Final Report
Storm Chasing Utah Style Study (SCHUSS)

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The University of Utah Department of Atmospheric Sciences was awarded a 1-month (21 Oct – 21 Nov 2001) deployment of the Doppler on Wheels (DOW6) for the following education and outreach activities:

1. Student-directed field research
2. Lecture and on-campus DOW demonstration for general education students
3. Class and capstone project educational activities
4. K-12 outreach.

This report summarizes the activities and outcomes in each of these areas and serves as the final report for the project. Originally proposed as the SOLPEX–REO (Sounding Observations of Lake-Effect Precipitation Experiment – Radar Education and Outreach) given an existing NSF-funded project examining lake effect, we subsequently renamed the effort the Storm Chasing Utah Style Study (SCHUSS) given the wide range of activities planned by the students prior to the arrival of DOW6.

1. Activities and outcomes

a. Student-directed field research

A group of 18 graduate and undergraduate students planned and led several field deployments of DOW6 to examine lake-effect, orographic, and frontal precipitation events (Fig. 1). Some of these deployments also involved the use of up to 2 GPS-sounding systems, relocatable surface mesonet stations, and a car-mounted mobile mesonet station. Beyond the 18 actively involved students, several additional undergraduate and graduate students participated in one or more of these field deployments. Prior to the arrival of DOW6, the students prepared short proposals and operations plans in four key areas: (1) lake-effect precipitation, (2) orographic precipitation, (3) fronts & severe weather (the latter a bit of a lark), and (4) microphysical processes and polarimetric radar. See *Doppler-on-Wheels Operations Plan for Orographic Precipitation Events* at the end of this document for an example of one of these proposals.

Figure 1. DOW photo collage. Upper left: Pre IOP planning (photo credit: J. Steenburgh). Upper-right: GPS-sounding launch near Kelton on the north end of the Great Salt Lake during IOP5 (photo credit: C. Wall/C. Ander). Bottom left: DOW6 during IOP8 (photo credit: T. Alcott). Bottom right: DOW training first full day of the visit (photo credit: J. Steenburgh).

DOW deployments were classified as either Educational Observing Periods (EOPs) or Intensive Observing Periods (IOPs). EOPs were training focused and designed primarily for students to learn how to deploy and operate the radar. IOPs involved deployments to examine specific weather phenomenon and were more strongly concentrated on education in radar interpretation and mountain meteorology, with an additional goal of obtaining high-quality datasets for future student research projects. A total of 4 EODs and 8 IOPs were executed (Table 1).

Several IOPs are worth noting. IOP3 examined the penetration of the Great Salt Lake breeze into Tooele Valley and gap flows through Stockton bar. Clear-air returns were surprisingly good and enabled the students to examine the complex three-dimensional structure of the lake breeze and returned flow aloft. During IOPs 5–8, the students examined major precipitation events,

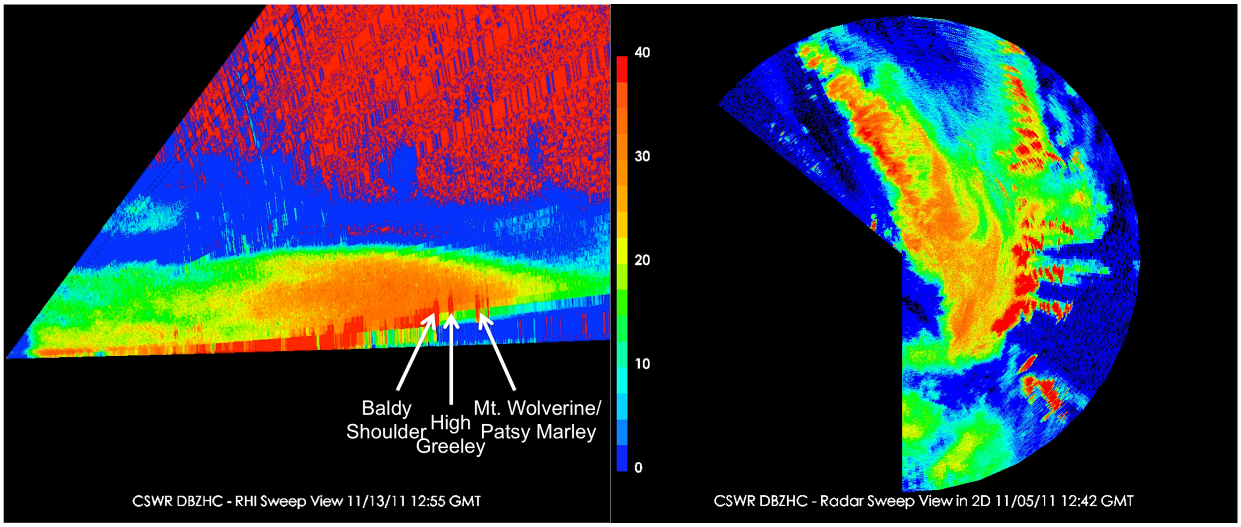

Figure 2. Sample DOW images. Left: RHI of orographic precipitation enhancement in Little Cottonwood Canyon with ground clutter from major topographic features annotated. Right: Lake-effect snowband.

including lake-effect and orographic precipitation (Fig. 2). These efforts also included GPS-sonde launches and observations with mobile and relocatable mesonet stations. The later IOPs were also designed to take advantage of a vertically pointing radar and ice crystal imager located at Alta ski area in Little Cottonwood Canyon (see also Appendix 1).

b. Lecture and on-campus DOW demonstration for general education students

Educational and outreach deployments (EODs) included a sidewalk demonstration on 27 Oct of DOW6 next to the primary buildings housing the College of Mines and Earth Sciences. Students enrolled in Atmos 1010 (Severe and Unusual Weather) received a sidewalk lecture from PI Steenburgh and then group tours of the DOW and radar imagery (Fig. 3). Students enrolled in Atmos 5110/6110 (Synoptic-Dynamic Meteorology) received a similar tour. Roughly 200 students and walk-up visitors were given tours.

Figure 3. Lecture and tour for Atmos 1010 (Severe and Unusual Weather) students.

c. Class and capstone project educational activities

Two deployments (EOP5 and EOD7) to a site along 13th avenue near the University of Utah campus that overlooks the Salt Lake Valley enabled several students who could not attend major field deployements to get some hands-on DOW use (Fig. 4). University of Utah undergraduate students work an average of 30 hours per week outside of school, and such deployments were critical for their participation.

An archive of data collected during the DOW visit has been created on the Department of Atmospheric Sciences computer system, which is accessible from iMac computers in the Department computer classroom. We are presently working to navigate and georeference this data, after which it will be available for classroom use, graduate student research, and undergraduate capstone projects.

Figure 4. DOW operations on 13th Ave (near the University of Utah campus) for students who were unable to attend other deployments.

d. K–12 Outreach

As summarized in Table 1, outreach visits were made to several area schools including Newman Elementary (~100 students), the Salt Lake Center for Science Education (~80 students), the Madeleine Choir School (~125 students), Highland High School (~30 students in an AP environmental science class), Nibley Park Elementary (~90 students), and Hillside Middle School (~95 students). Many students at Newman Elementary and the Salt Lake Center for Science Education are from traditionally underserved groups. The visits typically involved an outdoor lecture and tours of the DOW for all students. In some cases, a graduate fellow from the Thing Globally Learn Locally (TGLL) program provided a lecture on radar and severe weather to the students prior to the DOW arrival (Fig. 5).

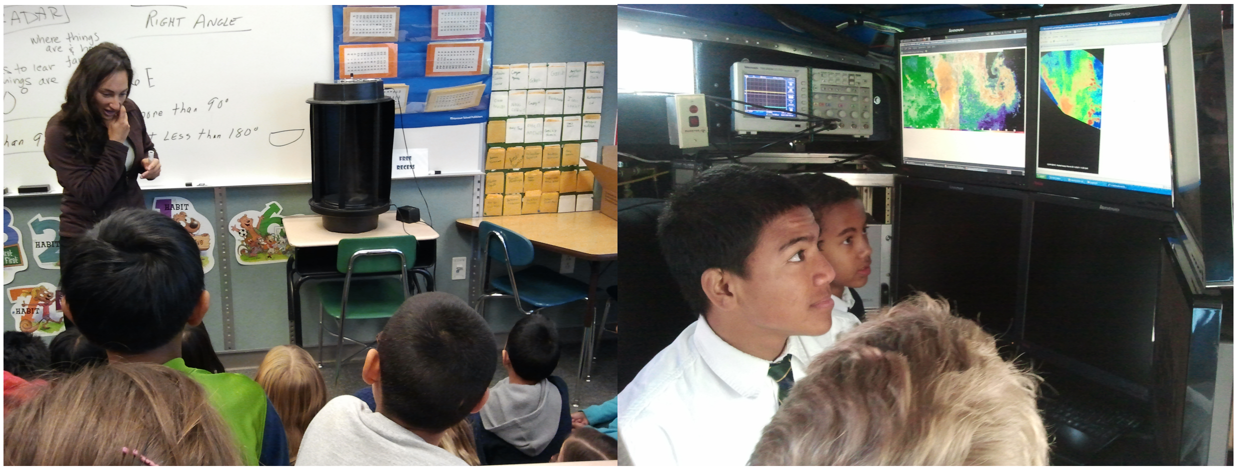

Figure 4. DOW outreach visits included instruction on radar and severe weather and tours of the DOW cab and images. At right, TGLL graduate fellow Carollyn Stwertka leads a discussion about tornadoes at Newman Elementary School. At left, Madeleine Choir School students examine radar imagery of tornadoes and local winter storms.

d. Public and media outreach

PI Steenburgh provided regular posts to his Wasatch Weather Weenies blog (http://wasatchweatherweenies.blogspot.com) during SCHUSS, including discussion of student activities and findings from field deployments. This not only enabled a way to communicate the University of Utah students that were not in the field, but also to the general public. During October and November, which bracket SCHUSS, pageviews for the Wasatch Weather Weenies blog exceeded 12,000. Data collected during SCHUSS was also presented at the Utah Snow and Avalanche Workshop, which was held at The Depot in downtown Salt Lake City and attended by ~500 people.

Student activities were widely covered in the local media. Segments were presented on all four major television stations (KUTV, KTVX, KSL, and KSTU) and the Salt Lake Tribune, which has Utah's largest circulation, published a major article (http://www.sltrib.com/sltrib/home2/52895985-183/weather-doppler-lake-salt.html.csp). The National Science Foundation featured a summary of SCHUSS on its web site (http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=122491&org=NSF).

2. Student and instructor outcomes

Student outcomes were not quantified as participation was voluntary and not part of a formal course. However, the level of participation and engagement amongst the core group of 18 graduate students was high throughout the period, even during the last IOP when several students were up late or all night collecting data. It is the view of the PI that this was the most engaging student activity in which he has participated. There is no way to replicate such an experience solely in the classroom. The ability for students to plan field activities and then execute them, including configuring and adjusting scanning strategies on-the-fly in response to evolving weather is a very powerful learning experience.

3. General comments

It is quite remarkable that with little training a portable radar can be placed in the hands of new users who are then able to efficiently operate and deploy it. Only a few minor glitches occurred during SCHUSS, all of which could be addressed easily over the phone. Ideally, however, a CSWR employee should remain with the radar for a full deployment, and perhaps serve as a full-time driver.

Some of our operations were unique in that they occurred in an area of complex terrain and much of the lake- and orographic precipitation we observed featured radar reflectivities that were much lower than observed in deep convection. Two improvements to the DOW radar visualization software would greatly help in these circumstances. One would be to have an alternate or adjustable color table that enables greater contrast during periods of less dramatic reflectivity gradients (some color blind students also struggled with the existing color tables). The other is the ability to loop and analyze the data on the DOW computers, which is especially important for ensuring that RHIs are collected precisely where desired relative to major terrain features. We opted to move the data to a laptop in order to do this, a process that worked, but was cumbersome.

4. Final thoughts

We thank Josh, Justin, Ab, and everyone at CSWR for a great experience. We hope to do it again.

Table 1. DOW activities including Educational Observing Periods (EOPs), Education and Outreach Deployments (EODs), and Intensive Observing Periods (IOPs).

Date (UTC)	Name	Summary
22 Oct	EOP1	Morning deployment to north airport site for DOW training and practice
23 Oct	EOP2	Morning deployment to north airport site for DOW training and practice
24–25 Oct	IOP1	Late afternoon/early evening deployment to Lake Point rest area on I-80 to observe approaching (dry) cold front and its interaction with the lake boundary layer and thermally driven flows from Tooele Valley
25 Oct	EOD1	Morning exhibition and interview with Grant Wayman, KSL-TV
25 Oct	EOP3	Afternoon deployment to Baccus site along SR-111. Hands-on use and instruction with DOW polarimetric capabilities under mostly cloudy skies with some light, widely scattered precipitation
26 Oct	EOP4	Highly experimental morning deployment to mouth of Weber Canyon to observe valley exit jet.
26 Oct	IOP2	Afternoon deployment to examine precipitating cumulus that popped up with surface heating, including melting band processes and sub-cloud sublimation and evaporation.
27 Oct	EOD2	Morning–early afternoon exhibition on the University of Utah campus including outdoor lecture, discussion, and tour for Atmos 1010 (Severe and Unusual Weather) and Atmos 5110/6110 (Synoptic-Dynamic Meteorology). Total visitation including students and walk-up visits about 200.
28 Oct	EOD3	Morning-early afternoon exhibition at Newman Elementary and the Salt Lake Center for Science Education involving 2 4th grade classes (25 students each), two 6th grade classes (25 students each), and a group of 80 junior high and high school students. Many of these students were from traditionally underrepresented groups in science.
30 Oct	IOP3	Deployment to Tooele Valley (Stansbury Island Road) and Rush Valley to examine lake-breeze in the morning and early afternoon and then gap flow in Stockton Gap during the late afternoon and evening.
1 Nov	IOP4	Deployed to Baccus/SR-111 observing site to examine a frontal precipitation event. Got great polarimetric data of the bright band that should be useful in future radar classes (e.g., http://wasatchweatherweenies.blogspot.com/2011/11/dow-adventures-in-transition-zone.html)
4–5 Nov	IOP5	Remarkable large-scale, orographic, and lake-effect event involving an all-night effort, two sounding teams, relocatable mesonet stations, and a car-mounted mobile mesonet station. Some preliminary analysis at http://wasatchweatherweenies.blogspot.com/2011/11/preliminary-analysis-of-iop5-storm.html
7 Nov	EOP5	Midday deployment to 13th avenue observing site, which overlooks the Salt Lake Valley, for atmospheric sciences students to see the DOW in action and observe some weak convection. This allowed five students (3 juniors, 2 graduate students) and one faculty member who were otherwise unable to participate in the DOW activities to get some education and training.
8 Nov	EOD4	Morning outreach visit to Madeleine Choir School involving grades 4–8 and 125 students. Afternoon outreach visit to Highland High School AP Environmental Sciences class, with about 30 highly engaged students.

9 Nov	EOD5	Outreach visit to Salt Lake City National Weather Service office
10 Nov	EOD6	Morning outreach visit to Nibley Park Elementary involving 3 6th grade classes (about 90 students total) and afternoon outreach visit to Hillside Middle School involving 2 7th grade classes (about 60 students total), one special education class (10 students), and one 8th grade ELP class (25 students). During these visits, we also did interviews with KTVX-TV, KCPW-Radio, KUTV-TV, and the Salt Lake Tribune.
12 Nov	IOP6	Deployment to Daybreak observing site to observe orographic enhancement in Wasatch Mountains and Little Cottonwood Canyon. In addition to the DOW, GPS-soundings were taken. Event also featured pronounced local precipitation shadowing downstream of the southern Oquirrh Mountains.
13 Nov	IOP7	Overnight extension of IOP6 (after a brief break) to examine another storm system and its interaction with the Wasatch Mountains and little Cottonwood Canyon. Event featured orographic enhancement under stable conditions. The following day, at least 10 human triggered avalanches were reported in Little Cottonwood Canyon, including one that killed professional skier Jamie Pierre
17 Nov	EOD6	Brief afternoon deployment to 13th Avenue observing site to allow seniors enrolled on Atmos 5110 (Synoptic-Dynamic meteorology) an opportunity to operate the DOW.
19 Nov	IOP8	Major overnight deployemtn to observe a frontal precipitation band and frontal and post-frontal orographic enhancement. Data was also collected by GPS sondes and a vertically pointing radar and ice-crystal imager in Little Cottonwood Canyon

Doppler-on-Wheels Operations Plan
for Orographic Precipitation Events

I. Background and Motivation

Elevated terrain has long been known to strongly influence the spatial distribution of precipitation across mountain and valley locations. This enhanced precipitation impacts a number of sectors including transportation safety, road maintenance, property damage, as well as the snow pack depth which is important for water storage and the ski industry. Though smaller in scale (cross-barrier distance), like the Cascades of the northwest United States and the Sierra Nevada, the Wasatch mountain range of northern Utah has been a focal point of orographic precipitation studies. Most notable, the Intermountain Precipitation Experiment (IPEX; 2000), based in Salt Lake City, used a unique suite of instrumentation to examine both the dynamical and microphysical structure of orographic precipitation events, with a particular emphasis on using results to understand the deficiencies of numerical modeling and their microphysical schemes on properly simulating orographic precipitation. Though the suite of observing platforms for this planned field exercise is limited to a single dual-polarimetric Doppler on Wheels (DOW) radar and conventional surface and upper-air observations, results should further understanding on not only the spatial distribution and temporal evolution of orographic precipitating cloud, but in particular, the evolution of their microphysical characteristics.

The relationship between observed (enhanced) precipitation patterns and elevated terrain is generally well understood. Previous work highlights a number of key observations that characterize orographic precipitation events, some of which are specific to the Wasatch mountain range. There exists a strong precipitation-altitude relationship; while windward slopes receive the greatest precipitation, a rain-shadow characterizes the pattern in the lee. For the northern Wasatch, not only is there enhanced precipitation over the elevated terrain, the northern and eastern portions of the windward mountain valleys (Salt Lake and Tooele) are also anomalously wet. In contrast, the areas in the lee of the Wasatch are anomalously dry (Cox et al. 2005; Shafer et al. 2006). Cox et al. (2005) describe both the kinematic and thermodynamic conditions during one event during IPEX IOP3. The event is characterized by weak stratification and, perhaps unusual compared to other barriers, no cold pool (though diabatic cooling from melting in the saturated low-levels may reinforce flow blockage). A narrow reflectivity band is observed over the Wasatch crest with little hydrometeor spillover; suppressed spillover is linked to mountain-wave induced subsidence in the immediate lee. They also identify flow splitting around the major peaks in the northern Wasatch, though little impact was observed in precipitation structures.

Perhaps less understood, though receiving more attention in the last decade, microphysical processes are critical in understanding reasons for enhanced precipitation in regions of upslope flow. Houze and Medina (2005) hypothesize that enhanced precipitation on the windward slopes during stable, or conditionally unstable moist upslope flow, is a consequence of cellular overturning due to the inherent vertical wind shear induced by near-surface blocked or retarded upslope flow. This cellular overturning, located in and above the melting layer, is responsible for the development of an enhanced amount of (super cooled) liquid water; a catalyst for the rapid growth of aggregates and graupel by riming, and facilitor of increased collisions (aggregation) of the more pristine ice crystals falling from higher altitudes. The combined growth due to increased aggregation and riming facilitates rapid hydrometeor fallout, and thus enhanced precipitation on the windward slope and decreased spillover in the lee. Woods et al. (2005) similarly observe that during one event in the Improvement of Microphysical Parameterization through Observational Verification Experiment (IMPROVE, 2001; located in the Cascade Mountains), excess cloud liquid water production in the orographic lifting zone is scavenged by ice crystals falling from aloft; surface ice crystal measurements indicated rimed ice crystals. Though Houze and Medina (2005) and Woods et al. (2005) benefited from substantially more data availability (which includes vertically pointing x-band dual-polarized radar as well as aircraft in-situ sampling), this hypothesis can be reasonably tested with the dual-polarization DOW.

A vast suite of instruments available during IOP3 of the Mesoscale Alpine Programme (MAP, 1999; Alps), which included the NCAR S-POL polarimetric Doppler radar, also offered a unique opportunity to characterize the microphysical processes occurring during orographic precipitation events. Pujol et al. (2005) describe both convective and stratiform processes occurring during an intense orographic precipitation event. The authors particularly note convective cell development on the order of an hour that exhibit “medium” to “heavy” rain below the melting layer due to coalescence of melting graupel (originating from layers above the 0°C isotherm). In stratiform regions, melting dry snow and graupel results in wet snow in and just above the melting layer, while rain below. In the composite framework, predominantly convective signatures are observed; below 0°C, rain is observed, while above 0°C, a mixture of wet snow, ice crystals and dry snow are embedded with 2 km deep graupel-hail cores.

II. Objectives

Though IPEX, IMPROVE and MAP studies benefit from a vast array of observing platforms, similar questions posed by those campaigns can be addressed in this exercise. Given the capability of the DOW to provide high resolution horizontal and vertical measurements of reflectivity, radial velocity as well as hydrometeor classification, in cooperation with conventional observing platforms, the following questions can be explored by data obtained of orographic precipitation events investigated by the DOW:

1) Are the highest reflectivity cores associated with the highest terrain?
2) What environmental and microphysical properties distinguish shallow orographic precipitating clouds from events that exhibit greater vertical depth?
3) What is the time evolution of orographic precipitation from a pre- to post-frontal environment? Do front-terrain interactions exhibit different reflectivity structures and microphysical properties than non-frontal orographic precipitation events?
4) Is orographic precipitation characterized by persistent updrafts or are high reflectivity cores periodic? Or in other words, what is the time evolution of any one particular high reflectivity core?
5) How does the precipitation and microphysics contrast in the canyons versus the higher terrain?
6) What stability profile favors spillover events? What hydrometeors characterize spillover?

Answering these questions will require data from not only the DOW, but also conventional observations. Conventional observations include the upper-air soundings from not only KSLC, but also mobile rawinsondes [GRAWs], the veritable surface observation platforms available in MesoWest, SNOTEL stations interspersed across the Wasatch, as well as reflectivity and radial velocity provided by the MTX WSR-88D and KSLC TDWR.

III. Deployment Strategies

a. DOW Siting [to be completed upon finishing siting]

Deployment locations will include the Mt. Timpanogos site (TIMP; presumably located in western Utah county on the western shore of Utah lake near Saratoga Springs), the South Valley site (SVLY) located near the Oquirrh Mountain Temple, 10863 Fern Ridge Dr.), and the Buccus site (BUCS) along Rt. 111 in the central west bench of the Salt Lake valley). Also, sites are to be determined on the windward slopes of the Wasatch north of Salt Lake City. These sites will allow direct line of sight to the highest peaks of the Wasatch as well as canyons such Little Cottonwood, Big Cottonwood and American Fork. During benign periods in northern Utah, additional deployments may be considered in southern Utah (perhaps in conjunction with TRMM for moderate to deep precipitating systems), as well as the northern Rockies near Grand Teton National Park. For investigating spillover, sites in outside of Heber and Park City will be considered.

b. General Scanning Strategies

Scanning strategies will be tailored to each case; however, the general distinction will be range-height indicator (RHIs) for microphysical investigations and for rapidly evolving phenomena, such as high reflectivity cores, and plan position indicator (PPIs) for more slowly varying interests, such as the spatial distribution of reflectivity. For looking at the spatial distribution of precipitation, PPIs should be executed at least every 5 min since the spatial distribution is (presumably) more slowly evolving than the individual high reflectivity cores. Full volume scans will be needed less frequently and may be most important during widespread and deep precipitation events. The radar can also be deployed in vertical scanning mode in the upstream blocked region below the upslope flow to aid in observing updraft properties, and perhaps (if the updraft is not tilted) deduce vertical motion from hydrometeor motion. For looking at spillover events, a high frequency of sector scans in the spillover layer will be more preferential over RHIs.

c. Supplemental instrumentation

1. Upper-air soundings

Salt Lake NWS rawinsondes at Salt Lake International Airport (KSLC) will provide routine upper-air profiles daily at 0000/1200 UTC. For most events, these will soundings provide upstream thermodynamic (stability) profiles, as well as an estimate of the magnitude of the cross-barrier flow. GRAW (mobile) soundings can also be strategically placed to obtain upstream thermodynamic (stability) conditions and provide a better estimate any along-barrier wind component that may exist. The mobile soundings will prove particularly important for events when information is needed between the routine rawinsonde launches. Though only one sounding will be necessary for a deployment in slowly-varying synoptic conditions, a second sounding may be required if synoptic conditions significantly change during a deployment period (say for a cold frontal or upper-level trough passage).

2. KMTX and KSLC TDWR

   Though one of the major motivations for this exercise is the failure of both the KMTX WSR88D and KSLC TDWR to provide sufficient coverage of orographic precipitation events to warrant close examination of the questions posed above, they may still offer some pertinent information on the radial velocity and reflectivity of targets on the windward slopes of the Wasatch, and can likewise be verified with the information from the DOW.

3. Surface observations

   MesoWest will provide a unique product to evaluate surface conditions at various altitudes and locations (ridge top, canyon, valley, etc.). Relevant information will include the surface temperature (for melting layer identification), 10 meter wind (for identification of cross and along barrier flow components), as well as snow water equivalent (precipitation amount) and snow accumulation (most likely provided by SNOTEL stations across the northern Wasatch). The precipitation amount may prove to be helpful to qualify distinctions between canyons and ridgelines in the spatial distribution of reflectivity.

4. Garrett camera

   This unique camera tailored to capturing visible images of hydrometeors at the surface may prove useful to connect observed hydrometeor characteristics with those identified within cloud using the dual-polarized DOW. Most likely deployment is at Alta ski area.

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