THE IMPACT OF GLACIOGENIC SEEDING ON OROGRAPHIC CLOUD PROCESSES: PRELIMINARY RESULTS FROM THE WYOMING WEATHER MODIFICATION PILOT PROJECT

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Cloud seeding has long been and remains the most widely practiced method of advertent weather modification (Qiu and Cressey, 2008). It is remarkable that notwithstanding all the data collected and the high level of experimental control compared to typical research on cloud and precipitation processes, the effectiveness of cloud seeding in enhancing precipitation remains uncertain (Bruintjes, 1999; National Research Council, 2003). Numerous statistical studies have been conducted to assess changes in surface precipitation, often with mixed or questionable results. The level of noise in natural systems compared to the magnitude of the signal makes verification of precipitation enhancement extremely difficult (Garstang *et al.*, 2005). Numerous studies and reports have pointed to the need for field measurements that document the cloud microphysical "chain of events" that lead to an alteration of surface precipitation.

Ground-based glaciogenic cloud seeding has been conducted over the mountains of southeast Wyoming as part of the Wyoming Weather Modification Pilot Project since the winter of 2007-08 (National Center for Atmospheric Research, 2009). A cross-over design involving two serial mountain ranges, both with control and target snow gauges, is being used in an ongoing randomized seeding experiment. Here we report on a piggy-back study that uses data from an airborne vertically-pointing mm-wave Doppler radar to study the cloud microphysical effect of glaciogenic seeding of cold-season orographic clouds. Fixed flight tracks were flown downstream of AgI generators in the Medicine Bow Mountains. The airborne radar data from seven flights, each with a no-seeding period followed by a seeding period, indicate that AgI seeding significantly increased radar reflectivity and thus snowfall rate near the ground.

The fixed flight legs and the terrain are shown in Fig. 1. The University of Wyoming King Air aircraft carried *in situ* cloud probes and the 94 GHz Wyoming Cloud Radar (WCR), with fixed antennas pointing to the nadir and the zenith. To our knowledge, this is the first time a nadir-pointing airborne radar has been used to assess the cloud microphysical impact of glaciogenic seeding. The nadir view provides radar data within ~30 m of the ground, whereas the commonly used ground-based scanning radars can only "look" above complex terrain.

A total of 70 seed and 44 no-seed passes were flown over the four downwind legs on seven days. (A "seed" pass is one with at least two of the three generators in operation.) All WCR reflectivity profiles have been synthesized in the form of a *frequency-by-altitude display* or FAD (Yuter and Houze, 1995), both for the no-seed passes (Fig. 2a) and the seed passes (Fig. 2b). In essence the WCR profiles, at ~30 m vertical and along-track resolutions, were remapped as a function of height above ground level (AGL), and the reflectivity values were then binned in the FADs. Most storms were rather shallow; in many cases the clouds were confined to the mountain proximity. WCR reflectivity generally increased towards the ground, indicating low-level ice crystal growth in both seeded and unseeded conditions. Snowfall occurred at all times, and it was generally light. The temperature at the level of the three generators was close to or just below -8°C.

High reflectivity values (>10 dBZ) were more commonly encountered during seeding. The average reflectivity (*Z*) near the ground was 1.0 dB higher (Fig. 2c). This converts to an average increase in snowfall rate (*S*) of about 25% during seeding, according to a theoretical *Z*-*S* relationship specific to 94 GHz radars (Matrosov, 2007). Flight-level microphysical probe data compared with near-flight-level WCR reflectivity data confirm that this theoretical *Z*-*S* relationship is representative. The shift in reflectivity in the boundary layer during

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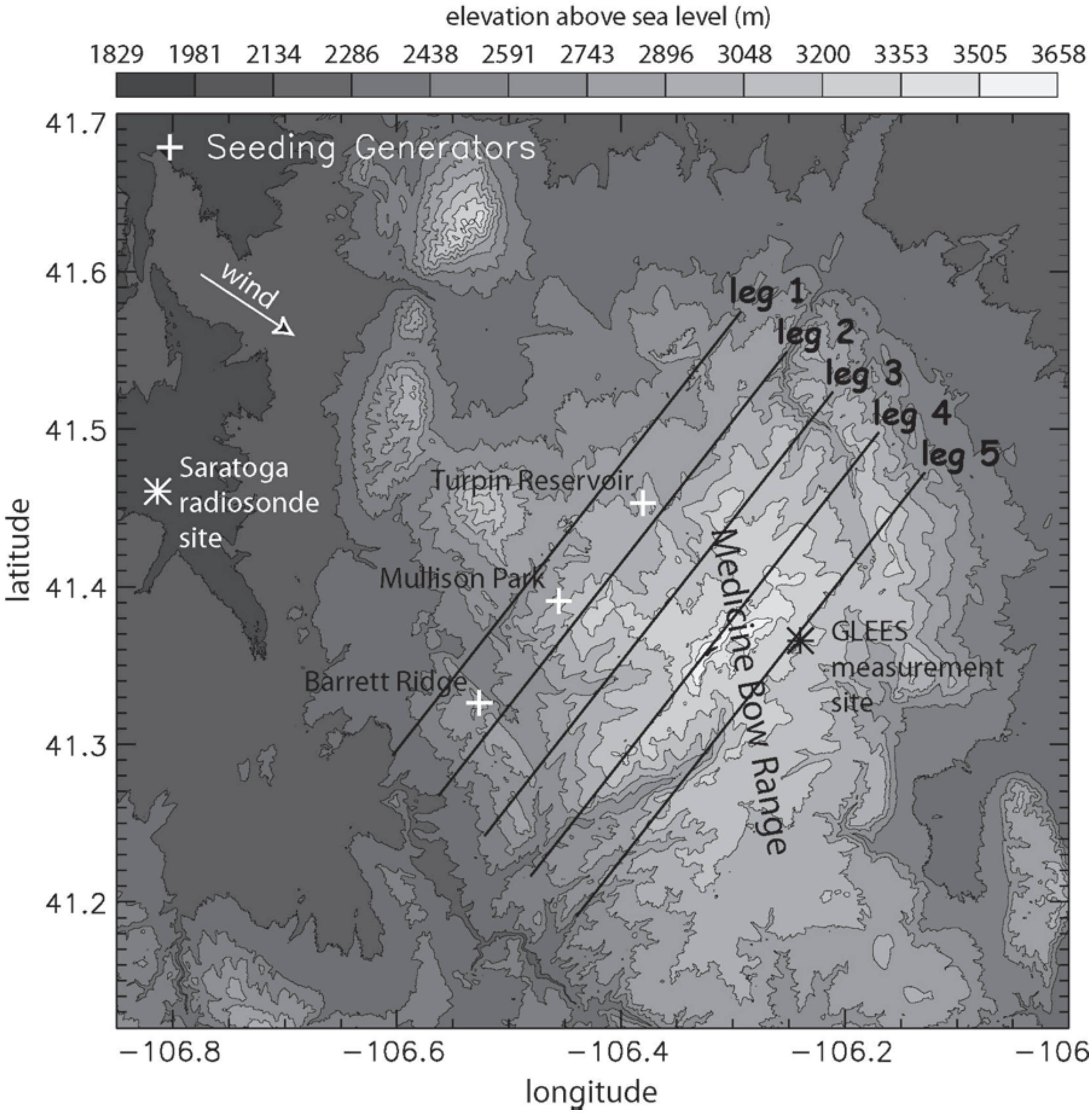

Figure 1: Terrain map of the Medicine Bow Range in Wyoming, showing the AgI generators and the fixed flight legs. The flight level was constant at 4267 m.

seeding, with an enhanced (reduced) probability in the >10 dBZ (-2 to +10 dBZ) range (Fig. 2c), is statistically significant at the 95% level, but not at the 99% level, according to a comparison of the seed – no-seed difference with 1000 random samples of all 114 flight passes. A partitioning of the data, into days with more stratified flow and less stable flow, yields physically meaningful results that corroborate our interpretation that the enhancement of near-surface reflectivity and snowfall is due to AgI seeding.

Caution is warranted in view of the large natural variability of weather conditions and the small size of the dataset. This work is preliminary and needs to be followed up with a longer field campaign under similar as well as more diverse weather conditions. Such a campaign should include ground-based instruments, such as vertically pointing or scanning radars and particle sizing and imaging probes.

More information can be found in a paper currently under review (Geerts *et al.* 2010).

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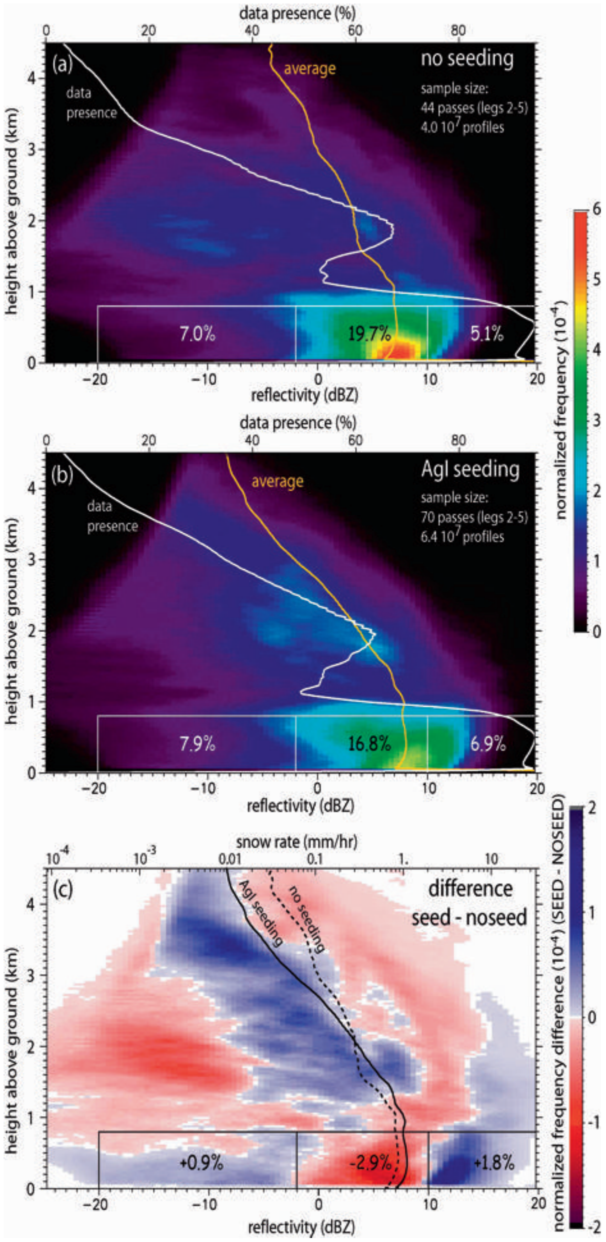

Figure 2: Normalized FAD of WCR reflectivity (Z) for all flight legs downwind of the AgI generators on seven flights, during (a) no-seed and (b) seed conditions. Also shown are cumulative normalized frequencies in three boxes near the ground, expressed as a percentage, the mean reflectivity profile (yellow line) and the "data presence" (white line), i.e. the percentage of WCR range gates with radar echo as a function of height. The difference between the data in (b) and in (a) is shown in (c), together with the mean profiles from (a) and (b), and the difference within the three boxes. The snow rate (S), shown in the upper abscissa of (c), is inferred from S=0.11 $Z^{1.25}$ (Matrosov, 2007).

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