Canada's Hail Climatology:
1977 - 1993

by:

David Etkin
Meteorological Service of Canada,
Institute for Environmental Studies, University of Toronto

and

Soren Erik Brun
Department of Geography
University of North Carolina, Chapel Hill

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For Further Information, please contact:
Institute for Catastrophic Loss Reduction
151 Yonge Street, Suite 1800
Toronto, Ontario, Canada M5C 2W7
Telephone: (416) 362-2031 – Extension 352
Fax: (416) 361-5952
E-mail: info@iclr.org www.iclr.org

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This paper was prepared by David Etkin, Adaptation and Impacts Research Group, Meteorological Service of Canada, Institute for Environmental Studies, University of Toronto and Soren Erik Brun, Department of Geography, University of North Carolina, Chapel Hill.

For further information, please contact:
David Etkin
Adaptation and Impacts Research Group
Meteoroligical Service of Canada, Institute for Environmental Studies
University of Toronto
33 Willcocks Street
Toronto, Ontario M5S 3E8
Tel: (416) 978-6310
Fax: (416)-978-3884

Abstract:

The last national hail climatology of Canada was based upon the 1951-80 time period. However, from 1977 to 1993, many more stations reported days with hail than prior to 1977. As a result, a more spatially detailed analysis is now possible. Unfortunately, after 1993 the observing network began to be replaced by automatic stations that do not report hail, and therefore a mesoscale analysis can only effectively use the time period of 1977-1993. Due to the fact that ice pellets have often been recorded as hail, this analysis restricted itself to the warm months of May to September. The current national hail climatology is broadly similar to the previous one (with a few notable differences) but is much richer in spatial detail. The highest hail frequencies occur in interior British Columbia and Alberta. Topography appears to be a significant control on patterns of hail occurrence.

Introduction:

Hailstorms pose a serious threat, particularly to Canada. Each year they cause significant amounts of damage to property and crops (Paul, 1991a; Charlton et al., 1995; Etkin and Maarouf, 1995) (Table 1). Typical hail stones are about pea size but under optimum conditions they can grow to very large sizes. The largest recorded hailstone, worldwide, was found in Coffeyville, Kansas on September 3, 1970. It was 14 cm in diameter, 44 cm in circumference and weighed 766 g (Eagleman, 1990). The most costly Canadian hailstorm occurred on September 7, 1991 in Calgary, Alberta causing an estimated $360 million in insured damage and $450 million in total damage (IBC, 1997). The most destructive hailstorm in North America, and possibly the world, occurred in Texas, May, 1995, causing an estimated $2 billion (US) damages (Hill, 1996). Hail has been known to cause fatalities as well - on April 30, 1888 the deadliest hailstorm on record killed 246 people and 1,600 domestic animals in India (Hughes and Wood, 1993). With respect to insured costs, hail ranks as one of the most costly natural hazards in Canada (Figure 1). Figure 1 illustrates major multiple insurance payouts (in 1995$) between 1984 – 1994; minor weather-related occurrences (below roughly $4 million) are not included. As well, Charlton et al. (1995, 1998) in studies of urban hail incidences, report that hailstorms are one of Canada's most costly natural disasters. On average, they destroy roughly 3 percent of Canada's prairie crop each year. Costs are conservatively estimated at $100 million per year (LaDochy and Paul, 1986). By comparison, in the United States crop hail losses represent 1 to 2 percent of the nation's annual crop value, though regionally it can be as high as 6%, and are between $1-1.5 billion US per year (Changnon, 1997)

Since the 1950's, much information has been compiled on hail occurrence in Canada and the United States (cf. Changnon, 1977; cf. Paul, 1991b). These research efforts were primarily motivated by the need for a greater understanding of: (1) the amount of agricultural and property losses stemming from hailstorms; (2) the detection and avoidance of hail for aircraft; and (3) storm dynamics for both hail forecasting and suppression. The impacts of hail on urban centres in Canada has been studied by Charlton et al. (1995), the relationship between hailswath dimensions and damage by Paul (1991b), and the implication of climate variability on hailstorm frequency by Paul (1990). A research project on hail in Alberta operated from 1956-85 (for more information refer to http://datalib.library.ualberta.ca/AHParchive), and highlighted its importance and frequency (Figure 2).

National hail climatologies (e.g. the number of hail days per year in Canada – Figure 3) serve as a foundation for most hail risk analyses. Although national hail climatologies cannot be used to determine hailstorm severity or to infer damage, they are used to help identify vulnerable regions, and thus areas where mitigation efforts (e.g. hail suppression) should be concentrated. The 1951 – 80 climate normals (Figure 3) were an important step in this process. However, since that time, data has become available which allows for a more detailed analysis. The objectives of this study are to, (1) produce an updated Canadian hail climatology, and (2) note the differences between the 1951- 80 and 1977-93 maps.

2 Data Analysis:

A hail days data set for the period 1955 – 96 was obtained from the Atmospheric Environment Service (AES), Environment Canada. A hail day is defined as a day during which hail was observed and recorded at a station. It does not record time of occurrence, hailstone size or hailstorm duration, nor does it convey any other meteorological information.

Hailstorms are warm season phenomena, typically occurring between May and September, associated exclusively with severe thunderstorms (LaDochy and Paul, 1986). Unfortunately, during cold months, ice pellets or snow pellets are sometimes reported as small hailstones by meteorological observers, resulting in classification errors (Kocot, 1997). Similar errors occur in the United States (Changnon, 1977). As a result, over half of the approximately 56,000 hail days reported in the Environment Canada climate database occurred during cold months. Relatively few cold month observations were reported by the western provinces of Alberta, Manitoba and Saskatchewan; the classification bias mainly occurred in the eastern provinces and British Columbia. In order to circumvent this bias, hail days between October and April were not included in the analysis. The resulting warm months dataset includes 20,912 haildays occurring between May and September (Table 2). Of the 2,528 stations reporting haildays, those with less than 760 observations (the equivalent of 5 years of warm months) were excluded from the analysis, leaving a total of 2,062 stations. The location of these remaining stations is shown in Figure 4, and the distribution of their observing records in Figure 5.

Figure 6 shows the number of hail days normalised by the number of stations. A substantial increase in hail days for each region is shown during the period 1977 to 1993, as compared to the pre-1977 and post-1993 periods. The reason for this is that in 1977 Environment Canada mandated that <u>all</u> stations were required to report days with hail. Previously only first-order climate stations were required to report hail days. Since the number of first-order stations are relatively few in number, data for hail occurrence is limited prior to 1977. Beginning in 1993, many meteorological observing stations became automated and unable to record hail days. As a result, the seventeen year period between 1977 and 1993 gives the most complete record of hail days in Canada. Since the 1951 – 80 hail climatology was based almost entirely on pre-1977 data, a much more detailed spatial analysis is now possible.

Table 2 gives the warm-month hail days for the sixteen year period between 1977 to 1993 for each province. For each station, the total number of hail and non-hail days was determined for the months of May to September, during the station's period of record. Hail day percentage frequencies were calculated by dividing the number of hail days by the total number of days (hail + no-hail). The number of hail days per May-September period were calculated by multiplying the hail day percentage frequency by 153 days.

The national annual average of warm month hail days for the period 1977–93 is shown in Figure 7. A Kriging algorithm (with a linear variogram) using a 2° search radius was used to grid the irregularly spaced station data. At least 3 stations had to be within the search radius for a grid value to be generated. Contour intervals were interpolated from the resulting $1^o \times 1^o$ gridcells. Higher frequencies are observed in central British Columbia and in Alberta, with the highest values of over 5 days/season located east of the Rockies. They diminish further east, being generally less than 1 day/season in Ontario and the Maritimes, with the exception of a region just east of James Bay that may well be the result of snow or ice pellets occurring in the lee of the Bay. Though the pattern is broadly similar to the previous national analysis shown in Figure 3 (note that the contours selected are the same), there are some notable differences. In British Columbia and Alberta, there are more centres of maxima, and some of the previous ones are slightly shifted; a region of greater than 3 days in the previous analysis in southern Saskatchewan and Alberta along the US border is missing in the current analysis; some new pockets of higher frequencies show up in the more northern latitudes; and some frequencies of greater than 1 that were in southwestern Ontario and the Maritimes are no longer present.

This map is not the most detailed one that can be analyzed, however. Paul (1991a) noted that large-scale (i.e. national studies) hail day averages based on first-order stations show a temporal and spatial regularity which can disagree with smaller-scale, more detailed studies. Therefore the 1977 – 93 data were subdivided provincially or regionally in order to produce smaller-scale analyses (Figures 8a-j). As before, a Kriging algorithm (with a linear variogram) was used, except a 1° search radius was used to produce a $0.1^o \times 0.1^o$ set of gridcells from the irregularly spaced station data for the provincial maps. Contours were then interpolated from the gridcells.

3 Synoptic Conditions That Favor Hail

Hail is one of the phenomenon associated with severe thunderstorms, the others being heavy downpours, tornadoes, lightning and strong winds. Severe thunderstorms are most likely to occur in an unstable atmosphere with abundant low level moisture, in the presence of strong wind shear, and accompanied by a trigger mechanism that can release instability. These conditions are strongly influenced by topography and airmass climatology. Hail is also favoured by strong updrafts, in order to allow particle growth to occur, and low freezing levels in the atmosphere, so that it is more unlikely to melt before it reaches the ground.

A number of authors have reviewed the synoptic occurrence of severe thunderstorms and hail over North America, especially in the United States. For example, Ludlum (1980) and Kessler (1986) discuss the importance of prevailing airstreams that affect the Great Plains of the United States. Westerly summer flows originating from the Pacific subtropical anticyclone and coming over the mountain chains of Western North America tend to be dry as a result of subsidence in the lee of, and precipitation resulting from upslope flow on the western side of the mountain chains. Southerly flows resulting from the western branch of the Atlantic subtropical high bring in low level moisture originating from the Gulf of Mexico or tropical Atlantic Ocean. This situation favors convective development over the Great Plains since warm moist air tends to underlie the dryer air aloft. Knight and Squires (1982) describe four patterns associated with thunderstorm development over Colorado. The first pattern is one of an advancing maritime Polar or Pacific cold front; with thunderstorm development along the front or in the unstable airmass behind it. The second pattern occurs when a quasistationary front induces an easterly flow north of it, resulting in an upslope flow that can trigger convection. The third pattern also favors an easterly upslope flow, but it is caused by a large high over the central U.S., that also transports moisture northward from the Gulf of Mexico. The fourth pattern occurs when 'lee-troughing' forms over eastern Colorado ahead of an approaching Pacific frontal system. Miller (1972) identified another synoptic pattern favourable to hail formation, when a cold low with significant amounts of low-level moisture is present. Cold lows tend to create unstable cloud formations in the presence of solar heating, since they are cool aloft.

A study of severe convective outbreaks in Alberta (Smith and Yau, 1993a,b) was used to develop a conceptual model of severe thunderstorm development in that region. In their model, a set of synoptic and mesoscale conditions that favor convection develop over a period of 2 to 3 days. The first stage, lasting about 1 to 2 days, occurs when an upper ridge lies west of Alberta, resulting in a subsidence inversion in the lower troposphere (the presence of this inversion, or cap, is important to the development of severe convection during stage two). Surface heating during the day can remove the inversion locally, resulting in local but probably fairly weak convection. The second stage occurs when the ridge has moved eastward, and an upstream trough at 500 mb lies just west of Alberta (also discussed by Chisholm, 1966). This trough will typically favor the development of a surface low, and when the low is south of Alberta, winds with an easterly component create an upslope flow that can act as a trigger and tend to advect moisture into the region in the low levels. This moisture, the source of which may be the Atlantic Ocean, the Gulf of Mexico or evapotranspiration, underlies the capping inversion and contributes towards instability. The role of the inversion is to inhibit the development of widespread convection that would have the effect of reducing the potential for locally severe convective events. Easterly surface winds ahead of an approaching upper trough also provide an environment with the large wind shear needed for the development of severe thunderstorms. Where a thickness trough is in phase with the approaching height trough, cooling aloft will also contribute towards increased instability. Smith and Yau also note the importance of the mesoscale mountain-plain circulation that creates a thermally induced upslope flow along the foothills of the Rocky Mountains and act to destabilize the atmosphere. In their analysis, the most common synoptic pattern during severe hail days occurred when a northern high and southern low created an easterly flow (62% of the time), while the second most common pattern was with a southerly low only (33% of the time).

Dudley (1998) confirms the importance of low level moisture in easterly upslope flows, in an unstable environment as a prerequisite for large hail formation, and notes that large hailstones (greater than 40 mm) are almost always produced by supercells (as discussed in Doswell, 1980). Favourable conditions for hail in Alberta begin in the spring, peak in July and August, and end in the fall as can be seen in Figure 2. This same pattern is reflected throughout the prairie provinces and in Ontario (Etkin and Leduc, 1994).

Hail in eastern Canada is more typically associated with synoptic scale mid-latitude storms, and tend to be triggered particularly by cold fronts, though isolated airmass storms can also produce hail if the atmosphere is unstable enough. This tends to occur when southerly flows bring in maritime tropical air from the Gulf of Mexico or tropical Atlantic latitudes (Ludlum, 1980).

4 Discussion

The 1951–80 national hail climatology (Figure 3) relied mainly on first-order stations, but supplemented the analysis, where possible, with second-order stations. Regions in Canada with the most frequent hail are the central and eastern prairies (parts of Alberta, Saskatchewan and Manitoba), south-central British Columbia and southwestern Ontario (LaDochy and Paul, 1986; Paul, 1991b; Charlton et al., 1995). This spatial distribution of hail places much of Canada's productive farmland and much of Canada's population at risk. The highest frequencies in Canada from the national 1977-93 analysis are between 3 and 7 hail days per warm months, similar to the 1951 – 80 climatology, and occur in central and western Alberta. Central and Eastern Canada generally have frequencies below 1 hail day per year.

Figures 8a-j show increases in the maximum frequencies of hail days in comparison to the national 1977 – 93 climatology (note: insufficient data existed for the Yukon and Northwest territories to complete a regional analysis). The greater detail and higher frequencies result from the fact that, on a smaller-scale, less data is smoothed and averaged by the Kriging process These maps show patterns that appear to be well correlated with many topographical features, and may provide a basis for further research on this issue. A brief discussion of the patterns follows, with suggestions as to their possible relationship to topographical features.

In B.C., the largest hail frequencies occur just northwest and northeast of Williams Lake, most likely as a result of a combination of daytime heating of the interior valley combined with upslope flow along the mountains adjacent to the valley. In Alberta, the largest frequencies occur just east of the Rockies. A series of maxima and minima appear well correlated with topography, with the minima along the river valleys and the maxima over higher terrain. Blow-ups of the Calgary, Red Deer and Edmonton areas using greater resolution show a relative maximum near Calgary, in an arc running northwest-southwest and southeast of Red Deer, and just north of Edmonton. The work of Charlton et al. 1994) supports the hail day frequencies shown for the areas surrounding Edmonton and Calgary, Alberta. Dudley (1996) reports even higher frequencies for Calgary than shown in Figure 8; an analysis of city records going back to 1955 suggests an average of 5 hail days per year at Calgary International Airport. He also reports that from 1982 to 1990 the city experienced only 3 severe hail events (hail diameter greater than 19 mm), whereas from 1991 to 1996, it experienced 12. Values decrease significantly in Saskatchewan, which generally has hail frequencies less than 2 days/warm season. A relative maximum might be expected in the extreme southwest over the Cypress Hills, but no observing stations used were located over the highest terrain, and therefore the analysis may well underestimate hail in that location. This analysis is in general agreement with LaDochy and Paul (1986) and Paul (1982; 1986; 1991b). In Manitoba hail frequencies are generally under 2 days, with relative maxima just southwest of Winnipeg, near Somerset and southwest of Rossburn on the southwest portion of Riding Mtn. Ontario also shows hail frequencies that are quite small, generally less than 1 day. Southern Ontario shows some interesting patterns, however, possibly resulting from the complicated interaction of topography and lake effects. Toronto lies in a relative minimum running from Georgian Bay southward to Lake Ontario, just east of the

Niagara Escarpment. This minimum is the expected result of downslope flow east of the Escarpment. Relative maxima lie just east and west of the Toronto minimum, and may in part result from a mesoscale wave phenomenon generated by terrain. The minimum at point 'A', which is over higher terrain, is surprising. The maximum near London is likely a function of terrain and convection associated with lake breezes. An interesting maximum lies just northeast (downstream) of Toronto, along the Oak Ridges Moraine. It is possible that Toronto provides a source of heat, moisture and/or condensation nuclei which enhance hail activity. Further northeast, another maximum lies near the higher ground of Haliburton. Quebec shows hail frequencies generally between 0.5 and 1.5 days in a rather complicated pattern related to a complex topography. Frequencies then diminish eastward, with the maritime provinces seeing less than 1 day/warm season.

In order to assess whether or not any trends were present in hail frequencies, all stations with a full period of record were used to create an average hail frequency indice for each province or region. Note that since the stations are not equally distributed across the province, these numbers do not represent an average regional frequency. They are, however, a homogeneous time series useful for trend analysis. This data is presented in Table 3. Except for Alberta, none of the series show a significant trend. In Alberta, however, the 1977-82 mean of 0.64 days is significantly smaller than the 1983-93 mean of 1.25 at a 99% significance level. The largest differences occur in areas most susceptible to hail occurrence, as can be seen in Figure 9. The patterns in this figure are intriguing, and suggest that hail formation was encouraged during the latter period in regions where it is prone to occur due to topography, at the expense of other areas.

5 Conclusion

The period 1977 to 1993 was associated with substantial increases in hail-observing stations, as a result of policy changes within AES. As the 1951 – 80 hail climatology was mostly based on pre-1977 data, it had a relatively coarse resolution in comparison. The provincial and regional hail climatologies for 1977–93 have a greater resolution than the national climatology, and particularly show the importance of some topographical features, such as the Rocky Mountains. The influence of local topographical features on mesoscale hail frequency is a major control, and deserves further study. Except for Alberta, the regional frequencies show no trend, however after 1982 hail frequencies in that province showed a significant increase.

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6 References

Charlton, R.B., Kachman, B.M. and Wojtiw, L., (1995), Urban hailstorms: a view from Alberta. Natural Hazards, vol. 12, 29-75.

Charlton, R.B., Kachman, B.M. and Wojtiw, L., (1998), The Edmonton Tornado and hailstorm: A decade of Research. CMOS Bulletin, vol. 26, 1-56.

Changnon, S.A., (1977), The scales of hail. Journal of Applied Meteorology, vol. 16, 626-648.

Changnon, S.A. (1997), Climatology of Hail Risk in the United States, CRR-40, Changnon Climatologist, Mahomet, Illinois, 89 pp.

Chisholm, A.J. (1966), Small Scale Radar Structure of Alberta Hailstorms. MSc Thesis, McGill University, Montreal, 75 pgs.

Doswell, C.A. III. (1980), Synoptic scale environment associated with high Plains severe thunderstorms. Bull, Amer. Metero. Soc. 61, 1388-1400.

Dudley, D. (1996). 1996 Severe Weather Report - Southern Alberta. Environment Canada, Calgary, Alberta, 18 pgs.

Dudley, D. (1998), Personal Communication. Nov. 23, 1998. Atmospheric Environment Service, Environment Canada.

Eagleman, J.R. (1990), Severe and Unusual Weather, 2nd ed. Lenexa: Trimedia Pub. Co., 372 pp.

Environment Canada (1987), Climate Atlas of Canada, map series 3, pressure, humidity, cloud, visibility, and days with thunderstorms, hail, smoke and haze, fog, freezing precipitation, blowing snow, frost, snow on the ground. Ministry of Supply and Services, Cat. No. EN56-63/3-1986.

Etkin, D.A. and Leduc, L. (1994). A Non-Tornadic Severe Storm Climatology of Southern Ontario Adjusted for Population Bias: Some Surprising Results. CMOS Bulletin, Vol. 22(3), 4-8.

Etkin, D.A. and Maarouf, A. (1995), An overview of atmospheric natural hazards in Canada. Proceedings of a Tri-lateral Workshop on Natural Hazards, Merrickville, Canada, Feb. 11-14.

Guillet, D. (1998). Personal communication, Atmospheric Environment Service, Environment Canada.

Hill, C. (1996), Mayday!. Weatherwise, June/July, 25-28.

Hughes, P. and Wood, R. (1993), Hail The White Plague. Weatherwise, April/May, 16-21.

IBC (1997), Facts of the General Insurance Industry in Canada, Insurance Bureau of Canada, Toronto, 37 pp.

Kessler, E. (1986), Thunderstorm Morphology and Dynamics, University of Oklahoma Press, London, 411 pgs.

Knight, C.A. and Squires, P. (1982), Hailstorms of the Central High Plains, Volume 1: The National Hail Research Experiment, Colorado Associated University Press, Colorado

Kocot, C. (1997), Personal Communication. Atmospheric Environment Services, Environment Canada, Downsview, Ontario.

LaDochy, S. and Paul, A., (1986), A climatology of hail for the southeastern prairies. 20th Annual Congress of the Canadian Meteorological and Oceanographic Society, Regina, Saskatchewan, June 5.

Ludlum, F.H. (1980), Clouds and Storms: The Behavior and Effect of Water in the Atmosphere. Pennsylvania State University Press, 405 pgs.

Miller, R.C.(1972), Notes on analysis and severe-storm forecasting procedures of the Air Force Global Weather Central. Tech, Report 200, Air Weather Service, Offutt Air Force Base, Nebraska.

Paul, A.H., (1982), The thunderstorm hazard on the Canadian Prairies. Geoforum, vol. 13, no. 4, 275-288.

Paul, A., (1986), A climatology of severe hailstorms in Saskatchewan. Annual meeting of the Association of American Geographers, Minneapolis, May 3–7.

Paul, A., (1990), Annual variability in hail damage in Saskatchewan. 24th Annual Congress of the

Canadian Meteorological and Oceanographic Soc., Victoria, B.C., May 28 – June 1.

Paul, A., (1991a), A review of hail climatology on the Great Plains. 25th Annual Congress of the Canadian Meteorological and Oceanographic Society, Winnipeg, Manitoba, June.

Paul, A., (1991b), Studies of long-lived hailstorms in Saskatchewan, Canada from crop insurance data. Natural Hazards, vol. 4, pp. 345-352.

Phillips., D., (1990), The Climates of Canada, Environment Canada. Supply and Services Canada, Publishing Centre, Catalogue No. En56-1/1990E, 176 p.

Renick, J. (1997), Hailstorms and Hail Suppression: Alberta's Unique Approach. In 'Hail, Tornadoes and Hurricanes, Employers Reinsurance Corp., Overland Park, Kansas.

Smith, S.B. and Yau, M.K. (1993a), The Causes of Severe Convective Outbreaks in Alberta. Part I: A Comparison of a Severe Outbreak with Two Nonsevere Events. Monthly Weather Review 121,1099-1125.

Smith, S.B. and Yau, M.K. (1993b), The Causes of Severe Convective Outbreaks in Alberta. Part II: Conceptual Model and Statistical Analysis. Monthly Weather Review 121,1126-1133.

Table 1: Major Canadian Hailstorms

Location	Date	Insured Damages (million $)
Calgary, Alberta	24/25 July, 1996	75
Calgary, Alberta	16-18 July, 1996	103
Winnipeg, Manitoba	16 July, 1996	105
Calgary, Alberta	13-15 July, 1995	52
Southern Alberta	10 July, 1995	26
Edmonton, Alberta	4 July, 1995	15
Southern Manitoba	27 Aug., 1994	7
Southern Alberta	18 June, 1994	8
Alberta	29/30 July, 1993	8
Alberta	1 Sept. 1992	7
Alberta	28 Aug. 1992	5
Calgary, Alberta	31 July, 1992	22
Calgary, Alberta	7 Sept., 1991	343
Calgary, Alberta	9 July, 1990	16
Calgary, Alberta	16 Aug., 1988	37
Montreal, Quebec	29 May, 1986	65
Southwestern Ontario	30 May, 1985	30–40
Calgary, Alberta	28 July, 1981	100
Montreal, Quebec	5 June, 1979	extensive property damage
Cedoux, Sask.	27 Aug., 1973	10
Western prairies	23 July, 1971	20
Edmonton, Alberta	4 Aug., 1969	17
Lambeth, Ontario	19 Aug., 1968	extensive crop and property damage
Central Alberta	14 July, 1953	unknown
Okanagan Valley, BC	29 July, 1946	2
Edmonton, Alberta	10 July, 1901	extensive damage

Source: Phillips (1990) for events prior to 1987; IBC (1997) for events after 1987. The Insurance Bureau of Canada (IBC) data is compiled for major multiple-payments occurrences where the loss is in excess of about $4 million. Note that the number of events has increased in the 1990s [1965-69:2 events, 1970-74:3 events, 1975-79:1 event, 1980-84: 2 events, 1985-89:3 events, 1990-95:8 events, 1996:3 events].

Table 2: Number of Observations by Province/Territory, 1977-93
Warm Months Only (May - September)

	Maritimes	Ontario	Quebec	Yukon and Northwest Territories	Saskatchewan	Manitoba	Alberta	British Columbia	Total
Days With Hail	616	1,842	3,813	328	2,458	1,426	6,708	3,623	20,814
Days Without Hail	442,362	720,864	904,803	192,905	460,477	312,806	729,499	863,918	4,627,634
Number of Stations	232	401	499	104	248	160	390	492	2,526

Table 3

Average Hail Frequency by Province/Territory.

Year	BC	**Alberta**	Sask	Manitoba	Ontario	Quebec	Maritimes	Yukon
1977	0.79	**0.72**	1.00	0.88	0.34	0.57	0.26	0.78
1978	0.79	**0.65**	0.95	1.03	0.26	0.43	0.18	0.48
1979	0.60	**0.68**	0.91	0.61	0.28	0.39	0.15	0.31
1980	0.46	**0.85**	0.74	0.47	0.57	1.04	0.27	0.39
1981	0.75	**0.41**	1.22	0.60	0.20	0.56	0.14	0.51
1982	0.56	**0.55**	0.79	0.72	0.41	0.53	0.11	0.28
1983	0.82	**1.21**	0.80	0.46	0.64	0.70	0.16	0.33
1984	1.07	**1.47**	0.66	0.78	0.51	0.92	0.21	0.35
1985	0.74	**1.44**	0.72	0.67	0.54	0.82	0.29	0.21
1986	0.77	**1.14**	0.86	0.90	0.39	0.67	0.28	0.25
1987	0.64	**1.22**	0.75	0.60	0.49	0.90	0.40	0.36
1988	0.68	**0.77**	0.66	0.50	0.36	0.54	0.15	0.40
1989	0.79	**1.34**	0.93	0.78	0.25	0.56	0.20	0.26
1990	0.57	**1.02**	0.81	0.76	0.39	0.59	0.20	0.29
1991	0.59	**1.22**	0.84	0.85	0.34	0.64	0.31	0.31
1992	0.55	**1.37**	0.67	0.64	0.28	0.45	0.17	0.28
1993	0.70	**1.56**	0.58	0.68	0.37	0.97	0.21	0.88
Mean	0.70	**1.04**	0.82	0.70	0.39	0.66	0.22	0.39
Standard Deviation	0.14	**0.35**	0.15	0.16	0.12	0.19	0.07	0.18

* Only stations with a full period of record were used, in order to create a homogeneous data series. Note that these numbers do not represent average hail frequencies for the province, but only of the available stations.

Figure Captions:

Figure 1: Weather Related Insurance Costs (1984-1996) from Major Multiple Payouts, in $1995 (IBC, 1997). Only events of greater than about $4 million are included.

Figure 2: Probability of hail occurrence in central Alberta., using data from the Alberta Hail Research Program (Renick, 1997).

Figure 3: Average number of hail days per year, based on the 1951-80 climate normals (Environment Canada, 1987). The contours were hand drawn, based primarily upon about 350 weather stations. Some secondary climate station data was included in a subjective way, but not documented (Guillet, 1998).

Figure 4: Location of stations that report 'days with hail' that were used in the current analysis.

Figure 5: This figure shows the observing record of the stations used in the analysis. The maximum number of 'observing days' in the 1977-93 period is 2,601, and stations with less that 755 'observing days' were not used. Of the 2,062 stations used, the average number of 'observing days' was 2,176.

Figure 6: Recorded hail days in Canada normalized by the number of observing stations. The increase in 1977 results from an Atmospheric Environment Service (AES) directive that climate stations shall report days with hail. The decrease after 1994 results from the beginning of the implementation of an automatic observing network.

Figure 7: Average number of hail days per warm season (May - September) at a national scale, during the period 1977-93. The raw station data was gridded on a 1.0 x 1.0 degree scale using a search radius of 3.0 degrees, and then contoured using SURFER.

Figures 8: Average number of hail days per warm season (May - September) at regional scales, during the period 1977-93. The raw station data was gridded on a 0.1 x 0.1 degree scale using a search radius of 1.0 degree, and then contoured using SURFER.

Figure 9: Differences in mean hail days per warm season (May - September) for Alberta, from 1977-82 to 1983-93. Note the large increases along the eastern edge of the Rocky Mountains.