLAN FOR 1997/98

Work in the forthcoming year will focus on refinement and testing of the uncoupled model WATFLOOD/CLASS. Parameter testing in southern regions will be completed using the southern Ontario 1993 data set. Preliminary northern latitude algorithms will be implemented as part of the analysis of the BOREAS transect data sets. A trial year (01Apr96 to 31Mar97) of RFE 35km archived data will be used to test the integrity of the modelling system, verify the drainage layer database for the Makenzie and to conduct preliminary calibration runs.

Preparation for coupled modelling will continue. We expect to implement the designed code for CLASS/WATFLOOD in CLASS 3.0 and to conduct preliminary tests on the research basins.

Phase III of the monthly water balance project will begin. Incorporation of the large lake effects will be completed and analysis of the information content of the winter flow records for joint mapping will be conducted at selected stations.
PART 1: DEVELOPMENT OF A DISTRIBUTED HYDROLOGICAL MODEL OF THE MACKENZIE BASIN

G.W. Kite, U. Haberlandt and B. Li
National Hydrology Research Institute, Saskatoon, Canada

Introduction

To complete a model of the global hydrological cycle, atmospheric and oceanic circulation models must be linked by a continental-scale hydrological model. Such a hydrological model will model land surface and subsurface interactions with the atmosphere and transfer land-phase water to the oceans. As a step towards such a model, a semi-distributed hydrological model of the 1.8 million km$^2$ Mackenzie Basin has been prepared for use with atmospheric data sets of different scales. The first version of this model (Kite et al., 1994) divided the basin into five sub-basins, used only five land cover types and used simple hydrological routing for the large lakes within the basin. The current version of the model uses thirty-nine sub-basins, ten land cover types and includes explicit lake routing. The earlier version of the model was used only with large-scale data from the CCC GCM; the current version has also been run with 35km resolution data from the RPN Regional Finite Element model and will be run with other data sets.

Data

Time-invariant data for the Mackenzie Basin are described in Kite et al. (1994). Elevation data are from digital NTS maps and land cover distribution was derived from 1km NOAA AVHRR data. Basin outlines and stream networks were obtained from Water Survey of Canada and stage-storage/stage-outflow relationships for Great Slave and Great Bear Lakes were derived by Kerr (1996). Observed air temperature, dewpoint temperature, precipitation and radiation for the Mackenzie Basin were obtained from AES archives, GCM data were obtained from CCC (1991) and RFE 35km data from Recherche en prévision numérique (RPN), Dorval, (Benoit et al., 1995).

Geostatistical interpolation techniques were used to derive areally-averaged data from recorded climate data. Precipitation and temperature data were adjusted for elevation using a rate of change of precipitation with elevation of 5% per 100 m and dry adiabatic lapse rates of 0.75EC/100 m for temperature and 0.15EC/100 m for dewpoint temperature. Temperature and precipitation data computed in the atmospheric models already account for elevation.

Model

SLURP (Kite, 1993) is a continuous simulation semi-distributed hydrological model in which the parameters (such as interception coefficients, surface roughness, infiltration coefficient, snowmelt rates, soil moisture and groundwater storage characteristics) are
related to land cover (vegetation type). The model can take into account changes in the
distribution and type of land cover over time. The model divides a watershed into
hydrologically-consistent sub-units known as aggregated simulation areas (ASA). An
ASA is a grouping of smaller areas with similar properties. For example, land cover may
be measured from satellite with pixels as small as 10m but it would be impracticable for a
hydrological model to operate at such a dimension for a macroscale basin. Instead, the
pixels are aggregated into larger ASAs. Similar constructs have been used by Kouwen et
al. (1993) and Stuttard et al. (1994).

Figure 1

Mackenzie Basin ASAs
for SLURP Model
At each time increment of the simulation period SLURP carries out a vertical water balance for each element of the matrix of ASAs and land covers. Each element is simulated by reservoirs representing canopy interception, snowpack, rapid runoff and slow runoff. Interception depends on the leaf area index (LAI) and the vegetation type and eventually either evaporates or falls onto a snowpack or bare soil. Evaporation occurs from the soil moisture in the rapid store and transpiration occurs from soil moisture in the slow store. The outputs from each vertical water balance include evaporation, transpiration, runoff and changes in canopy storage, snowpack, soil moisture and groundwater. Runoffs from each land cover are accumulated within an ASA and the combined runoff is converted to streamflow and routed through each ASA to the basin outlet.

**Results**

The model has been calibrated for the Mackenzie Basin using daily observed climate data for 1986-1987 for 39 ASAs (Figure 1). Figure 2 compares flows simulated by SLURP using 1986-1990 observed climate data, using 10 years of 1 x CO₂ and using 10 years of 2 x CO₂ data to the recorded flows for 1986-1990.

**Conclusions**

A semi-distributed hydrological model has been calibrated with observed climate data and run with GCM data and preliminary RFE data. Early RFE data are at 50km resolution and have no radiation data. The missing radiation data will be interpolated from climate stations or from other models and the data will be resampled to the 35km resolution. Data from other atmospheric models will also be used. The study will work closely with the GEWEX atmospheric moisture budget study (Strong et al., 1996) and the GEWEX cold region processes study (Pomeroy et al., 1997).

**References**


### Mackenzie Basin Water Balances, mm/yr
As Recorded and as Simulated by SLURP Hydrological Model

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\(^*\) daily data for 1986-1990 from the climate network.
\(^**\) daily data for 10-year experiments.
\(^***\) sum of flows at gauging stations 10LC014, Mackenzie River above Arctic Red River; 10LA002, Arctic Red River near the mouth; 10LC002, Peel River above Ft. McPherson, 1986-1990.
Comparison of simulated and recorded long term mean monthly streamflow, Mackenzie River above Arctic Red

Figure 2
PART 2: USING TOPEX/POSEIDON DATA TO ESTIMATE ELEVATIONS AND AREAS OF MACKENZIE BASIN LAKES

G.W. Kite\(^1\) and C.M. Birkett\(^2\)

\(^1\) National Hydrology Research Institute, Saskatoon, Canada
\(^2\) Mullard Space Science Laboratory, University College London, U.K.

Introduction

A hydrological model of the 1.8 million km\(^2\) Mackenzie River Basin was first prepared in 1994 but used only simple hydrological routing for water flows through the three main lakes - Lake Athabasca, Great Slave Lake and Great Bear Lake (Kite et al., 1994). These lakes occupy an area of 65,000 km\(^2\) and need to be modelled in more detail. However, the levels of the lakes are measured at only a few points and river flows are sometimes measured a considerable distance downstream of the lakes. It has previously been shown that satellite remote sensing can provide measurements of lake surface area using imaging techniques and lake level using radar altimetry (Birkett, 1994). These techniques were applied to estimate levels and areas of the Mackenzie Basin lakes. Full details of the study are provided in Birkett and Kite (1997).

Data

The derivation of lake level changes using satellite radar altimeter measurements has two main advantages (Birkett, 1994); the measurements are with respect to a single reference datum, and they can provide information for regions where access is restricted or data are unobtainable. TOPEX/POSEIDON is a joint NASA/CNES mission which carries two radar altimeters (NRA and SSALT). This study used data every 0.1s (or ~580m on the surface) for cycles 1 to 120 (September 23, 1992 to 27th December, 1995) from the CNES Geophysical Data Records. This analysis was limited to one pass per lake i.e. pass 095 for Athabasca, pass 254 for Great Slave Lake and pass 225 for Great Bear Lake (Figure 1). TOPEX/POSEIDON surface elevation estimates have an accuracy of 3-4 cm rms (Tapley et al., 1994).

Lake surface areas were estimated using the NOAA AVHRR Satellite Active Archive System (SAA) dataset from 1st March 1994 to date. 1km pixel resolution, 2048 pixel-wide swath width "LAC" images were utilised. Channels 1 (Visible) and 2 (Near Infrared) were used as ice detectors, with the thermal channels used in extreme cases if ice flow "patterns" were easily identifiable. The Mackenzie Basin lakes suffer from major cloud contamination. During winter no cloud-free scenes of Lake Athabasca could be located, the images split equally between partial and total cloud. Great Slave Lake had no cloud free images from October to December in 1994 and the statistics were so poor that analysis of 1995 images was abandoned. For Great Bear Lake, no cloud free images were located for October and November 1994, and October 1995.
Results

a) Lake Level

TOPEX/POSEIDON relative lake level time series were computed for the period September 1992 to December 1995 and compared with lake levels recorded at shoreline gauges for the three lakes (see Figure 1). The NRA and SSALT heights are only relative levels and must be related to a datum before being used as absolute lake levels. For all lakes the datum used was arbitrary but Figure 2 shows, for Lake Athabasca as an example, that the satellite lake levels agree reasonably well with recorded lake levels given that we are comparing areal averages with point measurements. For clarity, 20-point moving averages have been applied to all the data.

For all three lakes the correspondence between satellite and ground-based levels breaks down in winter. Microwave radiation has the ability to penetrate sea ice resulting in a lower than true estimate of the height, with height biases in the centimetre range (Birkett, 1995). The depth of penetration depends on the radar frequency and the ice temperature, density and thickness and will be offset by the freeboard of the ice itself. It is interesting to note the uniform decline in altimetric "lake surface" height during the winter months for Lake Athabasca and one may speculate that this is some representation of ice thickness/snow cover which increases as the winter progresses.
b) Lake Surface Areas

Estimates of lake surface area were made using a Local Isoluminance Contour routine. This is a standard software package which has been used previously with accuracies of ~1% (Harris, 1994); however, the routine had difficulty coping with the complex coastlines of the Mackenzie lakes and often failed to close the perimeter contour. Instead, a manual package (Macintosh/Quad IMAGE 1.2.3 software) was used. Pixel numbers were converted to km² using the satellite and lake altitudes, the latitude of the lake, and the location of a pixel marking the centre of the lake. Plotting the individual lake as measurements versus time showed considerable scatter and no clear seasonal variations. The following table shows the mean summer lake surface areas (areas of large islands not included).
## Conclusions

The radar altimeters on the T/P satellite can monitor both seasonal and interannual variations in lake level during ice-free conditions. All three lakes show level variations (expected accuracy "4cm rms) ranging from 0.18m (summer 1995, Great Bear) to 0.97m (summer 1994, Athabasca). Lake Athabasca has an unusual summer signature, with levels seemingly rising as the lake emerges from its thaw period, before finally reaching a peak and declining again. Great Slave Lake and possibly Great Bear Lake appear to have immediate declines in level as the lakes thaw. The large drops in level estimated by satellite during the ice-covered periods on all three lakes require further investigation.

The results of the area analysis are poor, with AVHRR imagery being hindered by cloud interference and an inadequate geometrical correction of the raw images. The results show that at best we can only assume the areas of the lakes remain constant during the summer. The errors, ~3%, reflect the 1 sigma variability in the area time series and the averaging of 1994/1995. These errors are much larger than the predicted 1% although the resulting areas are comparable to ground/areal survey results. Future work should consider the use of Radarsat; this provides data regardless of cloud cover.

## References


5.4 APPLICATION OF A RADIATION-TEMPERATURE INDEX SNOWMELT MODELS TO THE LOWER LIARD RIVER VALLEY

Alain Pietroniro\textsuperscript{1}, Larry Hamlin\textsuperscript{1}, Terry Prowse\textsuperscript{1}, Ric Soulis\textsuperscript{2} and Nick Kouwen\textsuperscript{2}

\textsuperscript{1} National Hydrology Research Institute, Environment Canada, Saskatoon, Sask.
\textsuperscript{2} Dept. of Civil Engineering, University of Waterloo, Waterloo, Ont.

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. Two indexed snowmelt algorithms derived for individual land-cover component characteristics of the wetland dominated region are compared. These algorithms use an hourly temperature index and a combination radiation-temperature 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 discretization. Snowmelt indices are estimated for both approaches using snowcover depletion data obtained during an extensive field campaign. Parameter optimisation is used to obtain the index values for this calibration period (Tables 1 and 2). The indices are then validated using historical data from complimentary studies. Results show that the radiation-temperature algorithm provided slightly improved calibration results, however both algorithms validated equally well (Table 3).

Table 1. Calibrated Snowmelt Parameters for the Temperature Index Model.

<table>
<thead>
<tr>
<th>Vegetation Regime</th>
<th>Melt Factor ($\alpha$) [$\text{mm} \cdot \text{C}^{-1} \cdot \text{h}^{-1}$]</th>
<th>Normalize dRMS Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous/Mixed Forests (Class 1)</td>
<td>0.075</td>
<td>0.222</td>
</tr>
<tr>
<td>Coniferous Forests (Class 2)</td>
<td>0.075</td>
<td>0.225</td>
</tr>
<tr>
<td>Transitional Forests (Class 3)</td>
<td>0.140</td>
<td>0.206</td>
</tr>
<tr>
<td>Open Wetlands (Class 4)</td>
<td>0.120</td>
<td>0.296</td>
</tr>
</tbody>
</table>
Table 2. Snowmelt Parameters for the Temperature-Radiation Index Model.

<table>
<thead>
<tr>
<th>Vegetation Regime</th>
<th>Melt Factor ((\alpha)) [mm (\cdot \degree C^{-1} \cdot h^{-1})]</th>
<th>Radiation Melt Factor (rn) [mm (\cdot (W/m^2)^{-1} \cdot h^{-1})]</th>
<th>Normalized RMS Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous/Mixed Forests (Class 1)</td>
<td>0.005</td>
<td>0.0112</td>
<td>0.202</td>
</tr>
<tr>
<td>Coniferous Forests (Class 2)</td>
<td>0.035</td>
<td>0.0070</td>
<td>0.196</td>
</tr>
<tr>
<td>Transitional Forests (Class 3)</td>
<td>0.045</td>
<td>0.0118</td>
<td>0.201</td>
</tr>
<tr>
<td>Open Wetlands (Class 4)</td>
<td>0.035</td>
<td>0.0128</td>
<td>0.291</td>
</tr>
</tbody>
</table>

Table 4. Statistical Evaluation of Results.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous/Mixed Forests TI</td>
<td>0.2796</td>
<td>0.0735</td>
<td>0.0892</td>
<td>0.2222</td>
<td>0.6645</td>
</tr>
<tr>
<td>Deciduous/Mixed Forests RTI</td>
<td>0.2562</td>
<td>0.0757</td>
<td>0.1068</td>
<td>0.2024</td>
<td>0.6411</td>
</tr>
<tr>
<td>Deciduous/Mixed Forests % Improv</td>
<td>+8.4</td>
<td>-2.9</td>
<td>-19.7</td>
<td>8.9</td>
<td>+3.5</td>
</tr>
<tr>
<td>Coniferous Forests TI</td>
<td>0.3205</td>
<td>0.0831</td>
<td>0.1546</td>
<td>0.2254</td>
<td>0.7836</td>
</tr>
<tr>
<td>Coniferous Forests RTI</td>
<td>0.2438</td>
<td>0.0734</td>
<td>0.2182</td>
<td>0.1962</td>
<td>0.7316</td>
</tr>
<tr>
<td>Coniferous Forests % Improv</td>
<td>+23.9</td>
<td>+11.6</td>
<td>-41.2</td>
<td>+13.0</td>
<td>+6.6</td>
</tr>
<tr>
<td>Transitional Forests TI</td>
<td>0.3124</td>
<td>0.1295</td>
<td>0.1740</td>
<td>0.2061</td>
<td>0.8219</td>
</tr>
<tr>
<td>Transitional Forests RTI</td>
<td>0.3662</td>
<td>0.1079</td>
<td>0.3379</td>
<td>0.2012</td>
<td>1.0132</td>
</tr>
<tr>
<td>Transitional Forests % Improv</td>
<td>-17.2</td>
<td>+16.7</td>
<td>-94.2</td>
<td>+2.4</td>
<td>-23.3</td>
</tr>
<tr>
<td>Open Wetlands TI</td>
<td>0.4597</td>
<td>0.1109</td>
<td>0.2864</td>
<td>0.2956</td>
<td>1.1526</td>
</tr>
<tr>
<td>Open Wetlands RTI</td>
<td>0.2486</td>
<td>0.2497</td>
<td>0.2346</td>
<td>0.2913</td>
<td>1.0241</td>
</tr>
<tr>
<td>Open Wetlands % Improv</td>
<td>+45.9</td>
<td>-125.2</td>
<td>+18.1</td>
<td>+1.5</td>
<td>+11.1</td>
</tr>
<tr>
<td>% Improvement By Year</td>
<td>+18.8</td>
<td>-27.6</td>
<td>-27.4</td>
<td>+6.4</td>
<td>+0.4</td>
</tr>
</tbody>
</table>

Note: The average normalized Root Mean Squared (RMS) error was calculated using Equation 3. 
TI represents the Temperature Index model 
RTI represents the Radiation-Temperature Index model
5.5 CLIMATE MODELLING OVER THE MACKENZIE BASIN, AND CLOUD FIELDS

Ron Stewart and Kit Szeto
Climate Research Branch, Downsview, ON

1. OBJECTIVES

The overall objectives of this project are to quantify the ability of the Regional Climate Model to represent the critical Basin water and energy cycles and it will in addition ensure that cloud fields and their impacts are properly accounted for in this model.

The project will be carried out over several years and will be comprised of several milestones. The 1996/97 goals were to address the following issues:

- The role of sub-cloud sublimation on the Basin’s water budget during BASE
- The development of a column model for assessing parameterizations
- The acquisition and initial use of ISCCP information
- Initial experiences with the regional climate model for MAGS

2. PROGRESS

All of these tasks were achieved in 1996/97 and in fact were exceeded. This is illustrated by the following overview information.

The regional climate model was initialized by AMIP fields in order to quantify differences in predictions over the Basin between the GCM and RCM. In order to accomplish this, a suite of diagnostic tools was developed with IDL software for displaying and diagnosing many parameters from the model and for comparing against available observations on time. The regional model being used within BALTEX is being applied to the MAGS region to begin the process of transferability. A journal article on the RCM effort has been started with completion in spring 1997.

The International Satellite Cloud Climatology Project (ISCCP) information was acquired to assess the impacts of clouds over the Basin on water and energy cycles. This information is being used to develop long-term climatology, to relate anomalous discharge and temperature years to cloud fields, and to act as a validation dataset for the RCM. A journal article should be completed in summer 1997.

A tool has been developed to allow for the testing of many parameters for the GCM/RCM. This is a column model that can be forced by a variety of large scale and surface conditions and within which one can alter the parameterizations used within larger models such as the GCM/RCM. It is being used first of all to assess the parameterizations of these large scale models to account for cloud fields but in general it can be applied to any other field.
The falling snow scientific project was completed and a journal article on the impacts for the MAGS region water budget is under preparation.

3. SCIENTIFIC RESULTS

The results of these efforts have led to several scientific results which are briefly summarized here:

From the RCM effort:

• For the selected AMIP run periods in the initial studies (1987), the GCM and RCM Basin-scale monthly precipitation amounts were similar but this is fortuitous since on a daily basis within the month there were many discrepancies on Basin averages.
• Lee cyclogenesis is not well handled in the GCM although it is critical to Basin water and energy cycles; the RCM is able to account for this phenomena in most instances.
• Development of secondary warm fronts over the Basin and the ensuing critical precipitation is missed in the GCM but simulated in the RCM.

From the cloud effort:

• The average cloud fraction over the Basin on a yearly basis is estimated to be about 60% with highest values in the summer
• There is a systematic difference in cloud fraction between years of anomalously high and low temperature over the Basin; this is consistent with our hypothesis of the role of moist processes on Basin warming signatures.
• Many of the clouds affecting the Basin are very inefficient at simulating snow and a model intercomparison study to assess needed changes to properly account for this in large scale models has been started.
• It was estimated from the basis of detailed observations and model runs that about 50% of the snow produced aloft within autumn clouds is sublimated before reaching the surface.

4. SUMMARY

1996/97 was a very critical year in which several major efforts really developed. There has been considerable time acquiring and developing the tools needed to realize the project’s objectives and this is now really paying off in terms of scientific productivity. 1997/98 and beyond will be able to further exploit these background efforts.

5. REFERENCES

Some scientific results from 1996/97 were published as follows:

MacKay, M. D., R.E. Stewart and G. Bergeron, 1997: Downscaling the hydrological cycle in the Mackenzie Basin with the Canadian Regional Climate Model. Workshop on Regional Arctic Climate Models, Nov 4-6, Bracknell (In press)


5.6 DEVELOPING A GLOBAL NUMERICAL WEATHER PREDICTION SYSTEM FOR THE CANADIAN GEWEX PROGRAMME

H. Ritchie, P. Gauthier, J. Mailhot, Y. Delage
Environment Canada, (CMC), Dorval, Quebec

The MacKenzie GEWEX Study goal to reach by the year 2000 is to have identified, understood and quantified the critical processes that influence the basin's water and energy cycles on periods of one to several months. The objective for the year 2005 is to examine the prediction of changes in water resources (including discharge into the Arctic Ocean) and surface moisture on seasonal to annual time scales. In order to achieve these goals, it will be necessary to have a state-of-the-science global data assimilation and forecast system that adequately resolves the MAGS region and has been validated for water and energy cycles on time scales of up to several months for the year 2000 objective, and even longer by the year 2005. The Canadian global spectral numerical weather prediction system is being extended to help achieve these goals.

The first step completed in 1996/1997 was to finalize the article by Ek and Ritchie (1996) whose objective was to quantify the uncertainty (due to uncertainties in the initial conditions) in water and energy budgets over the MAGS area in monthly simulations with the current operational monthly forecast version of our model. This was important to establish because it gives us a measure of the confidence that we can have in the budgets calculated in simulations on these important GEWEX space and time scales. It was found that the uncertainty increases rather markedly after two weeks.

Due to the reduced level of funding awarded for this project last year, it was necessary to temporarily interrupt the work until Zonghui Huo was hired under contract. Three months later he left to take up a longer term position at the University of Oklahoma, and was replaced by Ekaterina Radeva. Zonghui and Ekaterina have carried out a study similar to the Ek and Ritchie one, using an upgraded model which includes some changes to the surface layer parameterizations. The model generates nine-member ensemble simulations of one month duration from perturbed analyses produced by the bred-mode technique (Houtekamer et al.), for various times of the year. 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. Preliminary results show that the surface energy and water budget fields exhibit moderate variability that increases with time. The ensemble standard deviations 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 occurrence is delayed by five to ten
days. This investigation suggests that, with this version of the model, the forecasts of hydrological parameters on the basin scale have definite value out to about twenty days.

Work has begun to measure the budget impacts that will come from improved treatments of land-surface processes via the Canadian Land Surface Scheme (CLASS). The running of CLASS within this project will provide for continuous validation of the CLASS model in real time and an analysis of errors at a scale considerably larger than that being addressed in the regional climate model within the land surface node by Verseghy et al., and in the RFE-MC2 GEWEX projects by Benoit, Yau and Zhang, etc. This was identified as an important contribution in the funding decision that was rendered on this project last year. CLASS has already been tested out to five days in an earlier version of the global spectral forecast model, and appears to produce moisture forecasts that are superior to the current operational scheme. In addition, it makes provision for snow-melt - absent in the operational model - which is a major component of the Mackenzie River discharge in May and June. CLASS has been installed in the upgraded version of the forecast model mentioned above, and testing is in progress.

**PUBLICATION**

5.7 HIGH RESOLUTION SIMULATIONS OF "WARM" AND "COLD" MESOSCALE PRECIPITATION SYSTEMS OVER THE MACKENZIE RIVER BASIN

M.K. (Peter) Yau and D.-L. Zhang
McGill University, Montreal, Quebec

As detailed in our GEWEX proposal, research for the past year was focused on the implementation and evaluation of physics modules for MC2. Our emphasis was on warm and cold rain microphysics modules, as well as convective parameterization modules. The following tasks have been completed:

(1) An explicit, efficient warm rain and ice crystal microphysics scheme has been successfully implemented into MC2. The new scheme includes explicit predictive equations for cloud water, rain water, ice/snow, and graupel/hail. The scheme has been released in version 3.4.3 of MC2.

(2) Testing of the scheme in the context of "cold" and "warm" mesoscale precipitation systems is continuing. In the former case, the scheme produced many observed features in an explosive winter cyclone. They include realistic cloud and precipitation distributions compared to satellite measurements, intense cold and warm frontal structures, intense convection near the triple point, and the warm core seclusion. A case of severe convection over Alberta was selected to validate the scheme in a "warm" mesoscale system. It was shown that the timing and location of convection, and the distribution of humidity, cloud, and radar echoes were realistic as verified against observations. A study of the water vapor transport indicates the importance of the Gulf Stream as a source of moisture over Alberta during the summer season.

(3) A parameterization for slantwise convective adjustment has been developed and was tested under idealized conditions.

(4) Two BASE cases (September 8-11 and September 24-26) have been simulated using MC2 using a resolution of 50 km. Both cases satisfied the criteria for lee cyclogenesis. Strong interaction between the cyclone and the topography was found. The major physical processes are the formation of an upper-level short wave, the stretching of air columns, the enhancement of convergence and relative vorticity due to adiabatic warming, diabatic heating arising from the release of latent heat and the increase in baroclinicity due to low-level blocking by topography. Sensitivity experiments show that the mountains significantly influence the distribution of precipitation with climatological consequences for areas in the lee.

For the coming year, we will follow closely our schedule set forth in our proposed milestones. High resolution (grid size of several km) simulation of "warm" and "cold" mesoscale convective systems will be our focus in 1997. The following tasks are expected to be completed during this period:
(1) Implement and test the slantwise convective adjustment scheme in MC2.

(2) High resolution simulation of mesoscale convective systems. For the "cold" system, we will continue to work on the September 24-26 and September 8-11BASE cases. We have already obtained a good simulation on the meso-beta scale for this storm. The output from the 50 km run will be used to cascade higher resolution runs down to a grid mesh of 2-3 km. Our goal would be to simulate the layered clouds and to compare the model results with observations. For the "warm" system simulation, we will continue with our severe storm simulation over Alberta to validate the explicit scheme in treating graupel and hail.

PUBLICATIONS AND PRESENTATIONS

5.8 NORTHERN BOUNDARY-LAYER MODELLING

Peter Taylor
York University

Significant progress has been made in two areas:

1. Modelling Blowing Snow.

Our work on blowing snow started with John Pomeroy's Prairie Blowing Snow Model (the PBSM). From that basis we developed new time-dependent (TDBSM) and fetch dependent (FDBSM) models of blowing snow with a spectrum of particle sizes, coupled with the related moisture and thermodynamic equations. In these models sublimation from blowing snow causes significant increases in mixing ratio and decreases in temperature. Preliminary results from the FDBSM were presented at the May 1996 CGU and CMOS conferences and a journal paper is presently in preparation (Thermodynamic effects of blowing snow in the atmospheric boundary layer, by Stephen J. Dery, Peter A. Taylor and Jingbing Xiao). Recently we have conducted a series of sensitivity tests on the model, convinced ourselves that the results are "robust" and relatively insensitive to quantities such as diffusion coefficients for particles, ventilation velocities and reflectivity (affecting absorption of solar energy). Our main conclusion from these studies is that our models predict sublimation rates from blowing snow that are significantly less than those obtained with the PBSM, although transport rates are generally similar. The lower sublimation matches with the findings of King et al, 1996, (The surface energy and mass balance at Halley, Antarctica during winter, JGR, 1996) but conflict with the fact that there is good agreement between PBSM-based predictions and observations of snow budgets for monitored sites in the prairies (Pomeroy et al, 1993). If there were no, or much less, sublimation, it is claimed that Saskatoon and Regina would be completely buried in snow as "receptors" for all of the material removed and transported by the wind from upwind prairie areas. We are endeavouring to resolve these discrepancies, but it is our present belief that further investigation of blowing snow sublimation rates and careful assessment of their significance in Arctic and MAGS hydrology is needed. A carefully designed field experiment/process study may be required to resolve these issues.

Fig 1 shows vertically integrated sublimation rates as a function of fetch (distance downwind from a boundary between non-mobile and mobile surface conditions) for a 10m windspeed of 15m/s, an upstream temperature of -10C and upstream relative humidities of 70% and 20%. For the 70% case we have also made calculations with the thermodynamical effects of sublimation suppressed (i.e. with no change in temperature or humidity, as in the PBSM). It is clear that increases in humidity and decreases in temperature have a strong impact on the sublimation rate, especially at long fetches. Calculations with our version of the PBSM for 70%RH show even larger sublimation rates than our suppressed thermodynamics case, reaching more than 3mm/h at 10km fetch.
2. High order closure PBL modelling

Dapeng Xu's work on the development of a high order closure planetary boundary layer model for this project has continued. The first problem was to establish values for some of the constants used in high-order closure (E-epsilon-tau, LRR) turbulence models for atmospheric boundary-layer applications. These investigations led us to reject the traditional form assumed for the production term in the epsilon equation and to develop a new E-epsilon-l closure scheme. A note describing this work has been recently accepted for publication in Boundary-Layer Meteorology. Work on the stable boundary-layer model is in hand. The epsilon equation is in fact the key equation for most 2nd order turbulence closure models and in particular for the Launder, Reece and Rodi, full 2nd order closure model. We have implemented the modified epsilon equation in a neutral PBL model with LRR closure and assessed the coefficients needed to obtain agreement with expected PBL height and structure. A paper on this has also been accepted for publication.

List of publications

5.9 VSAS2 MODEL RESULTS: LINKS TO REGIONAL MODEL

Jean Stein¹ L.Martz² and Yan Ding¹.
¹ INRS-Eau, University of Quebec
² University of Saskatchewan

Summary

The main processes relevant to the hydrologic behavior in the Wolf Creek watershed include snow accumulation and ablation, freeze and thaw processes of permafrost and non-permafrost zones, surface and subsurface flow on slopes, evapotranspiration and stream network routing. Based on previous process studies on small experimental sites and ongoing process studies in the Wolf Creek watershed, the modeling will focus on a physically-based, distributed watershed model (VSAS2) which incorporates specific physical processes representing main characteristics of sub-arctic areas (Figure 1). The VSAS2 hydrologic model has been developed from a small experimental catchment. When applied to the larger Wolf Creek watershed, it will be modified by incorporating a series of physically-based process modules describing snow interception and sublimation losses from coniferous canopies and blowing snow transport and sublimation losses from tundra areas, snowmelt, freeze and thaw, evapotranspiration and flow routing. The up-scaling issue will also be addressed by use of field work and automated techniques to segment and characterize the watershed and flow parameters. Finally the proposed modeling strategy will not only supply a tool for various kinds of simulations for Northern studies, but also determine how physically-based hydrological models developed for small basins can be applied to larger basins (Figure 2).

The primary modeling and parameterization activities in 1996 concerned development of a conceptual and operational system for the automated parameterization of the VSAS2 hydrological model from digital elevation and other land surface data (Figure 3). The general approach to achieving this goal was through an interface between the VSAS2 hydrological model and the TOPAZ landscape analysis model. The objectives of the interface development were: (1) to translate watershed segmentation and parameterization information extracted using the existing TOPAZ software system to a format suitable for use by VSAS2, and (2) to identify other topographic and topologic information needs of VSAS2 that cannot be directly satisfied with the existing TOPAZ system, and to develop appropriate tools to provide this information. An initial conceptual model was developed for the representation of VSAS2 landscape segments (the fundamental hydrological modeling units) as equivalent geometric objects (Figure 4). This conceptual model required that several modifications and extensions be made to the TOPAZ system to extract additional information from digital elevation models. These changes were made. The initial conceptual model for parameterization was then made operational in a software package. Its functionality was tested using a range of hypothetical landscape data. These preliminary test results were very promising.
Figure 1: The general structure of the VSAS2 hydrological model.
Figure 2: Linkages between the VSAS2 hydrological model, physical process studies and the TOPAZ landscape analysis model.
Figure 3: Using the TOPAZ landscape analysis system to derive topographic parameters for the VSAS2 hydrological model.
HORIZONTAL (PLAN) REPRESENTATION

From TOPAZ:
- area
- stream-side width
- length (mean divide-to-channel distance)

Calculate:
- divide-side width

VERTICAL (PROFILE) REPRESENTATION

From TOPAZ:
- elevation (z) of each subwatershed cell
- distance-to-channel (x) from each subwatershed cell

Calculate:
\[ z = ax^4 + bx^3 + cx^2 + dx + e \]

Figure 4: A geometric basis for the automated topographic parameterization of the VSAS2 hydrological model.
6.1 MAGS DATA MANAGEMENT UPDATE

Bob Crawford
Environment Canada, Downsview, Ontario

The update on MAGS Data Management will be presented in the following manner: first there will be a brief discussion of the history of the MAGS homepage - talking briefly about the changes in the homepage before the last Workshop in 1995, and then more detail on the changes since the last workshop. Then information on the requests for data and the current status of the data management system will be presented. Finally, the objectives for the next year will be elucidated.

A Brief History:

The BASE and Canadian GEWEX home pages were started as an offshoot from my work on the hefty BASE Data Summary document, and the first official versions of the home page were unveiled in March 1995. They were quite wordy & descriptive with few links and followed much the same format as the summary document.

In the first few months, the home page primarily provided a promotion of Who/What MAGS is, with the addition of other documents such as the Science & Implementation Plan and the Background Document. (In these cases the WWW provided an active forum for the revision of documents as online versions could be seen by everyone, this necessary interaction is continued today by the many opportunities for comments on the pages). The "Who/What/Why" phase.

In late September there was finally some data available online (Discharge and Freezeup/Breakup plots) followed soon after by the basin vectors (MAGS was the 1st CSE to openly publish a definition of its basin area, and the 2nd didn't occur until late last year with BALTEX & GCIP).

As the homepage was moved to a new server and underwent a major re-organization in November 1995, more and more up-to-date information was added to the page and it became a valuable resource when looking to find upcoming meetings, meeting agendas, past meeting minutes etc. The "When" phase.

Since the last workshop much time has been spent identifying where the observations/stations are in the basin and a series of maps have been generated to show the various observational networks (and a program is being developed to allow users to define & customize the maps online). The "Where" phase.

As well numerous bits of data have been made generally available through the homepage, including the corrected annual precipitation amounts, daily max/min/mean Temperature
& precipitation for Inuvik and Tuktoyaktuk, snow course data, transpiration data and sample Rainsat imagery. Moving into the "Data" phase. The addition of these datasets has provided an opportunity to make the homepage even more user friendly through the addition of Forms and for requesting the necessary data and submitting comments to forums and to give the homepage a cleaner graphical interface through the use of buttons on screen.

Currently the efforts on the homepage center around increasing the amount of data available online, easing the previewing and displaying of that data through customized maps, location timelines, and maintaining the timeliness of the contents. Moving into the "Data Presentation/Manipulation" Phase.

Current Status:

Many of the requests for data are handled by the homepage - either by directly providing the data or providing a pointer to the location of the data (as in the case of the CMC Archives)
Since the new year there has been ~100 requests/day made to the homepage (although these are not all 'data' transfers). About 5.5Mb of data are transferred per day. The top pages statistics show that the basin vectors, discharge figures, and transpiration data are all popular as are the Introduction, Participants list, Science & Implementation Plan, and publications lists.

**Web Server Statistics for MAGS Homepage**


- **Total successful requests**: 45 237
- **Average successful requests per day**: 108
- **Total successful requests for pages**: 31 636
- **Total failed requests**: 1 428
- **Total redirected requests**: 256
- **Number of distinct files requested**: 806
- **Number of distinct hosts served**: 4 523
- **Corrupt logfile lines**: 2 159
- **Unwanted logfile entries**: 22 477 193
- **Total data transferred**: 2 277 Mb
- **Average data transferred per day**: 5 564 kbytes

There have been 4500+ different hosts connected to the home page from over 60 different domains (Commercial US sites lead the way - undoubtedly due to search bots, followed by Canadian .ca addresses, numerical IP and US Educational institutions.). In Figure 1, countries which retrieved 1 MB or more in the first 2 months of 97 are shaded. Canada and the US accounted for the majority of 'hits'.

Approximately 150 specific e-mail and phone requests for data from numerous locations (AES, NHRI, U. of T., McMaster, U. of Waterloo, etc) have also been handled. As well data has been received and generally made available through the WWW, from a number of sources: Yellowknife, AES, CMC, AES, Edmonton, NHRI, UofT, McGill etc. The pages occupy ~230Mb of which ~100Mb are data files. Also available are a number of CD-ROMs containing global and Arctic datasets.

**Future Objectives:**

Over the coming year the objectives of the MAGS Data Management system include increasing the usefulness of the common dataset and increase the number of links to external datasets of interest. This common database is a necessary component of to consolidate MAGS as one project rather than a series of individual investigations, as well there is a responsibility to the GHP to maintain such a database and provide some hardware and software standardization in order to help meet the global objectives of
GEWEX. There are a number of tasks necessary to meet this challenge. These include allowing user generated standard maps and production of timeline plots for selected sites, generation of specific CD-ROM archives, facilitating format transfers and conversions, keeping the home pages up-to-date and servicing requests for data. These objectives are obtainable within 1 PY (currently Data Management is handled on a half time basis).
6.2 MAGS OPERATIONAL STRATEGY

Gary Schram
(Presented by Bob Kochtubajda)
Environment Canada, Edmonton, AB

Text for presentation not available.

Slide 1

![Map showing Staffed Weather Offices in 1993-94]

- 3 Weather Centres
- 42 Weather Offices / Stations
- 15 Upper Air Stations
- HAWS
- Isachsen

Slide 2

![Map showing Staffed Weather Offices in 1997-98]

- 5 Weather & Environmental Services Offices
- 5 Upper Air Stations (non-contract)
- HAWS
### Program Changes Summary

<table>
<thead>
<tr>
<th>Year</th>
<th>Change in Budget</th>
<th>Number of FTEs</th>
<th>Centres/Offices/Stations</th>
</tr>
</thead>
</table>
| **1993-94** | $50.9 million ... 603 FTEs | • 3 Forecast Centres  
• 18 Weather Offices  
• 15 Upper Air Stations  
• 26 Weather Stations |  

| **1997-98** | $34.3 million ... 309 FTEs | • 5 Environ. Services Centres  
• No Weather Offices  
• 6 Upper Air Stations  
  – remainder contract  
• No Weather Stations  
  – all contract or automated |  

### Program Changes Summary (cont’d)

<table>
<thead>
<tr>
<th>Year</th>
<th>Change in Stations</th>
<th>Details</th>
</tr>
</thead>
</table>
| **1993-94** | 64 Automatic Weather Stations  
971 Climate Stations  
5 CapMon (air quality) Stations  
1560 Hydrometric Stations |  

| **1997-98** | 177 Automatic Weather stations (incl. 37 AWOS)  
420* Climate Stations  
1 CapMon (air quality) Station  
1380* Hydrometric Stations |  

*ongoing rationalization
6.3 OPERATIONAL HYDROLOGY PERSPECTIVE

Randy Weddell
(Presented by Chris Spence)

Abstract not available.
6.4 CMC MODEL ARCHIVES AND ACTIVITIES IN SUPPORT OF GEWEX

Richard Hogue, Hal Ritchie, Louis Lefairve  
(Presented by Maryse Beauchemin)  
DOE/AES/CMC, Dorval, Quebec

This report provides an overview of the GEWEX related activities at the Canadian Meteorological Center with respect to model outputs archiving. The first part summarizes the work done regarding the archiving aspect of the project (addition of new fields, development of new scripts, etc.). The second part relates to the data requests we have processed and our collaboration with researchers involved in the GEWEX project.

Data archiving:

During the past year we have paid a closer attention to some specific aspects of the archiving: the validity of the archived fields, the need for development of post-processed fields, the frequency of archiving, the number of location sites for time series, etc. In addition to the fields already archived regarding the energy and water budget and based upon basic GCIP requirements, we increased the lists of archived fields for GEWEX from 28 to 41. Some of these new fields were not direct model output and required therefore the development of scripts to calculate them. We also increased the frequency at which most of the data is archived: we are now archiving forecasts of surface fields and upper air fields on pressure levels at every 3 hours as opposed to 6 hours. The list of sites for which we are archiving time series have also been looked at carefully, and, again, following GCIP requirements, the list of locations was considerably increased by 93 to a total of 217. From these new sites, two are in the BOREAS area and one in the MAGS area. On February 24th 1997, a new regional model was implemented at CMC, the GEM model (Global Environmental Multiscale). It replaced the RFE model which had been producing operational short term forecasts since April 1986. We had to adjust the coupling of the GEWEX archive system to the new model. Other CMC Divisions were involved in ensuring that all the GEWEX needs were satisfied in terms of gridded data and time series type of data.

Detailed information on the CMC GEWEX archiving activity can be found on CMC’s WEB site (http://www.cmc.doe.ca/cmc/CMOI/htmls/Gewex_archa.html). In summary, the archiving area continues to cover most of the Canadian and American mainland as well as the adjacent waters. There are 28 vertical levels with 8 of them in the boundary layer (below 850 mb). There are 14 analysed fields archived and 41 prognostic fields (00 to 24 hour forecasts). Also, there are 217 point location time series for which 59 fields are archived.
Data requests and related topics:

During the past year, we processed requests from various researchers implied in the GEWEX project:

1. Dr. Alan Barr (NHRC) - we prepared two sets of about 15 days of gridded data and time series for the BOREAS area.
2. Ken Snelgrove and Dr. Ric Soulis (U. of Waterloo) - request for one year of data to couple with an hydrological model - in progress.
4. Dr. Laura Hinkelman (Pennsylvania State University) - we prepared a set of time series (March 1996 and April 1996) for a point location in the GCIP area.
5. Roy Jenne (NCAR) and Dr. Hugo Berbery (U. of Maryland) - prepared a three day sample (from May 15 to May 17, 1996) of MORDS (*Model Outputs Reduced Data Sets*) and MOLTS (*MOdel Location Time Series*) over the North American window (AWIPS 212 grid).

In order to transfer the data in a more universal format accessible to a wider group of people, we had to update our GRIB (GRIded Binary) encoder/decoder for the gridded data and develop a BUFR (Binary Universal Form for the Representation of meteorological data) encoder/decoder. Here again, this was done in close collaboration with other CMC Divisions.

We continued to be involved in the model intercomparison phase of the GCIP project exchanging 3 days sample of all the MORDS with Dr. Hugo Berbery (University of Maryland). We will eventually send a full year of data. These data have to be on an Lambert conformal conic projection (AWIPS 212 type grid). Collaboration with the standard file specialists at RPN (*Recherche en Prévision Numérique*) was required to modify our grid interpolator in order to reproduce data on this AWIPS 212 type grid.

Maryse Beauchemin participated to the Second International Scientific Conference on the Global Energy and Water Cycle held in Washington, D.C., from June 17 to June 21 1996. This conference was very interesting in many regards. It reinforces the importance of the CMC role in the project through the archiving of model outputs data and through the services provided to the scientific community.
3. Session Summaries
Session #1: Climatology of the Mackenzie Basin – Rapporteur: B. Goodison

Report.
- Version 1 (beta) implemented. Version 2 of correction algorithms for gauge catch developed and be applied.
- Niper (30 stns in NWT) has lowest correction of any snow gauge.
- Other sites est. snowfall from snow depth assuming density=100kg/m3
- Type B rain gauges also corrected.
- Data available now on Homepage at:

Precipitation (Proctor)
- Data density again declining due rationalization (PNR 420* climate stns 97-97) ~40 % 93-94 value.
- More autostns
- Few representative values at elevation (BC Hydro around Willistone Lake)
- Use RFE data and compare model to adjusted measured (winter&summer cases)
- Precipitation increases .75mm/100 m summer...2.0 mm/100m winter.. Have 2 years to process. Would Like Reanalysis if possible
- Precipitation peaks during the summer months, ~50% of the annual total throughout the basin;
- Peak is July in south (near Edmonton), lagging slightly to August in the north (Inuvik), with smaller secondary peak in October from Fort Simpson northward.
- Summer precip can not be neglected. CVCTN

Climatology (Hopkinson)
- Better baseline climatology of anomalies
- V1 corrected precipitation data interp to 50km grid
- Applied period 1950-1994
- Applied Thornwaite for ET estimates
- FUTURE improve rain snow separation, improve snowpack, change monthly to weekly
- Grid size

Discussion
Neglected data access difficulty getting climate data from various sources and with various levels of Q&C. ie) ATIS CAP, YXY, WVR, WEG etc.
- Common periods of normals ie) 61-90
Session #2: Atmospheric Moisture (and Energy) Budget Studies –
Rapporteur: Kent Moore

2.1 Surface-Atmospheric Energy Exchange (Peter Schuepp):

Schuepp described plans for using the Twin Otter aircraft to provide information on spatial distributions of sources and sinks for surface atmosphere exchange of heat and moisture that are not available from fixed tower observations, and at scales that can be related to remote sensing observations of the surface. Some preliminary results using BOREAS data showed more complex links between radiometric surface temperature and energy exchange than has been observed over simpler ecosystems. Aircraft-observed maps of sensible and latent heat flux differed significantly from those derived from satellite-based radiometric remote sensing. However, there was good agreement between aircraft and satellite-observed surface temperature patterns, done in collaboration with Bussieres (AES), and based on two days within the BOREAS 1994 data.

The results suggest that for areas with forest cover such as extensive parts of MAGS, a multi-layer approach may have to be employed to account for shifts in source/sink height within canopies, if the surface energy balance is to be inferred from satellite-based remote sensing. Major challenges for MAGS analysis will be to resolve ‘advection’ problems and temporal variability.

2.2 Moisture Budgets: Model Validation, Sources and Sinks (Geoff Strong and Muyin Wang):

The annual atmospheric moisture budget of the Mackenzie Basin has been investigated for the October/95 to September/96 period using CMC initialized output data from the RFE model. Moisture flux convergence was positive over the Mackenzie River Basin for this period. The annual total P-E was 315 mm/yr for a rectangular domain enclosing the Basin, and 279 mm/yr for the ‘basin’ domain using nearest grid points nearest to the basin perimeter. This compares favourably with the climatological annual average of 249 mm/yr obtained by Walsh et al. However, estimates in the literature using streamflow and precipitation data have been 25-50% lower, suggesting a major source(s) of error in one or both approaches.

There are strong seasonal variations of the moisture flux and flux convergence, with strongest convergence in the fall, and weakest in the summer when 50% of the annual precipitation occurs. They attribute the latter to high evapotranspiration and significant convective activity over the Mackenzie basin.

Comparisons of atmospheric vapour mass using observed and (RFE) model data yield a slight negative bias on vertically-integrated vapour mass compared with measured values. An anticipated diurnal cycle in integrated vapour mass during summer was not evident in
either the observed or modelled data, possibly because only two soundings per day (1200 and 0000 UTC) are available. If there is a significant summertime diurnal signal (as other indicators suggest) which is not being observed with only two soundings per day (1200 and 0000 UTC), then this has important implications for CAGES. A negative bias in vapour mass computations produced by this scenario would be cumulative, and could possibly explain the differences in P-E computations between the moisture budget and streamflow approaches.

During the next few months, computations of moisture flux convergence will be repeated using better-defined boundaries around the basin. The moisture budget will also be investigated over the sub-basins. Longer time series of MAMS analyses are important to consolidate current conclusions, as well as more detailed analyses of temporal and spatial resolution problems. If funding permits, sequential soundings may be carried out at an appropriate site in the basin this summer to try and detect the diurnal signature in vapour mass.

2.3 Cyclones and Role in High Latitude Vapour Transport (John Gyakum and Kent Moore):

This presentation focussed on a significant Mackenzie Basin precipitation event of 10-12 January 1996 simulated using the MC2 model. This type of heavy precipitation event is thought to constitute the bulk of the precipitation that falls into the region. To understand the dynamics of this case, a quasi-geostrophic potential vorticity inversion technique was used to isolate specific flow anomalies responsible for the moisture transport over the Rocky Mountains in the Mackenzie River Basin. Results confirm the importance of moist convection, and suggested a downstream transfer of energy to another synoptic system southeast of the Bsin.

Future work will attempt to specific circulation anomalies to the water vapour transport into the Mackenzie Basin during important precipitation events which contribute to changes in the water resources of the Mackenzie Basin. These anomalies will help to predict the discharge of the Mackenzie River into the Arctic Ocean.
Session #3: Land Surface Process Studies – Rapporteur: J. Pomeroy

Advection - E or W

Rouse - Landscape Evaporation (Tundra) A
Pomeroy - Snowcover Development and Ablation A
Gray - Hydrological Processes A
Marsh - Snowmelt Water/Energy Fluxes A
Woo - Frozen Ground on Runoff A
Leighton - Surface Shortwave Budgets
Prowse - Isotopic Tracing of Water Balance (Granger) - Evapotranspiration (Forest) A

Key Themes

• Variability in Processes over Landscape
• Small-scale to large-scale (+ reverse)
• Measurement/Data Difficulty

Variability

Investigators using surface characteristics (veg., topo, soils, frost) with different results for stand/landscape.

Scaling

Landsat, DEM being used to scale-up or basin response used for isotope - Compatible? Very different ET in tundra - Rouse & Prowse.

Measurement

Co-located experimental Basins helping but outside of these, real problems exist. Leighton, Prowse, Granger showing techniques to scale to MacKenzie.

LSP - Issues

1. Processes described or modelled in LSP had a “dismal” representation in the modelling session. Major effort required to start addressing this and incorporate new work in models.
2. Process Integration. To correctly characterize water and energy budgets at various scales, processes must be distributed and linked e.g. snow accum $\rightarrow$ snow melt $\rightarrow$ infiltration $\rightarrow$ evaporation $\rightarrow$ runoff Scaled up Together. Scaling up processes in isolation may lead to incorrect representation at the atmospheric interface.

3. Hence - We need to balance critical need for hydrological models to immediately incorporate processes with the requirement for integration before the atmospheric interface can be properly dealt with.

Approach

1. Continue developing CAGES process understanding/representations.
2. Improve information given to hydrological modellers for improved runoff estimation.
3. Integrate Processes and scale-up $\rightarrow$ link to atmospheric models then revise hydrological routing.
**Session #4: Remote Sensing Studies** – Rapporteur: A. Walker

7 Presentations; 5 satellite investigations, 2 ground-based doppler radar

**Presentation Summaries:**

**Bussieres**
- land surface temp - comparison between RFE output and AVHRR derived temperature → very good match
- evapotranspiration derived from AVHRR using Granger algorithm - August 1994
- 3 zones identified - low in northern part of study area, increases towards south
- validation needed - eddy correlation measurements?

**Garand**
- monthly averages of cloud, radiation and humidity from AVHRR - BASE period
- comparisons with MC-2 model - validation
- MC2 - warm bias during BASE period
- cloud fraction too high at 500m
- precipitation strongly linked with topography → need more stations in mountains for precipitation measurement

**Walker**
- snow cover and lake ice from satellite passive microwave
- gridded SSM/I data - 25km for snow, 12.5 for lake ice
- boreal forest SWE algorithm developed using BOREAS data
  - will be tested for Mags study area
  - need land cover data set for Mags basin
  - validation data needed for SWE product
- Great Bear and Great Slave lake ice break-up documented for 1988

**Maxfield**
- wet snow and soil moisture mapped over Trail Valley Creek using satellite SAR
- single image and multitemporal analyses
- multitemporal - 5 snow types identified and 3 soil moisture classes
- quantitative soil moisture algorithm planned

**Hudak**
- doppler radar measurements during BASE
- changes in vertical precipitation flux over time for specific events
  - deduce precipitation processes
- correlation between highest vertical velocities and highest cloud heights
- Spirit River - installation of radar in progress
- acquisition of C-band portable doppler radar
Bellon
- satellite rainfall estimates using VIS/IR technique - Rainsat
- comparisons with rainfall rates from CARVEL radar
  → max & mins comparable
  → radar - higher rainfall amounts
- comparison between VIS-IR, VIS & IR methods
  - IR lower correlation coeff.
- rainfall totals - Rainsat vs CMC model analysis
  - min’s & max’s → good match

Pasika
- cloud profiling from IPIX radar
- IPIX radar - high sensitivity → 10 dbz at 150 km
- sensor fusion
  → creation of virtual radar using satellite and ground measurements using artificial neural networks
  - need a lot of data for training
  - output - layering profile of clouds
- Fort Simpson - IPIX site location for CAGES
  - topography may affect siting

Discussion - Issues
- Need to summarize remote sensing capabilities re: MAGS study area
  → What is being derived, using which methods?
  → Confidence in retrievals? Validation done?
  → Use of derived information?
- Will remote sensing fill spatial & temporal data gaps?
- Role of remote sensing outputs?
  - model verification or model input
  - satellite output is type of model output
  → validity of “model vs model” comparisons
- Can remote sensing data be incorporated into data assimilation routines?
  - potential contribution of GEWEX → a new data assimilation method incorporating remote sensing products.
- What data is needed for long term and what can be derived for short IFC periods?
  - Cost of data acquisition a consideration.
- Remote Sensing is a tool which can contribute to:
• developing MAGS climatologies
• land surface process studies
• modelling studies

• Modellers need to identify their needs re: remote sensing data/products
Session #5a: Hydrologic Measuring (Hydrologic)

Modelling Teams Underway

- SIMMAC - Routing (Kerr et al.)
- SLURP - RFE (Kite et al.)
- WATFLOOD - CLASS; RFE (Soulis et al.)

Database almost in place

- DEM O.K (USGS 1km)
- Land Cover → Evaluation needed (MCRS, MBLS, CCRS, USGR)
  - Link to CRYSYS, BOREAS may be helpful
  - 1km AVHRR

Scaling-up Beginning

- VSAS2 underway in Wolf Creek (Stein et al.)
- WATFLOOD/CLASS to be tested at Simpson (Pietroniro et al.)

Process work needs to be integrated:

- Wetlands (organic Soils) - CCRNet Land-Air
- Permafrost (will CLASS do?) - WC, FTS (Stein et al, Peitroniro et al.)
- Snow pack (who?) - Pomeroy/Soulis
- Advection?

Hydrologic Modelling – Session Report

- Advection
  - Need sub-grid parameterizations
  - But may have to approximate for now
Session #5b: Modelling Studies (Atmospheric)

27 Climate Modelling - Stewart
• RCM of GCM 11
  • Patterns Similar
  • RCM (45km) more detailed
  • Both have ~2* pcpn cf obs and RFE
  • Need to improve pcpn and clouds in GCM physics

28 Global NWP - Ritchie
• NWP + 4DDA as bridge between obs and climate GCMs
• CLASS features and impact: more realistic, more variable.
  PR-EV=WE=ER
• To validate (archive, CAGES)

29 MC2 Pcpn Systems - Yau
• Microphysics in MC2
• Detailed case studies at high resolution to diagnose processes
• Topography important
• GCM improvement needs high resolution modelling diagnostic studies for process + parameterization understanding.

30 Northern B.L. - Taylor
• Blowing snow model of PBSM
• Diffusion \rightarrow sublimation \rightarrow humidity ↑
• Some discrepancies.
• Settling velocity? Eddy diffusivity?

Discussion:
• PR-EV = Water Excess
  = Effective Rainfall
  (Meteorology - hydrology terminology)
• Changes important approximately \leq 12 months
• Land cover maps
  • Need to establish standard data set and aggregation
  • Also need global map for transferability
• Results are sensitive
Session #6: MAGS Support and Operational Inputs – Rapporteur: Geoff Strong

6.1 Data Management Update (Bob Crawford):

A review of the GEWEX/MAGS homepage was presented, including examples of various data sets and analyses, synthetic sounding sites, links to other web sites such as Zawadzki’s RAINSAT maps, a publications list, minutes of meetings, etc.

The presenter discussed new additions and improvements, and appealed for feedback from the MAGS community.

6.2 Operational Meteorology Perspective (Bob Kochtubajda for Garry Schram):

Kochtubajda presented the current and near-future outlook for AEP operations, with a distinct emphasis on downsizing, including significant 50% cuts to regional budgets which are roughly 60% salary. Most surface data collection sites in Prairie and Northern Region have now been automated, while most sounding sites now use less well-trained contract staff to carry out the two soundings per day.

Some details of what the region will or will not be able to do for MAGS were reviewed. This includes installation and maintenance of sites in return for travel costs, training for upper air personnel at any special MAGS sites, and the loan of equipment including one or two radiosonde systems if required. We may need to contact Pacific Region as well, since they oversee the Yukon region.

6.3 Operational Hydrology Perspective (Chris Spence):

This presentation also emphasized operation problems, with cutbacks in climatological monitoring, streamflow discharge, etc. Water Surveys have been hit very hard, and there is virtually no funding for any field operations. MAGS’ needs for enhanced streamflow measures during spring breakup need to be discussed with regional people, bearing in mind that the ‘breakup’ period is the ‘busy’ period for Water Surveys staff, especially June. Dale Ross is the contact, and he needs firm workplan by October.

6.4 CMC Model Archives and Activities in Support of GEWEX (Maryse Beauchemin for Richard Hogue):

A brief review of the evolution of GEWEX modeling right up to the GEM model was presented. At the moment, the GEM data archive contains 14 fields, but more could be added if required. Synthetic soundings are produced for both MAGS and GCIP for model
inter-comparisons, and these include time series for 217 locations (mostly GCIP sites) and 59 variables.

The web page is easily accessed and is continually updated. Pre-packaged 3-D data sets have been made available for MAGS, BOREAS, and GCIP in FST, ASCII, PDF, and GRIB formats. CMC needs feedback so that they know what our needs are!

Some discussion focused on raw sounding archive access and hydrometric data.
4. Workshop Summary Statements
STATEMENT ON THE STATUS OF MAGS:

As one measure of the progress of the Canadian GEWEX program towards achieving our international commitments, a simple statement will be issued each year in conjunction with our Science Workshop.

November, 1995: The statement arising from the first MAGS Workshop was:

Preliminary assessments of the water budgets of the Mackenzie Basin, as well as initial energy studies, have been carried out, but critical variables have not been measured adequately. We are completing the identification of key processes, we are carrying out background climatologies, and we are improving the representations of physical processes in our models.

March, 1997
All components of our overall strategy have been started. Assessments of the water budgets of the MacKenzie Basin are well underway, energy studies have been started, and plans to improve our measurement of critical variables have progressed substantially. We have identified the key processes, we have carried out several background climatologies, we are improving the representation of physical processes in our models, and we have started to assess the ability of our climate model to represent the Basin’s climate systems. Our archiving systems are in place and we, as part of our strategy, will focus on collective studies of appropriate water-years.
5. Registered Participants
The Canadian GEWEX Program  Mackenzie Basin GEWEX Study (MAGS)

Annual Workshop - NHRC, Saskatoon - 23-26 March, 1997

Participant List:

Barr, Alan, AES, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-4324 Fax: 306-975-6516 E-Mail: barra@nhrisu.nhrc.sk.ec.gc.ca

Beauchemin, Maryse, CORC/AES/Dorval, 2121 Trans-Canada Highway, Dorval PQ H9P 1J3 Tel: 514-421-4646 E-Mail: maryse.beauchemin@ec.gc.ca

Bellon, Aldo, McGill Radar, J.S. Marshall Obser, Ste Anne De Bellevue PQ Tel: 514-398-7733 Fax: 514-398-7755 E-Mail: aldo@radar.mcgill.co

Bussières, Normand, AES, CCRP Downsview, Tel: 416-739-4352 Fax: 416-739-5700 E-Mail: normand.bussieres@ec.gc.ca

Cattanach, Dave, BC Hydro, 6911 Southpoint Drive, Burnaby BC V3N 4X8 Tel: 604-528-2711 Fax: 604-528-2558 E-Mail: dave.cattanach@bchydro.bc.ca

Eley, Joe, AES, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-5685 Fax: 306-975-5700 E-Mail: louis.garand@ec.gc.ca

Garand, Louis, AES/ARMA, Dorval Tel: 514-421-4749 Fax: 514-421-2106 E-Mail: louis.garand@ec.gc.ca

Gibson, John, NHRI, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-5744 Fax: 306-975-5143 E-Mail: gibsonj@nhrisu.nhrc.sk.ec.gc.ca

Goodison, Barry, EC-Downsview, 4905 Dufferin Street, Downsview ON M3H 5T4 Tel: 416-739-4345 Fax: 416-739-5700 E-Mail: barry.goodison@ec.gc.ca

Granger, Raoul, NHRI, NHRI 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-5758 Fax: 306-975-5311 E-Mail: raoul.granger@ec.gc.ca

Gray, Don, Department of Agriculture and Bioresource, University of Saskatchewan, Tel: 306-966-7828 Fax: 306-966-8710 E-Mail: grayd@skyway.usask.ca

Gyakum, John, Department of Meteorology, McGill University, 805 Sherbrooke Street West, Montreal PQ Tel: 514-398-6076 Fax: 514-398-6115 E-Mail: uwe.haberlandt@ec.gc.ca

Hopkinson, Ron, Environment Canada, 2365 Albert Street, Regina SK Tel: 306-780-5739 Fax: 306-780-5311 E-Mail: ron.hopkinson@ec.gc.ca

Hudek, Dave, AES, King City, 14780 Jane Street, King City ON S7B 1A3 Tel: 905-833-3896 Ext: 242 Fax: 905-833-0398 E-Mail: david.hudek@ec.gc.ca

Kite, Geoff, NHRI, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-5687 Fax: 306-975-5143 E-Mail: kitech@ec.gc.ca

Kochtubajda, Bob, EC-Edmonton, 4999-98 NE Edmonton AB Tel: 403-951-8811 Fax: 403-951-8634 E-Mail: bob.kochtubajda@ec.gc.ca

Lettenmaier, Dennis, Department of Civil Engineering, University of Washington, Box 352700, Seattle WA Tel: 206-543-2532 Fax: 206-685-3836 E-Mail: lettenma@ce.washington.edu
MacPherson, J.I., NRC, U 61, NRC, Ottawa ON K1A 0R6 Tel: 613-998-3014 Fax: 613-952-1704 E-Mail: ian.mapherson@ncr.ca
Marsh, Philip, NHRI, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-5752 Fax: 306-975-5143 E-Mail: marshp@nhrisv.nhr.sk.doe.ca
Martz, Lawrence, University of Saskatchewan, Tel: 306-966-5667 Fax: 306-966-5667 E-Mail: martz@sask.usask.ca
Maxfield, Anthony, NHRI, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-373-0686 Fax: 306-975-5143 E-Mail: anthony.maxfield@ec.gc.ca
Neumann, Natasha, NHRI, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 975-5755 E-Mail: natasha.neumann@ec.gc.ca
Nissen, Robert, AES, King City, 14780 Jane Street, King City ON L7B 1A3 Tel: 519-884-4567 ext: 287 Fax: 905-833-0398 E-Mail: robert.nissen@ec.gc.ca
Pasika, Hugh, McMaster University, CRL 102 McMaster University Tel: 905-525-9140 ext: 27282 Fax: 905-521-2922 E-Mail: pasika@mcmaster.ca
Petrone, Richard, Department of Geography, McMaster University, 1280 Main Street West, Hamilton ON L8S 4K1 Tel: 905-525-9140 ext: 24082 Fax: 905-546-0463 E-Mail: petronrm@mcmaster.ca
Pietroniro, Al, EC-NHRI, NHRC, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-4394 Fax: 306-975-5143 E-Mail: al.pietroniro@ec.gc.ca
Pomeroy, John, NHRI, Environment Canada, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-5511 Fax: 975-5143 E-Mail: pomeroyj@nhrisu.nhrc.ec.gc.ca
Proctor, Brian, AES, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-5688 Fax: 306-975-6516 E-Mail: brian.proctor@ec.gc.ca
Prowse, Terry, NHRI, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-5737 Fax: 306-975-5143 E-Mail: terry.prowse@ec.gc.ca
Ritchie, Hal, RPN/AES/Dorval, 2121 Trans-Canada Highway, Dorval PQ H9P 1J3 Tel: 514-421-4739 Fax: 514-421-2106 E-Mail: harold.ritchie@ec.gc.ca
Schuepp, Peter, McGill University, Department of Natural Resources Sciences, Macdonald Campus Ste Anne De Bellevue PQ Tel: 514-398-7935 Fax: 514-398-7990 E-Mail: pschuepp@nrs.mcgill.ca
Seglenieks, Frank, University of Waterloo, Department of Civil Engineering, Waterloo ON N2L 3G1 Tel: 519-888-4567 E-Mail: frank@sunburn.uwaterloo.ca
Shewchuk, Stan, Saskatchewan Research Council, Saskatoon Tel: 306-933-5431 Fax: 306-933-7817 E-Mail: shewchuk@src.sk.ca
Snelgrove, Ken, University of Waterloo, Department of Civil Engineering, Waterloo ON N2L 3G1 Tel: 519 888-4567 ext: 6112 E-Mail: krsnelgr@uwaterloo.ca
Soulsis, Ric, University of Waterloo, Waterloo ON Tel: 519-888-4567 Fax: 519-888-6197 E-Mail: ric@sunburn.uwaterloo.ca
Spence, Chris, Environment Canada, Box 970 Yellowknife YT Tel: 403-920-8492 Fax: 403-873-6770 E-Mail: chris.spence@ec.gc.ca
Stein, Jean, INRS-EAU, University of Quebec, Tel: 418-654-3834 Fax: 418-654-2600 E-Mail: steinj@inrs-iau.uquebec.ca
Stewart, Ron, AES, 4905 Dufferin Street, Downsview ON Tel: 416-739-4122 Fax: 416-739-5700 E-Mail: ron.stewart@ec.gc.ca
Strong, Geoff, AES, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-5809 Fax: 306-975-6516 E-Mail: geoff.strong@ec.gc.ca
Taylor, Peter, EATS York University, 4700 Keele Street, North York ON M3J 1P3 Tel: 416-736-5245 Fax: 416-736-5817 E-Mail: fs300016@sol.yorku.ca
Walker, Anne, AES, 4905 Dufferin Street, Downsview ON M3H 5T4 Tel: 416-739-4357 Fax: 416-739-5700 E-Mail: anne.walker@ec.gc.ca
Wang, Muyin, Dalhousie, Department of Physics, Dalhousie, Halifax NS Tel: 902-494-2952 Fax: 905-494-5191 E-Mail: muym@atm.dal.ca
Wrona, Fred, NHRI, 11 Innovation Boulevard, Saskatoon SK S7N 3H5 Tel: 306-975-6099 Fax: 306-975-6414 E-Mail: fred.wrona@ec.gc.ca
Yau, Peter, McGill University, Department of Atmospheric and Ocean Sciences, 805 Sherbrooke Street West, Montreal PQ H3A 2K6 Tel: 514-398-3719 Fax: 514-398-6115 E-Mail: yau@rainband.metco.mcgill.ca