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MICROPHYSICAL STRUCTURE OF OROGRAPHIC PRECIPITATION ALONG THE WASATCH MOUNTAINS DURING IPEX

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1. INTRODUCTION

Improvements in quantitative precipitation forecasting over the western United States require advances in several areas including the understanding of key dynamic and microphysical processes in orographic precipitation. In response to this need, the Intermountain Precipitation Experiment (IPEX) was conducted in northern Utah from 31 January to 25 February 2000, with an emphasis on sampling orographic precipitation along the Wasatch Mountains. One of the key observing platforms for IPEX was the NOAA P3 aircraft, which was used to examine precipitation dynamics and microphysics upstream, over, and to the lee of the Wasatch Mountains. The P3 was equipped with an X-band Doppler radar to map precipitation structure and three-dimensional air motions. It was also instrumented with several in situ sensors to measure air, cloud, and precipitation characteristics. Among these, this study primarily makes use of the microphysical probes (King, FSSP, 2DGC, 2DP) to document the sizes, concentrations, habits, and masses of cloud and precipitation particles.

Six Intensive Operation Periods (IOP's) involving the P3 were executed during IPEX. This study focuses on the microphysical aspects of an orographic precipitation event that occurred on 12-13 February during IOP 3, a storm that produced more than two feet of snow at some locations along the Wasatch. Over a six-hour period, the P3 executed four separate microphysics stacks across the Wasatch Mountains near Ogden (Fig. 1). Each stack was composed of four level flight legs oriented WSW-ENE at altitudes corresponding to critical air temperatures for microphysical processes (-5 to –20 °C). In this paper, we focus on data from the second microphysics stack, occurring during the period 1907-2007 UTC on 12 February.

2. ANALYSIS

To provide some context for the precipitation and kinematic structure occurring at the time and location of the second stack, a vertical cross section of P3 tail Doppler radar data is presented in Fig. 2. This data was collected on a leg at 3.75 km MSL tracking toward 252°. The cross-section is parallel to and 4.8 km south of the flight track (Fig. 1). Due to a radar malfunction, only forward-directed conical scans were executed on this leg.

Cox et al. (2001, 2002) have documented the flow structure of this event. Near the surface, they observed southwesterly flow 40-80 km upstream of the Wasatch transitioning to a narrow band of south-southeasterly flow lodged against the barrier, a pattern attributed to blocked or partially blocked flow. Farther aloft, a trough was evident with west-northwesterly flow to the west and west-southwesterly flow closer to the Wasatch. Radial velocities from the P3 are consistent with this structure (Fig. 2). On the west end of the cross section (-70 to -40 km), strong negative radial velocities at low levels are associated with the southwesterly flow and the weakly positive radial velocities at 2.7-3.7 km MSL are associated with northwesterly flow. At about -30 km, the strongest negative radial velocities begin to ascend to the 2.2-2.7 km level. The hypothesis is that this sloping structure represents the ascent of the southwesterly flow over the low-level blocked or partially blocked south-southeasterly flow near the Wasatch. Although we can not necessarily infer vertical motion from this structure, it is noteworthy that this region coincides with enhanced depth and intensity of precipitation echoes. Further east, precipitation depth and intensity exhibits a local minimum (-10 to 0 km),

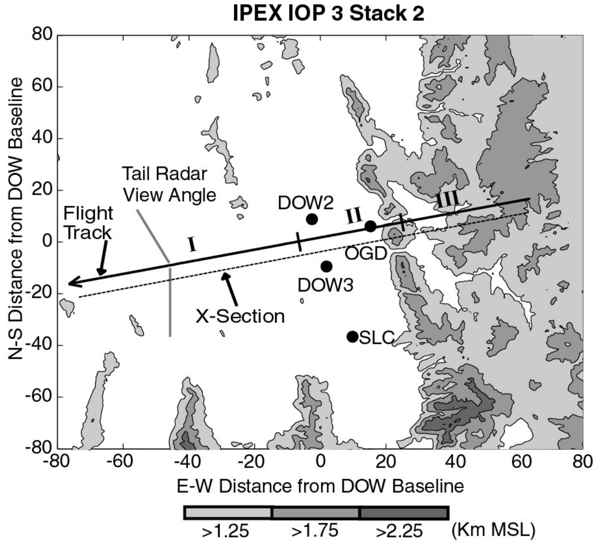

Figure 1. Topographic map of northern Utah. Coordinate system is relative to a point in between DOW2 and DOW3 Doppler radars. Locations of Salt Lake City (SLC) and Ogden (OGD) are indicated. The light, medium, and dark gray shading show contours of elevation greater than 1.25, 1.75, and 2.25 km, respectively. P3 flight track location and orientation for IOP 3 microphysics stack 2 is shown by the bold line. The viewing angle of fore-scans from the tail radar is also indicated for a west-southwest bound leg of the stack. Dashed line shows the location and orientation of the vertical cross-section in Fig. 2. See text for an explanation of I, II, and III.

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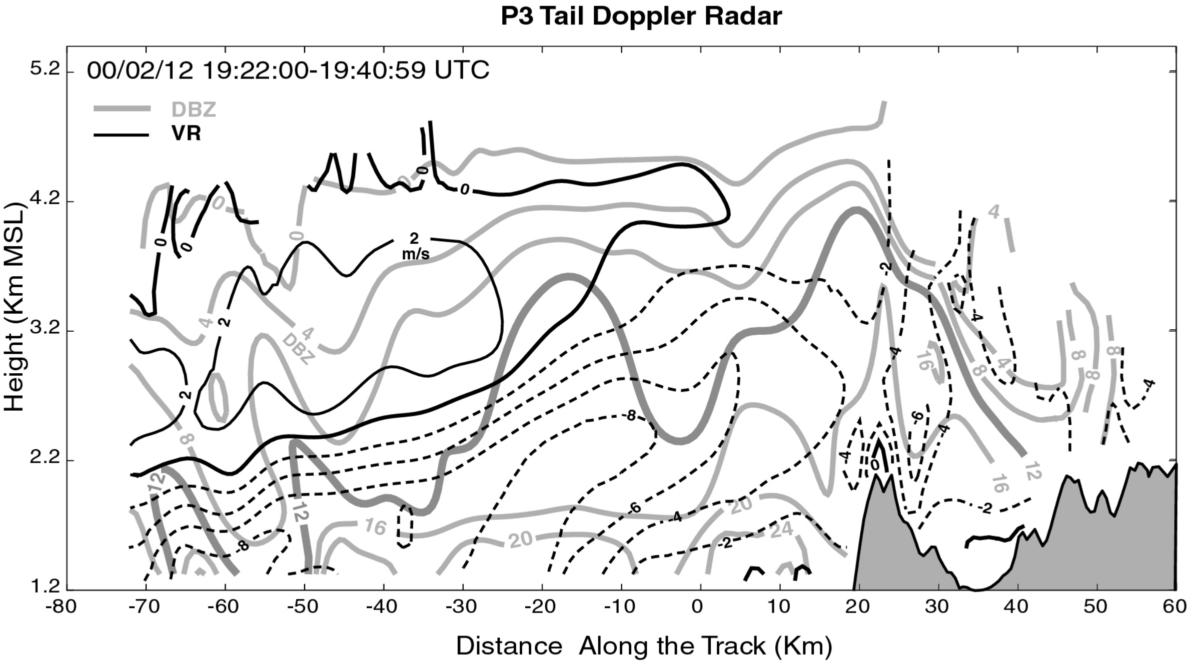

Figure 2. Vertical cross-section of radial velocity and reflectivity from the P3 tail Doppler radar. Location and orientation of cross-section as well as viewing angle of radar beams shown in Fig. 1. Topography is shaded in gray.

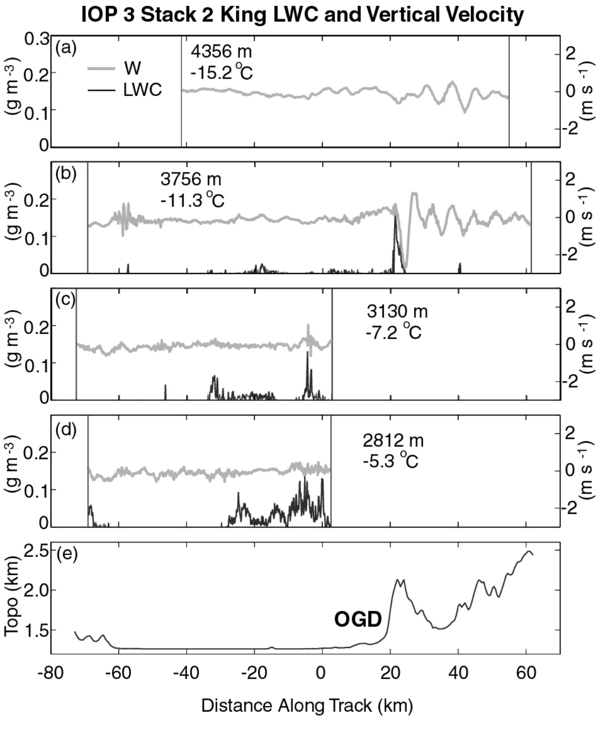

Figure 3. Traces of cloud liquid water content from the King probe (black) and vertical velocity (gray) for microphysics stack two at (a) 4356 m, (b) 3756 m, (c) 3130 m, and (d) 2812 m MSL. The topography along this transect is shown in (e). OGD corresponds to the location of Ogden. Legs (c) and (d) are truncated due to terrain-based flight restrictions.

then increases again near the barrier (20 km), presumably in response to orographic lift.

In situ observations from the P3 reveal some of the details associated with the radar-observed precipitation structure. Figure 3 shows that cloud liquid water content is relatively small (<0.2 g m^{-3}), even non-existent at the 4356 m level. The largest value occurred at the 3756 m level over the Wasatch crest, in association with a 0.5-1.0 m s^{-1} updraft. There are also smaller spikes in cloud liquid water content at the lower two levels that are linked to transient updrafts. The strongest vertical velocity signature is in the lee of the Wasatch, where a wave pattern is evident. This pattern, seen most clearly at the 3756 m level, starts as a strong (> 2 m s^{-1}) downdraft followed by a series of damped updrafts and downdrafts at 6-7 km wavelength.

Optical array probe data has also been utilized to document the cloud and precipitation microstructure of this event. The instruments are a two-dimensional grey cloud probe (2DGC), characterizing particles 30-1920 μm in diameter, and a two-dimensional precipitation probe (2DP), characterizing particles 200-6400 μm in diameter. Subjective and objective analysis of the 2DGC imagery suggests that the vast majority of particles were of irregular shape, likely ice crystal aggregates. Only about 10-20% of particles were of round shape, indicative of graupel, an observation that is consistent with the small amounts of cloud liquid water that were present.

Size distributions from these probes for stack 2 are shown in Fig. 4. The overall stack average spectra (Fig. 4a) indicates a broad (i.e., small slope) distribution at sizes less than 1 mm and a narrower (i.e., larger slope) distribution at sizes greater than 1 mm. Decreasing concentrations at the small size end of each spectrum are artifacts caused by electronic limitations inherent in these types of probes.

Mean spectra for each leg of the stack show systematic trends (Fig. 4b, 4c). 2DGC spectra exhibit a bimodal character on legs 1-3. The particle size associated with the larger, secondary mode increases as altitude decreases. This is most evident in the transition from leg 1 to leg 2. At the lowest level, leg 4 shows only a plateau structure near the secondary mode of the other levels. Spectra for legs 2-4 are nearly coincident at larger sizes, in sharp contrast to the smaller particles observed on leg 1. This trend is also seen in the 2DP spectra, with the exception that leg 3 is associated with somewhat larger particles.

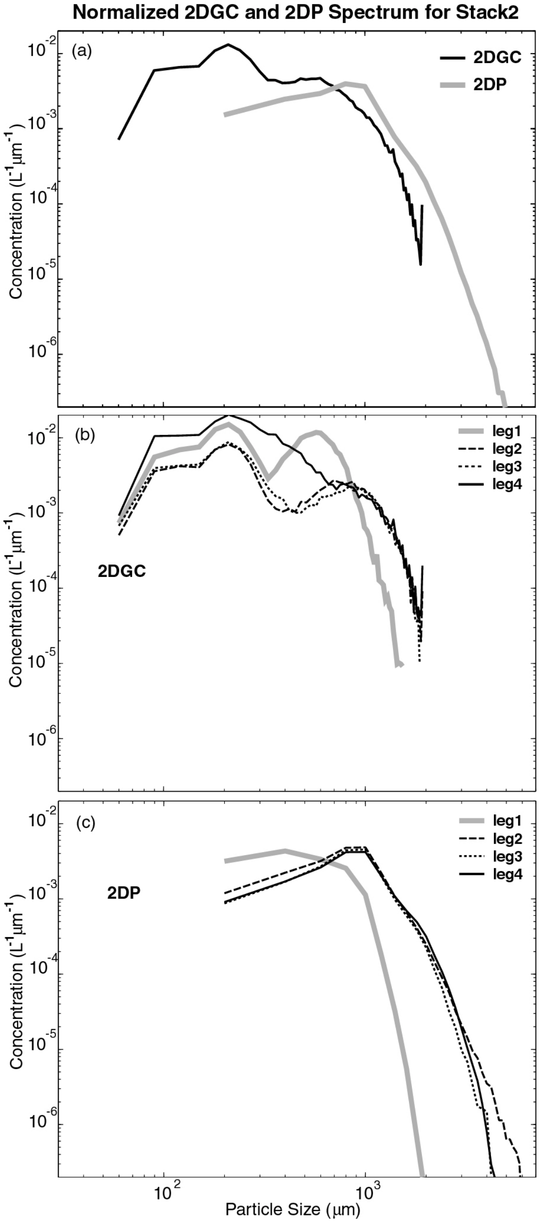

Figure 4. (a) Mean 2DGC and 2DP size distributions for stack2. Size distributions from the (b) 2DGC and (c) 2DP averaged for leg 1 (4356 m), leg 2 (3756 m), leg 3 (3130 m), and leg 4 (2812 m). All concentrations are normalized by the 2DGC and 2DP bin widths, 30 and 200 µm, respectively.

Parameters derived from these spectra can be used to further examine the horizontal and vertical variation of cloud and precipitation particle characteristics. Total concentrations show a general decreasing trend in going from leg 1 (Fig. 5a) to leg 3 (Fig. 5c). Interestingly, there is no systematic variation of this variable in the region near the Wasatch crest. The strongest signal in total concentration is on the east end of leg 4 (Fig. 5d), where a 2DGC spike of greater than 30 L^{-1} is evident. This occurs in close proximity to the region of hypothesized sloping ascent of southwesterly flow shown in Fig 2.

Volume weighted mean diameters (or mean volume diameters) show a general increasing trend as altitude decreases, especially those from the 2DP(Fig. 6). With the bimodal spectral structure (Fig 4b) and decreasing total concentrations with altitude (Fig. 5), this relationship is suggestive of an aggregation process, a notion that is consistent with the aforementioned observation of predominantly irregular shaped particles in the probe imagery. The strongest signal in mean volume diameter is on leg 2 (Fig. 6b) where a dramatic increase in particle size is evident on the windward slopes of the Wasatch crest, followed by a dramatic decrease in particle size on the lee slopes. This pattern is most pronounced in the 2DGC data. On the east end of leg 4 (Fig. 6d), 2DGC mean volume diameters show a local minimum that is coincident with the total concentration maximum shown in Fig. 5d). This suggests that the small (< 1 mm) particles in this localized region were distributed in a steeply sloped manner. In contrast, the local maximum in 2DP mean volume diameter at this location suggests a relatively broad distribution for particles larger than 1 mm.

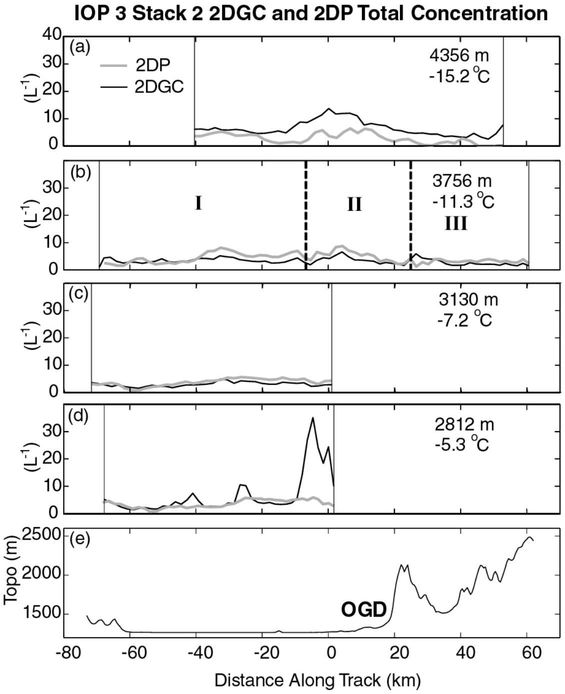

Figure 5. Same as Fig. 3 except for 2DGC and 2DP total concentrations. The regions I, II, and III in (b) correspond to upstream, blocked, and lee-side flow regimes.

As the aircraft crossed the full horizontal extent of stack 2, it encountered three distinctly different flow regimes: upstream (region I), blocked (region II), and lee-side (region III). The locations of these flow regimes for stack 2 are shown in Figs 1, 5 and 6. Mean 2DGC and 2DP spectra for these flow regimes on leg 2 (3756 m) are in Fig. 7. The largest sized particles and, to some extent, the largest concentrations are found in the blocked regime, just upwind of the Wasatch. Although the low-level flow is southerly in this regime, southwesterly flow exists at mid-mountain level to provide some orographic uplift that may be responsible for this trend. Conversely, the smallest sizes and concentrations of particles occur in the lee-side flow regime, where the in situ vertical velocity data indicated a mountain wave pattern (Fig. 3). This observation may result from the largest particles falling out on the windward slopes of the Wasatch, leaving only the smaller particles with low values of terminal fallspeed.

3. DISCUSSION

The Wasatch Mountains are a steeply sloped barrier typical of the Intermountain West. Their small-scale structure presents unique challenges to numerical models attempting to make quantitative precipitation forecasts. Among these challenges are to accurately represent the microphysical processes associated with cloud and precipitation development in this environment. The analyses presented in this paper are a first step in trying to address these issues. Future work will involve detailed examination of data from the other three microphysics stacks during IOP 3 and comparisons of these observations with similar parameters derived from 2-D and 3-D numerical simulations of this event

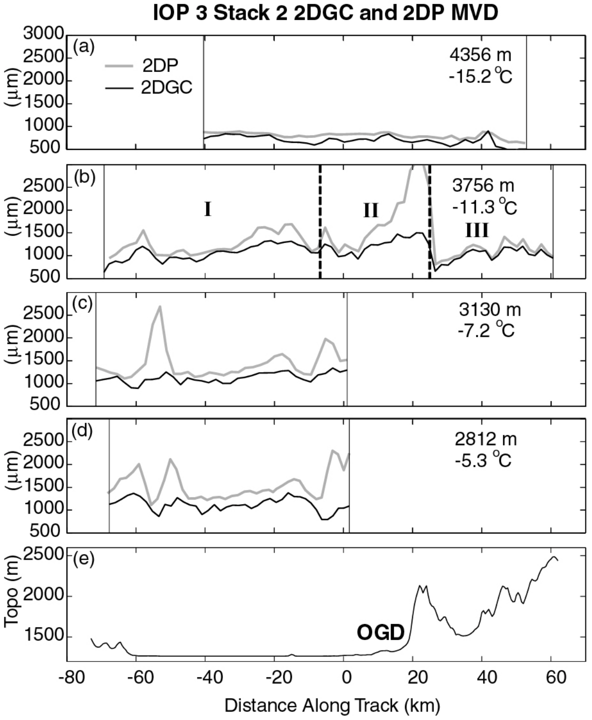

Figure 6. Same as Fig. 3 except for 2DGC and 2DP volume weighted mean diameters. The regions I, II, and III in (b) correspond to upstream, blocked, and lee-side flow regimes.

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REFERENCES

Cox, J. A. W., W. J. Steenburgh, D. E. Kingsmill, and B. A. Colle, 2001: Orographic precipitation processes associated with the Wasatch Mountains during IPEX IOP 3. Preprints, *9th Conference on Mesoscale Processes*, Fort Lauderdale, AMS 196-197.

Cox, J. A. W., W. J. Steenburgh, and D. E. Kingsmill, 2002: Dual-Doppler analysis of the kinematic structure of a Wasatch Mountain winter storm. Preprints, *10th Conference on Mountain Meteorology*, Park City, AMS, this volume

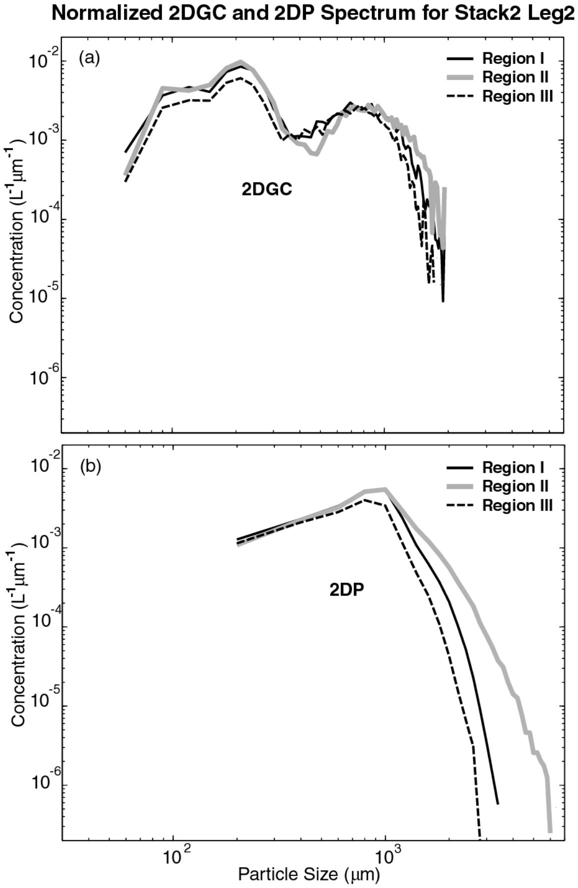

Figure 7. Size distributions from the (a) 2DGC and (b) 2DP on leg 2 of stack 2 (3756 m) averaged for the upstream (region I), blocked (region II), and lee-side (region III) flow regimes defined in Figs. 1, 5, and 6. All concentrations are normalized by the 2DGC and 2DP bin widths, 30 and 200 μm, respectively