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INVESTIGATION OF THE EFFECT OF ICE NUCLEI FROM A CEMENT PLANT ON DOWNWIND PRECIPITATION IN SOUTHERN ALBERTA

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Abstract. In an earlier study, ice nuclei were measured in airborne effluent over a cement producing facility in southern Alberta. To investigate the possibility of inadvertent weather modification due to the effluent, two predictor schemes were developed using five weather stations to determine whether precipitation amounts or precipitation events were anomalous at a sixth station downwind of the facility. Despite departures from predicted values, no linear correlation could be confidently made between mill production and precipitation anomalies at Calgary, the downwind and sixth station, during the ten year analysis period from 1981 to 1990. Inadvertent precipitation modification does not seem to have taken place.

1. INTRODUCTION

In southern Alberta, on the eastern edge of the Rocky Mountains, there is situated a large, isolated industrial complex that has been in operation since the late 1800's. Located on the Bow River at Exshaw, three cement and calcination plants produce large quantities of waste heat, water vapour and airborne particulate matter. Located 80 km downwind of the facility (Fig. 1) and situated in rolling prairie farmland, is the city of Calgary, a large urban centre with a population of 775,000. The hub of farming, ranching and oil and gas activity in western Canada and the site of the 1988 Winter Olympics, Calgary has a large regional recreational and agricultural economy that is particularly sensitive to precipitation amounts and events.

In June of 1985, *ad hoc* Alberta Research Council airborne particle sampling flights using an NCAR (National Centre for Atmospheric Research) IN (ice nuclei) counter were made over and downwind of the Exshaw site, the author in attendance. Nuclei concentrations from the single cement producing plant measured several km downwind were 5/litre at an altitude of 7,500 feet, with an NCAR chamber temperature of -20°C. In direct plume penetration, however, concentrations became comparable to those produced by commercial airborne cloud-seeding equipment (Heimbach, 1986). Over 3300 IN were measured in a single penetration pass of less than 1 minute, producing a measured IN concentration minimum of 320/litre. However, unlike a commercial seeding operation, this IN source is virtually a continuous one running 24 hours a day, 365 days a year, barring equipment overhaul or breakdown (J. Brown, personal communication, 1986), and only two complete shutdowns occurred in the ten year period from 1981 to 1990. The aim of this paper is to determine whether Calgary shows climatological evidence of anomalous precipitation and, if present, whether such precipitation can be unequivocally related to industrial output at the suspect Exshaw facility.

2. WEATHER MODIFICATION PRINCIPLES

Modification of supercooled clouds using ice nucleating agents is possible due to a lower saturation vapour pressure over ice than over liquid water. This difference, an important component of the Bergeron nucleation process (Dennis, 1980), causes an ice crystal to grow by vapour deposition at the expense of nearby supercooled liquid water droplets. The two results of this process are that ice crystals grow faster than they would through normal coalescence and collision, and that increased buoyancy results from latent heat release, augmenting cloud updrafts (Braham, 1986). The role of most seeding agents (natural and artificial) is to mimic the inter-molecular dimensions and hexagonal shape of a natural ice

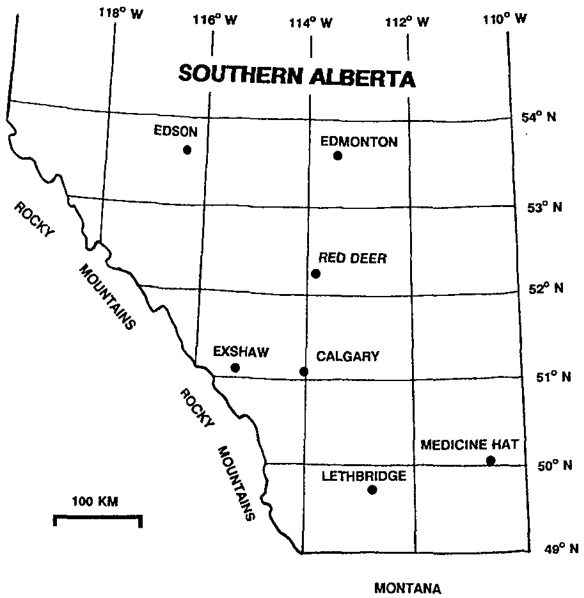

Figure 1. Map of southern Alberta. The five predictor control stations are shown (Edson, Edmonton, Red Deer, Lethbridge and Medicine Hat) as well as the ice nuclei source (Exshaw) and the target station (Calgary).

crystal and thus provide a substrate for ice deposition. This improves the efficiency of precipitation processes and consequently increases rain and snow fall, and through embryo competition, reduces hail size. Naturally occurring IN include true ice crystals from the glaciation of strong vertical cumuliform growth as well as solid particles of dust swept aloft by wind, volcanic aerosols, meteoritic debris, gas precipitates, spores and bacteria (e.g., Pseudomonas Syringae).

While the introduction of IN improves precipitation processes to a point, overseeding by the same mentioned cloud processes has the potential of reducing and even preventing precipitation where natural IN concentrations are optimal. An excess of IN can result in smaller sized precipitation droplets or crystals, thus increasing the likelihood of complete evaporation prior to reaching the ground. Virga, consequently, is more likely to occur in overseeded situations. Incomplete or insufficient seeding of hail situations also has the potential of creating unexpected hail damage by increasing the number of stones but not sufficiently to limit their growth. Indeed the attendant risks associated with deliberate weather modification programs has seen a number of States in the USA and Provinces in Canada enact legislation to regulate or at least monitor such operations (Miller, 1992).

3. ICE NUCLEI AND ACCIDENTAL INDUSTRIAL WEATHER MODIFICATION

High concentrations of IN from industrial sources have rarely been directly observed in experiments to date. However, the release of such nuclei has often been hypothesised where climate data reveals anomalous precipitation or storm events. One of the first observations made of weather modification through industrial process was in England by Ashworth (1929). He noted that Sunday rainfall amounts, the day factories were regularly shut down, were lower than during the rest of the week and hypothesized that "the fine flue dust ejected by the draught up the chimney may supply an abundance of nuclei which promote the formation of rain". Almost forty years later, an association between increased iron and steel production in Chicago, Illinois and increased precipitation and storm events downwind at La Porte, Indiana was evaluated and statistically defended as being plausible (Changnon, 1968). The conclusions drawn in METROMEX (Metropolitan Meteorological Experiment) similarly suggested that increased rainfall and storm activity observed over and downwind of St. Louis, Missouri were due to urban/industrial effects, with anthropogenic IN considered to be a contributing factor (Changnon, 1981).

In contrast, some instances have been noted where a suspect industrial complex does not show evidence of downwind weather modification, despite favourable indicators for the contrary. Although investigation by Telford (1960) revealed IN concentrations of 300/litre at -22°C in the effluent of steel plants in the Newcastle/Sydney (Australia) area, downwind impact was determined to be negligible (Ogden, 1969). The validity of some of Ogden's results, however, was challenged in later discussion (Changnon, 1971). In an investigation of the downwind climatological impact of a single steel complex in Hungary, Lowry and Probald (1978) similarly found no evidence to support the release of IN and consequent weather modification.

A hybrid situation arose in the results presented by Hobbs *et al.* (1970). In their investigation of airborne effluent from a variety of isolated industrial complexes in the State of Washington, using airborne IN detection equipment, they noted anomalously high CCN (cloud condensation nuclei) concentrations but low or absent IN concentrations. They sampled plumes from a copper smelter, a steel furnace, a ferroalloy plant, an aluminum smelter, a Kraft mill and a saw mill, with only the ferroalloy plant producing measurable IN at close to background levels. However, annual precipitation and stream flow amounts were found to increase in the vicinity of many of these operations, despite the low IN values. The excess CCN appeared to provide fertile ground for periodic injections of naturally occurring IN, triggering, through this two-step process, anomalously high precipitation amounts. It is considered to be a hybrid situation as weather modification evidence is present, but IN are absent.

None of the above mentioned industrial processes contains any reference to cement production. Furthermore, the literature is exceedingly sparse in discussions of the nucleating and hygroscopic effects of cement kiln effluent. Budilova *et al.* (1969) noted that a possible 5 % increase in precipitation fall could be realized during seeding of convective clouds with a halite and cement mixture, and Murty and Murty (1972) confirmed the nucleating properties of Portland cement through laboratory testing. They showed that the threshold nucleation temperature of Portland cement to be -4.6°C to -5.0°C, between that of silver iodide (-4.0°C) and lead iodide (-6.5°C).

4. EXSHAW INDUSTRY

Three separate mineral beneficiation processes take place at the industrial complex at Exshaw, each under the auspices of a separate company. These companies are Lafarge Canada Inc., Continental Lime Ltd., and Baymag, all three providing data and information on their operations for this study, as presented below.

Lafarge Canada Inc. (Lafarge), one of Canada's largest producers of cement, is believed to be the source of ice nuclei detected in aerial sampling tests reported by Heimbach (1986). In the manufacture of cement, raw materials are initially crushed, blended, ground together and then introduced into long, gently sloping rotating kilns. At 900°C, calcination takes place, and at final temperatures of 1450 - 1650°C, aluminum and calcium complexes form. The kiln product, referred to as clinker, is ground and with a small amount (5%) of gypsum becomes Portland cement. Lafarge currently uses two such kilns, each kiln having a primary kiln stack and secondary cooler stack.

The principal sources of heat, vapour and particulates are the kiln stacks, located at the upper end of the kiln complex. The exhaust gas temperatures average 146°C for kiln five and 336°C for kiln four. Kilns one and two were shutdown in 1976 and kiln three was transferred in October 1982 to Baymag (see below).

Particles released include complex dicalcium and tricalcium silicates, tricalcium aluminate and tetracalcium alumino ferrite. Chemical assays provided by Lafarge show highest concentrations by weight of calcium and silicon, with decreasing amounts of magnesium, potassium, sulphur, aluminum and iron. The greatest percentage of particles released are less than 0.3 μ in diameter, accounting for approximately 83% (by weight) of the solids released, with 6% between 0.3 and 10 μ, and 11% larger than 10 μ. It was noted by Telford (1960) that effluent from Australian steel mills was inert, with high amounts of manganese and silicon, and that particles released were initially in the size range of 0.1 to 1.0 μ, with later coagulation to larger than 10 μ. Table 1 presents a comparison of particle size distributions for the three facilities.

The cooler stacks, located at the lower end of the kiln complex, release gas at comparable velocities but at lower temperatures than the main stacks - kiln four at an average of 146°C and kiln five at an average 169°C. These stacks exhaust air used in cooling the resulting clinker to temperatures that can be handled elsewhere in the facility. Both kilns are fuelled by natural gas, using some 400,000 cubic metres per day. The raw materials used in the process include limestone from the Palliser Formation of Exshaw Mountain, immediately behind the plant, sandstone from the Belly River Formation, shale from the Wapiabi Formation, industrial iron and fly ash. Ash and shale are recognized as common, naturally occurring ice nucleating agents (Dennis, 1980) although during the manufacturing process they become part of the complex cement phyllosilicate and tectosilicate structure, and their individual mineralogical structure is lost. On hydration, the cement complex becomes extensively cross-linked and hardens to form the construction material known as concrete.

Exhaust that exits each of the two kiln stacks is cleaned of 99.7 % of particulates by an electrostatic precipitator (ESP). The secondary cooler stack exhaust is cleaned by gravel bed filters of similar efficiency. The ESP, responsible for limiting average particulate outputs to less than 55 kg/hour, is periodically subject to shutdown for a number of production reasons, including but not limited to the presence of explosive concentrations of volatiles. During these brief transient events, which are carefully logged and reported to Alberta Environment, the Provincial Government department responsible for air quality, particulate loading can increase, theoretically, by two orders of magnitude. This would be anticipated to result in a similar increase in the downwind IN concentration of the effluent from the observed 5/litre to 500/litre, comparable in magnitude with those concentrations measured by Telford (1960) over steel mills in Australia.

Table 1. Average size distributions of effluent particles based on particulate weight. Reported size refers to particle diameter.

	< 0.3 μ	0.3 - 10 μ	> 10 μ
Lafarge	83 %	6 %	11 %
Continental Lime Ltd.	2 %	64 %	34 %
Baymag	1 %	34 %	65 %

The other two facilities located at Exshaw include Continental Lime Ltd. and Baymag. Both firms, like Lafarge, are mineral processors. Continental Lime Ltd., located 5 km east of Lafarge, uses two rotating horizontal kilns for the calcination of limestone ($CaCO_3$) into quicklime (CaO), and a short kiln for drying crushed limestone. Limestone is from the Mount Head

Formation, located 13 km away. Particulate output is significantly lower than at Lafarge, averaging less than 5 kg/hour. Baymag, adjacent to Lafarge, uses the former Lafarge kiln 3 for the formation of magnesium oxide (MgO) through the calcination of magnesite and dolomite, obtained from the Cathedral Formation of Brussilof Mountain, 70 km away. Despite low production amounts, typically 180 tonnes/day, and the use of an ESP, exhaust stack particulate amounts are comparable to Lafarge kiln stacks, averaging 45 kg/hour.

5. METHODOLOGY

The evaluation of a potential seeding impact at Calgary due to anthropogenic ice nuclei (ANIN) was carried out in two parts. The first sought to determine whether the precipitation at Calgary (both amount and number of events) was anomalous by developing a scheme for predicting what the unseeded precipitation at Calgary should be and thereby produce residuals. The second part was dependent on the first, with an attempt to quantify the relationship between Lafarge production over the ten year period from 1981 to 1990 and both (i) calculated event and amount residuals and (ii) the ratio of observed to predicted events and observed to predicted amounts (eg. Thompson and Griffith, 1981).

5.1 Part 1

In attempting to determine any anomalous nature to the precipitation at Calgary, methodologies frequently used by researchers, and in particular by weather modification operators, were considered. The most difficult problem posed here, and indeed in most weather modification evaluation schemes, was determining what would have happened had there been no seeding treatment. As it is not possible to observe what naturally happens and then retroactively apply a seeding agent, indirect schemes for predicting the background or natural state have been developed over the years. These include the target-only, target-control and crossover designs. All three, however, require that for some period, weather parameters (in this case precipitation amount and incidence) be measured when seeding *isn't* or *hasn't* happened. This presents considerable difficulty in the present case as mill records prior to 1980 are vague and shutdown periods cannot be determined prior to this period. Furthermore, in the 120 month sample data set complete shutdown of both kilns occurred only on 4 months (January 1981, February 1981, November 1984, December 1984), insufficient to create a predictor useful for the entire 10 year period. Monthly Lafarge production is presented in figure 2.

A solution to this problem was to use data from other Alberta meteorological stations in a modified target-control approach, and determine whether there was a relationship between precipitation and an independent variable that could be used for predicting what the "unseeded" precipitation at Calgary should be. Partial support for this approach was the good correlation observed by Longley (1974) between precipitation amounts at prairie stations with less than 400 km separations. Five first order stations were used, all latitudinally displaced from Calgary but in a band of roughly equivalent longitudinal displacement from the mountain barrier (Fig. 1). The stations included Red Deer, Edmonton, Medicine Hat, Lethbridge and Edson.

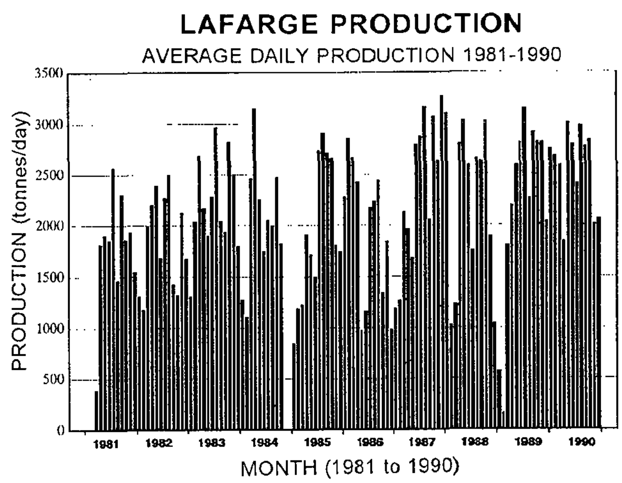

Figure 2. Average daily cement production at Lafarge. Only four months had zero output (January 1981, February 1981, November 1984, December 1984).

Testing of various relationships between monthly precipitation (e.g., measurable precipitation amounts and events in westerly flow, total precipitation, precipitation in non-westerly flow, and ratios of the above) and time (e.g., days per month of westerly flow, days per month of westerly flow in which measurable precipitation fell, days of non-westerly flow, days of non-westerly flow with precipitation, and ratios of the above) were carried out. It was found that the most consistent relationships were between the number of days in a given month that the prevailing surface wind was from the west (250 to 290 degrees) and both the amount of precipitation that fell in westerly flow (type A predictor) and the number of precipitation events during westerly flow (type B predictor). By combining data from all five stations, the strength of a least squares linear correlation could be evaluated for each predictor on a month by month basis, 120 months in total. The coefficients of determination for each predictor and for each month of the ten year period are presented in figures 3 and 4.

Of concern was spacial variability of precipitation due to geographic situation, particularly latitude, and rigorous filtering of the predictor months was initiated to eliminate suspect values. A threshold coefficient of determination of 0.90 was established as the minimum, corresponding to a significance level of approximately 0.01. Any predicted value from a month with an r^2 value below 0.90 was rejected.

TYPE A PREDICTORS

COEFFICIENT OF DETERMINATION BY MONTH

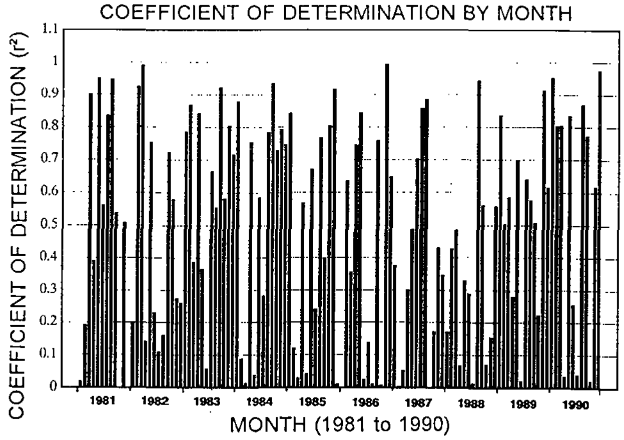

Figure 3. Coefficients of determination (r^2) for the type A predictor. Type A used a correlation between the amount of monthly precipitation that occurred during west flow and the number of days for a given month that had prevailing westerly winds.

TYPE B PREDICTORS

COEFFICIENT OF DETERMINATION BY MONTH

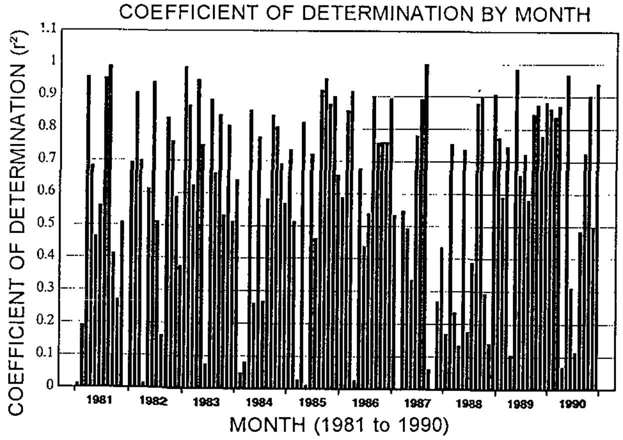

Figure 4. Coefficients of determination (r^2) for the type B predictor. Type B used a correlation between the number of monthly precipitation events that occurred during west flow and the number of days for a given month that had prevailing westerly winds.

As a check of the validity of the relationships as predictors, it was noted that for January 1981, February 1981, November 1984, and December 1984, the inclusion of Calgary data did not change the coefficient of determination by more than 0.04. While this supports the premise that Calgary precipitation should not be anomalous for those months in which there was no seeding taking place, it is by no means conclusive as the coefficient of determination in all four cases was below the 0.90 rejection threshold.

5.2 Part 2

The type A and type B residual data, extracted as above, as well as the ratios of observed to predicted precipitation amounts and precipitation events were then compared through a least squares linear regression with weighted production amounts at the Lafarge facility. Raw Lafarge production data took the form of total monthly kiln production measured in tonnes, and the weighted production values took the form of daily estimated production (monthly tonnage divided by the number of days in the month) multiplied by the number of days for that month in which prevailing wind at Calgary was from the west. Type A results are presented in table 2 and type B results are presented in table 3.

Figure 5 illustrates the relationship between residual precipitation amounts (the difference between what was observed and what was predicted to have fallen had there been no seeding influence) and weighted production, the three positive values indicative of precipitation augmentation and the nine negative values indicative of precipitation suppression. The single zero value indicated no seeding influence. Figure 6 illustrates the same relationship for precipitation events, rather than amounts, with five instances of augmentation, eight instances of suppression, and three instances of no impact.

Figures 7 and 8 illustrate the relationship between ratios of observed to predicted precipitation amounts (figure 7) and precipitation events (figure 8). Values in excess of unity suggest precipitation augmentation and values below unity suggest precipitation suppression. Values of unity indicate no seeding influence, and values of zero indicate a complete absence of a precipitation event where one was predicted. Figure 7 presents three instances of augmentation and nine of suppression, and figure 8 presents four instances of augmentation, eight of suppression, and one of no impact. Data points in both figures were culled (one in figure 7 and three in figure 8) where the predicted precipitation amount or event value was zero, resulting in a zero in the ratio denominator and an undefined ratio value.

In all four figures the least squares linear regression coefficients of determination were low (0.04 for figure 5, 0.23 for figure 6, 0.02 for figure 7 and 0.03 for figure 8) and clearly not significant at a 0.05 confidence level. These results are discussed further in section 7.

6. DATA

Lafarge Canada Inc., the suspected IN producer, has provided monthly production data for the 1981-1990 period. These production figures can be concluded to be proportional to stack effluent amounts, the electrostatic precipitation (ESP) equipment used in particulate capture being fairly uniform in efficiency

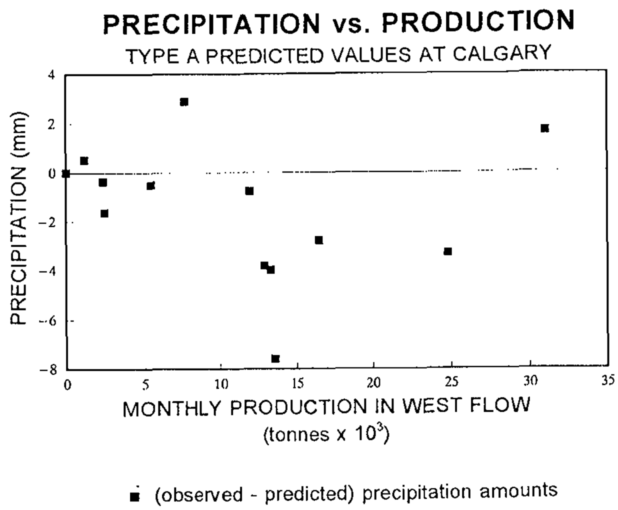

Figure 5. Relationship between type A residual precipitation amounts (determined when the predictor coefficient of determination was in excess of 0.90) and production amounts during westerly flow.

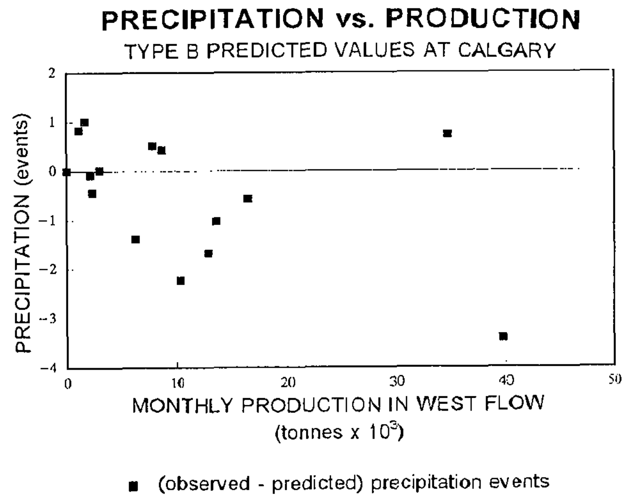

Figure 6. Relationship between type B residual precipitation events (determined when the predictor coefficient of determination was in excess of 0.90) and production amounts during westerly flow.

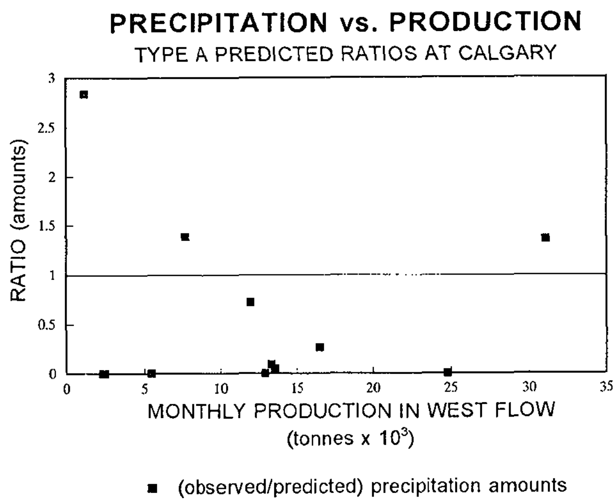

Figure 7. Relationship between the ratio of observed and type A predicted precipitation amounts (determined when the predictor coefficient of determination was in excess of 0.90) and production amounts during westerly flow.

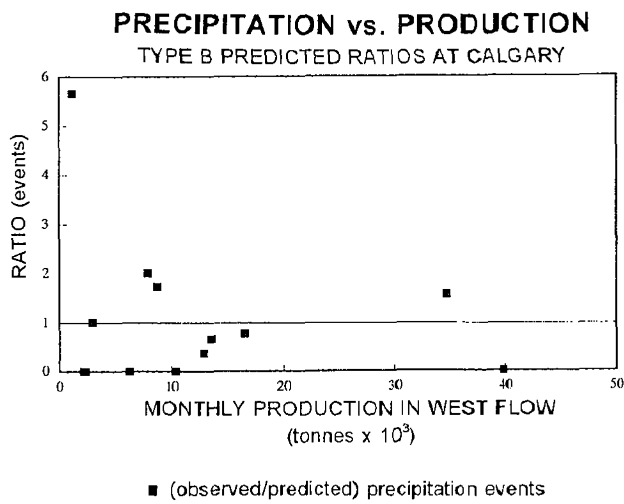

Figure 8. Relationship between the ratio of observed and type B predicted precipitation events (determined when the predictor coefficient of determination was in excess of 0.90) and production amounts during westerly flow.

regardless of the output rate (J. Brown, personal communication, 1988). In order to make the target-control separation, the production amount under downwind conditions had to be separated from the production amount under non-downwind conditions.

Particulate emission data were obtained from independent laboratory results provided by Lafarge and Continental Lime Ltd., and by personal communication for Baymag (B. Walsh, personal communication, 1986).

All precipitation data was provided by the Atmospheric Environment Service, Canada's national weather forecasting and climate data service. As indicated, only first order meteorological stations in southern Alberta with precipitation and daily prevailing wind data were used. Prevailing wind was defined as the most commonly occurring two minute mean wind as measured every hour in a 24 hour period, and in this case covered azimuths of 250 to 290 degrees true. Precipitation was measured in millimetres, or the

Table 2. Type A observed, predicted and residual precipitation amounts as used in figures 5 and 7. Weighted production amounts and coefficients of determination are also shown.

Month	Observed Pcpn (mm)	Calculated Pcpn (mm)	Residual Pcpn (mm)	Ratio (Obs/Cal)	Predictor r^2 value	Weighted Production (tonnes)
3: Mar 81	0.8	0.28	+ 0.5	2.9	0.902	1163
5: May 81	10.4	7.53	+ 2.9	1.4	0.952	7624
8: Aug 81	0.0	0.0	0.0	undefined	0.948	0
14: Feb 82	0.0	0.36	- 0.4	0.0	0.926	2365
15: Mar 82	2.0	2.77	- 0.8	0.7	0.992	11953
33: Sep 83	0.4	8.00	- 7.6	0.1	0.923	13562
45: Sep 84	0.0	1.63	- 1.6	0.0	0.938	2472
59: Nov 85	0.0	0.52	- 0.5	0.0	0.916	5433
71: Nov 86	0.0	3.82	- 3.8	0.0	0.995	12908
92: Aug 88	0.4	4.48	- 4.0	0.1	0.944	13307
107: Nov 89	6.2	4.57	+ 1.6	1.4	0.915	31051
109: Jan 90	0	3.32	- 3.3	0.0	0.954	24791
120: Dec 90	1.0	3.80	- 2.8	0.3	0.976	16491

melted equivalent if the precipitation was snow or hail, and precipitation events were marked by any day in which measurable precipitation was received.

7. RESULTS

An initial total of 13 type A and 16 type B residual and ratio values were produced after filtering. Paired t test comparisons of the calculated precipitation amounts with the observed values (type A predictor) indicated significant differences at the 0.07 confidence level for precipitation amounts alone and 0.11 for ratios of observed to calculated precipitation amounts. Comparison of the calculated precipitation events with the observed events (type B predictor) had significance differences at the 0.15 confidence level for events alone and 0.89 for ratios of observed to calculated events. Nonparametric comparisons using Mann-Whitney U tests revealed threshold confidence levels of 0.05 and 0.02 for the type A residuals and ratios, and 0.24 and 0.25 for the type B residuals and ratios, similar to t test values. As noted by Griffith *et al.* (1991), these statistical tests are indicators of validity rather than proof, the randomness and independence requirements not being completely fulfilled.

Despite the statistical strength of the type A predictor in producing residual and ratio values indicative of anomalous precipitation at Calgary, no linear correlation was evident between precipitation amounts or events and weighted Lafarge production. In all four cases (type A and B), the coefficient of determination was below 0.23 and not significant at the 0.05 confidence level. However, the type A residual results did have a nonlinear trend (Fig. 5). Below 11000 tonnes weighted monthly production, residual precipitation wavers between mild surplus and deficit. Between 11000 and 29000 tonnes, there was a strong deficit in precipitation, and beyond 29000 tonnes a surplus, as if the negative effect of possible overseeding gave way to some other factor at high production amounts, possibly heat or water vapour (e.g., Hindman, 1977). The pattern is almost sinusoidal, with the amplitude of the residual increasing with increasing production amounts. If the initial fluctuations are discounted, the curve is also suggestive of a cubic function.

8. CONCLUSION

Cement production at the Lafarge facility, on the basis of the tests carried out in this study, cannot be confidently linked to precipitation amount or event anomalies determined at Calgary. Despite the majority of points in figures 5 to 8 lying in the precipitation suppression zones of these graphs, the trend described in the results section must be considered consequential rather than causal, with concrete evidence of cement plant effluent affecting Calgary's precipitation still lacking.

There are a number of reasons why the indicators are inconclusive. Anomalous precipitation at Calgary could be due to some situational feature not present at the other five stations used in producing the residual. Also, there may not be a completely linear relationship between kiln production and stack effluent

Table 3. Type B observed, predicted and residual precipitation events as used in figures 6 and 8. Weighted production amounts and coefficients of determination are also shown.

Month	Observed Pcpn Events	Calculated Pcpn Events	Residual Pcpn Events	Ratio (Obs/Cal)	Predictor r^2 value	Weighted Production (tonnes)
3: Mar 81	1	0.18	+ 0.8	5.6	0.957	1163
7: Jul 81	1	2.68	- 1.7	0.4	0.954	12847
8: Aug 81	0	0.00	0.0	undefined	0.991	0
14: Feb 82	0	0.44	- 0.4	0.0	0.908	2365
18: Jun 82	1	0.00	+ 1.0	undefined	0.942	1687
25: Jan 83	1	0.49	+ 0.5	2.0	0.988	7878
28: Apr 83	0	0.10	- 0.1	0.0	0.948	2168
56: Aug 85	1	0.58	+ 0.4	1.7	0.918	8729
57: Sep 85	2	3.00	- 1.0	0.7	0.953	13588
63: Mar 86	2	1.28	+ 0.7	1.6	0.915	34689
80: Aug 87	0	0.00	0.0	undefined	0.998	0
96: Dec 88	0	1.39	- 1.4	0.0	0.907	6283
101: May 89	0	2.23	- 2.2	0.0	0.984	10376
113: May 90	1	0.99	0.0	1.0	0.968	3012
118: Oct 90	0	3.42	- 3.4	0.0	0.902	39766
120: Dec 90	2	2.58	- 0.6	0.8	0.941	16491

amount (varying ESP efficiency). Furthermore, it is possible that there exists a sink that deactivates or scours IN from the air downwind of Exshaw. This may be manifest simply as deactivation through particulate coagulation, as noted in steel mill plumes in Australia (Telford, 1960) and in cement effluent in the former Soviet Union (Vdovin *et al.,* 1974), or as aggravated particulate settling due to mesoscale phenomena (i.e., subsidence over Ghost Lake, located 20 km east of Exshaw).

It is also possible that the source of IN was mis-identified during the original sampling flights, and that Continental Lime Ltd. or Baymag may contribute to the release. Murty and Murty (1974) noted that quicklime (CaO) also acted as a nucleating agent in laboratory tests, although they also noted that the nucleating effect decayed rapidly on wetting due to solution effects.

Planned further study will take the form of analyzing ESP dust samples for nucleating ability and collecting rain samples in Calgary in order to carry out an analysis for cement plant effluent. Such effluent has a distinctive mineralogical signature (Arslan and Boybay, 1990) and downwind samples should be distinguishable from natural dust on the basis of the mineralogical "fingerprint" determined from ESP dust samples provided by Lafarge.

9. ACKNOWLEDGEMENTS

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