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Foreword / Avant-Propos

After an eagerly awaited article in August on precipitation over the northeast Pacific Ocean, we have a companion piece from the Grand Banks and Scotian Shelf in this number. Any charges that the *Bulletin* has a prairie bias are laid to rest by this December issue, which also features the Mackenzie Valley, Quebec and the entire Northern Hemisphere.

We thank Jerry Hall who has completed his term on the editorial board, and welcome Lawrence Mysak from McGill University as his replacement.

Apres avoir publié en août un article longtemps attendu sur les précipitations du nordest de l'Océan Pacifique, on reprend ici le même sujet mais cette fois du côté Atlantique. Ce numéro de décembre nie complètement l'accusation que nous favorisons les prairies, vu la présence du Québec, du Grand Nord et même de l'Hémisphère Nord entier.

Nos remerciements à Jerry Hall qui a complété son terme de rédacteur associé, et bienvenue à Lawrence Mysak (McGill) qui le remplace.

Alec Paul
Editor/Rédacteur en chef

The Representativeness of Precipitation Measurements on Canadian East Coast Drilling Platforms

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and
Roderick Shaw[2]
[Original manuscript received 20 April 1991;
in revised form 27 November 1991]

ABSTRACT

Measurements of monthly precipitation on drilling platforms on the Scotian Shelf and the Grand Banks off the Atlantic coast of Canada are compared, using the Sign Test, with those at the nearest available land stations: Sable Island and St. John's Airport, respectively. Because of periods of missing data on the platforms, the land data sets had to be modified accordingly. It was concluded that neither the Scotian Shelf nor the Grand Banks platform measurements were from the same population as the corresponding land station. The Scotian Shelf platforms, at distances of between 20 and 300 km from Sable Island, received only about 58% of the Sable Island precipitation amounts, with correlation coefficients ranging from 0.32 to 0.85. A regression relationship was derived between Sable Island precipitation and the combined data from the platforms which explained 64% of the variance.

Similar results were obtained for the Grand Banks: the platform measurements were about 54% of those at St. John's; correlation coefficients ranged from −0.13 to 0.72 for the various platforms. Because of the greater average distance (about 300 km) of St. John's from the Grand Banks platforms, the latter results are less certain than those for the Scotian Shelf.

RÉSUMÉ

Nous avons mesuré les précipitations mensuelles sur les plate-formes de forage du plateau continental et du Grand Banc au large des côtes de la Nouvelle-Ecosse et de Terre-Neuve (Canada) dans l'océan Atlantique et en avons respectivement comparé les résultats avec ceux de l'île au Sable et de l'aéroport de St-John's à l'aide du test Sign. Toutefois, à cause de données manquantes sur les plate-formes, nous avons dû modifier les données terrestres en

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conséquence. Suite à ces modifications, nous avons conclu que le plateau continental néo-écossais et le Grand Banc ne faisaient pas partie du même groupe que les stations terrestres correspondantes. Les plate-formes du plateau continental néo-écossais situées entre 20 et 300 kilomètres de l'île au Sable n'ont reçu que 58% de la quantité totale des précipitations enregistrées à l'île au Sable avec des coefficients de corrélation variant de 0,32 à 0,85. Une courbe de régression calculée à partir des données des précipitations de l'île au Sable et de celles des plate-formes de forage n'a expliqué que 64% de la variance totale.

Des résultats semblables ont été obtenus pour le Grand Banc où les données des plate-formes ne représentaient que 54% de celles mesurées à St-John's; les coefficients de corrélation des diverses plate-formes s'échelonnaient de −0,13 à 0,72. Mais, à cause des distances plus grandes (environ 300 kilomètres) entre St-John's et le Grand Banc, ces mêmes résultats sont un peu moins convaincants que ceux du plateau continental néo-écossais.

1. INTRODUCTION

More than two-thirds of the earth's surface is covered with water; the distribution of precipitation on oceanic areas is a fundamental part of meteorological and oceanographic knowledge. Without this knowledge, it seems impossible to obtain a reliable estimate of the earth's water budget. In particular, in oceanography the water budget including the input of fresh water from the atmosphere affects the distribution of salinity and consequently, the circulation patterns in the ocean (Pond and Pickard, 1983). Precipitation patterns over both land and oceanic areas are also needed to verify the predictions of numerical models of the atmosphere.

Measurements of precipitation over oceanic areas are difficult to obtain because of the scarcity of observing points (islands, ships, etc.). Furthermore, the accuracy of precipitation measurements on ships (Knox 1991) and drilling platforms is affected by several factors, as summarized in WMO (1962):

(a) the disturbing effect of the observing platform on the air flow
(b) the disturbing effect of the rain gauge on the air flow
(c) the effect of the motion of the gauge as caused or initiated by the platform's movement
(d) the effect of windborne spray, or of water dripping from parts of the superstructure of the platform that may be above the gauge.

During the past several years there have been many oil and gas drilling platforms off the Atlantic coasts of Nova Scotia and Newfoundland. Since 1981, a number of them have been fitted with precipitation gauges. Although Canadian offshore platforms have decreased in number lately, there are many offshore structures elsewhere and there is a continuing need to understand the limitations of the data they produce or, better, to improve their observations. Whiffen (1984) made a preliminary time series analysis of the precipitation data from the drilling platforms on the Grand Banks and Scotian Shelf. He concluded that platforms consistently undercatch actual precipitation amounts, the degree of undercatch varying from platform to platform. He reported that the platform operators observed that the positioning of the rain gauge relative to the wind (upwind or downwind) had a great effect upon its collection efficiency.

Whiffen's results support those reported earlier. WMO (1962) states that precipitation amounts measured by three different types of gauges at a height of 33 m on a tower in the river Elbe near Hamburg were 17 to 117% of those measured at a well-protected site nearby, depending upon the type of gauge and the wind speed (the greater the wind speed, the greater the undercatch of the tower-mounted gauges). Austin and Geotis (1980) report a comparison of rainfall amounts measured by five gauges mounted at different locations on R/V Gillis in an 83-day period during GATE. The five gauges agreed to within 12% for the total accumulated catch, and the standard deviation of individual 6-h samples was only 17%. There was no comparison with land-based measurements, but Rao *et al.* (1976) compared satellite-borne microwave radiometer measurements with data from ship-borne gauges in the GATE area during the summer of 1974. There was fair agreement between the two types of measurements for the overall average, the microwave measurements being 30–40% less than those from the ship gauges. However, for periods of 2 to 7 days, the differences were quite large and could be in either direction. Austin and Geotis (1980) conclude that satisfactory depiction of the distribution of precipitation over the oceans can best be obtained by coordinating observations from several techniques: ship-borne gauges, radar, salinity profiles, and satellite-borne visible, infrared and microwave imagery.

The purpose of this paper is to further assess the representativeness of monthly precipitation measurements taken on drilling platforms off the Atlantic coast of Canada and to attempt to find a relationship between the platform measurements and those at the nearest available land stations. More detailed results of the work reported here may be found in Bursey and Shaw (1990).

2. COMPARISON OF PRECIPITATION MEASUREMENTS ON SCOTIAN SHELF DRILLING PLATFORMS WITH THOSE ON SABLE ISLAND

a) *Measurements on Drilling Platforms*

Figure 1 shows the locations of the drilling platforms on which precipitation measurements were taken on both the Scotian Shelf and the Grand Banks, as well as the land stations with which comparisons are made. On the platforms, precipitation amounts (for both rain and snow) were measured for six-hour intervals ending at 00, 06, 12 and 18 UTC by a standard Meteorological Service of Canada rain gauge strapped to the railing of the bridge or the helicopter deck, at heights ranging from 19 to 40 meters above sea level. WMO (1962) recommends that gauges be mounted as high as possible to reduce the effect of airflow around the platform, and the effect of spray. However, Austin and Geotis (1980) reported that it is the airflow around the gauge rather than the height *per se* that is the important factor. Since there was considerable superstructure of the platforms (jack-up legs, drilling derricks, cranes, satellite dishes, radio shacks, etc.) near

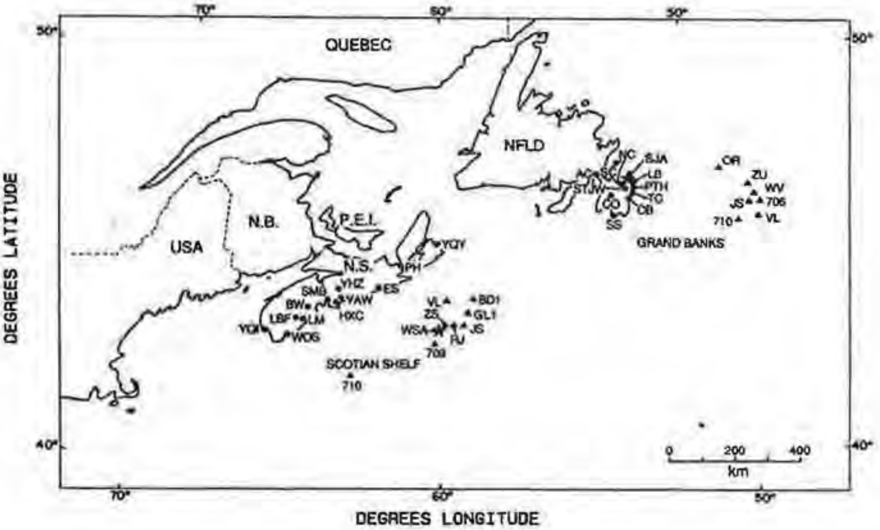

FIGURE 1. Location of Scotian Shelf and Grand Banks drilling platforms, and Nova Scotia and Newfoundland coastal stations that were used in the analysis. Key to identifiers can be found in Tables 1 through 7.

and/or above the gauges, it is safe to assume the the airflow was probably disturbed around the gauge for most wind directions. Whether or not spray was a factor in the measurements is unknown; salinity measurements of the precipitation were never taken. WMO (1962) also recommends that the gauge be mounted rigidly (rather than on gimbals) with its orifice horizontal. The gauges were probably rigidly fixed to the railings and there would be less movement of an anchored drilling platform than of a ship, but Atmospheric Environment Service inspectors frequently noted that the gauges needed to be levelled.

If measurements were missing on the platform for more than half of the 6-hour periods during a given month, that month was considered to be "missing". Because of the scarcity and uncertainty of other types of surface observations over the ocean, no attempt was made at salvage (even if synoptic charts indicated that there may have been no precipitation anyway), and the data were not included in this analysis. Table 1 lists, for each drilling platform on the Scotian Shelf, latitude and longitude, period of record and the months during which 6-hourly measurements were missing more than half of the time. Missing months accounted for 13 to 47% of the period of record at a given platform. Note that the periods of observation at the platforms were relatively short. However, it is likely, because of the large differences (to be discussed) between platform observations and those at nearby land stations, that there would also have been differences with a longer period of record.

TABLE 1: Summary of available precipitation data from drilling platforms on the Scotian Shelf.

PLATFORM	AVERAGE LOCATION	PERIOD COVERED	MISSING MONTHS
Rowan Juneau (RJ)	44.0 N, 59.6 W	Apr. 81 - Sep. 83 (30 months)	Sep. 81, Jan. 82 - Mar. 82, Jan. 83, Jul. 83 (6 months)
Zapata Scotian (ZS)	44.0 N, 59.7 W	Jun. 82 - Jun. 85 (37 months)	Jun. 83, Oct. 84 - Feb. 85, Apr. 83 (7 months)
Bow Drill 1 (BD1)	44.6 N, 58.8 W*	Sep. 82 - Mar. 84 (19 months)	Dec. 82 - Feb. 83, Oct. 83, Dec. 83 (5 months)
Vinland (VL)	44.6 N, 59.6 W	Nov. 82 - Sep. 84 (23 months)	Feb. 83, Jul. 83, Aug. 84 (3 months)
Sedco 709 (709)	43.8 N, 60.1 W	Jul. 83 - Dec. 85 (30 months)	Nov. 83, Jan. 84 - Mar. 84, Jul. 84, Aug 84, Mar. 85 - Oct. 85 (14 months)
John Shaw (JS)	44.0 N, 59.1 W	Feb. 83 - Aug. 83 (7 months)	May 83 (1 month)
Glomar Labrador 1 (GL1)	44.3 N, 58.8 W	Apr. 84 - Jun. 85 (15 months)	Jul. 84, Oct. 84, Dec. 84, Apr. 85, May 85 (5 months)
Sedco 710 (710)	42.7 N, 63.2 W	Dec. 84 - Sep. 85 (10 months)	Apr. 85 - Jul. 85 (4 months)

* From February 1984; 42.4 N, 65.1 W

b) *Selection of a Nearby Station for Comparison*

If possible, it was desirable to compare the platform measurements with those at a nearby high quality observing station, to determine whether or not precipitation data collected from drilling platforms are accurate. Sable Island was a likely candidate because it was nearest to the drilling platforms, and also an Atmospheric Environment Service first-order observing station. However, it was also desirable to demonstrate that precipitation measured on Sable Island is representative of that falling on other stations on the Atlantic Coast of Nova Scotia. (However, it does not necessarily follow that any observations at any of these coastal stations also represent those over the Scotian Shelf). Therefore, monthly and annual precipitation measurements at Sable Island were compared with those at 13 stations along the Atlantic Coast whose locations are shown on Figure 1. Occasionally, some of the land stations had brief periods (up to 7 days) of missing data during 1981–1985. These gaps were filled in with estimates obtained from a nearby station. As will be shown later (in Figure 3), measurements between land stations that are separated by less than 100 km are highly correlated.

In all comparisons between precipitation measurements at various stations, the null hypothesis (H_O) was chosen to be the one that the decision maker wished to disprove. The risk of error, i.e. rejecting H_O when it is indeed true, was chosen to be 0.05 (i.e., a 95% confidence level).

Non-parametric statistics were used for the comparisons between Sable Island, the other land stations and the drilling platforms because the coefficients of skewness and kurtosis in the precipitation amounts indicated that they were not distributed normally. For this reason, the Sign Test (Lapin, 1975; Lehmann, 1975) was used because it does not depend upon the form of the distribution of the data. The Sign Test compares the sign of the differences between matched pairs from the two data sets. Two-tailed tests were used to compare the land stations with Sable Island because there was not a great deal of difference in the mean values of any of the stations. The null hypothesis "H_O: Sable Island precipitation amounts are not significantly different from those at the land stations", was tested; this corresponded to a Z-value from the Sign Test of less than 1.96.

Table 2 shows that, for the five-year period 1981–1985, monthly precipitation amounts measured at Sable Island could be considered to be from the same population as those from two-thirds of the land stations, at a 95% confidence level. For the 30-year period 1951–1980, annual values at Sable Island could be considered to be from the same population as those from *all* of the land stations, at the 95% confidence level.

Station elevation and local topography were examined in an attempt to explain those cases where Sable Island precipitation measurements were significantly different from those at the other stations. No consistent relationship could be found between mean monthly precipitation amount and station location or elevation. Furthermore, there were no obvious characteristics (i.e. elevation, location, etc.) which distinguished between the stations whose precipitation amounts differed significantly from those at Sable Island and those where they did not. It is possible that both year-to-year variability in regional precipitation patterns and local topographic effects influenced the comparisons between Sable Island and the other land stations. The former factor may be more important, because the agreement in Table 2 between Sable Island and the other stations is

TABLE 2: Results of Sign Test to determine if precipitation measurements at Sable Island are representative of the Atlantic coast of Nova Scotia.

STATION COMPARED	Z-STATISTIC FROM SIGN TEST			
	ANNUAL AMOUNTS 1951-80		MONTHLY AMOUNTS 1981-85	
	Z	SAME POPULATION?	Z	SAME POPULATION?
Yarmouth Airport (YQI)	1.826	YES	-0.775	YES
St. Margaret's Bay (SMB)	1.826	YES	-1.549	YES
Shelburne (WOS)	1.600	YES	-1.033	YES
Port Hastings (PH)	0.435	YES	-3.098	NO
Shearwater Airport (YAW)	1.095	YES	-0.911	YES
Sydney Airport (YQY)	-0.365	YES	-2.324	NO
Liverpool Big Falls (LBF)	-0.730	YES	-1.033	YES
Halifax Citadel (HXC)	0.000	YES	-1.807	YES
Bridgewater (BW)	-0.453	YES	-1.549	YES
Halifax Airport (YHZ)	-1.119	YES	-1.291	YES
Ecum Secum (ES)	-1.826	YES	-2.066	NO
Liverpool Milton (LM)	-1.342	YES	-2.324	NO
All Stations Average	0.000	YES	-1.807	YES

Note: (-) means that in the majority of paired comparisons, the Sable Island data set was smaller.

better for the 30-year period than it is for the 5-year period; the longer period would tend to average out the year-to-year variability but not the topographic effects. However, the possibility of topographic effects cannot be eliminated at the land stations although such effects should be, in comparison, minimal at Sable Island.

It is interesting to note that, among the stations on the Atlantic coast of Nova Scotia, there was a factor of only 1.24 to 1.28 between the greatest and smallest precipitation amounts for the 30 and 5-year sampling periods, respectively. It will be seen later that these factors are smaller than the ratio between Sable Island precipitation amounts and those measured at nearby drilling platforms.

The relationship between Sable Island precipitation and that which falls over the nearby portions of the Scotian Shelf should be better than those that have been found between Shearwater (an Atmospheric Environment Service first-order observing station) and other coastal stations in Nova Scotia (to be shown later as Figure 3). Correlation coefficients greater than 0.85 were found between Shearwater and other coastal stations within 75 km of it. Sable Island (another first-order station) is only 4 m above sea level, has excellent exposures in all directions and minimal orographic effects including coastal convergence.

One may infer from the above that, considering the year-to-year variability of precipitation patterns, mean monthly and annual precipitation amounts measured at Sable Island should be representative of at least that portion of the Scotian Shelf where all but one of the drilling platforms are located, i.e., that portion within 75 km of Sable Island.

c) *Modification of Sable Island Data Set*

As mentioned earlier, the measurements from a given drilling platform contained a number of 6-hour periods where the rain gauge was not read. Even when the platform measurements covered more than 50% of a month (and therefore that month was not counted as "missing"), there were still gaps in the record. It was necessary, therefore, before comparing data from a given platform with Sable Island measurements, to modify the Sable Island data set so that it covered exactly the same periods as the set from the drilling platform. This was done by deleting from Sable Island the intervals of data that were missing from a given drilling platform. Next, for both locations, the sum of the precipitation was reduced to daily averages (based on the number of days of useful information), and then prorated to monthly values. Since measurements from each drilling platform covered a different period, the Sable Island data set had to be modified in a different way for comparison with each drilling platform.

d) *Comparison of Scotian Shelf Platform Data with Sable Island Data*

In each pair of lines in Table 3, platform data can be compared with the modified Sable Island data. Note that the various modified Sable Island data sets have different means and variances, etc., because of the slightly different periods they cover after modification. The comparison of the "Combined Platform" data

TABLE 3: Comparison of precipitation measurements on Scotian Shelf drilling platforms with the corresponding modified data set at Sable Island (WSA).

LOCATION	MEAN (mm/mo)	PLATFORM/ SABLE	S.D. (mm/mo)	COEF. OF SKEWNESS	COEF. OF KURTOSIS	NO. OF MONTHS
Rowan Juneau (RJ) Modified WSA	72.1 125.0	0.58	29.2 69.8	0.4 1.5	2.3 5.1	24
Zapata Scotian (ZS) Modified WSA	55.6 116.3	0.48	32.9 48.2	0.7 0.9	2.5 5.7	30
Bow Drill 1 (BD1) Modified WSA	118.3 134.1	0.88	81.7 90.8	1.6 2.7	5.3 9.8	14
Vinland (VL) Modified WSA	65.4 123.0	0.53	28.8 55.8	0.4 1.6	2.5 7.3	20
Sedco 709 (709) Modified WSA	77.2 110.9	0.70	26.5 27.5	-0.3 -0.9	2.6 2.9	16
John Shaw (JS) Modified WSA	95.2 116.8	0.82	37.4 17.3	0.4 -0.8	1.8 2.2	6
Glomar Labrador 1 (GL1) Modified WSA	50.3 107.3	0.47	26.5 29.8	0.5 -0.3	2.4 2.7	10
Sedco 710 (710) Modified WSA	37.1 101.2	0.37	21.7 54.9	1.0 0.5	2.4 2.8	6
Combined Platforms (CP) Modified WSA	69.1 118.2	0.58	32.3 56.2	1.5 1.6	7.1 7.6	51
Sable (WSA) Modified WSA*	117.3 118.2	0.99	50.3 56.2	1.4 1.6	6.5 7.6	51 51

Note: * indicates the data set that was modified for comparison with combined platforms (Modified WSA) is also compared to unmodified data from Sable Island, i.e. Sable (WSA).

(determined by averaging the precipitation value from drilling platforms that were available each month and then finding mean monthly precipitation from all of the available months) and the corresponding Sable Island data set for the periods when platforms were operating is also shown in Table 3. The bottom two lines in Table 3 show that modifying the Sable Island data set to compare it with the combined platform data changed its mean, standard deviation, skewness and kurtosis very little.

The mean monthly precipitation measured on the platforms was 37 to 88% of that measured at Sable Island during the same period, while the average ratio for all platforms combined was 58%. These results are consistent with those of Whiffen (1984).

The mean monthly precipitation value from each platform was then compared against the corresponding "modified" monthly value from Sable Island, using the null-hypothesis "H_O: Drilling platforms receive at least as much precipitation as Sable Island". To test this hypothesis, a one-tailed test was used because visual inspection of the data indicated that the drilling platforms received less precipitation than Sable Island; in this case a Z-value of less than 1.64 would indicate no significant difference. Table 4 shows that, with the exception of the platform John Shaw (where only six months of data are available), the precipitation measurements from the platforms could not be considered to be from the same population as the modified Sable Island data. The combined monthly precipitation data from the platforms were also significantly different from the modified Sable Island measurements. On the other hand, the bottom line of Table 4

TABLE 4: Results of Sign Test to determine if precipitation measurements taken on Scotian Shelf drilling platforms are from the same population as the corresponding modified data sets at Sable Island.

PLATFORMS COMPARED	Z STATISTIC FROM SIGN TEST	SAME POPULATION AS SABLE ISLAND? (MODIFIED DATA)
Rowan Juneau (RJ)	-4.082	NO
Zapata Scotian (ZS)	-4.382	NO
Bow Drill 1 (BD1)	-1.900	NO
Vinland (VL)	-4.025	NO
Sedco 709 (709)	-3.390	NO
John Shaw (JS)	-0.402	YES
Glomar Labrador 1 (GL1)	-3.080	NO
Sedco 710 (710)	-2.155	NO
Combined Platforms (CP)	-6.581	NO
Sable Island (WSA)	-0.146	YES

Note: (-) means that in the majority of paired comparisons, the modified Sable Island data set was larger.

shows that modifying the Sable Island data set to allow for comparison with the platform data did not alter it significantly.

Catch ratios of Scotian Shelf platforms to modified Sable Island data were then found both by month and by season. Monthly ratios ranged from a low of 0.42 in December to a high of 0.82 in July. Seasonal ratios varied as follows: January through March 0.50; April through June 0.67; July through September 0.71 and October through December 0.57. Because of the shortness of the records, it was not felt advisable to carry out Sign Tests on seasonal data.

The above findings suggest that wind velocity and precipitation type may be important factors in collection efficiencies of precipitation gauges on drilling platforms. (The same gauge was used for all types of precipitation). The mean wind speed at Sable Island during the period December-March, when about 22% of the precipitation falls as snow, is 31 kph (about 35% greater than the remainder of the year); both these factors would accentuate the undercatch at drilling platforms during the wintertime.

e) *Adjusting Platform Measurements of Precipitation to Allow for Undercatch*
To make allowance for the above-noted undercatch, and the otherwise unreliable nature of platform observations, a linear regression was carried out between the Sable island data (P_{Sable}) and the combined platform monthly precipitation values (P_{cp}) with the result:

$$P_{Sable} = 1.40\,P_{cp} + 21.5 \quad (R = 0.80) \qquad (1)$$

If one makes the assumption that Sable Island measurements are regionally representative, equation (1) in theory could be used to estimate regional values (P_{ocean}) from the combined platform measurements. However, the relationship in (1) explains only 64% of the variance in the measured values.

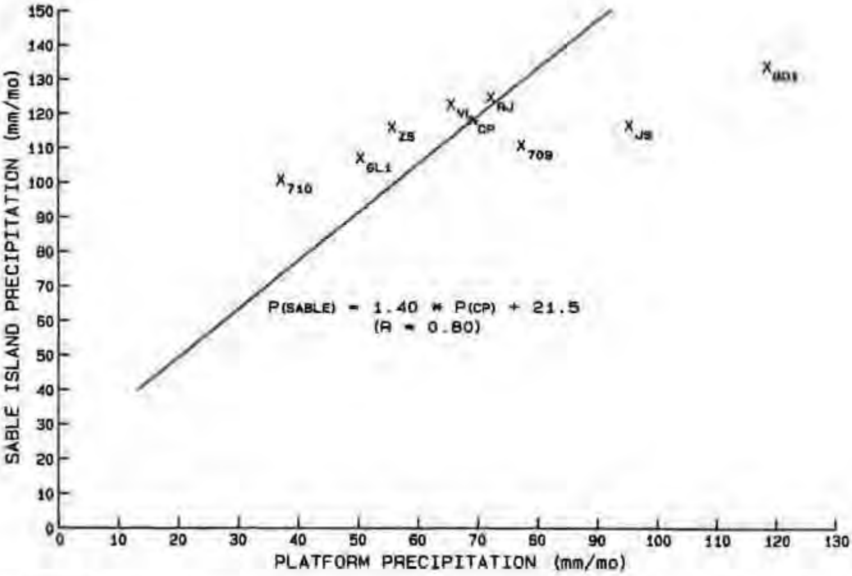

FIGURE 2. Linear regression between monthly Sable Island precipitation data (modified as described in the text) and combined Scotian Shelf platform data. Star shows mean value of combined Scotian Shelf platform (CP) versus corresponding Sable Island data. Each X shows the same information, but for individual platforms.

The regression line in (1) is shown in Figure 2. The figure also shows the mean monthly precipitation amounts observed at the various Scotian Shelf platforms and at Sable Island for the same periods. With the exception of the mean monthly values for the combined platform data and Sable Island (marked "*" in the figure) upon which the regression line (1) was based, the points (X's) comparing mean monthly values from individual platforms and Sable Island were widely scattered about the regression line. It is, of course, not surprising that the points for individual platforms do not lie on the regression lines based upon the combined platform data. One possible reason for the scatter is that each platform has its own aerodynamic characteristics.

Next, regression equations were calculated for each platform. There was considerable platform-to-platform variability among the coefficients of the regression equations. With the exception of John Shaw, the correlation coefficients between monthly precipitation measured at the various Scotian Shelf platforms and that at Sable Island ranged from 0.61 to 0.85. The poorest correlation (0.32) was for the John Shaw, which also had the shortest record (6 months).

The possibility exists that correlation among land stations would be no better. To examine this, the correlations between monthly precipitation amounts measured at Shearwater and those measured at other Nova Scotian stations are

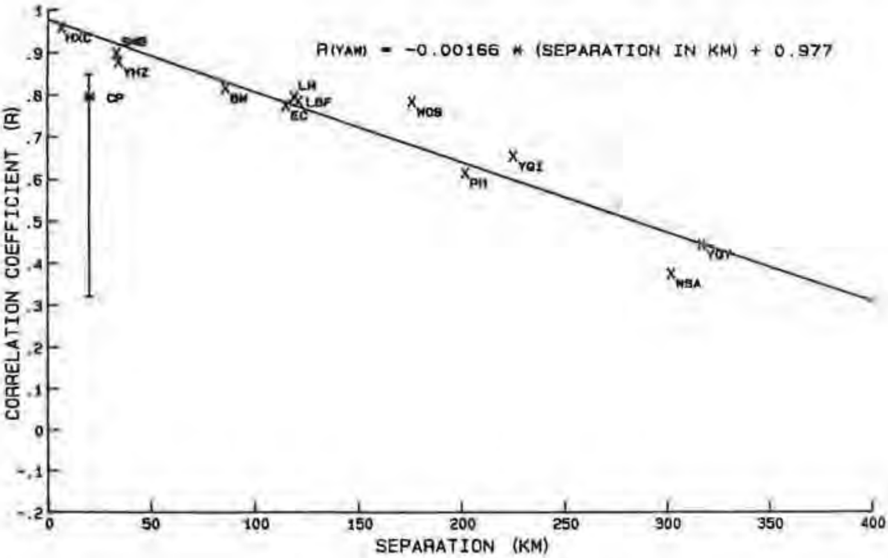

FIGURE 3. Each X shows the correlation between monthly precipitation values at the specified Nova Scotia coastal station and Shearwater, plotted against distance from Shearwater. Line of best fit is also shown. Vertical bar shows range and mean value of correlations between Sable Island precipitation and Scotian Shelf platform measurements at a nominal separation of 20 km. Star (CP) shows the value for Scotian Shelf combined platform data.

plotted in Figure 3 against distance separating the stations. For comparison, the correlations (mean value and range) between Sable Island and the Scotian Shelf drilling platforms are also plotted at a nominal distance of 20 km. As would be expected, the correlations between monthly precipitation amounts at the land stations decrease with increasing separation. Of more interest in Figure 3 is the indication that the correlations between monthly precipitation measured at Sable Island and those at nearby drilling platforms are lower than those for land stations separated by a similar distance.

In conclusion, monthly measurements of precipitation on individual drilling platforms on the Scotian Shelf are not well correlated with values measured several tens of kilometres away at Sable Island and, therefore, may be poor indicators of regional precipitation amounts. However, if one assumes that Sable Island data are representative of regional values (an assumption that could be challenged), regression equation (1) does contain predictive skill, from which regional precipitation estimates can be obtained by adjusting for the undercatch.

3. COMPARISON OF PRECIPITATION MEASUREMENTS ON GRAND BANKS DRILLING PLATFORMS WITH THOSE AT A LAND STATION

a) *Measurements on Drilling Platforms*

Table 5 lists the period of record and the months where data are missing.

b) *Selection of a Representative Station for Comparison*

Unlike the Scotian Shelf with Sable Island, there were no nearby land stations with which to compare the precipitation measurements at the Grand Banks platforms. Mean annual precipitation measurements along the Atlantic coast of Nova Scotia, Sable Island and the Avalon Peninsula of Newfoundland are approximately the same, about 1400 mm (AES 1986). However, that does not necessarily mean that data from any land station in the above area can be used for comparison with observations on the Grand Banks platforms. The time required for a storm to traverse such a large area would result in lags of up to 20–30 hours in precipitation events observed at opposite sides of the area. For that reason, it is important to choose a land station that is as close as possible to the Grand Banks.

The results of the Sign Test comparing St. John's Airport monthly precipitation with that at other locations on the Avalon Pensinsula indicate that, for the period 1981–85, St. John's measurements are from the same population as the *average* of all of the other Avalon Peninsula stations. However, when comparing St. John's Airport with *individual* stations, measurements are from the same population in only 30% of the comparisons. For the period 1951–80, annual measurements from St. John's Airport were from the same population as only two of the Avalon Peninsula stations (Cape Broyle and Petty Harbour). The poorer correlations found on the Avalon Peninsula as compared to those in Nova Scotia may be due to the more rugged topography. Because St. John's Airport is the only

TABLE 5: Summary of available precipitation data from drilling platforms on the Grand Banks.

PLATFORM	AVERAGE LOCATION	PERIOD COVERED	MISSING MONTHS
Ocean Ranger (OR)	47.4 N, 49.4 W	Mar. 81 - Jan. 82 (11 months)	Mar. 81, Jun. 81, Aug. 81, Dec. 81 (4 months)
Sedco 706 (706)	46.4 N, 48.2 W	Mar. 81 - Jan. 85 (47 months)	Mar. 81, Oct. 81, Dec. 81 - Feb. 84, Apr. 84, May 84 (31 months)
Zapata Ugland (ZU)	47.0 N, 48.3 W	Mar. 81 - Dec. 83 (34 months)	Mar. 81 - May 81, Oct. 81, Jan. 82, Mar. 82, May 82, Jul. 82, Nov. 82 - Sep. 83 (19 months)
John Shaw (JS)	46.5 N, 48.3 W	Oct. 83 - Sep. 85 (24 months)	Feb. 85, Mar. 85 (2 months)
West Venture (WV)	46.4 N, 48.5 W	Jan. 83 - Jul. 84 (19 months)	Jan. 83, Jul. 84 (2 months)
Sedco 710 (710)	46.3 N, 49.1 W	Oct. 83 - Oct. 84 (13 months)	Apr. 84 - Jun. 84 (3 months)
Vinland (VL)	46.3 N, 48.3 W	Nov. 84 - Dec. 85 (14 months)	Feb. 85 - Jun. 85, Aug. 85 - Oct. 85 (8 months)

first-order observing station on the land mass closest to the Grand Banks, it was decided to use it as a basis of comparison with the Grand Banks drilling platforms. However, it was recognized that its distance of about 320 km from the platforms could result in lower correlations between the platform and land station data.

c) *Comparison of Grand Banks Platform Data with St. John's Airport Data*
Because of the distance between St. John's Airport and the Grand Banks platforms and the lags in precipitation amounts that this separation might introduce, the St. John's Airport data set was not modified (as indicated in Section 2c for the Scotian Shelf case) by removing 6-hourly amounts when platform data were not available. Instead, if at least half of the monthly observations were available, the observations from each drilling platform were then prorated to a full month's precipitation amount based on the fraction of the month that was sampled. This value was then compared to the actual precipitation received at St. John's Airport.

Table 6 shows results similar to those in Table 3 for the Scotian Shelf, i.e. monthly precipitation amounts on Grand Banks platforms were much less than those measured at the benchmark station, St. John's Airport. On average, the catch on the Grand Banks platforms was only 54% of that at St. John's Airport. It is interesting to note that the undercatch for the Grand Banks platforms appears to be about the same as that for the Scotian Shelf platforms.

The results of the Sign Test (Table 7) show that monthly precipitation amounts at only one of the seven Grand Banks platforms (the Ocean Ranger) could be considered to be from the same population as the corresponding data from St. John's Airport, and then only marginally so ($Z = -1.534$). Furthermore, the combined platform measurements were not from the same population as the St. John's Airport measurements ($Z = -5.196$). Therefore, the measurements of

TABLE 6: Comparison of precipitation measurements taken on Grand Banks drilling platforms with the corresponding data sets at St. John's Airport.

LOCATION	MEAN (mm/mo)	PLATFORM/ SABLE	S.D. (mm/mo)	COEF. OF SKEWNESS	COEF. OF KURTOSIS	NO. OF MONTHS
Ocean Ranger (OR)	84.4	0.49	24.6	-0.6	3.0	7
St. John's Airport (SJA)	170.7		91.4	0.3	2.2	7
Sedco 706 (706)	57.9	0.47	42.5	0.5	2.5	16
St. John's Airport (SJA)	124.2		47.7	0.0	2.1	16
Zapata Ugland (ZU)	107.4	0.72	50.8	0.5	2.4	15
St. John's Airport (SJA)	148.9		47.4	0.6	2.7	15
John Shaw (JS)	60.0	0.46	30.9	1.2	3.9	22
St. John's Airport (SJA)	131.2		50.3	0.3	2.5	22
West Venture (WV)	83.3	0.56	29.9	0.5	3.6	17
St. John's Airport (SJA)	149.9		41.1	0.4	2.6	17
Sedco 710 (710)	68.1	0.48	42.7	0.9	3.3	10
St. John's Airport (SJA)	141.2		54.8	-0.4	2.2	10
Vinland (VL)	50.2	0.46	16.2	0.1	2.2	6
St. John's Airport (SJA)	108.0		4.9	-0.4	1.8	6
Combined Platforms (CGBDP)	75.3	0.54	32.8	0.6	2.7	48
St. John's Airport (SJA)	138.7		55.4	0.9	4.1	48

ERRATA

In the article by J. Bursey and R. Shaw on "The representativeness of precipitation measurements on Canadian East Coast drilling platforms" in *Climatological Bulletin*, 25, 3, December 1991: 131–146, the following corrections should be made:

Column 3, Table 6, p. 143 should be headed "PLATFORM/ST. JOHN'S".

Column 3, Table 7, p. 144 should be headed "SAME POPULATION AS ST. JOHN'S?"

TABLE 7: Results of Sign Test to determine if precipitation measurements taken on Grand Banks drilling platforms are from the same population as the corresponding data sets at St. John's Airport.

PLATFORMS COMPARED	Z STATISTIC FROM SIGN TEST	SAME POPULATION AS SABLE ISLAND? (MODIFIED DATA)
Ocean Ranger (OR)	-1.534	YES
Sedco 706 (706)	-2.303	NO
Zapata Ugland (ZU)	-2.680	NO
John Shaw (JS)	-3.080	NO
West Venture (WV)	-3.030	NO
Sedco 710 (710)	-3.080	NO
Vinland (VL)	-2.155	NO
Combined Drilling Platforms (CGBDP)	-5.196	NO

Note: (-) means that in the majority of paired comparisons, the St. John's Airport data set was larger.

precipitation at Grand Banks platforms are no more closely related to St. John's Airport than those from the Scotian Shelf drilling platforms are to Sable Island.

Linear regressions with St. John's Airport measurements were also carried out for monthly precipitation observations on the Grand Banks platforms. The correlation coefficients varied from −0.13 to 0.73 and, therefore, were even more erratic than those discussed in Section 2e for the Scotian Shelf platforms. The correlation coefficient between the combined Grand Banks platform data and those from St. John's Airport was only 0.35. From this, we conclude that there is a poor relationship between individual monthly precipitation amounts measured by Grand Banks platforms and values at St. John's Airport. However, it is recognized that this relatively low correlation may be due as much to the geographical separation as to the collection efficiency of the platforms.

d) *Comparison of Grand Banks Platform Data with Scotian Shelf Platform Data*
The Sign Test was carried out between the data from combined Grand Banks drilling platforms and combined Scotian Shelf platforms. The Z statistic was zero, indicating that the data from both sets of platforms was from the same population. Because the catch efficiency (albeit based upon land stations) for both sets of platforms is about the same (averaging about 56%), one may infer that the amount of precipitation falling in both the Scotian Shelf and Grand Banks areas is about the same. The result is consistent with the observations on the corresponding nearest land areas.

4. CONCLUSIONS

a) *Precipitation Measurements Taken on Scotian Shelf Drilling Platforms*
Precipitation measurements on Scotian Shelf drilling platforms are not well related to those at Sable Island, only a few tens of kilometres away. The platforms

measured from 37 to 88% of the monthly precipitation amounts at Sable Island and, when combined, they measured only 58% of the Sable Island amounts.

A linear regression equation was developed between Sable Island measurements and the combined data from the drilling platforms. It explained 64% of the variance in the measured values and could be used to adjust the platform measurements to allow for undercatch and other deficiencies. Linear regressions between the Sable Island and individual Scotian Shelf platform measurements showed that the correlation between monthly precipitation amounts measured on the Scotian Shelf platforms and that at Sable Island varied from 0.32 to 0.85. These values are lower than would be expected from land stations along the Nova Scotia coast separated by the same distance.

b) *Precipitation Measurements Taken on Grand Banks Drilling Platforms*
Comparisons with St. John's Airport, the nearest first-order station on the Avalon Peninsula, showed the same results as those from the Scotian Shelf platforms: measurements on Grand Banks platforms did not belong to the same population as those at St. John's Airport. The mean monthly amounts measured on the Grand Banks platforms (when combined) were only 54% of those measured at St. John's Airport while the individual correlation coefficients varied from −0.13 to 0.72. Undoubtedly the lower correlation coefficients in the case of the Grand Banks drilling platforms were partially due to the greater distance of the platform from the land station (St. John's Airport). For this reason, we are less confident of our results for the Grand Banks than we are for the Scotian Shelf.

c) *General*

The month to month mean values of precipitation and poorer correlations between measurements on drilling platforms and those at the nearest land stations separated by similar distances indicate that individual platform measurements may not provide a good measure of inter-monthly variability in areal precipitation. However, when data from a group of platforms were combined either in the Scotian Shelf or Grand Banks area, the percentage catch was similar for the two areas (58% for Scotian Shelf, 54% for Grand Banks). Therefore, it may be possible to obtain long-term estimates (say over several years) of regional oceanic precipitation amounts off the Atlantic coast of Canada by combining data from a group of nearby platforms and multiplying by a factor of about 1.8 to allow for the undercatch. However, combining data from a group of platforms may smooth out but would not eliminate the month to month variability caused by the aerodynamics of each individual platform.

For the period of study, the similar catch efficiency for the two sets of platforms, and the finding that their data are from the same population indicate that the precipitation amounts falling on the Scotian Shelf and Grand Banks areas are similar.

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On the Applicability of GCM Estimates to Scenarios of Global Warming in the Mackenzie Valley Area

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and
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[Original manuscript received 24 June 1991;
in revised form 30 August 1991]

ABSTRACT

The temperature and precipitation climate of the Mackenzie Valley area is reviewed, and is shown to be highly dependent on the topography of the region, including the mountain ranges of the Yukon Territory to the west of the Valley itself which extends for approximately 1000 km along the eastern edge of the Western Cordillera. The capability of three General Circulation Models (GCM's) to reproduce the present temperature and precipitation climate of the Mackenzie Valley area is examined and all are found to have large errors. These errors can be partly attributed to the fact that the Mackenzie Valley itself is not recognized as a topographic feature in any of the models. This is true of all GCM's, however, and cannot explain the large differences between the three models in terms of their treatment of the Mackenzie Valley region. These differences are attributed to differences in the simulation of clouds and cloud-climate feedback processes.

The temperature and precipitation values projected by the three models for the Mackenzie Valley region under conditions of doubled concentrations of greenhouse gases in the atmosphere are then reviewed. Since the size of the projected climate change signal is comparable with the errors made by the models in attempting to simulate the current climate, there can be little confidence in the projected values. Current state-of-the-art GCM's are incapable of accurately modelling the present-day special climate of the Mackenzie Valley, and any impact studies that use grid-point values of projected temperature and/or precipitation from these models will incur large errors.

RÉSUMÉ

Cet article examine les données climatiques de températures et de précipitations de la vallée du Mackenzie. Ces données dépendent fortement de la topographie de la région, dont font partie les chaînes de montagne du Yukon à l'ouest et la vallée du Mackenzie qui s'étend sur une distance de 1 000 kilomètres le long de la limite est de la Cordillère de l'ouest. Nous

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avons également étudié la représentativité de trois modèles de circulation globale sur les températures et les précipitations, et nous y avons trouvé d'importants écarts. Ces écarts peuvent être partiellement expliqués par le fait que la vallée du Mackenzie ne fait pas partie d'une entité topographique reconnue par ces modèles. C'est le défaut commun à tous les modèles de circulation globale qui ne peuvent du reste, expliquer les importants écarts existant avec les données de la vallée du Mackenzie. Ces écarts sont attribuables à des différences dans la simulation des nuages et des procédés de rétroaction nuage-climat.

Nous avons ensuite critiqué les valeurs de températures et de précipitations prédites par les trois modèles pour une concentration double de gaz d'effet de serre. Puisque les valeurs de la courbe du changement climatique sont comparables aux écarts expérimentés par la modélisation du climat actuel, nous pouvons conclure qu'on ne peut faire confiance aux valeurs obtenues par ces modèles. Les plus récents modèles de circulation globale sont incapables de prédire avec précision les conditions spécifiques existant dans la vallée du Mackenzie, et toute étude utilisant les valeurs sur un quadrillage de températures et de précipitations provenant de ces modèles pourraient être sources d'importantes erreurs.

1. INTRODUCTION

In its Green Plan, the Government of Canada (1990) identified the Mackenzie River Basin as one of the three regions of the country for which studies to determine the socio-economic repercussions of climate change will be carried out. These studies will be based to a considerable extent on scenarios of climate change generated by General Circulation Models (GCM's) of the global atmosphere and ocean systems. The aim of the study reported here is to determine the degree to which current state-of-the-art GCM's are able to simulate the present temperature and precipitation climate of the Mackenzie Valley. In addition, it examines temperature and precipitation projections of climate change resulting from increased concentrations of greenhouse gases as simulated by the models.

2. THE CLIMATE OF THE MACKENZIE VALLEY

An extensive review of the climate of the Mackenzie Valley (Figure 1) was completed by Burns (1973) and was recently updated by Stuart *et al.* (1991). For the purposes of this study, the Mackenzie Valley is bounded by the Yukon-NWT border to the west, the Arctic Ocean to the north, 110°W longitude to the east, and 60°N latitude to the south. Burns (1973) outlined the topographic effects on the climate of the Mackenzie Valley, many of which are only qualitatively understood. A few can be associated with observed climate patterns in the Mackenzie Valley; none of them are adequately accounted for in state-of-the-art GCM's.

As we examine temperature and precipitation patterns in this region, the importance of topography becomes apparent. For January and July, the western Canada sections of the standard maps of mean daily temperature and total

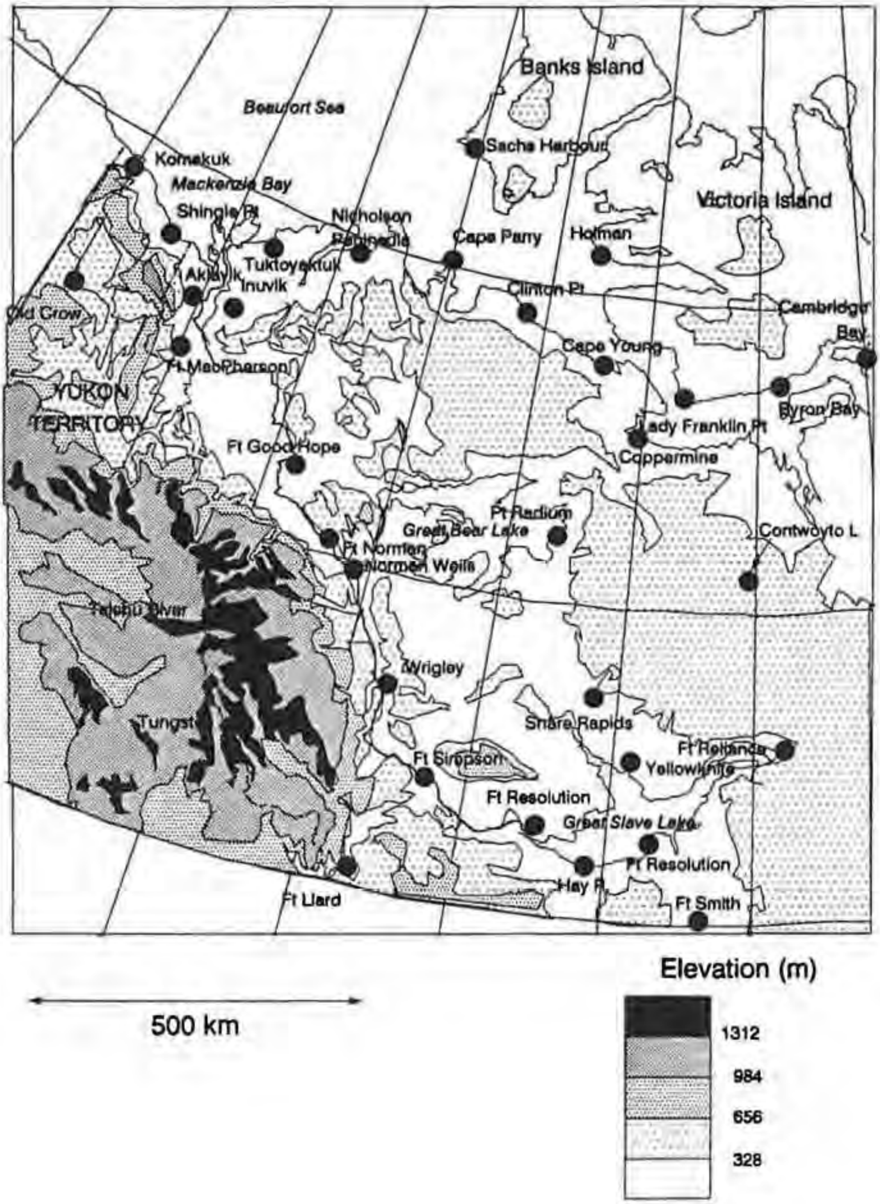

FIGURE 1. Topography of the Mackenzie Valley study area (taken from Burns, 1973).

monthly precipitation available from Environment Canada (1984a,b) are reproduced here in addition to detailed maps of the Mackenzie Valley complete with station normals and periods of record as provided in Environment Canada (1982). Considering the remote location of the study area and its low population, there are a surprisingly large number of observing sites. Many have 25–30 years of data in the 1951–80 period, particularly those stations along the Mackenzie River itself. Stations along the Arctic coast typically have shorter periods of record, but most are in the 20–24 year range. The remaining stations are identified as having "adjusted" normal values, which means that they have 5–19 years of observations in the 1951–80 period which have been supplemented with any available other data from the 1931–50 period.

The January map of mean daily temperature for western Canada and for the study area (inset) is given in Figure 2A. Mean daily temperatures around −10°C near the Alaska panhandle area of the Pacific coast decrease rapidly inland through the mountains of the Yukon Territory. These mountains block the easterly movement of warm, moist Pacific air masses with the result that the Mackenzie Valley area comes under the influence of the much colder Arctic air mass. The study-area map shows almost uniform mean daily temperatures at most stations, in the −28°C to −30°C range. One notes very little change in temperature with latitude, but there is an inverse relationship between temperature and altitude as temperatures along the Mackenzie River are decidedly colder than those

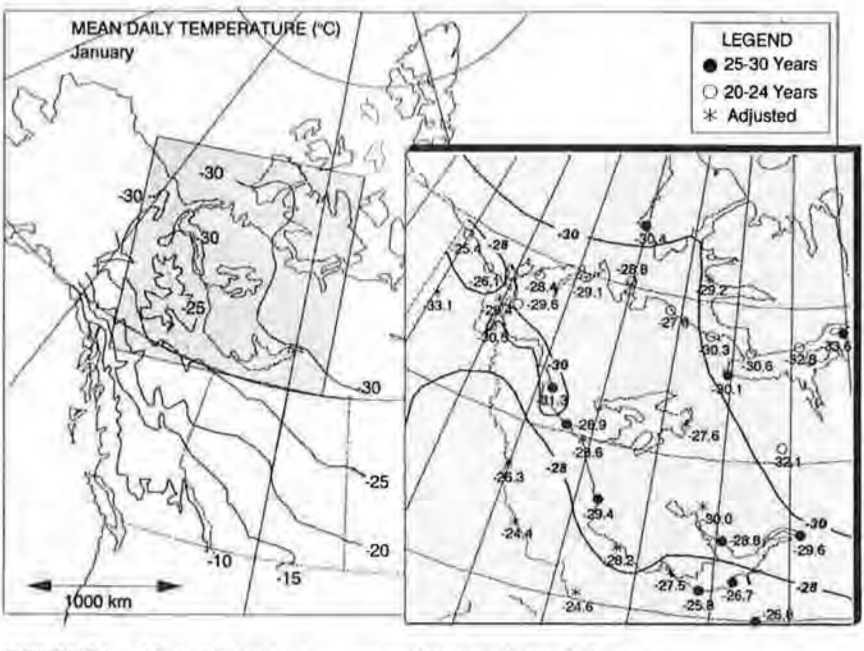

FIGURE 2A. Mean daily surface temperature for the study area in January.

elsewhere, particularly at higher elevations to the west. At this time of year, the Arctic receives little or no incoming radiation as the sun is below the horizon for all or most of the day, depending on latitude. Radiational cooling from the surface produces strong inversion conditions in which temperatures increase with latitude. In river valleys, inversions are further reinforced by the drainage of cold air from the surrounding mountain slopes to areas of lower elevation, as along the Mackenzie River.

By summer (Figure 2B), nearly 24 hours of sunshine per day have warmed the inland mountain valleys so that the Pacific coast is now cooler than the Cordillera. Preferential heating affects the entire Valley south of the Mackenzie Delta and Arctic coastal area. Mean daily temperatures for July along the Mackenzie River from Great Slave Lake to Fort Good Hope (66°16'N, 128°38'W) are virtually uniform around 16°C, and represent the warmest temperatures in Canada for this laitude range.

In both summer and winter the temperature regime in the Mackenzie Valley is very strongly affected by the valley and the surrounding topography. Temperatures change very little with latitude from the river's headwaters to the Mackenzie Delta. Summer conditions are warmer than in the nearby hills while winter conditions are colder. In each case, the importance of the topography is clear.

Precipitation may be anticipated to be even more strongly affected by

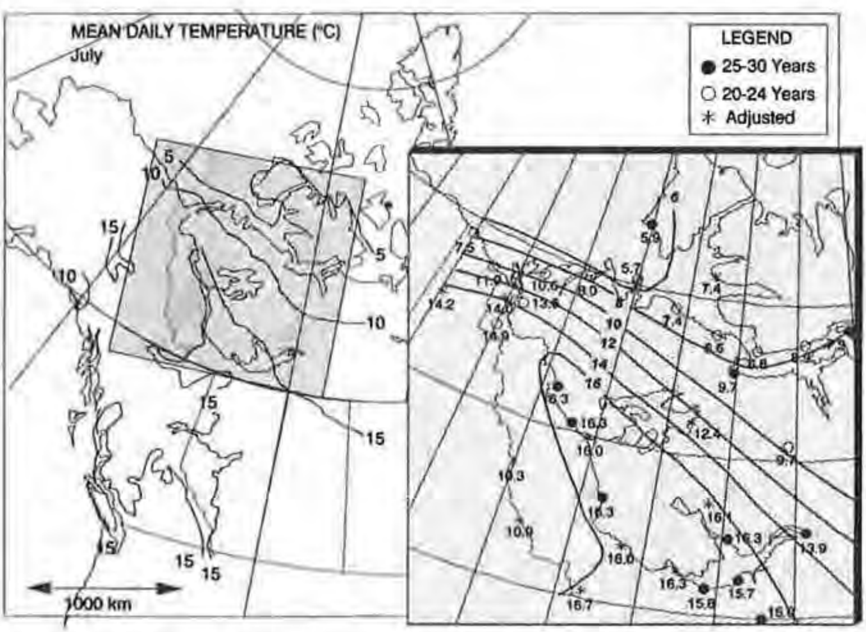

FIGURE 2B. Mean daily surface temperature for the study area in July.

local conditions than is temperature. Point observations are unlikely to be applicable to areas any significant distance away, and the very act of drawing isohyetal maps becomes problematic. In this report, we restrict ourselves to mean monthly total precipiation amounts for which it may be hoped that most of the temporal noise has been removed. Nevertheless, the strong influence of topography will remain, and interpolation contours must be interpreted with considerable caution.

Figure 3A shows the mean monthly total precipitation for January. As moisture-laden Pacific air masses move eastward, their encounter with the mountain ranges of the Yukon results in the removal of most of their moisture on the windward slopes of these mountains within 100–200 km of the coast. Most of the Cordillera north of 60°N averages approximately 25 mm of precipitation; the insert map shows that Mackenzie Valley stations collect 10–25 mm in January with higher values in the west. The very low temperatures of the entire region ensure that all local sources of moisture are frozen over and, even if sources of water were available, low temperatures would make the atmosphere incapable of holding it. As a result, precipitation amounts throughout the Arctic are very low in winter.

Precipitation amounts in July (Figure 3B) also show maximum values along the Great Divide, with almost uniform amounts recorded all along the Mackenzie River. In July, a 100–200 per cent increase in total precipitation over January values is noted for most locations. Summer is the wettest season of the year.

In both major seasons of the year, precipitation totals are reasonably uniform throughout the entire Mackenzie Valley, with lesser values noted near the Arctic coast in winter. As is the case with temperature, the mountains and the valley again play a major role in the climatology of precipitation. It follows that any attempt to model the temperature and precipitation climatology of the Mackenzie Valley must take this topographic influence into account. This issue is addressed in the following section.

3. THE APPLICATION OF THREE U.S. GENERAL CIRCULATION MODELS TO THE MACKENZIE VALLEY REGION

A variety of procedures have been proposed to develop regional-scale scenarios of climate change. Jager and Kellogg (1983) used existing climate records to ascertain how temperature and precipitation respond in unusually warm periods. Kellogg (1977) and others have studied previous epochs when the earth was warmer than it is now. Scenarios may also be created assuming arbitrary increments in temperature and precipitation from current values (e.g., Cohen, 1991). In their review of these procedures, Pittcock and Salinger (1982) suggest that a combination of these procedures with GCM-based scenarios would result in the most reliable estimates of regional-scale impacts of climate change. In the ten years since the publication of their paper, however, GCM-based scenarios of

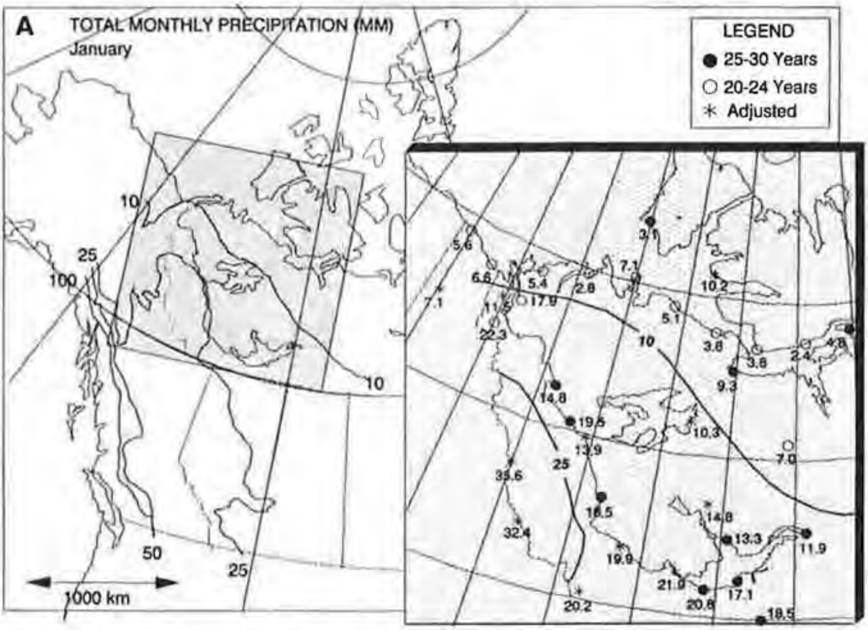

FIGURE 3A. Mean total monthly precipitation amounts for the study area in January.

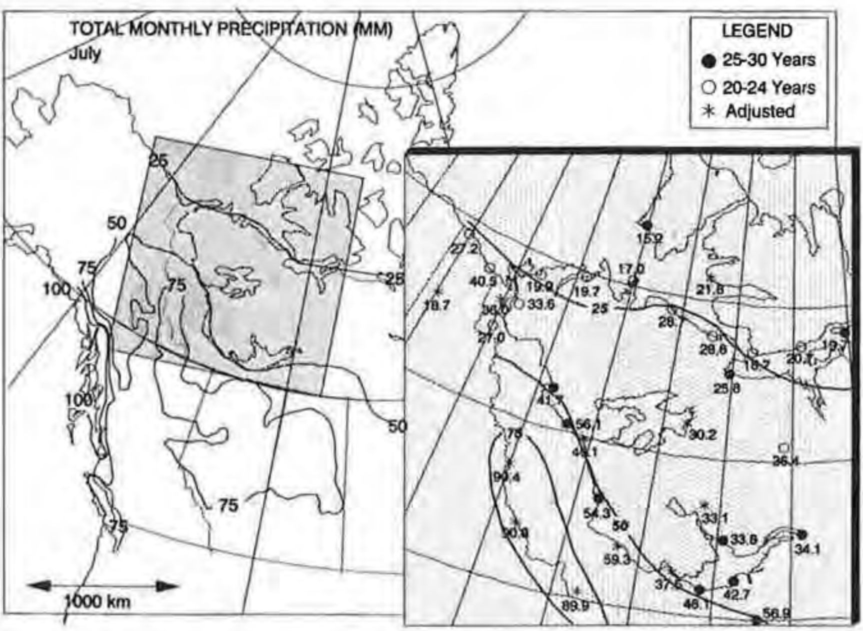

FIGURE 3B. Mean total monthly precipitation amounts for the study area in July.

climate change have received much greater emphasis than scenarios developed from alternative procedures.

In a recent study Cohen (1991) uses the GISS, GFDL and OSU model scenarios of climate change in a regional impact assessment, but instead of a direct application of the $2xCO_2$ scenario, he adds 1951–80 norms to $2xCO_2$ – $1xCO_2$ differences to simulate the changed climate. Implicit in this procedure is the assumption that model errors in each scenario will "cancel out", at least to some extent, resulting in a better estimate of the effects of global warming. For temperature projections, this would require that model errors at any grid point remain relatively constant from one scenario to another while the simulated climate changes by up to 10°C or more. This seems unlikely for the case of the Mackenzie Valley where scenario temperature differences and model errors are approximately equal, but further study would be required for definitive conclusions to be made.

As the impact studies proposed by the Canadian government go forward, it is anticipated that they will rely on GCM scenarios of climate change as has been done in most other recent studies. For example, when the United States Congress asked its Environmental Protection Agency (EPA) to initiate broad studies on the effects of climate change in that country, 35 Principal Investigators were provided with output from three GCM's – the Goddard Institute for Space Studies (GISS) model, the Geophysical Fluid Dynamics Laboratory (GFDL) model and the Oregon State University (OSU) model. The results of the various applications of these models have been summarized by EPA (1989). In this work, we will follow the lead of the United States by examining the three GCM's that they used. We would also have used the GCM of the Canadian Climate Centre, but unfortunately the output of this model was not available in time to be included here.

These three GCM's have grid-point separations of several hundred km, separations much larger than the scales of many processes important in the determination of climate. These "sub-grid scale processes" include the turbulent transfer of heat, moisture and momentum from the boundary layer to the atmosphere, and similar transfers within the atmosphere (dry and moist convection), the condensation of water vapour, the formation of clouds, the formation and dissipation of snow, and the physics of moisture and heat transfers in the soil. These processes thus must be parameterized by the model, and it is in these parameterizations that the various models derive much of their uniqueness. One of the principal activities of the large groups of scientists and engineers who develop these models is the study of various possible parameterizations to determine the response of the model to the myriad of assumptions that could be applied.

In deciding how their model will be specified, model developers look very carefully at the model response on a global or zonal (averages over a given latitude) scale. All GCM's are extremely complex, with a very large number of parameters and processes that are specified with a greater or lesser degree of subjectivity. For example, Hansen *et al.* (1983) describe 60 different sensitivity tests for different parameters or processes within the GISS model. For each test, the variation of the process under consideration changed the simulation of the control climate and the climate projected to occur with increasing concentrations of carbon dioxide. In all of these sensitivity tests, the primary concern is to produce the current global climate as realistically as possible when the current concentrations of greenhouse gases are specified. Once global mean values are modelled with reasonable accuracy, researchers are able to consider zonal averages and regional climates. Hansen *et al.* (1983) report that some model variation experiments result in changes in individual grid point surface temperature of as much as 5°C. Consequently, models cannot be tuned for any specific geographical area, and it must be anticipated that GCM's will be more reliable at global and continental scales and less useful at the larger scales that are contemplated in most impact studies.

Further information on the models used in this study may be obtained from Hansen *et al.* (1983), Manabe and Weatherald (1987) and Schlesinger (1983) for the GISS, GFDL and OSU models respectively. More general discussions of GCM's are given by Schlesinger (1984) and Schlesinger and Mitchell (1985, 1987). Without attempting to duplicate these reviews we would emphasize the following points:

(1) These models are still under development, and there is still considerable work to do. Many aspects of all models are introduced and modified in an essentially *ad hoc* fashion in an attempt to produce a control climate as close as possible to current observations.

(2) Given the grid-point separation of all GCM's, it would be fortuitous if any of them were able to reproduce the climate of the Mackenzie Valley with much accuracy. This is because the climate of the Mackenzie Valley depends to a very large extent on the local topography of the valley and the surrounding mountains. None of the models knows that the Mackenzie Valley is there.

(3) Experiments with the models demonstrate that varying the model assumptions changes the control climate in inverse proportion to the size of the region that is being considered. Since the models are always being tuned to simulate the current global climate, all experiments select against simulations that cause changes in the simulated climate on a global scale. Zonal means can and do change at a larger rate when the model assumptions are changed, and regional climates change even more than zonal averages. It must be expected that GCM simulations of the Mackenzie Valley climate will not only differ from reality due to the problems with unresolved topography, but also from one another because of different model assumptions.

With this in mind, we now embark on a review of the three selected GCM's in their simulation of the climate of the Mackenzie Valley. For an accurate simulation of a future climate to be made by any GCM, it is necessary but not sufficient that the model successfully simulate the current climate. As has been seen in the previous section, the decisions made in the development of these models are based on the performance of the models in the simulation of the present climate. Whatever level of success is gained by this procedure, however, might well be due to a cancellation of two or more erroneous processes in the control climate which turn out not to cancel each other in the climate resulting from a doubling of greenhouse gases. Hence, an agreement of the control-run model with the present climate, while certainly encouraging, cannot be regarded as conclusive.

We limit the following section to a consideration of mean monthly surface temperature and total monthly precipitation for the months of January and July in the current climate. In both months, the temperature fields in the Mackenzie Valley are quite uniform, with colder values prevailing in winter and warmer values in summer relative to neighbouring areas of higher elevation. Precipitation contours tend to follow the topography of the valley in all seasons.

3.1 *Simulations of the Present Climate of the Mackenzie Valley*

3.1.1 *Surface Air Temperature*

Figure 4 shows the maps of surface air temperature in January output from the three GCM's described in the previous section. As expected, none of the models is able to simulate the ponding of cold air in the Mackenzie Valley and warmer temperatures at high elevations in winter. Instead, surface temperature fields for all models give similar isotherm patterns in the Yukon mountains, the Mackenzie Valley and the eastern portion of the study area. In two of the three models, temperatures decrease from south to north, but there are very strong differences in the rates of decrease. The GFDL model temperatures (Figure 4A) are approximately −20°C in the upper Mackenzie area and around Great Slave Lake, falling to −30°C in the Mackenzie Delta. The GISS model results (Figure 4B) are somewhat similar to those from GFDL in the upper Mackenzie Valley, but north of 65°N the rate of temperature decrease with increasing latitude is greatly reduced in the GISS model. The OSU model output (Figure 4C) is markedly different from the other two models, in that temperatures throughout the study area are relatively constant, with values around −18°C on the Arctic coast and near the Alberta border, decreasing to approximately −21°C in between.

None of these simulations bears much resemblance to actual winter conditions in the Mackenzie Valley (Figure 4D) where mean January temperatures for most stations fall within the −28°C to −30°C range throughout the entire extent of the valley. If we were required to choose one model over the others, then the GISS model would appear to simulate temperature conditions in the Mackenzie Valley in winter better than the other two. The GFDL model shows a high degree of variability with latitude that is unrealistic. While the GISS model also shows this characteristic, it is confined to the southern part of the valley. In the north, the field is much more uniform and the value is correct at around −30°C. The OSU

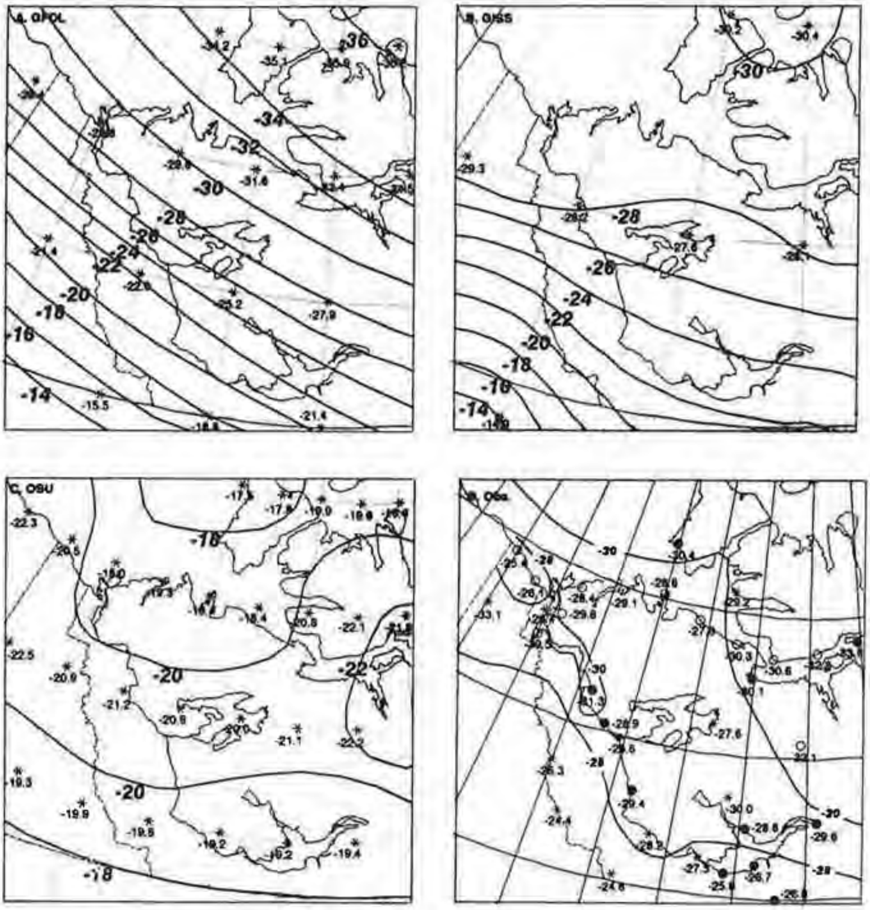

FIGURE 4. GCM model projections of mean surface temperatures (°C) in January for the present climate along with values from actual observations. Grid-point values as well as contoured isotherms are shown for the GFDL (map A), GISS (map B) and OSU (map C) models. Map D, reproduced from Figure 2A, shows actual station normals.

model shows a uniform temperature field over the entire area in which it is superior to the other models, but its value is 10°C too warm.

July temperature maps are shown in Figure 5. For this season the higher-resolution GFDL and OSU simulations are quite similar to one another. For each model, output temperatures decrease from high values of 16°C near Great Slave Lake to values in the 7–9°C range on the Arctic coast. Neither model is able to simulate the uniform temperature field which prevails in the Mackenzie Valley in this season (Figure 5D). The GISS model, on the other hand, shows very uniform values around 12°C from Great Slave Lake to Norman Wells and then a rapid decrease to around 6°C on the Arctic coast. Again, its agreement with the

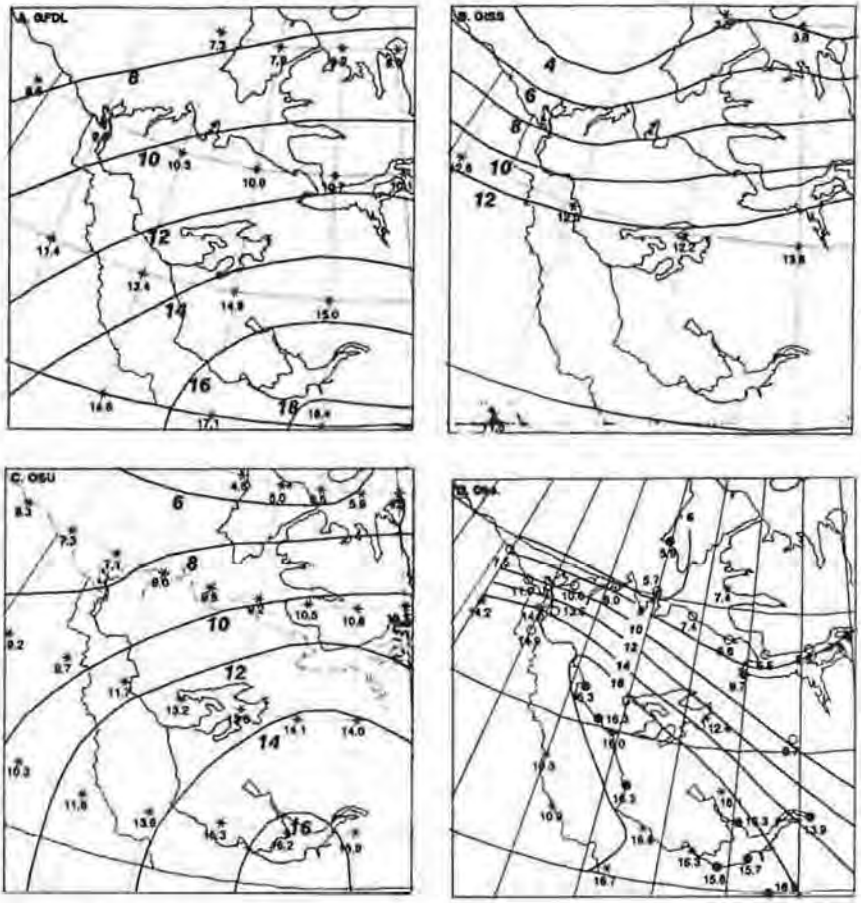

FIGURE 5. As in Figure 4 but for the month of July

observed temperature distribution is judged to be the best of the three models, but its values are about 4°C too cold.

3.1.2 *Precipitation*

Displaying the geographical distribution of precipitation is always a difficult task given the sensitivity of precipitation amounts to local topographic features, and the associated problems with generalizing point observations to large areas. In the Mackenzie Valley these problems become much more significant given the importance of topography to the climate.

As shown previously, AES maps of monthly precipitation totals for the study area indicate that in January (Figure 6D) approximately 25 mm of precipitation is observed all along the upper Mackenzie Valley, with lower

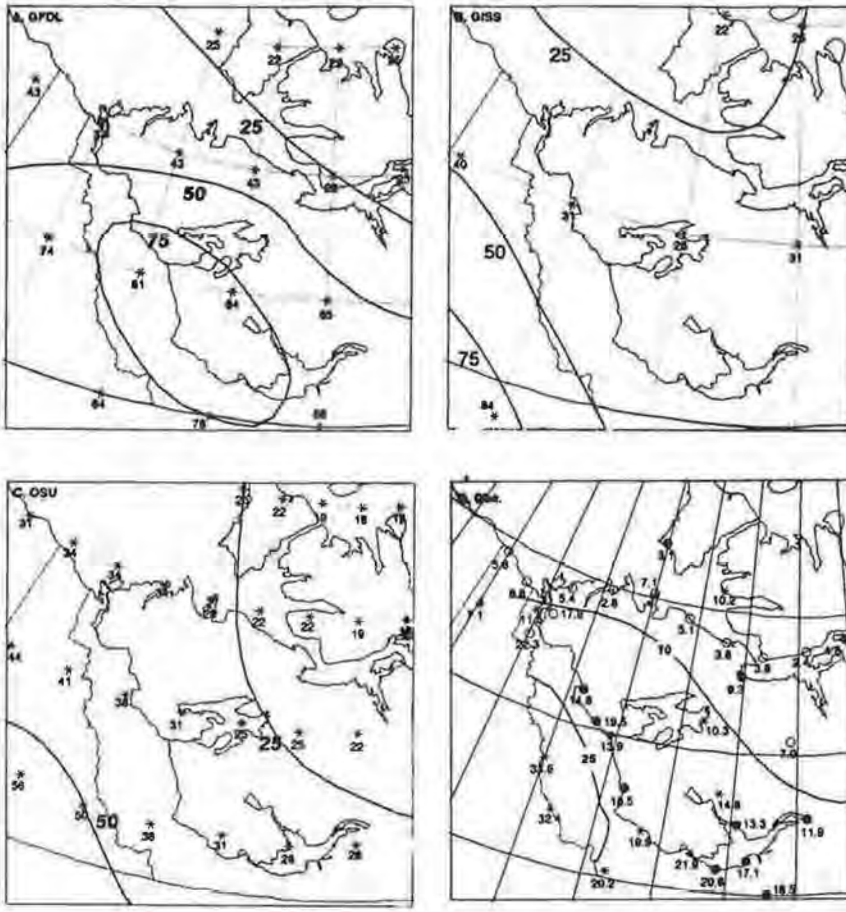

FIGURE 6. As in Figure 4 but for total monthly precipitation in equivalent millimetres of water for January.

amounts further north decreasing to approximately 10 mm in the Mackenzie Delta area. In July (Figure 7D), the same general pattern is observed, but the amounts everywhere are increased. July precipitation totals in the upper valley are approximately 50 mm, while values of 25 mm are observed along the Arctic coast. Maximum amounts in the study area in July are along the Yukon-NWT boundary, where 75 or more mm of precipitation are recorded.

Figure 6 shows precipitation totals for January as estimated by the three GCM's. The GFDL model (Figure 6A) shows reasonably constant values in the upper Mackenzie Valley, decreasing northward, but the amounts are approximately three times too large. The GISS model (Figure 6B) is somewhat better with amounts that are about twice as large as observations, while the OSU model (Figure 6C) seems superior to the other models in the upper Valley but fails

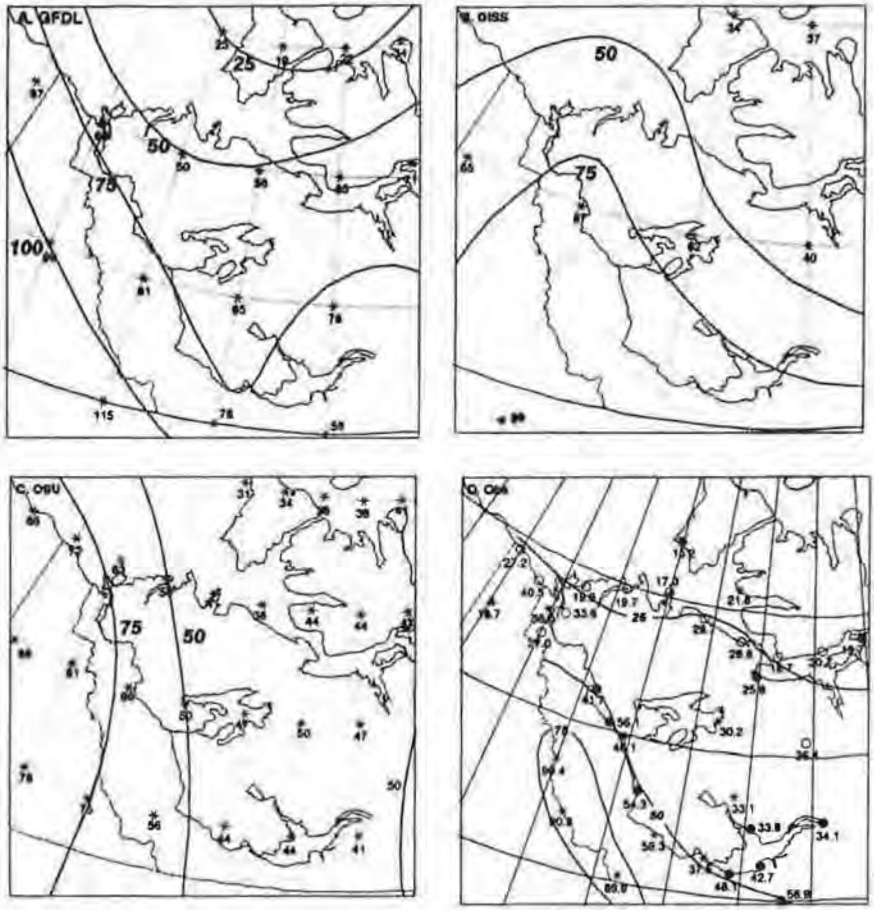

FIGURE 7. As in Figure 5 but for total monthly precipitation in equivalent millimetres of water for July.

to simulate precipitation decreases in the Mackenzie Delta. Figure 6D shows actual precipitation normals for the study area.

Results for July are shown in Figure 7. The GFDL GCM (Figure 7A) is unable to simulate decreasing amounts in the northern part of the study area, but does show relatively uniform monthly precipitation totals along the Mackenzie Valley, totals which are about 50 per cent too large. The GISS model (Figure 7B) does show lower values on the Arctic coast, but the values are twice as large as actual observations (Figure 7D). Values in the upper Valley are close to those of the GFDL model. Again, the OSU model (Figure 7C) provides the best estimates along the upper Valley, but fails to simulate decreasing amounts along the coast.

We may conclude from these results that the models are able to capture some of the topographic influence of the extensive mountain range to the west of the Mackenzie Valley in their estimates of precipitation. This is evident in the fact that values throughout the Mackenzie Valley are relatively uniform in all models. However, the models are not able to reproduce precipitation amounts with any consistent accuracy.

3.1.3 *Conclusions*

It has been shown here that the three models often produce large errors in their attempts to reproduce the general temperature and precipitation patterns in the Mackenzie Valley region. This result is not surprising, and is similar to results from other studies which have looked at the abilities of GCM's to simulate regional climates. The most comprehensive of these studies was carried out by Grotch (1988), with results recently reported by Grotch and MacCracken (1991). In the former study report, the following appears:

> The major conclusion of this study is that, although the models often agree well when comparing seasonal or annual averages over large areas, substantial disagreements become apparent as the spatial extent is reduced, particularly when detailed regional distributions are examined . . . At scales below continental, the correlations observed between different model predictions are often very poor, particularly for land gridpoints during the Northern Hemisphere summer, with differences as much as 5 degrees C between models and observations and between one model and another over relatively large areas.
>
> The implications of this work for investigation of climate impacts are profound. For these two very important variables [surface air temperature and precipitation] at least, the poor agreement between model simulations of the current climate on the regional scale calls into question the ability of these models to project the amplitude of future climate change on anything approaching the scale of only a few (10) gridpoints, which is essential if useful resource assessment studies are to be conducted. Much more work needs to be done by the modelling community to better resolve the sources of disagreements among models and between models and observations so that model improvements can be made which will improve the climatic projections produced by these models.

Despite these somewhat disappointing but not unexpected conclusions, it seems inevitable that these GCM's – or others very similar to them – will be used in the development of all impact assessments of climate change. With all their problems, GCM's remain the best tools available for providing quantitative scenarios of climate change. For many geographical areas, GCM's can have value in global warming studies, but only so long as their limitations are recognized and they are not applied to spatial scales, weather elements or geographical areas where it has been shown that they contain errors comparable with the climate change they are attempting to quantify.

In the next section we will review the performance of the three GCM's in the simulation of the Mackenzie Valley climate in equilibrium with a $2XCO_2$ atmosphere. We realize at the outset that these scenarios of climate change will contain substantial errors since none of the models is able to simulate the current climate in the study area. This fact must be kept in mind in any studies that makes use of $2XCO_2$ scenarios of temperature or precipitation for this region.

3.2 *The Application of Three General Circulation Models to Climate Change in the Mackenzie Valley*

3.2.1. *Surface Air Temperature*

Projected surface air temperatures in January for the Mackenzie Valley region in a

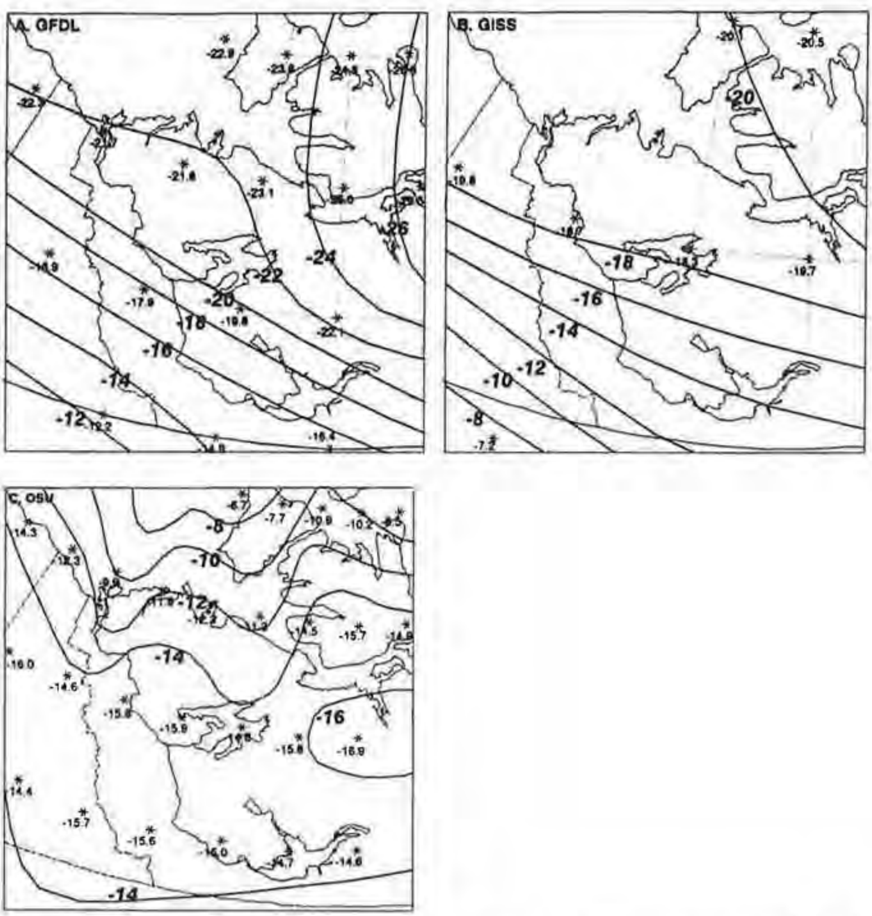

FIGURE 8. Mean surface temperatures (°C) for January for the $2XCO_2$ scenario for the GFDL, GISS and OSU GCM's.

$2XCO_2$ world are shown in Figure 8 for the three GCM's. When compared with the results in the control climate (Figure 4) each model shows a significant warming trend throughout the study area. A simple comparison of the grid points which appear on the map indicates that the GFDL and OSU models (17 and 27 grid points respectively) project a warming of about 7°C in the study area while the GISS model (with only 7 grid points) suggests a warming of approximately 9°C. Isotherm patterns for each model are quite similar to those of the control climate, suggesting that the circulation patterns which give rise to these temperature variations will not be greatly affected by global warming as it is simulated by these models. Projected July temperatures are shown in Figure 9. When compared with $1XCO_2$ results in Figure 5, it can be seen that the distinctive patterns for each model again are preserved, and the temperatures are increased. In summer,

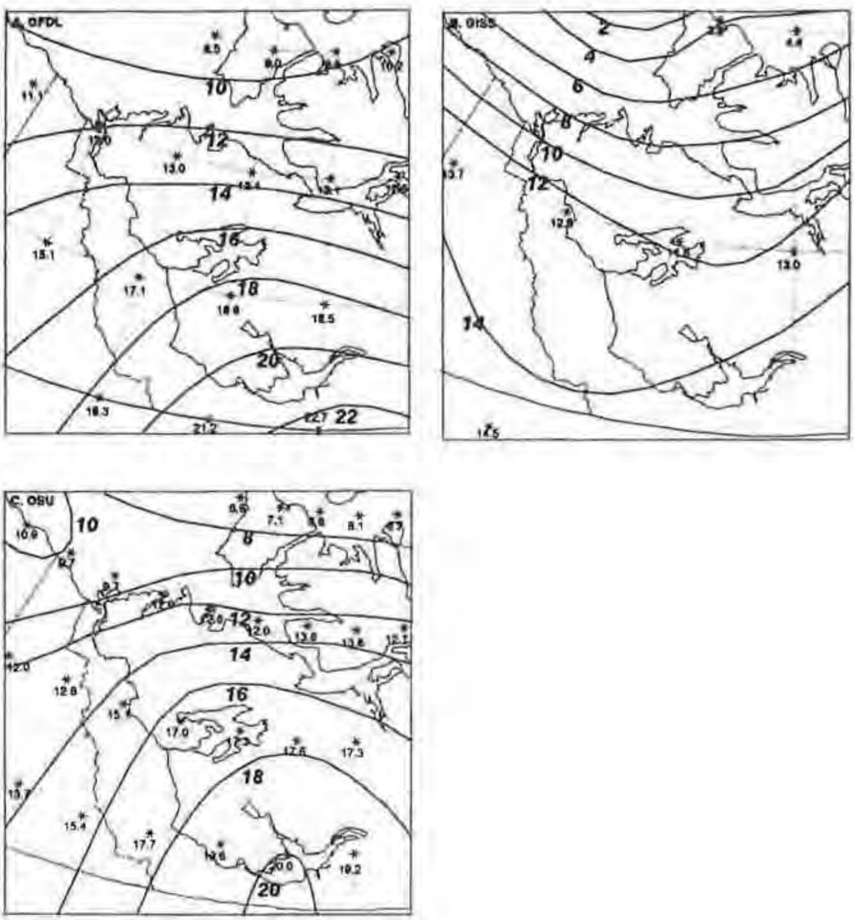

FIGURE 9. As in Figure 8 but for the month of July

however, these increases are more modest than in winter; GFDL and OSU models both suggest increases of approximately 3°C while the GISS model projects an increase of less than 1°C.

3.2.2 *Precipitation*

Total monthly precipitation amounts projected by the three GCM's for increased levels of greenhouse gases in the atmosphere are shown in Figures 10 and 11 for January and July respectively. The GFDL model (Figure 10A) for January precipitation indicates little change in precipitation amounts in the upper Valley, but increases of about 50 per cent are projected for the Arctic coast. The GISS model (Figure 10B), on the other hand, projects increases of about 50 per cent for the entire study area. The OSU model (Figure 10C) projects very little change in

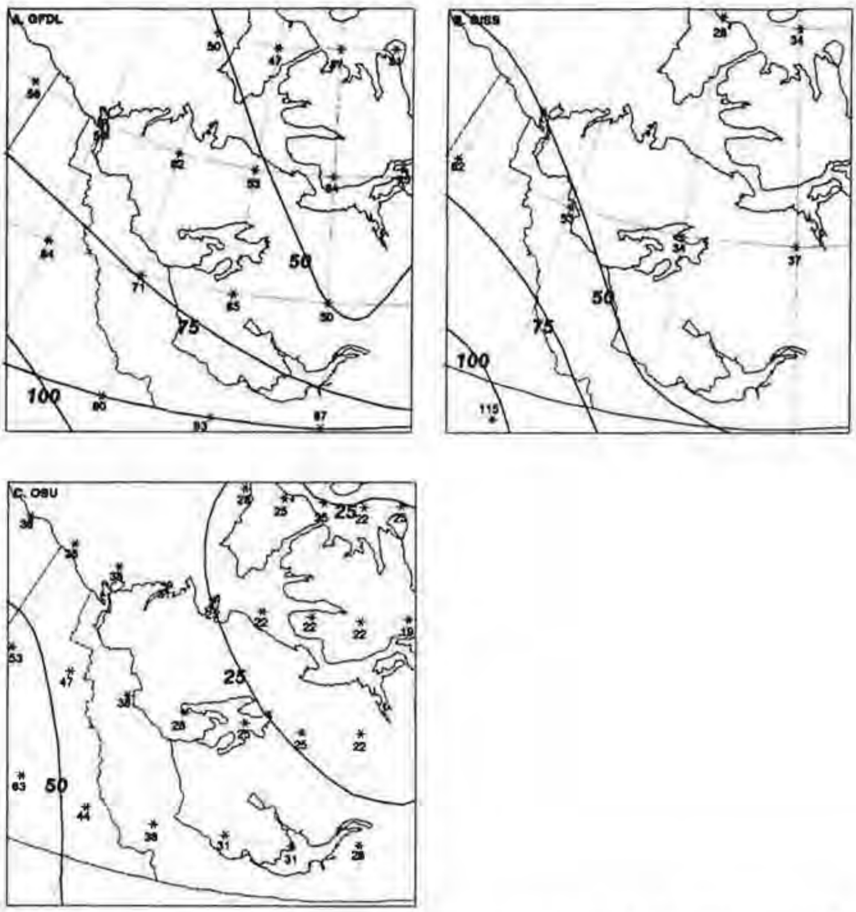

FIGURE 10. Total mean monthly precipitation (mm) maps for January for the $2XCO_2$ scenario for the GFDL, GISS and OSU GCM's.

precipitation amounts in all parts of the study area. In July (Figure 11), the GISS model (Figure 11B) projects substantial increases in precipitation amounts throughout the study area while the OSU model (Figure 11C) shows little change from its $1XCO_2$ estimates. The GFDL model (Figure 11A) runs a middle course suggesting increased amounts on the Arctic coast and little change in the river valley.

3.2.3 *Conclusions*

Whether the differences in temperature and precipitation that have been identified above are "significant" or not for the purposes of impact studies depends on a variety of factors involving both the characteristics of the models and the actual simulation runs as well as the intended application of these results. The variability

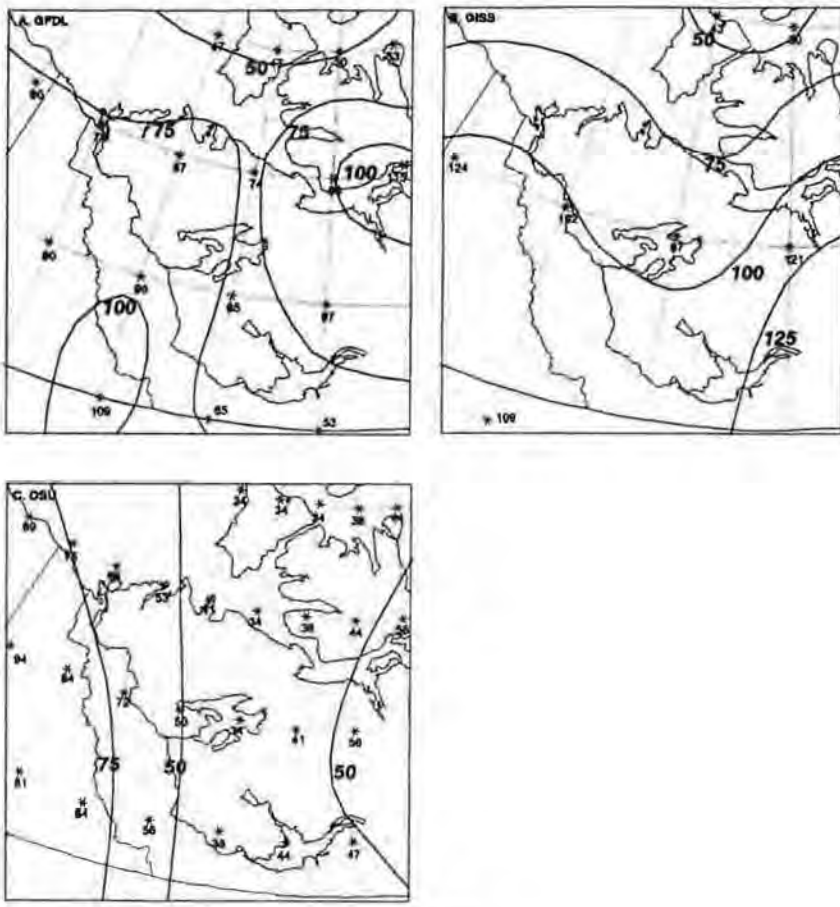

FIGURE 11. As in Figure 10 but for the month of July.

of year-to-year monthly temperatures and precipitation amounts about their mean values may be so large that the differences are not statistically significant. Even if the differences are significant, the errors made by the control simulation in its attempt to model the present climate may be so large that comparisons using control climate as a baseline may be quite meaningless. This is particularly worrisome in the Mackenzie Valley where none of the models is able to include one of the most significant climate controls – namely the Valley itself. All of these questions need to be addressed in any impact studies which are done on the region.

4. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

In the course of this paper a series of observations have been made which will come as no surprise to climatologists. First, the Mackenzie River, which cuts a 1000 km long valley through the eastern edge of the western Cordillera, has a climate which is determined to a great extent by topography. Secondly, all General Circulation Models (GCM's) are unaware of the existence of the Mackenzie Valley since their spatial resolutions are too large to resolve single river valleys. These two observations imply that GCM's cannot be expected to simulate the temperature or precipitation climate of the Mackenzie Valley very well. Thirdly, since GCM's cannot simulate the present climate of the Mackenzie Valley, they cannot be expected to simulate future, hypothetical climates for this area either. Fourthly, most studies of the economic or social impact of climate change are based on GCM simulations of both current and projected temperature and precipitation climates, and such impact studies for the Mackenzie Valley must be expected to contain large errors.

We are left with the conclusion that a simple application of GCM grid-point values of temperature and precipitation for the Mackenzie Valley to any social or economic impact analysis would have serious credibility problems. First, the models are unable to accurately replicate the current climate of the Mackenzie Valley. Secondly, in their projections of future climates, the models differ considerably from one another. Certainly, not all of the models can be correct, and it may be that all are wrong. If the results of any socio-economic analysis turn out to be critically dependent on which one of the many well-regarded, internationally recognized GCM's is used, then the credibility of the process and the entire global warming issue may be easily undermined. Any contrary-minded interest group can overturn the results by simply repeating the analysis using a model whose projections are more favourable to their point of view. It would appear that, for this geographical area at least, the commissioning of detailed socio-economic studies using only GCM-based scenarios of climate change is premature. More research is required on the application of scenarios developed from alternative methodologies (e.g., Isaac and Stuart, 1992), on the estimation of errors associated with these as well as GCM-based scenarios, and on the implications of these errors on socio-economic impact studies that use these scenarios.

There are at least two scientific questions that must be addressed before we may have any confidence in quantitative estimates of the impact of global warming on local temperature and precipitation regimes in the Mackenzie Valley. The first question has to do with the effect of topographic features currently unresolved by the GCM's on the climatology of the Mackenzie Valley. This can be addressed by improved GCM's and nested local area models (LAM's) which are described below. The second question has to do with why the models produce results so different from one another's now. The GFDL and OSU models have similar horizontal spatial resolution, but their temperature and precipitation fields are very different from one another. Clearly, these differences are due to features of the model other than topography. It is important to determine what these features are, and how they might be improved.

If GCM's are to resolve the topography of the Mackenzie Valley, their horizontal spatial resolution must be increased by approximately one order of magnitude. However, this would require a thousandfold increase in computer speed which is not projected to occur before the end of this century (Schlesinger and Mitchell, 1987). One promising alternative to waiting for more computer power is the nesting of LAM's with resolutions around 50 km within current GCM's which would continue to specify the large-scale motions. Giorgi (1990) has recently reported on attempts at NCAR to combine LAM's and GCM's for the western Cordillera of the United States. Unfortunately, many of the topographic effects noted by Burns (1973) are not currently amenable to treatment even in LAM's.

The second question regarding the differences in model projections which are not due to topography will require research in a subject area on which the original Green Plan document is completely silent. Ramanathan *et al.* (1989) have shown that the albedo of the Earth is raised from 17 per cent to 30 per cent because of the presence of clouds. If planetary albedos are increased a further 0.1 per cent because of global warming, more evaporation and cloud cover, then the projected warming due to a doubling of CO_2 would be reduced by 50 per cent. It is clear that any global warming scenario is extremely sensitive to clouds. Cess *et al.* (1989 and 1990) performed comparison studies on 14 and 19 GCM's respectively. Each model was initially run with clear skies in which clouds were prohibited and subsequently with each model's full cloud-climate feedback process. The authors found that the models (which included the GFDL, OSU, NCAR, UKMO and Canadian Climate Centre GCM's in the first study and added the GISS model in the second) produced very similar results in clear-sky mode, but demonstrated a threefold variation when clouds were included.

We conclude that the current state of the art of General Circulation Models is inadequate to accurately model the detailed climatology of the Mackenzie Valley. Impact studies that extract raw temperature and/or precipitation grid-point values from these models will fail to provide convincing quantitative estimates of the impact of global warming. This should be clearly recognized in any impact studies by conducting a complete error analysis of any projections and by fully discussing the implications of all uncertainties.

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Vents violents au Québec: une évaluation en termes de menace aux populations et à leurs biens

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RÉSUMÉ

Dans cette note nous résumons une recherche sur les dégats dûs aux vents violents au Québec. Nous avons étudié les données tirées des sommaires annuels de temps violents dans la province émanant du Service de l'Environnement Atmosphérique pour la période 1979–88 ainsi que celles en provenance de la Régie de l'Assurance-Auto du Québec pour l'année 1986. Ces vents constituent une menace pour les populations et leurs biens et devraient être considérés dans le cadre de la protection civile et de vulnérabilité municipale.

ABSTRACTS

This note summarizes a study of damage from violent winds in the province of Quebec. Data are derived from the severe weather annual summaries for Quebec produced by the Atmospheric Environment Service for the ten-year period 1979–88 and from Quebec automobile insurance statistics for 1986. Violent winds pose a threat to persons and property which should receive more attention in the context of hazard-preparedness planning.

1. INTRODUCTION

Dans le cadre d'une recherche sur la vulnérabilité municipale face aux phénomènes météorologiques violents, nous avons étudié les vents violents et les vents en rafales. Une première analyse statistique fut faite à partir de données météorologiques recueillies à 23 stations synoptiques au Québec (Lacroix et Boivin, 1991). Cette analyse nous a montré que les vents violents et les vents en rafales dont la vitesse atteint ou dépasse 90 km/h sont des phénomènes fréquents dans toutes les régions du Québec, particulièrement le long de l'axe du Saint-

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Laurent et sur les côtes du golfe et de l'estuaire du Saint-Laurent. Ils se produisent à l'année longue mais tout spécialement dans les mois de janvier, novembre et décembre.

En complément à cette étude, nous avons examiné des données historiques de vents et/ou de rafales de vents violents, afin d'évaluer sommairement la menace que pose ces phénomènes, en termes d'atteintes aux populations et à leurs biens. Nous avons également analysé quelques statistiques d'accidents routiers survenus par vents forts. Ce sont les résultats de ces deux dernières analyses que nous vous présentons.

2. MÉTHODOLOGIE

Comme les vents violents et les vents en rafales sont des phénomènes imprévisibles qui n'affectent généralement qu'une petite région, la détection de tels événements peut s'avérer parfois difficile, bien que ceux associés à des cellules orageuses soient prévisibles. Les données utilisées dans cette étude sont celles recueillies dans les "Sommaires de temps violents au Québec" et représentent les cas vérifiés de temps violents. Bien qu'on puisse s'attendre à ce qu'elles soient un peu incomplètes, par suite de l'éparpillement du réseau de mesures sur le territoire québécois, celles-ci nous donnent un bon aperçu des zones à risques, surtout dans le sud de la province (sous le 50ème parallèle). Le tableau 1 énumère les cas vérifiés de vents violents, associés ou non avec d'autres phénomènes météorologiques violents, pour la période échelonnée entre janvier 1979 et décembre 1988 (Service de l'Environnement Atmosphérique, 1979–1988).

En ce qui concerne les accidents routiers survenus par vents forts, nous avons utilisé des données qui proviennent de la RAAQ (Régie de l'Assurance-Auto du Québec), ceci pour l'année 1986 (figures 1 à 5).

3. RÉSULTATS

3.1 *Les sommaires de temps violents au Québec*

L'analyse du tableau 1, sur les cas vérifiés de vents et/ou de rafales de vents violents, fait ressortir les points suivants:

i) les cas de vents violents ou de rafales sont fréquents à l'échelle du Québec, en particulier dans les régions bordières du Saint-Laurent. On recense 98 cas en 10 ans à la grandeur du Québec, soit environ 10 épisodes par année. De ces cas, 27 n'affectent que des zones locales, surtout diverses municipalités des Municipalités régionales de comté (MRC) de La Mitis et de Matane, de Francheville, de la moyenne et de haute Côte Nord. On note que toutes ces zones sont situées le long de l'axe du Saint-Laurent. On dénombre 40 cas où des régions entières sont affectées. Ce sont surtout les régions de l'Abitibi-Témiscamingue (9 cas), de Québec (6 cas), de Montréal (4 cas) et de Trois-Rivières (4 cas). Finalement, 31 cas touchent une bonne partie de la province, soit 12 cas pour le sud

Tableau 1. Résumé des vents violents et rafales, selon les sommaires de temps violents d'Environnement Canada (1979-1988).

endroit	région	code région	local	régional	provincial partiel	dommages humains	dommages matériels	phénomènes associés
Cap aux Meules	Iles de la Madeleine	100	*				aucun	tempête de vent
Iles Madeleine, Est Canada	Est du Canada	100			*		aucun	dépression migratoire
Montréal, l'ouest de l'île	CUM	111	*				mineurs	orage violent
Région de Montréal	CUM	111		*			majeurs	pluie
Montréal, l'ouest de l'île	CUM	111	*				majeurs	violent orage
Région de Montréal	CUM	111		*			mineurs	vents
Montréal	CUM	111		*			mineurs	violent orage, grêle, fortes bourrasques
Laval, région de Montréal	CUM	111		*			majeurs	grêle
Lac Éon	Mingamie	130	*				mineurs	vents forts
Blanc Sablon	Basse Côte-Nord	140	*				aucun	poudrerie
Gaspésie	Gaspésie	145		*			mineurs	poudrerie-neige
Gaspé	Gaspésie	145		*			aucun	vents
Cap-Chat	Gaspésie	145	*				aucun	rafales vents
Région de Matane	Bas-du-Fleuve	160		*		5 morts noyés	aucun	fortes vagues
Matane	Bas-du-Fleuve	160	*				mineurs	tempête, accident environnemental
Matapédia et Bas du Fleuve	Bas-du-Fleuve	160		*			aucun	neige abondante, poudrerie
Pohénégamook	Bas-du-Fleuve	160	*				majeurs	grêle, violent orage
Bas Fleuve	Bas-du-Fleuve	160		*		plusieurs accidents routiers	mineurs	poudrerie
Saguenay Lac St-Jean	Saguenay	210		*		1 blessé foudre	majeurs	orage violent, foudre
Région de Chicoutimi	Saguenay	210		*			mineurs	ligne de grain
Bagotville	Saguenay	210	*				majeurs	orage
Laterrière	Saguenay	210	*				majeurs	vents forts
Québec, Sillery, St-Malo et	CUQ	222		*			mineurs	orage
Notre-Dame -des-Laurentides	*	*						
St Raphael (50 km E de Qué.)	CUQ	222	*				majeurs	orage violent, tornade possible
Québec	CUQ	222		*			mineurs	vents violent
Région de Québec	CUQ	222		*			majeurs	orage
Québec	CUQ	222		*			mineurs	vents
Québec	CUQ	222		*			mineurs	vents
Région de Québec	CUQ	222		*			mineurs	tempête de vents
Québec Méridional	Sud du Québec	333			*		majeurs	tempête de vent
Sud de la province	Sud du Québec	333			*		aucun	vent de tempête
Sud Québec	Sud du Québec	333			*		majeurs	vent de tempête
Sud Québec	Sud du Québec	333			*		majeurs	neige-poudrerie
Sud Québec	Sud du Québec	333			*	4 morts, 15+ blessés routes	mineurs	tempête de neige-poudrerie
Sud et Est Québec	Sud du Québec	333			*		mineurs	vents
Sud Québec	Sud du Québec	333			*		mineurs	pluies torrentielles, inondations
Sud Québec	Sud du Québec	333			*		aucun	vents forts
Sud Québec	Sud du Québec	333			*	2 morts CUQ	mineurs	tempête de neige-poudrerie

Sud Québec	Sud du Québec	333			*	1 mort route	majeurs	tempête de neige
Sud Québec	Sud du Québec	333			*		mineurs	orage
Trois Rivières et Québec	Sud du Québec	333			*		mineurs	grêle, orage
Thetford Mines	l'Amiante	345	*				majeurs	tempête de vents
Ste-Malachie et Valcartier	Bellechasse et J. Cartier	360 et 380		*			majeurs	grêle et orage
St Marc des Carrières	Portneuf	378	*				mineurs	orage
St-Albert, Victoriaville	Arthabaska	410	*			1 mort route	aucun	poudrerie
Tingwick, Sherbrooke	Arthabaska, Estrie	410 et 560		*			majeurs	vents forts
Nicolet et Baieville	Nicolet	420	*			1 blessé	majeurs	orage violent
Nicolet, Ste-Foy	Nicolet	420		*			majeurs	ligne de grain
Nicolet	Nicolet	420	*				mineurs	orage
Deschaillons	Bécancour	425	*			1 pilote blessé	mineurs	forts coups de vents
Trois-Rivières	Francheville	435		*			majeurs	orage violent
Trois-Rivières	Francheville	435		*			majeurs	violent orage, tornade possible
Lac au Sable et	Parc Mauricie et	436		*		1 mort noyé	aucun	vents forts à violents
Ste Marguerite	Haut St-François	"					majeurs	vents forts à violents, feux de forêt
Est du Québec	Est du Québec	444			*		majeurs	pluie
Est du Québec	Est du Québec	444			*		mineurs	tempête-neige-pluie
Est du Québec	Est du Québec	444			*	accidents routiers	mineurs	tempête de neige, pluie, orage
Est du Québec	Est du Québec	444			*	accrochages routiers	aucun	poudrerie-neige
Est du Québec	Est du Québec	444			*		mineurs	tempête de neige-poudrerie
Est du Québec	Est du Québec	444			*	5 morts noyés	mineurs	tempête de neige-poudrerie
Gaspé et Basse-Côte Nord	Est du Québec	444			*		mineurs	tempête neige
Sept Iles et Gaspé	Est du Québec	444			*		mineurs	tempête neige
Extreme sud-ouest du Québec	Sud-ouest du Québec	555			*		majeurs	violent orage
Sud-ouest du Québec	Sud-ouest du Québec	555			*	plusieurs blessés auto.	mineurs	orage
Sud-ouest du Québec	Sud-ouest du Québec	555			*	5 blessés Trois-Rivières	majeurs	tempête de grêle
Sud-ouest du Québec	Sud-ouest du Québec	555			*		majeurs	orage et tornade possible
Sud-ouest du Québec	Sud-ouest du Québec	555			*		mineurs	vents forts à violents
Sud-ouest du Québec	Sud-ouest du Québec	555			*		mineurs	orage violent, grêle
Sud-ouest du Québec	Sud-ouest du Québec	555			*		aucun	vents
Sud-ouest du Québec	Sud-ouest du Québec	555			*		aucun	vents violents
Entre Montréal et la Mauricie	Sud-Ouest du Québec	555			*	plusieurs accidents routiers	mineurs	tempête de verglas
Trois-Rivières et	Sud-Ouest du Québec	555		*			aucun	grêle
Ste Eustache et Ste Agathe	"	"			*			
Abitibi et SO Québec	Sud-Ouest du Québec	555					majeurs	violent orage, grêle, pluies abondantes
Hemmingford	Jardins de Napierville	615	*				aucun	vents destructeurs, grêle
Huntington (sud de Montréal)	Haut Saint-Laurent	620	*				aucun	pluie-grêle
Nord de Montréal et Joliette	Laurentides	689		*			mineurs	orage
Jonquières, Chicoutimi N. et	Laurentides et parc	689		*1			mineurs	grêle, orage, front froid
Nord de St-Jérome, Chertsey	"	684		*2			majeurs	orage, forte pluie, front froid
Région de Maniwaki	Vallée de la Gatineau	730		*			majeurs	vents violents

Outaouais	Outaouais	739		*			majeurs	vents violents
Fort Rupert	Nord du Québec	777	*				majeurs	orage, front froid
La Grande rivière	Nord du Québec	777		*			aucun	front froid
Témiscamingue	Témiscamingue	810		*			majeurs	grêle, violent orage
90 km E de Ville-Marie	Témiscamingue	810		*			mineurs	vents
Région de Val-d'Or	Vallée de l'Or	830		*			majeurs	orage-averses
50 Km SE de Val d'Or	Valleé de l'Or	830	*				aucun	grêle
Région de Malartic	Vallée de l'Or	830		*			majeurs	grêle, front froid très actif
Val d'Or	Vallée de l'Or	830		*			mineurs	front froid
Val d'Or	Vallée de l'Or	830		*			mineurs	vents
Ville-Marie et région	Abitibi	850		*			mineurs	vent violent
Abitibi	Abitibi	850		*			mineurs	violent orage
Amos	Abitibi	850	*				mineurs	grêle
Abitibi	Abitibi	850		*			mineurs	grêle, vent violent
Sept-Iles	Sept-Rivières	920	*				aucun	pluie-neige
Sept-Iles	Sept-Rivières	920	*				aucun	poudrerie
Baie Comeau	Manicouagan	930	*				aucun	nuages entonnoirs sur le fleuve
Sherbrooke	Estrie	996	*				mineurs	-
East Angus	Estrie	996	*				majeurs	violent orage, tornade possible
Cantons de l'Est	Cantons de l'Est	997		*			majeurs	violent orage, pluie abondante
Cantons de l'Est	Cantons de l'Est	997		*			mineurs	grêle

du Québec, 10 cas pour le sud-ouest du Québec, 8 cas pour l'Est du Québec et un cas qui a affecté l'extrême Est du Canada y compris les Iles-de-la-Madeleine.

ii) les situations météorologiques auxquelles sont associés les épisodes de vents violents et de rafales peuvent être divisées en 3 catégories: les tempêtes de vents où aucun autre phénomène météorologique n'est associé; les vents violents associés aux phénomènes convectifs estivaux (orage, grêle, pluie torrentielle, front froid, ligne de grain) et les vents violents associés aux tempêtes d'hiver.

Sur les 98 cas recensés on dénombre 29 occurrences de vents violents et/ou rafales qui ne sont strictement reliées qu'aux tempêtes de vents; dont 7 à l'échelle locale, 14 à l'échelle régionale et 8 à l'échelle provinciale. On note 47 occurrences associées à des phénomènes convectifs estivaux, soit: 13 à l'échelle locale, 24 à l'échelle régionale et 10 qui affectent une partie de la province. On dénote aussi 20 occurrences associées à des tempêtes d'hiver dont: 5 à l'échelle locale, 3 à l'échelle régionale et 12 à l'échelle provinciale.

iii) Les 7 occurrences de vents violents associés aux tempêtes de vents à l'échelle locale ont affecté presque toutes les principales zones sous le 50e parallèle nord, alors que les tempêtes de vents régionales frappent, dans 8 cas sur 14, les régions le long de l'axe du Saint-Laurent (de Montréal à Gaspé). L'Abitibi-Témiscamingue est aussi frappé 3 fois, la Gatineau 2 fois et l'Estrie 1 fois. Les tempêtes de vents à l'échelle provinciale frappent exclusivement le sud et/ou le sud-ouest du Québec.

En ce qui concerne les vents associés aux phénomènes convectifs, 9 des 13 occurrences locales affectent des zones le long du Saint-Laurent, entre Montréal et Matane, 2 sont notées en Abitibi et 1 dans l'Estrie (Sherbrooke) et dans le Nord du Québec (Waskaganish). A l'échelle régionale, seules les régions à partir du Québec métropolitain vers l'ouest sont touchées. Sur les 24 cas recensés de l'ouest vers l'est, l'Abitibi-Témiscamingue est touché 6 fois, le Nord du Québec 1 fois, les Hautes-Laurentides et la grande région de Montréal 3 fois chacune, la région Francheville-Mauricie 4 fois, les Cantons de l'Est et le Saguenay 2 fois chacune et le Québec métropolitain 3 fois. A l'échelle provinciale, 9 des 10 cas dénombrés frappent le sud et/ou le sud-ouest du Québec. Un seul cas a été noté dans l'est de la province.

Pour ce qui est des vents violents associés aux tempêtes d'hiver, on note que 7 des 12 tempêtes à l'échelle provinciale ont affecté l'est du Québec, 4 le sud et 1 le sud-ouest. Les 3 tempêtes régionales ont touché la Gaspésie et/ou le Bas-du-Fleuve et 4 des 5 tempêtes locales ont affecté le Bas-du-Fleuve ou la haute et moyenne Côte-Nord.

Il est très intéressant de noter que les vents violents et/ou rafales sont généralement associés aux tempêtes d'hiver dans l'est de la province, alors qu'ils sont surtout liés aux phénomènes convectifs dans le sud et l'ouest.

iv) En termes de blessures, mortalités et dommages matériels qui résultent des temps violents associés aux vents de tempêtes (vents violents et/ou rafales), on fait les observations suivantes:

Seulement 7 des 98 cas recensés de temps violents impliquent des pertes en vies humaines. Les tempêtes d'hiver sont responsables de 5 de ces 7 cas soit: un cas de noyade (5 pêcheurs morts) sur la basse Côte-Nord et 4 accidents de la route dans le sud du Québec qui ont fait deux fois 1 mort, une fois 2 morts et une fois 4 morts. Finalement, deux tempêtes de vent ont provoqué la mort par noyade d'une personne dans un lac de la Mauricie et de 5 pêcheurs dans la région de Matane.

Les cas où des blessures furent rapportées sont au nombre de 5, soit: un blessé par la foudre au Saguenay (vents violents associés aux phénomènes convectifs estivaux), 15 blessés de la route lors d'une tempête d'hiver dans le sud du Québec, ainsi qu'un blessé par le vent (pilote dont l'hélicoptère s'est écrasé au décollage) dans la région de Bécancour. Deux violents orages avec grêle ont aussi entraîné des blessures chez deux personnes.

La majorité des cas recensés, soit 78 sur 98, dénotent des dommages matériels, dont 43 avec dégâts mineurs et 35 avec dommages majeurs. Par dégâts mineurs nous entendons des antennes ou des bardeaux de toits arrachés, des vitres brisées et des dommages superficiels à des bâtiments, des dommages légers aux automobiles, des fils électriques arrachés et des poteaux ou des arbres inclinés de même que des inondations isolées. Les dommages majeurs concernent des toits de maisons arrachés et des atteintes aux structures mêmes des bâtiments, des véhicules mis hors d'état, des poteaux électriques et arbres arrachés ou déracinés, des inondations généralisées à un grand secteur, des cultures agricoles détruites et des feux de forêt associés à la foudre et au vent. Les dommages mineurs sont provoqués, 25 fois sur 35, par des vents violents et/ou rafales associés à des phénomènes convectifs estivaux, en particulier par des orages accompagnés ou non de grêle (23 cas sur 25). Dans 8 des 10 autres cas, le vent seul (tempêtes de vents) est l'artisan des dommages alors que les vents violents associés aux tempêtes d'hiver ne sont responsables que de 2 cas. Les dommages majeurs sont provoqués 18 fois sur 43 par des vents associés à des phénomènes convectifs estivaux, surtout les orages avec ou sans grêle (17 cas). Les tempêtes d'hiver sont à l'origine de 12 cas, surtout des accidents routiers, alors que les vents de tempête sont responsables de 13 des 43 cas.

3.2 *Les accidents routiers par vents forts*

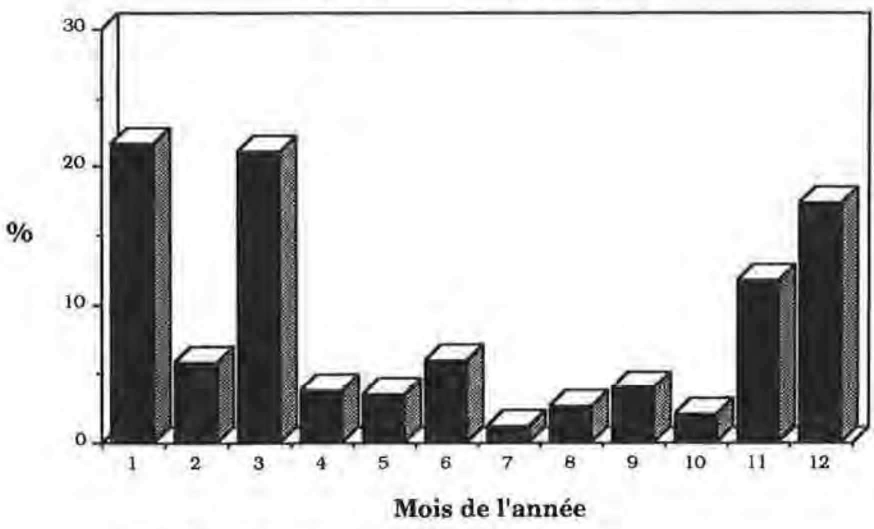
Selon des données qui proviennent de la RAAQ (Régie de l'Assurance-Auto du Québec), pour l'année 1986, nous avons examiné certaines caractéristiques des accidents routiers en tenant compte de la contrainte de conduite que représente des vents forts.

En premier lieu, l'analyse de la répartition mensuelle des accidents routiers survenus par temps de vents forts démontre que décembre, janvier et mars sont, et de loin, les mois les plus touchés, avec des valeurs respectives de 17, 22 et 21% des accidents (figure 1). En février, pour l'année 1986, ne sont survenus que 6% des accidents. Le mois de juillet est celui qui compte le moins d'accidents, soit 1.2% du total. Les mois d'hiver sont donc les plus dangereux pour la conduite routière lors de vents forts. Considérant l'état souvent déplorable des routes en hiver, chaussée englacée et/ou enneigée, les résultats s'expliquent très bien.

La gravité des accidents survenus par vents forts implique, dans 70% des cas, des dommages matériels seulement et, dans 20% des cas des blessures légères (figure 2). La surface des routes, lors de ces accidents, était glacée dans 33% des cas et enneigée dans 38% des cas (figure 3). Il faut cependant noter que 17.5% de ces accidents se produisent lorsque la chaussée est sèche. Le mauvais temps (soit dans ce cas-ci les vents forts) semble être la cause de 26% des accidents routiers (figure 4). On doit noter toutefois que 66% des accidents routiers survenus durant l'année 1986 sont survenus par bonne visibilité. Ces résultats sont fort intéressants puisqu'ils montrent jusqu'à quel point les automobilistes sont prudents ou en mesure de bien contrôler leur véhicule lorsque celui-ci est soumis à des vents forts.

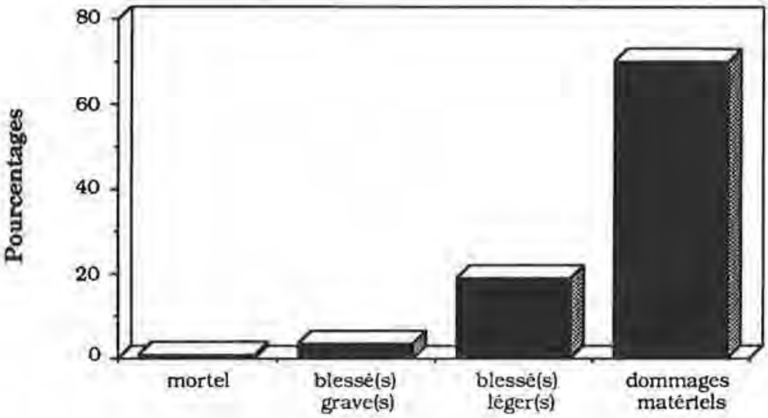
Finalement, lorsqu'on regarde les heures auxquelles se produisent les accidents routiers par temps de vents forts, on remarque différents paliers avec une pointe entre 16 et 17 heures qui correspond au retour du travail. Il est surprenant de constater le pourcentage relativement faible d'accidents lors de la pointe du matin entre 7 et 9 heures (figure 5).

Figure 1:
Répartition mensuelle des accidents routiers survenus par vents forts en 1986



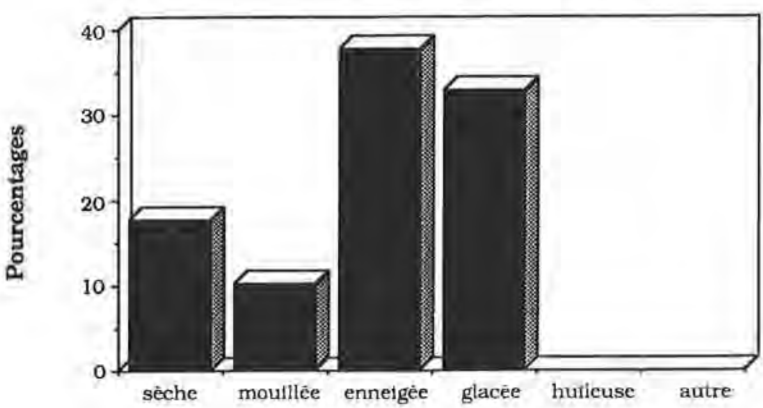
source: Régie de l'Assurance-Auto du Québec

Figure 2:
Gravité des accidents routiers survenus par vents forts en 1986



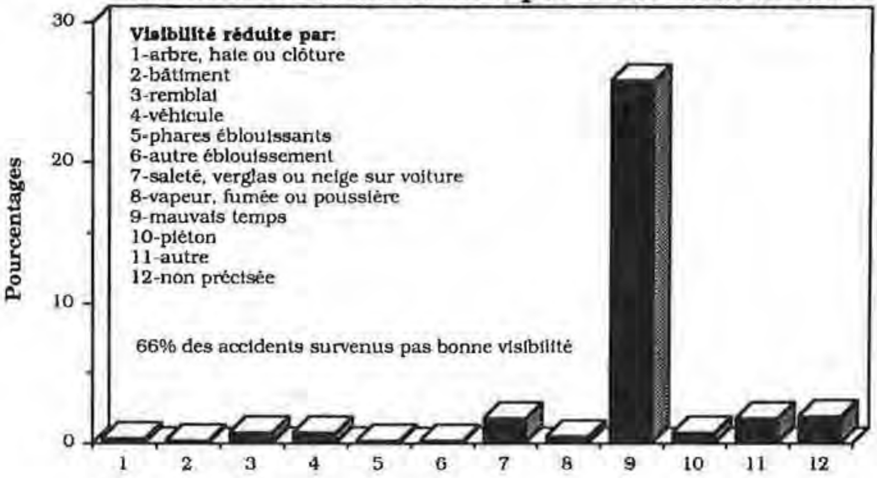
source: Régie de l'Assurance-Auto du Québec

Figure 3:
État de la surface lors des accidents routiers survenus par vents forts en 1986



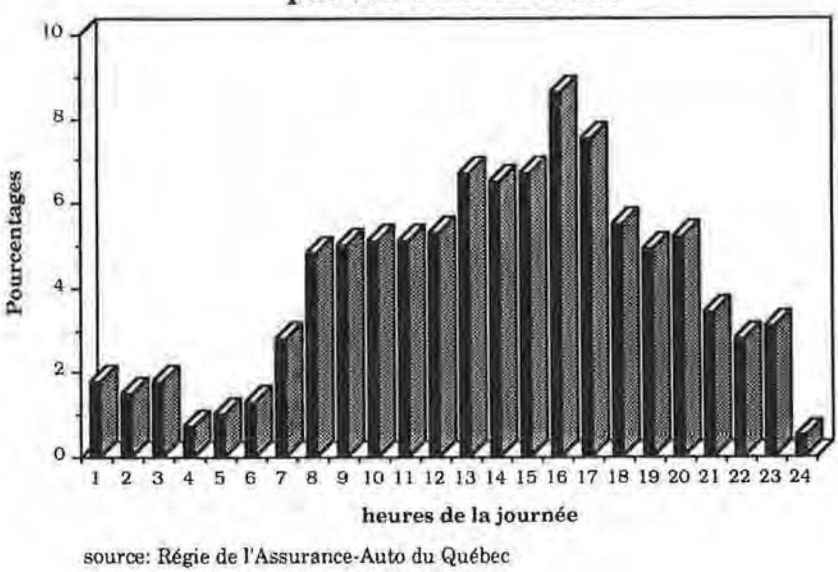
source: Régie de l'Assurance-Auto du Québec

Figure 4:
Caractéristiques de visibilité invoquées lors des accidents routiers par vents forts en 1986



source: Régie de l'Assurance-Auto du Québec

Figure 5:
Heure des accidents routiers survenus par vents forts en 1986



source: Régie de l'Assurance-Auto du Québec

4. DISCUSSION

On peut faire un lien direct entre la vitesse des vents et la gravité des dommages. Ainsi, des dégâts mineurs, comme la perte d'antennes de télévision ou de bardeaux sur les toits se produisent dès que les vents atteignent des vitesses d'environ 50 km/h. Lorsque les vents atteignent 80 km/h, ils peuvent donner naissance à des dommages intermédiaires aux vitres et à certaines structures, alors que des vents excédant 100 km/h peuvent causer des dommages structuraux majeurs. En plus des dommages aux structures, les vents violents peuvent amener le renversement et même la destruction de maisons mobiles, d'avions, de voitures, d'ateliers d'entreposage ainsi que l'effondrement de bâtiments en construction. Il faut aussi noter que les dommages causés par les débris volants peuvent être aussi sérieux que ceux causés par la pression des vents. Les blessures et mortalités résultant de tempêtes de vents sont faibles comparé avec celles causées par les tornades, mais la tendance des dernières décennies montre une augmentation de leur nombre. Le regroupement des populations urbaines amène une plus grande vulnérabilité face aux pertes majeures et les nouvelles maisons unifamiliales, en proportion croissante, sont plus exposées aux dommages. Il y a des façons de modifier l'impact des vents violents, comme l'établissement d'une barrière d'arbres, qui protège autant les structures que les cultures, ou l'installation de volets verrouillables aux fenêtres.

Des rafales sévères et de forts cisaillements du vent, comme il s'en produit sous un courant-jet de basse altitude, présentent des dangers pour le vol. La connaissance de la turbulence probable dans cette couche de l'atmosphère est critique. De plus, comme des forts vents et de la turbulence de basse altitude se produisent dans toutes les régions du Québec, il est important de tenir compte du facteur de charge due au vent dans la construction. Les édifices en hauteur et surtout les structures comme les ponts suspendus, les pylônes et les tours sont particulièrement sensibles à la charge due au vent. Dans le cas des ponts au Québec, on les trouve souvent à l'emplacement où la vallée se rétrécit ou s'encaisse. A ces endroits, il y a augmentation de la vitesse du vent et de la turbulence en certaines situations synoptiques. Les pylônes qui supportent les lignes de transport d'énergie électrique entre les régions montagneuses du nord et les basses-terres du Saint-Laurent sont fréquemment exposées sur des crêtes de haut relief. De par leur rôle, les tours de radio et de télévision sont, elles aussi, placées à des endroits exposés. Aussi bien pour les piétons que pour les conducteurs, la situation et l'orientation des rues de la ville, des voies rapides surélevées comme des grandes routes modernes, modifient et influencent les vents locaux et la turbulence en basse altitude. Ces considérations en termes de vents régionaux et locaux sont aussi très importantes pour la planification des pistes d'atterrissage.

Il faut considérer, surtout aux stations côtières où il y a une haute fréquence des vents très forts, les fatigues et les ruptures de charpentes pouvant résulter de vents violents soutenus. L'étude des vents soutenus et violents est importante pour la planification à long terme de terminus aériens, dans la lutte aux congères sur les routes, les voies ferrées et les pistes, dans l'orientation des extensions urbaines et dans le zonage industriel par rapport à la pollution de l'air (Wilson, 1973). Les vents violents d'hiver, surtout dans les régions côtières et de plaines, créent des conditions sévères de poudrerie. Les autoroutes à travers les basses-terres, comme celles du Saint-Laurent, sont exposées et sont particulièrement vulnérables à l'amoncellement de neige, de même que les routes étroites flanquées par de hauts bancs de neige (Plamondon, 1979). Ces dernières sont surtout dangereuses pour les conducteurs qui, soudainement, se retrouvent confrontés à un voile de neige flottant et pour qui la visibilité devient nulle.

5. CONCLUSION

Les vents et/ou les rafales de vents violents sont fréquents au Québec et ils se font particulièrement sentir dans les régions bordières de l'axe du Saint-Laurent, soit dans des zones où l'on retrouve la plus forte concentration de population. En général, ces vents sont associés aux tempêtes d'hiver dans l'est de la province, alors qu'ils sont surtout liés aux phénomènes convectifs estivaux dans le sud et l'ouest.

L'analyse de quelques données historiques et statistiques sur les méfaits causés par les vents et/ou rafales de vents violents nous a montré que les dommages matériels reliés à ces vents et aux phénomènes météorologiques qui leur sont associés peuvent être considérables et que les cas de blessures ou de mortalités humaines, bien que peu fréquents, ne sont pas à dédaigner. Dans une optique de protection civile, il pourrait s'avérer judicieux, à l'avenir, que les vents et/ou rafales de vents violents soient considérés comme une menace possible pour les populations et leurs biens, au même titre que le phénomène des tornades.

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Winter and Summer Surface Air Temperature Trends in the Northern Hemisphere: 1950 to 1988

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ABSTRACT

Winter and summer temperature trends over the northern hemisphere are examined over a hemispheric cooling period (1950 to 1976) and a hemispheric warming period (1977 to 1988). The regional trends were quite different during the two periods and during the summer and winter seasons. Trends were larger in the winter than in the summer and also during the hemispheric warming period. The regional trends were largest during the winter hemispheric warming period, with the largest regional trends exceeding +0.5°C/year in south-central Canada and southwestern Yukon. During this period, the trends correlated well with amplification of wave number three in arctic latitudes, showing an alternating warming and cooling system. Statistical tests indicate that the patterns of regional trends are not inconsistent with patterns due to chance, as opposed to a long term climate forcing.

RÉSUMÉ

Les tendances de la température d'hiver et d'été de l'hémisphère nord sont examinées pendant une période de refroidissement hémisphérique (1950 à 1976) et une période de réchauffement hémisphérique (1977 à 1988). Les tendances régionales étaient très différentes pendant les deux périodes et pendant les saisons d'été et d'hiver. Les tendances ont été plus prononcées en hiver qu'en été et, aussi, pendant la période de réchauffement hémisphérique. Les tendances régionales ont été les plus prononcées pendant la période de réchauffement hémisphérique d'hiver, les tendances régionales les plus prononcées dépassant +0,5 °C par an dans le centre sud du Canada et le sud-ouest du Yukon. Pendant cette période, les tendances correspondaient bien à l'amplification de l'ondulation numéro trois aux latitudes arctiques, indiquant une alternance de réchauffement et de refroidissement. D'après les essais statistiques, les configurations des tendances régionales ne sont pas incompatibles avec les configurations aléatoires, par opposition à un forçage climatique à long terme.

1. INTRODUCTION

Trend analysis is interesting not only because it provides information about what has happened in the past, but because it can potentially provide clues about what might happen in the future. If sufficient detailed and reliable data from many hemispheric or global warming periods existed, then an analysis of these data might provide information about the response of regional climates to large scale climate change. If it could be established that the warming periods were caused by some external or internal forcing, such as a change in the solar constant or an increase in atmospheric CO_2, then climatologists would have a more acceptable basis for their speculations regarding enhanced greenhouse warming. Unfortunately this is not the case, and there is a very limited time-series available with comprehensive data that can be used for such a purpose.

The purpose of this note is to examine the spatial distribution of winter and summer temperature trends during a period of hemispheric warming and a period of hemispheric cooling, and to assess the significance of these trends. If, in some areas, the trends and confidence levels are high, then one can speculate on whether certain regions of the hemisphere respond to climate forcing more so than other regions (an analysis of the events considered here is not sufficient to arrive at any firm conclusions). A statistical test on a trend can indicate how likely it is that the trend was produced due to noise (short term climate variability) or due to a long term process on a scale similar to the time frame of the data being analyzed.

The idea for this study was triggered by Jones (1988) who produced a map of annual linear trends for both hemispheres for the period 1967 to 1986. Of particular interest was the maximum of warming over northern British Columbia, Yukon Territory and western Mackenzie, northern Alberta, northern Saskatchewan and Alaska. Most of this area is underlain by continuous and discontinuous permafrost, much of which is sensitive to climate warming in terms of its possible impact on slope failures and active layer depth. The presence of gas pipelines that are often buried in the permafrost makes the issue of regional climate change in that part of North America of particular interest.

2. METHODOLOGY

Trends were calculated by linearly regressing winter and summer air temperature anomalies against time. Monthly surface air temperature anomalies (relative to a 1951–70 base period) in a 5° latitude by 10° longitude gridded format (Jones *et al.*, 1986, Jones *et al.*, 1990) have been published and are available from the Carbon Dioxide Information Centre at Oak Ridge, Tennessee. This data set is comprehensive over land areas where most climate stations are located but sparse over most ocean regions and arctic (north of 60° north) latitudes. Since arctic latitudes were of particular interest, especially over northern Canada, and a reasonable data coverage only exists since the early 1950's, no data prior to 1950 were used. Of the 648 grid points in the northern hemisphere, only about half had

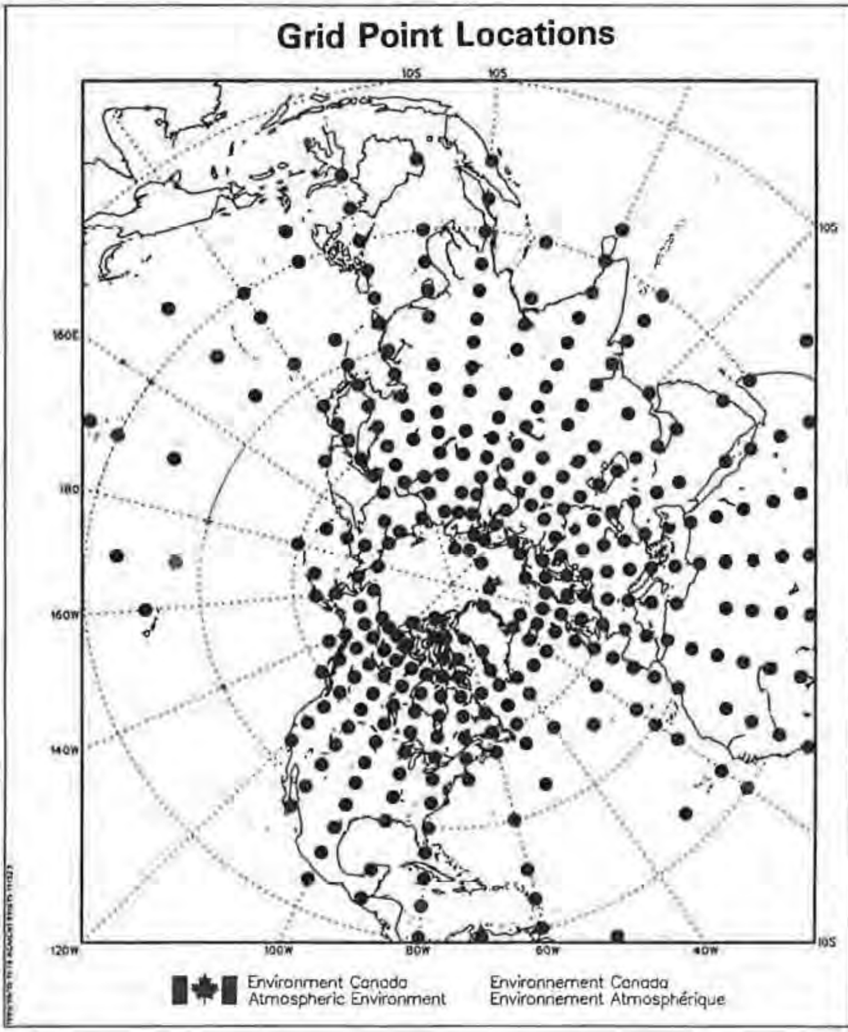

FIGURE 1. Location of grid points where trends were analyzed

enough data for analyis, and these are shown on Figure 1.

The monthly anomalies were rolled up into winter (DJF) and summer (JJA) anomalies for each grid point over the period 1950 to 1988 inclusive. If a month was missing in either season, no seasonal value was calculated. Linear regression analyses were done for a period of Northern Hemispheric cooling (1950 to 1976) and Northern Hemispheric warming (1977 to 1988) using SAS on the mainframe computer resident at the Canadian Climate Centre. Warming and cooling periods were selected in order to highlight possible regional responses to

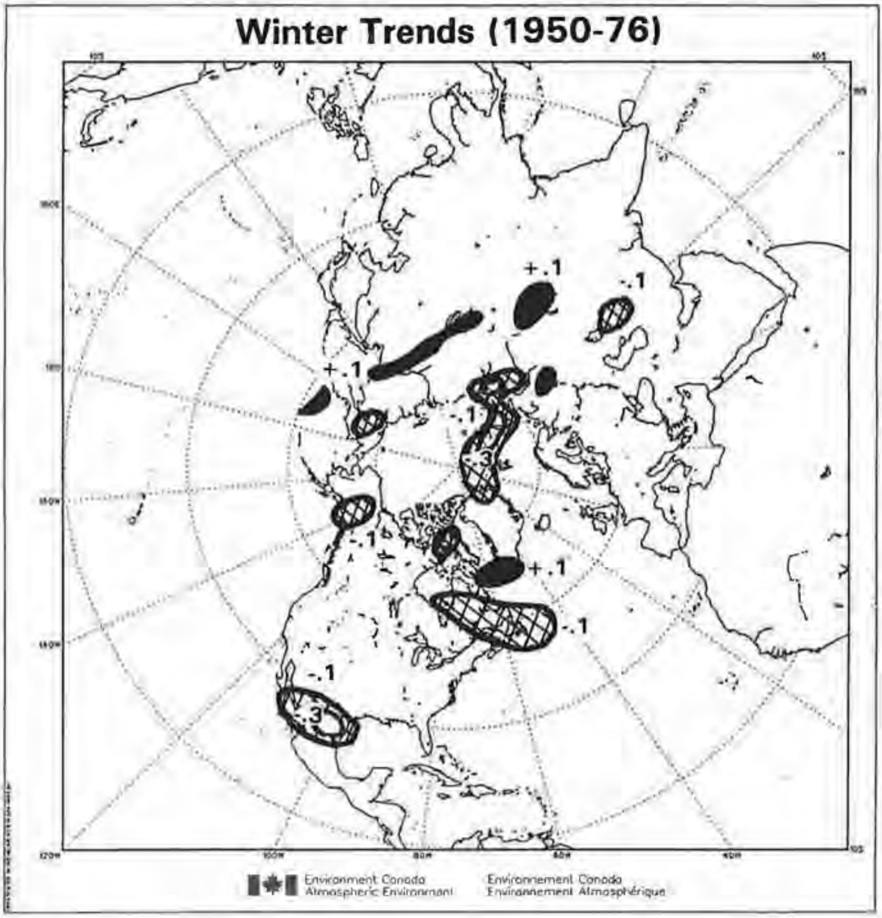

FIGURE 2. Linear winter trends (°C/yr) during the period of hemispheric cooling, 1950–1976.

hemispheric trends. Both the slope of the curve (the trend) and P were analyzed. P is the probability that a student-t statistic would obtain a greater absolute value than that observed, given that the true slope is zero. Thus, P is an estimate of the likelihood of obtaining a slope estimate greater than the observed slope under the hypothesis that the slope is zero. Small values of P indicate that the observed slope is not consistent with respect to the zero slope hypothesis and thus suggest that this hypothesis should be rejected. The results of this test must be viewed with caution, as this statistical procedure is based upon the assumption that the errors are not correlated in time. This assumption is not exactly true and the confidence in the slopes indicated by the P statistic is an overestimate (Zwiers, 1990, Thiebaux and Zwiers, 1984). As well, chance alone will likely account for a number of significant slopes, given that 310 points were evaluated (Livezey and Chen,

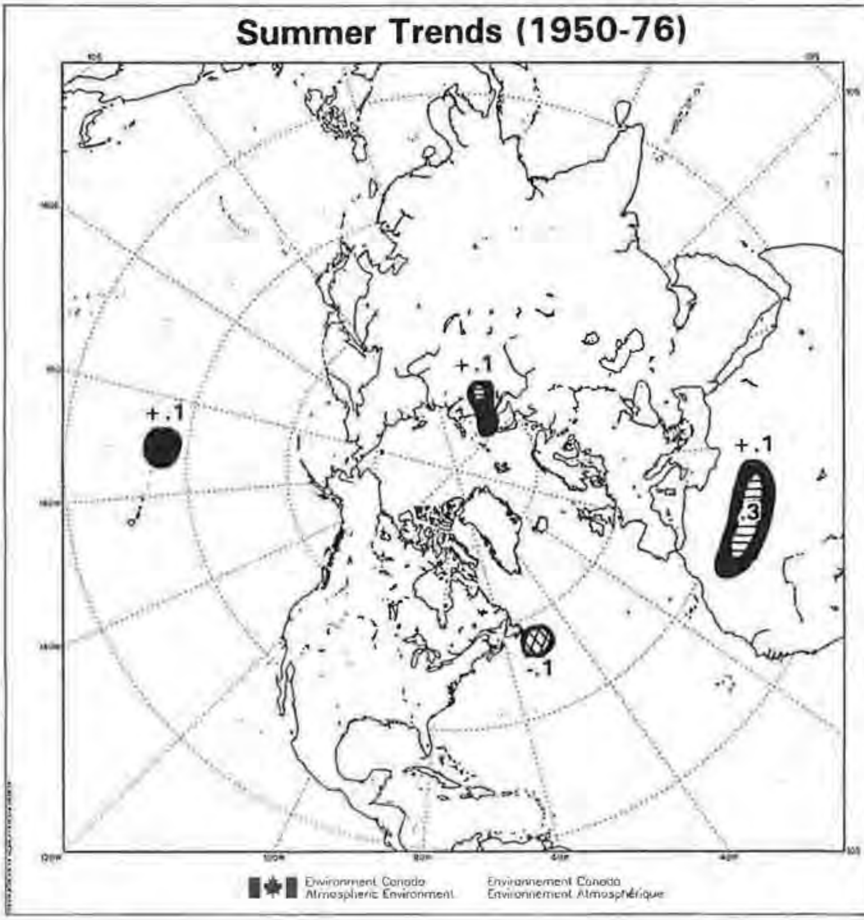

FIGURE 3. Linear summer trends (°C/yr) during the period of hemispheric cooling, 1950–1976.

1983). For example, at the 5% significance level, 5% of the slopes being tested would, on average, be significant even in the absence of a real trend embedded in the random nature of the data. Spatial correlation between the grid points would provide coherence to areas of large slope, variance or significance. Large standard deviations and small numbers of data points, as in the warming period of 1977 to 1988, give small student-t values and low significance levels.

Figures 2 to 5 illustrate the trends for these periods. For all figures the contouring was performed manually. During the contouring process, a few large slopes not coherent with surrounding data (outliers) were ignored. The trend maps were contoured at levels of +/− .1, .3, .5 °C/year.

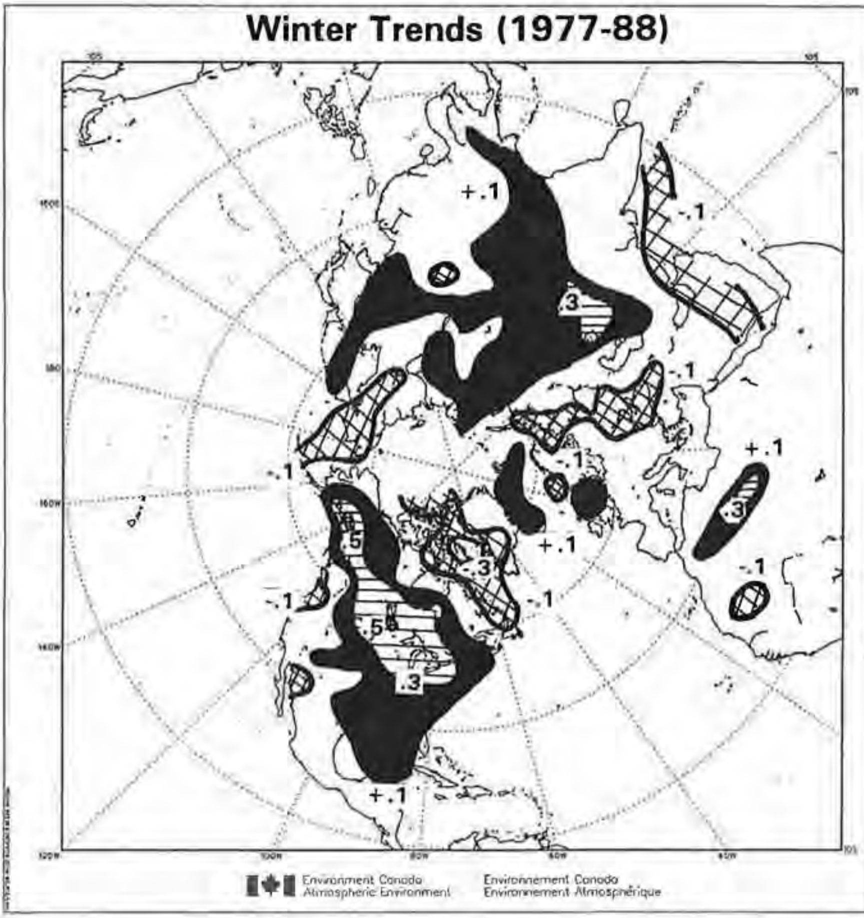

FIGURE 4. Linear winter trends (°C/yr) during the period of hemispheric warming, 1977–1988.

3. ANALYSIS

Northern Hemisphere Cooling Period (1950–1976)

Winter trends (Figure 2) show several areas of cooling, the strongest of which are centered over Mexico and parts of the North Polar Basin. Other areas of cooling lie over northern Canada and Alaska. Over parts of the former USSR areas of warming are evident. The summer trends (Figure 3) are generally very small and less than in winter, with the largest values occurring in northern Africa. There is no obvious pattern in the trend regions, and the areas with summer trends do not necessarily correspond with the winter trends.

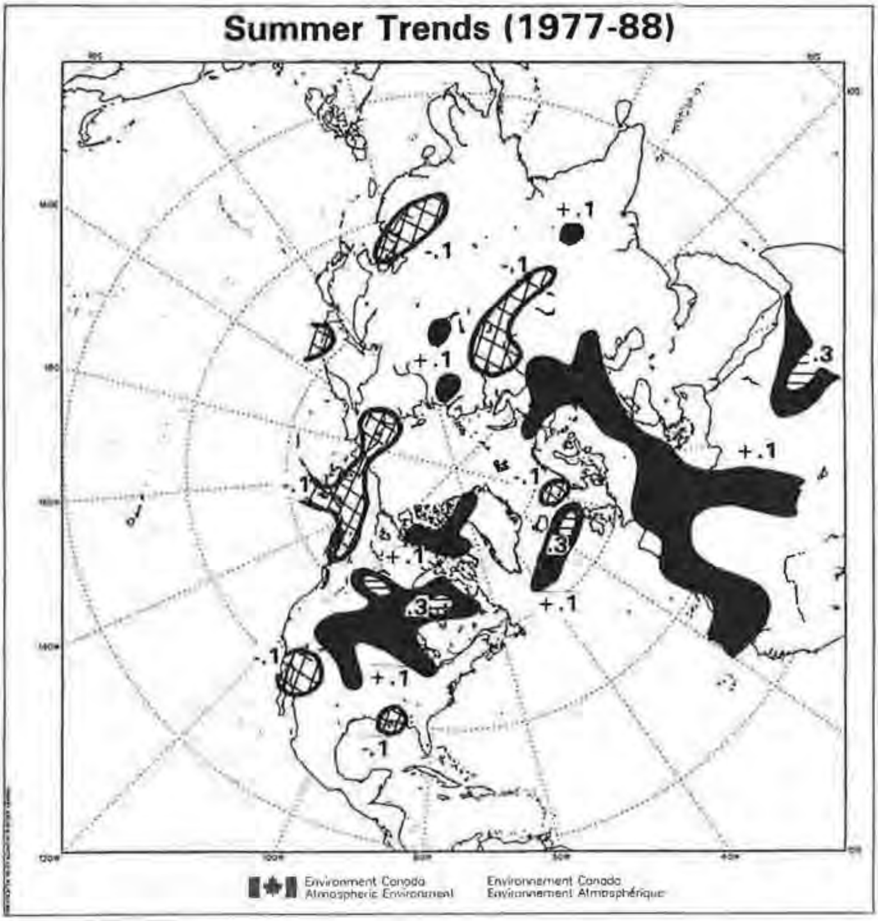

FIGURE 5. Linear summer trends (°C/yr) during the period of hemispheric warming, 1977–1988.

Northern Hemisphere Warming Period (1977–1988)

The winter trends (Figure 4) are stronger than in the 1950–1976 period and cover larger areas. In part, this may be due to the shorter time period. Over much of the USA, central and western Canada lies a region of strong warming, contrasted by an area of cooling over the eastern Canadian Arctic. This pattern is very similar to that shown in Jones (1988). Another large area of warming covers much of the former USSR. It is interesting that over arctic latitudes, the pattern is of alternating warming and cooling regions. An analysis of the 500 mb winter anomaly chart (Figure 6) for the 1977–88 period as compared to the 1953–76 period (the upper air data for the years 1950–52 were not available in digital form) shows an increase in amplitude of the upper air circulation pattern which can be used to explain much

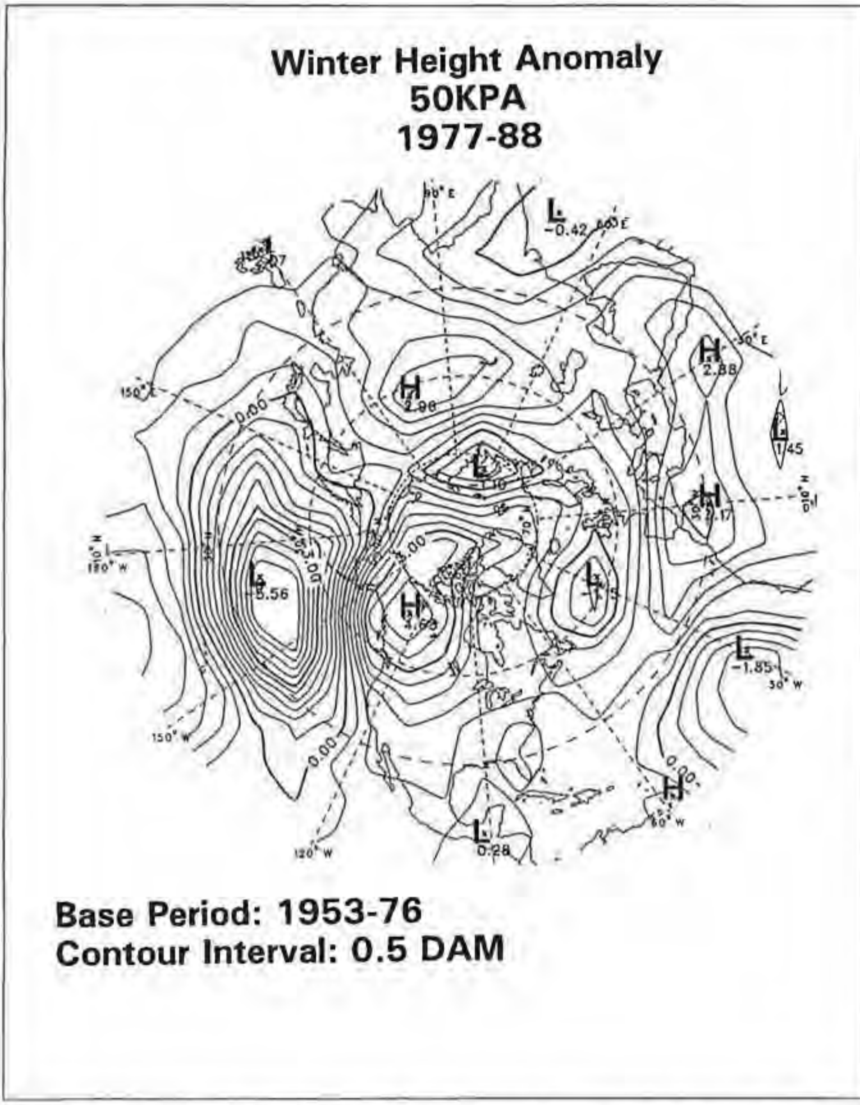

FIGURE 6. Anomalies of 500 mb heights during the period of 1977 to 1988 (Northern Hemispheric warming) as compared to the period of 1953 to 1976 (Northern Hemispheric cooling).

of the trends shown in Figure 4 (it should be noted that a comparison of Figures 4 and 6 compares trends to a difference between averages). A circuit around a line of latitude on Figure 6 (e.g. 60°N) shows that the amplification occurs over three wavelengths. In particular a deeper Aleutian low suggests stronger advections that may be responsible for the warming in Alaska and northwestern Canada and cooling over the Bering Sea and adjacent USSR land regions. Stronger ridging at

500 mb over western Canada and the central and western USA correlates well with the warming trend there, while a somewhat deeper Icelandic low would lead to stronger cold advection over Baffin Island and Davis Strait and stronger warm advection east of Greenland. Warming trends over northern Africa and the central USSR are co-located with above-normal heights, while cooling from the Black Sea northward can be correlated with a sharp trough of low heights extending southwestward from the Kara Sea.

The summer trends (Figure 5) also show large areas of warming, notably central Canada and the Arctic islands, northern Africa, portions of Europe, and the Atlantic north and west of the British Isles. Some regions that experienced winter warming show cooling during the summer, Alaska for example, while the reverse is true for Baffin Island, which shows winter cooling but summer warming.

In an attempt to assess whether the trends might be occurring through

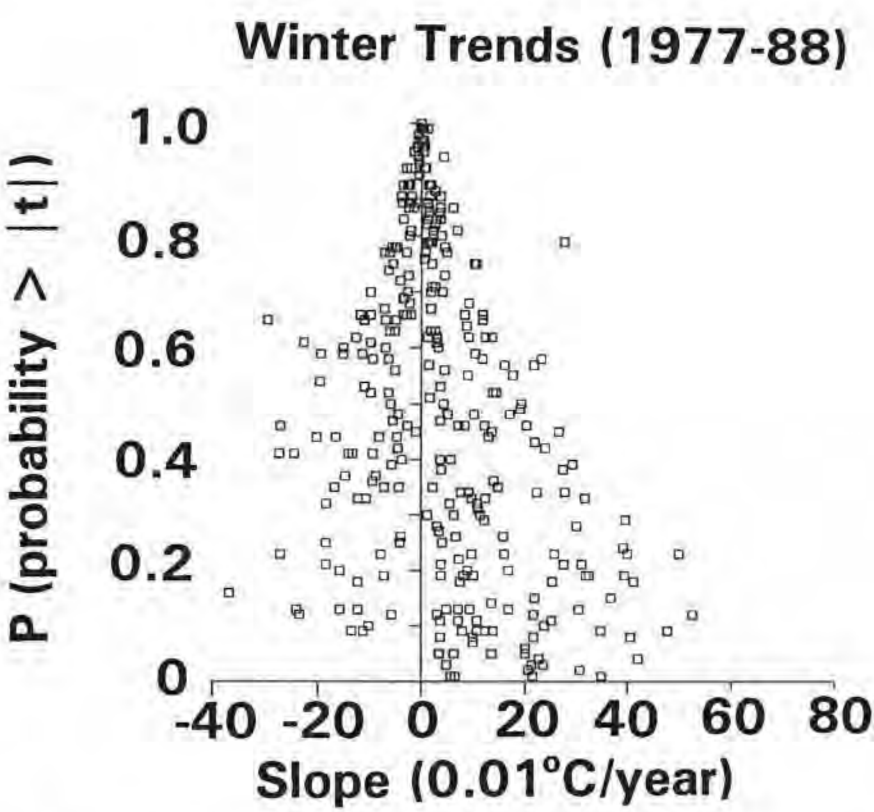

FIGURE 7. Scatter plot of trend vs. probability (P). Note the tendency for large slopes to be more significant.

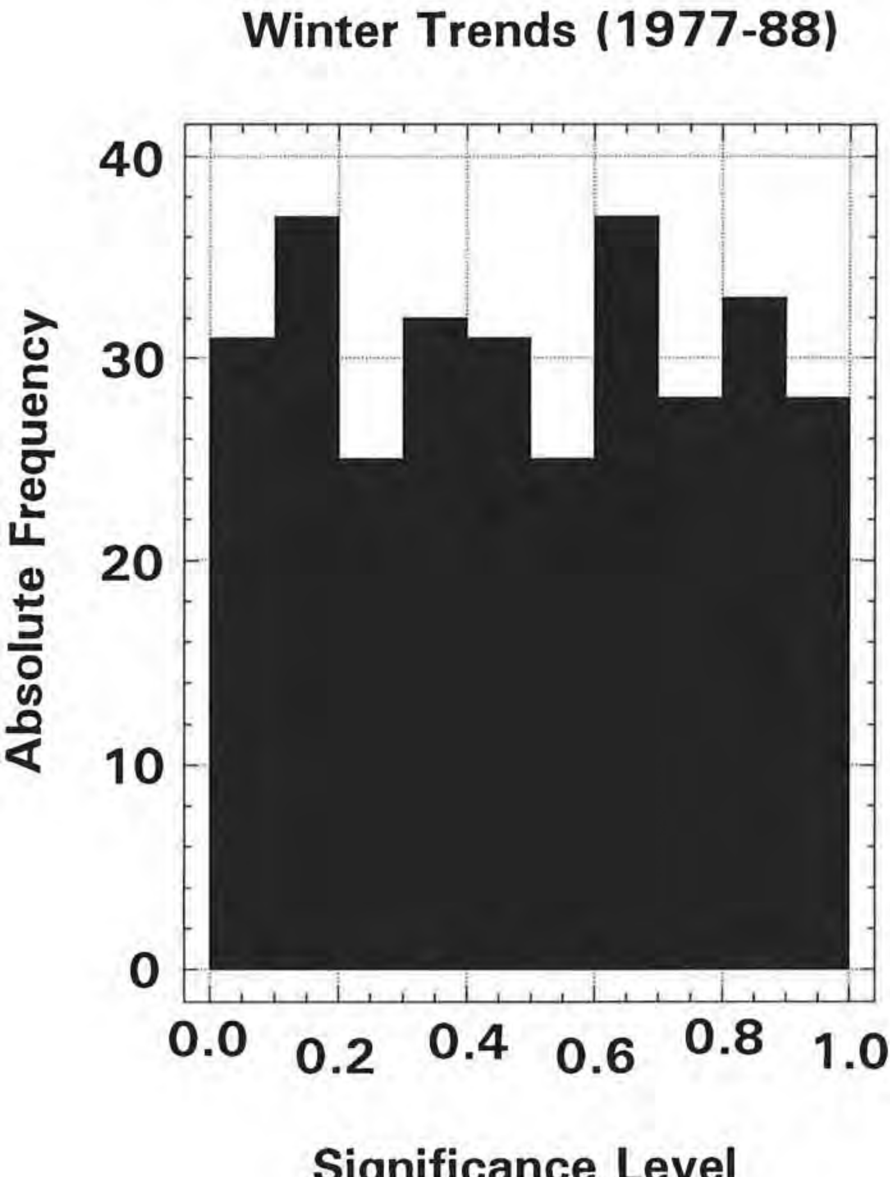

FIGURE 8. Absolute frequency histogram of the significance levels of the slopes for winter during the period of hemispheric warming (1977 to 1988).

random processes (climate noise) or whether they are the result of longer term climate forcing, their significance levels were calculated as described above. Figure 7 shows that the probability that some random processes are responsible for the trend diminishes as the slope increases. The significance levels of slopes range from 0.01 to 1.00, but become increasingly smaller (i.e. show increasing confidence that the slope is real) as slope increases. For trends greater than +/− 0.2°C/yr., the confidence level generally is greater than 50%. As noted, sampling variation alone would generate some large and significant trends and the relatively flat frequency histogram of the significance levels in the Northern Hemisphere winter warming case (Figure 8) does not imply that more significant warming or cooling trends occurred than could happen through chance. This implies that the regional trends calculated during the period of Northern Hemispheric warming do not necessarily result from the presence of long term forcing (of course, it does not prove that they do not, either). It is not valid to extrapolate trends into the future without establishing clear physical cause and effect mechanisms.

4. CONCLUSIONS

An examination of winter and summer trends during a period of Northern Hemispheric cooling (1950 to 1976) and warming (1977 to 1988) shows regions of both warming and cooling. The regional trends during the hemispheric warming period were larger than during the hemispheric cooling period, and winter trends tended to be larger than summer trends. Some areas, such as Baffin Island, showed a negative trend in winter but a positive trend in summer during the 1977 to 1988 period. Regions which show sensitivity (large trends) during the hemispheric warming period do not necessarily show sensitivity during the cooling period. During the winter hemispheric warming period of 1977 to 1988 surface trends can be explained by 500 mb anomalies relative to the cooling period. An examination of the significance levels of the trends shows that although there is a tendency for greater trends to be associated with higher confidence levels, the number of significant trends on the map could be accounted for by chance. A longer time series is required to better assess the meaning of such trends.

ACKNOWLEDGEMENTS

I would like to thank Lucie Vincent, Dr. F. Zwiers and Dr. Neil Sargent for their useful comments regarding the statistical aspects of this paper. Most of the programming was done by Lucie Vincent.

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Book Reviews
Compte-rendu de lecture

SNOWSTORMS ALONG THE NORTHEASTERN COAST OF THE UNITED STATES: 1955 TO 1985

Paul J. Kocin and Louis W. Uccellini. Meteorological Monographs, No. 44, American Meteorological Society, Boston, 1990, ISBN 0-933876-90-4, 293 pp.

This impressive monograph contains eight chapters and a list of references:
Introduction
Historical overview: a breif review of major snowstorms of the 18th, 19th and 20th centuries
Climatological overview of the period from 1955 to 1985
Description of 20 major snowstorms
Description of the upper-level features associated with the snowstorms
Summary of the physical and dynamical processes that influence northeastern snowstorms
Analyses of 20 major snowstorms: 1955–1955
Analyses of snowstorms during 1987

This work is strictly limited to storms of the east coast of the United States; there is no information for Quebec, Ontario or the Atlantic provinces. However, the concepts developed in this volume are certainly relevant to the eastern Canadian situation, since a good many of our storms develop or follow trajectories along the east coast.

In Chapter 3 the reader will find some interesting snowstorm statistics, while Chapter 4 describes 20 major storms, i.e. with snowfalls greater than 25 cm. Storm trajectories, cyclogenesis, rates of deepening and the characteristics of the cold air west or northwest of the storms are all discussed. Chapter 5 presents a synthesis of the typical upper-air circulations associated with the storms, dealing with vorticity, jet streams and low-level jets. It includes beautiful color illustrations of the characteristic circulations which appear to be important factors in these storms. Chapter 6 summarizes the principal physical and dynamic factors which influence the origin of the storms. In the following chapter, the major storms are analyzed in greater detail, including the snowfall amount, surface and upper-air charts, satellite images and other types of information. Chapter 8 examines the snowstorms of 1987.

AMS publications are always thorough, and this is no exception. The interested reader will find a host of relevant information on the snowstorms discussed. The volume contains a vast number of weather maps which illustrate the cases analyzed. The authors have certainly attained one of their basic objectives, that of providing a guide which will assist forecasters in the effective prediction of major snowstorms. The publication of a similar work dealing with the Canadian scene would be more than welcome.

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WEATHER SATELLITES: SYSTEMS, DATA, AND ENVIRONMENTAL APPLICATIONS

Edited by P. Krishna Rao, Susan J. Holmes, Ralph K. Anderson, Jay S. Winston, and Paul E. Lehr. American Meteorological Society, Boston, 1990, ISBN 0-933876-66-1.

This is a book with some 100 contributors, mainly from the United States NOAA/NESDIS and other well-known institutions. The editors state that the book is aimed at students and general practitioners in atmospheric science. The publication provides a comprehensive overview of the field. The topics covered by the book are:

1. Introduction to weather satellites.
2. Elements of remote sensing from space.
3. National observing capabilities.
4. Satellite sensors and their data.
5. Satellite command and data reception.
6. Central data processing and distribution.
7. Applications of satellite data in meteorology.
8. Applications to land and ocean sciences.
9. Climate applications.
10. Agricultural applications.
11. Feature satellite systems and applications.

At the end of the book the reader will find lists of acronyms and abbreviations, glossaries and an index.

The material included here on Russian, Japanese and Indian satellites is very hard to find in other sources and so is extremely useful. A comparison between these different satellites would have been very helpful, but one should not ask for the earth. The information on mapping of imagery data is very original, and particularly valuable to those of us working with Geographic Information Systems. The calibration information is required in our modem use of GIS.

The chapter on stereoscopic measurements of clouds from meteorological satellites presents a very useful analytical tool. The techncique allows cloud height estimates to be made with a vertical resolution of 500 metres and a horizontal resolution of one kilometre. The editors state that this technique was initially used by Roach in 1967 from high-flying aircraft and in 1966 by Ondrejka and Conover from satellites.

Most of the applications in Section 7 to meteorological problems relate to severe local storms, tropical cyclones and estimates of vertical motion. The book makes a good comparison between the satellite imagery and the use of point or other data such as those from radiosonde stations. The authors consider the combination of what we term ground data or ground truth with satellite data to achieve continuous calibration. However, although the book talks about validation and the question of accuracies, there is little discussion of the sensitivity or redundancy capability of the systems. Also there are no references here later than 1986. One wonders whether the information supplied by the contributors is dated to that point or whether the contributors themselves are considered to be the sources of material between 1986 and 1990 when the book was published. Certainly the contributors are well-known names, but one would expect the editors at least to include works published by these recognized authorities since 1986.

Section 8, Applications of Satellite Data to Land and Ocean Sciences, is a little skimpy. The references for this section also leave something to be desired, particularly in quoting only U.S. authors and neglecting Canadian and Scandinavian work on snow cover, for example. Greater complementarity could also have been attained by combining Section 10, which is entitled Use of Weather Satellite Data in Agricultural Applications, with Section 8.

The secion on aerosols is extremely relevant in this time of global climate change. The book also deals with tropospheric and stratospheric monitoring, a very useful piece for all who are interested in global change.

The concluding chapter, Chapter 11–2, starts with an old meteorological doggerel "more data, more data, from pole to equator, measuring everything, everywhere, all the time." Environmental satellites have brought the fulfilment of this weatherman's dream closer to reality. The availability of these platforms and their vast array of measurements raises unresolved issues, however, that will have significant bearing upon the long-term nature of their use in the future. The book closes with the comment "Finally there is an issue, larger than any other, of the ability of those who receive environmental data from space to use those data purposefully, particularly for the protection of life and property."

The interpretations and conclusions are sound and well justified. The book presents its material, much of which is new and original, in well organized and precisely documented manner. However, the black-and-white illustrations or figures are of poor quality and detract from the overall impression. The color pictures in the second half of the volume are of good quality and add considerably to the portrayal of the information. The title of the book is clear and sufficiently reflects its content, which seems to be aimed at a U.S. rather than an international audience.

If I needed a thorough reference volume on weather satellites and their uses, then this is the one I would choose for my shelf. However, if I wanted a book to tell me which weather satellites can be used for environmental applications, I would perhaps think twice. The treatment is a little heavy for students but I think acceptable for general practitioners who can wade through the voluminous amount of detail presented. I take my hat off to the editors for managing to put it all together.

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HISTOIRE DE LA MÉTÉOROLOGIE

A. Fiero, 1991. Denöel, Mediations, Paris, ISBN 2-207-23838-5, 315 pp.

Voici enfin un volume sur l'histoire de la météorologie publié en français. On peut certes trouver de éléments historiques dans d'autres ouvrages mais ceux-ci datent d'au moins une quinzaine d'années; des articles sont aussi souvent publiés mais le volume de Fiero est plus que le bienvenue puisqu'il englobe d'un seul trait une large partie de l'histoire de la météorologie. Notons que Fiero n'est pas météorologiste mais bien historien (conservateur en chef à la Bibliothèque historique de la Ville de Paris). Ceci confère à son ouvrage un dynamisme et une saveur particulière, tout à son avantage.

Le volume comprend 11 chapitres: entre mythes et nuages: la météorologie primitive; la météorologie populaire; naissance d'une science (17e–18e siècle); un siècle de tâtonnements (1778–1878); organisation de la météorologie internationale; la météorologie maritime; le Bureau central météorologique; météorologie et transports aériens; l'Office national météorologique; la météorologie nationale depuis 1945; quel climat pour demain? Il comporte de plus une bibliographie et un index des noms.

Le volume est agrémenté de plusieurs photos ou illustrations et de tableaux ou d'encarts qui agrémentent le texte. L'auteur insiste sur le développement de la météorologie en France mais quand même sans oublier, là où c'est nécessaire, de mettre les étapes dans leur contexte international. Le volume est donc riche en faits et anecdotes qui démontre l'ampleur de la recherche effectuée par l'auteur. Je vous recommande donc fortement la lecture de Histoire de la météorologie.

En terminant je ne peux que me demander: à quand donc notre histoire de la météorologie au Canada? Cette histoire est assurément suffisamment riche pour nous permettre de mesurer la distance parcourue et nous faire prendre connaissance, en tant que canadien, de l'importance de notre passé scientifique.

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News and Comments
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THIRTEENTH INTERNATIONAL CONGRESS OF BIOMETEOROLOGY

THEME: Adaptations to Global Atmospheric Change and Variability

The Convention Centre, Calgary, Alberta, September 12–18, 1993

The International Society of Biometeorology announces its 13th Congress, which will address issues of human, animal, plant, invertebrates, and microorganisms in relation to climatic change and variabilty. Interactions related to health and disease, production and performance, dwelling, architecture, clothing, energy and transport will all be within the scope of the congress.

We invite you to attend and participate in this timely and important international congress. Plans are underway to make the congress a scientifically and socially rewarding experience. It is not too early to make your plans now for the thirteenth international congress of biometeorology in 1993.

For further information, please write to:

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