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MOUNTAINTOP AND RADAR MEASUREMENTS OF SNOW GROWTH AND SNOWFALL RATE

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1.0 INTRODUCTION

The primary goal of the Inhibition of Snowfall by Pollution Aerosols 2001 (ISPA-2001) experiment is to investigate the effect of aerosol pollutants in cloud on snowfall accumulation at the ground. Our working hypothesis is that an abundance of aerosols, primarily pollution-derived and acting as cloud condensation nuclei, shift the cloud droplet spectrum to smaller drop sizes. These smaller drops are below the riming threshold of approximately 10 microns diameter, and ice crystals do not efficiently accrete this supercooled cloud water as compared with a spectrum dominated by cloud drops larger than 10 microns (Pruppacher and Klett, 1980). Therefore, there is less accumulated snowfall water equivalent (SWE) at the surface from cloud air affected by pollution aerosol than there would be in a cleaner situation.

Measurements were made at Storm Peak Laboratory (SPL, www.dri.edu/Projects/SPL) at the summit of Mt. Werner (3210m MSL) and an NCAR Integrated Sounding System (ISS) in the valley 6.5 km upwind and 2076m MSL. This allowed characterization of the cloud and snowfall in situ while the remote sensing radar monitored the winds and snowfall speeds upwind. This equates to about 10 minutes drift time in a typical 10 m/s wind speed at the level of SPL. We present measurements from two days to support the working hypothesis and demonstrate the coherence among the data sets and instrumentation on ISPA.

February 15 and February 19, 2001 were two snowfall events which had contrasting snow growth processes. Feb. 15 is a case where clouds were shallow and growth was primarily by diffusion. On Feb. 19 the clouds were deeper but in both cases the clouds had the same supercooled cloud liquid water (SCLW, gm^{-3}) content in the lower orographic cloud to contribute to snow growth by riming.

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2.0 BASE STATION AND REMOTE SENSOR OBSERVATIONS

The Integrated Sounding System (Parsons et al.) at the base of Mt. Werner consisted of the Multiple Antenna wind profiler (MAPR) (Cohn et al., 2001), a GLASS rawinsonde system and surface instruments including two snow gages. Unlike Doppler beam swinging wind profilers, MAPR measures the vector wind using spaced antenna methods and a continuously vertically directed beam. Therefore it can measure the snow fallspeed (relative to the ground) with very good time resolution.

Figure 1 shows time-height plots of the profiler signal to noise ratio, vertical velocity, and horizontal wind measured by MAPR on February 15 and 19. On Feb. 15 in situ measurements were taken at SPL between 1515 and 1830 UTC. During this time, the top of the backscatter layer is about 2 km above the radar site with typical fallspeeds of 1.0 m/s. On Feb. 19 SPL in situ measurements were taken at SPL from 1815 to 1845 UTC and MAPR backscatter extends to about 3.5 km AGL. During this time, fallspeeds consistently increase with decreasing altitude suggesting continued snowgrowth at low elevations. The lower portion of the cloud is enhanced by orographic lifting and is likely to contain supercooled liquid water (SCLW). Fallspeeds are generally 1.5 m/s in the lower part of the cloud, and the low level growth of the snow could be attributable to accretion of the SCLW. A rawinsonde launched at 1823 UTC on February 19 (Figure 2) shows cloud top to be at 3.5 km AGL, where MAPR shows the first returns from snow.

The surface meteorology at the ISS site recorded precipitation from two gages separated by approximately 30m. Figure 3 shows precipitation from one of the gages along with other meteorological parameters on Feb. 15. The ISS snow gage measured no snow accumulation during the period of measurement at SPL (1545-1630 UTC) while on Feb 19 (Fig. 4) the snow gage measured SWE of about 1.1 mm/hr from

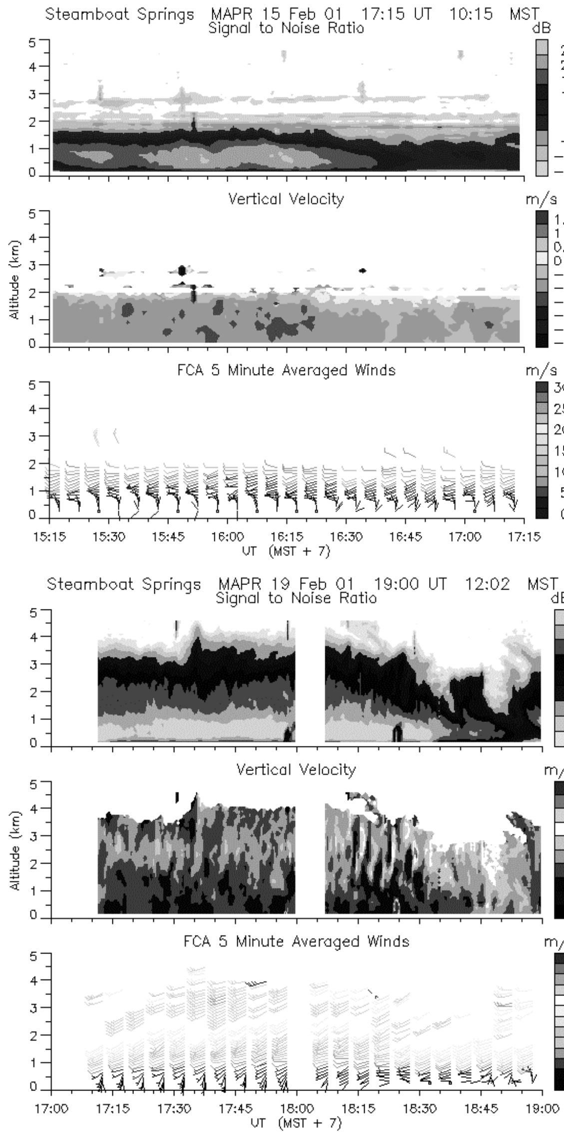

Fig. 1 Time-height plots from MAPR for Feb. 15 and 19, 2001. See the poster for color plots.

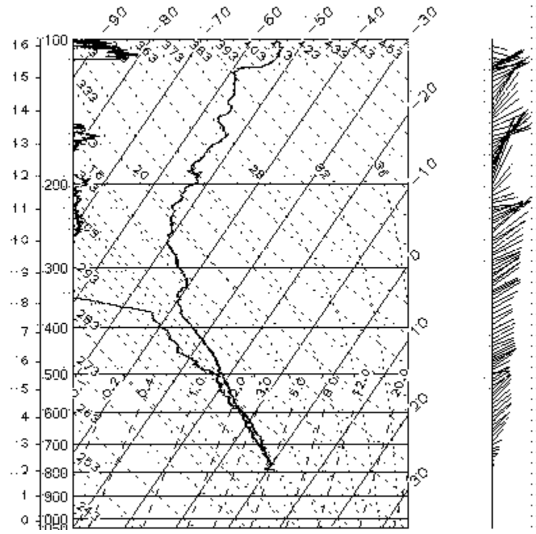

Fig. 2 Rawinsonde launched at 1823 UT on Feb. 19

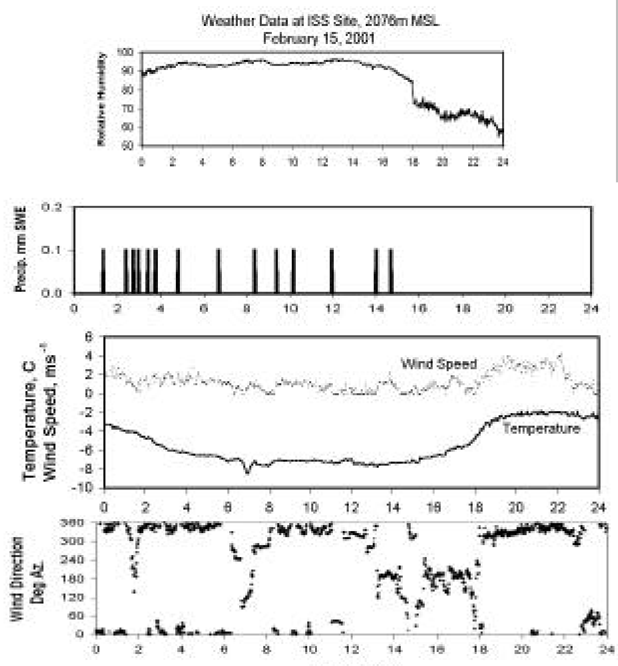

Fig. 3 Surface meteorology data on February 15 at the ISS site, 2076m MSL.

1815 to 1845 UTC. Note the other measured quantities, such as the wind speed, direction, and surface temperature, were similar on the two days.

Figure 5 shows Mosimann's riming index (Rm) (Mosimann, 1995) derived from the snow fallspeed. For this measurement we adjust the equation of Mosimann for air density and assumed that vertical air motion was negligible. Rm ranges from 0 to 5, with 0-3 indicating crystals which are unrimed, 25, 50, and 100% rimed. An index of 4 or 5 indicates crystals with several layers of rime ice or graupel. Figure 5 shows that at the altitude of SPL, the index was less than 1 for the observation period on Feb. 15 and between 2 and 3 for the observation period on Feb. 19. Note that this index is only meant to be a guide.

3.0 IN-SITU MEASUREMENTS AT STORM PEAK LABORATORY

Cloud droplet and snow size spectra from DMT SPP-100 and 2DP particle probes were integrated over the entire sampling period on each day and plotted in Figure 6.

A sample set at SPL consists of integrated cloud droplet and snow size spectra, a video record of the snow crystal habit and riming extent, and snowfall rate. The snow and cloud water were analyzed later for ionic and oxygen isotopic content. The sample sets

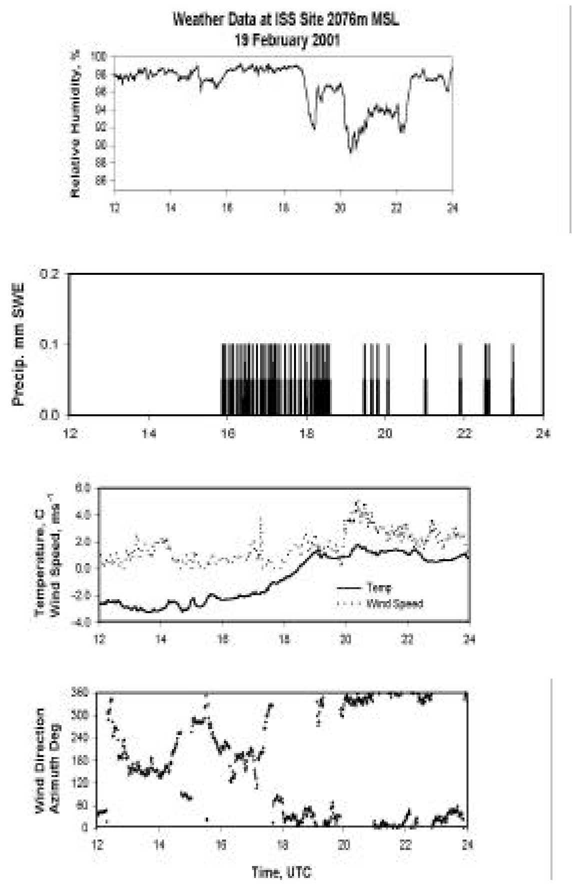

Fig. 4 Surface meteorology data on February 19 at the ISS site, 2076m MSL.

were collected on Feb. 15 from 1545 – 1630 UTC and on Feb. 19 from 1815 – 1845 UTC.

Video images from the Snow Video Spectrometer (SVS) of snow crystal habits are shown in Figure 7. The transparent appearance of the images on Feb. 15 indicates there are no rime ice deposits on the crystals. Habits are dominated by dendrites. On Feb. 19 (magnification slightly greater) crystals are opaque indicating moderate to heavy rime ice deposits. The degree of rime was confirmed by detailed visual observation of snow crystals on black felt under high magnification during the course of all sample collections. Habits on this day include sector plates, broken dendritic branches, and some needles.

Feb. 15, the unrimed case day, the cloud droplet mean diameter was 8.3 microns, the concentration was 311cm^{-3} and the SCLW content was 0.13 gm^{-3}. In contrast the droplet spectra on Feb. 19, the rimed case day, had a mean diameter of 13.6 microns, a concentration of only 27 cm^{-3}, and a SCLW content of 0.14 gm^{-3}. Most droplets in the rimed case had diameters well above the riming threshold size of 10 microns. In contrast, most droplets in the unrimed case had diameters well below this threshold.

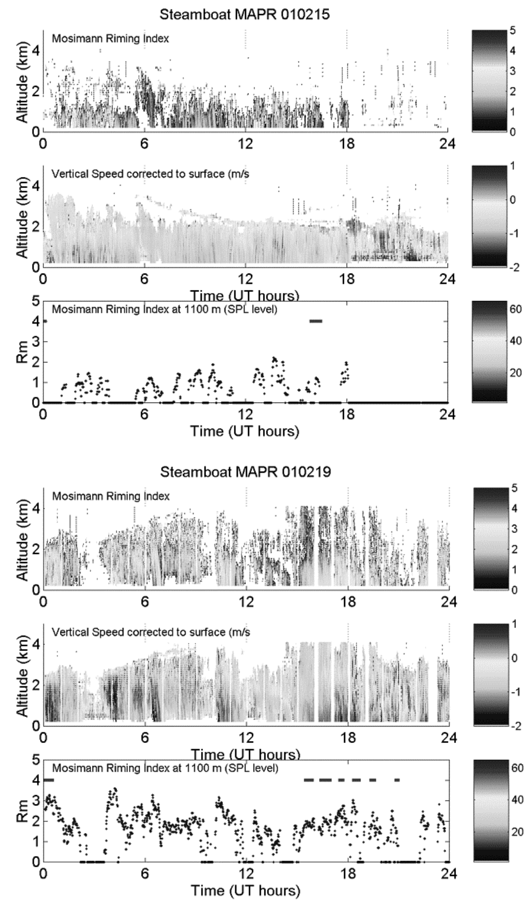

Fig. 5 MAPR derived vertical cross-section of riming index, corrected fall speed and riming index at SPL elevation for Feb. 15 and 19, 2001. See poster for color plots.

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The snow size spectra for the two cases show more subtle differences. The mean diameters differed by only 0.3 mm with the rimed case being larger. However, the rimed case had a five-fold higher snow number concentration which would result in a six-fold larger number flux to the surface. These measurements are consistent with the ISS snow measurements, showing a significantly greater precipitation rate for the rimed snowfall case on Feb. 19 in the valley.

4.0 INTERPRETATION

The smaller mean droplet diameter on Feb. 15 may be related to the level of cloud base below SPL or to the cloud condensation nuclei (CCN) that produced the cloud. The cloud base height was not measured. However, the clear-air-equivalent (CAE) concentration of sulfate in the CCN (the product of the SCLW content and the cloud water sulfate concentration) is closely correlated with the cloud droplet size and number concentration at SPL (Borys et al., 2000). The CAE

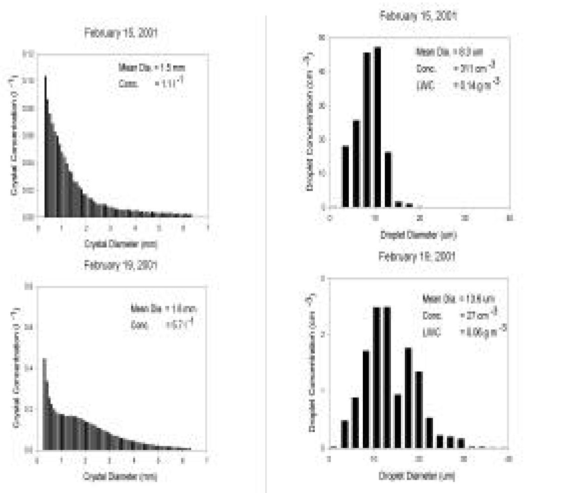

Fig. 6 Cloud droplet and snow size spectra for Feb. 15 and 19, 2001

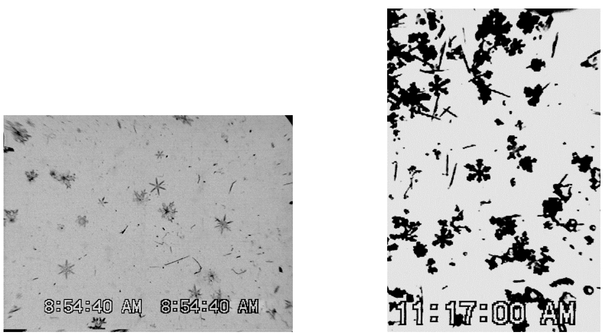

Fig. 7 Video images of snow crystals on Feb. 15 (left) and Feb. 19 (right).

sulfate concentration for the unrimed case on Feb. 15 (1.07 ìgm^{-3}) was 8.9 times higher than that found in the rimed case (0.12 ìg/m^{-3}) on Feb. 19. It follows that there were more CCN present on Feb. 15 that resulted in a 7.4-fold larger concentration of smaller droplets.

The ISS SWE was 0.6 mm on Feb 19 and zero on Feb. 15. At SPL, the snowfall rate was 17-times higher on Feb. 19 than on the 15th. Figure 6 indicates that while the snow sizes were similar on the two days, the snow number concentration was 5-times higher on Feb. 19. Thus, the differences between the snow number and size were insufficient to account for the difference in precipitation rates between the two cases.

When cloud droplets are sufficiently large to efficiently rime snow crystals, the rimed-mass-fraction may contribute significantly to the snowfall rate. The visual (SVS) observations of rimed crystals and higher fallspeeds from the MAPR suggest the higher snowfall rate on the Feb. 19 was due in part to snow growth by riming. The rimed mass fraction can be estimated quantitatively using the method of Pauxbaum and Tescherwenka (1998) assuming that fine-particle sulfate aerosols were scavenged mainly by cloud droplets. Based on the sulfate ion concentrations in snow and cloud water, 4.5 and 51% of the snow mass was attributable to riming on Feb. 15 and 19, respectively. This supports the conclusion that the higher snowfall rate on Feb. 19 could not be explained solely by the higher snow crystal concentration.

5.0 SUMMARY

The ISS played an important role in providing a time-height measure of the storm clouds, snowfall vertical velocities, an estimate of cloud top height and temperature, and precipitation rates in the valley upwind of SPL. In situ measurements at SPL were corroborated by the ISS. Mountaintop measurements of cloud and precipitation microphysics and chemistry can be an important tool in developing an understanding of the interaction of aerosols and clouds.

6.0 ACKNOWLEDGMENTS

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