Appendix I – Daily Meteorological Forecast Statistics

June 2013

2013 Date	Forecast CDC	Precipitable Water (inches)	0°C Level (kft)	-5°C Level (kft)	-10°C Level (kft)	Cloud Base Height (kft)	Cloud Base Temp (°C)	Maximum Cloud Top Height (kft)	Temp. Maximum (°C)	Dew Point (°C)	Conv Temp (°C)	CAPE (J/kg)	Total Totals	Lifted Index	Showalter Index	Cell Direction (deg)	Cell Speed (knots)	Storm Direction (deg)	Storm Speed (knots)	Low Level Wind Direction (deg)	Low Level Wind Speed (kts)	Mid Level Wind Direction (deg)	Mid Level Wind Speed (knots)	High Level Wind Direction (deg)	High Level Wind Speed (knots)	Observed CDC
1-Jun	1	0.59	9.4	11.1	13.5	8.8	1.5	20.2	16.5	5	15.5	221	53.2	-0.6	-0.2	215	9	235	10	195	4	215	22	210	31	1
2-Jun	2	0.66	8.6	11.3	14.0	6.3	5.5	30.6	13	8	13	488	55.1	-1.8	-1.3	80	9	115	5	30	10	125	10	160	14	1
3-Jun	-2	0.56	8.2	10.7	13.7	6.4	4.7	17.8	12.5	6.5	12.3	177	51.5	0.6	0.8	100	15	135	9	80	11	110	16	180	20	0
4-Jun	-2	0.54	10.3	12.7	15.3	9.4	1.3	21.6	20	5	20.7	20	51.7	-0.1	0.3	270	11	300	6	290	10	275	11	335	47	-1
5-Jun	2	0.78	10.6	13	15.8	8.9	4.7	26.3	22	9	21.7	314	50.4	-1.7	0.6	265	24	300	20	270	24	270	33	285	60	0
6-Jun	-2	0.69	11.5	14.5	17.3	8.7	4.8	20.7	20	8	21.1	12	47.7	0.8	1.6	285	29	310	15	270	19	290	28	310	53	-2
7-Jun	2	0.79	9.6	12.4	15.0	7.6	5.5	28.7	19	9	17.6	532	54	-2.5	-1.3	285	23	310	14	290	24	265	20	280	39	3
8-Jun	2	0.62	9.5	11.6	14.0	8.2	4.7	22.8	18	7	17.6	582	53.2	-4.1	-0.2	290	32	310	36	275	22	285	44	295	118	0
9-Jun	1	0.53	8.3	10.7	13.1	7.3	2.5	22.5	13	5.5	13.1	256	56.7	-2	-1.5	280	22	315	18	300	14	280	30	275	87	2
10-Jun	0	0.51	9.4	11.2	14.0	8.5	2.2	18.0	16.5	5	14.3	187	50.1	0.5	1.2	280	22	305	18	265	15	275	34	270	79	-1
11-Jun	-1	0.69	9.0	12.4	16.0	6.9	4.6	12.3	16	7.5	15.2	46	46.7	2.5	2.9	235	21	255	14	225	11	235	31	225	65	-1
12-Jun	3	0.63	9.8	11.7	14.0	8.4	4.3	30.0	20	9	18.3	703	58.1	-4	-3.3	230	22	240	20	200	10	210	41	220	40	2
13-Jun	1	0.62	8.9	11.3	13.7	7.4	3.6	22.1	16.5	7	15.8	233	53.8	-1.2	-0.4	255	1	245	7	350	4	220	15	200	54	2
14-Jun	2	0.71	8.4	11.1	13.7	5.9	5.8	28.5	14	8.5	13.2	345	54.2	-1.6	-0.5	325	24	355	18	325	27	325	24	285	5	2
15-Jun	2	0.61	9.7	12	14.5	8.4	3.3	28.3	17	6.5	16.7	392	53.8	-1.5	-0.8	320	26	345	18	315	25	310	38	295	24	2
16-Jun	1	0.67	10.3	12.9	15.8	8.3	5.2	30.8	18.5	8	17.4	405	53.1	-1.5	-1.1	305	18	340	10	300	13	305	17	250	7	-1
17-Jun	3	0.81	11.5	14	16.3	8.7	7.3	35.9	22	11	20.8	1227	56.6	-4.8	-3.6	260	25	275	16	250	17	250	28	255	54	4
18-Jun	4	0.93	12.2	14.9	17.3	7.5	10.1	39.5	22	13	18.6	1454	54.8	-4.3	-3.5	230	26	250	15	190	13	230	35	215	39	2
19-Jun	2	1.07	12.1	14.7	14.4	5.9	11.8	37.8	18	13	16.8	891	52.3	-2.9	-2.9	140	23	163	18	118	24	157	28	155	33	2
20-Jun	2	0.75	9.8	12.7	15.8	5.8	10.1	26.3	16	12	13.2	626	53.2	-3	-2.2	95	18	130	20	90	14	105	35	65	72	2
21-Jun	1	0.71	9.1	11.9	10.9	5.9	7.9	29.5	14	10	12.7	567	54.1	-2.5	-1.3	19	10	50	10	30	17	17	11	33	9	2
22-Jun	2	0.63	9.9	12	14.4	8.3	4.6	29.2	18	8	17.2	579	55.6	-3.0	-2.1	320	19	350	11	320	15	320	19	20	7	2
23-Jun	2	0.69	9.6	12.1	14.7	7.1	6.0	30.0	18	9	17.1	640	54.2	-2.8	-1.2	315	11	340	9	300	7	315	17	300	29	2
24-Jun	2	0.94	11.2	14	16.7	7.8	8.0	35.0	22	12	19.4	761	52.2	-3	-1.2	205	16	230	11	180	14	220	17	255	58	1
25-Jun	3	0.88	10.9	13.9	16.6	5.6	11.5	34.0	19	14	18.7	1117	52	-3.8	-1.6	250	16	275	9	280	14	220	16	155	41	3
26-Jun	1	0.67	10.6	12.9	15.4	9.1	4.2	28.0	22	11	21.8	541	54.5	-3.2	-1.6	275	20	290	14	275	17	255	21	260	55	2
27-Jun	0	0.83	11.5	14	16.7	9.6	4.5	24.0	24	10	23.4	214	51.4	-1.2	-0.4	275	25	300	17	280	14	270	35	275	103	-2
28-Jun	-1	0.92	13.1	16.9	20.0	9.8	7.1	27.5	25	11	24.4	178	48.5	-0.5	0.1	280	21	300	14	260	11	275	29	280	54	-2
29-Jun	4	1.18	13.4	16	18.7	8.6	11.5	41.0	28	17	26.6	2063	56.2	-5.9	-4.7	245	14	275	10	210	6	260	26	250	49	4
30-Jun	3	1.02	14.1	17.5	20.0	8.3	12.8	40.4	26	16	25.9	1831	52.9	-4.3	-3.9	290	22	320	14	290	9	285	31	295	64	-3

WEATHER MODIFICATION
INCORPORATED

July 2013

2013 Date	Forecast CDC	Precipitable Water (Inches)	0°C Level (kft)	-5°C Level (kft)	-10°C Level (kft)	Cloud Base Height (kft)	Cloud Base Temp (°C)	Maximum Cloud Top Height (kft)	Temp. Maximum (°C)	Dew Point (°C)	Conv Temp (°C)	CAPE (J/kg)	Total Totals	Lifted Index	Showalter Index	Cell Direction (deg)	Cell Speed (knots)	Storm Direction (deg)	Storm Speed (knots)	Low Level Wind Direction (deg)	Low Level Wind Speed (kts)	Mid Level Wind Direction (deg)	Mid Level Wind Speed (knots)	High Level Wind Direction (deg)	High Level Wind Speed (knots)	Observed CDC
1-Jul	-3	0.93	16.2	18.3	20.4	7.8	14.1	46.6	28	18	31.4	1773	52.3	-4.6	-3.9	305	14	310	8	280	7	290	20	270	26	-3
2-Jul	4	1.23	15.4	17.7	20.3	9.4	14.3	46.5	32.5	19	34	3339	56.6	-8.4	-4.8	250	27	280	19	240	16	255	38	270	46	-2
3-Jul	-2	0.85	14.2	17.1	19.8	7.6	9.6	13.8	21	12	22.3	0	45	0.9	1.5	280	22	310	14	270	19	280	24	280	57	2
4-Jul	4	0.98	11.9	14.4	17.2	6.8	11	34.9	22	14	22.2	1071	50.3	-3.6	-0.6	280	21	270	12	215	10	260	26	250	67	4
5-Jul	2	0.71	10.3	12.8	15.5	7.9	5.8	34.5	20	9	19.5	559	53.6	-2.5	-1.2	275	25	300	12	310	10	255	26	245	45	2
6-Jul	2	0.71	9	11.6	14.2	7	5.5	30.3	17	9	14.7	652	56.2	-2.8	-2.1	270	15	290	10	280	12	250	18	250	41	3
7-Jul	3	0.74	11	13.5	16.1	8.4	6.4	33.0	20	9.5	19.3	718	55.4	-3.4	-2.7	275	20	305	12	290	9	275	24	265	58	0
8-Jul	2	0.90	10.5	13.2	15.9	5.6	10.4	33.4	18	13	17.3	821	52.6	-3	-1.5	285	2	260	3	245	2	235	7	235	48	2
9-Jul	1	0.92	12.3	14.8	17.3	6.9	5.5	35.0	26	13	25.6	651	53.1	-2.8	-1.6	280	18	300	10	265	13	285	18	270	39	0
10-Jul	2	0.87	12.8	15.1	17.6	10	5.5	34.0	25.5	15	27.9	628	53.4	-3.1	-1.9	255	31	275	21	235	20	250	40	250	32	0
11-Jul	3	0.58	11.6	14.5	17.1	9.2	6.9	32.6	23	11	20.4	963	55.6	-4	-3.3	245	39	270	28	265	25	235	51	235	94	3
12-Jul	2	0.56	9.2	11.1	13.4	8.3	2.4	24.3	18	7.5	17.8	417	56.4	-3	-1.7	265	28	290	17	260	10	260	32	245	76	1
13-Jul	2	0.68	9.3	11.6	14.2	7	6.0	30.2	17.5	10	16.1	661	55.9	-3	-1.9	290	18	305	11	290	10	280	22	260	41	2
14-Jul	3	0.87	10.8	13.1	15.7	7.8	8.1	34.8	22	14	21	1097	56.2	-4.6	-3.2	250	23	270	14	220	13	250	30	260	69	4
15-Jul	1	0.64	9.4	12.1	14.7	7.1	5.6	25.9	18	9	10	387	52.6	-2	-0.1	300	21	340	16	330	22	295	23	270	56	1
16-Jul	-3	0.53	13.4	16.5	18.8	9.5	6.1	13.1	23	8	20.4	39	41.4	4.2	5.1	280	20	305	12	95	4	275	32	265	80	-3
17-Jul	2	1.15	13.8	16.2	18.7	7.5	11.9	40.2	23	15	24.9	1094	53.7	-4.5	-3.7	220	20	250	16	225	15	230	31	230	50	2
18-Jul	1	0.86	12.6	15	17.8	9.8	7.1	35.2	25	11	24.2	964	54.5	-3.8	-2.7	300	16	335	13	305	14	310	23	290	23	2
19-Jul	3	0.95	12.4	14.9	17.5	9.2	9	40.0	25	14	22.3	1318	56.3	-5.6	-3.9	305	27	335	15	300	18	300	27	295	32	4
20-Jul	4	1.05	12.6	15	17.7	8.3	10.6	39.7	26	14	23.6	1880	56.7	-5.9	-4.7	290	36	320	20	285	24	295	38	300	66	5
21-Jul	2	1.03	13.3	16.3	19.1	8.5	10	37.5	24	13	22.6	1275	52	-2.9	-2.5	290	31	315	14	260	21	300	26	265	26	1
22-Jul	4	1.08	12.8	15.3	18.0	7.8	11.4	37.4	23	15	23.2	1663	54.8	-5.0	-4	275	25	310	15	265	12	285	33	275	19	5
23-Jul	3	0.94	12.7	15.2	17.8	7.5	11.0	37.6	22	15	23.3	1637	54.3	-5	-3.4	285	26	320	16	285	13	290	35	290	58	4
24-Jul	4	0.91	12.8	15.4	17.9	7	12	37.0	21	14	20.6	1359	55.1	-4.8	-4.4	300	24	335	14	315	13	300	29	295	48	4
25-Jul	3	1.00	13.5	15.9	18.2	9.0	10	37.4	22.5	13	25.1	1355	54.6	-4.2	-3.9	285	20	315	11	265	12	300	25	295	49	3
26-Jul	1	0.81	13.6	16.0	18.5	9.5	10	40.0	24	15	29.4	1190	52.7	-3.5	-2.9	260	23	275	13	250	14	260	25	265	55	0
27-Jul	2	0.66	11.2	13.3	15.5	7.8	7.2	34.6	19	10	20.1	997	57.5	-4.5	-3.9	265	30	300	19	275	18	270	38	255	69	2
28-Jul	2	0.62	10.2	12.6	15.0	8.4	4.5	34.4	18	7	16.8	709	56.5	-3.0	-2.6	285	20	315	13	305	15	270	23	260	36	2
29-Jul	1	0.66	8.3	11.1	13.7	6.4	5.0	25.6	15	6.5	13.4	277	53.1	-1.1	0.3	290	20	310	14	305	10	275	28	270	41	2
30-Jul	-1	0.61	10.8	13.6	16.5	8.6	4.8	28.8	19	8	19.2	275	52	-1.2	-0.4	310	24	350	12	305	19	325	20	355	20	-3
31-Jul	0	0.82	11.7	14.5	17.7	8.1	8.2	39.8	23	12	22.1	667	50.7	-1.7	-0.7	310	24	350	14	325	21	310	21	300	18	2

WEATHER MODIFICATION INCORPORATED

000332

August 2013

2013 Date	Forecast CDC	Precipitable Water (inches)	0°C Level (kft)	-5°C Level (kft)	-10°C Level (kft)	Cloud Base Height (kft)	Cloud Base Temp (°C)	Maximum Cloud Top Height (kft)	Temp. Maximum (°C)	Dew Point (°C)	Conv Temp (°C)	CAPE (J/kg)	Total Totals	Lifted Index	Showalter Index	Cell Direction (deg)	Cell Speed (knots)	Storm Direction (deg)	Storm Speed (knots)	Low Level Wind Direction (deg)	Low Level Wind Speed (kts)	Mid Level Wind Direction (deg)	Mid Level Wind Speed (knots)	High Level Wind Direction (deg)	High Level Wind Speed (knots)	Observed CDC
1-Aug	2	0.95	11.8	14.7	17.5	6.9	10.8	35.1	21	13	18.5	1211	52.9	-3.5	-2.6	230	6	240	4	160	5	240	10	205	11	2
2-Aug	2	0.85	10.7	14	17.5	7.4	9.2	40.0	22	11	19.9	781	51.1	-1.7	-1.5	110	8	140	8	105	14	95	11	115	9	2
3-Aug	1	0.79	12.1	15.0	17.9	7	10	35.5	19.5	12	19.3	705	50.6	-1.7	-1.4	310	3	100	2	285	2	65	7	40	11	-1
4-Aug	2	0.87	12.1	14.9	17.7	8	8.6	36.0	21	12	20.6	747	51.8	-2.3	-1.6	260	10	285	7	235	7	255	13	255	23	3
5-Aug	2	0.84	11.3	14.1	16.9	7.9	7.8	34.7	20	11	19.1	734	53.2	-2.6	-2.1	335	19	5	12	345	18	330	17	20	19	2
6-Aug	3	0.89	11.8	14.4	17.1	7.7	9.5	35.9	21	13	21.3	1340	54.4	-4.1	-3	305	16	325	16	310	11	295	17	285	50	1
7-Aug	3	0.86	11.3	14	16.8	6.6	10.6	35.8	21	14	19.2	1107	53.6	-3.9	-2.6	300	13	340	9	335	3	310	23	300	30	2
8-Aug	0	1.00	11.9	14.7	17.3	6.1	10.5	30.8	16	13	17.2	345	50.0	-1.8	-0.9	290	17	320	11	280	8	295	24	300	41	0
9-Aug	1	0.96	12.6	15.1	17.8	7.9	9.3	37.5	21	12	21.3	810	53	-3.1	-2.6	310	15	325	8	290	9	305	15	285	26	1
10-Aug	2	0.82	13.2	15.6	18.2	6	9.0	40.5	26.5	13	25.7	1340	57.4	-5.3	-5	355	9	5	3	5	5	335	7	300	25	2
11-Aug	3	1.12	13.4	15.6	18.1	8.7	10.8	39.9	26	15	27.5	1324	56.3	-5.6	-4.6	230	13	255	9	220	11	240	16	295	16	4
12-Aug	3	1.07	13	15.3	17.9	6.9	12.6	40.0	24	16	22.5	1726	55.1	-5.4	-4.4	340	3	215	1	0	0	335	1	150	28	3
13-Aug	3	0.91	13.3	15.6	18.1	8.1	11.8	40.0	26	16	26.8	2255	57.4	-6.2	-5.8	280	14	290	6	275	7	265	9	220	30	2
14-Aug	1	0.80	13.8	16.2	18.9	11	7.2	40.0	27.5	12	28.1	1325	54.7	-3.6	-3.2	280	14	285	9	245	9	265	17	305	19	-3
15-Aug	1	1.03	13.5	16.2	18.9	9.7	7.4	40.0	26	12	28.8	528	51.4	-2.2	-1.3	280	33	285	18	250	22	260	30	280	51	2
16-Aug	3	0.80	13	15.5	18.1	8.6	9.9	39.8	25	15	26.7	1336	54.3	-4.2	-3.5	270	33	290	19	270	23	255	33	245	66	4
17-Aug	1	0.91	12.6	15.0	17.6	10	6.1	36.2	25	12	24.3	724	54.7	-3.5	-2.8	255	25	280	16	250	17	250	25	255	39	1
18-Aug	-1	0.84	11.8	15.2	18.5	9.2	6.5	19.7	24.5	12	24.2	154	47.8	-0.2	0.9	265	27	290	21	255	17	265	44	275	82	-2
19-Aug	1	0.82	10.3	12.5	15.7	8.8	4.7	20.5	21.5	10	21	256	50.5	-0.8	0.3	270	33	295	29	275	22	265	59	265	107	2
20-Aug	1	0.53	10.9	12.6	14.9	10.6	0.8	20.2	21	5	19.3	188	51.7	-0.7	-0.1	280	35	310	29	275	15	275	59	270	107	2
21-Aug	-3	0.45	11.1	14	17.6	9.9	2.2	13.1	22	7	24.9	0	42.4	3.3	4.8	295	23	320	18	290	20	290	38	265	69	-3
22-Aug	-1	0.50	13.6	15.9	18.4	13	0.4	32.3	28	10	30.4	272	51.8	-1.7	-1	260	21	285	15	270	12	260	35	260	56	-3
23-Aug	2	0.88	12.2	14.4	17.3	8.8	8.2	35.9	25	12	25.5	1119	54	-3.9	-2.6	190	13	240	11	200	9	215	24	210	38	2
24-Aug	0	0.74	12.6	14.8	17.5	12	2.3	34.0	26	7	25.3	440	53.3	-1.9	-1.6	255	30	275	17	255	16	245	30	230	41	0
25-Aug	1	0.94	11.7	14.5	17.3	9.6	5.7	35.0	25	11	24.9	597	52.5	-2.4	-1.3	240	33	265	21	230	18	235	39	235	67	2
26-Aug	3	0.84	11.9	14.3	16.9	8.9	7.7	34.9	25	12	24.4	1117	53.9	-4.5	-2	230	23	265	17	235	19	230	29	230	62	3
27-Aug	-1	0.76	11.9	14.1	17.8	10.3	3.7	39.8	24	9.5	25.4	30	47.4	0.8	1.6	245	31	270	22	235	22	240	42	250	55	-3
28-Aug	1	0.86	13.3	15.3	17.6	10	7.7	35.1	27	14	29.5	1324	55.9	-5.1	-3.4	230	34	260	20	215	22	240	40	260	53	2
29-Aug	3	1.11	13.2	15.5	17.9	9.5	8.8	39.9	26	12	27.6	1070	55.5	-4.4	-3.8	230	33	255	19	215	20	235	39	230	50	4
30-Aug	2	0.78	11.8	14.4	17.2	9.2	5.9	33.2	24	10	21.5	669	53.2	-2.3	-1.8	255	22	285	18	270	22	245	30	240	41	3
31-Aug	-3	0.86	12.2	16.1	18.5	8.1	7.1	13.0	22	10	21.9	25	47.2	0.9	1.1	265	13	315	10	280	9	290	24	290	62	-3

WEATHER MODIFICATION INCORPORATED

September 2013

2013 Date	Forecast CDC	Precipitable Water (inches)	0°C Level (kft)	-5°C Level (kft)	-10°C Level (kft)	Cloud Base Height (kft)	Cloud Base Temp (°C)	Maximum Cloud Top Height (kft)	Temp. Maximum (°C)	Dew Point (°C)	Conv Temp (°C)	CAPE (J/kg)	Total Totals	Lifted Index	Showalter Index	Cell Direction (deg)	Cell Speed (knots)	Storm Direction (deg)	Storm Speed (knots)	Low Level Wind Direction (deg)	Low Level Wind Speed (kts)	Mid Level Wind Direction (deg)	Mid Level Wind Speed (knots)	High Level Wind Direction (deg)	High Level Wind Speed (knots)	Observed CDC
1-Sep	-2	0.53	14.2	16.3	18.7	15.6	-3.2	29.8	27	11	33	136	49.7	-1	0	275	27	295	18	280	20	265	27	265	68	-3
2-Sep	1	0.80	14.0	16.2	19.3	12.5	4.3	34.6	30	10	29.8	524	53.7	-2.7	-2.2	250	14	280	12	255	10	255	25	245	73	-1
3-Sep	1	1.11	14.4	16.7	19.4	10.5	7.5	37.0	27.5	11.5	27.9	669	53.4	-2.9	-2.7	230	12	250	11	230	12	230	21	220	65	-2
4-Sep	-3	0.71	14.1	17	20.1	13.4	1.6	19.2	27	10	30	31	48.1	0	0.6	255	16	270	10	280	11	225	19	235	44	-3
5-Sep	1	1.20	14.1	16.7	19.8	9.6	9.7	37.2	27	13	26.7	830	53.5	-3.5	-3.3	200	11	225	6	200	6	195	15	220	58	0
6-Sep	0	1.13	13.5	16.3	19.3	5.8	12.0	17.7	20	14	18.7	78	42.8	0.4	3.4	185	14	205	8	145	9	195	18	200	68	0
7-Sep	0	1.07	12.2	14.9	17.6	4.8	12.7	33.3	15	13.5	15	411	48.5	-1.3	-0.3	175	15	200	10	155	15	190	17	215	24	0
8-Sep	1	0.90	11.7	14.6	17.3	8	8.5	34.9	21	11	19.8	899	53.5	-3.0	-2.5	20	10	45	7	5	12	30	10	35	17	3
9-Sep	0	0.68	12.7	16.1	18.3	9.3	6.6	39.9	23	10	23.4	394	50.7	-1.8	-0.6	310	20	345	13	305	20	310	22	330	34	-2
10-Sep	-3	0.79	14.3	17.4	19.9	11.2	3.9	12.0	24	8	26.6	0	44	2.5	3.0	320	29	350	17	310	19	320	30	330	48	-3
11-Sep	-3	0.74	15.4	18	20.2	10	6.6	38.2	25	9	31.4	9	45.5	1.3	1.7	340	10	340	6	315	7	320	15	270	19	-3
12-Sep	-3	0.60	15.8	18.1	20.5	12	5.6	38.0	30	10	34.5	516	50.4	-1.3	-0.8	245	9	250	7	245	8	230	12	145	15	-3
13-Sep	-3	0.72	14.7	17.2	19.9	10.9	6	37.0	27	10	29.9	249	49.2	-0.7	-0.2	300	16	355	11	335	9	310	21	350	22	-3
14-Sep	-3	0.78	14.7	18.2	20.4	10.1	5.4	40.3	24	9	27.5	0	41.7	3.2	4	10	12	35	4	305	6	15	10	285	16	-3
15-Sep	-2	0.60	16.1	18.3	20.3	9.9	3.9	40.1	24	6	39	0	39	5.5	5.6	190	19	220	15	200	10	190	26	205	26	-3
Average	1	0.8	11.9	14.5	17.1	6.5	7.1	32.0	21.9	10.3	22.0	740.5	52	-2.4	-1.4	253	20.0	271	13.4	246	13.7	252	25.3	245	45.5	0.8
StdDev	2	0.2	1.9	1.9	2.0	1.8	3.3	8.0	4.1	2.9	5.5	595.7	4	2.3	2.2	64	8.1	74	5.9	75	6.0	63	10.8	66	23.8	2.3
Maximum	4	1.2	16.2	18.3	20.5	15.6	14.3	46.6	32.5	19.0	39.0	3339	58	5.5	5.6	355	39.0	355	36.0	350	27.0	335	59.0	355	118.0	5
Minimum	-3	0.5	3.2	10.7	10.9	4.6	-3.2	12.0	12.5	5.0	10.0	0	39	-8.4	-5.6	10	1.0	5	1.0	0	0.0	15	1.0	20	5.0	-3

Appendix J – Project Personnel and Telephone List

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ATC EDMONTON OSS	Notification to Launch Aircraft	Phone: 888-882-2254	
ATC SHIFT MANAGER EDMONTON		Phone: 780-890-8397 Fax: 780-890-4710	
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ATC CALGARY TOWER		Phone: 403-216-7121 Fax: 403-216-7122	
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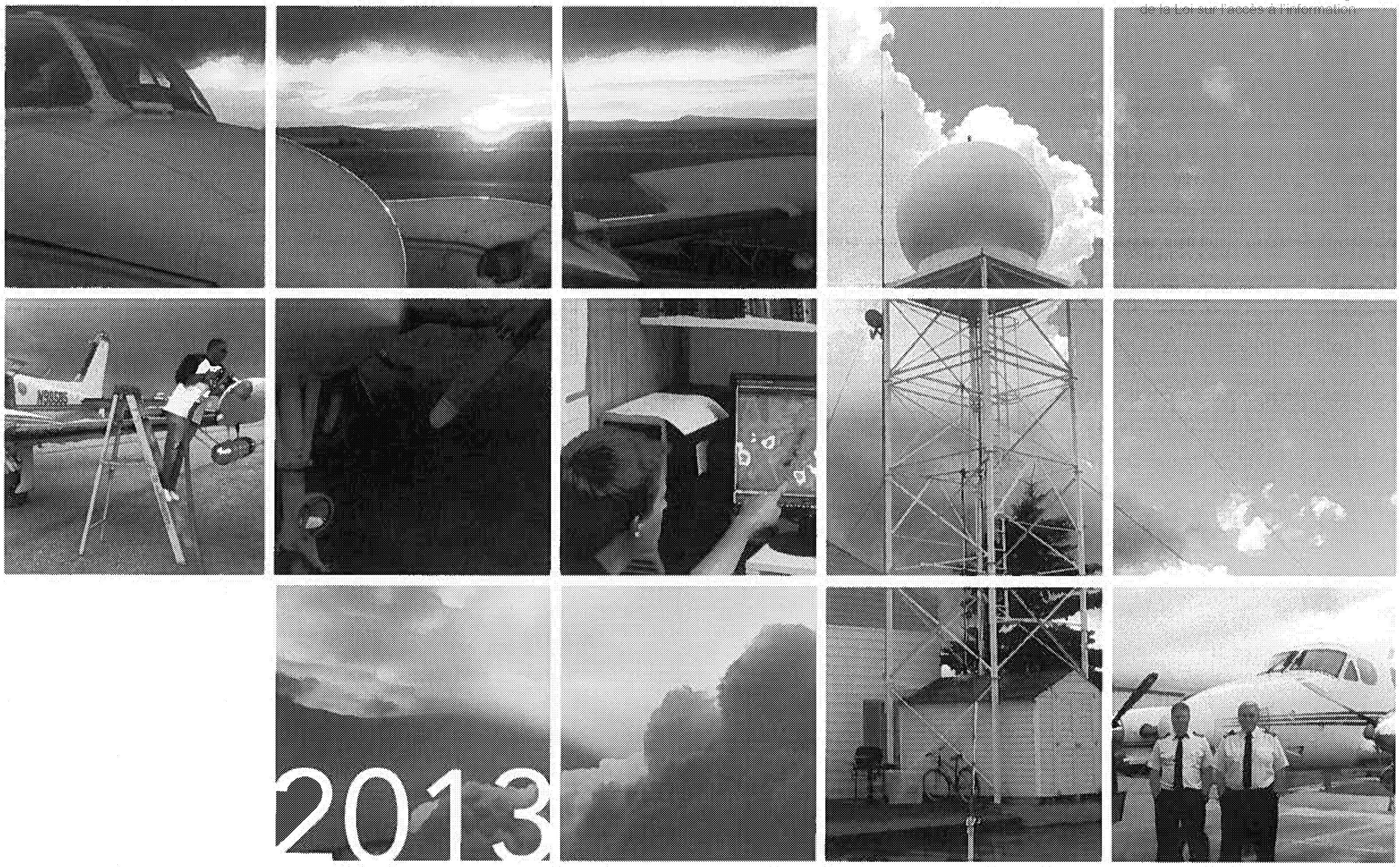

2013 ANNUAL REPORT

Alberta Hail Suppression Project

Alberta Severe Weather Management Society

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Alberta Hail Suppression Project
Final Operations Report 2013

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

by

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for the

Alberta Severe Weather Management Society
Calgary, Alberta
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December 2013

Executive Summary

This report summarizes the activities during the 2013 field operations of the Alberta Hail Suppression Project. This was the eighteenth year 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 third 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 the severe storm that struck Calgary on August 12, 2012 caused an estimated $500 million dollars damage, indicating that a billion dollar storm within Calgary is now possible.

A Doppler weather radar replaced the previous unit in 2011. This radar is more sensitive, better depicting the developing cloud turrets of interest for seeding, and 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 2013. Air traffic at the Calgary International Airport (CYYC) by 2012 had grown to the point where arrival and departures at that airport had to be scheduled well in advance, so midway through the 2012 season operations were relocated to Springbank (CYBW), approximately 25 km to the west of the Calgary Airport.

The project design has remained the same throughout the period, but a fourth seeding aircraft 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 is another twin-engine turboprop King Air, the same model aircraft as Hailstop 1 and 3 have been in recent seasons. This fifth aircraft was based in Springbank with Hailstop 1 and Hailstop 2.

The program was operational from June 1st to September 15th, 2013. 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.

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, and 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 impacted portions of the protected area until June 27th.

The flooding caused the ASWMS to formalize a policy for suspension of seeding activities. Guidelines for such suspensions had been previously established by the Weather Modification Association (WMA). The new ASWMS guidelines are presented within this 2013 final project report.

Hail was reported within the project area (protected area and buffer area) on 65 days. Larger than golf ball size hail was reported on July 20th in Red Deer. On the 22nd of July, larger than golf ball size hail was also reported near the town of Dogpound.

Golf ball size hail was reported or observed by radar signature on June 17th east of Strathmore; June 29th north of the town of Caroline and west of Sylvan; on the 4th of July north of Cochrane and north of Airdrie; on July 14th east northeast of Rocky Mountain House; the 19th of July north of Three Hills; on the 23rd of July west of Sundre, southwest of Cremona, southwest of Calgary, west of Okotoks, and in High River; and the 24th of July northeast of Rocky Mountain House. The month of August saw golf ball size hail on the 11th, north of Cochrane and north of Calgary; on the 16th west northwest of Sylvan; and the 29th north of Cochrane.

Walnut size hail was reported or observed by radar signature on June 7th northeast of Airdrie; on June 25th northwest of the town of Rimbey; the 6th of July east northeast of Airdrie and east of the town of Irricana; on the 11th of July southwest of Sylvan; July 25th south of High River; the 4th of August north of Cochrane; on August 12th east of Olds and west southwest of Three Hills; August 26th northwest of Rocky Mountain House and east of the town of Rimbey; east northeast of Innisfail on the 30th of August; and on September 8th south of Cremona.

The weather pattern during the summer of 2013 was less active than the previous two summers, closer to the climatological average. In June, 21 seeding missions were flown, and an additional two flights flown for patrol. 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. All five Hailstop aircraft flew on six days. Forty-seven seeding missions were flown, and 7 more patrol flights. A severe hailstorm moved through Red Deer during the evening of July 20th. Though seeded by multiple aircraft, larger-than-golf ball hail still fell in the city.

The active weather pattern slowed in August, as only 15 seeding missions were flown. Ten patrol missions were needed, however.

No seeding was conducted in September, and only one patrol mission was flown, that on the 9th.

There were thunderstorms reported within the project area on 77 days this summer, compared with 70 days in 2012. Hail fell on 65 days. During this season, there were 229.6 hours flown on 31 days with seeding and/or patrol operations. A total of 70 storms were seeded during 83 seeding flights (170.9 flight hours) on the 26 seeding days. There were 21 patrol flights (22.2 hours), and 24 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 2013 field season totaled 233.3 kg. This was dispensed in the form of 6,311 ejectable (cloud-top) flares (126.22 kg seeding agent), 636 burn-in-place (cloud-base) flares (95.4 kg seeding agent), and 131.7 gallons of silver iodide seeding solution (11.6 kg seeding agent).

For the first time, five specially equipped cloud seeding aircraft were dedicated to the project. Two Beech C90 King Airs and one Cessna 340A were based in Springbank, and a C90 and another C340A were based in Red Deer. The procedures used in 2013 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.

The aircraft and crews provided a 24-hour service, seven days a week throughout the period. Thirteen 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 2013 crew was very experienced. The Red Deer aircraft team was led by Mr. Roger Tilbury, who has been flying cloud research and cloud seeding missions since the 1970s, and Mr. Joel Zimmer who has been with the Alberta program for 11 years. The Springbank team was anchored by Mr. Jody Fischer and Mr. Brook Mueller. The radar crew was anchored by WMI's Chief Meteorologist, Mr. Daniel Gilbert, now with four 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 exceptionally well and there were no interruptions or missed opportunities.

There were two minor radar issues during the course of the summer, neither of which impacted seeding operations. The first, initially manifested on the afternoon of July 2nd, was resolved by re-seating a card in the radar and slowing, ever-so-slightly, the antenna rotation speed. The second, an antenna elevation issue, occurred in the early morning of July 14th. Work to replace damaged drive gears began than afternoon and was completed just before seeding began that evening.

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 2014 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 eighteenth 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.
- Lynne Fawcett of Intact Insurance is thanked for organizing the 12 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.
- Kevin Gies and the staff of Springbank Aero are 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 2013: project manager Jody Fischer, meteorologists (Dan Gilbert, Brad Waller, and Joe Pehoski), electronics-radar technicians (Dave Civil, and Todd Schulz), pilots in command (Roger Tilbury, Brook Mueller, L.J. Dunn, John Lisberg, Mathias Morel, and Mark Zuccon); the co-pilots (Joel Zimmer, Jenelle Newman, Brent Shewchuk, Michael Torris, and Jacob Eeuwes). 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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Fig. 6. Precipitation efficiency for High Plains convective storms. Known supercell hailstorms are labeled "S". Storms that produced rain only are labeled "R". Figure from Browning 1977, copyright American Meteorological Society, Boston, MA, used by permission. 25

Fig. 7. Base seeding with wing-tip ice nucleus generators is conducted by Hailstop 2 in organized updraft beneath developing cumulus turrets on the flank of a mature thunderstorm. WMI photograph by Jacob Eeuwes. 27

Fig. 8. Separation of aircraft by altitude. This diagram illustrates how the separation of cloud-base and cloud-top seeding aircraft is achieved. WMI graphic by Bruce Boe. 29

Fig. 9. When seeding nocturnal thunderstorms lightning is a friend. It illuminates, if only sporadically, many cloud details that would otherwise go unseen. The single lightning flash in the upper image reveals a developing cloud turret at aircraft seeding altitude, while the multiple flashes in the lower time-exposure from the ground reveal much more: the rain-free cloud base (near which base-seeding aircraft would operate), smaller, developing turrets that might be seedable if cold enough, larger maturing cells that are too cold and ice-laden (and close to being detected by radar), and the mature thunderstorm behind that has produced the lightning. WMI photographs: Matthias Morel (top) and Bruce Boe (bottom). 30

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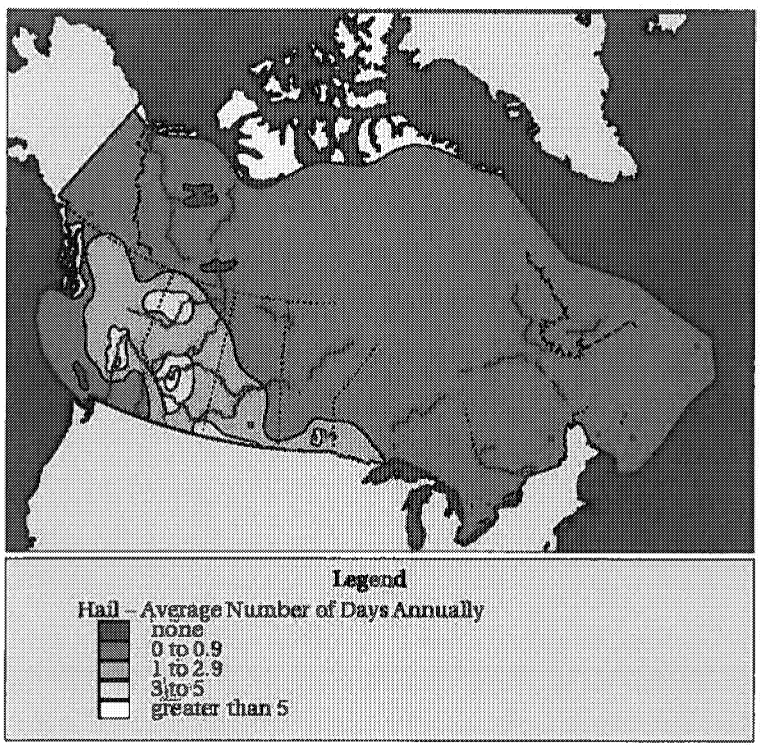
1.0 Introduction

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 coincides with the greatest population density of the province, and 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.



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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 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. 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.

Five significant changes have been made to the project scope during the eighteen 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.

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

The final change was implemented just this season, with the addition of a fifth aircraft to the project, another King Air, based at the Springbank Airport.

Calgary, the focus of southern Alberta population (and thus risk) is located very near the Rocky Mountains, and a favored location for storm genesis is the foothills immediately west. The mountains are a great target when it comes to showing up on radar. Thus, the "clutter" produced by the "rocks" was significant. The radar upgrade in 2012 reduced this problem significantly.

This final operations report summarizes, in detail, all the activities during the 2013 field operations of the Alberta Hail Suppression Project, the eighteenth summer of operations by Weather Modification, Inc. of Fargo, North Dakota under contract with the Alberta Severe Weather Management Society of Calgary, Alberta.

2.0 The 2013 Field Program

The program again conducted operations to mitigate hail storms threatening cities and towns from June 1st through September 15th, 2013. 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 2013 was less active than the previous two summers, closer to the climatological average. Hail was reported within the project area on 65 days this past summer.

The present 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 $>10^{11}$ ice nuclei per gram of AgI active at a temperature of -4°C, and produce between 10^{13} and 10^{14} 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.
- The deployment of sensitive, 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 340A, or C340A) were based in Springbank west of Calgary, and two aircraft (one Beechcraft King Air C90 and one C340A) 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 no. 71359 and the ICAO identifier is CEA3. The project area dimension is approximately 240 km (N-S) by 120 km (E-W) or 28,800 square km.

3.0 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 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 2. 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.

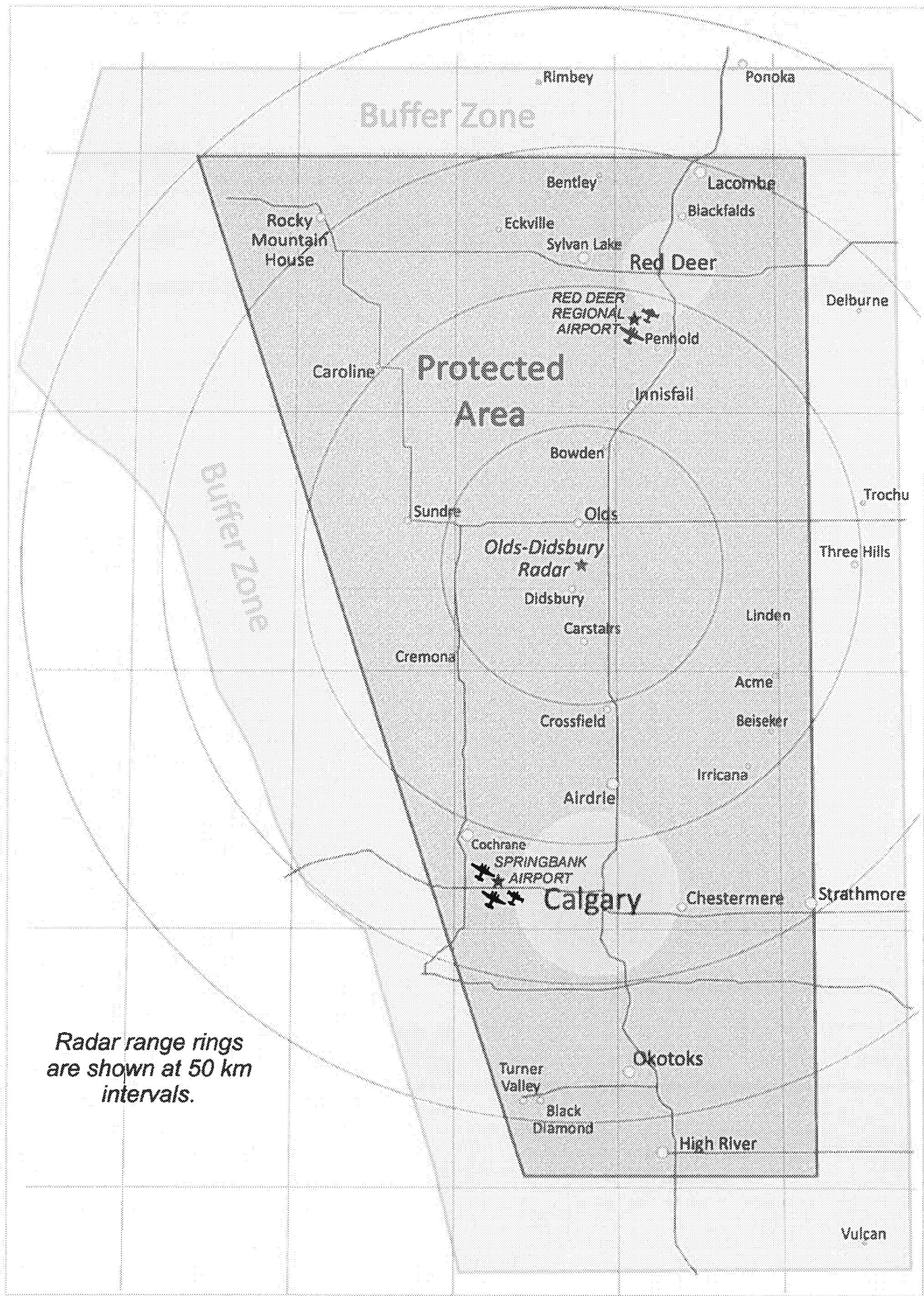

Fig. 2. Map of southern Alberta showing the project target area. The major cities and towns in and near the protected area are shown, along with the location of the Olds-Didsbury Operations Centre identified by a red star. Aircraft bases are designated by aircraft symbols.

4.0 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. Since 2006 Calgary has grown 11%, Red Deer 9%, Airdrie 47%, Okotoks 43%, and Chestermere 49%. Most storms are not seeded after they cross the QE II highway, except for storms east of Airdrie and Calgary that might threaten Strathmore.

Table 1. AHSP Priority List Based on City Population.

Priority	City/Town Name	Population 2011	Population 2006	Percent Change
1	Calgary	1,096,833	988,812	10.9%
2	Red Deer	90,564	83,154	8.9%
3	Airdrie	42,564	28,927	47.1%
4	Okotoks	24,511	17,150	42.9%
5	Cochrane	17,580	13,760	27.8%
6	Chestermere	14,824	9,923	49.4%
7	High River	12,920	10,716	20.6%
8	Sylvan Lake	12,327	10,250	20.3%
9	Strathmore	12,305	10,280	19.7%
10	Lacombe	11,707	10,752	8.9%
11	Olds	8,235	7,253	13.5%
12	Innisfail	7,876	7,331	7.4%
13	Rocky Mountain House	6,933	6,874	0.9%
14	Blackfalds	6,300	4,618	36.4%
15	Didsbury	4,957	4,305	15.1%
16	Turner Valley & Black Diamond	4,540	3,808	19.2%
17	Carstairs	3,442	2,699	27.5%
18	Crossfield	2,853	2,668	6.9%
19	Sundre	2,610	2,523	3.4%
20	Penhold	2,375	1,971	20.5%
21	Bowden	1,241	1,210	2.6%
22	Irricana	1,162	1,243	-6.5%
23	Eckville	1,125	951	18.3%
24	Bentley	1,073	1,083	-0.9%
25	Beiseker	785	804	-2.4%
26	Linden	725	660	9.8%
27	Acme	653	656	-0.5%
28	Caroline	501	515	-2.7%
29	Cremona	457	463	-1.3%

5.0 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.

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.

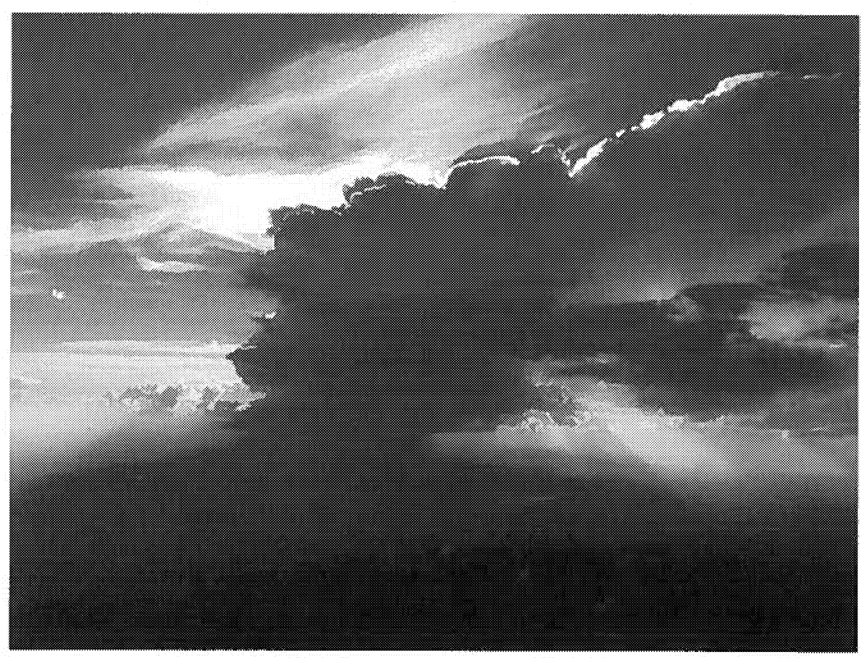

Fig. 3. A thunderstorm develops just east of Rocky Mountain House at 7:22 PM on August 16, 2013, as seen from Hailstop 4. The image was captured during patrol (seeding had not yet occurred). WMI photograph by Jenelle Newman.

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.

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.

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 focus of the Alberta project.

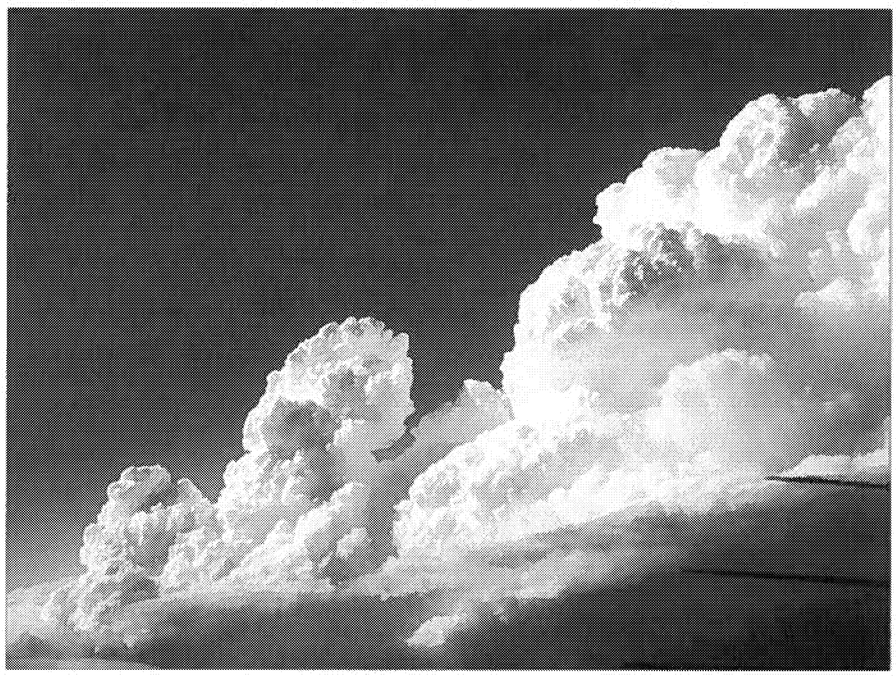

Fig. 4. Hailstop 1 was seeding at cloud top on July 4, 2013; this picture of developing cloud turrets was photographed at 4:54 PM. The billowing, crisp cloud tops are indicative of supercooled, unglaciated updraft, that is, seedable clouds. WMI photograph by Andreas Bertoni.

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 9. 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 5. 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 with certainty 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.

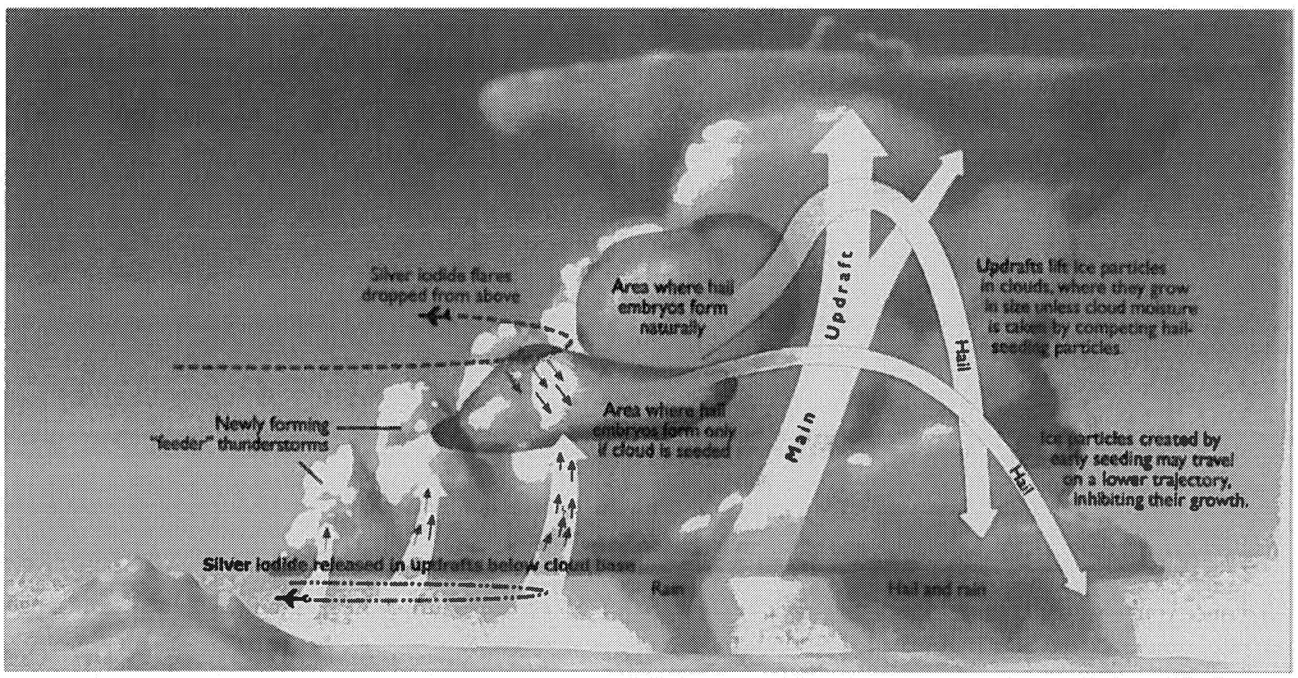

Fig. 5. The conceptual model for hail suppression is illustrated graphically (adapted from WMO 1995). This schematic shows generalized cloud seeding flight paths at feeder-cloud tops and below cloud bases, those typically employed for mature thunderstorms.

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, and a step in this direction was taken in 2011 when two of the companies participating in the AHSP through the ASWMS provided limited storm loss data to Dr. Terry Krauss, the ASWMS Director. However, such data are considered proprietary and the other companies have not yet followed suit. 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.

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 by much of the public and even a few meteorologists 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 6.

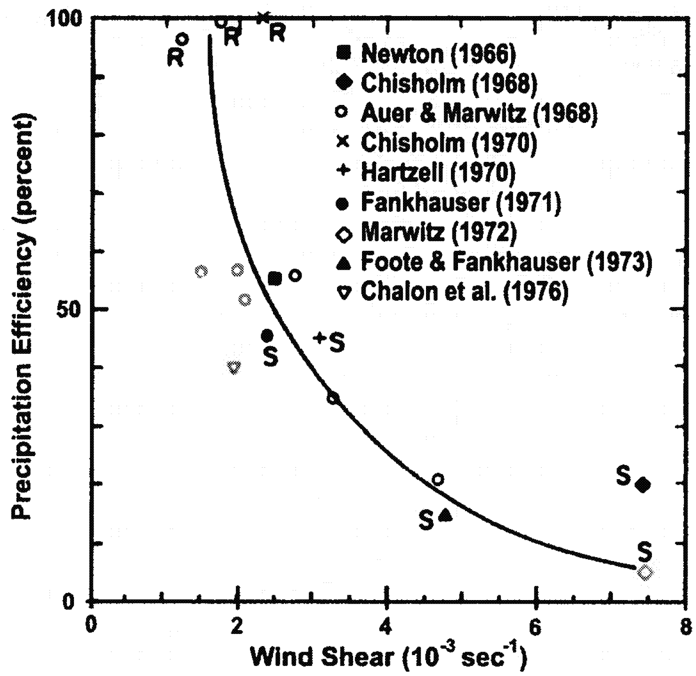

Fig. 6. Precipitation efficiency for High Plains convective storms. Known supercell hailstorms are labeled "S". Storms that produced rain only are labeled "R". Figure from Browning 1977, copyright American Meteorological Society, Boston, MA, used by permission.

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 6). 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 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.

6.0 The Operations Plan

Identification of Hail-Producing Storms

The height of the 45 dBZ contour (a radar echo-intensity level) was a criterion tested in the 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 set to track any cell having more than 10 km^3 of 40 dBZ reflectivity, extending above 3 km altitude (MSL). 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 (as defined by TITAN) is moving towards, and is expected to reach, a town or city within the target area in less than 30 min.

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), the 30 minute lead time is generally thought to be advisable.

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.

Fig. 7. Base seeding with wing-tip ice nucleus generators is conducted by Hailstop 2 in organized updraft beneath developing cumulus turrets on the flank of a mature thunderstorm. WMI photograph by Jacob Eeuwes.

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 hailstorms.*

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.

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 about 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 8).

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.

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.

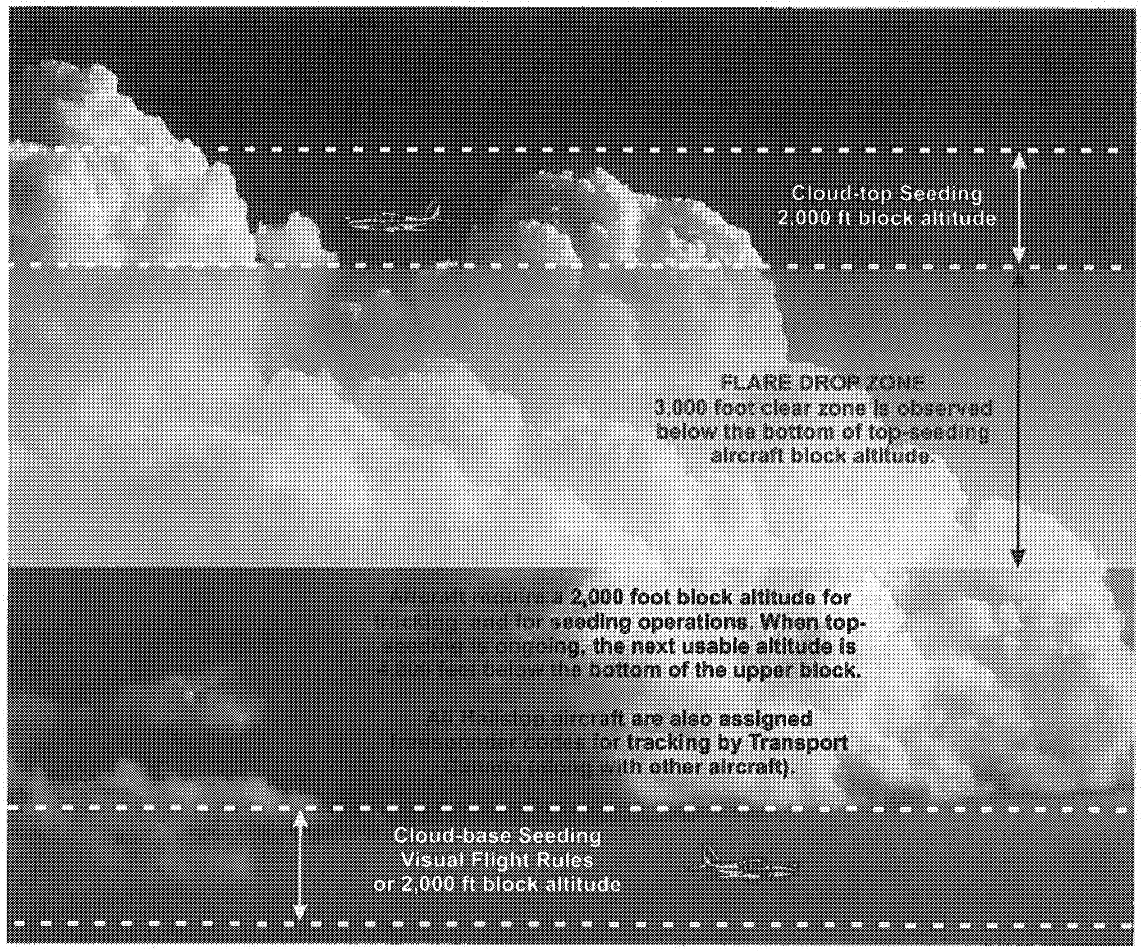

Fig. 8. Separation of aircraft by altitude. This diagram illustrates how the separation of cloud-base and cloud-top seeding aircraft is achieved. WMI graphic by Bruce Boe.

An idea of what night seeding is like is provided by Figure 9. 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, though the number of such flights had been increasing recently (2011, 2012).

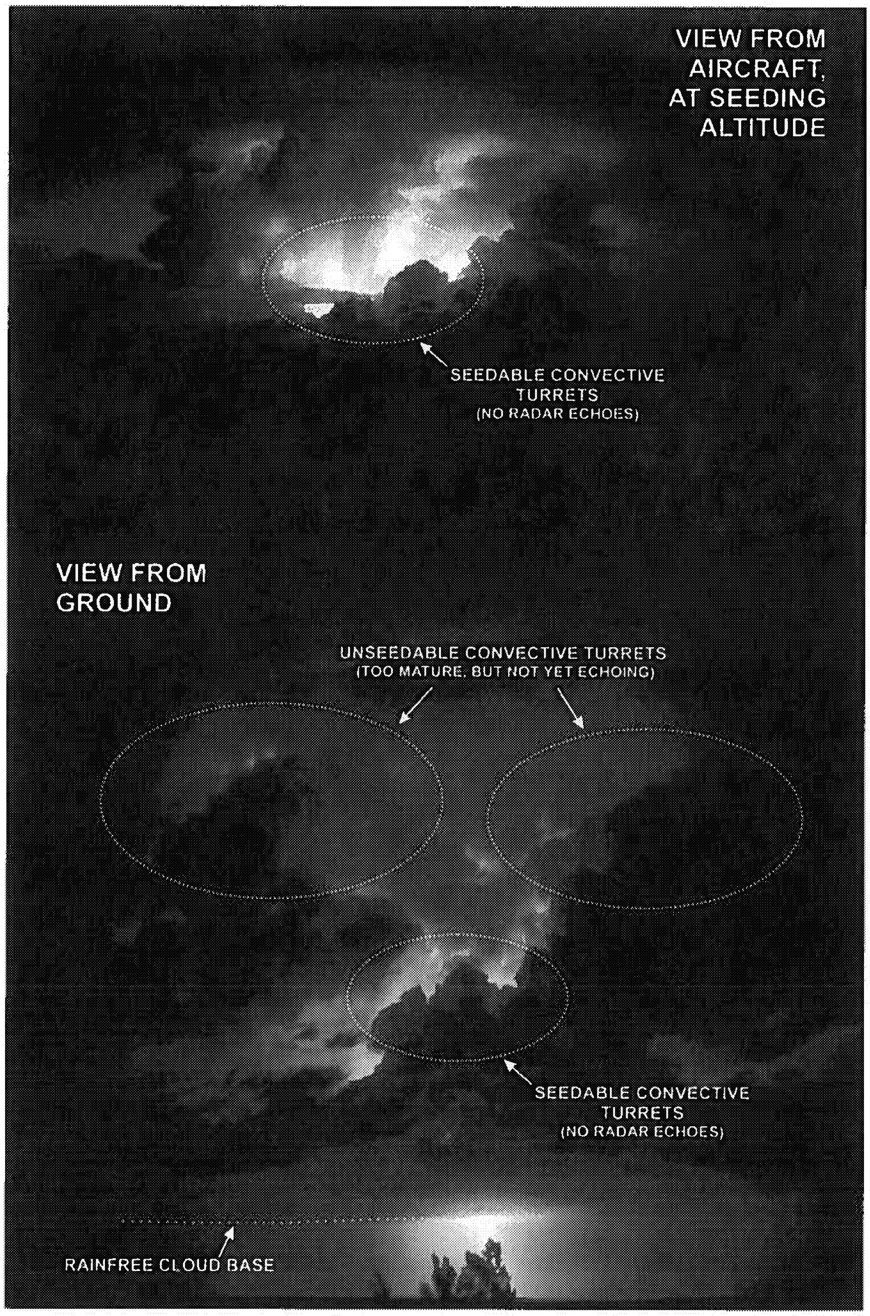

Fig. 9. When seeding nocturnal thunderstorms lightning is a friend. It illuminates, if only sporadically, many cloud details that would otherwise go unseen. The single lightning flash in the upper image reveals a developing cloud turret at aircraft seeding altitude, while the multiple flashes in the lower time-exposure from the ground reveal much more: the rain-free cloud base (near which base-seeding aircraft would operate), smaller, developing turrets that might be seedable if cold enough, larger maturing cells that are too cold and ice-laden (and close to being detected by radar), and the mature thunderstorm behind that has produced the lightning. WMI photographs: Matthias Morel (top) and Bruce Boe (bottom).

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 reflectivities 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.

Seeding Rates

Silver iodide is dispensed in three ways: (1) a seeding solution can be burned from wing-tip-borne ice nucleus generators (see Figure 7), (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 (assuming a true-airspeed of 80 m s^{-1}) intervals 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.

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 10 and are tabulated in Table 2.

Flare Effectiveness

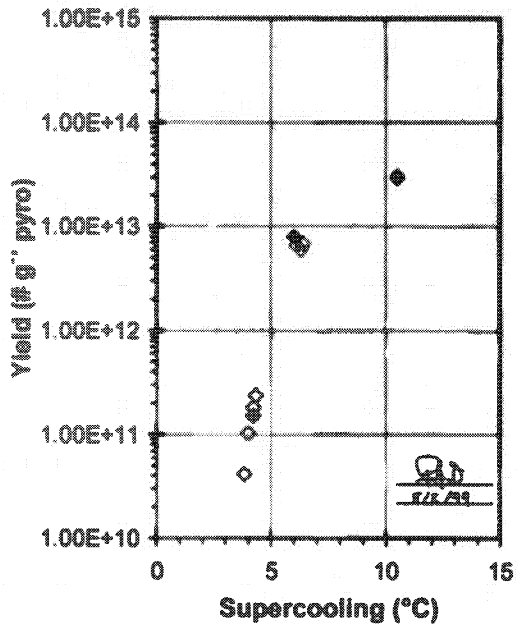

Fig. 10. Yield of ice crystals per gram of pyrotechnic burned is shown as a function of cloud supercooling temperature (T < 0°C). Open diamond symbols are for tests with cloud LWC (liquid water content) of 1.5 g m^{-3}, while the filled symbols are for experiments with LWC equal to 0.5 g m-3. The lack of any dependence upon cloud liquid water content indicates that the nuclei thus produced function by the condensation-freezing mechanism. (Figure from DeMott 1999)

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

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	3.72×10^{11}	3.87×10^{11}	4.01×10^{10}	4.18×10^{10}	8.36×10^{11}
-4.0	1.5	9.42×10^{11}	9.63×10^{11}	1.02×10^{11}	1.04×10^{11}	2.08×10^{12}
-4.2	1.5	1.66×10^{12}	1.70×10^{12}	1.80×10^{11}	1.84×10^{11}	3.67×10^{12}
-4.3	1.5	2.15×10^{12}	2.21×10^{12}	2.32×10^{11}	2.39×10^{11}	4.77×10^{12}
-6.1	1.5	6.01×10^{13}	6.13×10^{13}	6.49×10^{12}	6.62×10^{12}	1.32×10^{14}
-6.3	1.5	5.44×10^{13}	5.56×10^{13}	5.87×10^{12}	6.00×10^{12}	1.20×10^{14}
-6.4	1.5	6.22×10^{13}	6.34×10^{13}	6.72×10^{12}	6.85×10^{12}	1.37×10^{14}
-10.5	1.5	2.81×10^{14}	2.85×10^{14}	3.03×10^{13}	3.07×10^{13}	6.15×10^{14}
-10.5	1.5	2.34×10^{14}	2.37×10^{14}	2.87×10^{13}	2.91×10^{13}	5.81×10^{14}
-4.2	0.5	1.41×10^{12}	1.45×10^{12}	1.53×10^{11}	1.57×10^{11}	3.14×10^{12}
-6.0	0.5	7.42×10^{13}	7.73×10^{13}	8.01×10^{12}	8.34×10^{12}	1.67×10^{14}
-10.5	0.5	2.38×10^{14}	2.41×10^{14}	2.91×10^{13}	2.96×10^{13}	5.92×10^{14}

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 11 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 $1x10^{12}$, $5x10^{13}$ and $3x10^{14}$ 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.

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

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

The CSU isothermal cloud chamber tests indicate that, on a per gram basis of pyrotechnic, these values are comparable to the best product available worldwide in the pyrotechnic format. 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.

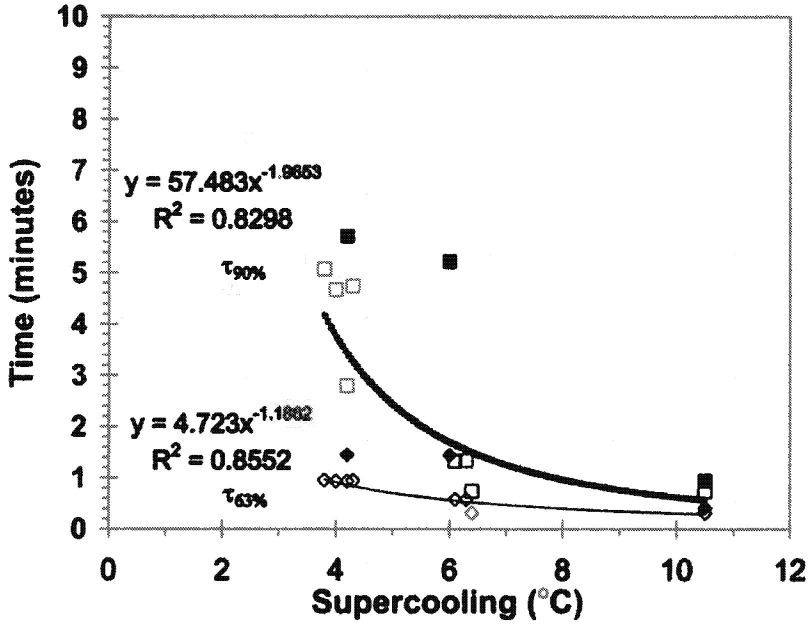

Fig. 11. Activation time as a function of supercooling. Times for 63% (diamond symbols) and 90% (square symbols) ice formation versus supercooling (T<0°C) for the ICE pyrotechnic aerosols. Open and filled symbols are for cloud LWC (liquid water content) of 1.5 and 0.5 g m-3, respectively. (DeMott 1999)

7.0 Program Elements and Infrastructure

Infrastructure

The flow of information within the project is illustrated in block diagram form in Figure 12. 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.

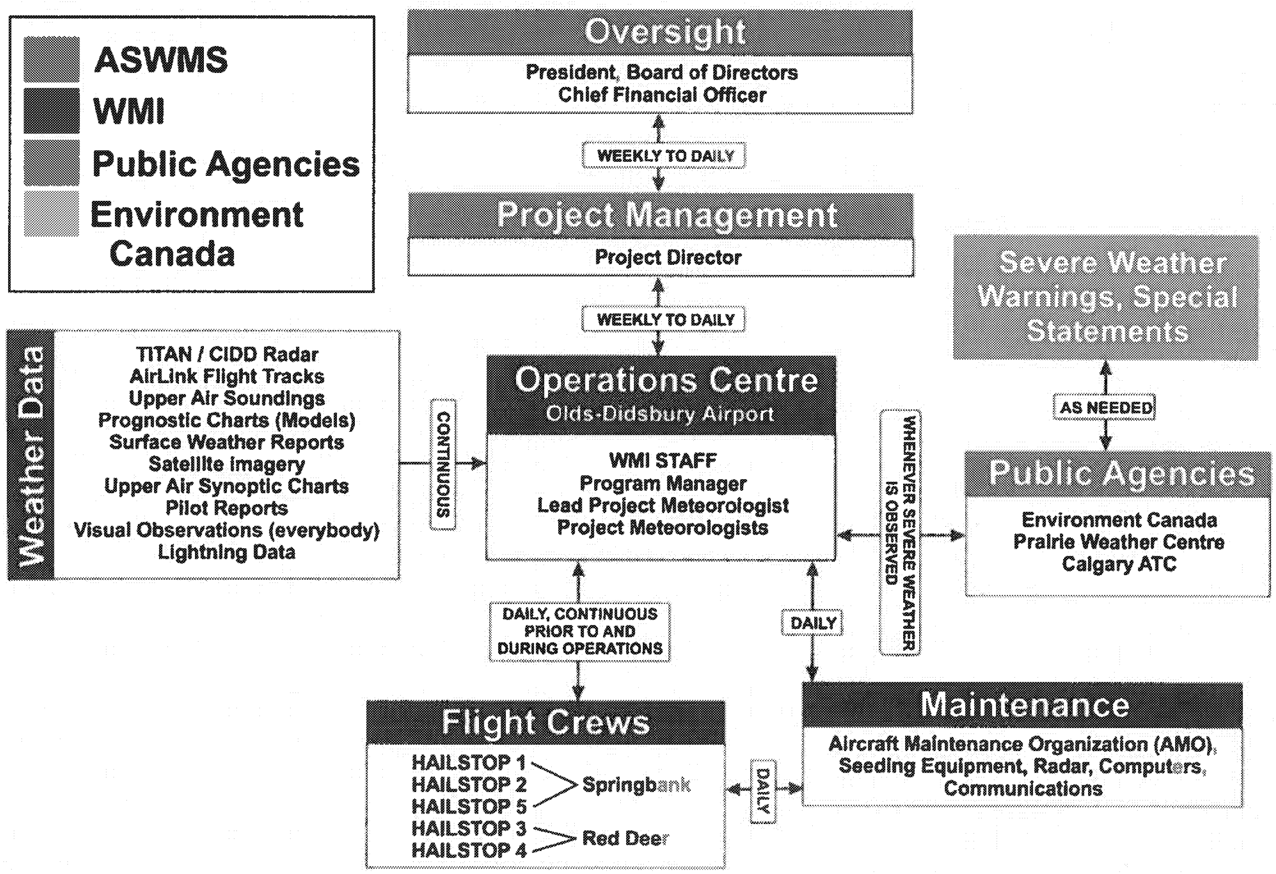

Fig. 12. Schematic of Program Infrastructure. Though program objectives and directives originate with the project sponsor, the Alberta Severe Weather Management Society (ASWMS), the majority of project communications occur among the meteorologists (Operations Centre), pilots (Calgary/Springbank and Red Deer), and the various maintenance providers. The approximate frequencies of these interactions are also shown.

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.

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 2).

An illustrated schematic diagram (Figure 13) 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.

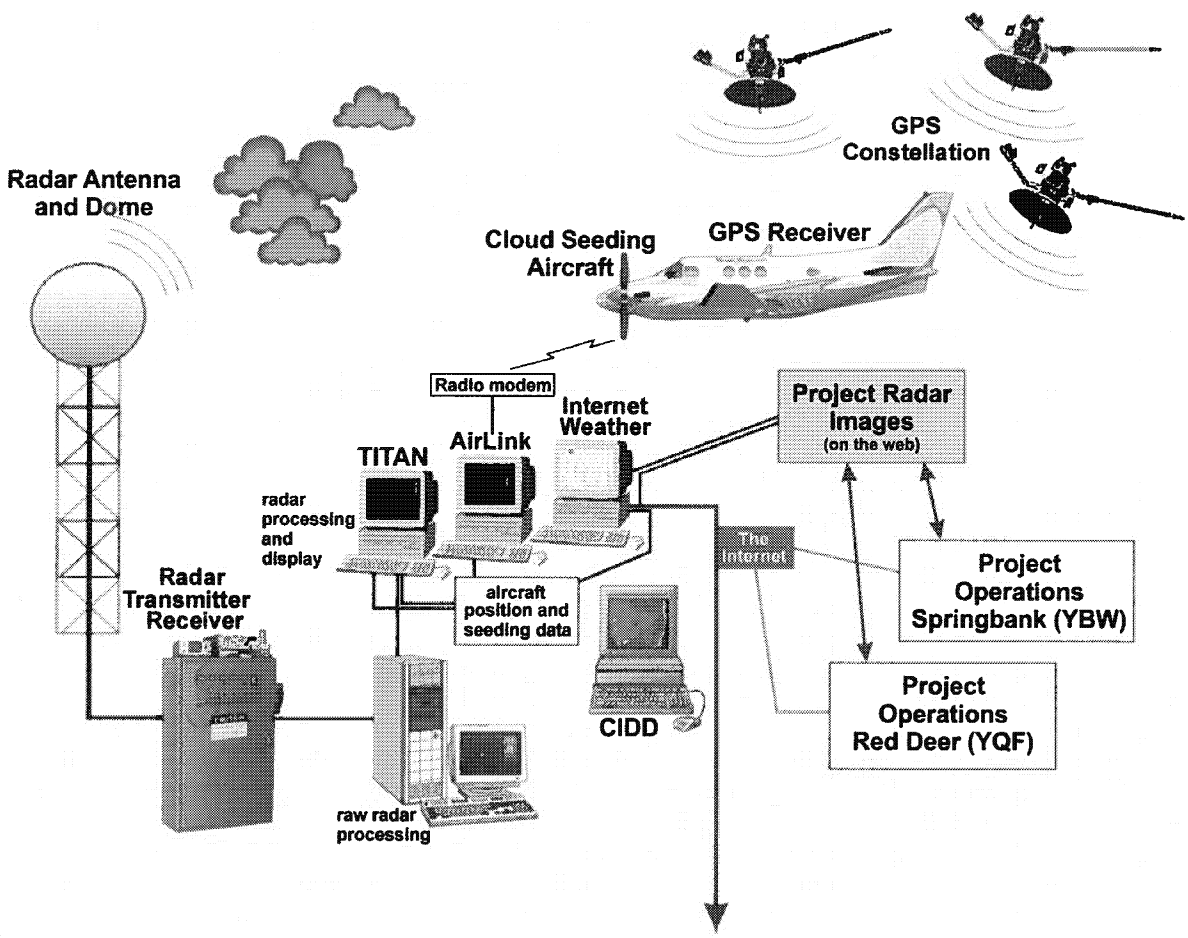

Fig. 13. Alberta Hail Suppression Program operational elements. Position and seeding data from each of the four aircraft are telemetered in real-time, ingested, and displayed. Positions are plotted directly on the radar display to optimize pilot-meteorologist interactions. Updated radar images are sent to the internet every five minutes, and are thus available to any flight crews not yet airborne. The only regular upper air sounding in Alberta is released from Edmonton, well north of the protected area, so model-derived soundings are used for operational forecasting.

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 14).

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.

Fig. 14. The WMI project Operations Centre is located at the Olds-Didsbury Airport, about 70 km (44 miles) north of the Calgary Airport, roughly halfway between the project's most important cities: Calgary and Red Deer. The radar antenna is housed within the dome, and the transmitter and receiver in the shed at the tower base. Operations are conducted from within the meteorological office housed within the adjacent hangar. In this image from 7 June 2013 at 4:36 PM, the darkening, yet rain-free cloud base overhead signals the organization of updrafts ferrying moisture into the developing storm above. WMI photograph by Bradley Waller.

Digital Weather Radar

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 five minutes are required for the radar to complete each volume scan.]

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, at approximately 5 minute intervals.

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 volume scan made by the radar. This is done so that the web image always has the same information and appearance for all scans.

Ground School

A ground school was conducted prior to the commencement of the project field operations on May 28th, 2013 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.

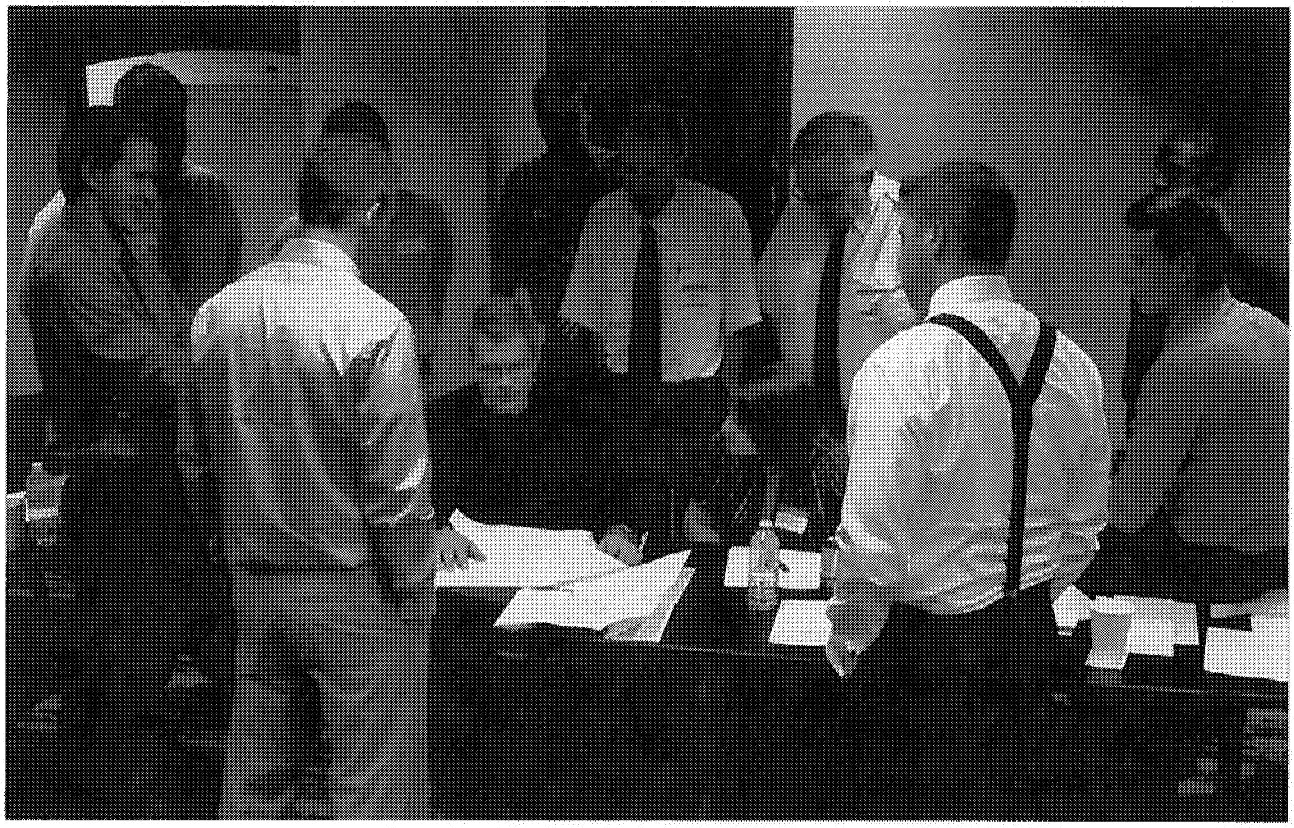

Fig. 15. Dmitri Limitovski (seated) of the NAV Canada Calgary Traffic Control Unit, Edmonton, leads a discussion about air space considerations during seeding operations with the pilots during pre-project AHSP ground school on May 28, 2013. WMI photograph by Bruce Boe.

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

Public Relations

A total of fourteen groups toured the project Operations Centre at the Olds-Didsbury airport as part of the Alberta Insurance Council accreditation program. The tours, organized and led by Ms. Lynne Fawcett of Intact Insurance, 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 16). Recent storms were also replayed on the radar. In total over 200 persons took part in this program, which helps those working in the industry understand the program.

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.

Fig. 16. Insurance industry employees visit the AHSP Operations Center at the Olds-Didsbury Airport on August 28, 2013. Captain Brook Mueller explains the functionality and equipment on Hailstop 1, a King Air C90 (top), and visitors pay rapt attention as Project Lead Meteorologist Dan Gilbert replays the radar data from a recent seeded storm (below). WMI photographs by Bradley Waller.

8.0 Flight Operations

For the first time, five specially equipped cloud seeding aircraft were dedicated to the project. Two Beech C90 King Airs and one Cessna 340A were based in Springbank, and a C90 and another C340A were based in Red Deer. The procedures used in 2013 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.

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 9).

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 C340A aircraft (N457DM) based in Springbank, Hailstop 3 for the King Air C90 aircraft (N522JP) stationed in Red Deer, Hailstop 4 for the C340A aircraft (N98585) based in Red Deer, Hailstop 5 for the King Air C90 aircraft (N518TS) based in Springbank.

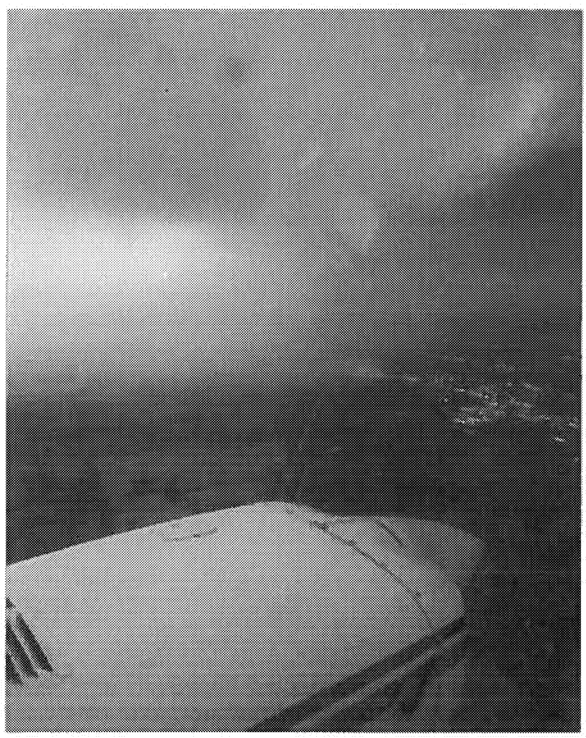

Fig. 17. Hailstop 4 seeds at cloud base while northbound on August 16, 2013, at 9:14 PM. The lights of Red Deer are visible in the deepening twilight. WMI photograph by L.J. Dunn.

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 given a ± 1,000 ft altitude clearance (see again Figure 8). 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.

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, a 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 18. 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. The King Airs were equipped with three belly-mounted racks each having the capacity for 102 20-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 twenty-four 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.

Fig. 18. Hailstop 1, one of three King Air C90 aircraft on project, taxies for takeoff at Springbank on August 12, 2013, at 8:12 PM. A "double-rack" of burn-in-place cloud seeding pyrotechnics is clearly visible aft of the engine on the near wing. The racks for smaller, ejectable flares mounted on the aircraft belly are more difficult to discern. WMI photograph by Brent Shewchuk.

The three turboprop 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, as shown previously in Figure 8. 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.

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 19). Complete specifications for the C340A are given in the Appendix.

The C340A aircraft both carry a 102-position belly rack for 20-gram ejectable flares (used in cloud top seeding, which they also can do very effectively), and wing racks for at least 24 150-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 C340A 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. 19. Hailstop 4, a Cessna 340A seeding aircraft is shown on the ramp in Red Deer. Notable on the aircraft (and absent from the turboprop aircraft such as Hailstop 3, seen in the background) are the wing-tip ice nucleus generators, the silver torpedo-like appurtenances below the wing-tip fuel tanks. The photograph was taken just prior to the daily weather briefing, during preflight inspection. The compressor is used to fill a pressure vessel in the front of the generator that provides the flow of seeding solution to the rear, where it is burned. WMI photograph by L.J. Dunn.

9.0 Radar Control and Communication Centre

The project Operations Centre was once again 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.

The project's radar control room contains 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 a VHF radio. The controlling duties were led by Dan Gilbert, who was assisted by Brad Waller and Joe Pehoski.

The operations room is configured to place all the needed resources within easy reach of the operations director. Project reference and equipment manuals are shelved on the upper left. Telephones are 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 is placed directly in front of the operations director. To the far right is a third computer with dual monitors (Figure 20, I, J), for continuous, dedicated access to internet weather data from other sources. There is ample room for a second meteorologist in the operations room when needed to assistance with radio communications, data entry, or general weather surveillance.

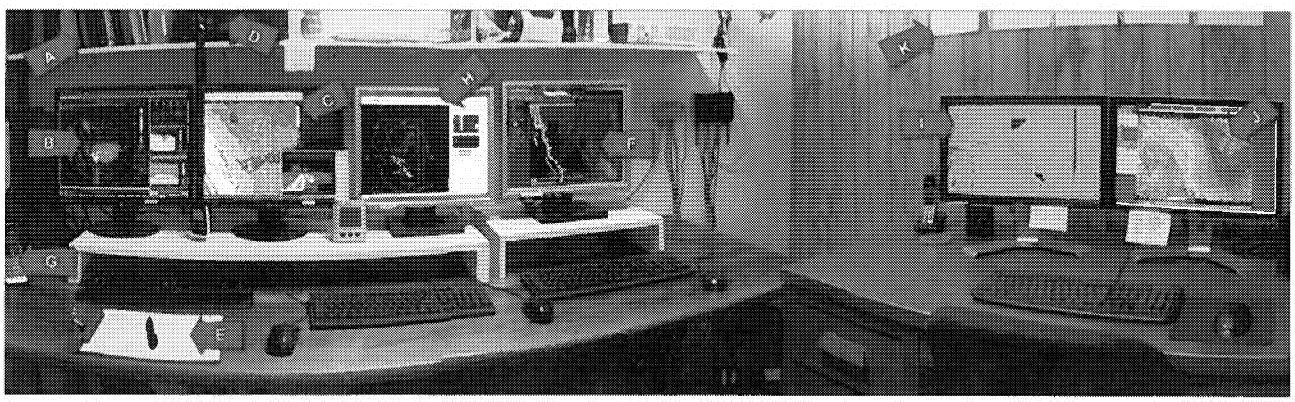

Fig. 20. The configuration of the Operations Room. Equipment includes (A) reference manuals, (B) TITAN displays, (C) CIDD, (D) VHF radio for communications with aircraft, (E) radar log, (F) internet data displays, (G) telephone, (H) AirLink display, (I and J) forecasting/nowcasting support displays, 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 take off. This gave crews better comprehension of the storm situation they were going to encounter when they were launched.

Fig. 21. The project Operations Centre at the Olds-Didsbury Airport. WMI photograph by Bradley Waller.

Fig. 22. The new Davis weather station deployed at the Operations Centre in 2013 is shown. Components are: Precipitation gauge, temperature, and humidity sensors (upper left), wind vane and anemometer (upper right), and wireless transmitter from wind tower to the operations room (both lower images). Wireless transmitters at both sensors allow the instruments to be placed at optimum locations, rather than compromises often made to afford wired connections directly to the office.

In 2013 the aging weather station at the Operations Centre was replaced with new equipment (Figure 22). A weather 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.

Weather Radar

In 2011 the WR-100 radar that had served the project from 1996 through 2010 was replaced with a new set built by WMI that has significantly increased sensitivity as well as Doppler capability. This new transmitter and receiver has allowed improved detection of developing storms, but also displays mature storms with greater clarity. This change has had a significant, positive impact on operations.

An upgraded TITAN radar display and analysis computer system was installed in 2010. This system was further updated prior to the 2011 season with a new operating system, and the backup computer was pre-loaded with an image of the primary so that in the event of a system failure an immediate swap would be possible. No TITAN failures occurred during the 2012 or 2013 seasons, however.

The TITAN radar images were sent to the WMI web server at 5 minute intervals. A larger 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 should it have been needed, but it was not.

Radar Calibration Checks

The radar was thoroughly calibrated when set up prior to the beginning of the 2013 season, and features routine automatic calibration of receiver and peaking of the transmitter automatic frequency control. Radar specifications are given in Table 4, below.

Table 4. Specifications of the WMI C-Band Weather Radar.

Parameters	Units / Values
Minimum Detectable Signal	-108 dBm
Radar Noise Figure	2.9 dB @ 1 MHz
Dynamic range	70 dB Receiver noise-dominated 100 dB compressed; @150 m range gate
Bandwidth	Automatically matched to gate spacing: .738 MHz at 150 m
Sensitivity	Reflectivity 0 dB RF SNR -9 dBZ @ 50 km 0.8 μ sec pulse length
Frequency Range	Tuneable, 5.30 – 5.8 GHz (C-band) (5.62 GHz 2013 value)
Pulse Repetition Frequency	800

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 permitted 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 July 20, 2013 storm that moved over Red Deer.

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.

10.0 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 2013 was less active than the previous two summers, closer to the climatological average. In June, 21 seeding missions were flown, and an additional two flights flown for patrol. 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. All five Hailstop aircraft flew on six days. Forty-seven seeding missions were flown, and 7 more patrol flights. A severe hailstorm moved through Red Deer during the evening of July 20th. Though seeded by multiple aircraft, larger-than-golf ball hail still fell in the city.

The active weather pattern slowed in August, as only 15 seeding missions were flown. Ten patrol missions were needed, however. No seeding was conducted in September, and only one patrol mission was flown, that on the 9th.

For the first time, five specially equipped cloud seeding aircraft were dedicated to the project. Two Beech C90 King Airs and one Cessna 340A were based in Springbank, and a C90 and another C340A were based in Red Deer. The procedures used in 2013 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.

The aircraft and crews provided a 24-hour service, seven days a week throughout the period. Thirteen 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 2013 crew was very experienced. The Red Deer aircraft team was led by Mr. Roger Tilbury, who has been flying cloud research and cloud seeding missions since the 1970s, and Mr. Joel Zimmer who has been with the Alberta program for 11 years. The Springbank team was anchored by Mr. Jody Fischer and Mr. Brook Mueller. The radar crew was anchored by WMI's Chief Meteorologist, Mr. Daniel Gilbert, now with four 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 exceptionally well and there were no interruptions or missed opportunities.

There were two minor radar issues during the course of the summer, neither of which impacted seeding operations. The first, initially manifested on the afternoon of July 2nd, was resolved by re-seating a card in the radar and slowing, ever-so-slightly, the antenna rotation speed. The second, an antenna elevation issue, occurred in the early morning of July 14th. Work to replace damaged drive gears began that afternoon and was completed just before seeding began that evening.

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 2014 program.

Flights

There were thunderstorms reported within the project area on 77 days this summer, compared with 70 days in 2012. Hail fell on 65 days. During this season, there were 229.6 hours flown on 31 days with seeding and/or patrol operations. A total of 70 storms were seeded during 83 seeding flights (170.9 flight hours) on the 26 seeding days. There were 21 patrol flights (22.2 hours), and 24 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.

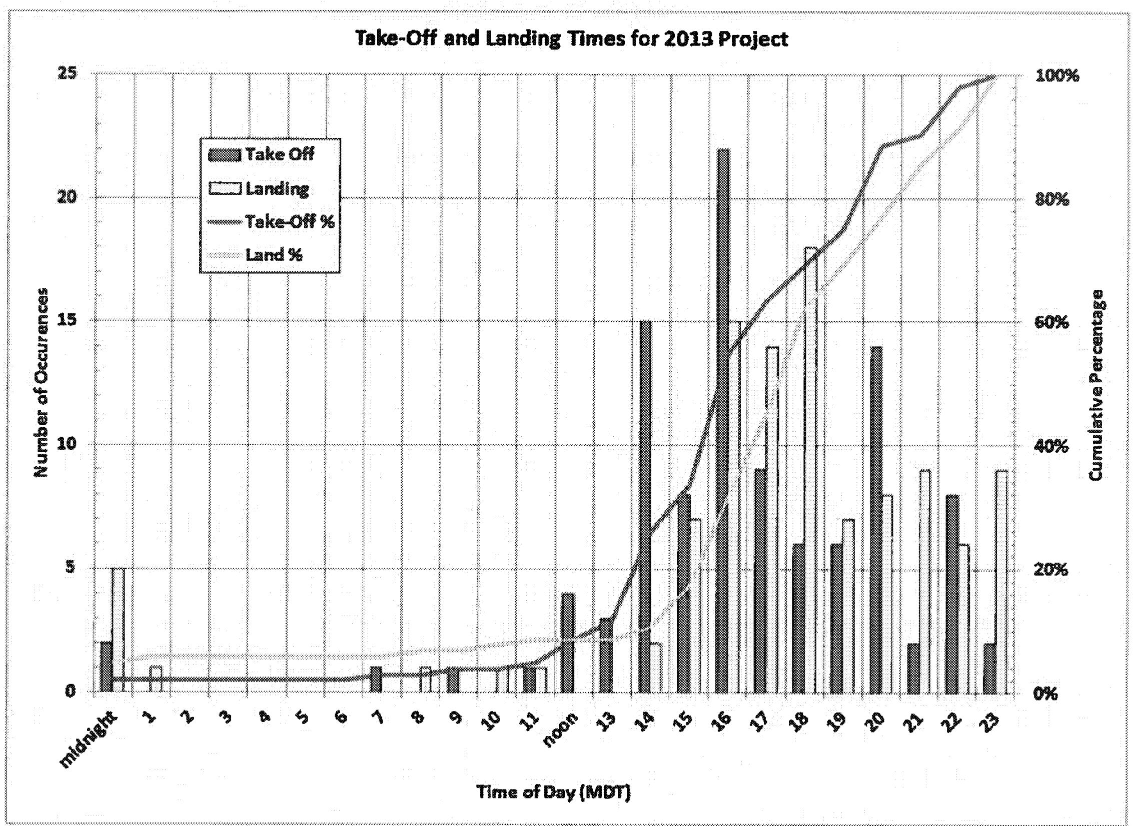

Fig. 23. Takeoffs and landings by time of day (Mountain Daylight Time). As has been the history of the project, most flight operations were conducted during the afternoons and evenings, strongly synchronized with the diurnal heating, and thus convection. An increased percentage of the flights were initiated between midnight and the noon briefing times, reflecting the increased attention to stronger nocturnal storms.

Seeding Amounts

The amount of silver-iodide nucleating agent dispensed during the 2013 field season totaled 233.3 kg. This was released in the form of 6,311 ejectable (cloud-top) flares (126.22 kg seeding agent), 636 burn-in-place (primarily cloud-base) flares (95.4 kg seeding agent), and 131.7 gallons of silver iodide seeding solution (11.6 kg seeding agent).

The amount of AgI dispensed on each day of operations in 2013 is shown in Figure 24. There were 8 days on which greater than 10 kg (10,000 grams) of seeding material was dispensed. Most of these were days on which all five aircraft seeded. The amount of seeding agent dispensed per storm was above average (3.3 kg per storm), significantly more than the long-term project mean of 2.24 kg.

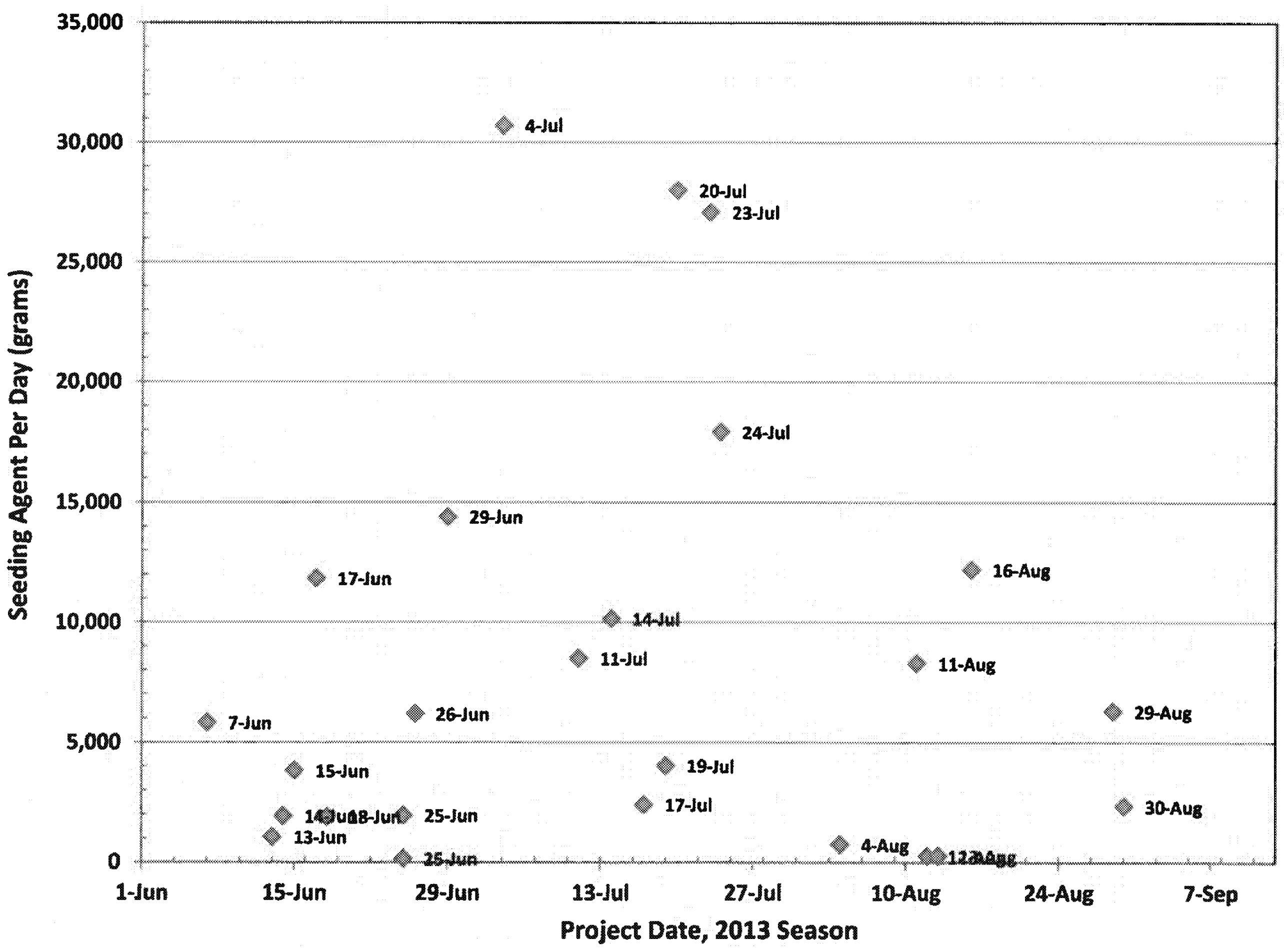

Fig. 24. Amount of seeding material dispensed per operational day in 2013.

Table 5 gives a list of the operational statistics for the past eighteen seasons of the Alberta Hail Suppression Project. These statistics can be useful in understanding how the current season compared with those before, and for planning purposes. This summer ranked ninth all-time in terms of activity. Seeding occurred on 26 days [mean is 32 days, record (2011) was 48 days]; 103 project missions were flown for patrol and seeding.

The *Season Activity Rank* shown at the far right of Table 5 was calculated as follows: Each parameter for each year was divided by the project mean for that parameter to produce a normalized value. Then, the normalized values of *Storm Days with Seeding*, *Aircraft Missions*, *Total Flight Time*, *Number of Storms Seeded*, *Ejectable Flares*, *BIP Flares*, and *Seeding Solution* were summed for each season. The seasons were then ranked. *Total Seeding Agent*, *Seeding Agent per Day*, *Seeding Agent per Hour*, and *Seeding Agent per Storm* were not included in the ranking as those are all quantities derived from the others.

A summary of the flare usage, by aircraft, during the past 18 years is given in Table 6. The Cessna 340s (Hailstop 2 and Hailstop 4) are used mainly as cloud base seeding aircraft because they have less performance than the three turbine aircraft and are equipped with the liquid AgI solution burners. Hailstop 1 (Calgary and now Springbank) had been a Piper Cheyenne II for all 15 seasons through 2010, but was replaced with a Beech C90 King Air beginning with the 2011 season. The King Airs are newer, have the same powerful engines as the Cheyenne (the Pratt and Whitney of Canada PT-6A), but parts are more readily available. Hailstop 2, now based in Springbank, has been a Cessna 340A for all 18 years. Hailstop 3 in Red Deer was a C340A for 4 years (1996-99), a Cheyenne II in 2000, 2003 and 2005, and a King Air C90 in 2004, and now from 2006 to present. The advantages of the C90 are that it has slightly longer endurance for increased seeding time, and good performance for reaching the far western regions of the target area near Rocky Mountain House in a reasonable amount of time (i.e. less than 30 min). The second C340A, Hailstop 4, was added in 2008 and based in Red Deer. This season, a fifth aircraft, Hailstop 5, a third King Air C90, was added to the project and based at Springbank.

All aircraft remained serviceable for the entire operational period and there were no significant maintenance issues.

The best seeding coverage consists of seeding a storm simultaneously using two aircraft; one at cloud base and another at cloud top (-10°C) along the upwind "new growth" side of the storm. The King Air aircraft have proven themselves as excellent cloud-top seeders. The seeding strategy has been to stagger the launch of the seeding aircraft, and use one aircraft to seed at cloud base and one aircraft at cloud top when the storm is immediately upwind or over the highest priority areas. However, if multiple storms threaten three or more areas at the same time, generally only one aircraft is used on each storm, or more aircraft are concentrated on the highest population area around Calgary.

Seeding was conducted on the following 26 days: June 7th, 12th, 14th, 15th, 17th, 18th, 25th, 26th, 27th, and 29th; July 2nd, 4th, 6th, 11th, 14th, 17th, 19th, 20th, 22nd, 23rd, 24th, and 25th; and August 4th, 7th, 11th, 13th, 16th, 22nd, 26th, 29th, and 30th. No seeding was conducted in September. All five aircraft were used for operations on the following 6 days (local time) this season: July 4th, 19th, 20th, 22nd, 23rd, and 24th. Four of the five aircraft flew seeding and/or patrol missions on an additional five days: June 17th and 29th, July 14th, and August 12th and 29th.

Patrol flights were flown on June 12th and 18th, July 4th, 6th, 14th, 19th, 22nd, and 24th, August 4th, 7th, 13th, 16th, 21st, 26th, 29th and 30th, and September 9th.

Table 5. Operational Statistics for Seeding and Patrol Flights, 1996 through 2013.

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	10
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

***The 1996 and 1997 seasons began on June 15, not June 1, which has been the norm ever since.**

Table 6. Cloud Seeding Pyrotechnic and Seeding Solution Usage by Aircraft, through the 2013 Season.

AIRCRAFT LEGEND:	C340	Cessna 340A	C90	Beech King Air C90	CHEY	Piper Cheyenne II

hours = flight hours, EJ = ejectable pyrotechnic, BIP = burn-in-place pyrotechic, gen hr = hours wingtip solution-burning time

SEASON	Hailstop 1 Springbank (Calgary prior to 2012)		Hailstop 2 Springbank (Calgary prior to 2012)		Hailstop 3 Red Deer		Hailstop 4 Red Deer		Hailstop 5 Springbank	
	FLIGHT HOURS, EJ FLARES, BIP FLARES		FLIGHT HOURS, EJ FLARES, BIP FLARES, GEN HOURS		FLIGHT HOURS, EJ FLARES, BIP FLARES		FLIGHT HOURS, EJ FLARES, BIP FLARES, GEN HOURS		FLIGHT HOURS, EJ FLARES, BIP FLARES	
2013	C90	41 hours, 1149 EJ, 115 BIP	C340	58 hours, 0 EJ, 148 BIP, 37 gen hr	C90	42 hours, 3381 EJ, 166 BIP	C340	48 hours, 0 EJ, 78 BIP, 31 gen hr	C90	40 hours, 1781 EJ, 129 BIP
2012	C90	76 hours, 3250 EJ, 232 BIP	C340	87 hours, 0 EJ, 224 BIP, 72 gen hr	C90	83 hours, 4464 EJ, 198 BIP	C340	85 hours, 3 EJ, 260 BIP, 63 gen hr		
2011	C90	97 hours, 4783 EJ, 239 BIP	C340	105 hours, 244 EJ, 269 BIP, 91 gen hr	C90	99 hours, 5646 EJ, 273 BIP	C340	108 hours, 106 EJ, 239 BIP, 92 gen hr		
2010	CHEY	62 hours, 1612 EJ, 132 BIP	C340	82 hours, 74 EJ, 236 BIP, 53 gen hr	C90	96 hours, 4154 EJ, 200 BIP	C340	68 hours, 2 EJ, 286 BIP, 64 gen hr		
2009	CHEY	22 hours, 250 EJ, 27 BIP	C340	31 hours, 0 EJ, 65 BIP, 6 gen hr	C90	24 hours, 201 EJ, 48 BIP	C340	33 hours, 0 EJ 97 BIP, 17 gen hr		
2008	CHEY	65 hours, 953 EJ, 88 BIP	C340	44 hours, 0 EJ, 171 BIP, 27 gen hr	C90	51 hours, 695 EJ, 169 BIP	C340	35 hours, 0 EJ, 120 BIP, 19 gen hr		
2007	CHEY	40 hours, 979 EJ, 81 BIP	C340	41 hours, 0 EJ, 155 BIP, 31 gen hr	C90	34 hours, 643 EJ, 177 BIP				
2006	CHEY	54 hours, 3217 EJ, 179 BIP	C340	70 hours, 72 EJ, 248 BIP, 58 gen hr	C90	66 hours, 1640 EJ, 276 BIP				
2005	CHEY	49 hours, 2750 EJ, 169 BIP	C340	45 hours, 0 EJ, 121 BIP, 38 gen hr	CHEY	64 hours, 1020 EJ, 225 BIP				
2004	CHEY	83 hours, 5574 EJ, 359 BIP	C340	62 hours, 0 EJ, 196 BIP, 53 gen hr	C90	82 hours, 939 EJ, 322 BIP				
2003	CHEY	64 hours, 3598 EJ, 250 BIP	C340	54 hours, 0 EJ, 130 BIP, 37 gen hr	CHEY	46 hours, 867 EJ, 138 BIP				
2002	CHEY	57 hours, 1994 EJ, 163 BIP	C340	49 hours, 2 EJ, 73 BIP, 32 gen hr	CHEY	51 hours, 1112 EJ, 141 BIP				
2001	CHEY	62 hours, 3174 EJ, 216 BIP	C340	75 hours, 4 EJ, 215 BIP, 56 gen hr	CHEY	68 hours, 2093 EJ, 102 BIP				
2000	CHEY	90 hours, 4755 EJ, 379 BIP	C340	77 hours, 164 EJ, 193 BIP, 56 gen hr	CHEY	97 hours, 4734 EJ, 368 BIP				
1999	CHEY	91 hours, 3795 EJ, 313 BIP	C340	81 hours, 244 EJ, 197 BIP, 60 gen hr	C340	79 hours, 400 EJ, 180 BIP, 59 gen hr				
1998	CHEY	62 hours, 1880 EJ, 107 BIP	C340	68 hours, 134 EJ, 199 BIP, 29 gen hr	C340	59 hours, 9 EJ 190 BIP, 48 gen hr				
1997	CHEY	70 hours, 1828 EJ, 62 BIP	C340	58 hours, 264 EJ, 128 BIP, 26 gen hr	C340	60 hours, 284 EJ, 166 BIP, 32 gen hr				
1996	CHEY	62 hours, 2128 EJ, 143 BIP	C340	46 hours, 895 EJ, 192 BIP, 9 gen hr	C340	52 hours, 794 EJ, 207 BIP, 23 gen hr				

Storm Tracks

A map of all hailstorm tracks (determined by radar) during 2013 is shown in Figure 25. July was the busiest month, as is typically the case. There were twelve storms that tracked across or within the city limits of Calgary during the 2013 season. None of these resulted in major damage in the Calgary metropolitan area. The most notable storm of the season was the storm of July 20, which moved southeast across Red Deer and produced considerable hail.

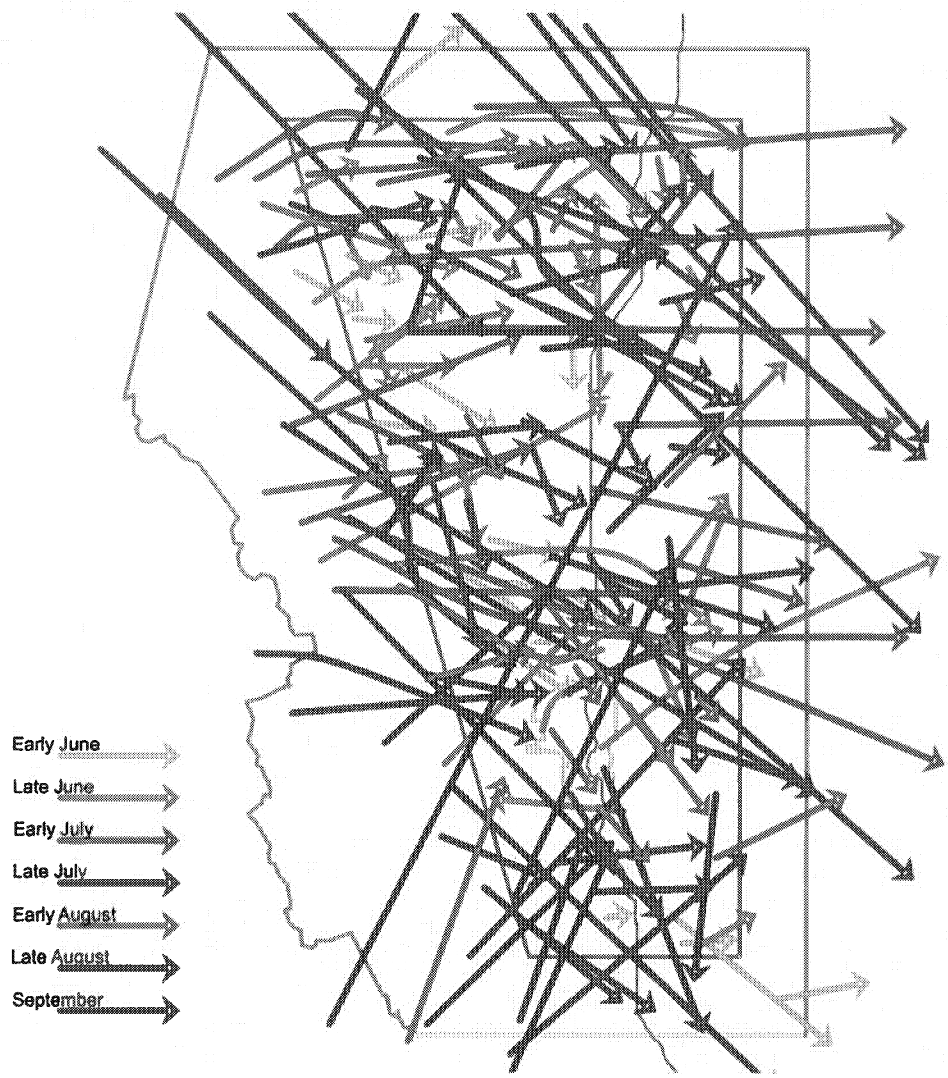

Fig. 25. Map of all potential hailstorm tracks within radar coverage during 2013, as indicated by a minimum vertically-integrated liquid (VIL, from the radar) of at least 30. This map shows all of the 116 storms seeded, plus others of hail potential that did not move near cities or towns. All storms must be carefully monitored because as the tracks show, direction of movement often changes. June storms are green, July red, August blue, and September violet. For each, the lighter color denotes storms that occurred during the first half of the month.

The number and distribution of storm tracks during 2013 were very similar to previous seasons with July being the most active month, and August second most active. There were very few storms in late August, and only six cells are plotted for September. Plotting of the storm tracks includes more than just start and end points when storms turned appreciably during their lives, to afford the reader a better perspective of actual storm behavior.

Hail was reported within the project area (protected area and buffer area) on 65 days. Larger than golf ball size hail was reported on July 20th in Red Deer. On the 22nd of July, larger than golf ball size hail was also reported near the town of Dogpound.

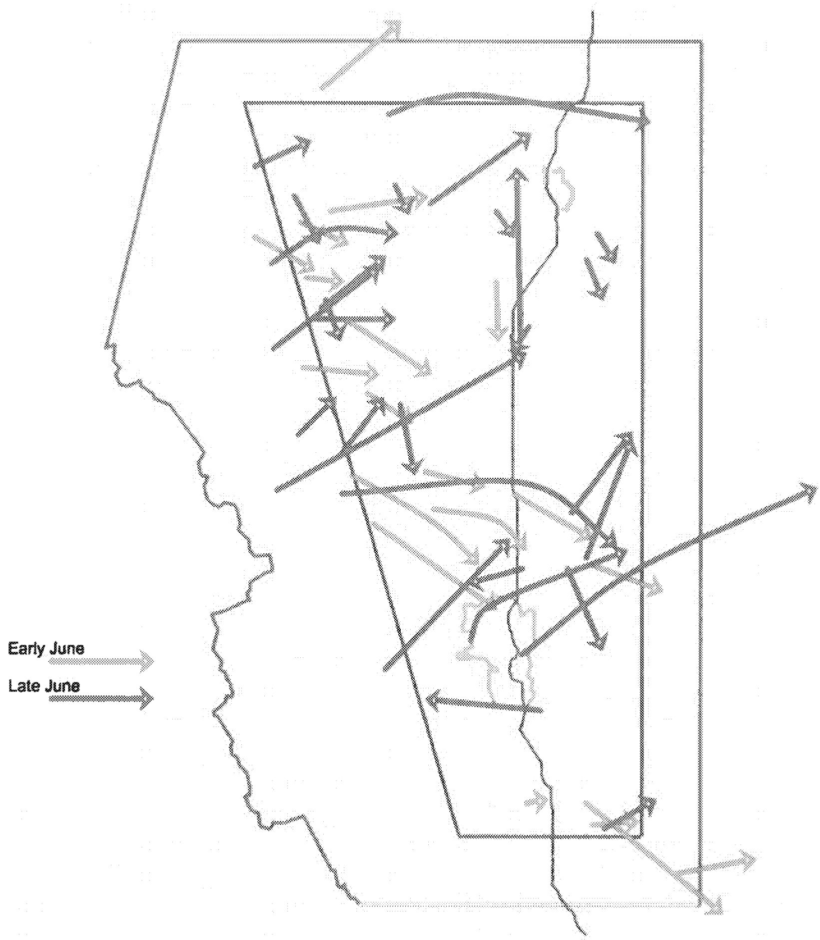

Fig. 26. Storm Tracks for the month of June 2013. The lighter green is those storms occurring in the first half of the month, the darker shade the latter half. All storms having VIL of at least 30 are plotted; the boundary of the operations area and protected area also are shown.

Golf ball size hail was reported or observed by radar signature on June 17th east of Strathmore; June 29th north of the town of Caroline and west of Sylvan; on the 4th of July north of Cochrane and north of Airdrie; on July 14th east northeast of Rocky Mountain House; the 19th of July north of Three Hills; on the 23rd of July west of Sundre, southwest of Cremona, southwest of Calgary, west of Okotoks, and in High River; and the 24th of July northeast of Rocky Mountain House. The month of August saw golf ball size hail on the 11th, north of Cochrane and north of Calgary; on the 16th west northwest of Sylvan; and the 29th north of Cochrane.

Walnut size hail was reported or observed by radar signature on June 7th northeast of Airdrie; on June 25th northwest of the town of Rimbey; the 6th of July east northeast of Airdrie and east of the town of Irricana; on the 11th of July southwest of Sylvan; July 25th south of High River; the 4th of August north of Cochrane; on August 12th east of Olds and west southwest of Three Hills; August 26th northwest of Rocky Mountain House and east of the town of Rimbey; east northeast of Innisfail on the 30th of August; and on September 8th south of Cremona.

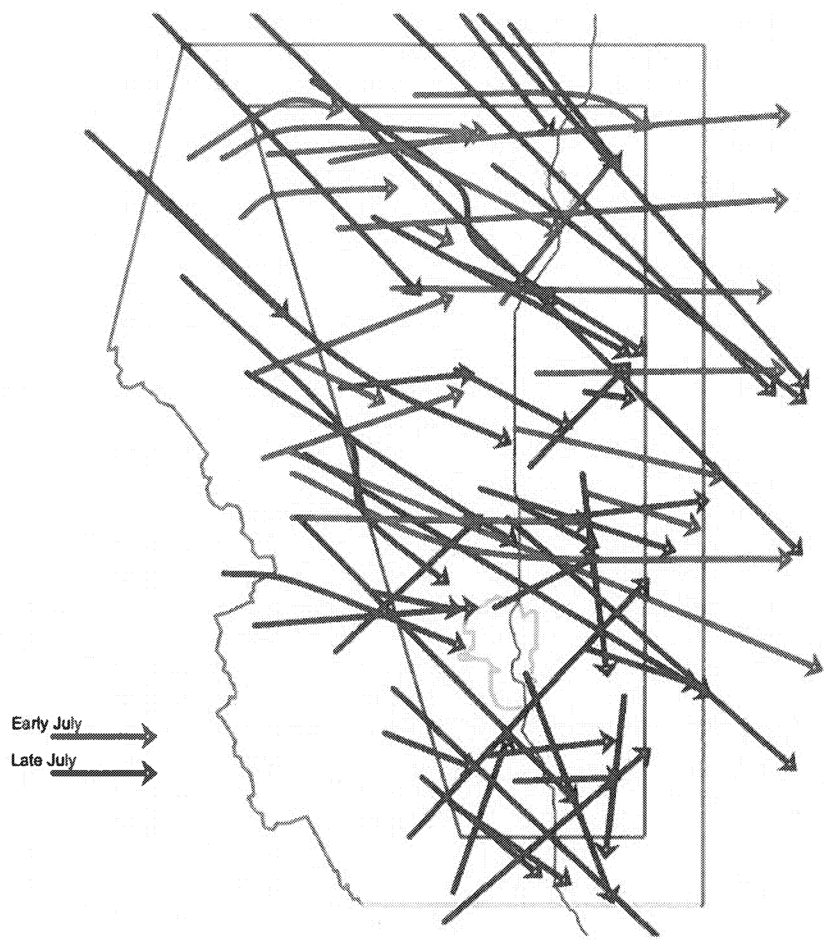

Fig. 27. Storm Tracks for the month of July 2013. The lighter red is those storms occurring in the first half of the month, the darker shade the latter half. All storms having a VIL of at least 30 are plotted; the boundary of the operations area and protected area also are shown.

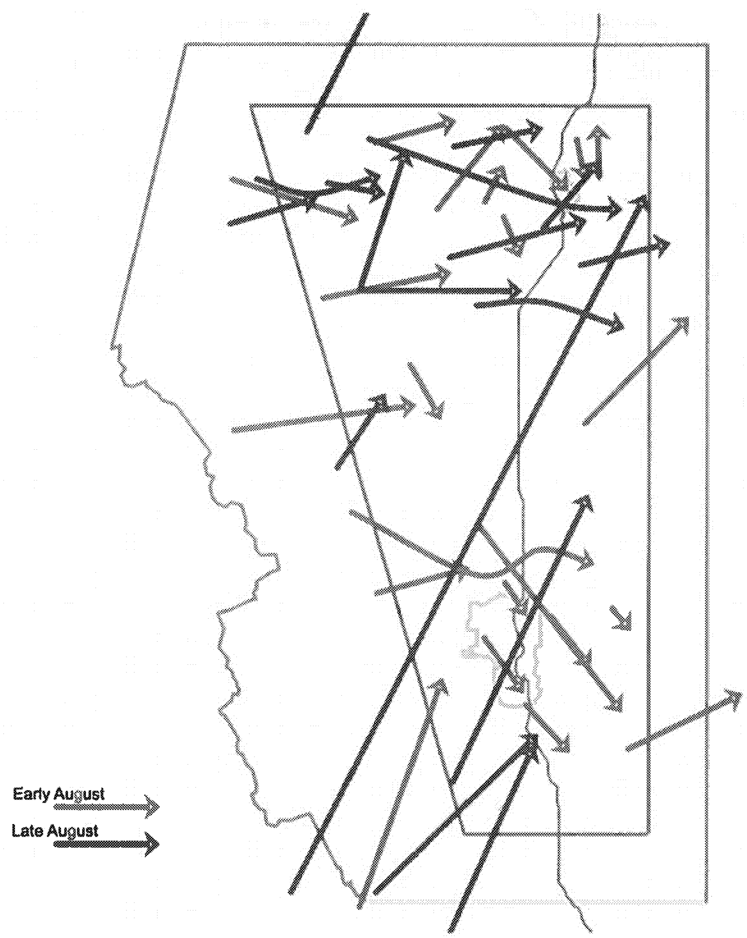

Fig. 28. Storm tracks for the month of August 2013. The lighter blue is those storms occurring in the first half of the month, the darker shade the latter half. All storms having a VIL of at least 30 are plotted; the boundary of the operations area and protected area also are shown.

The weather pattern during the summer of 2013 was less active than the previous two summers, closer to the climatological average. In June, 21 seeding missions were flown, and an additional two flights flown for patrol. 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.

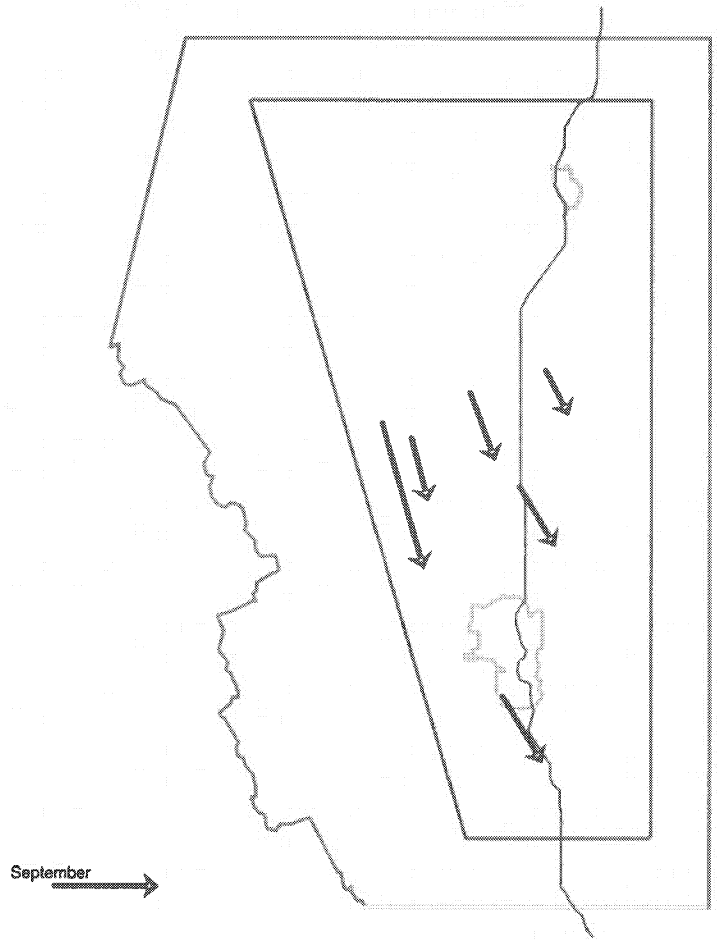

Fig. 29. Storm tracks for the month of September 2013, up to the end of project on the 15th. All storms having a VIL of at least 30 are plotted; the boundary of the operations area and protected area also are shown.

11.0 Weather Forecasting

A project forecast was prepared each operational day throughout the project period by the assigned project meteorologist. In addition to the real-time information available from the project radar at the Olds-Didsbury Airport, the forecasting meteorologist used local weather observations as well as a vast array of weather data available on the internet.

Coordinated Universal Time

The standard reference time chosen for the project field operations is universal time coordinates (UTC), also known as coordinated universal time (CUT), or Greenwich Mean Time (GMT). This is the accepted international standard of time for general aviation and meteorological observations, reporting, and communication. In Alberta, UTC is 6 hours ahead of local Mountain Daylight time (MDT). For example, 12:00 noon local Alberta time is equal to 18:00 UTC, and 6:00 PM local is equal to 24:00 or 00:00 UTC. This causes some confusion, especially with non-project personnel, since many of the thunderstorms occurred late in the day and continue beyond 6:00 PM local time, which is midnight or 00:00 hours UTC. The standard convention incorporated by the Alberta project is to report all aircraft, radar, and meteorological times in UTC; however, the for convenience summary tables are all organized according to the local calendar "storm" day with respect to Mountain Daylight Time.

Purpose

The primary function of the daily forecast is to impart to project personnel a general understanding of that day's meteorological situation, particularly as it relates to the potential for hail-producing storms. In this role it is useful, but because the data in hand are limited in temporal and spatial resolution, and because the forecasters themselves are human and thus fallible, the forecast can never be taken as the final word as to whether activity will or will not develop. Forecasts of no or limited convective activity do not relieve any project personnel of their hail-fighting responsibilities, and *should not reduce vigilance or readiness of meteorological staff or flight crews.* In theory, the project could function effectively without project forecasts. In reality, the forecasts are useful for a number of reasons:

- Elective maintenance of project-critical facilities (radar and aircraft) can be conducted on days when the probability of workable storms is less.
- Forecasts offer insight regarding the time at which convection is likely to initiate, thus allowing some intelligence in handling decisions about aircraft standby times.
- Preferred areas, *e.g.* northern, central, or southern portions of the protected area that are more prone to see action are identified in the forecasts, providing the logical basis for assignment of which aircraft are initially placed on standby.
- Forecasts attempt to quantify the available atmospheric instability, and thus the likelihood of explosive cloud/storm development. Days having high potential for rapid cloud growth require more immediate action.
- Post-hoc forecast verification conducted by the meteorologists is a helpful tool to increase our understanding of Alberta thunderstorms, especially the atmospheric indicators (precursors) in the pre-storm environment. As this knowledge improves, so will our ability to anticipate and react to the initial deep convection.

So, while in *theory* the forecasts are not needed, they are useful and probably essential. The ultimate defense against the unexpected, unforecast, explosively-developing severe storm would be to always have aircraft airborne, patrolling the skies, scanning for the first sign of intense vertical cloud growth. More realistically, one might have flight crews constantly waiting, ready to scramble. The funding available for the project does not allow either of these, however, so the forecast becomes the primary tool through which the available resources can be allocated in the most effective manner.

It is also worth noting that even when equipment and personnel work together efficiently as a well-oiled, smooth-running machine, hail damage can still occur. A typical thunderstorm releases as much energy in its lifetime as a nuclear bomb. Cloud seeding can affect the microphysical (precipitation) processes, but we do not yet have the knowledge or tools to affect the energy released. Nature, in the end, sometimes offers more than can be handled.

Process and Dissemination

Project forecasts were valid from 6:00 AM through 6:00 AM the next day, and also include a day-two outlook. The daily forecast preparation began with an assessment of the current weather conditions. The latest METARs (hourly surface weather reports), weather station data, radar and satellite imagery were noted and saved. The latest surface and upper air analysis maps were printed and saved. All data were saved with file names that utilize the proper WMI file naming procedures, with YYYYMMDD (year-month-day) at the beginning of the file name. Once the forecaster had a grasp of the current conditions, outside agency forecasts were examined in order to give a first-best-guess of the day's probable events. Often times, project personnel would request a "pre-forecast" before the official forecast is ready. NAV Canada, Environment Canada forecasts and BUFKIT soundings are always useful for this purpose.

The forecaster then examined the various operational prognostic model output. Typically, the WRF was the most up to date in the early morning. All forecasters had their own preference for operational models, but some of the choices available include the WRF/NAM, GFS, ECMWF, SREF and the Canadian models. Model data were archived daily (but not printed) for the 250 mb, 500 mb, 700 mb, and pressure surfaces. Saved maps include the most current map (usually 12Z) through hour 48. Certain features are always of interest at certain levels:

- The 250 mb best reflects the location of the upper jet stream winds, around 35,000 feet. This map was analyzed for the general wave pattern (ridge/trough), upper level diffluence, and jet streaks. The right entrance and left exit quadrants of an upper jet streak are considered favorable regions for enhanced upward motions. Storm days with "upper support" tend to produce more vigorous convection than days without.

- The 500 mb level reflects the middle of the atmosphere around 18,000 feet, which is generally the boundary between upper and lower level weather features (aka: the level of non-divergence). 500 mb charts were examined for temperatures, humidity, wave pattern, and especially vorticity. Advection of 500 mb vorticity from broad scale troughs, lows, or shortwaves tends to "force" air parcels to rise. This can be a trigger to help break through low level temperature inversions, or just simply enhance the amount of vertical motion in the atmosphere. Cold, dry conditions at this level are conducive to an unstable atmosphere. Many convective stability indices utilize temperature and dew point between the surface and 500 mb. History shows that some of the worst hail storms occurred on days with only moderate instability but with strong 500 mb vorticity advection and upper jet support.

- 700 mb is the lower to mid-level of the atmosphere around 10,000 feet near the convective cloud base. The 700 mb charts are most typically used to determine the amount of low level moisture over a region. High amounts of 700 mb moisture are conducive to an unstable atmosphere. Relative Humidity, theta-E (equivalent potential temperature), and vertical velocity charts are all useful tools at this level. Shortwave troughs are sometimes evident on 700VV charts when they are not easily identified at 500 mb. The presence of a theta-E ridge at or below 700 mb should be a red flag that nocturnal convection is possible. 700 mb charts should also be analyzed for the presence of an inversion or "cap" that inhibits surface based convection, although this is usually more easily identified on a sounding than on a map.

- Surface prognostic (forecast) charts (progs) were analyzed for the presence of lifting mechanisms such as troughs, lows, fronts, and dry lines. Such lifting mechanisms are triggers for initiating thunderstorms when the atmosphere is unstable. Moist, warm surface conditions are indicative of an unstable atmosphere. After sunset however, the lowest levels of the atmosphere tend to "decouple" from the upper and middle atmosphere as the air mass cools from the bottom up. This means that surface temperature and moisture are most important during the daytime and evening hours and can have less impact at night. It is a good idea to consult multiple sources for surface prog charts, as some analyses will omit important features. There can be major differences from one source to the next when it comes to surface analysis and timing. In general, surface dew points greater than 9°C are considered sufficient for large hail storms. Thunderstorm development becomes unlikely with dew points less than 5°C. Surface charts may also be utilized to determine areas with upslope flow. Low-level easterly winds flowing up the eastern slopes of the mountains are frequently the cause for storm initiation for the project.

After all model charts have been saved, the forecaster created a daily meteorogram. This is a one-page tool that includes multiple strip charts of the forecaster's choosing. Typical parameters for the meteorogram include temperature and dew point, cloud cover, wind direction/speed, CAPE, Lifted Index, Convective Inhibition, etc. The meteorogram is typically created for both Calgary and Red Deer every morning, but other locations can be utilized depending on where the forecaster thinks the best chance for deep convection (thunderstorms) will occur on that day. The meteorogram is printed and saved in the archives. The strip charts are valid through at least three days and can be a great tool for determining the extended outlook.

The next step was to create a daily sounding, or Skew-T diagram. Unfortunately, the closest real weather balloon site is Edmonton, which is too far away to use for forecasting in the project area. Forecast soundings from the numerical models were thus preferred, which could be generated through a host of different internet sources.

The 12Z and 00Z WRF/NAM soundings were archived for both Red Deer and Calgary on a daily basis. These data were also utilized for running the HAILCAST model when necessary. At this point the forecaster chose a location and valid time for the daily forecast sounding. This was the time and place with the worst-case scenario for the highest CDC (Convective Day Category) through the next 24 hours, typically Red Deer or Calgary. Most forecasts were made based on expected conditions at 00Z because the atmosphere is usually most unstable in the late afternoon; this may be sooner or later depending on the timing of surface features, etc. Once the place and time were decided, the selected forecast sounding was opened with the RAOB software and modified as deemed physically plausible, to provide a worst-case scenario (most intense convection possible). This often involved raising or lowering the surface temperature to best represent the expected maximum temperature for the day. The amount of surface moisture could be modified as well, but this was done with care so as not to overdo it. This has a large effect and can be the cause of busted forecasts. Once the sounding was modified, all convective parameters were recorded on the *daily metstats sheet*, and the sounding was printed. An image of the sounding was always saved, which was emailed with the rest of the forecast.

The forecaster then completed the daily forecast sheet. The map interpretation was drawn by hand, and included the following for the chosen valid time: 500 mb height analysis, surface analysis (including fronts, lows, highs, troughs, and dry lines), position of upper jet streaks, and position of any shortwaves or vorticity maxima/lobes. The Synopsis section included a brief explanation of the features that were most relevant to the forecast. Each forecast box contained a concise description of the expected weather for the entire 24 hour period through the next morning at 9:00 AM. The rest of the forecast parameters and winds were taken directly from the modified sounding, and were identical to the forecast sounding that was printed out. The forecast sheet also included a checklist. The purpose of the checklist is to make sure the forecaster does not inadvertently miss or forget an important weather feature.

Before making the final decision about the likelihood and size of hail, the forecaster sometimes needed to run the HAILCAST model (Brimelow et al., 2006). To determine whether or not to run the model, a decision tree is used (Figure 30). Research has shown that the model works well with some conditions, but has been found lacking under other scenarios. The decision tree is meant to remove situations where the model is not helpful. If the model is to be run, the forecast sounding data was modified to the required HAILCAST sounding format and saved as text files in the appropriate folder. Then the model was run with the expected high temperature and dew point for the day. The average output from the models is included on the forecast sheet.

Finally, the decision was made as to the Convective Day Category (CDC). This was the last decision before the forecast was sent out to project personnel. The CDC was marked on the forecast sheet, and the sheet scanned and saved according to WMI file naming procedures. It was then emailed to the "forecast" list through the company email exchange using the Olds radar email account. The subject line of the email uses the format "YYYYMMDD AB forecast". The forecaster attached the scanned forecast sheet and saved sounding image to the email and sent it at 11:30 local time, or about 30 minutes prior to the daily briefing.

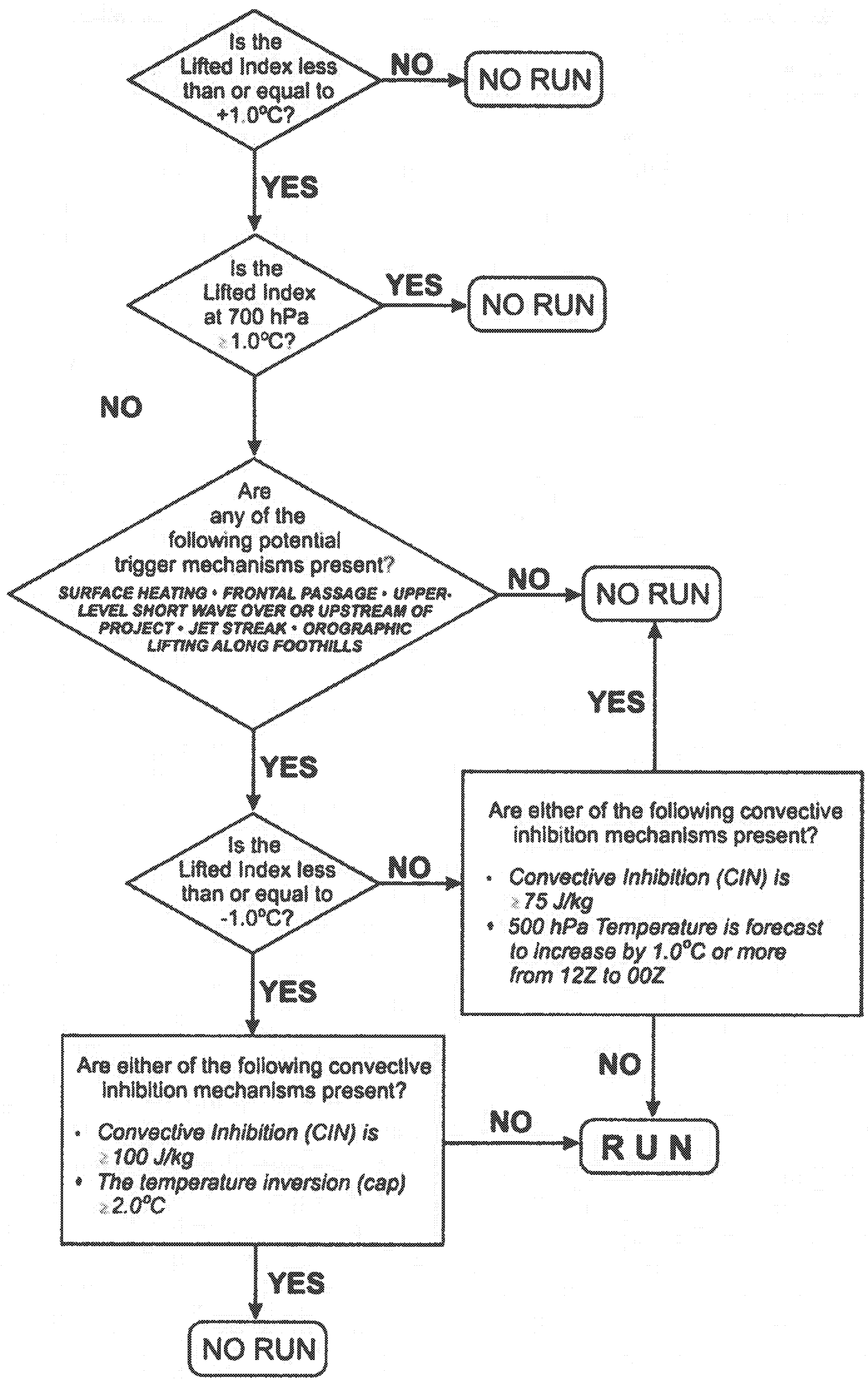

Fig. 30. The flow chart used to determine if the Hailcast model (Brimelow et al. 2006) should be run. Essentially, the chart process eliminates the model runs from those days when hail is unlikely.

Daily Briefings

All project staff participated in a telephone conference call weather briefing each day at 12:00 noon (local time). Teamwork depends on good communications, and so all personnel were required to attend the daily briefing at one of three locations: the radar, the Calgary Airport office, or the Red Deer Airport office. This briefing session included a debriefing and summary of the previous day's operations (if any), discussion of the weather situation, presentation of the weather forecast and operational meteorological statistics, predicted hail threat, cloud base heights and temperatures, upper level winds, storm motion, equipment status reports, and operational plans for the day. After the briefing, crews were put on telephone standby or asked to remain at the airport on standby. All personnel were equipped with telephones to allow quick access and constant communications, day or night.

Fig. 31. A noon weather briefing is conducted daily by speakerphone from the Olds Operations Centre, as shown here. WMI Project Manager Jody Fischer and Lead Project Meteorologist, Dan Gilbert (L to R, foreground), listen attentively to crews at Springbank and Red Deer. Photograph courtesy of Terry Krauss.

If no seeding was expected within the next few hours after briefing (i.e. clear skies), flight crews were put on telephone standby. If operations were likely within the next few hours or actively growing cumulus were present, then crews were put on Airport Standby immediately following the briefing. During briefing, one crew at each site was always designated as "first up" or the first aircraft to be called if needed. Weather conditions and aircraft maintenance dictated which crews will be first up on any given day. If ceilings are very low, top seeders were designated as first up. If an aircraft is scheduled for maintenance, however routine, then it will not be first up since it may have delays in launch time. When not on airport standby, crews are on telephone standby (maximum 60 minutes from airport) at any time unless consulting with the project manager or meteorologists.

The Convective Day Category (CDC)

The daily weather forecast established the *Convective Day Category* (CDC) that best described the conditions that were expected for each day. The CDC (Strong 1979) is an index that gives the potential for hailstorm activity and thus seeding operations. A description of the weather conditions for each CDC is given in Table 7. The distinction between the -2 and -1 category is sometimes difficult, since overcast or prolonged rains eventually break up into scattered showers. The maximum vertically-integrated liquid (VIL) recorded by TITAN is used for forecast verification of hail size in the absence of surface hail reports. Radar VIL values are used within the project area or buffer zones on the north, east, and south sides (not including the mountains or foothills of the western buffer zone). This may have increased the number of declared hail days from the early project years, which relied on a human report of hail fall at the surface; however, it is believed to be a more realistic measure of hail. The +1 category minimum hail size is assumed to be 5 mm since this is a common minimum size for hail used by numerical modelers, and also the recognized size threshold for hail. Smaller ice particles, those less than 5 mm diameter, are generally called snow pellets or graupel.

Table 7. The Convective Day Category.

CDC	Strategy	Description
-3	No Seed	Clear skies, fair weather cumulus, or stratus (with no rain). No deep convection.
-2	No Seed	Towering cumulus, altocumulus, alto-stratus, or nimbostratus producing rain for several hours or weak echoes (e.g. virga).
-1	No Seed	Scattered convective rain showers but no threat of hail. No reports of lightning.
0	Patrol flights and potential seeding.	Thunderstorms (at least one) but no hail. VIL < 20 kg/m^2 within the project area or buffer zones on north, east, and south sides.
+1	Seed	Thunderstorms with pea or shot size hail (0.5 to 1.2 cm diameter). 20 kg/m^2 < VIL < 30 kg/m^2
+2	Seed	Thunderstorms with grape size hail (1.3 to 2.0 cm diameter). 30 kg/m^2 < VIL < 70 kg/m^2
+3	Seed	Thunderstorms with walnut size hail (2.1 to 3.2 cm diameter). 70 kg/m^2 < VIL < 100 kg/m^2
+4	Seed	Thunderstorms with golf ball size hail (3.3 to 5.2 cm diameter). VIL > 100 kg/m^2
+5	Seed	Thunderstorms with greater than golf ball size hail (>5.2 cm diameter).

Various meteorological parameters were also forecast in addition to the CDC. These parameters were used in developing a seeding strategy and were passed on to pilots during the weather briefing. The meteorological parameters were recorded each day and archived for future analysis.

Meteorological Statistics

A complete listing of the daily meteorological statistics is given in the Appendix. A summary of the important daily atmospheric parameters used as inputs for the daily forecast of the CDC and threat of hail is given in Table 8. Hail days are defined by either a report of hail at the surface or by a vertically-integrated-liquid water (VIL) measurement from the radar of at least 20 kg/m^2.

Table 8. Summary of Daily Atmospheric Parameters (All Days)

	All Days (107)			
Parameter	Average	StdDev	Maximum	Minimum
Forecast Convective Day Category	+1.1	2.0	+4	-3
Precipitable Water (inches)	0.8	0.2	1.2	0.5
0°C Level (kft)	11.9	1.9	16.2	8.2
-5°C Level (kft)	14.5	1.9	18.3	10.7
-10°C Level (kft)	17.1	2.0	20.5	10.9
Cloud Base Height (kft)	8.5	1.8	15.6	4.6
Cloud Base Temp (°C)	7.1	3.3	14.3	-3.2
Maximum Cloud Top Height (kft)	32.0	8	46.6	12.0
Temp. Maximum (°C)	22.0	4.1	32.5	12.5
Dew Point (°C)	10.9	3.0	19.0	5.0
Convective Temp (°C)	22.0	5.5	39.0	10.0
Conv. Available Potential Energy (J/kg)	740.6	595.7	3339.0	0.0
Total Totals	52.4	3.7	58.1	39.0
Lifted Index	-2.4	2.3	5.5	-8.4
Showalter Index	-1.4	2.2	5.6	-5.8
Cell Direction (deg)	256	64	355	10
Cell Speed (knots)	20.0	8.1	39.0	1.0
Storm Direction (deg)	271	74	355	5
Storm Speed (knots)	13.4	5.9	36.0	1.0
Low Level Wind Direction (deg)	246	75	350	0
Low Level Wind Speed (knots)	13.7	6.0	27.0	0
Mid-Level Wind Direction (deg)	252	63	335	15
Mid-Level Wind Speed (knots)	25.3	10.8	59.0	1.0
High Level Wind Direction (deg)	245	66	355	20
High Level Wind Speed (knots)	45.5	23.8	118.0	5.0
Observed Convective Day Category	+0.80	2.30	+5	-3