6.3 USE OF A DUAL-CHANNEL MICROWAVE RADIOMETER TO DETECT LIQUID CLOUD WATER UPWIND OF THE MEDICINE BOW TARGET AREA IN WYOMING

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1. INTRODUCTION

For glaciogenic cloud seeding programs to be successful, many conditions must be satisfied, and myriad other things must be done correctly. An illustration of the "chain of events" involved in glaciogenic cloud seeding is shown in Figure 1.

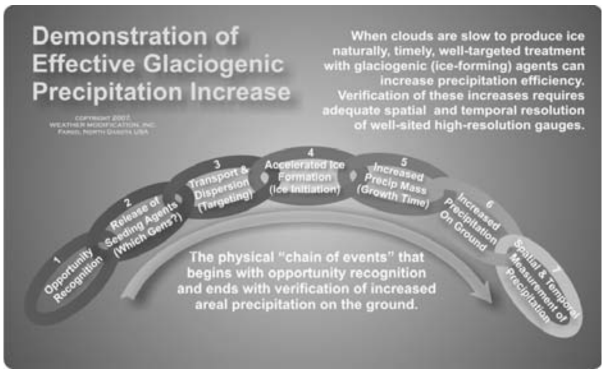

Figure 1. The "chain of events" involving demonstration of effective glaciogenic cloud seeding to increase precipitation is illustrated (and simplified).

The first step is opportunity recognition. One must be able to consistently recognize when atmospheric conditions are amenable for an attempt to be made. Since the intent of glaciogenic seeding is to increase conversion of cloud water to cloud ice, it logically follows that for the sake of efficiency one must discern when cloud liquid water (CLW) is present. This is especially true for programs intent on demonstrating their efficacy.

It is toward this end that the Wyoming Weather Modification Pilot Project (WWMPP) has deployed microwave radiometers. Herein, a description of the utilization of one such unit, and a "first look" at some of the project data from the 2007-2008 season is provided.

2. WATER OR NOT?

There are several ways to detect liquid cloud water in real-time, so that such information can be used effectively in glaciogenic cloud seeding decision-making. The most common methods are high-elevation icing rate meters, microwave radiometers, and certain satellite imagery products such as the current icing product (CIP) from the NOAA Aviation Weather Center; see http://adds.aviationweather.gov/icing/icing_nav.php.

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To be useful, the information must be readily available in real- or near real-time. While forecasts are helpful (and improving) they do not always reflect reality.

2.1 Icing Rate Meters

Icing rate meters have been used on many projects for at least the last 20 years (e.g. Super *et al*. 1988). Such units measure *in situ* the accretion of cloud liquid water (icing), so to be effective, they must be exposed directly to the supercooled cloud. Such installations are usually thus made on towers at high elevations upwind of target areas. A constant source of electricity and provision for frequent data telemetry is required. The principle advantage is the simultaneous measurement of two project-critical variables, the presence of CLW and supercooling sufficient to result in icing. If the unit is sited upwind of the target, there can be little doubt that conditions are favorable for seeding. The primary disadvantage is the fixed sampling location. For example, imagine a situation where a supercooled cloud is ideally situated for seeding, but the cloud base is 100 m above the height of the icing rate meter.

2.2 Microwave Radiometers

Microwave radiometers have also been utilized for decades in weather modification programs (*e.g*. Boe and Super 1986). Such units are passive, and measure total integrated atmospheric water vapor and liquid water along their sensing "beam" path. Details of the use of these instruments can be found in Boe and Super (1986), Rauber *et al*. (1986), Super and Boe (1988), Super and Holroyd (1989), Huggins (1995), and others.

Radiometers are remote-sensing instruments, and as such need not necessarily be sited so as to be in cloud. A water cloud well above the unit will be detected as readily as a cloud in which the unit is immersed. Units have frequently been sited on the upwind slopes of winter orographic cloud seeding targets and operated in a vertically-pointing mode, and thus measuring CLW as it passes overhead. Many radiometers of more recent manufacture have the ability to operate in "scanning" modes wherein the elevation angle, azimuth, or both can be varied sequentially, allowing different beam paths to be sampled repeatedly for extended periods. These units are often sited further from the orographic barrier of interest to allow effective sampling in multiple directions some distance from each unit.

Like icing rate meters, radiometers also require electricity and telemetry provisions for real-time applications. Unlike icing rate meters, they do not indicate supercooling.

2.3 Satellite Icing Imagery

Satellite imagery such as the CIP can be helpful, but is of limited spatial and temporal resolution. Fine-scale features may not be captured, and delays between sampling and imagery availability reduce usefulness for real-time decision-making.

2.4 Other Measurements

Other icing information can sometimes be gleaned from Federal Aviation Administration pilot reports, *e.g*. http://adds.aviationweather.gov/pireps/displaypireps.php. While useful, such reports are serendipitous and cannot be relied upon routinely.

The advent of polarimetric weather radar offers the ability to differentiate between water-phase and ice-phase precipitation. Such instruments offer the potential for much improved spatial and temporal resolution of CLW as compared to microwave radiometers, and will likely prove very helpful in weather modification applications.

The utilization of such an instrument in the context of the WWMPP is likely during the 2008-2009 season, as the next-generation Wyoming Cloud Radar, flown on the University of Wyoming King Air, will be polarimetric. (Geerts 2008).

3. RADIOMETERS IN THE WWMPP

In the WWMPP three microwave radiometers have been deployed each of the last two seasons. During the 2007-2008 winter season, these radiometers were set out as shown in Table 1. Each of these units was deployed on the western side of the respective mountain range.

TABLE 1. WWMPP Radiometers

Designator	*Lat*	*Lon*	*Target*	*Owner*	*Oper.*
Cedar Creek	41.4030	106.5900	Med. Bows	WMI	WMI
Savery	41.0509	107.4420	Sierra Madre	IAS SDSM&T	NCAR
Boulder (East Fork)	42.7523	109.6697	Wind River	lease	NCAR

IAS SDSM&T – This radiometer loaned from the Institute of Atmospheric Science, South Dakota School of Mines and Technology, Rapid City, SD, to NCAR/Research Applications Laboratory

The remainder of this paper focuses on the Cedar Creek radiometer, a scanning, dual-channel microwave radiometer was deployed and operated by WMI near the Upper Cedar Creek ground generator. This unit, a Radiometrics model WVR-1100, was the only radiometer of the three having full azimuth and elevation scanning capability.

4. DATA COLLECTION

During the 2007-2008 season the unit was programmed to make measurements at 10, 12, 30, and 90 degrees elevation angles at 80, 110, and 135 degree (true) azimuths. These angles intersected orographic clouds upwind of the Medicine Bow Range target area in southwesterly (135^o azimuth), westerly (110^o azimuth, Figure 2), and northwesterly (80^o azimuth) winds. The standard scanning sequence adopted for the season began at the 80^o azimuth, then progressed to 110^o, then 135^o. At each azimuth, vertically-pointing measurements of total integrated water vapor and liquid water were made, followed by measurements at elevation angles of 30^o, 12^o, and 10^o. When measurements at each of the three azimuths had been completed, the sequence (cycle) began again. After every six cycles, a calibration (tipping) curve was performed.

Figure 2. The WMI Radiometrics WVR-1100 dual-channel radiometer at Cedar Creek, shown sampling at the 110^o azimuth. Kennaday Peak, Medicine Bow Range, is visible in the upper left.

4.1 Case-calling

A criterion for declaring cases in the context of the WWMPP randomized statistical experiment is the existence of CLW (NCAR 2007). Though several possible avenues for establishing the presence of CLW are delineated (*ibid*), the most reliable of those available is real-time integrated liquid water as measured by the WWMPP radiometers.

To make this possible for the Cedar Creek unit, WMI established Internet connectivity and the ability to log in remotely to that radiometer's computer. Though it was possible to check data recently acquired by the unit without interference with ongoing data collection, viewing data older than the most recent few minutes was cumbersome. In addition, with the existing protocol only one person could access the radiometer at a time. Work is ongoing to improve this prior to the 2008-2009 season, which will including real-time scripting of the data flow (from Cedar Creek and the other WWMPP radiometers) to a common project web site.

This having been said, the real test of the ability of forecasters' case-declaration skills, bolstered by the availability of real-time radiometer data, is the *post hoc* examination of radiometer data for period during which experimental units were declared. Toward that end, a cursory first-look at some of the Cedar Creek 2007-2008 data is herein provided.

A plot of Upper Cedar Creek radiometer liquid and vapor data for the period beginning 00 UTC on 25 March and ending at 00 UTC on 01 April 2008 is shown in Figure 3.

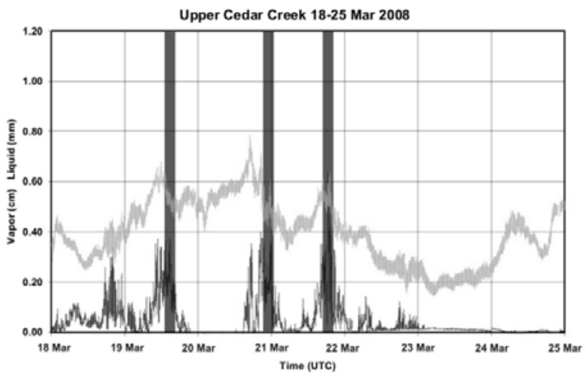

Figure 3. Plots of water vapor (top trace, light grey), and liquid water (lower, darker trace) are shown for the week beginning at 00 UTC, Tuesday, 18 March 2008. The three dark "bars" in the background indicate the four-hour blocks when seeding was being conducted as part of the randomized statistical experiment.

The liquid water trace in figure three confirms the presence of liquid water over the Medicine Bow Range in all three cases declared that week, as measured at a 9 degree elevation angle at three differing azimuths over the range. Though differences are observed from azimuth-to-azimuth, liquid was observed consistently at each of the three—when liquid was observed—suggesting that cloud water, when it forms, is usually present range-wide. This was not always the case, however. The following week, three additional cases were called, and on the second (from 21:30 27 March through 01:30 UTC 28 March 2008), little liquid was observed over the range (Figure 4).

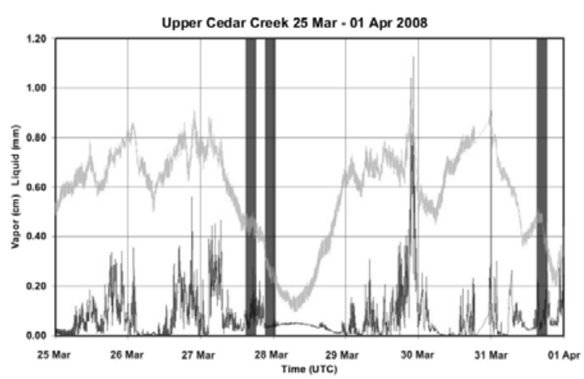

Figure 4. A plot analogous to Figure 3 but for the following week shows liquid water observed over the Medicine Bow Range for three more seeding cases called as part of the randomized statistical experiment. Little water was observed during the second case.

This case was called immediately after the two-hour "buffer" period had expired for a preceding case. At the time it was declared, the radiometer continued to observe liquid water over the range, and thus the criteria for seeding were all satisfied. This physical evidence gathered during the case will be used by the NCAR evaluation team.

4.2 The "Sierra Madre" Radiometer

As previously noted, an additional radiometer was also deployed during the WWMPP 2007-2008 season in support of the randomized statistical experiment. An analogous unit to the Upper Cedar Creek unit, but upwind (west) of the Sierra Madre Range, was deployed by NCAR northeast of Savery, Wyoming.

It will be interesting to compare the observations of these two unit during cases called for the randomized statistical experiment since a prerequisite condition is that conditions be similar over both ranges. Such comparison should include the assessment of any advantage that may result from the azimuth-scanning capability of the Upper Cedar Creek unit, which is not present in the Savery radiometer.

5. CONCLUSIONS

Observations provided by the Cedar Creek radiometer have already proven useful. However, additional experience in future seasons will likely better define the utility of such units for real-time decision-making.

Though data from the WMI Cedar Creek unit were available for the latter part of the season in real-time, efforts are being made to send real-time data from all three project radiometers in real-time for subsequent seasons to a common project web site. This will make the data accessible to all the project meteorological staff, and from a single source. The present WMI system allows access by only one user at a time.

6. ACKNOWLEDGEMENTS

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