The same parameters given in Table 8 are also provided in Table 9, but specifically for those days on which hail was reported. During the 2013 season, hail was observed or detected by radar on 65 of the 107 project days, or 61% of all days. Comparison of Tables 8 and 9 reveals what one would expect: hail is more common when moisture (precipitable water) is greater, when stability is less (Lifted Index), and when convective available potential energy, or CAPE, is greater. This is not surprising. One interesting note is that though a CDC of +5 was never forecast in 2013, two +5 days occurred. The forecasting for the season is examined in greater detail in the following section.

Table 9. Summary of Daily Atmospheric Parameters for Hail Days.

	Hail Days (65)			
Parameter	Average	StdDev	Maximum	Minimum
Forecast Convective Day Category	+2.1	1.1	+4	-2
Precipitable Water (inches)	0.8	0.2	1.2	0.5
0°C Level (kft)	11.4	1.6	14.2	8.3
-5°C Level (kft)	13.9	1.6	17.1	10.7
-10°C Level (kft)	16.4	1.8	19.8	10.9
Cloud Base Height (kft)	7.9	1.2	10.6	5.6
Cloud Base Temp (°C)	7.8	2.9	12.6	0.8
Maximum Cloud Top Height (kft)	33.4	6.1	41.0	13.8
Temp. Maximum (°C)	21.1	3.7	28.0	13.0
Dew Point (°C)	11.3	2.7	16.5	5.0
Convective Temp (°C)	20.4	4.4	29.5	10.0
Conv. Available Potential Energy (J/kg)	914.8	498.7	2255.0	0
Total Totals	54.1	2.2	58.1	45.0
Lifted Index	-3.3	1.5	0.9	-6.2
Showalter Index	-2.3	1.5	1.5	-5.8
Cell Direction (deg)	255	67.3	355	19
Cell Speed (knots)	20.3	8.8	39.0	1.0
Storm Direction (deg)	266	79.8	355	5
Storm Speed (knots)	13.6	5.8	29.0	1.0
Low Level Wind Direction (deg)	240	85.3	350	0
Low Level Wind Speed (knots)	14.3	6.4	27.0	0
Mid-Level Wind Direction (deg)	252	63.6	335	17
Mid-Level Wind Speed (knots)	25.3	11.5	59.0	1.0
High Level Wind Direction (deg)	235	70.0	300	20
High Level Wind Speed (knots)	43.5	22.9	107.0	5.0
Observed CDC	+2.4	1.0	+5	+1

Forecasting Performance

The following tables indicate the forecasting performance for the summer season with respect to the forecast and observed weather conditions as defined by the "Convective Day Category" or CDC within the project area. A CDC greater than zero indicates hail. The forecasts were verified by the weather observations as reported by Environment Canada, crop insurance reports received from the Agriculture Financial Services Corporation in Lacombe, and also by public reports of hail in the press, radio, and television, as well as by the reports from project personnel. The Vertical Integrated Liquid (VIL) radar parameter was also used as a verification tool, but secondary to actual hail reports. The CDCs forecast compared to those actually observed in 2013 are summarized in Table 10.

Table 10. Comparison of Forecast & Observed CDCs.

		Observed Days		
		No Hail	Hail	Totals
Forecast Days	No Hail	28 [26%]	2 [2%]	30 [28%]
	Hail	14 [13%]	63 [59%]	77 [72%]
	Totals	42 [39%]	65 [61%]	107

Hail fell within the project area on 65 of 107 days (61%), leaving 42 days without hail (39%). The forecast was correct in forecasting "no-hail" on 28 of 42 observed no-hail days (67%) but more importantly, correctly forecast "hail" days on 63 of 65 days (97%). The forecast failed to correctly predict hail on just two of the 65 hail days (3%) and incorrectly forecast hail (false alarms) on 14 of the 42 days when no-hail was observed (33%), thus the successful prediction of hail was with minimal cost. Overall, the WMI meteorologists did an excellent job with forecasting large hail this year.

The Heidke Skill Score (HSS) for WMI this past year (from Table 11) was 0.66, down very slightly from 0.68 in 2012. The HSS varies from –1 for no skill to +1 for perfect forecasts. The forecasting skill is considered significant if HSS is greater than 0.4, which was greatly exceeded in 2013.

Table 11. Probability of Detection (POD), False Alarm Ratio (FAR), Heidke Skill Score (HSS) and Critical Success Index (CSI) performance of Hailcast and WMI from 2002 to 2013.

	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002
POD (Hailcast)	.89	.75	.72	.77	.91	.80	.82	.69	.84	.91	.76	.81
POD (WMI)	.97	.98	.85	.85	.83	.68	.76	.69	.61	.60	.86	.83
FAR (Hailcast)	.15	.22	.21	.31	.29	.35	.30	.31	.45	.47	.56	.34
FAR (WMI)	.18	.23	.13	.14	.13	.20	.11	.14	.18	.30	.16	.33
HSS (Hailcast)	.66	.51	.49	.46	.44	.43	.46	.35	.31	.39	.33	.56
HSS (WMI)	.67	.68	.65	.72	.63	.49	.66	.55	.42	.51	.63	.59
CSI (Hailcast)	.77	.62	.64	.56	.45	.52	.50	.42	.40	.51	.39	.57
CSI (WMI)	.80	.76	.75	.73	.56	.52	.62	.53	.42	.49	.59	.59

The Critical Success Index (CSI) is the ratio of the successful hail forecasts divided by the sum of all hail forecasts plus the busts. The CSI does not incorporate the null event (no-hail forecast and no-hail observed), and is also a popular measure of the skill of forecasts. The CSI for WMI this past season was 0.80, compared to 0.76 for 2012.

Comparisons of the CDCs that were forecast and observed on a daily basis are made in Table 12. The exact forecast weather type (CDC) was observed on 45 of 107 days or 42% of the time. The forecast was correct to within one CDC category on 85 days or 79% of the time. There were only two days when, according to the radar-estimated VIL, grape size hail fell and hail was not forecast.

Overall the WMI forecasters and Hailcast displayed considerable skill in forecasting large hail since all 22 days with walnut or larger size hail were correctly forecast to produce large hail. There were no "surprise storms" this season.

Table 12. Forecast vs. Observed CDC Daily Values - 2013

Green shading indicates that the forecast and observed CDCs were the same (perfect forecasts).
Gray shading indicates that the observed CDC was greater than those forecast (underforecasts).
Blue shading indicates that the observed CDCs were less than those forecast (overforecasts).

Observed Convective Day Category (CDC) 2013

Forecast CDC	-3	-2	-1	0	1	2	3	4	5	
-3	10									10
-2	2	1	1	1		1				6
-1	3	2	1							6
0		2	1	4		1				8
1	1	1	3	3	4	11	1			24
2				3	4	17	4			28
3	1			1	1	3	5	7		18
4		1				1		3	2	7
5									0	0
	17	*7*	*6*	*12*	*9*	*34*	*10*	*10*	*2*	107

Percent correct exact CDC category = 45/107 = 42% (38% in 2012)
Percent correct within one CDC category = 85/107 = 79% (76% in 2012)

Table 13. Seasonal Summary for 2013 of Observed Convective Day Categories (CDCs).

	Days With No Seeding				Days with Hail (maximum hail size)					
	Mostly Clear Skies	Clouds, Virga	Showers	Thunder But No Hail	Pea	Grape	Walnut	Golf Ball	> Golf Ball	
Season	CDC -3	CDC -2	CDC -1	CDC 0	CDC +1	CDC +2	CDC +3	CDC +4	CDC +5	TOTAL
1996	27	21	12	11	5	12	3	1	1	93
1997	7	19	6	28	19	11	3	0	0	93
1998	14	24	2	29	23	8	2	4	1	107
1999	21	18	8	24	22	10	2	1	1	107
2000	13	21	8	26	18	9	2	9	1	107
2001	20	4	19	18	19	18	5	4	0	107
2002	27	8	20	16	15	17	3	1	0	107
2003	24	7	20	28	8	12	2	5	1	107
2004	11	4	28	29	15	11	3	5	1	107
2005	13	13	22	28	17	9	1	2	2	107
2006	19	14	15	24	19	5	6	3	2	107
2007	15	17	15	26	17	8	5	2	2	107
2008	15	7	10	34	17	15	2	6	1	107
2009	22	11	10	41	15	2	3	2	1	107
2010	3	10	9	37	11	27	8	1	1	107
2011	15	5	14	8	7	22	20	15	1	107
2012	8	7	22	14	4	16	12	22	2	107
2013	17	7	6	12	9	34	10	10	2	107
TOTALS	291	217	246	433	260	246	92	93	20	1898
Average	16	12	14	24	14	14	5	5	1	
Maximum	27	24	28	41	23	34	20	22	2	
Minimum	3	4	2	8	4	2	1	0	0	

The breakdown of CDC values for each of the past 16 seasons is shown in Table 13. This year again had an above average number of large (walnut or larger) hail days (22 in 2013, 11 is average), and above average number of thunderstorm days (77 in 2013, 63 is average). Golf ball or larger hail fell on 12 days in 2013; the average is 6 days.

For Table 13 and the other tabulations in this report, the "observed CDC" is taken to be the greater of the hail sizes reported by Environment Canada, and the Agricultural Financial Services in Lacombe, or the hail sizes estimated from the vertically-integrated liquid (VIL) measured by the project radar.

In general, Alberta had a near normal summer temperature-wise. Spring and summer were active until the latter half of August, when activity diminished sharply. Until then, thunderstorms were frequent, and many tended to be severe and produce larger hail than the historical average for the previous 15 years.

The Hailcast Model

The Hailcast model (Brimelow, 1999, Brimelow *et al.,* 2006) was again used this summer to objectively forecast the maximum hail size over the project area. Hailcast consists of two components, namely a steady-state one-dimensional cloud model and a 1-dimensional, time dependent hail model with detailed microphysics. The reader is referred to Brimelow (1999) for a detailed explanation of the model.

Forecast soundings for Red Deer and Calgary were downloaded daily from the Storm Machine website. A decision tree scheme was used to determine whether or not the soundings should be used to initialize the model. The decision tree is based on the work of Mills and Colquhoun (1998). The Hailcast model was not run if the atmospheric profile showed significant inhibition at 700 mb (approximately 10,000 feet) or warming greater than 1°C aloft during the day. Table 11 shows the Hailcast Forecast versus Observed table of Daily CDC values for the period June 1st to September 15th 2013.

The performance of the HAILCAST model in 2013 was good. The probability of detection (POD) of hail events was 0.89, but not as high as the WMI forecaster (0.97). The false alarm ratio (FAR) for HAILCAST in 2013 was 0.15, while for the WMI forecasters it was 0.18, both improvements over 2012.

The Heidke Skill Score (HSS) for Hailcast was 0.66 due to the false-alarms, well above the value of 0.4 which is generally considered to be the threshold level of skill. The Critical Success Index (CSI) for Hailcast was .77, minimally less than the .80 for the WMI forecasters. These results demonstrate that while Hailcast is a useful tool it has weaknesses similar to many models and the results need to be interpreted within the context of the overall meteorological situation, taking into consideration other synoptic, mesoscale, and dynamic aspects that are not included in the one-dimensional model. One must also keep in mind that the input to Hailcast was routinely the 12-hour prognostic soundings of the WRF model. It is important to look at the full 24 hours of forecast soundings to use as input for Hailcast. Further research into the refinement of the Hailcast decision tree remains warranted, and of course, due care must be taken to input the proper sounding.

12.0 Communications

Reliable communications for all project personnel and managers is essential for smooth and effective operations. These communications take place on a number of levels, with mixed urgencies. Real-time information-sharing and operational decision-making require immediate receipt of messages so appropriate actions can be taken. Time is of the essence. Routine daily activities such as completion of project paperwork and reports manifest less urgency, but still require due short-term attention. There are also project matters of importance on a weekly (or longer) time frame; these can be handled still more casually.

In the current age of widespread cellular telephone usage and coverage, mobile telephones have proven to be the most dependable means for project communications. Other real-time, project-essential communications occur between the Operations Centre and project aircraft; these are accomplished by voice radio transmissions. Aircraft positions and seeding actions are communicated to the Operations Centre via data radio.

For intra-project communications, all project personnel have cellular telephones. Pilots, who were on-call and have flexible hours, always carried their mobile phones, and kept them well-charged and turned on. Meteorological staff did likewise, but because of their more structured hours and location (primarily the Operations Centre) were more reliably contactable via land (telephone) lines.

Internet Access

High-speed internet access was established at the airport offices for the flight crews based in Springbank and Red Deer. Such access ensured real-time awareness of storm evolution and motion prior to launches, while giving the pilots better knowledge of the storm situation they would encounter once launched.

Use of E-Mail and Text Messages

E-mail and text messaging were discouraged when immediate receipt of information was essential because the sender would not know with certainty if/when the recipient had received or would receive the message. Both were acceptable for non-urgent situations; however in that context e-mail was preferred whenever any record of the message content and/or timeliness is needed. The on-site program manager routinely sent blanket text message notifications of aircraft launches to all project field personnel, so everybody knew when operations commenced, and which aircraft was (were) flying.

Weather Radios

In 2010, WMI added alarm-equipped weather radios at the residences of project personnel in Calgary and Red Deer to heighten the awareness of thunderstorms within the province as a whole. These radios sound an alert tone whenever Environment Canada issues a warning. The radios were added as a precautionary measure to further ensure awareness of such warnings when personnel were not at their duty stations (respective airports or the radar). Since that inaugural season the weather radios have proven to be of little use, as crews have generally been either flying or at their respective airports awaiting launch when the warnings were issued. Such was the case in 2013.

13.0 Case Study

A detailed review and summary of the largest event of the 2013 season is provided below. The recapitulation reveals the sequence of events in dealing with the storm: when various aircraft were dispatched to respond to the developing threats, how the storms evolved and where they moved, when seeding began and ended by each aircraft, and how (in a general sense) the storms responded to treatment.

20 July 2013 Case Study: Twin Supercells over Red Deer and Lacombe

Weather Synopsis and Forecast

The daily forecast for July 20th called for severe hailstorms during the evening hours. The Convective Day Category was +4 indicating golf ball size hail was possible within the project area. The Hailcast model predicted 3.9 cm (diameter) hail over Red Deer. Morning forecast model output indicated ample moisture at all levels with expected surface dew points around 14°C in Red Deer (Figure 32).

Fig. 32. The 850 mb Theta-E analysis 6 PM MDT on 20 July 2013. The "hotter" (reds and oranges) indicate the presence of moisture-rich low level air, fuel for potentially severe storms.

Model soundings for Red Deer were highly unstable during the afternoon and evening with a CAPE of 1880 J/kg, and a Lifted Index of -5.9°C expected at 6 pm (Figure 33). Surface winds were expected to be from the southeast. The model soundings also indicated a modest cap which would inhibit storm growth until the midafternoon hours. The convective temperature was 23.6°C with a forecast high temperature of 26°C. Convective inhibition (stability) was expected to erode completely by late afternoon.

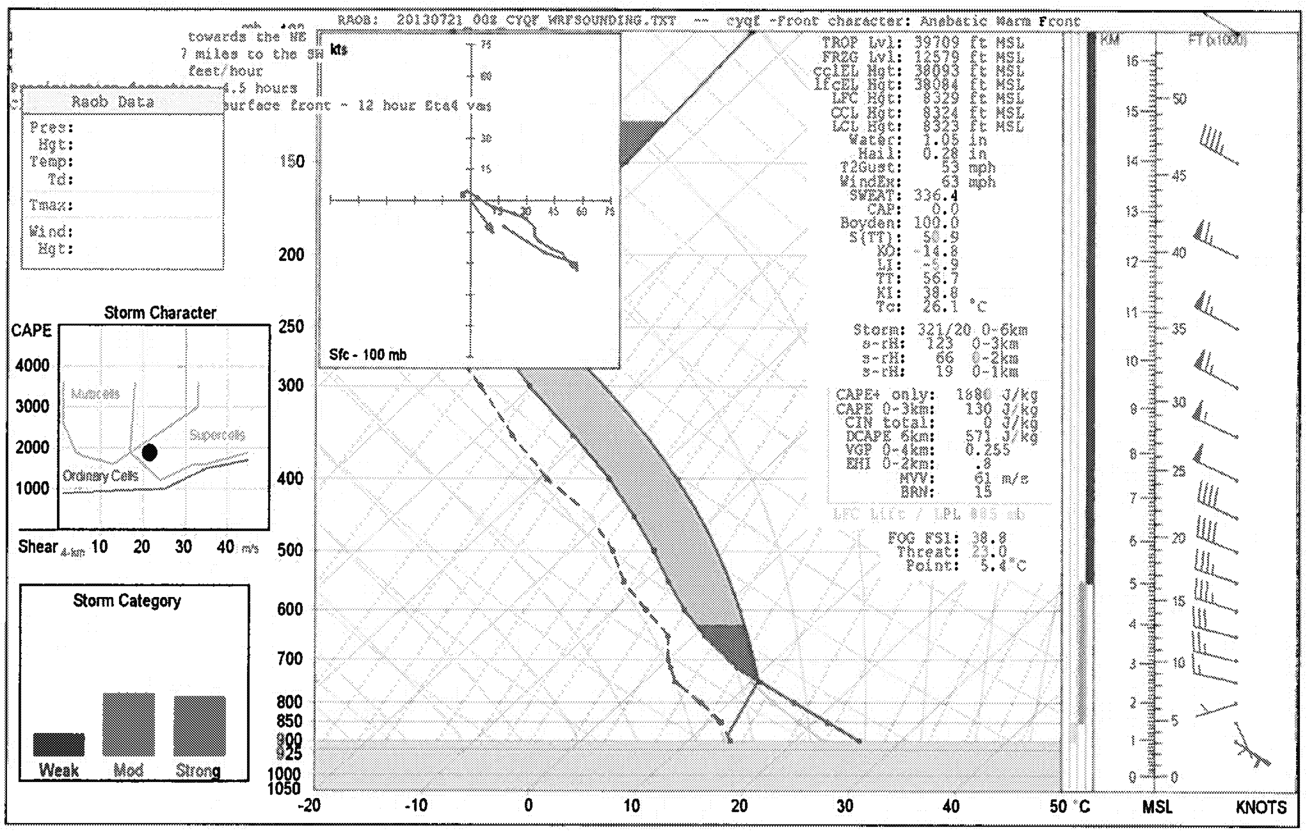

Fig. 33. Modified Skew-T WRF model sounding, plotted for Red Deer, valid at 6 PM MDT on 20 July 2013. The shaded pink and red area in the center depicts convective available potential energy, or CAPE, which when released, would drive strong storms.

An upper level jet streak (Figure 34) was nosing into the region from the northwest which provided highly sheared winds on the model sounding, favoring storm development. The best trigger for thunderstorm initiation was midlevel vorticity advection associated with the jet streak (Figure 35), prognosticated to clip the northern project area during the evening around 9 pm.

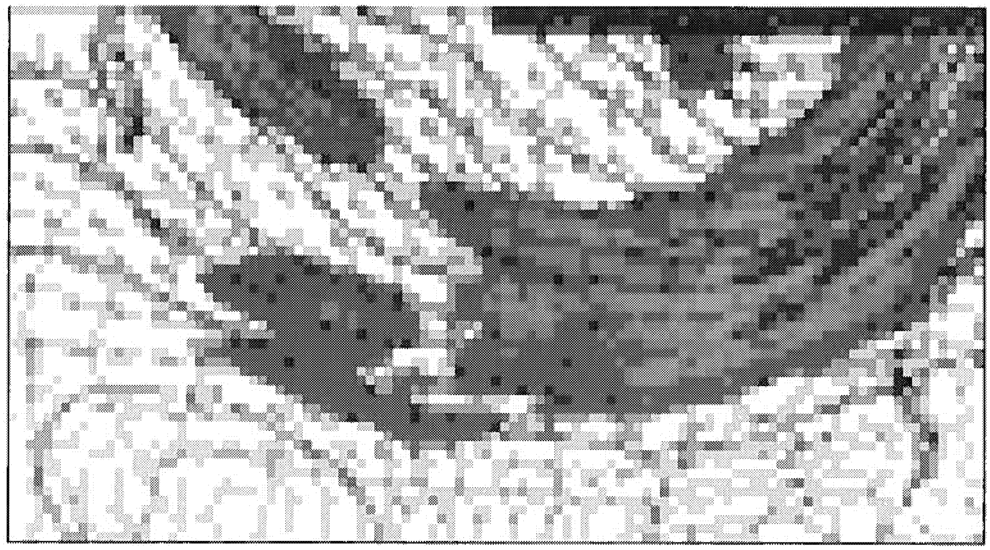

Fig. 34. The 250 mb jet stream winds at 5 PM MDT on 20 July 2013. The shaded areas mark regions of stronger winds at about 10.5 km altitude. Note the band of strong winds blowing from the northwest to southeast from BC into Alberta (upper left). Such winds can enhance upward motions in the atmosphere, strengthening storm updrafts, and thus increasing the potential for large hail.

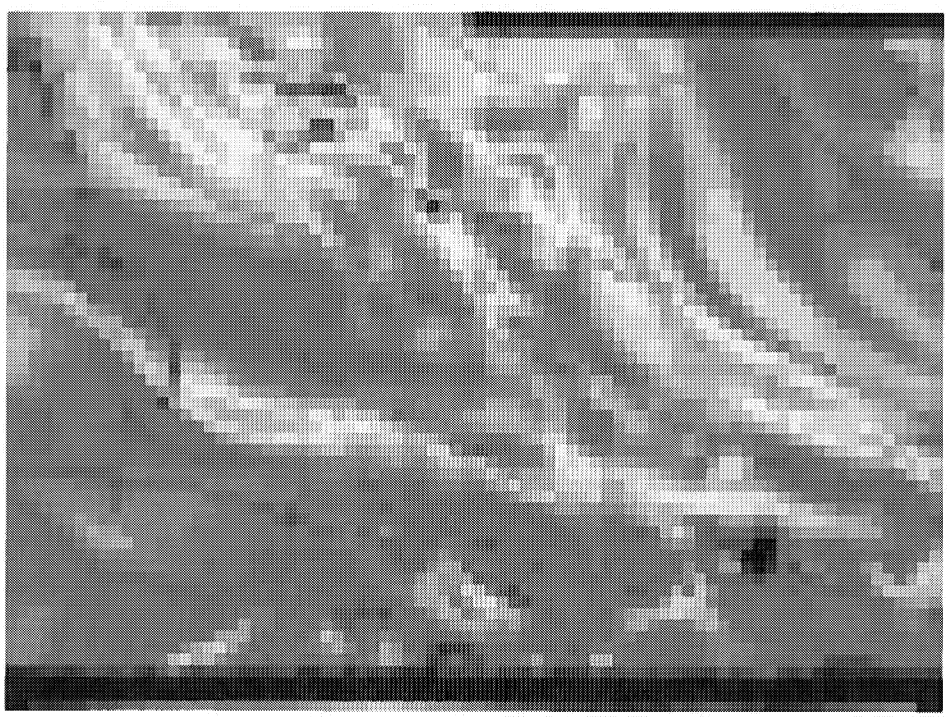

Fig. 35. The 500 mb vorticity plot at 6 PM MDT on 20 July 2013. The orange and red areas denote centres of cyclonic vorticity (spin) at about 5.5 km altitude in the atmosphere. Such spin induces lift in the atmosphere that can trigger and/or intensify storms. The black lines approximate the direction of the flow at that level.

Surface charts projected low pressure developing north of the project area during the evening, ahead of the vorticity. Associated with the surface low was a cold front which was forecast to push southward into the northern project area during the evening (Figure 36). The expected storm motion vector was from 320 degrees (toward the SE) at 20 knots.

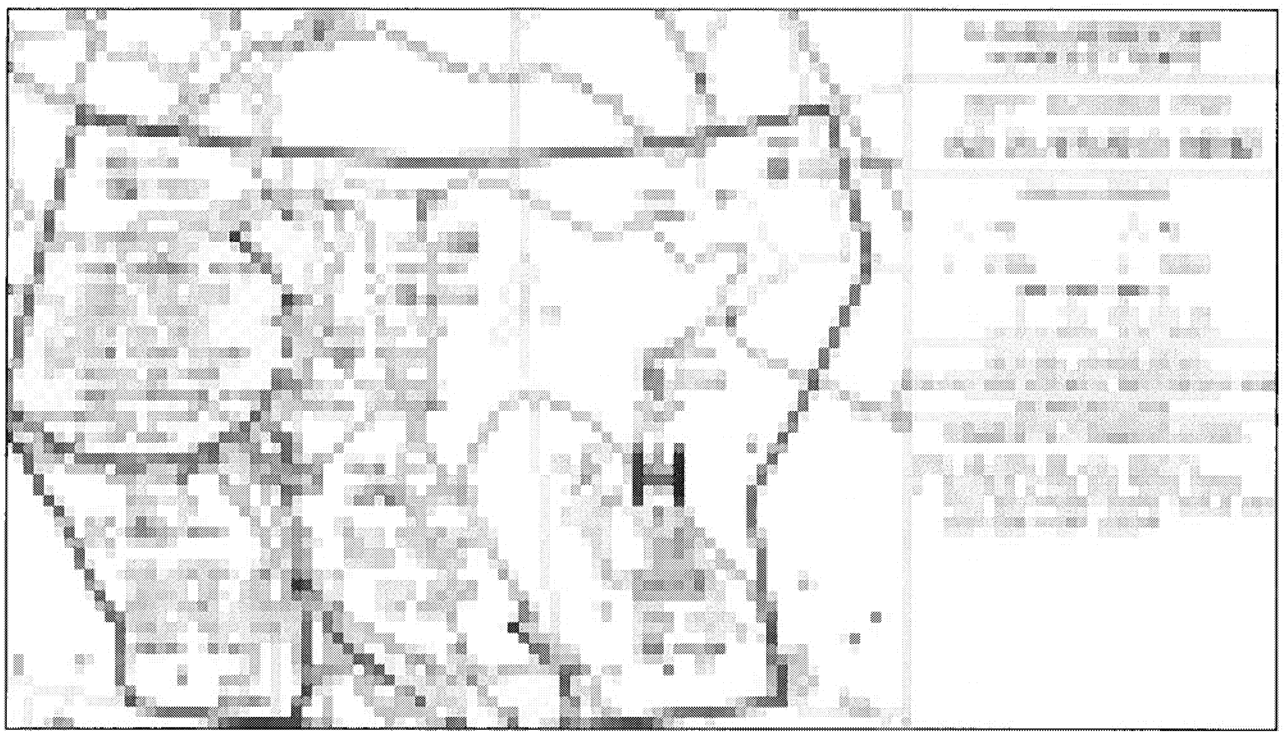

Fig. 36. The surface weather analysis and weather depiction for 6 PM MDT on 20 July 2013.

Chronology

With severe hail in the forecast, Hailstop 2, 3, and 4 (HS2 in Springbank, HS3 and HS4 in Red Deer) were at the airport on standby beginning at 2 pm. Severe thunderstorms moved into the far northern radar coverage area at 7:30 pm. These intense storms were tracking southeastward at 20 knots. HS2 (orange track) was launched from Springbank at 7:39 pm. Both Red Deer aircraft were launched shortly after that with HS4 (green track) launched at 7:59pm and HS3 (blue track) launched at 8:05 pm. HS5 (pink track) was called into the airport at this time and launched from Springbank at 8:24pm. Storm #1 was a severe supercell which would move directly through Lacombe. HS4 began base seeding storm #1 at 8:33 pm as it approached the northern buffer zone. HS4 utilized both wingtip generators and burn-in-place flares (BIPs), finding abundant inflow along a shelf cloud on the south to southwestern flank of the storm. HS3 climbed to cloud top and began top seeding with BIPs and ejectable flares (EJs) at 8:43 pm. Explosive growth and ample seeding targets were observed at cloud top. Storm positions, projected motions, and aircraft tracks at 8:44 PM (2:44 UTC) are shown in Figure 37(a).

HS2 joined HS4 at cloud base at 8:49 pm and began base seeding with wingtip generators and BIPs. All three aircraft continued seeding the supercell as it moved into Lacombe.

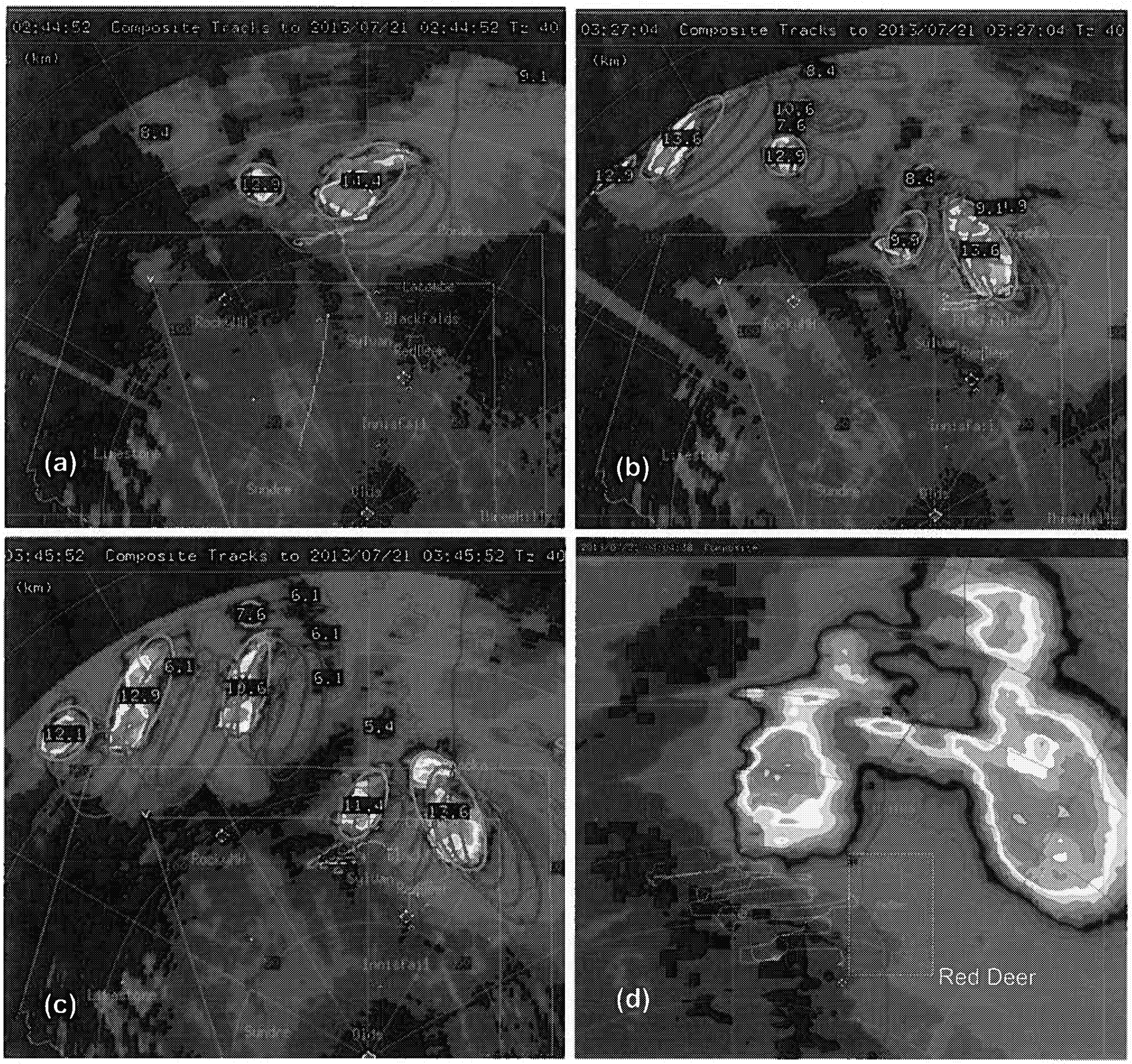

Fig. 37. The storm evolution of 20 July 2013 is shown by data recorded by the Olds Radar at 8:44 (a), 9:27 (b), 9:45 (c), and 10:04 (d). The red ovals shown in (a), (b), and (c) are the projected storm positions at 10 minute intervals from the current times. The flight tracks are as described in the text for each aircraft. The radar detects primarily precipitation-size particles, not developing clouds, so plots reveal flight tracks relative to precipitation, not visible (developing but not yet precipitating) cloud mass.

While storm #1 was being seeded near Lacombe, a second developing cell (storm #2) began to intensify 20 miles to the west near Rimbey, and tracking toward Red Deer. At 9:25 pm, HS5 began top seeding storm #2 in the buffer zone utilizing BIPs and EJs. At 9:34 pm, storm #1 had moved through Lacombe so base seeding aircraft were diverted toward storm #2. HS3 landed in Red Deer to replenish flares and fuel at this time. HS4 repositioned at 9:34 pm and began base seeding storm #2 at 9:40 pm near Blackfalds along an inflow shelf on the south flank of the cell. HS2 was repositioned at 9:39 pm and began base seeding storm #2 at 9:44 pm along with HS4. All three seeding planes continued seeding aggressively until the storm moved through Red Deer. At 10:42 pm, storm #2 had moved through Red Deer as an intense supercell. Seeding of storm #2 ended at this time, and all aircraft either returned to base or were diverted to another marginal hailstorm inside the project area southeast of Rocky Mountain House.

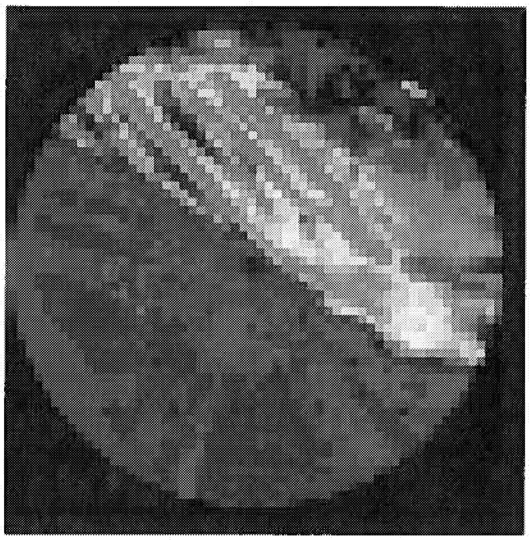

Fig. 38. The plot of maximum radar reflectivity reveals the locations of the most intense portions of the July 20th storms. The tracks of the storms through Lacombe and Red Deer are easily discerned.

Hailstop 1: HS1 flew one seeding flight. They were airborne at 10:05pm and seeded storm #3 (Rocky Mountain House to Innisfail) from both top and base during the course of the flight. The flight landed at 11:58pm. During the course of the 1 hour 53 minute flight, they dispensed 3,850 grams of seeding material. However, they were not involved with seeding the two most severe threatening storms of the day which were over Lacombe and Red Deer. The availability of the new fifth seeding aircraft this season meant that there were enough resources available for seeding to occur on the less severe hail storms on this day. Without the fifth aircraft available, HS1 would not have been able to seed storm #3. It would have likely gone unseeded until it was nearly on top of Innisfail.

Hailstop 2: HS2 flew one seeding flight. They were airborne at 8:13pm. They base seeded three storms including #1 Lacombe, #2 Red Deer, and #4 Sylvan. They landed at 11:27pm. Storm #1 (Lacombe) was seeded with 12 BIPs (1,800 grams) and 122 minutes generators (349 grams). Storm #2 (Red Deer) was seeded with 12 BIPS (1,800 grams) and 86 minutes generator time (246 grams). The weaker storm #4 was seeded with only 24 minutes of generator time (no BIPs). HS2 utilized 24 burn-in-place flares in total and ran wingtip generators for a combined 232 minutes. During the 3 hour 14 minute flight, they released a total of 4,263 grams of seeding material.

Hailstop 3: HS3 flew two seeding flights. The first flight was airborne at 8:29pm and landed at 9:47pm. They top seeded storm #1 (Lacombe) on this flight. During the course of the 1 hour 18 minute flight near Lacombe, they dispensed 3,050 grams of seeding material in the form of 145 EJs (2,900 grams) and 1 BIP (150 grams). HS3 then flew a second seeding flight over the Sylvan and Innisfail areas seeding storms #3 and #4. This second flight was airborne at 10:10pm and landed at 11:40pm. During the course of this 1 hour 30 minute flight, HS3 dispensed 4670 grams of material in the form of 196 EJs (3,920 grams) and 5 BIPs (750 grams). On the day, HS3 released a total of 7,720 grams. There were no AirLink tracks recorded for the second flight due to pilot error.

Hailstop 4: HS4 flew one seeding flight. HS4 was airborne from Red Deer at 8:18pm. They base seeded a total of two storms including #1 Lacombe and #2 Red Deer. They landed at 11:00pm at Olds-Didsbury. Storm #1 (Lacombe) was seeded with 8 BIPs (1,200 grams) and 122 minutes generators (348 grams). Storm #2 (Red Deer) was seeded with 10 BIPs (1500 grams) and 138 minutes combined generator time (394 grams) during the 2 hour 42 minute flight. They released a total of 3,443 grams of seeding material during the entire flight.

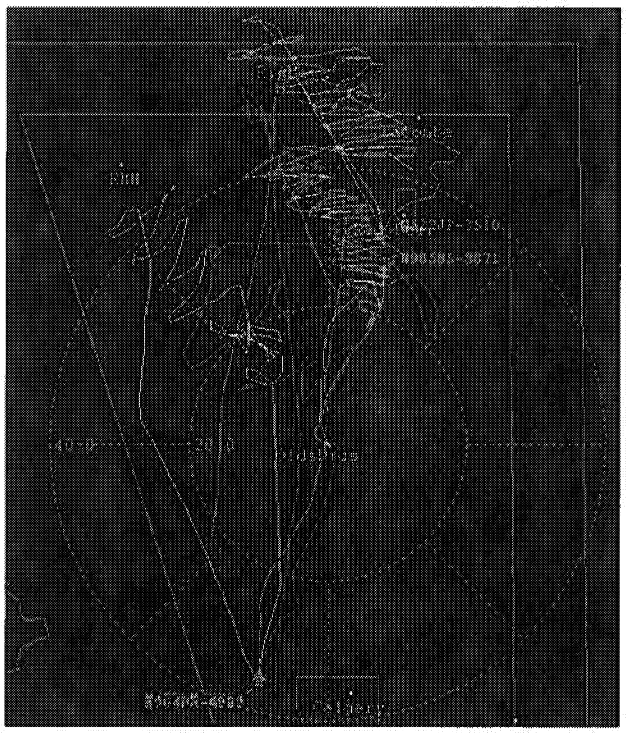

Fig. 39. The AirLink aircraft seeding tracks for entire storm day of 20 July 2013 are plotted. Track colors: **HS1, white**; HS2, orange; HS3, light blue; HS4, green; and HS5, pink.

Hailstop 5: HS5 flew one seeding flight. They were airborne at 8:50pm and landed at 12:01am. HS5 was the top seeder for storm #2 over Red Deer. The crew included WMI's Chief Pilot. During the course of this 3 hour 11 minute flight, HS5 dispensed a total of 8,720 grams of seeding material in the form of 301 EJs (6,020 grams) and 18 BIPs (2,700 grams). All of the 301 EJs were utilized on storm #2 for Red Deer along with 13 BIPs. HS2 top seeded the Red Deer storm with 7,970 grams of material. They also base seeded storm #3 with 5 BIPs (750 grams). The seeding of the four storms on the evening of July 20th are summarized in Table 14.

Table 14. Seeding agent by Targeted Storms, 20 July 2013.

	Storm #1 Lacombe	Storm #2 Red Deer	Storm #3 & #4
HS 1 EJ grams	0	0	1,900
HS1 BIP grams	0	0	1,950
HS2 Gen grams	349	246	69
HS2 BIP grams	1,800	1,800	0
HS3 EJ grams	2,900	0	3,920
HS3 BIP	150	0	750
HS4 Gen grams	349	394	0
HS4 BIP grams	1,200	1,500	0
HS5 EJ grams	0	6,020	0
HS5 BIP grams	0	1,950	750
Total grams	6,747	11,910	9,339

EJ = ejectable flare
BIP = burn-in-place flare
Gen = wingtip generators (two per aircraft)

Conclusions

Storms #1 affected Lacombe, and #2, Red Deer. Also seeded were the weaker storms #3 and #4 which were less threatening and impacted cities such as Sylvan, Rocky Mountain House, and Innisfail. During the course of the entire storm day, 27,996 grams of AgI seeding material was released in the form of 737 ejectable flares (20-gram EJs), 79 burn-in-place flares (150 gram BIPs), and 492 minutes of wingtip generator time (2.858 grams AgI per minute). Storm #1 (Lacombe) was seeded with 6,747 total grams. The most damaging storm was storm #2 (Red Deer) seeded with 11,910 total grams which included 301 EJs, 35 BIPs, and 224 minutes of wingtip generator time. By comparison, the August 12, 2012 Calgary hailstorm was seeded with 26,455 grams which included 584 EJs, 90 BIPs, and 446 minutes of wingtip generator time.

The WMI AirLink aircraft tracks show the storms that moved through Lacombe and Red Deer were well seeded with consistant passes well upwind of the protected cities. The onset of seeding occurred at the appropriate time for seeding effects in the protected cities. Also note seeding tracks for HS1 (white tracks) from Rocky Mountain House to near Innisfail. While this hailstorm (#3 of the day) was weaker and only threatened lower priority cities, it was still able to be seeded since there were five seeding aircraft available this year. There were six storm days this season in which all five seeding aircraft were needed.

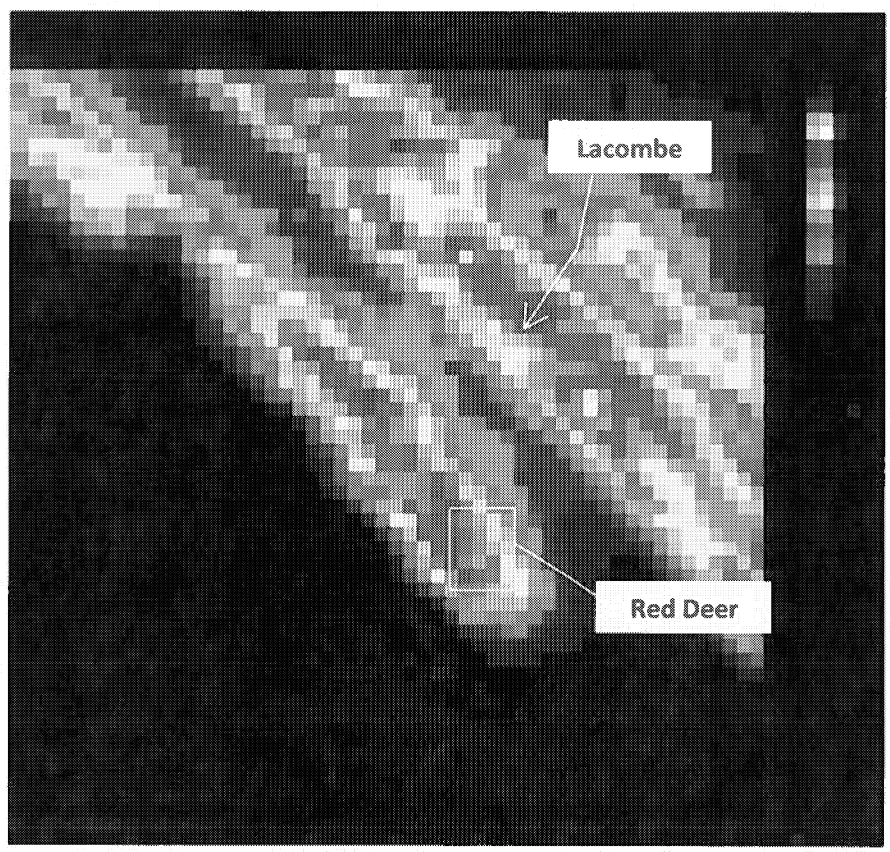

Fig. 40. The maximum vertically-integrated liquid (VIL), a radar parameter used to estimate hail size, is shown for the storms that passed through Lacombe and Red Deer. The VIL values decreased significantly after the onset of seeding upwind of Lacombe. VIL values slowly increased as storm #2 approached Red Deer. This is likely because the storm was still in its initial building phase. The unseeded part of storm #1 north of the buffer zone shows large cores of 100+ white VIL (golf ball or greater hail). All areas that were seeded in the buffer zone and inside the project area show mostly less than 100 VIL.

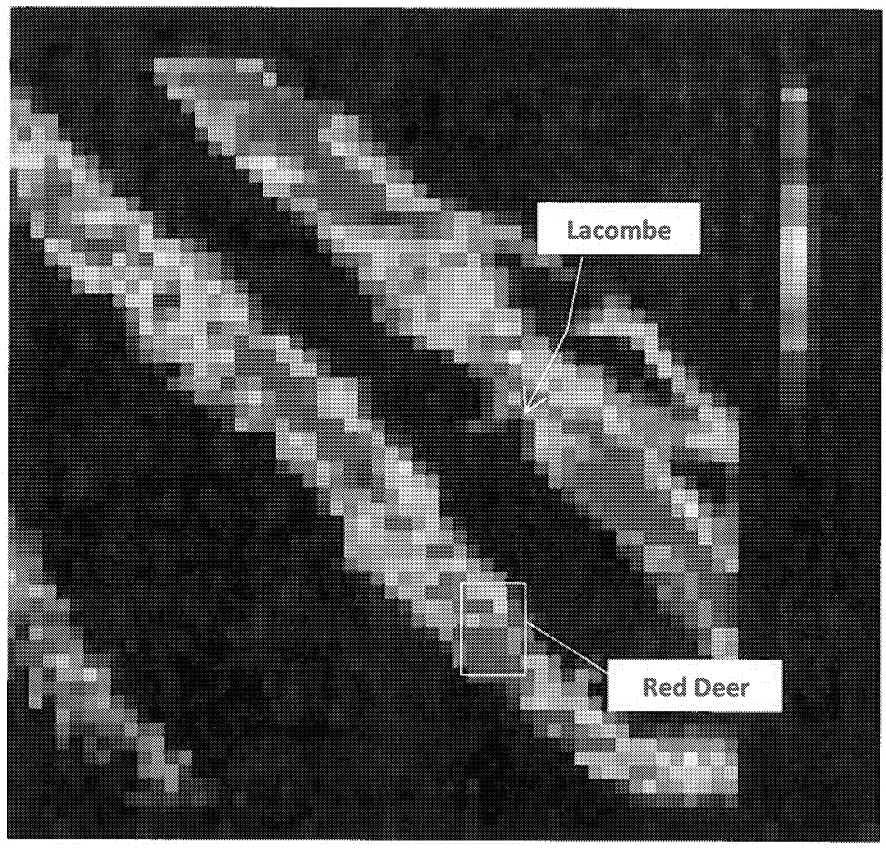

Fig. 41. The maximum hail mass flux radar parameter for the storms that passed through Lacombe and Red Deer on July 20th is shown. The parameter is used as a tool to estimate hail volume. Values appear to indicate lower values after the onset of seeding upwind of Lacombe and Red Deer. Values then increase again downwind of the protected cities after seeding has ended. While this could, of course, be attributed to natural variability in storm strength, it is certainly consistent with the desired effects of seeding.

July 20th was the most severe storm day of the 2013 season. Dr. Terry Krauss reported 3cm hail at his house in Red Deer. WMI pilot Joel Zimmer reported walnut size hail. The public reported marble size hail in western Red Deer, and the Weather Network posted pictures of a few stones slightly larger than golf balls which are believed to have fallen in Red Deer. The hail damage from these storms will likely add up to several hundred million dollars, but radar parameters indicate that it could have been worse.

14.0 Climate Perspectives

The daily and accumulated rainfall for Calgary and Red Deer from October 18, 2012 through October 17, 2013 are shown in Figures 42 and 43 respectively. Calgary was relatively dry until mid-May, while Red Deer received much earlier, in March and April. By project start in June both locations were more than 50 mm above normal.

Calgary finished the project (15 September) more than 100 mm above average, at about 120% of normal. Conditions became much drier in Red Deer in later August, and remained dry through October. Red Deer finished the season at about 60 mm below normal. It should be noted that operations diminished considerably by mid-August, and the last day on which seeding occurred was August 30th.

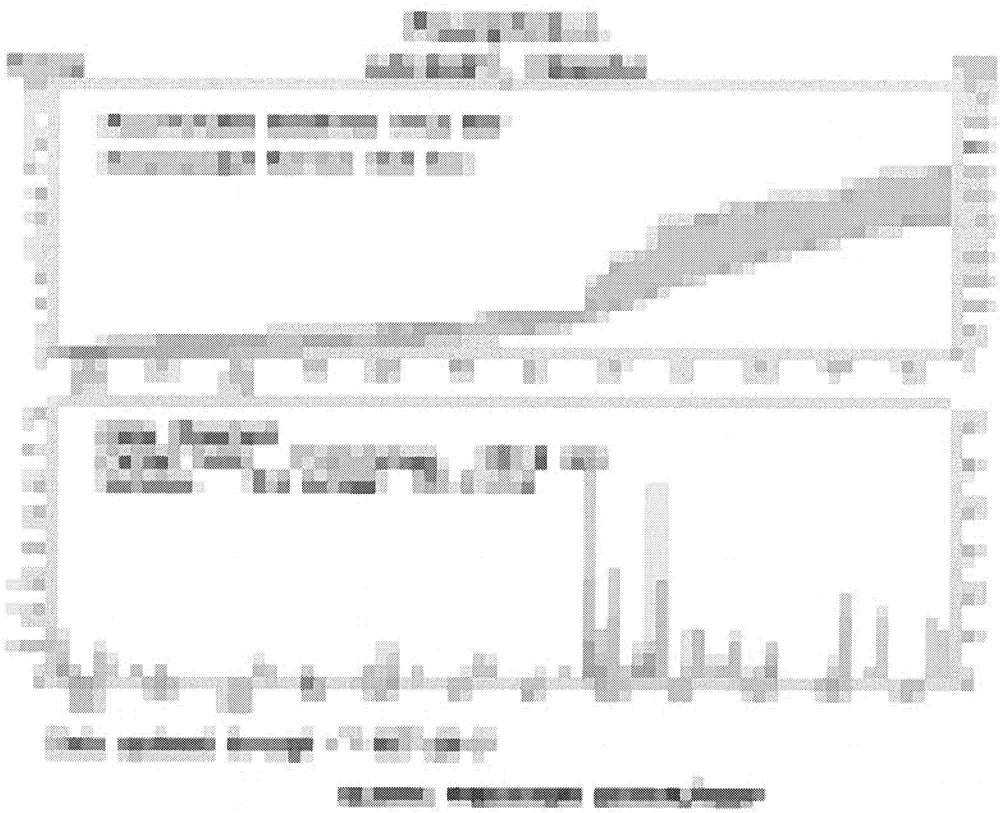

Fig. 42. Daily and accumulated rainfall for Calgary from October 18, 2012 through October 17, 2013.

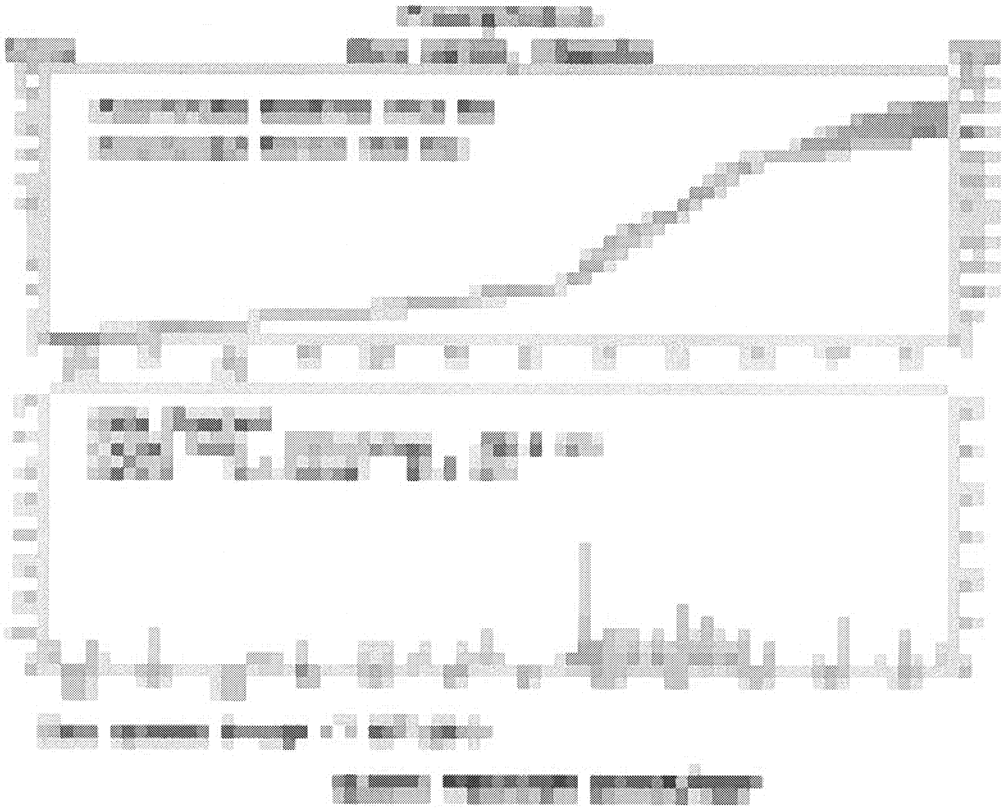

Fig. 43. Daily and accumulated rainfall for Red Deer from 18 October 2012 through 17 October 2013.

This report would normally include precipitation and temperature summary graphics for all of Canada, but these graphics are not yet available for the summer of 2013, and will not be until perhaps sometime in January 2014. The interested reader may wish to try the following web link, which we are told, will eventually have these graphics: http://ec.gc.ca//adsc-cmda/default.asp?lang=En&n=4A21B114-1.

Previous research (Krauss and Santos 2004) has suggested that the cloud seeding increases the rainfall; therefore, the increased rainfall around Calgary, compared with the surrounding area shown in Figure 36 is consistent with previous findings.

El Niño/Southern Oscillation (ENSO) Discussion

The links between sea surface temperatures in the equatorial Pacific Ocean and the weather and climate of Alberta are not clearly defined. However, there has been a slightly positive correlation between hot, dry summers and El Niño (warm ocean) conditions; and cool, wet, stormy summers with La Niña (cool ocean) conditions.

Equatorial Pacific Ocean sea surface temperature (SST) anomalies for the period November 2012 to October 2013 are shown in Figure 44, below http://www.cpc.ncep.noaa.gov/products/. The eastern Pacific averaged slightly cooler than average while the western Pacific was slightly warm. Average SST anomalies were mostly Niño neutral for the past year. The 2013 season was a change from the past two seasons. The winters of 2010-2011 and 2011-2012 saw La Niña (cool SST) episodes during the winter/spring months with subsequent transition (warming) to Niño neutral conditions through the summer months. Following these La Niña winters, the summers of both 2011 and 2012 saw similar well above average storm frequency and severity. The winter of 2012- 2013 was different from these previous two winters in that it had neutral ENSO SST conditions rather than La Niña. As ENSO conditions have changed, the summer storm season has also changed. The 2013 summer experienced far fewer severe hailstorms than the last two years, which is somewhat closer to climatological normal. During 2012 and 2011, radar indicated walnut or greater hail on 36 days for each season. The 2013 season had just 20 days with walnut or greater hail in the project area.

This discussion is a consolidated effort of the National Atmospheric and Oceanic Administration (NOAA), NOAA's National Weather Service, and their funded institutions. Oceanic and atmospheric conditions are updated weekly on the Climate Prediction Center web site (El Niño/La Niña Current Conditions and Expert Discussions).

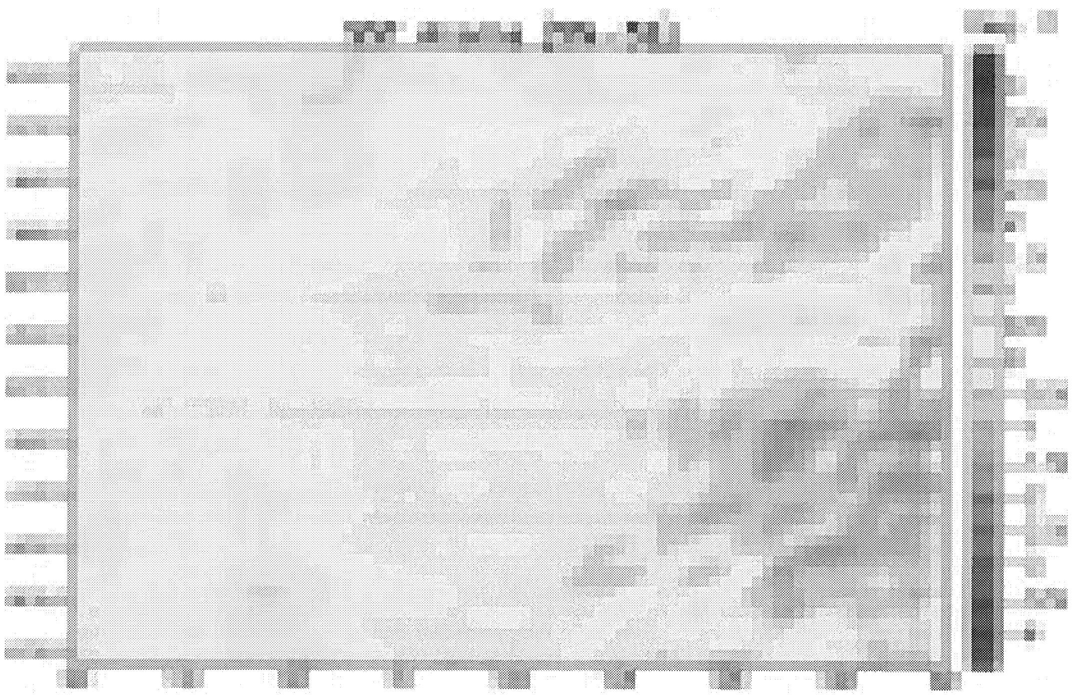

Fig. 44. Pacific Ocean sea surface temperature (SST) anomalies for the period November 2012 to October 2013. Source: http://www.cpc.ncep.noaa.gov.

15.0 Alberta Crop Hail Insurance Summary

Figure 45 shows the annual Loss-to-Risk ratios for the Province of Alberta as determined by the straight hail crop insurance statistics collected by the Alberta Financial Services Corporation in Lacombe, Alberta. These statistics are for the entire province of Alberta. The average loss-to-risk ratio for the period 1978 to 1995 (before this project began) is 4.4% and the average for the period 1996 to 2013 (the current project period) is 5.04%. In considering these numbers it is important to remember that the AHSP targets only those storms threatening cities and towns in the protected area. Thus, many storms, even those within the protected area but not posing threats to urban areas are not treated. When coupled with the large number of hailstorms that occur within Alberta but outside the protected area, this implies that the frequency of damaging hailstorms is increasing climatologically.

The crop-hail loss data are presented herein exactly for that reason, to provide a baseline of sorts as to the natural frequency of storms, and how that may be changing.

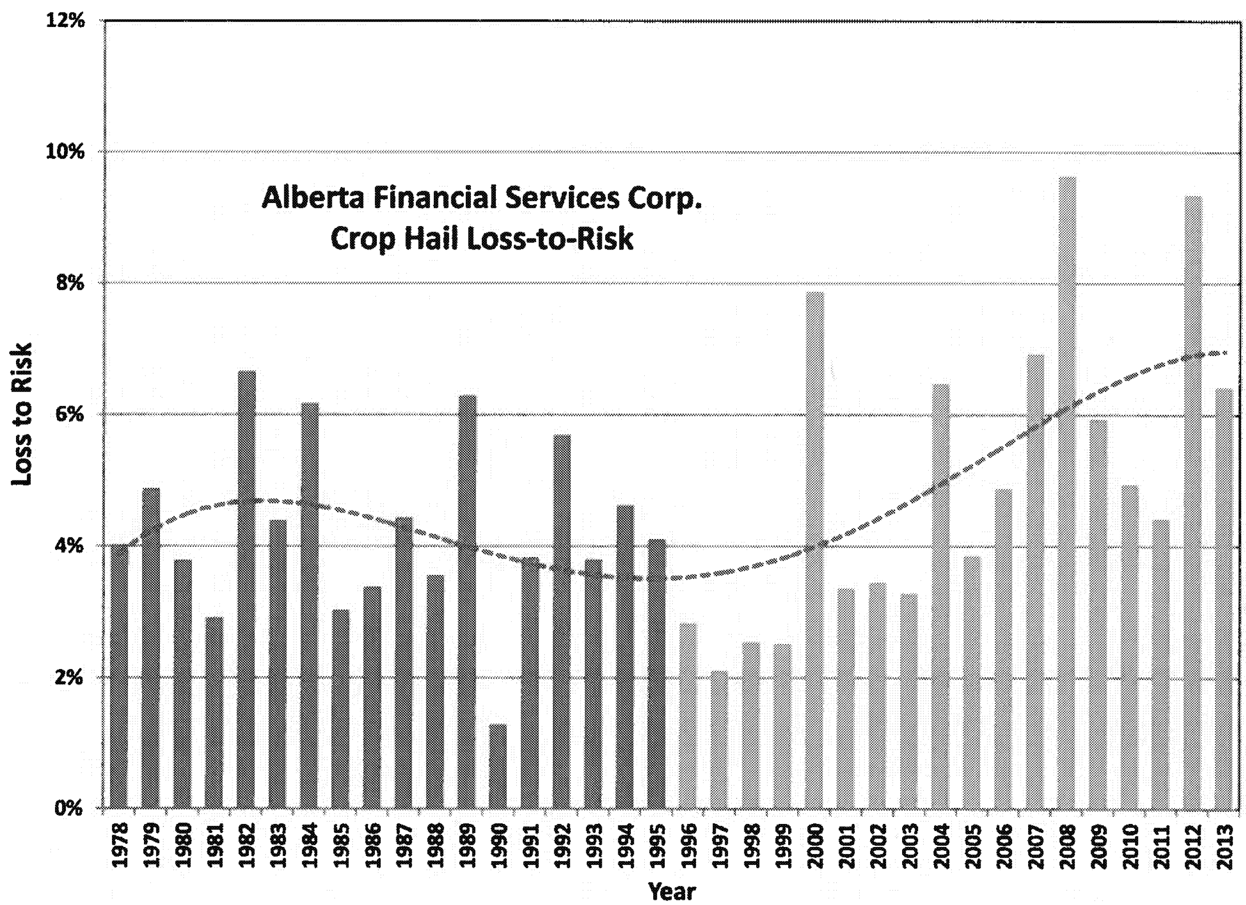

Fig. 45. Alberta Financial Services Corporation straight hail insurance loss-to-risk statistics for the entire Province of Alberta from 1978 through 2013.

Eight of the first ten years of the project period (1996-2005 inclusive) had below-average crop-hail damage in the province, and the hail damage during 2000 and 2004 appeared as spikes with above-average damage. However, the next 3 years experienced an exponential increase in crop-hail damage. Though followed by a decline in the following three years (2009-2011), all of those years are still well above the long-term climatological mean. In 2012, crop-hail losses spiked again, exceeding 9.3%. Losses in 2013 were 6.4%, not as severe as 2012, but still above the long-term average. These data indicate that the threat of damaging hail storms in Alberta has increased, especially over the past 8 years.

While the area planted each year to crops remains essentially unchanged, the amount of insurance purchased each growing season varies. This depends largely upon the crops planted and growing conditions (anticipated harvests). There has been no marked trend in the last decade in either the dollar amount of insurance sold, nor in the number of acres insured, so the observed trend is not due to either of these.

The property and casualty insurance industry is quite different, however. Each of the companies belonging to the ASWMS considers its premiums and losses to be confidential, and there at present exists no analog to the Alberta Agriculture Financial Services Corporation, so the changes in risk and losses are not known outside each company. However, it is widely acknowledged that with the population growth of southern Alberta has become significantly increased exposure to property. The Calgary metropolitan area has increased dramatically since the program began in 1996, and most other communities have followed suit. It stands to reason that the apparent increase in damaging hailstorms coupled with the dramatically increased urban area demonstrates the need for this program.

16.0 Project Suspension

The most notable weather event this summer was not a hailstorm, but rather flooding that occurred in Calgary and High River as a result of a quasi-stationary low pressure center that produced sustained upslope precipitation totaling more than 325 mm over the foothills west of Calgary between June 19th -22nd. No seeding was conducted during any part of this event, but the resulting high waters caused sufficient damage and a declared state of emergency, so project seeding was suspended for the entire project area until June 24th and for the most greatly impacted portions of the protected area until June 27th.

The severe flooding in Southern Alberta this June caused the ASWMS to formally adopt a policy for suspension of seeding activities. The suspension criteria follow the guidelines established by the Weather Modification Association (WMA). The specifics of the WMA statement can be found by visiting the following link: http://www.weathermodification.org/standards_ethics.php

The new ASWMS guidelines are as follows:

The following criteria and procedures for suspending operations in the face of impending severe weather to avoid contributing to, or appearing to contribute to, damaging weather situations shall be followed:

1. An emergency shutdown of seeding operations can be declared when there is a situation that poses an immediate threat to life and property. A logical criterion would be when a community is under a declared State of Emergency for flooding or tornado.

2. If the field meteorologist has any doubt about whether suspension criteria are met, he or she should order seeding stopped, and then contact the Project Director for clarification.

3. The Alberta Severe Weather Management Society policy of suspension of seeding during severe weather activity is strictly for reasons related to public perception and aircraft safety.

4. Resumption of normal seeding operations would be conditional on the emergency situation no longer posing a reasonable threat, such as a declared State of Emergency being lifted. However, if a storm forecast is of significant threat (3.3 cm diameter hail or greater), the Project Director has the authority to resume operations at any time.

17.0 Conclusions

The 2013 field program ran smoothly, without any significant equipment issues. All storms worthy of treatment were seeded in a timely way. The most significant storm of the season was the July 20th hailstorm that moved over Red Deer. A detailed storm summary of the Red Deer storm is included in the full final report. Even though a dozen storms were recorded over the Calgary metroplex, all were treated effectively; none are known to have produced significant damage.

The aging weather station at the operations centre was replaced, affording more reliable real-time data at that site, fully accessible via the internet.

The fifth aircraft, another twin-engine turboprop King Air C90, was a positive asset to the program. Though the storm frequency and severity was more normal in 2013 and significantly less than the two preceding seasons, all five aircraft flew operational flights on six days during the course of the summer. Having the fifth aircraft available allowed the project Lead Meteorologist to increase aircraft coverage when long-lived storms moved through or near a succession of municipalities, and to seed earlier and at a heavier rate when a severe storm threatened a high priority city or town. The additional aircraft allowed the highest average seeding rate per storm (3.33 kg per storm) in the history of the project.

Bruce Boe, Director of Meteorology
Jody Fischer, Project Manager, Chief Pilot
Daniel Gilbert, Chief Meteorologist, Alberta Lead Meteorologist
Hans Ahlness, Vice President of Operations
Bradley Waller, Field Meteorologist

December 2013

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NOTICE OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES
PURSUANT TO THE WEATHER MODIFICATION INFORMATION ACT AND REGULATIONS
SCHEDULE I

PART 1. GENERAL IDENTIFICATION OF ACTIVITY

Date of notice: May 14, 2014
Proposed starting date: June 1st, 2014
Expected duration: September 15th, 2014

Province and area to be affected: Central Alberta, covering the Red Deer to Calgary regions (see attached map showing project area which has remained the same since 1996).

Weather elements to be modified: Thunderstorms
Modification expected: Hail Suppression
Class of operation: Operational
Operating method: airborne
Class of economy to benefit: insurance industry: private and public property primary, agriculture secondary.

PART 2. GENERAL INFORMATION CONCERNING WEATHER MODIFIER

Organization name: Weather Modification Inc. (WMI)
http://www.weathermodification.com/
Parent Organization: Weather Modification Inc. (WMI)
3802 20th Street North
Fargo, ND USA 58102
Chief Officer: Mr. Patrick H. Sweeney, President Tel: (701) 235-5500
pat@weathermod.com
Local Organization: Weather Modification, Inc. Tel. (403) 335-8359
Olds-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

Name and relevant qualifications of officer(s) designated in charge of project:

Chief Officer: Mr. Daniel Gilbert, Chief Meteorologist
B.S., 11 years' experience
WMA Certified Weather Modification Operator #78
Office Tel: (403) 335-8359
(see Part 5 for details of qualifications and experience)

Director of Meteorology Mr. Bruce Boe
Project Manager/Meteorology, 40 years' experience
Tel: (701) 235-5500

Primary activities of organization (see web page at www.weathermodification.com):

- cloud seeding
- atmospheric research
- air pollution monitoring
- meteorological radar monitoring
- equipment design and fabrication
- aircraft modifications

Amount of public liability insurance carried applicable to activity: CAD$50 million by the Alberta Severe

Weather Management Society and US$5 million by Weather Modification, Inc.

List of similar weather modification activities previously undertaken:

a. Canada: The Alberta Hail Project has been operating in its present form since 1996. The contractor (operator) for this entire period has been WMI.

b. Elsewhere:
- WMI has conducted the hail suppression cloud seeding in North Dakota for more than 50 years. This is an ongoing project.
- WMI conducted hail suppression in Mendoza, Argentina using 3 to 4 Cheyenne II aircraft and a Lear Jet 1998-2004.
- WMI conducted operational cloud seeding in Oklahoma for Rain Enhancement and Hail Suppression 1997-2001.
- WMI has conducted operational cloud seeding in Alberta, Burkina Faso, California, California, Idaho, Mexico, UAE, India, Indonesia, Mali, Nevada, North Dakota, Saudi Arabia, Senegal, and Wyoming within the last 10 years.

4. References:

1. Dr. Terry Krauss
   Krauss Weather Services
   79 Irving Crescent
   Red Deer, AB T4R 3S3 Tel. 403-318-0400
2. Mr. Darin Langerud, Director
   State of North Dakota Atmospheric Resource Board
   900 E. Boulevard Ave.
   Bismarck, ND 58505 Tel. 701-328-2788
3. Mr. James Renick
   Alberta Severe Weather Management Society (ret.)
   11 Warwick Drive
   Red Deer, AB T4N 6L4 Tel. 403-347-1545
4. Dr. Paul L. Smith
   South Dakota School of Mines & Technology
   501 E. St. Joseph Street
   Rapid City, SD 57701-3995 Tel. 605-394-2291

List of subcontractors: WMI owns and operates its own fleet of aircraft and weather radars. No major sub-contractors are being used on the Alberta Hail project for aircraft or radar services.
Solution Blend Services, Calgary, Alberta (403) 207-9840 will be handling and mixing seeding solutions for the project.

PART 3. GENERAL INFORMATION CONCERNING ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED.

Name of organization: Alberta Severe Weather Management Society (ASWMS)

Chief officers: Mr. Todd Klapak, President
todd.klapak@intact.net
Ms. Catherine Janssen, Secretary-Treasurer
janssenc@telus.net

Nature of organization: A not-for-profit society of the property and casualty insurers and brokers operating in Alberta. The society was formed for the purpose of collecting funds from its members to operate a hail suppression program to help reduce insurance payout due to hail and stabilize insurance rates throughout the province.

PART 4. GENERAL INFORMATION CONCERNING FIELD BASES OF ACTIVITY

Address and location of project primary field base:
Olds-Didsbury Airport, Alberta. tel. 403-335-8359
Address(es) and locations(s) of project secondary field base(s):
- Springbank airport tel. 403-247-0001
- Red Deer industrial airport tel. 403-886-7857

PART 5. GENERAL INFORMATION CONCERNING OPERATING FIELD PERSONNEL

Name and title of field officer in charge: Mr. Daniel Gilbert, Chief Meteorologist
Old-Didsbury Airport, Highway 2A
Olds, AB T4H 1A1

tel. & fax. 403-335-8359,
e-mail: dgilbert@weathermodifcation.com
home page: http://www.weathermodification.com/

Qualifications of field officer in charge (Gilbert):

Education
Bachelor of Science, Meteorology and Environmental Studies (double major) May 2004, Iowa State University, Ames, IA
Associate of Arts, Liberal Arts, May 2000, Iowa Central Community College, Fort Dodge, IA

Weather Modification Experience
Chief Meteorologist, Weather Modification, Inc. (Wyoming and Alberta) - November 2009 to present
Forecaster, radar operator, rawinsondes, direction of seeding aircraft. Case declarations, wintertime (Wyoming) research program.
Meteorologist, RHS Consulting (Fresno, CA) – November 2008-February 2009
Directed airborne and ground based cloud seeding operations over portions of the central and southern Sierra Nevada Mountains. Set up and performed routine maintenance of ground based ice nucleus generators. Provided daily forecasts for clients and project personnel.
Meteorologist, Independent Contractor, (Boise, ID) – October 2007 to April 2008
Provided meteorological services to support Idaho Power Company's winter cloud seeding project in West Central Idaho, directed airborne and ground seeding operations, directed rawinsonde releases, provided short-term operational forecasts and nowcasts for pilots, communicated with aircraft via two-way radio
Field Meteorologist, North Dakota Cloud Modification Project, (Stanley or Bowman, ND) – Summers, 2003-2009
Operated 5 cm weather radar equipped with TITAN software package, launched and directed seeding aircraft using two-way radio and GPS tracking, performed data recording and documentation of cloud seeding operations, prepared silver iodide seeding solution, assisted with radar calibrations, prepared forecasts and briefed pilots daily, supervised intern meteorologists, presented case studies for ground school, operated cloud condensation nuclei counter for joint research with South Dakota School of Mines
Forecaster, Atmospherics Incorporated, (Fresno, CA) - October 2006 - May 2007
Field Meteorologist, Atmospherics, Inc. (Modesto, CA) - November 2005 - April 2006
Field Meteorologist, Atmospherics, Inc. (Paso Robles, CA) - December 2004 - February 2005
Provided daily forecasts for seeding operations and/or clients, operated 5cm weather radar, directed winter cloud seeding operations over the Sierra Nevada utilizing both glaciogenic and

hygroscopic seeding agents, traced radar overlays, performed data recording of operations, wrote monthly and annual reports

Memberships and Honors

- Meteorologist Distinguished Service Award, 2013, Weather Modification Association
- Member, Weather Modification Association (certified operator #78)
- Member, American Meteorological Society
- Iowa Central Community College Honor Society, inducted April 27, 2000
- Wilbur E Brewer Professionalism Award, 2007 North Dakota Cloud Modification Project

Field Address: Olds-Didsbury Airport, Highway 2A, Olds, AB
Field Telephone no. 403-335-8359
Field personnel: full time = 3
part time = 12

Daily records of activities: Custodian = Ms. Erin Fischer
WMI Project Operations Centre
Olds-Didsbury Airport, Highway 2A, AB T4H 1A1

All records are maintained June 1st -Sept. 15th annually.

- daily weather synopsis and forecast report
- radar echo storm data report and maps
- daily operations summary report
- chemical inventory report
- equipment status report
- aircraft flight track maps
- flight log report
- project aircraft maintenance report

PART 6. GENERAL INFORMATION CONCERNING PROPOSED ACTIVITY

Reasons for organization seeking modified weather: The hailstorm on Sept. 7, 1991 caused >$400 million damage in the City of Calgary alone. Hailstorms in the City of Calgary caused >$500 Million in 2010 and again in 2012. In addition, hailstorms have caused >$100 Million damage to crops annually since 2007 and the damage to crops was >$400 Million in 2012. Hailstorms have now become a billion dollar problem to the economy of Alberta. The 20 largest insurance companies and their affiliates have banded together to conduct hail suppression operations in the "hail alley" of central Alberta to combat urban hail damage in the Calgary to Red Deer area. The current program has conducted cloud-seeding operations in central Alberta each summer since 1996.

Specific modification sought: Diminish hail damage to property in central Alberta with special priority given to the urban areas of Calgary and Red Deer.

Quantitative estimate of modification expected: Even very small positive results (+1%) will be economically beneficial, however, it is hoped that reductions in damage on the order of 25% or greater will be realized. The insurance industry has been encouraged by the results, estimating a savings of several hundred-million dollars to the industry, paying out approximately 50% of what they expected.

Secondary effects anticipated: Reductions in crop damage due to hail should also be realized. Seeding may also provide an increase in precipitation according to recent analyses of radar data. The crop hail insurance data for the first 10 years of the project indicated a reduction in the loss-to-risk values compared with the historical 58 year average for the province as a whole. However, a recent analysis shows increased variability and an increasing trend in hail damage over the last 5 years both inside and outside the project area which is likely due to climate change. The effect of the seeding on crop damage is inconclusive at this time.

Geographic area affected (see attached map): The main project area is from Calgary to Red Deer, Alberta and west to the foothills of the Rocky Mountains.

Estimate of adjoining geographic area possibly affected: Areas downwind (east) of highway no. 2 to highway no. 21 may also benefit from the seeded storms.
Approximate total cost: approx. $3.1 million per year.

Funds to be expended in Canada: est. $600,000 per year.

General period of operation: June 1st - Sept. 15th annually.

PART 7. GENERAL INFORMATION CONCERNING OPERATIONS AND TECHNIQUES

A. GENERAL: The following text describes the methods to be used, general principles of techniques, description of specific techniques, and a brief description of typical operations:

OVERVIEW OF METHOD

For hail suppression, aircraft patrolling based upon forecasts and hourly weather reports will be used to initiate seeding as soon as appropriate conditions develop. Storms will be seeded if they have radar reflectivities of approximately 35 dBZ at heights above the -5°C temperature level, and are considered to be a potential hail threat to an urban or populated area. When large hail is forecast, seeding will commence when radar reflectivities reach approximately 20 dBZ in order to start the microphysical suppression process as early as possible within the potential hailstorms. Storms will be seeded by aircraft using either droppable AgI pyrotechnics and/or wing mounted AgI pyrotechnics or AgI-solution burners.

The amount of seeding material used will depend upon the lifetime and size of the cloud or storm and other meteorological conditions. The seeding rates are about double those used during the 1970's and 1980's in Alberta. Seeding will be focused on the feeder clouds of the storm's new growth zone and will be conducted at cloud top and cloud base. Further details of the seeding method are discussed below.

HAIL SUPPRESSION HYPOTHESIS

The cloud seeding hypothesis is based on the cloud microphysics concept of "beneficial competition". Beneficial competition assumes a lack of natural ice nuclei in the environment effective at temperatures warmer than -20°C and that the injection of AgI will result in the production of a significant number of "artificial" ice nuclei. The natural and artificial ice crystals "compete" for the available supercooled liquid cloud water within the storm. Hence, the hailstones that are formed within the seeded cloud volumes will be smaller and produce less damage if they should survive the fall to the surface. If enough nuclei are introduced into the new growth region of the storm, then it is possible that the hailstones will be small enough to melt completely before reaching the ground.

Cloud seeding operations are intended to alter the cloud microphysics of the treated clouds, assuming that the present precipitation process is inefficient due to a lack of natural ice nuclei. The seeding is based on a conceptual model of Alberta hailstorms that evolved from the studies of Chisholm (1970), Chisholm and Renick (1972), Barge and Bergwall (1976), Krauss and Marwitz (1984), English and Krauss (1986) and English (1986).

It is assumed that hail embryos grow within the time evolving "main" updraft of single cell storms and within the updrafts of developing "feeder clouds" or cumulus towers that flank mature "multi-cell" and "super-cell" storms (see e.g. Foote 1984). The growth to large hail is hypothesized to occur along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft.

For hail suppression, seeding with a large amount of silver-iodide will dramatically increase the ice crystal concentration in thunderstorm clouds and compete for the available supercooled cloud water to prevent the growth of large, damaging, ice particles. Based on WMI's experience, the cloud seeding will be targeted on the feeder cloud updraft regions associated with the production of hail and will leave unseeded those regions of the storm associated with the production of rain only. This will make efficient use of the seeding material (AgI) and will reduce the possible risk of overseeding rain clouds.

CLOUD SEEDING METHODOLOGY - SEEDING TECHNIQUES

Convective cells (defined by radar) with maximum reflectivity approximately >35 dBZ within the cloud layer above the -5°C level, located within the project areas or within a 20 min travel time "buffer zone" upwind of the project area, will be seeded if they pose a potential threat of damaging hail for an urban or populated area. Radar observers/controllers will be responsible for making the "seed" decision and directing the cloud seeding missions.

Patrol flights will be launched before clouds within the target area meet the radar reflectivity seeding criteria. These patrol flights are meant to provide immediate response to developing cells. In general, a patrol is launched in the event of visual reports of vigorous towering cumulus clouds near Calgary or Red Deer, or when radar cells exceed 25 kft height over the higher terrain along the western border and begin moving towards the urban areas.

Launches of more than one aircraft are determined by the number of storms in each area, the lead time required for a seeder aircraft to reach the proper location and altitude, and projected overlap of coverage and on-station time for multiple aircraft missions. In general, only one aircraft can work safely at cloud top and one aircraft at cloud base for a single storm. The operation of three aircraft is recommended to provide uninterrupted seeding coverage at either cloud-base or cloud-top and to seed three storms simultaneously if required.

The program is designed to seed convective clouds, before they achieve radar reflectivities associated with hail, and deliver seeding material to regions of updraft and supercooled liquid water i.e. the primary conditions responsible for the growth of hailstones.

Factors that determine cloud top or cloud base seeding are: storm structure, visibility, cloud base height, or time available to reach seeding altitude. Cloud base seeding is conducted by flying at cloud base within the main inflow of single cell storms, or the inflow associated with the new growth zone (shelf cloud) located on the upshear side of multi-cell storms.

Cloud top seeding is conducted between typically between -5°C and -10°C. The pencil flares fall approximately 1.5 km (approximately 10°C) during their 35-40 second burn time. The seeding aircraft will penetrate the edges of single convective cells meeting the seed criteria. For multi-cell storms, or storms with feeder clouds, the seeding aircraft will penetrate the tops of the developing cumulus towers on the upshear sides of convective cells, as they grow up through the aircraft's altitude.

Occasionally, with embedded cells or convective complexes, there are no clearly defined feeder turrets visible to the flight crews or on radar. In these instances, at an altitude between -5°C and - 10°C, a seeding aircraft will penetrate the storm edge (region of tight radar reflectivity gradient) on the upshear side and burn a burn-in-place flare and inject droppable pencil flares when updrafts are encountered.

Seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing, and mature stages in the evolution of the classic thunderstorm conceptual model. The dissipative stages of a storm would be seeded only if the maximum reflectivity is particularly severe and there is evidence (visual cloud growth, or tight reflectivity gradients) indicating the possible presence of embedded updrafts.

SEEDING RATE

A seeding rate of one 20 g flare every 5 s is typically used during cloud penetration. A slightly higher rate

is used (e.g. 1 flare every 2 s) if updrafts are very strong (e.g. > 2000 ft/min) and the storm is particularly intense. Calculations show that this seeding rate will produce >1300 ice crystals per litre which is more than sufficient to deplete the liquid water content produced by updrafts of 10 m/s (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes.
A cloud seeding pass is repeated immediately if there are visual signs of new cloud growth or radar reflectivity gradients remain tight (indicative of persistent updrafts). A 5 to 10 min waiting period may be used, to allow for the seeding material to take effect and the storm to dissipate, if visual signs of glaciation appear or radar reflectivity values decrease and gradients weaken. This waiting period precludes the waste of seeding material and ensures its optimum usage.

For cloud base seeding, a typical seeding rate of 1 burn-in-place flare (150 g each) is used. Cloud seeding runs are repeated until no further inflow is found. Acetone burners will also be used to provide continuous silver iodide seeding if extensive regions of weak updraft are observed at cloud base and the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

The cloud seeding flares are silver-iodide pyrotechnics with an ice nuclei effectiveness of approximately 10^{14} nuclei per gram of pyrotechnic, active at -10°C, as determined by independent cloud chamber tests at Colorado State University.

Sufficient dispersion of the particles is required for AgI plume overlap from consecutive flares by the time the cloud particles reach hail size for effective hail suppression. The work by Grandia et al. (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, was 140 seconds. This is insufficient time for ice particles to grow to hail size. Therefore, dropping flares at 5 sec intervals should effectively deplete the supercooled liquid water and prevent the growth of hail particles. The use of the 20 gram flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the center of the ice crystal plume center will have a higher concentration of crystals.

B. EQUIPMENT

Type:

- one WMI-C band weather radar, 250 kw peak power, with 1.65 deg. beam width, located at the Olds-Didsbury airport, 50ft tower mounted including radome.
- Three Beechcraft C90 King-Air prop-jet aircraft (two in Springbank and one in Red Deer).
- Two Cessna 340 aircraft (one in Springbank and one in Red Deer).

C. MATERIALS TO BE EMITTED:

- Cloud top (ejectable) pyrotechnic flares are 20g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- Cloud base (burn-in-place) flares are 150g AgI formulation manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota, USA (www.iceflares.com)
- A solution of acetone, silver iodide, sodium perchlorate, paradichlorobenzene, and ammonium iodide will also be burned for continuous seeding at cloud base. The products of combustion yield silver iodide (AgI) ice nuclei, carbon dioxide (CO_2), and water (H_2O).

Activation tests performed at Colorado State University indicate greater than10^{14} ice crystals per gram of seeding agent burned, active at -10°C.

Total flight hours and quantities to be dispersed: We estimate the project may use 5000 twenty-gram flares and 500 one hundred-fifty gram flares, plus approximately 150 gallons of the seeding solution (2% AgI by volume) will be burned. The number of operational days, flights, and amount of seeding material dispensed over the past fifteen years is summarized in the attached table. No harmful effects from these materials is expected. This is based on years of studies (both in the USA and Canada) to detect silver in precipitation (above background levels) following cloud seeding. The amount of silver distributed by the cloud seeding is small compared to the output from industry. Silver amounts from cloud seeding are far, far less than the USA EPA guidelines.

PART 8. GENERAL INFORMATION CONCERNING USE OF AIRCRAFT.

- Three C90 King Air prop-jet aircraft, two in Springbank (N904DK and N518TS) and one based in Red Deer (N522JP).
- Two Cessna 340 aircraft, one in Springbank (N457DM) and one in Red Deer (N98585).

PART 9. GENERAL INFORMATION CONCERNING USE OF GROUND VEHICLES.

No special project ground vehicles will be used on the project. (Only private vehicles for personal transportation will be used.)

PART 10. GENERAL INFORMATION CONCERNING ANY MEASUREMENTS OR OBSERVATION INSTRUMENTATION.

No special surface observations are planned for this project. The primary instrumentation is the weather radar and special aircraft instrumentation. Daily weather charts will be recorded for documentation and reporting purposes.

AIRCRAFT TRACKING GLOBAL POSITIONING SYSTEM (GPS): The WMI weather radar control and communications center will be equipped to receive and record data from the GPS aircraft tracking system. The GPS system displays the exact position of aircraft superimposed on the radar display to enable the controller to accurately direct the seeding aircraft to optimum seeding locations within the storm system. The color-coded aircraft position on the PPI will be marked with a small symbol. Electronic coding will enable radar controllers to discriminate between all project aircraft.

TEMPERATURE INSTRUMENTATION: Each of the cloud seeding aircraft will have a temperature sensor to ensure that the cloud penetration seeding runs are conducted at the proper temperature levels.

WEATHER RADAR: The C-band radar will be equipped with a computerized radar recording and display system. The radar recording system will be capable of providing numerous cell statistics and colour products including plots of radar PPI displays and maximum reflectivity maps. The sophisticated radar tracking software called TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) has been used since 1997 and has proved to be very useful. TITAN is licensed from NCAR.

PART 11. CERTIFICATION BY ORGANIZATION FOR WHOM ACTIVITY IS TO BE CONDUCTED:

State type of working agreement entered into with the weather modifier: Contract.

I HEREBY CERTIFY THAT ALL STATEMENTS MADE IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES ARE TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE, AND REPRESENT IN SUBSTANCE AN ACCURATE DESCRIPTION OF A PROPOSAL TO UNDERTAKE WEATHER MODIFICATION ACTIVITIES ON BEHALF OF THE ORGANIZATION NAMED HEREIN.

Name of organization: Alberta Severe Weather Management Society

Full name of certifying officer and title:

Todd Klapak
President, Alberta Severe Weather Management Society
(403) 231-1357, Todd.Klapak@intact.net

Signature: Date: May 14, 2014

PART 12. CERTIFICATION BY PERSON PROPOSING TO CONDUCT ACTIVITY.

I HEREBY CERTIFY THAT INFORMATION PROVIDED IN THIS NOTIFICATION OF INTENT TO ENGAGE IN WEATHER MODIFICATION ACTIVITIES IS A TRUE AND COMPLETE DESCRIPTION OF MY PROPOSED PLANS TO ENGAGE IN THE SPECIFIC WEATHER MODIFICATION ACTIVITIES HEREIN DESCRIBED.

Name of organization: Weather Modification, Inc.

Full name of certifying officer:
Bruce A. Boe
Director of Meteorology
(701) 235-5500

Bruce A. Boe

Signature: Date: May 14, 2014

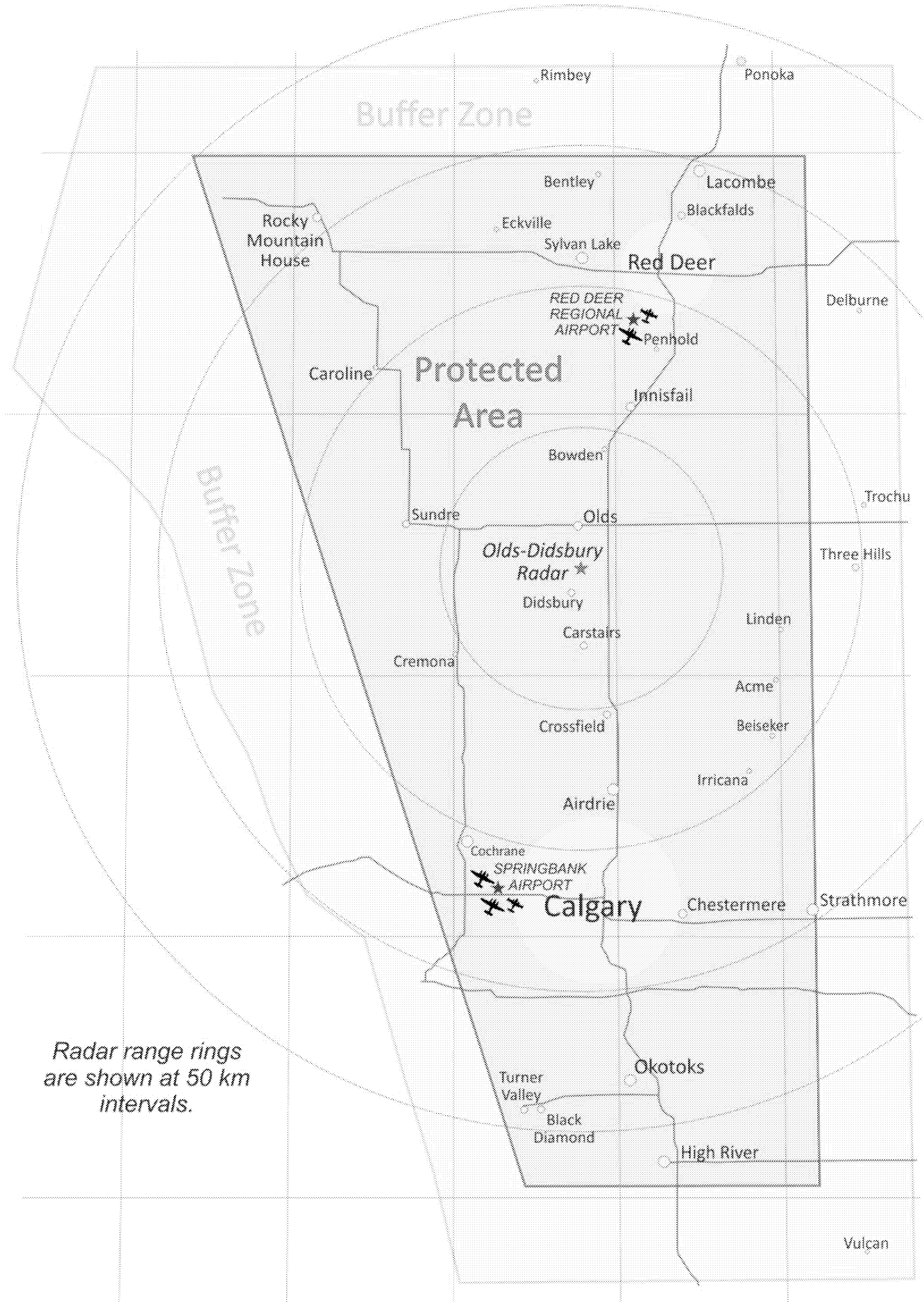


Figure 1: Map of south-central Alberta showing the project area, outlined in green, covered by the Hail Suppression activities.

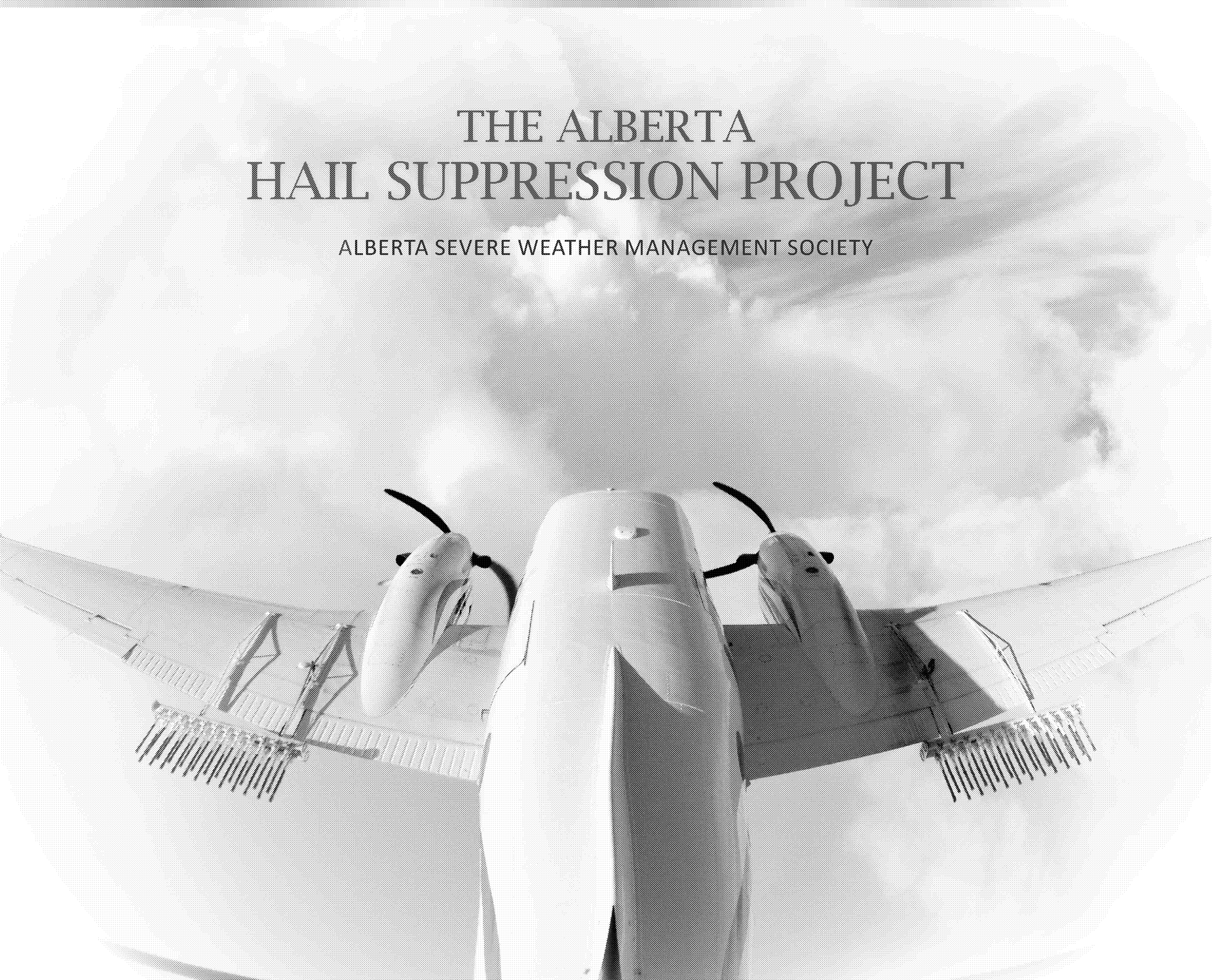
Table 1: Operational Statistics for 1996 to 2013.

Table 1. Seeding Activity by Season												
Season	Storm Days With Seeding	Aircraft Missions (Seeding & Patrol)	Total Flight Time (hours)	Number of Storms Seeded	Total Seeding Agent (kg)	Seeding Agent Per Day (kg)	Seeding Agent Per Hour (kg)	Seeding Agent Per Storm (kg)	Ejectable Flares	Burn-in-place Flares	Seeding Solutions (gallons)	Season Activity Rank
2013	26	103	229.6	70	233.3	9.0	1.02	3.33	6311	636	131.7	9
Mean	31.2	101.2	209.0	91.9	197.8	6.2	0.97	2.24	4705	620	153.3	
2012	37	143	300.1	116	314.6	8.5	1.16	2.70	7717	914	260.3	2
2011	48	158	383.0	134	400.1	8.3	1.13	3.00	10779	1020	350.2	1
2010	42	115	271.8	118	263.8	6.3	1.10	2.20	5837	851	227.5	5
2009	20	38	109.3	30	48.4	2.4	0.84	1.60	451	237	56.5	18
2008	26	112	194.7	56	122.9	4.7	1.00	2.20	1648	548	113.5	13
2007	19	76	115.3	41	99.7	5.2	0.90	2.40	1622	413	77	17
2006	28	92	190.2	65	214	7.6	1.10	3.30	4929	703	145.4	9
2005	27	80	157.9	70	159.1	5.9	1.00	2.30	3770	515	94.2	14
2004	29	105	227.5	90	270.9	9.3	1.20	3.00	6513	877	132.7	6
2003	26	92	163.6	79	173.4	6.7	1.10	2.20	4465	518	92.6	12
2002	27	92	157.4	54	124.2	4.6	0.80	2.30	3108	377	80.3	16
2001	36	109	208.3	98	195	5.4	0.90	2.00	5225	533	140.8	7
2000	33	130	265.2	136	343.8	10.4	1.30	2.50	9653	940	141.3	3
1999	39	118	251.3	162	212.7	5.5	0.80	1.30	4439	690	297.5	4
1998	31	96	189.9	153	111.1	3.6	0.60	0.70	2023	496	193.8	8
1997	38	92	188.1	108	110.8	2.9	0.60	1.00	2376	356	144.3	11
1996	29	71	159.1	75	163.3	5.6	1.00	2.20	3817	542	80.5	15

FINAL OPERATIONS REPORT 2015

THE ALBERTA HAIL SUPPRESSION PROJECT

ALBERTA SEVERE WEATHER MANAGEMENT SOCIETY



WEATHER MODIFICATION INCORPORATED

20th OPERATIONAL SEASON

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ALBERTA HAIL SUPPRESSION PROJECT
FINAL OPERATIONS REPORT 2015

A Program Designed for Seeding Convective Clouds
with Glaciogenic Nuclei to Mitigate Urban Hail Damage
in the Province of Alberta, Canada

by

WEATHER MODIFICATION INCORPORATED

Weather Modification, Inc.
3802 20th Street North
Fargo, North Dakota
U.S.A. 58102

for the

Alberta Severe Weather Management Society
Calgary, Alberta
Canada

DECEMBER 2015

EXECUTIVE SUMMARY

This report summarizes the activities during the 2015 field operations of the Alberta Hail Suppression Project. This was the twentieth season of operations by Weather Modification, Inc. (WMI) of Fargo, North Dakota under contract with the Alberta Severe Weather Management Society (ASWMS) of Calgary, Alberta. This season was the fifth year of the current 5-year contract cycle for this on-going program; WMI has been the contractor since operations began in 1996. The program was again directed for the ASWMS by Dr. Terry Krauss. The program continues to be funded entirely by private insurance companies in Alberta with the sole intent to mitigate the damage to urban property caused by hail.

The cloud-seeding contract with WMI was renewed in 2001, 2006, and again in 2011. Calgary, Red Deer and many of the surrounding communities have seen significant growth in population and area since 1996. Calgary's population exceeded 1 million in 2006, and property values have more than doubled since the program's inception. In 2008 it was estimated that a hail storm similar to that which caused $400 million damage in Calgary in 1991 would now cause more than $1 billion damage. New record Alberta hailstorms have recently occurred in 2009 and 2010, and in 2012, a severe storm that struck Calgary on August 12 caused an estimated $500 million dollars damage, indicating that a billion dollar storm within Calgary is certainly now possible.

A Doppler weather radar replaced the previous unit in 2011. In 2014, the second weather radar was replaced with an even more modern set. This latest radar is more sensitive, better depicting the developing cloud turrets of interest for seeding, and also has Doppler capability which provides additional information about internal storm circulations that would not otherwise be available.

Springbank Airport (CYBW) continued to be the southern operational base in 2015, while the northern base remained at the Red Deer Regional Airport (CYQF).

The project design has remained the same throughout the period, but a fourth seeding aircraft (Hailstop 4) was added to the project in the summer of 2008 to increase seeding coverage on active storm days. In 2013, a fifth aircraft (Hailstop 5) was added, which was another twin-engine turboprop King Air, the same aircraft type as Hailstop 1 and 3 have been in recent seasons. Hailstop 5 was based at CYBW with Hailstop 1 and Hailstop 2. Hailstop 3 and 4 were based at CYQF.

The program was operational from June 1st to September 15th, 2015. Only storms that posed a hail threat to an urban area as identified by the project's weather radar situated at the Olds-Didsbury Airport were seeded. The project target area covers the region from High River in the south to Lacombe in the north, with priority given to the two largest cities of Calgary and Red Deer.

Ten industry-accredited tours of the operations centre located at the Olds-Didsbury Airport were conducted for insurance company staff. At each, a lecture on the history and science of the hail suppression program was given, the radar facility was explained and demonstrated, and one of the five Hailstop aircraft flew in to provide firsthand observation of the seeding equipment and allow some interaction with a flight crew. A total of 198 attended.

Hail was reported within the project area (protected area and buffer area) on 46 days. Larger than golf ball size hail was reported on July 21st in the city of Lacombe. Then, on July 22nd, larger-than-golf ball size hail was reported in Calgary.

Golf ball size hail was reported or observed by radar signature on June 11th south of Ponoka; June 30th southwest of Calgary; near Bentley on July 3rd; the 11th of July southwest of Calgary; on July 23rd east of Lacombe; and on the 5th of August in Calgary.

Walnut size hail was reported or observed by radar signature on June 10th south of Rocky Mountain House; southeast of Airdrie and near Chestermere on July 12th; July 14th southeast of Chestermere; southwest of Cremona on July 26th; July 29th west of Red Deer; and in Calgary on August 4th.

The weather pattern during the summer of 2015 was less active than the previous summer, closer to the storm frequency of 2010. All five Hailstop aircraft flew on six days and all five aircraft "seeded" on four of those days.

In June, 30 seeding missions were flown on 7 days, and an additional four flights flown for patrol on 4 days. A "patrol" flight is a flight flown to check cloud intensity or in anticipation of clouds becoming intense enough to warrant seeding, but during which no seeding was actually conducted.

July was the most active month. Fifty-six seeding missions were flown on 14 days, and 7 more patrol flights on 4 days. The heaviest seeded day of the season occurred on July 21st over Red Deer, Blackfalds, and Lacombe when a line of supercell hailstorms pushed through the northern project area.

Activity diminished significantly in August, with 14 seeding missions flown on five days, the last occurring on August 15th. Four patrol missions were also flown on 2 days. The vast majority of August seeding occurred on the 4th and 5th when hailstorms moved through Calgary on back-to-back days.

No seeding was conducted in September, and no patrol missions were needed.

There were thunderstorms reported within the project area on 64 days this summer, compared with 65 days in 2014. Hail fell on 46 days. During this season, there were 233.3 hours flown on 35 days with seeding and/or patrol operations. A total of 79 storms were seeded during 100 seeding flights on the 26 seeding days. There were 15 patrol flights, and 16 short "public relations" flights on which one aircraft was flown to the Olds-Didsbury Airport to be available for viewing by insurance company employees attending tours of the operations centre and radar.

The amount of silver-iodide nucleating agent dispensed during the 2015 field season totaled 349.2 kg. This was dispensed in the form of 8,127 ejectable (cloud-top) flares (162.5 kg seeding agent), 1138 burn-in-place (cloud-base) flares (170.7 kg seeding agent), and 262.9 gallons of silver iodide seeding solution (16.0 kg seeding agent).

Five specially equipped cloud seeding aircraft were dedicated to the project. Two Beech C90A King Airs and one Cessna 340A were based in Springbank, and a C90A and another C340A were based in Red Deer. The procedures used in 2015 remained the same as the previous years. The Springbank office and aircraft were at Springbank Aero Services, at that airport. The WMI Red Deer office was again set up in the Air Spray hangar at the Red Deer Regional Airport, as had been done in the four previous seasons.

The aircraft and crews provided a 24-hour service, seven days a week throughout the period. Ten full-time pilots and three meteorologists were assigned to the project this season. In addition, WMI's Chief Pilot, Mr. Jody Fischer, served as overall project manager. The 2015 crew was very experienced. The Red Deer aircraft team was led by Mr. Mike Torris and Ms. Jenelle Newman, both project veterans, and Mr. Joel Zimmer who has been with the Alberta program for 13 seasons. The Springbank team was anchored by Mr. Jody Fischer and Mr. Jake Mitchem. The radar crew was anchored by WMI's Chief Meteorologist, Mr. Daniel Gilbert, now with six seasons' experience in Alberta, in addition to seven seasons' work in a similar capacity on a hail suppression program in North Dakota.

Overall, the personnel, aircraft, and radar performed well and there were no interruptions or missed opportunities. A radar calibration at the beginning of the project season ensured that during the 2015 season the radar was calibrated correctly. On the afternoon of July 14th, the radar power went out for two hours during intensive operations. The backup power system (UPS and generator) worked flawlessly. There was not a single missed scan and ops continued normally.

The current Doppler weather radar was installed in May of 2014. This new system was developed and is supported by Advanced Radar Corporation (ARC), of Boulder, Colorado. The new radar performed well in its second season, but there were occasional minor glitches. One of these was that small portions of volume scans would now and then be missing, resulting in incomplete storm recording. This generally did not occur in consecutive scans, but since all data were archived, these instances infrequently resulted in small gaps in the radar data archive.

High speed Internet service was once again obtained at the Springbank and Red Deer offices for the pilots so that they could closely monitor the storm evolution and storm motion using the radar images on the web prior to take-off. All of the project's radar data, meteorological data, and reports have been recorded onto a portable hard drive as a permanent archive for the Alberta Severe Weather Management Society. These data include the daily reports, radar maps, aircraft flight tracks, as well as meteorological charts for each day. The data can be made available for outside research purposes through a special request to the Alberta Severe Weather Management Society. In addition, ASWMS Program Director Dr. Terry Krauss was provided the entire season's TITAN (radar) data, as he has that software running on a computer in his office. This will enable mutual (WMI and ASWMS) examination of the data set in the off season, prior to the 2016 program.

ACKNOWLEDGEMENTS

WMI acknowledges the continuing, kind support of Todd Klapak, Catherine Janssen, Dr. Terry Krauss, and the entire Board of Directors of the Alberta Severe Weather Management Society (ASWMS). The understanding, support, and cooperation of the ASWMS are greatly appreciated.

A number of organizations and people deserve recognition and thanks. The cooperation of these persons and agencies is very important in making the project successful, in positive working environments.

- Edmonton Area Control Center and Calgary Terminal Air Operations. The excellent cooperation by the ATC once again played a very important role in allowing the project pilots to treat the threatening storms in an efficient and timely manner as required, often directly over the city of Calgary.
- Saroj Aryal and Kathleen Cleveland of Alberta Financial Services Corp. (AFSC) in Lacombe are thanked for providing the crop insurance information.
- For the twentieth year, special thanks go to Bob Jackson for sharing his office and hangar at the Olds-Didsbury airport, used for the radar and communications control center.
- Ashley Batke is thanked for organizing the 10 informational seminars that were conducted at the Olds radar this summer as part of the Alberta Insurance Council accreditation program.
- Perry Dancause, Ross Katterhagen and the staff of Air Spray Ltd are sincerely thanked for providing offices, ramp space, and timely reliable aircraft maintenance this season at the Red Deer Airport.
- Gary Hillman of Hillman Air is thanked for allowing WMI to use his self-serve fuel tank at the Red Deer Regional Airport.
- The staff of Springbank Aero is thanked for providing office space, ramp space, and other operational support to the project at the Springbank Airport.

Weather Modification, Inc., wishes to acknowledge the contributions of the staff who served on the project during the summer of 2015: project manager Jody Fischer, meteorologists (Dan Gilbert, Brad Waller, and Adam Brainard), electronics-radar technicians (Barry Robinson and Todd Schulz), pilots in command (Lee Goodyear, Brian Kindrat, Jake Mitchem, Michael Torris, and Janelle Newman); and the co-pilots (Joel Zimmer, Jacob Eeuwes, Matthew Thompson, Andrew Brice, and Steve Dimitrov). The staff performed very well as a team. The support of the WMI corporate head office in Fargo, North Dakota is also acknowledged, specifically, the efforts of Erin Fischer, Cindy Dobbs, Patrick Sweeney, James Sweeney, Randy Jenson, Hans Ahlness, Bruce Boe, Dennis Afseth, Mike Clancy and Mark Grove are greatly appreciated.

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1. INTRODUCTION

Hail has long been a problem for both agriculture and municipalities in the Province of Alberta. Figure 1 shows the average number of hail days throughout Canada. It is notable that there is a bull's eye on the area from Calgary to Red Deer, which also coincides with the greatest population density of the province, which continues to increase. In 1956, under the aegis of the Alberta Research Council, a research program was undertaken that sought to develop and evaluate the effectiveness of cloud seeding from aircraft to mitigate crop-hail damage. Though never "operational", the program continued to research the hail problem and ways to reduce the hail impact on agriculture until 1985, when it was discontinued.

The hail problem did not end with the hail research program, and in 1991 a severe hailstorm caused several hundred million dollars damage in the City of Calgary and adjacent metropolitan areas. This storm, though by no means the first of its kind, was of sufficient magnitude to rekindle interest in hail damage mitigation through cloud seeding.

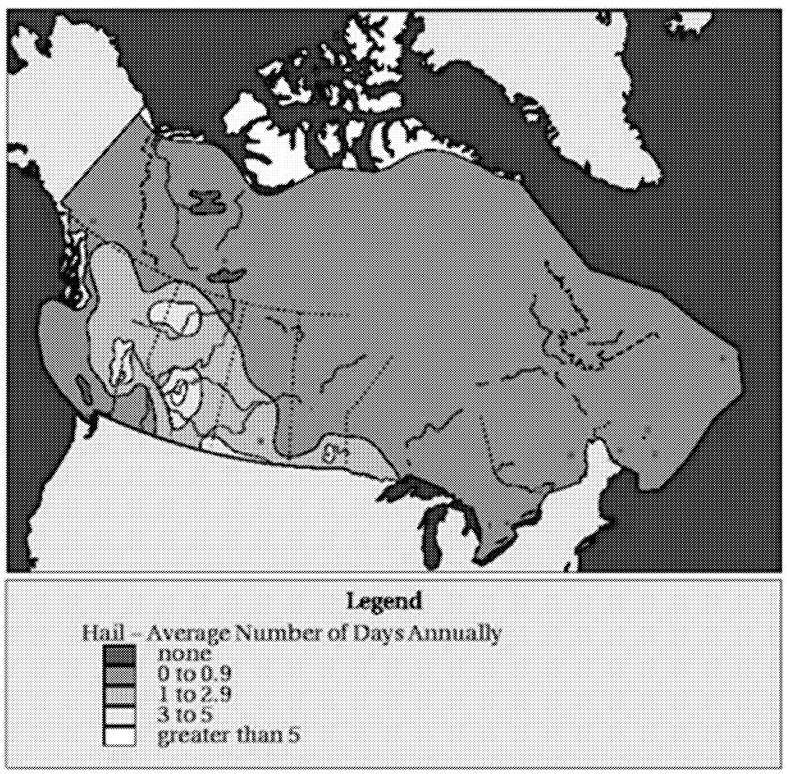

Fig. 1. The hail climatology of Canada, from Etkin and Brun (1999). The average number of hail days per year, based on the 1951-1980 climate normal of Environment Canada (1987).

A consortium of underwriters of property and casualty insurance in Alberta was formed in the wake of the 1991 Calgary storm, and named itself the Alberta Severe Weather Management Society (ASWMS). From its formation, the ASWMS was focused on establishing a renewed Alberta Hail Suppression Program through cloud seeding, but this time, the focus was to be on protecting municipalities, not crops. The necessity for such a program was presented to the Insurance Bureau of Canada (IBC), and though the IBC was encouraging it offered no financial support. The Province of Alberta was itself approached for funding of the program. Though the need was acknowledged by the provincial leaders funding was not forthcoming.

In 1995 the ASWMS developed a protocol through which its members would pay into a common project fund, amount proportional with market share, and the current Alberta Hail Suppression Project finally became possible. An international tender was issued, and Weather Modification, Inc. (WMI) was awarded an initial five-year contract to conduct operations from June 15 through September 15 each summer, beginning in 1996.

The goal of the project from the beginning has been the protection from the ravages of hailstorms to property concentrated in urban areas, to the maximum extent technology and safety will allow. The two largest such areas within the project target area are Calgary and Red Deer, but there are dozens of additional cities and towns that also warrant attention. To do this, the project established a weather radar and Operations Centre at the Olds-Didsbury Airport, approximately halfway between the two largest metropolitan areas. Two aircraft were based in

Calgary, a third in Red Deer. At the conclusion of the initial five-year period the contract between the ASWMS and WMI was renewed for a second 5-year period (2001-2005), a third (2006-2010), and in 2011, a fourth.

Six significant changes have been made to the project scope during the first twenty seasons. Early on (season 2) it was recognized that the hail problem begins earlier in the year than June 15, so since 1998, the project has begun each season on June 1.

Beginning in the 2006 season the protected area was expanded somewhat to the east, to include the town of Strathmore and communities east of Calgary.

The third change did not occur until the 13th season, 2008. The unrelenting expansion of the metropolitan areas within the project area meant increasing risk, and a fourth cloud seeding aircraft was added to the project. This aircraft is based in Red Deer.

Fig. 2. The anvil (cloud top) of a thundershower lingers in the Calgary twilight on 8 August 2015. (WMI photograph by Adam Brainard.)

The fourth change was the replacement in 2011 of an aging WR-100 weather radar with a new set built by WMI. This radar possessed significantly increased sensitivity which meant that clouds could be detected sooner than they were previously (earlier in their development), and Doppler capability meant that internal storm motions could also be observed.

The fifth change was implemented in 2013, with the addition of a fifth aircraft to the project, another King Air, based at the Springbank Airport.

The last significant change occurred in 2014, with the replacement of the 2011 Doppler radar with an even-newer Doppler weather radar. This newest Doppler weather radar was installed in May, prior to the 2014 project start. Improvements, in addition to the new transmitter and receiver, included a new antenna pedestal. The pedestal precisely rotates and elevates the radar antenna. This new radar system was developed and is supported by Advanced Radar Corporation (ARC), of Boulder, Colorado. During 2012 and 2013 there were pedestal drive failures that had to be repaired "on the fly", while operations were imminent. Though operations those seasons were not compromised, the upgrade included the new pedestal in part to avoid any further gear failures. Improvements realized from the radar included implementation of the latest version of the TITAN radar software, state-of-the-science radar antenna control, and improved data processing. The last allowed the time required for each volume scan to be decreased from five to less than four minutes, which meant the radar updated 15 times per hour, rather than 12. In addition, the porting of data to the WMI website was also improved.

Fig. 3. A strong thunderstorm approaches the Operations Centre on 19 June 2015, at 7:21 PM. (WMI photograph by Bradley Waller.)

This final operations report summarizes, in detail, all the activities during the 2015 field operations of the Alberta Hail Suppression Project, the twentieth summer of operations.

2. THE 2015 FIELD PROGRAM

The project conducted operations to mitigate hail storms threatening cities and towns from June 1st through September 15th, 2015. Only those storms posing hail threats to an urban area were treated by the project aircraft. The project target area covers the region from High River in the south to Lacombe in the north, with priority given to the two largest cities of Calgary and Red Deer.

The weather pattern during the summer of 2015 was less active than the previous summer, closer to the storm frequency of 2010. Hail was reported within the project area (protected area and buffer area) on 46 days.

The program utilizes the latest cloud seeding technology available, incorporating several notable improvements over previous projects in the province. These improvements include:

- Fast-acting, high-yield mixtures for the silver-iodide flares and the liquid seeding solution. The flares are manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota. The new generation ICE pyrotechnics produce >1011 ice nuclei per gram of AgI active at a temperature of -4°C, and produce between 1013 and 1014 ice nuclei per gram of pyrotechnic active between cloud temperatures of -6°C and -10°C. Colorado State University (CSU) isothermal cloud chamber tests (DeMott 1999) indicate that at a temperature of -6.3°C, 63% of the nuclei are active in <1 min, and 90% active within 68 seconds. This high-yield, fast-acting agent is important for hail suppression since the time window of opportunity for successful intervention of the hail growth process may be less than 10 minutes for each maturing cloud turret.
- Use of the latest GPS tracking and advanced TITAN (Thunderstorm Identification Tracking Analysis and Nowcasting) computer software to accurately display the aircraft locations on the radar displays to improve the controlling of aircraft and facilitate the direction of seeding operations to the most critical regions of the storms.
- Injection of the seeding material directly into the developing cloud turrets as the most frequent seeding method.
- Use of experienced meteorologists and pilots to direct the seeding operations.
- Sensitive, state-of-the-science Doppler weather radar.

The target or "protected" area presently focuses on the area from Lacombe in the north, to High River in the south, with priority given to the cities of Calgary and Red Deer. In 2006, the target area was increased slightly towards the east to include the town of Strathmore and some of the smaller towns east of the QE II highway. Five aircraft specially equipped to dispense silver iodide were used. Three aircraft (two Beech King Air C90s and one Cessna 340, or C340) were based in Springbank west of Calgary, and two aircraft (one Beechcraft King Air C90 and one C340) were based in Red Deer. The radar remained located at the Olds-Didsbury airport. The radar coordinates are 51.71 N latitude, 114.11 W longitude, with a station elevation of 1024 m above sea level. The WMO station identifier is 71359, and the ICAO identifier is CEA3. The protected project area dimension is approximately 240 km (N-S) by 120 km (E-W) or 28,800 square km.

3. PROJECT OBJECTIVES

The project has two main objectives:

- To conduct cloud seeding operations to suppress hail and reduce property damage, and
- To develop a data archive that may eventually be used for the scientific assessment of the program's effectiveness.

The first of these is met by using the five aircraft and experienced pilots and meteorologists to identify potential threats and react appropriately. The second is being achieved through the operation of a C-band Doppler weather radar with full archival, and the collection of other weather information by project meteorologists. These efforts include the comprehensive archival of all project decision records, as well as a wealth of additional weather data from the internet and other sources.

The project operations area is illustrated in Figure 4. The boundaries of flight operations (actual seeding) are indicated by the broad yellow line, which actually includes the foothills of the Rocky Mountains, west of the protected area. This is very important, for the foothills are an important zone for storm genesis. The broad green line denotes the boundary of the protected area, *i.e.*, storms threatening any of the communities within this area will be seeded, as resources allow.

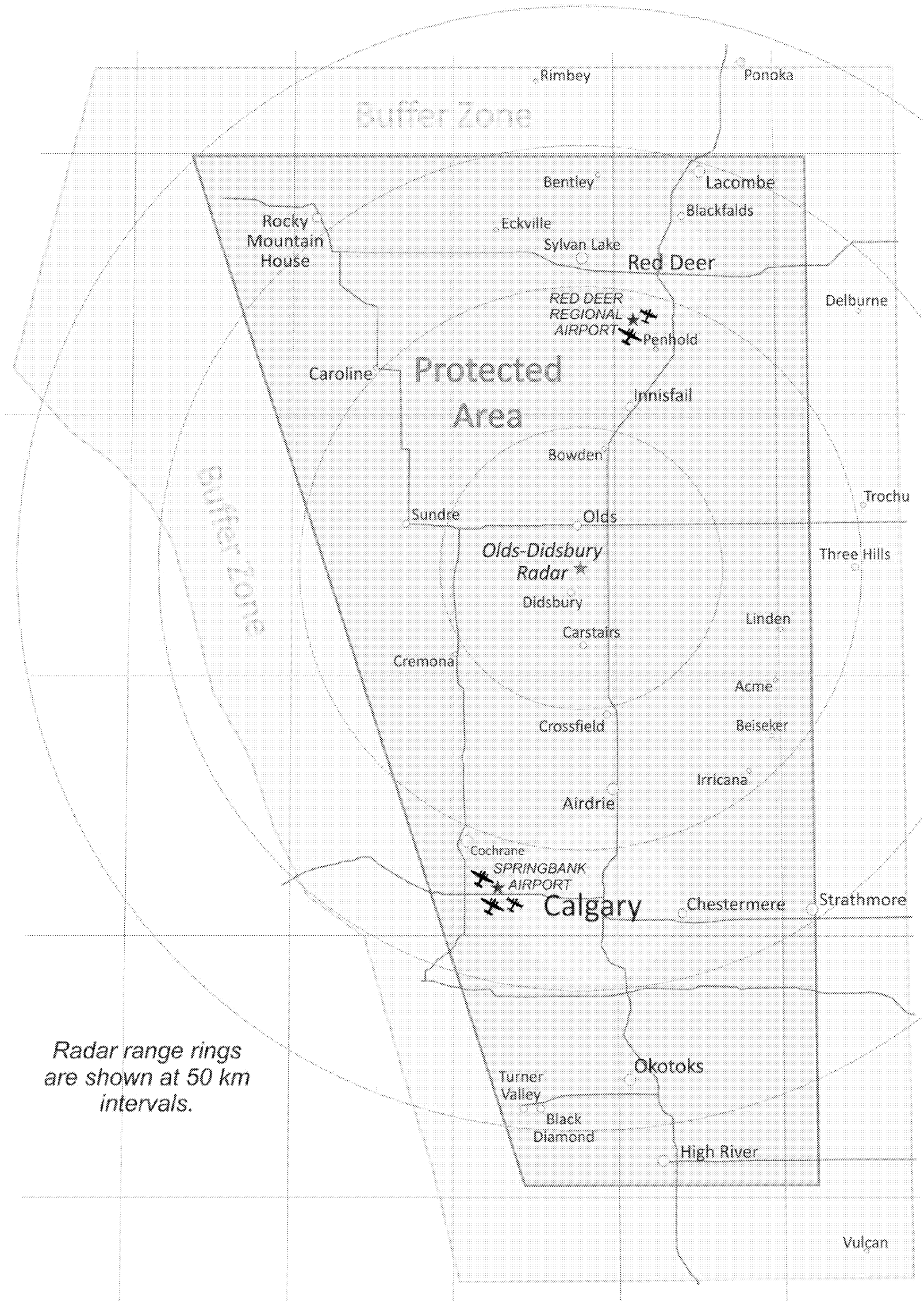

Fig. 4. A map of southern Alberta showing the project protected area. The major cities and towns in and near the protected area are shown, along with the location of the Olds-Didsbury Operations Centre (red star). Aircraft bases as shown by aircraft symbols.

4. PRIORITIES

Cities and towns are protected according to priority and proximity of aircraft, with greatest attention given to Calgary and Red Deer. Priority is determined based on rank in population, as shown in Table 1, below.

AHSP Priority List Based On City Population

Priority	City/Town Name	Population as of		Population Change as of 2014			
		1996	2014	From 2011	Since Project Start (1996)		
					Percentage	Factor	More People
1	Calgary	767,059	1,195,194	9.0%	55.8%	0.56	428,135
2	Red Deer	59,834	98,585	8.9%	64.8%	0.65	38,751
3	Airdrie	14,506	54,891	29.0%	278.4%	2.78	40,385
4	Okotoks	7,789	27,331	11.5%	250.9%	2.51	19,542
5	Cochrane	6,612	20,708	17.8%	213.2%	2.13	14,096
6	Chestermere	1,603	17,203	16.0%	973.2%	9.73	15,600
7	Sylvan Lake	4,815	13,015	5.6%	170.3%	1.70	8,200
8	High River	6,893	12,920	0.0%	87.4%	0.87	6,027
9	Lacombe	7,580	12,728	8.7%	67.9%	0.68	5,148
10	Strathmore	5,273	12,352	0.4%	134.2%	1.34	7,079
11	Olds	5,542	8,617	4.6%	55.5%	0.55	3,075
12	Innisfail	6,064	7,922	0.6%	30.6%	0.31	1,858
13	Blackfalds	1,769	7,858	24.7%	344.2%	3.44	6,089
14	Rocky Mountain House	5,684	7,300	5.3%	28.4%	0.28	1,616
15	Didsbury	3,399	4,957	N/A	45.8%	0.46	1,558
16	Turner Valley & Black Diamond	3,269	4,540	N/A	38.9%	0.39	1,271
17	Carstairs	1,796	3,442	N/A	91.6%	0.92	1,646
18	Crossfield	1,800	2,918	2.3%	62.1%	0.62	1,118
19	Penhold	1,609	2,842	19.7%	76.6%	0.77	1,233
20	Sundre	2,027	2,695	3.3%	33.0%	0.33	668
21	Bowden	936	1,241	N/A	32.6%	0.33	305
22	Irricana	822	1,162	N/A	41.4%	0.41	340
23	Eckville	899	1,125	N/A	25.1%	0.25	226
24	Bentley	930	1,122	4.6%	20.6%	0.21	192
25	Beiseker	640	785	N/A	22.7%	0.23	145
26	Linden	563	725	N/A	28.8%	0.29	162
27	Acme	590	653	N/A	10.7%	0.11	63
28	Caroline	452	501	N/A	10.8%	0.11	49
29	Cremona	393	457	N/A	16.3%	0.16	64
	Total Population In Protected Urban Areas	921,148	1,525,789	N/A	65.6%	0.66	604,641
15th?	Ponoka - if protected would rank 15th	5,861	6,773	3.0%	15.6%	0.16	912

Table 1. AHSP Priority List Based on City Population.

Since 2011 Calgary has grown another 9.0%, Red Deer 8.9%, Airdrie 29.0%, Okotoks 11.5%, Cochrane 17.8% and Chestermere 16%. Since the project start in 1996 urban population growth within the protected area has increased by 65.6%.

At the end of the 2015 season it was agreed that for 2016, the protected area will be extended north sufficiently to include Ponoka, which having a population of more than six thousand will rank it 15^{th} (see again, Table 1). Also newly-included in the protected area in 2016 will be Rimbey.

5. THE SCIENTIFIC BASIS FOR HAIL SUPPRESSION

Hail is formed when small ice particles known as hail embryos are held aloft by strong thunderstorm updrafts within regions of unfrozen supercooled cloud water. This supercooled cloud water is collected by the hail embryos and freezes to them, resulting in growth to hail (greater than 5 mm diameter) sizes. Growth continues until (1) the supporting updraft weakens, (2) the in-storm motion of the growing hailstone moves it to the downdraft side from whence it can fall, or (3) the hailstone grows so large that the updraft can no longer support it. In most situations the subcloud layer is relatively warm (much warmer than 0°C) so hailstones begin to melt during the final portion of their plummet to earth, but in many cases the hailstones are too large for melting to be complete, and hail reaches the ground.

5.1 THE FORMATION OF HAIL

Understanding of the development of hail includes knowledge gained from work in Alberta by Chisholm (1970), Chisholm and Renick (1972), Marwitz (1972a, b, and c), Barge and Bergwall (1976), Krauss and Marwitz (1984), and English (1986). Direct observational evidence from the instrumented aircraft penetrations of Colorado and Alberta storms in the 1970s and early 1980s indicates that hail embryos grow within the evolving main updraft of single cell storms and within the updrafts of developing feeder clouds (the cumulus towers) that flank mature multi cell and supercell storms (see *e.g.* Foote 1984, Krauss and Marwitz 1984). The computation of hail growth trajectories within the context of measured storm wind fields provided a powerful new tool for integrating certain parts of hail growth theories, and illustrated a striking complexity in the hail growth process.

Fig. 5. Hailstop 4 seeds a thunderstorm between Sylvan Lake and Gull Lake at 3:37 PM on 29 July 2015. (WMI photograph by Jenelle Newman.)

Some of this complexity is reviewed in the paper of Foote (1985) that classifies a broad spectrum of storm types according to both dynamic and microphysical processes thought to be critical to hail production. Small precipitation embryos that eventually grow into hailstones are called hail embryos. Hail embryo sources identified by Foote (1985) include the following:

- Embryos from first-ice in a time-developing updraft
- Embryos from first-ice in the core of a long-lived updraft
- Embryos from flanking cumulus congestus
- Embryos from a merging mature cell
- Embryos from a mature cell positioned upwind
- Embryos from the edges of the main updraft
- Embryos created by melting and shedding
- Embryos from entrainment of stratiform cloud
- Embryos from embedded small-scale updrafts and downdrafts
- Recirculation of embryos that have made a first pass through the updraft core

Hail embryos grow into hailstones by collecting unfrozen, supercooled liquid water through collisions. This water freezes to the already-frozen embryo, increasing the size, weight, and fall speed, and also the potential for damage at the surface. This growth to large hail is theorized to occur primarily along the edges of the main storm updraft where the merging feeder clouds interact with the main storm updraft (WMO 1995). However, the mature hailstorm most certainly consists of complicated airflow patterns and particle trajectories.

Studies of the internal structure of large hailstones in Alberta and elsewhere have shown that hailstones can have either a graupel (snow pellet) embryo or a frozen drop embryo. The different hail embryos indicate different growth histories and trajectories and illustrate the complexity within a single hailstorm.

5.2 *HAIL SUPPRESSION CONCEPTS*

The hail suppression conceptual model utilized in the Alberta Hail Suppression Project is based on the results of the former research program of the Alberta Research Council and the experiences of WMI in the USA, Canada, Argentina, and Greece. It involves the use of glaciogenic (ice-forming) materials to seed the developing feeder clouds near the -10°C level in the upshear, new growth "propagation" region of hailstorms. The glaciogenic reagents initiate the rapid development of small ice particles through the condensation-freezing nucleation process, and thus produce enhanced concentrations of ice crystals that compete for the available, supercooled liquid water in storms. This helps prevent the growth of large, damaging hail. The seeding also stimulates the precipitation process by speeding the growth of ice-phase hydrometeors, initially into snow pellets (also called graupel) which fall from the cloud earlier, melt, and reach the ground as rain, instead of continuing to grow into large ice particles that reach the ground as damaging hail.

Fig. 6. Developing (seedable) cloud turrets grow toward the cloud anvil of the mature storm in front of Hailstop 3 on 11 June 2015, at 5:52 PM. (WMI photograph by Joel Zimmer.)

The present seeding methodology modifies the graupel embryo hail development process. Frozen drop hail embryos are thought to originate from secondary sources (shedding from large existing hailstones, or via a recirculation process at the edge of the main updraft). Cloud seeding can only reduce the hail that grows from frozen drop embryos if the available liquid water can be reduced to limit their growth, or if the dynamics of the storm can be affected to eliminate the recirculation processes that formed the drop embryo in the first place. Both are extremely complex, and are not the primary focus of the Alberta project.

The governing premise of the Alberta cloud seeding operations is the cloud microphysical concept called beneficial competition. The premise of beneficial competition is that the well-documented natural deficiency of ice nuclei (ice-forming particles) in the atmosphere can be corrected by the release of additional ice nuclei (glaciogenic seeding material) into developing storm clouds. This is done by the combustion of small amounts of reagent and/or solutions containing silver iodide (AgI), either as pyrotechnics (flares) or from wing-borne solution-burning ice nucleus generators. With either method, from 10^{13} to 10^{14} (or from 10,000,000,000,000 to 100,000,000,000,000) ice nuclei are produced for each gram of silver iodide burned, *e.g.*, see Figure 12. This potentially increases greatly the number of precipitation embryos in the cloud. These natural and human-made ice crystals, many of which become precipitation, then "compete" for the available supercooled liquid cloud water within the storm. Because the total amount of supercooled liquid remains essentially unchanged, that same mass is divided among the increased number of embryos, meaning the final maximum size of each individual ice particle is significantly decreased. Hence, the hailstones that form within seeded clouds will be smaller and produce less damage if they should survive the fall to the surface. If they are sufficiently small, they will melt completely in the warmer subcloud layer and reach the ground as rain.

Cloud seeding alters the microphysics of the treated clouds, assuming that the existing precipitation process is inefficient due to a lack of natural ice nuclei. This deficiency of natural ice has been documented in the new growth zone of Alberta storms (Krauss 1981). Cloud seeding does not alter directly the energy or dynamics of the storm. Any alteration of the storm dynamics that does occur results as a consequence of the increased ice crystal concentrations and the development of additional precipitation-size ice particles earlier in the cloud's lifetime.

Because the mature hailstorm consists of complex airflows and precipitation trajectories cloud seeding does not affect all hail embryo sources. It does, however, modify the primary hail formation process. In other words; the cloud seeding cannot eliminate all of the hail, but can reduce the size and amount of hail.

A schematic diagram of the conceptual storm model showing the hail origins and growth processes within a hailstorm is shown in Figure 7. The cloud seeding methodology applied to the new growth zone of the storm is illustrated. As mentioned previously, cloud seeding cannot prevent or completely eliminate the occurrence of damaging hail. We presently do not have the ability to predict with any certainty exactly the amounts and sizes of hail that would occur if cloud seeding did not take place. Therefore, we do not have the ability to predict or determine by measurements with confidence the net effect of the seeding. The new growth zones of potential hailstorms are seeded, and the amounts and types of precipitation at the surface are observed, as well as the radar reflectivity characteristics of the storm before, during, and after seeding. It is anticipated that the successful application of the technology will yield a decrease of damaging hail by approximately 50% from what would have occurred if seeding had not taken place.

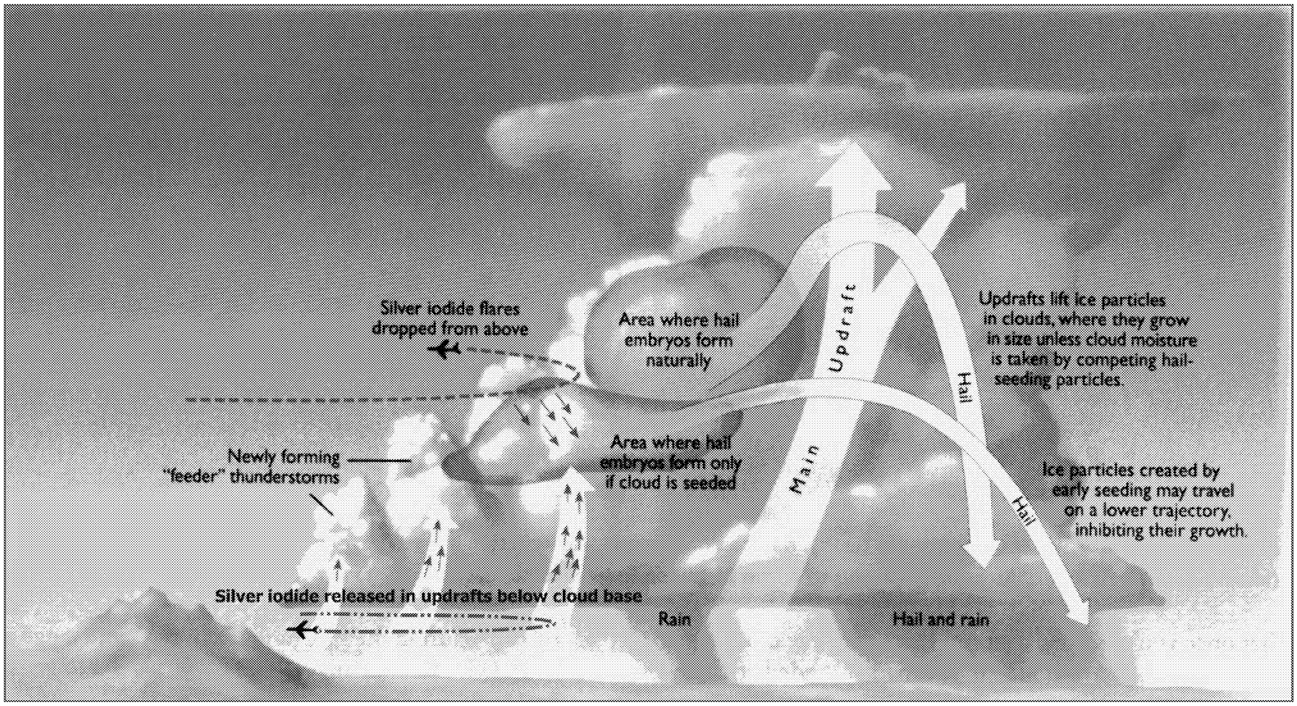

Fig. 7. Conceptual model for hail suppression is illustrated graphically, as adapted from WMO (1995). This schematic shows generalized cloud seeding locations at cloud base and at cloud tops, as employed for mature thunderstorms. (Original graphic prepared by Canadian Geographic.)

This expectation is consistent with the results reported in North Dakota (Smith *et al.* 1997) and in Greece (Rudolph *et al.* 1994). The decrease in hail can only be measured as an average over time (*e.g.* 5 years or more) within the operations area, and then compared with the historical values for the same area. Because of these uncertainties, the evaluation of any hail mitigation program requires a statistical analysis. The characteristics of both seeded and unseeded storms vary considerably, such that any storm trait can be found in either category.

A meaningful evaluation of the project might be feasible if insurance loss data for hailstorms was made available; however, such data are considered proprietary and presents obstacles to analyses. (This kind of evaluation is mentioned further in the recommendations at the conclusion of this report.) An additional complicating factor is that hail, by itself, is not always differentiated as the cause of the insured damage, *e.g.*, a window might be broken by hail, high winds, or by surface-based debris borne by the high winds, and to the insurance adjuster it makes little difference; storm damage has occurred.

5.3 EFFECTS OF HAIL SUPPRESSION EFFORTS ON RAINFALL

A common question about cloud seeding concerns the effect on the rainfall. The effects of seeding to mitigate hail damage on storm rainfall are not dramatic, but slightly positive. The target area specifically, and Alberta as a whole, lack the high density time-resolved precipitation measurements necessary to provide a scientifically-meaningful rainfall analysis. However, evaluation of another long-term hail suppression program in neighboring North Dakota that does have such a precipitation network found that rainfall is increased about 5 to 10 percent compared to that from similar unseeded clouds (Johnson 1985). Since methodology, seasons, and seeding agents are the same, and since the storms themselves are very similar, it is reasonable to believe that effects in rainfall in Alberta are similar. All this is wholly consistent with the concept that the number of precipitation embryos is increased by glaciogenic seeding.

There is a common (yet quite false) belief that thunderstorms operate at near 100% efficiency in producing rainfall. This is not logical, for 100% efficiency would require that all moisture processed by a storm would fall to the ground; no cloud, even, could remain. This is far from the case. There have been numerous studies of the fluxes of air and water vapor through convective clouds; these are summarized in Figure 8.

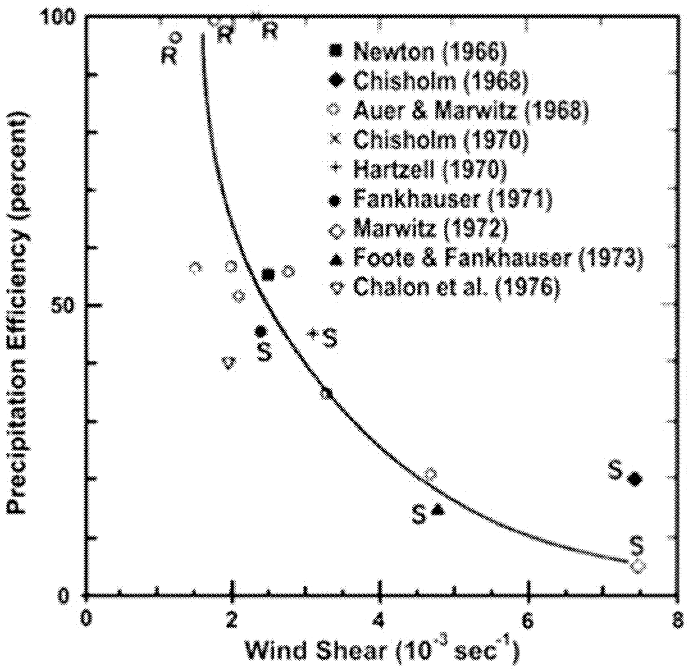

Fig. 8. Precipitation efficiency for High Plains thunderstorms, from Browning (1977). Known supercells are labeled "S". Storms that produced only rain are labeled "R". (Copyright American Meteorological Society, Boston, MA, used by permission.)

Precipitation efficiencies can vary widely from as little as 2% for storms studied by Marwitz (1972) and Dennis *et al.* (1970) to near 100% for a select few. Marwitz (1972d) and Foote and Fankhauser (1973) show that in the case of High Plains storms there is an inverse relation between the precipitation efficiency and the environmental wind shear in the cloud-bearing layer. [Wind shear is the change in wind speed and direction at various altitudes.] The least efficient storms tend to be supercell hailstorms; the highly efficient storms tend not to produce hail at all. The average wind shear on hail days in Alberta is approximately 2.5 x 10^{-3} sec-1. This average shear value corresponds to an average precipitation efficiency of approximately 50% (see again Figure 8). For reasons previously stated, it logically follows that the production of large, damaging hail is largely a result of natural storm inefficiency.

Krauss and Santos (2004) performed an exploratory analysis of the project volume-scan C-band radar data, using the TITAN storm tracking software, to obtain radar-derived rainfall from 160 seeded and 1167 non-seeded storms, on 82 days with seeding, during the summers of 2001 and 2002 in Alberta. The seeded storms (stratified according to maximum radar-derived cell top height) had greater mean durations (+ 50%), greater mean precipitation fluxes (+ 29%) and had greater mean total area–time integral of precipitation (+ 54%). There was statistical evidence to support the claim that seeding caused an increase in rainfall. The seeding effect was estimated to be a factor of 2.2 increase in the mean rainfall volume (averaged for categories 7.5–11.5 km height storms) with an average 95% confidence interval of (1.4, 3.4). The effect on point rainfall is less than the effect on rain volume because the seeding effect is composed of increases in the mean area and duration of the precipitation as well as the flux. The average increase in rainfall depth was approximately 12% which agrees well with the results from North Dakota.

The introduction of more precipitation embryos through seeding earlier in a clouds lifetime is generally highly advantageous, reducing the amount and size of any hail, and making the cloud more efficient as a rain producer in the process. Seeding a hailstorm means that less water is lost via the entrainment of dry environmental air through the sides and top of the cloud, or lost by ice crystals vented through the cloud anvil at high altitudes.

6. THE OPERATIONS PLAN

6.1 IDENTIFICATION OF HAIL-PRODUCING STORMS

The height of the 45 dBZ contour (a radar echo-intensity level) was a criterion tested in a Swiss hail suppression program. The Swiss research found that all hailstorms had 45 dBZ contours above the altitude of the –5°C temperature level (Waldvogel *et al.* 1979). There was a False Alarm Rate (FAR) of 50%, largely because some strong rainstorms also met the criterion. However, it is much preferable to make an error and assume that a heavy rainstorm is going to produce hail than to mistakenly believe that a hailstorm is only going to produce heavy rain. Studies of Alberta hailstorms also indicated that 50% of all Alberta hail storms had a maximum radar reflectivity greater than 45 dBZ, above the -5°C level (Humphries *et al.* 1987). The Russian criteria for hail identification stated that the height of the 45 dBZ contour had to exceed the height of the 0°C isotherm by more than 2 km (Abshaev 1999). Similarly, the criteria used by the National Hail Research Experiment in the USA (1972-1974) for a declared hail day was defined by radar maximum reflectivity greater than 45 dBZ above the -5°C level (Foote and Knight 1979). Our experience suggests that the Swiss/Alberta/Russian/USA criterion is reasonable (Makitov 1999). The physical reasoning behind it is simply that radar reflectivity (≥45 dBZ) implies that significant supercooled liquid water exists at temperatures cold enough for large hail growth.

In Alberta, the TITAN cell identification program is now set to track any cell having more than 10 km^3 of 45 dBZ reflectivity, extending above 3.5 km altitude (MSL). In all previous seasons the reflectivity threshold had been 40 dBZ, to be "safe", absolutely certain that every cell having even a slight chance of producing hail would be recognized by the radar-processing software as such. The drawback to this was that many, many cells not realistically having much potential for hail were being flagged. With the latest radar upgrade, however, the project radar now has a more sensitive receiver, smaller pulse length, and other radar processing improvements, such that ASWMS Project Manager Dr. Terry Krauss became confident that the 45 dBZ threshold could be used. This change was implemented for the 2015 season. As such, each such cell tracked by TITAN is then considered to be a potential hail cell; therefore, this represents our seeding criterion. A storm is a candidate for immediate seeding if the storm cell within the project boundary (as identified by TITAN with the criteria above) is moving towards and is expected to reach a protected town or city.

The impact on the 2015 project was immediate and very helpful. Shallow stratiform rains were no longer identified as TITAN cells. Also, when larger mesoscale convective systems developed the updated reflectivity criterion resulted in far fewer immense, sprawling and complex TITAN cells. In previous seasons it was common to be tracking three or more cells, only to see TITAN merge them into one very large, convoluted entity as their developing anvils merged. Because the cells remain separate longer, this is a significant plus for post-analysis, concentrating on the radar reflectivity volumes associated with hail. That rain showers are no longer identified as cells is not operationally significant.

6.2 ONSET OF SEEDING

In order for cloud seeding to be successful, it is the goal of the program to seed (inject ice nucleating agents) the developing "new growth" cloud towers of potential hail-producing storms at least 20 minutes before the storm cell moves over a town or city within the target zone. For the Alberta project, the principal targets are the towns and cities within the project area (Table 1). Since 20 minutes is the minimum time reasonably expected for the seeding material to nucleate, and have the seeded ice crystals grow to sufficient size to compete for the available supercooled liquid water (and yield positive results), a 30 minute or greater lead time is generally thought to be advisable.

6.3 CLOUD SEEDING METHODOLOGY

Radar meteorologists are responsible for initiating cloud seeding and patrol flights, alerting air crews of the presence of developing weather sufficiently in advance that aircraft will be ready for immediate flight when that time comes, in accordance with operational protocols. The meteorologists advise the Hailstop aircraft when to takeoff, and guide them to the storms of concern. Patrol flights are often launched before clouds within the target area meet the radar reflectivity seeding criteria, especially over or near the cities of Calgary and Red Deer.

These patrol flights ensure a quicker response to developing cells. In general, a patrol flight is launched in the event of visual reports of vigorous towering cumulus clouds, or when radar cell tops exceed 25 kft (7.6 km) height over the higher terrain in the western part of the operations area, especially on those days when the forecast calls for damaging hailstorms.

Fig. 9. Hailstop 4, 3 July 2015 at 8:20 PM. (WMI photograph by Jenelle Newman.)

Launches of additional aircraft are determined by the number and spacing of storms and the flight time required for each seeding aircraft to reach the desired location and altitude. Overlap of coverage (airspace) and on-station time are also considered. In general, to avoid collisions and for air traffic control (ATC) considerations only one aircraft can work safely at cloud top for each active thunderstorm complex. If multiple storms develop that are sufficiently spaced, more than one aircraft can work at cloud top simultaneously. Horizontal separation must be sufficient to ensure there is no chance of either aircraft impinging on the other's assigned airspace. [Cloud top seeding is always done under instrument flight rules (IFR), so separation is required by regulation as well as for safety.]

When the storm clouds of interest are relatively small (especially common when storms first develop), there is often room only for one seeding aircraft to operate beneath the rain free cloud base as well. However, when storms are larger and visibility is good, multiple aircraft can often be used safely at cloud base on the same complex. This is possible because flight operations below cloud base are usually conducted under visual flight rules (VFR) and out of cloud, so separation of aircraft can be ensured visually. To accomplish this, all cloud base seeding aircraft must be constantly aware of each other's locations. In addition, a landing light may be turned on to aid spotting by other Hailstop aircraft. Responsibility for safe separation of aircraft is not a responsibility of the project meteorologists, though they can usually monitor the relative positions in real-time through the *AirLink* tracking system. Rather, the flight crews have this responsibility. Multiple aircraft are most often used on the same storm when the storms assume a linear structure and develop new growth (towering cumulus) along the leading edge of the line. The project utilizes five aircraft to provide uninterrupted seeding coverage (at either cloud-base or cloud-top) and/or to seed multiple storms simultaneously, if required.

Factors that determine which seeding strategy is used (cloud top or cloud base seeding) include: storm structure, visibility, cloud base height, and/or time necessary for Hailstop aircraft to reach seeding altitude. Cloud base seeding is conducted by flying just below the cloud base within the developing inflow of growing *cumulus congestus* (towering cumulus) clouds, or the inflow associated with the new growth zone in advance of the shelf cloud located on the upshear side of linear multi cell storms (squall lines). Care is taken not to seed the strong updrafts of mature storms, for such clouds are too advanced in their development and hail development, if it has occurred, is too far advanced to be averted, and the seeding material would most likely be swept upward into the storm anvil without providing "beneficial competition" to the developing hail zone

6.4 SEEDING PROCEDURES

Cloud top seeding is usually conducted at altitudes where cloud temperatures are between the -5°C and -15°C and closer to the former when possible, typically at altitudes of about 16,000 to 18,000 feet MSL. Cloud top seeding is done primarily with small pyrotechnics, comprised of 20 grams of silver iodide seeding agent, which are ejected into updrafts in the upper regions of developing supercooled cloud towers. Each flare burns for ~37 seconds, while falling a maximum of 2,700 ft (0.8 km). Nevertheless, a minimum 3,000 ft vertical separation (~1.5 km) is always maintained between cloud top and cloud base seeding aircraft (Figure 10).

The cloud top seeding aircraft penetrate or skim the tops of developing, supercooled, largely ice-free (and therefore free of radar echo), *cumulus congestus* cells as they mature. When multicell storms are present or when more isolated storms have feeder clouds, the seeding aircraft penetrate or skim the tops of the developing cumulus towers as they grow up through the -10°C flight level. The direction of flight is determined by the location of any more mature, adjacent cells, which cannot be safely penetrated.

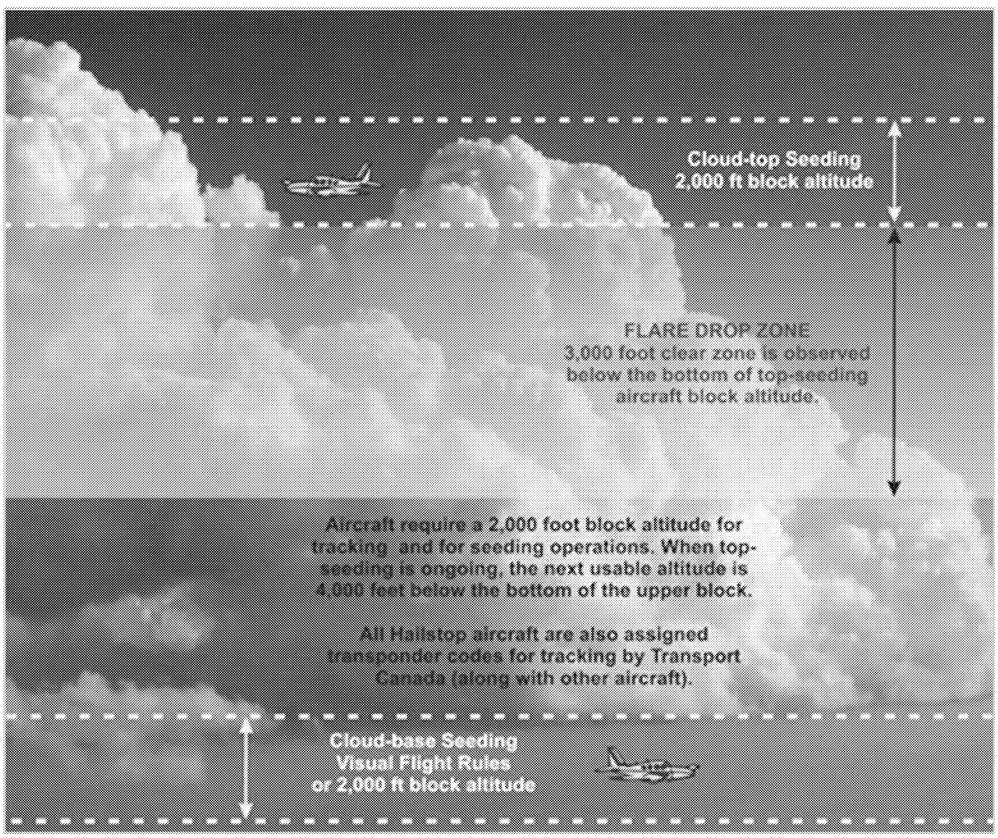

Fig. 10. Separation of aircraft by altitude. This diagram illustrates how vertical separation of cloud-base and seeding aircraft is achieved. (WMI graphic.)

When the growing cells of interest are embedded within surrounding cloud, and also with most convective complexes at night, there are no clearly defined feeder turrets visible to the flight crews. Seeding aircraft can use their on-board weather radars to help position themselves in these cases; however, aircraft radars are designed for weather avoidance, not for the detection of non-precipitating clouds, and so "see" only mature cells - those beyond the growth stage where seeding can be effective. In these instances, seeding aircraft will skim the storm edge at altitudes between -5°C and -10°C, near the region of tightest radar reflectivity gradient.

Seeding is done primarily by ejecting multiple 20-gram flares into cloud elements when updrafts and liquid water are encountered. A burn-in-place flare may be ignited also, especially when turrets are closely spaced and seedable cloud volumes are frequently encountered. Nocturnal seeding may also be performed from below the cloud base altitude when visibility is sufficient.

An idea of what night seeding is like is provided by Figure 11. Lightning can often help provide illumination at the cloud base and at cloud top, but such illumination is irregular, very brief, and by nature, "flat", meaning that human eyes struggle to perceive much depth and distance perception. Nevertheless, lightning does help in conducting nocturnal operations. On occasion, additional illumination may be provided by moonlight, especially if the upper reaches of the storm anvil do not shadow the developing turrets. In any case, the seedable clouds are those that have not yet produced precipitation, and therefore those devoid of radar echoes. For safety reasons flight operations require aircraft to avoid heavily electrified regions, and also close proximity to known hail and hail aloft, as indicated by the project radar. Wind shear and terrain clearance pose additional hazards. Though operations after dark are infrequent in Alberta because of the long summer days and lingering twilight hours, seeding operations are conducted whenever storms develop, even in the wee hours of the morning. Typically, this happens only a few times each season.

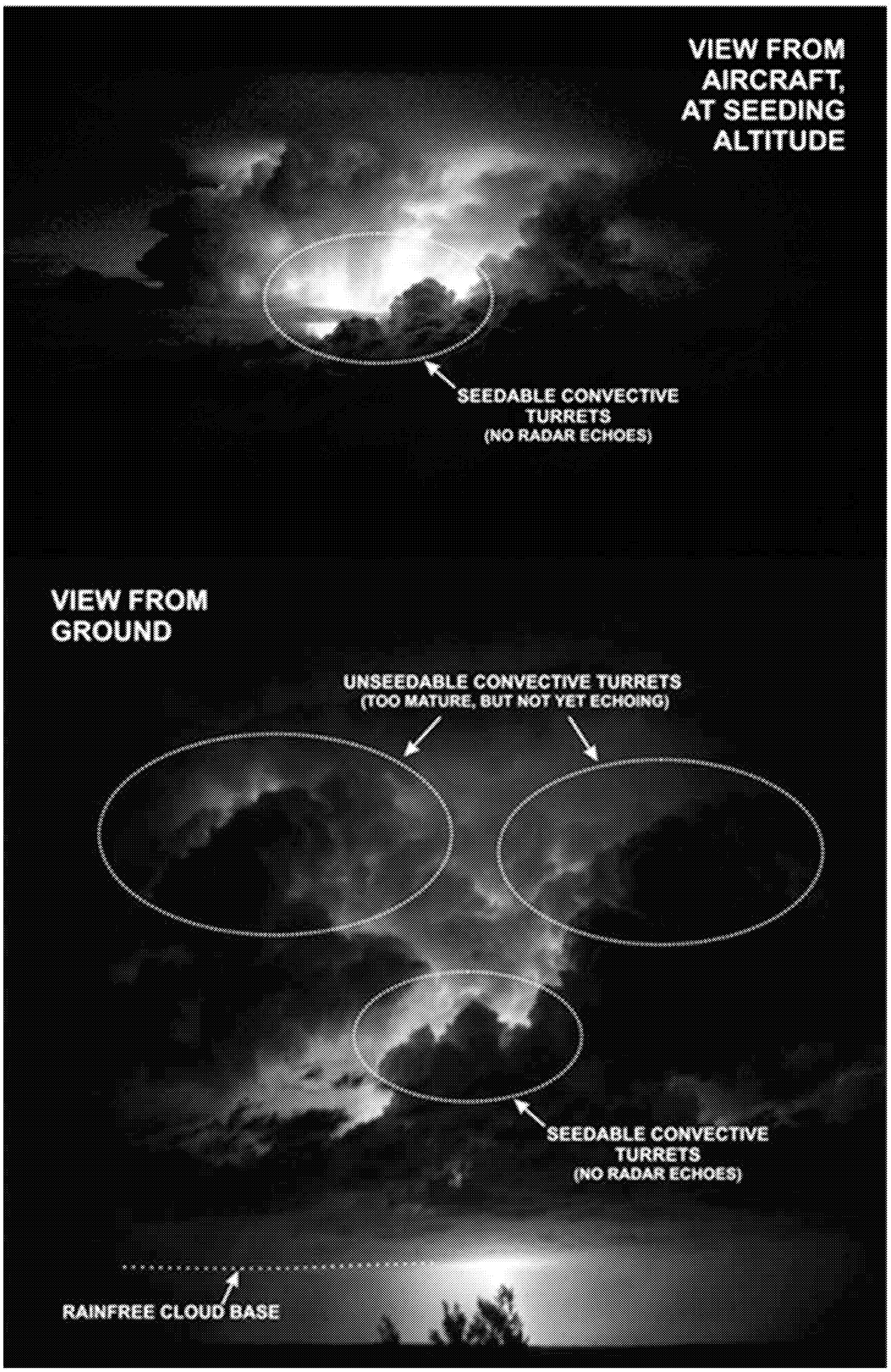

Fig. 11. Nocturnal lightning from the ground and from the air.

6.5 CESSATION OF SEEDING

If the radar reflectivity criteria continue to be met, seeding of all cells still in a position to threaten damage to towns or cities is to be continued. However, seeding is effective only within cloud updrafts and in the presence of supercooled cloud water, i.e. the developing stage in the evolution of the thunderstorm. The mature and dissipating stages of a storm cannot be effectively seeded because seeding only works by enhancing ice development in clouds that are primarily ice-free, characteristics which only are manifest in developing cloud turrets. Storm complexes having no new development are destined for decay. While a few storms simply develop, mature, and decay without initiating secondary development, those that have the potential to produce hail almost always produce cool outflows that initiate more new growth adjacent to the mature and dissipating portions of the storm. This new growth extends storm life and is seedable, so aircraft must operate in some proximity to mature, electrified clouds and dangerous wind shears, which include violent up- and downdrafts. Safety thus becomes of paramount importance. The history of aviation is filled with accounts of aircraft destroyed by thunderstorms, and the potential today is just as real as ever.

Safety of project aircraft and crews is ensured by strict adherence to flight policies that are designed to keep aircraft from ever entering mature portions of the storms, and from flying into extreme winds, hail, and lightning.

Strong radar reflectivity can only persist when new cloud development continues; when it doesn't, decay is inevitable. Thus, when storms maintain their intensities, developing cloud regions must exist, even though it is sometimes hard to find them. Such mature storm complexes are seedable only when the developing clouds are accessible to the seeding aircraft. If they are embedded within the mature clouds, hidden by decaying clouds, and cannot be approached from below (cloud base), seeding cannot safely occur. Storm cells being tracked by radar are not seeded if there are no indications of developing updraft or supercooled liquid water, or when the storm does not threaten a town or city.

6.6 SEEDING RATES

Silver iodide is dispensed in three ways: (1) a seeding solution can be burned from wing-tip-borne ice nucleus generators, (2) pyrotechnics can be burned "in place", while held to special racks affixed to the trailing edges of the aircraft wings, and (3) small pyrotechnics can be ignited and ejected into cloud tops from racks mounted on the belly of the aircraft fuselage.

A seeding rate of one 20 gram flare every 5 sec while in supercooled updraft is typically used during cloud penetrations. A higher rate is used (*i.e.* 1 flare every 2 to 3 sec) if updrafts are very strong (i.e. greater than 2000 ft/min) or if the storm is particularly intense. Cloud seeding passes in the same region are immediately warranted if there are visual signs of continued new cloud growth or if the radar reflectivity gradient of the parent cell remains tight (indicative of continued growth and persistent updrafts). If not, a 5 to 10 min waiting period may be used between penetrations, to allow the seeding to take effect and for visual signs of glaciation to appear, or for radar reflectivities to decrease and gradients to weaken. Such waiting reduces the amount of seeding material used. Calculations show that the seeding rate of one flare every 5 sec will produce >1300 ice crystals per litre averaged over the plume within 2.5 min. This is more than sufficient to deplete the liquid water content produced by updrafts up to 10 m s-1 (2000 ft/min), thereby preventing the growth of hailstones within the seeded cloud volumes (Cooper and Marwitz 1980).

For effective hail suppression, sufficient dispersion of the particles from consecutive flares is required for the AgI plume to overlap by the time the cloud particles reach hail size. The work by Grandia *et al.* (1979) based on turbulence measurements within Alberta feeder clouds indicated that the time for the diameter of the diffusing line of AgI to reach the integral length scale (200 m) in the inertial subrange size scales of mixing, is 140 seconds. This is insufficient time for ice particles to grow to hail size, therefore, dropping flares at 5 sec intervals (assuming a true-airspeed of 80 m s^{-1}) should provide sufficient nuclei and allow adequate dispersion to effectively deplete the supercooled liquid water and reduce the growth of hail particles. The use of the 20 gram flares and a frequent drop rate provides better seeding coverage than using larger flares with greater time/distance spacing between flare drops. In fact, the above calculations are conservative when one considers that the centre of the ice crystal plume will have a greater concentration of ice crystals.

For cloud base seeding a seeding rate using two solution-burning generators or one burn-in-place flare is typically used, dependent on the updraft speed at the cloud base. For an updraft >500 ft min^{-1}, generators and consecutive flares per seeding run are typically used. Cloud seeding runs are repeated until inflow (updraft area) has diminished or until the storm of concern has passed all urban areas. Solution-burning ice nucleus generators are used to provide continuous silver iodide seeding if extensive regions of light or moderate updraft are found at cloud base in advance of the shelf cloud region. Base seeding is not conducted if only downdrafts are encountered at cloud base, since this would waste seeding material.

6.7 SEEDING AGENTS

The cloud seeding pyrotechnics used by WMI are exclusively silver iodide formulation flares manufactured by Ice Crystal Engineering (ICE) of Kindred, North Dakota. The ejectable flares contain 20 grams of seeding material and burn for approximately 37 sec and fall approximately 3000 ft before burning up. The burn-in-place (BIP) flares contain 150 grams of seeding material, and burn for approximately 4 min. Arrangements were made with Solution Blend Services, a Calgary-based company, to pre-mix all seeding solution from reagent grade raw materials provided by WMI. All handling, mixing, storage, and labelling requirements established by law and regulation were fully satisfied.

The Cloud Simulation and Aerosol Laboratory (SimLab) at Colorado State University (CSU) has tested the ice nucleating ability of aerosols produced from cloud seeding flares and solutions for many years (Garvey 1975, DeMott 1999). [Note: The SimLab is now closed and no longer performs such tests; a new testing facility to conduct these standardized tests is not yet available.] The current ICE pyrotechnics were tested at CSU in 1999 as reported by DeMott (1999). Aerosols were collected and tested at nominal temperatures of -4, -6 and -10°C. At least two tests were done at each temperature, with greater emphasis placed on warmer temperatures. The cloud chamber liquid water content (LWC) was 1.5 g m^{-3} for most tests, but 0.5 g m^{-3} for some, enough to confirm the dependence of nucleation rate upon cloud droplet concentration. The primary product of the laboratory characterization is the "effectiveness plot" for the ice nucleant which gives the number of ice crystals formed per gram of nucleant as a function of cloud temperature. Yield results for the ICE flares at various sets of conditions are shown in Figure 12 and are tabulated in Table 2.

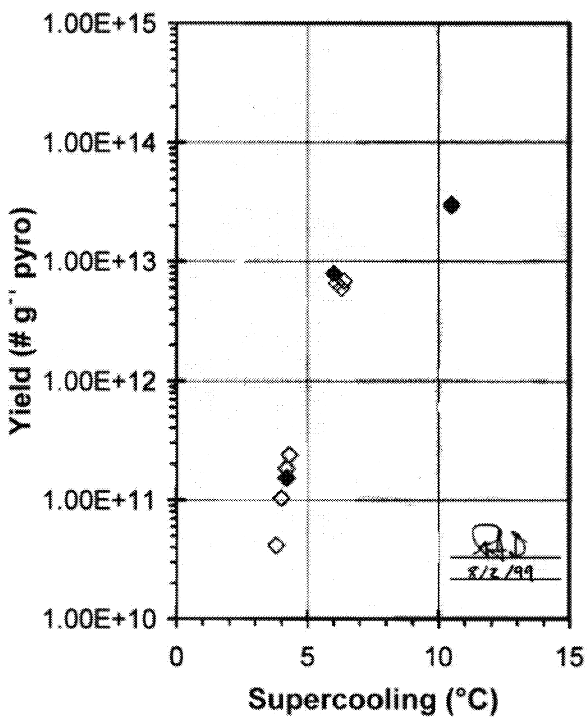

Fig. 12. Yield of ice crystals per gram of pyrotechnic as a function of supercooling.

Temp (°C)	LWC ($g\ m^{-3}$)	Raw Yield (g^{-1} AgI)	Corr. Yield (g^{-1} AgI)	Raw Yield (g^{-1} pyro)	Corr. Yield (g^{-1} pyro)	Yield (per pyro)
-3.8	1.5	$3.72x10^{11}$	$3.87x10^{11}$	$4.01x10^{10}$	$4.18x10^{10}$	$8.36x10^{11}$
-4.0	1.5	$9.42x10^{11}$	$9.63x10^{11}$	$1.02x10^{11}$	$1.04x10^{11}$	$2.08x10^{12}$
-4.2	1.5	$1.66x10^{12}$	$1.70x10^{12}$	$1.80x10^{11}$	$1.84x10^{11}$	$3.67x10^{12}$
-4.3	1.5	$2.15x10^{12}$	$2.21x10^{12}$	$2.32x10^{11}$	$2.39x10^{11}$	$4.77x10^{12}$
-6.1	1.5	$6.01x10^{13}$	$6.13x10^{13}$	$6.49x10^{12}$	$6.62x10^{12}$	$1.32x10^{14}$
-6.3	1.5	$5.44x10^{13}$	$5.56x10^{13}$	$5.87x10^{12}$	$6.00x10^{12}$	$1.20x10^{14}$
-6.4	1.5	$6.22x10^{13}$	$6.34x10^{13}$	$6.72x10^{12}$	$6.85x10^{12}$	$1.37x10^{14}$
-10.5	1.5	$2.81x10^{14}$	$2.85x10^{14}$	$3.03x10^{13}$	$3.07x10^{13}$	$6.15x10^{14}$
-10.5	1.5	$2.34x10^{14}$	$2.37x10^{14}$	$2.87x10^{13}$	$2.91x10^{13}$	$5.81x10^{14}$
-4.2	0.5	$1.41x10^{12}$	$1.45x10^{12}$	$1.53x10^{11}$	$1.57x10^{11}$	$3.14x10^{12}$
-6.0	0.5	$7.42x10^{13}$	$7.73x10^{13}$	$8.01x10^{12}$	$8.34x10^{12}$	$1.67x10^{14}$
-10.5	0.5	$2.38x10^{14}$	$2.41x10^{14}$	$2.91x10^{13}$	$2.96x10^{13}$	$5.92x10^{14}$

Table 2. Yield (per gram) of the ICE Glaciogenic Pyrotechnic (DeMott 1999).

Tests were also performed using the method of DeMott *et al.* (1983) to determine the characteristic times for effective ice nuclei activation; these are summarized in Figure 13 and Table 3. The primary results of the CSU SimLab tests of the glaciogenic cloud seeding pyrotechnics manufactured by ICE are summarized as follows (from DeMott 1999):

- The aerosol particles produced by the new ICE pyrotechnics were highly efficient ice nucleating aerosols. Yield values were approximately 1x1012, 5x1013 and 3x1014 ice crystals per gram pyrotechnic effective at -4, -6 and -10°C in 1.5 g m-3 clouds in the CSU isothermal cloud chamber. Improvement compared to the previous pyrotechnic formulation used by ICE was modest at -6°C, but most significant (factor of 3 increase in yield) at -4°C.
- The ICE pyrotechnics burned with a fine smoke and a highly consistent burn time of ~37 s.
- Rates of ice crystal formation were very fast, suggestive of a rapid condensation freezing process. The balance of observations showed no significant difference in the rate data obtained at varied cloud densities, supporting a conclusion that particles activate ice formation by condensation freezing.

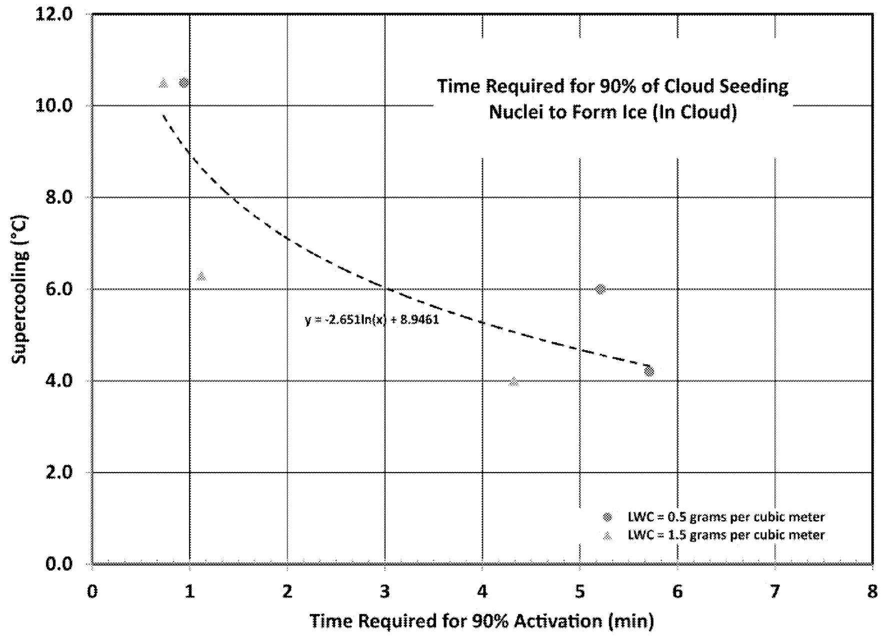

Fig. 13. The time required for 90% of the seeding agent (nuclei) to form ice, as a function of supercooling. At temperatures colder than about -9°C (9° supercooling), 90% of the seeding agent produces ice in cloud. (Data from DeMott 1999.)

The CSU isothermal cloud chamber tests indicate that, on a per gram basis of pyrotechnic, the output and effectiveness indicate that the best available worldwide. High yield and fast acting agents are important for hail suppression since the time-window of opportunity for successful intervention of the hail growth process is often less than 10 minutes. More information about the ICE glaciogenic pyrotechnics can be found on the internet at www.iceflares.com.

Temp (°C)	LWC (gm-3)	k (min-1)	kdil (min-1)	kact (min-1)	T1/e (min)	T90% (min)	Yield Correction
-4.0	1.5	1.093	0.023	0.935	0.94	4.32	1.023
-4.2	0.5	0.713	0.019	0.694	1.44	5.71	1.028
-6.3	1.5	1.775	0.038	1.737	0.48	1.12	1.020
-6.0	0.5	0.724	0.028	0.696	1.43	5.21	1.041
-10.5	1.5	3.200	0.045	3.155	0.32	0.73	1.014
-10.5	0.5	2.488	0.040	2.448	0.41	0.94	1.016

Table 3. Activation Rate of Nuclei Produced by ICE Pyrotechnic (DeMott 1999).

6.8 *SUSPENSION*

Criteria are in place that define when seeding should be stopped, or not be conducted. These criteria were developed in accordance with the Weather Modification Association (WMA) statement recommending such criteria be established for all projects. The specifics of the WMA statement can be found by visiting the following link: http://www.weathermodification.org/standards_ethics.php.

The ASWMS suspension guidelines are as follows:

The following criteria and procedures for suspending operations in the face of impending severe weather to avoid contributing to, or appearing to contribute to, damaging weather situations shall be followed:

1. An emergency shutdown of seeding operations can be declared when there is a situation that poses an immediate threat to life and property. A logical criterion would be when a community is under a declared State of Emergency for flooding or tornado.

2. If the field meteorologist has any doubt about whether suspension criteria are met, he or she should order seeding stopped, and then contact the Project Director for clarification.

3. The Alberta Severe Weather Management Society policy of suspension of seeding during severe weather activity is strictly for reasons related to public perception and aircraft safety.

4. Resumption of normal seeding operations would be conditional on the emergency situation no longer posing a reasonable threat, such as a declared State of Emergency being lifted. However, if a storm forecast is of significant threat (3.3 cm diameter hail or greater), the Project Director has the authority to resume operations at any time.

7. PROGRAM ELEMENTS AND INFRASTRUCTURE

7.1 INFRASTRUCTURE

The flow of information within the project is illustrated in block diagram form in Figure 14. The focal point of the project is the Operations Centre, located at the Olds-Didsbury Airport, approximately halfway between the two largest metropolitan areas, Calgary and Red Deer.

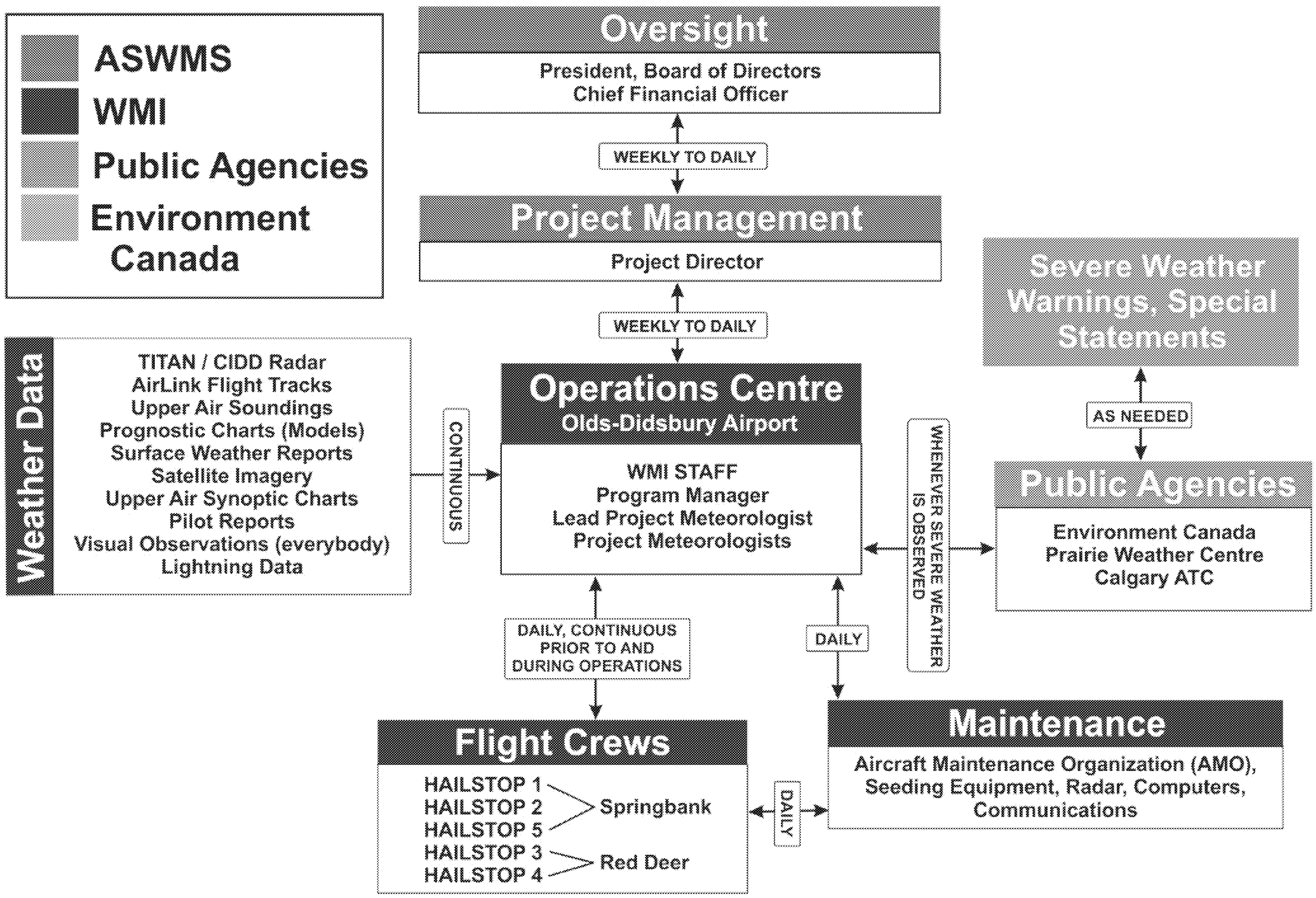

Fig. 14. Schematic of Program Infrastructure. Arrows denote direction of information flow. Arrow labels show typical frequency of communications.

The ASWMS Board is comprised of individual insurance industry employees nominated by their respective companies. The ASWMS President serves as the primary liaison between the Board and Weather Modification, Inc. (WMI), though all Board members receive the project summary reports compiled and disseminated weekly by WMI during the operational period, which is June 1 through September 15, annually.

7.2 THE OPERATIONS CENTRE

Environment Canada operates two weather radars in Alberta, one in Carvel, near Edmonton, and the other at Strathmore, east of Calgary. While good for surveillance of the province, neither provides the detail and flexibility needed for hail suppression operations in the target area. Thus, radar support for the project required that a third radar be installed. Since the project's inception in 1996 the Operations Centre and radar have been based at the Olds-Didsbury Airport, centrally located in the target area (see again Figure 4).

An illustrated schematic diagram (Figure 15) of project activities occurring at and around the Operations Centre provides more detail about the origins and flow of data critical for operations. Technical specifications of all project-operated facilities and equipment are given in the appendix of this report.

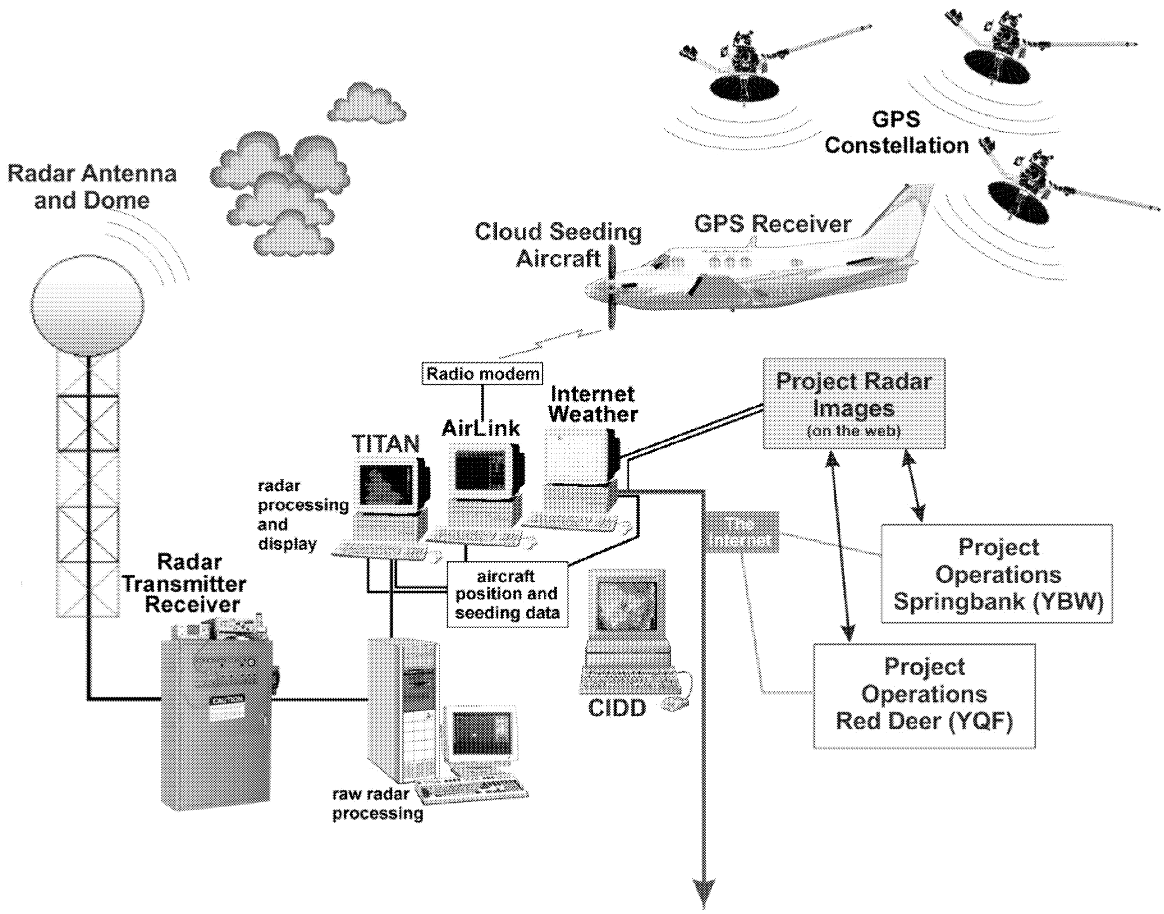

Fig. 15. AHSP Operational Elements. The radar and associated equipment shown are all at the Project Operations Centre, located at the Olds-Didsbury Airport, approximately halfway between Calgary and Red Deer.

All project operations are directed and monitored from the WMI radar installation at the Olds-Didsbury Airport (official airport identifier: CEA3). Project offices for radar operation and monitoring, weather forecasting, recordkeeping, and overall administration are located on the airfield just south of the main ramp. Immediately adjacent to the Operations Centre offices is the easily recognizable radar tower and radome (Figure 16).

The project control room contains the following: radar displays and processing computers, the *AirLink* flight telemetry system, computers with internet connectivity for access to external weather data, VHF radios for direct communication with project aircraft, and telephone.

The primary radar display and control is achieved through the Thunderstorm Identification, Tracking, Analysis, and Nowcasting (TITAN) acquisition and processing software. The TITAN software processes and displays the full-sky volume scan radar data, producing a variety of graphical images that are useful in real-time as operations are conducted, and also in post-analysis. [Note: the term volume scan refers to radar data collected during a complete set of 360°, full-azimuth scans, each at progressively higher antenna elevation angles. About four minutes are required for the radar to complete each volume scan.]

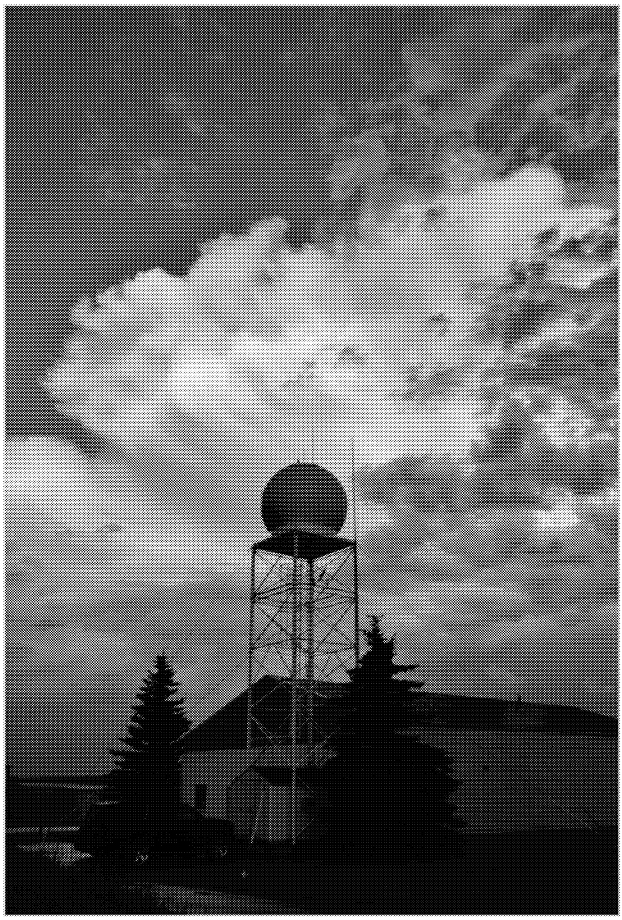

Fig. 16. The glow of the evening sun paints the top of a strong thunderstorm at 9:56 PM on 3 July 2015, as the passing storm finally moves east of the Operations Centre. (WMI photograph by Adam Brainard.)

7.3 DIGITAL WEATHER RADAR

The TITAN software helps the meteorologists identify potential hailstorms and, with the flight tracks of project aircraft superimposed, improves the guidance of aircraft to the hail-growth regions of active thunderstorms. The primary (and largest) TITAN display window is referred to as the RVIEW window. The operator can select the RVIEW window to display any of a number of TITAN parameters either as observed for specific constant altitude plan views (called CAPPIs), or as a composite view, that shows the maximum value observed at each coordinate anywhere above the surface. Composite reflectivity TITAN images are sent to the WMI web server after the completion of each volume scan.

Operating in tandem with TITAN is the Configurable Interactive Data Display (CIDD) radar processing system. The CIDD is similar to TITAN in function. There are advantages to both systems, so WMI uses both. The CIDD is typically set up to run a continuous animated 1-hour movie loop.

Both TITAN and CIDD are available in the operations room on dedicated displays, that is, flat-panel monitors dedicated full-time to those purposes. In addition, a supplemental TITAN RVIEW window is not used interactively, but used to port (send) TITAN data to the web upon the completion of each complete radar volume scan. This is done to ensure that the web image is consistent from scan to scan.

7.4 GROUND SCHOOL

A ground school was conducted prior to the commencement of the project field operations on 28 May 2015, for project personnel at the Intact Insurance training room in downtown Calgary. Operational procedures about who does what, where, when and why, as well as general conduct and reporting requirements were presented and reviewed at the ground school. A representative of NAV Canada's Air Traffic Control Unit for Calgary participated in the ground school. A copy of the ground school program and samples of the flight log and radar log forms are included in the appendices.

The pre-project ground school training topics included:

i. program overview and design, project area, target areas, and priorities
ii. overview of operations and procedures
iii. cloud seeding hypotheses for hail suppression
iv. cloud seeding theory and techniques
v. aviation weather problems and special procedures
vi. aircraft controlling techniques and procedures
vii. seeding aircraft equipment and characteristics
viii. weather radar equipment and basic principles

ix. basic meteorological concepts and severe weather forecasting
x. weather phenomena, fronts, and storms
xi. daily routines and procedures
xii. communications procedures
xiii. computers, documentation, and reporting procedures
xiv. safety, security precautions and procedures

7.5 PUBLIC RELATIONS

A total of ten groups toured the project Operations Centre at the Olds-Didsbury airport as part of the Alberta Insurance Council accreditation program. Tours were conducted on June 18, 24, 30; July 14, 22, 28; and August 6, 12 18, 24. In total 198 persons took part in this program, which helps those working in the industry understand the program.

The tours, organized and led by Ms. Ashley Batke, each included a presentation by ASWMS Program Director Dr. Terry Krauss, a tour of the room and equipment used to direct the cloud seeding operations, and a chance to see one of the project seeding aircraft and its associated equipment (Figure 17). Recent storms were also replayed on the radar. In addition to the equipment used in the project, attendees learn about Alberta's long history in hail suppression research and operations, the scientific basis for the program, and how the seeding agent (silver iodide) functions to reduce hail. They also learn how the operations are conducted, hearing the information from the meteorologists and pilots who actually perform the operations.

8. FLIGHT OPERATIONS

Five specially equipped cloud seeding aircraft were dedicated to the project. Two Beech C90A King Airs and one Cessna 340A were based in Springbank, and a C90A and another C340A were based in Red Deer. The procedures used in 2015 remained the same as the previous years. The Springbank office and aircraft were at Springbank Aero Services, at that airport. The WMI Red Deer office was again set up in the Air Spray hangar at the Red Deer Regional Airport, as had been done in the four previous seasons.

When convective clouds were detected by radar or visually observed to be developing, the seeding aircraft were placed on standby status, and the crew of at least one sent to their airport. Aircraft on standby status are able to launch and reach a target cloud within about 30 min after the request to launch has been made by the controlling meteorologist. When seedable clouds are imminent, the seeding aircraft are dispatched to investigate. Aircraft were available and prepared to commence a seeding mission at any time, and the seeding of storms often continued after dark, with due regard to safety (see again Figure 11).

Fig. 17. Captain Jenelle Newman (center) explains the seeding equipment on Hailstop 4 to some of the participants in the 18 August 2015 continuing education tour and seminar at the Olds-Didsbury Airport. (WMI photograph by Bradley Waller.)

8.1 AIR TRAFFIC CONTROL

Prior to the start of field operations, arrangements were made with NAV Canada managers of Air Traffic Services in Calgary and Edmonton to coordinate the cloud seeding aircraft operations. Permission was granted to file pre-defined flight plans for the project aircraft, with special designations and fixed transponder codes. The designated aircraft were as follows: Hailstop 1 for the King Air C90 airplane (N904DK) based in Springbank, Hailstop 2 for the C340 aircraft (N457DM) based in Springbank, Hailstop 3 for the King Air C90 aircraft (N522JP) stationed in Red Deer, Hailstop 4 for the C340 aircraft (N37356) based in Red Deer, and Hailstop 5 for the King Air C90 aircraft (N518TS) based in Springbank.

Fig. 18. Hailstop 3 turns back toward the thunderstorm of interest while seeding at cloud top on 19 June 2015, at 7:07 PM. Note the ice on the windscreen (to the right), accumulated evidence of supercooled cloud water, the raw ingredient for hail. (WMI photograph by Joel Zimmer.)

Direct-line telephone numbers were used to notify air traffic controllers of cloud seeding launches. Aircraft were launched to specific locations defined by VOR and DME coordinates. Distinct air traffic clearance was given to project aircraft within a 10 nautical mile radius of the specified storm location. Cloud top aircraft were given a 2,000 ft block with 6,000 ft clearance below bottom of their block. Cloud base aircraft were typically given a ± 1,000 ft altitude clearance (see again Figure 10). This procedure works very well in general. On a few occasions, seeding aircraft are asked to briefly climb to higher altitudes while passing over the city of Calgary, or to suspend seeding for a few minutes to allow other commercial aircraft to pass below them, but such interruptions are infrequent.

8.2 CLOUD SEEDING AIRCRAFT

Two different models of twin-engine aircraft were utilized on the project. Hailstop 1, Hailstop 3, and Hailstop 5, the cloud-top seeding aircraft, were Beech King Air C90s, turboprop (propjet) aircraft. Both cloud-base seeding aircraft (Hailstop 2 and 4) were Cessna model 340A aircraft. All five aircraft were equipped with fuselage-mounted flare racks carrying ejectable flares, and also wing racks for burn-in-place flares. The two Cessna 340As also were equipped with solution-burning ice nucleus generators affixed to their wingtips.

Beech King Air C90

A photo of one of the Beechcraft King Air C90 (Hailstop 1) is shown in Figure 19. Complete aircraft specifications are given in the Appendix. The King Air C90 is a high-performance twin engine turboprop aircraft that has been proven repeatedly in seeding operations. Each of the King Airs was equipped with three belly-mounted racks each having the capacity for 102 twenty-gram ejectable cloud seeding flares, for an aircraft total of 306 flares. Each also carried racks affixed to the trailing edges of the wings that held up to forty-eight 150-gram "burn-in-place" flares per wing. As this nomenclature implies, the burn-in-place pyrotechnics are not ejected, but are burned while attached to the wing rack.

The three turboprop King Air seeding aircraft (Hailstop 1 and 5, Springbank, and Hailstop 3, Red Deer) were used primarily for seeding at cloud top by direct penetration of growing cloud turrets, most often those flanking large storm complexes. Such turrets are precipitation-free at the time of seeding, and consequently (radar) echo-free as well, though more mature adjacent cells may be producing strong radar returns. This means that those monitoring operations will often see the flight tracks of properly positioned aircraft near the echoing storm complexes, but not necessarily in them. This direct targeting makes very effective use of these aircraft, which function most efficiently at higher altitudes.

Fig. 19. A King Air model C90, Hailstop 1, awaits the development of convective weather on the morning of 2 July 2015. Racks of burn-in-place pyrotechnics are visible aft of the near wing. (Photograph courtesy of Terry Krauss.)

Cessna 340A

The two other seeding aircraft, Hailstop 2 (Springbank) and Hailstop 4 (Red Deer), were Cessna 340A aircraft whose primary role was seeding the growing cloud turrets while within updrafts at cloud bases. The Cessna 340s are pressurized, twin engine, six cylinder, turbocharged and fuel injected all weather aircraft, equipped with weather avoidance radar and GPS navigation system (Figure 20). Complete specifications for the C340 are given in the Appendix.

The C340 aircraft both carry a 204-position belly rack for twenty gram ejectable flares (used in cloud top seeding, which they also can do very effectively), and wing racks for at least twenty-four 150 gram burn-in-place flares, as well as two wing-tip ice nucleus generators that burn silver iodide seeding solution. Each generator has a capacity of 26.5 litres (7.0 U.S. gallons), sufficient for continuous seeding for about 2.5 hours.

Although the C340 can seed effectively at cloud top, even in known icing conditions, these aircraft are not as fast or powerful as the turboprop aircraft and so are more efficient and cost-effective when utilized in cloud-base seeding operations, their primary role in Alberta.

Fig. 20. A Cessna model 340A, Hailstop 2, rests on the ramp at the Olds-Didsbury Airport, awaiting the afternoon insurance industry tour of 24 June 2015. (WMI photograph by Adam Brainard.)

9. RADAR CONTROL AND COMMUNICATIONS CENTRE

The project Operations Centre was located at the Olds-Didsbury Airport (identifier CEA3), near the geographical centre of the protected area, and approximately equidistant from Calgary and Red Deer. The office contains a modest reception and work area, the operations room from which the weather is monitored and operations conducted, and a washroom. The reception/work area has two desks, telephone, a printer/copier/scanner/fax, and a digital projector used for presentations about the program. A small refrigerator, coffee pot, and water cooler were also available for staff use.

The project's radar control room contained an *AirLink* computer with radio telemetry modem for GPS aircraft tracking acquisition, as well as the TITAN computer and display for the radar, and the meteorological data acquisition (internet) computer. Controllers communicated with the seeding aircraft using VHF radio. The controlling duties were led by Dan Gilbert, who was assisted by Brad Waller and Adam Brainard.

The operations room was configured to place all the needed resources within easy reach of the operations director. Project reference and equipment manuals were shelved on the upper left. Telephones were available, with remote handsets. The desk top provides the space needed for data recording (logs) and data entry (keyboard/mouse). The VHF radio needed for ground-to-air communication was placed directly in front of the operations director. To the far right was a third computer with dual monitors (Figure 21, I, J), for continuous, dedicated access to internet weather data from other sources. There was ample room for a second meteorologist in the operations room when needed to assist with radio communications, data entry, or general weather surveillance.

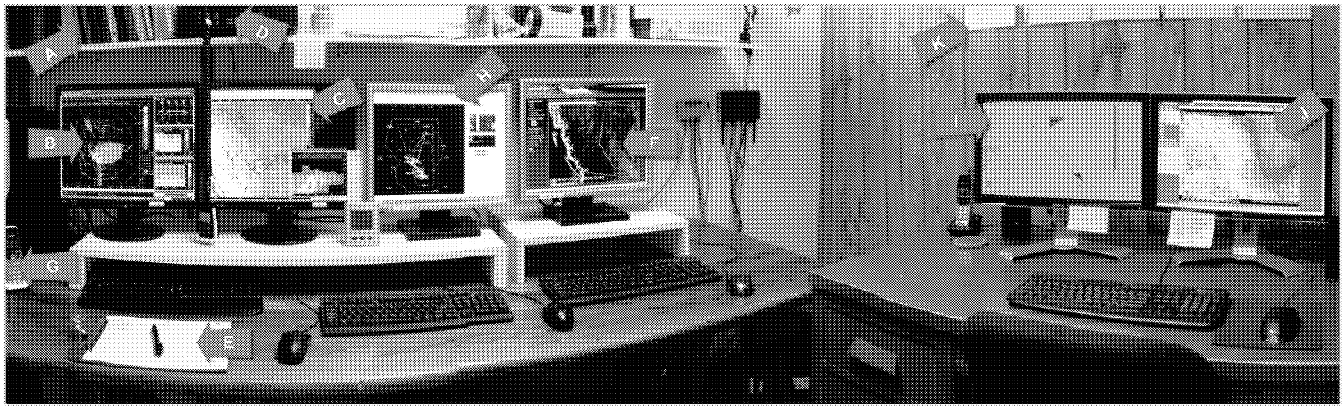

Fig. 21. The configuration of the Operations Room. Equipment includes (A) reference manuals, (B) TITAN displays, (C) CIDD, (D) VHF radio for communications with aircraft, (E) radar log, (F) internet data displays, (G) telephone, (H) *AirLink* display, (I and J) forecasting/nowcasting support displays, and (K) radio and radar licenses. (WMI wide-angle photograph by Daniel Gilbert.)

High speed internet was again installed at the Springbank and Red Deer airport offices so that the pilots could closely monitor the storm evolution and motion prior to takeoff. This gave crews better comprehension of the storm situation they were going to encounter once airborne.

A Davis weather station was installed at the Operations Centre. This station, affixed to the sub-structure of the airport's non-directional radio beacon (NDB) tower, telemetered temperature, pressure, wind, and humidity into the office, where it was displayed in real-time and recorded. Data from the station were also made available in real-time through the Internet.

9.1 RADAR

The current Doppler weather radar was installed in May 2014, prior to the project start. Improvements realized included implementation of the latest version of the TITAN radar software, state-of-the-science radar antenna control, and improved data processing. The last allowed the time required for each volume scan to be decreased from five to less than four minutes (beginning in 2014), which meant the radar updated 15 times per hour, rather than 12. In addition, the porting of data to the WMI website was also improved.

A large battery backup system for the radar, TITAN, and the other mission-critical equipment in the operations room made it possible to hold all essential computers on battery more than long enough to start the backup generator and switch over to local power. The backup generator was run for a short period (10-15 minutes) each month during the season to ensure functionality for when it is needed. Radar calibration data and system specifications are given in Table 4.

WMI Radar, Olds-Didsbury Airport

CALIBRATIONS ***Parameter***	***June 2015 (dBm)***	
Radar Constant	77.2577	
Noise	-64.5418	
Minimum Detectable Signal	-106.945	
Receiver Gain	42.4013	
Minimum dBZ at 1 km Range	-29.6555	
SYSTEM SPECIFICATIONS		
Frequency (C-band)	5.975	GHz
Peak Power	250	KW
Average Power	150	W
Range Gate (length)	150	m
Pulse Repetition Frequency	600	sec^{-1}
Pulse Width	1.0	µsec
Range	180	km
Beam Width	1.65	deg
Volume Scans	15	per hour

Table 4. Calibrations and Specifications of the Advanced Radar Corporation WMI Radar located at Olds-Didsbury Airport.

9.2 AIRCRAFT TRACKING

The project Operations Centre was equipped to receive and record data from all project aircraft, using data radio and WMI's *AirLink* tracking system. These GPS-based systems provided the exact real-time positions of the aircraft, allowing them to be superimposed on the TITAN RVIEW display. This allowed the meteorologist(s) controlling flight operations to accurately direct the aircraft to optimum seeding positions relative to each storm system. Each aircraft track was displayed in a different color, providing unambiguous identification. Examples of the raw *AirLink* data flight tracks, as well as 10-minute track segments superimposed on the TITAN displays are provided later in this report in the detailed descriptions of the storms of 4 and 5 August 2015 that struck Calgary.

AirLink also displays where the seeding events took place, but these were not displayed on the tracks in the TITAN RVIEW because doing so adds excessive clutter to the already "busy" image. In addition to being telemetered to the Operations Centre, the position and seeding event data are recorded on board the aircraft, and thus are not lost if the telemetry between aircraft and radar is interrupted.

10. SUMMARY OF SEEDING OPERATIONS

A brief summary of each day recounting the weather and operational activities is given in the Appendix. Further details regarding flight times and the amount of seeding are given in the Flights and Operations Summary tables, also in the Appendix.

The weather pattern during the summer of 2015 was less active than the previous summer, having 26 seeding days, while the twenty-season average is about 31. However, those twenty-six days were active, for all five Hailstop aircraft flew on twelve days, and all five aircraft seeded on ten of those twelve days.

Five specially equipped cloud seeding aircraft were dedicated to the project. Two Beech C90A King Airs and one Cessna 340A were based in Springbank, and a C90A and another C340A were based in Red Deer. The procedures used in 2015 remained the same as the previous years. The Springbank office and aircraft were at Springbank Aero Services, at that airport. The WMI Red Deer office was again set up in the Air Spray hangar at the Red Deer Regional Airport, as had been done in the three previous seasons.

In June, 29 seeding missions were flown on 7 days, and an additional four flights flown for patrol on 4 days. A "patrol" flight is a flight flown to check cloud intensity or in anticipation of clouds becoming intense enough to warrant seeding, but during which no seeding was actually conducted.

July was the most active month. Fifty-six seeding missions were flown on 14 days, and 10 more patrol flights on 4 days. The heaviest seeded day of the season occurred on July 21st over Red Deer, Blackfalds, and Lacombe when a line of supercell hailstorms pushed through the northern project area. A detailed analysis of the July 21st storm is provided as a case study later in this report.

Activity diminished significantly in August, with 14 seeding missions flown on five days, the last occurring on August 15th. Four patrol missions were also flown on 2 days. The vast majority of August seeding occurred on the 4th and 5th when hailstorms moved through Calgary on back-to-back days. A detailed analysis of the August 4th-5th storms is provided as a case study later in this report.

No seeding was conducted in September, and no patrol missions were needed.

The aircraft and crews provided a 24-hour service, seven days a week throughout the period. Ten full-time pilots and three meteorologists were assigned to the project this season. In addition, WMI's Chief Pilot, Mr. Jody Fischer, served as overall project manager. The 2015 crew was very experienced. The Red Deer aircraft team was led by Mr. Mike Torris and Ms. Jenelle Newman, both project veterans, and Mr. Joel Zimmer who has been with the Alberta program for 13 seasons. The Springbank team was anchored by Mr. Jody Fischer and Mr. Jake Mitchem. The radar crew was anchored by WMI's Chief Meteorologist, Mr. Daniel Gilbert, now with six seasons' experience in Alberta, in addition to seven seasons' work in a similar capacity on a hail suppression program in North Dakota.

Overall, the personnel, aircraft, and radar performed well and there were no interruptions or missed opportunities. A radar calibration at the beginning of the project season ensured that during the 2015 season the radar was calibrated correctly. On the afternoon of July 14th, the radar power went out for two hours during intensive operations. The backup power system (UPS and generator) worked flawlessly. There was not a single missed scan and ops continued normally.

Fig. 22. A wide-angle camera on Hailstop 2 recorded this approach to the next cloud turret to be seeded on 21 July 2015, near Lacombe, one of the case-days summarized later in this report. (WMI photograph by Mike Torris.)

High speed Internet service was once again obtained at the Springbank and Red Deer offices for the pilots so that they could closely monitor the storm evolution and storm motion using the radar images on the web prior to take-off. All of the project's radar data, meteorological data, and reports have been recorded onto a portable hard drive as a permanent archive for the Alberta Severe Weather Management Society. These data include the daily reports, radar maps, aircraft flight tracks, as well as meteorological charts for each day. The data can be made available for outside research purposes through a special request to the Alberta Severe Weather Management Society. In addition, ASWMS Program Director Dr. Terry Krauss was provided the entire season's TITAN (radar) data, as he has that software running on a computer in his office. This will enable mutual (WMI and ASWMS) continued examination of the data set in the off season prior to the 2016 program.

10.1 FLIGHTS

There were thunderstorms reported within the project area on 64 days this summer, compared with 65 days in 2014. Hail fell on 46 days. During this season, there were 233.3 hours flown on 35 days with seeding and/or patrol operations. A total of 79 storms were seeded during 100 seeding flights on the 26 seeding days. There were 15 patrol flights, and 16 short "public relations" flights on which one aircraft was flown to the Olds-Didsbury Airport to be available for viewing by insurance company employees attending tours of the operations centre and radar. The distribution of flight time by purpose is given in Figure 23. The distribution of flights by time of day is given in Figure 24.

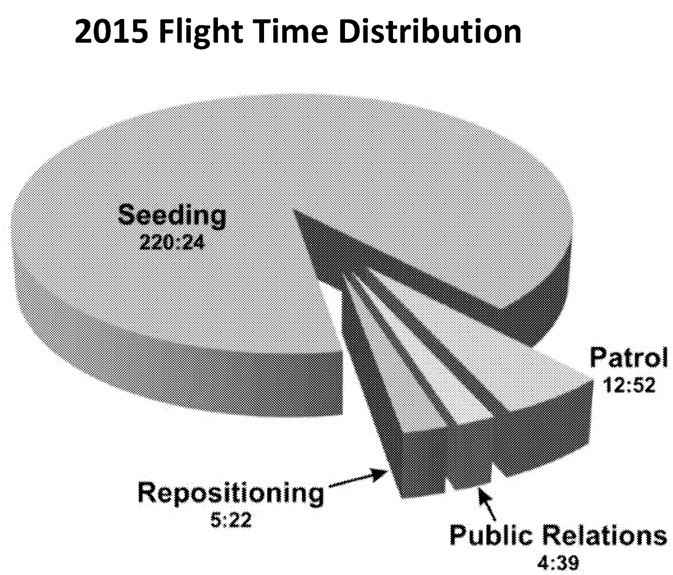

Fig. 23. The distribution of flight time during the 2015 season are shown, by purpose. "Public relations" flights were those from the aircraft's base to the Olds-Didsbury Airport on days that insurance industry continuing education training sessions were given.