1. Project summary

The Sierra Hydrometeorology Atmospheric River Experiment (SHARE) is a multi-agency field program focused on the multi-scale physics of orographic precipitation development and air mass transformation associated with frontal systems crossing the northern California Sierra Nevada mountain range. The SHARE field phase will take place from December 2008 to January 2009, coinciding with a major winter season of the NOAA Hydrometeorology Testbed (HMT) program in the California Sierras. SHARE builds on previous orographic field studies and incorporates several unique elements. The large-scale characteristics and evolution of the air mass moisture flux associated with an atmospheric river as it approaches the California coast and crosses the Sierra mountains will be observed in conjunction with the medium-scale interactions of the atmospheric river, frontal system, barrier jet, and the smaller-scale orographic precipitation processes, their variability. and their impact on the basin hydrology.

Requested NSF facilities include the University of Wyoming King Air, NCAR G-V HIAPER, NCAR S-POL, the Doppler on Wheels radars, and a variety of smaller surface-based remote sensing and in situ instruments. The NSF facilities will be deployed in conjunction with NOAA and university facilities to create a network that will permit coordinated observations of each storm as it moves toward the mountains, over the windward slope, and downstream of the mountain crest.

1.1 Intellectual merit

SHARE is the first orographic field program to integrate the larger scale issue of airmass transformation with the smaller-scale issues of cloud structure, cloud physics, and precipitation distribution. Comparison of observations from recent field programs such as IMPROVE and IPEX to regional model output have revealed both overpredication and underprediction errors in cloud water and surface precipitation depending on the case examined. Recent work has also shown the importance of sub-barrier scale 3-D topography and the associated 3-D velocity structure to orographic precipitation variability. While the diagnosis of precipitation prediction errors is straightforward, the treatment necessary for improved model performance is not. By placing equal emphasis on 3-D microphysics and kinematic measurements at a range of spatial scales, SHARE is poised to improve understanding of the joint interactions between 3-D microphysics and kinematics and to improve representations of these processes in numerical models. Additionally, SHARE will utilize a combination of atmospheric and hydrologic measurements to examine the link between small-scale precipitation variability and basin runoff response.

1.2 Broader impacts

The findings from SHARE will have potential extensions to other regions of the world and to longer time scales. Atmospheric rivers are an important mechanism for meridional transport of water vapor from the tropical oceans to midlatitudes. Improved knowledge of the interaction of atmospheric rivers and topography may be applicable to other north-south mountain ranges such as the Andes in South America. The physical process studies in SHARE are focused on the time scale of individual storms but will have applicability to longer time scales associated with climate issues. Improvements in the representation of precipitation in storm-scale hydrologic models will be applicable to hydrological models that focus on intra- and interseasonal scales. Understanding the fine-scale precipitation structures over a topographic barrier is important for hydrologic modeling and geologic studies of local debris-flow and long-term erosion. SHARE will also have large societal impacts, spanning issues related to public safety, commerce, and human resources development. Knowledge gained from the project will contribute to improvement of forecast tools for warning of floods and other severe weather that may endanger lives, property, and impact the U.S. western regional economy in the sectors of freshwater management (quality and quantity), commercial transportation, fisheries, and recreation. Human resources development includes meteorological and hydrological field observation training for undergraduate and graduate students and classroom training modules based on SHARE case studies and findings.

Note to the Reader: The Scientific Program Overview (SPO) and Experimental Design Overview (EDO) together constitute a complete description of the proposed field program. The SPO emphasizes the scientific background and justification for the project while the EDO emphasizes the experimental plan. To facilitate use of the documents together, we have utilized the same outline and section numbers for both the SPO and EDO.

Project Description

2. Program rationale and scientific objectives

Hydrometeorological processes are those that lead to the development of precipitation and determine its distribution and fate on the ground. SHARE is a multi-agency field program focused on orographic precipitation and air-mass transformation over the northern California Sierra Nevada mountain range. The SHARE field phase will take place from December 2008 to February 2009 coinciding with a major winter season of the NOAA HMT program in the California Sierras (EDO, Sec. 4.3). This document focuses on the atmospheric components of SHARE related to the development of precipitation aloft and its distribution on the ground and the impact of the variability in small-scale precipitation intensity and type (rain vs. snow) on the basin hydrology. NOAA HMT (Ralph et al. 2005b) will address operational applications of hydrometeorology.

2.1 Rationale

Extratropical baroclinic waves pass over the west coast after developing over the Pacific Ocean. These precipitating cloud systems are modified as they approach the rugged terrain of the far western region of the continent, where airflow is strongly influenced by the mountains lying ahead of and beneath the storms. The orographic modification of the baroclinic flow profoundly influences the precipitation processes. The orographic processes increase precipitation on the windward slopes (windward enhancement) and decrease it on the lee slopes where the term "rainshadow" applies (Fig. 2.1-1). Upslope flow and precipitation enhancement can also occur for large barriers in the absence of upward motion induced by a baroclinic wave.

Along the west coast of the U.S., concentrated bursts of low-level water vapor are associated with "atmospheric rivers". Atmospheric river was a term coined by Zhu and Newell (1998) to describe narrow plumes of moisture associated with fronts in oceanic cyclones. The atmospheric rivers intermittently emanate from the reservoir of water vapor in the tropical oceans and extend into midlatitudes. Atmospheric rivers typically transport water vapor in narrow corridors (<1000 km wide) from southwest to northeast (in the northern hemisphere) over several thousand km (Neiman et al. 2007). A significant portion of meridional transport of water vapor occurs within the discrete atmospheric rivers (Ralph et al. 2004, 2005). Most (~75%) of the water vapor transport within these rivers occurs within the lowest 2.5 km of the atmosphere. Atmospheric rivers emanating from the eastern tropical Pacific can intersect the U.S. west coast supplying large amounts of moisture to a small cross section of land, a key ingredient for flooding events (White et al. 2003, Neiman et al. 2007). Over the Pacific Northwest, atmospheric rivers are often referred to as the "Pineapple Express" (Lackmann and Gyakum 1999; Colle and Mass 2000) because the origin of the moist flow is usually near Hawaii. Moisture transported northeastward from near Hawaii produces severe flooding events as it interacts with the steep terrain of the PNW. Extreme flooding events occur when the low-level jet required by hydrostatic and semigeostrophic balance ahead of a front transports moisture towards the mountains (Buzzi et al. 1998; Doswell et al. 1998; Lin et al. 2001; Rotunno and Ferretti 2001; White et al. 2003; Ralph et al. 2004, 2005, Neiman et al. 2007).

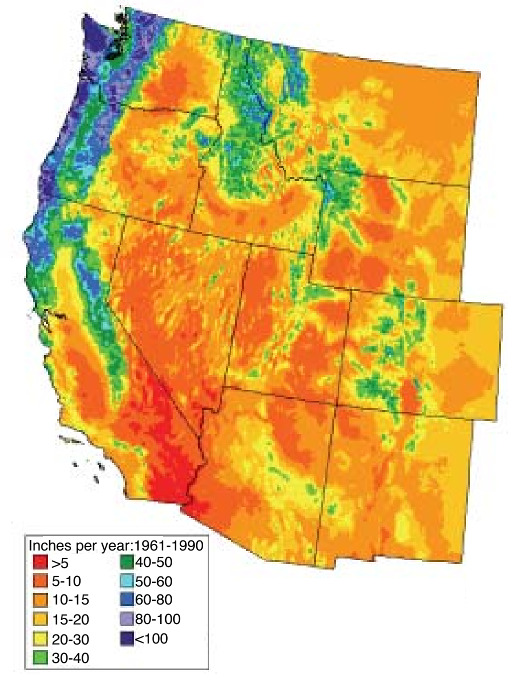

Figure 2.1-1 Average annual precipitation over the western United States (www.wrcc.dri.edu).

On the large scale, orographic precipitation intensity is proportional to the horizontal flux of water vapor (Smith 1979, 2006). The transformation of the moist oceanic airmass as it passes over the mountains can be described in terms of the relation between the incoming water vapor flux and the precipitation falling over mountains. The drying ratio (Smith et al. 2003) encapsulates the moisture budget of the large-scale air mass transformation. Factors influencing the drying ratio are the timescales of precipitation growth and fallout (bulk conversion time scales), and the joint interaction of the wave response to the mountain barrier and the pattern of precipitation fallout.

The orographic precipitation mechanisms consist of a sensitive interdependence of orographically induced flow dynamics (channeling, blocking, orographically triggered convection or turbulence, and gravity-wave responses), cloud microphysics, and joint interactions among the moisture source, barrier jet, and frontal system. Together these mechanisms yield a pattern of small-scale precipitation variability embedded within the large-scale air mass transformation.

2.2 Objectives

The overarching science objective of SHARE is to: **investigate the multi-scale physics of orographic precipitation development and air mass transformation associated with frontal systems crossing the northern California Sierra Nevada mountains.** SHARE will combine selected NSF facilities (NCAR HIAPER, University of Wyoming King Air, NCAR S-POL, and a variety of smaller surface-based sensors) with an extensive network of NOAA long-term monitoring instrumentation, NOAA Hydrometeorological Testbed seasonal instrumentation including the NOAA P-3 aircraft, and university instrument assets to comprehensively observe the large-scale water vapor budget over northern California and the small-scale precipitation and wind variability on the windward slope of the Sierras (Sec. 7). Datasets from a particular observing system will often address several scientific objectives. The details of the mapping of each facility to each scientific objective are discussed in Sec. 7.1. SHARE is designed to address the following five key questions:

1. How does the water vapor flux in an atmospheric river change as it passes over the coastal and Sierra ranges?

The bulk effect of the orographic precipitation system is to remove water vapor from the incident “atmospheric river”, strongly reducing the moisture reaching the intermountain west and the Great Plains. A simple measure of this removal is the Drying Ratio (DR) defined by DR=Total Precipitation/ Incoming Water Vapor Flux. This quantity has significant implications for regional climate and for the transport of fresh water between ocean basins. Several methods for estimating DR from conventional data and models are discussed by Smith et al. (2003) and Smith (2006) and involve calculating the water budget across the mountain range using estimates of the surface precipitation and incoming and outgoing water vapor fluxes. DR can also be estimated using stable isotopes of water obtained from streams and sapwood (Smith et al. 2005, Smith and Evans 2007). Smith’s studies have yielded estimates of DR of ~35% for the Alps, ~44% for the Oregon Cascades, and ~50% for the southern Andes.

Other types of airmass transformation by mountain ranges have been suggested. A precipitating cloud system over a complex mountain range can add non-uniform amounts of latent heat to the airstream (Doyle and Smith, 2003). As buoyancy adjustments occur downstream, the entire lower and middle troposphere becomes “scrambled” (Smith et al. 2003).

SHARE is the first field study to integrate the larger scale issue of airmass transformation with the smaller-scale issues of cloud structure, cloud physics, and precipitation distribution. SHARE facilities will be used to observe the temporal history of incoming water vapor flux and to construct a 2-D water budget for the coastal and Sierra ranges. The ability of numerical models to predict airmass drying is a critical constraint on the quantitative precipitation forecast over the windward and lee sides of the Sierra mountains.

2. What are the nature and impacts of the joint interactions among the atmospheric river, frontal system, and barrier jet and how do they alter precipitation processes, rates and spatial distribution and the associated wind field upstream and over the windward slope of the mountain barrier?

Horizontal water vapor fluxes accompanying land-falling cold fronts are frequently concentrated into narrow regions known as atmospheric rivers (Ralph et al. 2004). These rivers, which are collocated with the pre-cold-frontal low-level jet, are embedded within a broader region of poleward heat and moisture transport commonly referred to as the warm conveyor belt (e.g., Carlson 1980; Browning 1990). Substantial orographic precipitation enhancement occurs when the prefrontal atmospheric river and embedded low-level jet are oriented normal to a topographic barrier and cross-barrier moisture fluxes are maximized (Neiman et al. 2004, 2007). Weak moist static stability within the atmospheric river environment can further contribute to orographic precipitation enhancement (Ralph et al. 2005a).

Less well known is how the distribution and intensity of orographic precipitation is modified by the interaction of landfalling fronts and atmospheric rivers with mountain barriers. For example, although rain rates at mountain top locations are strongly correlated with the magnitude of the cross-barrier flow (and hence moisture flux), at lowland locations they are poorly correlated due to the influence of low-level blocking (e.g., Neiman et al. 2002). There have been several field studies of frontal precipitation interacting with coastal orography over the Pacific Northwest (Bond et al. 1997) and southern California coast (Ralph et al. 1999) but little recent work with a mountain as high and wide as the Sierras. These field studies, as well as other idealized simulations, have shown that partially or fully blocked low-level flow by steep coastal terrain can lead to low-level frontogenesis and enhancement of the frontal precipitation bands as they approach the barrier (Yu and Smull 2000; Colle et al. 2002; Neiman et al. 2004; Braun et al. 1999; among others), while the frontal bands and temperature gradient weaken over the windward slope (Colle et al. 1999). Braun et al. (1999) showed that wider barriers with a downstream plateau, such as the Sierras, can generate a larger barrier jet and windward frontogenesis than a narrower barrier of equivalent height.

The barrier jet is a dominant feature in Sierra Nevada storms (Parish 1982; Marwitz 1986), yet knowledge of its contribution to orographic storms remains elusive. For example, Marwitz (1986) suggests that “the barrier jet transports large quantities of sensible heat and water vapor to the northern end of the Sierra Nevada”, in essence, acting as a topographically induced atmospheric river. In contrast, the barrier jet may also tap into an airmass with a significant saturation deficit, which may result in substantial sub-cloud evaporation. Finally, incomplete understanding of the physics of and joint interactions between frontal systems and blocked flow, including the processes that promote the maintenance or decay of blocked flow with the passage of frontal systems (e.g., Cox et al. 2005), limits our ability to identify the factors affecting the distribution and intensity of precipitation across a mountain barrier, including the magnitude of orographic precipitation enhancement. It is abundantly clear, however, that terrain-blocked flows do indeed significantly modulate precipitation distributions and intensities when a frontal zone accompanied by an atmospheric river interacts with the blocked flow (Neiman et al. 2004,2007).

The SHARE field program will provide an unprecedented dataset with which to examine the interaction between frontal systems, atmospheric rivers, and the barrier jet. SHARE aircraft facilities will examine frontal systems and moisture fluxes upstream of topography, with both ground-based and airborne assets ideally positioned to examine the development and evolution of the barrier jet, its interaction with landfalling fronts and atmospheric rivers, and its role in orographic snowstorms. The precipitation evolution of frontal bands will be monitored using the WSR-88D, S-POL, and X-POL radars while the DOW radars and aircraft radar will provide the three-dimensional flow. The study region is well known for frequent and intense atmospheric rivers and the Sierra Nevada barrier jet is one of the most pronounced in the world.

3. What is the relative importance to precipitation generation of different sources of localized upward motions at a given location on the windward slope: advection of upstream convective cells, turbulence generated by shear, friction, topographically induced gravity waves parallel and perpendicular to the slope, and embedded convection generated over mountains?

It is well recognized that the precipitation distribution is sensitive to how much of the low-level flow is blocked by the terrain as determined by the Froude number ($Fr=U/HN$, where U is the upstream wind towards the barrier, N is the upstream moist static stability over depth H, and H is the height of the barrier), where a $Fr < 1$ favors blocked flow and more precipitation upstream of the barrier (Grossman and Durran 1984; Chu and Lin 2000; Sinclair et al. 1997; Houze et al. 2001; Neiman et al. 2002; Colle

2004; Cox et al. 2005; Chen and Lin 2005; Medina et al. 2005). When the layer of air approaching the mountain barrier has a high Fr, there is little upstream effect and the air rises directly over the terrain, following the details of the individual small-scale peaks, so that the largest orographic enhancement occurs over the first sharp peak of terrain (Medina and Houze 2003; Rotunno and Ferretti 2003). For large Froude number flow, the amount of stable orographic uplift and precipitation growth aloft is determined by the size and shape of the barrier, wind speed, and stability, as given by linear gravity wave theory (Colle 2004; Smith and Barstad 2004). A complication in determining the Froude number is that the upstream environment is often ill-defined.

To characterize events by Fr alone [with a low Fr (stably stratified) as exhibiting blocked flow and high Fr (potentially unstable) as exhibiting unblocked flow perpendicular to the slope] is an over-simplification. The horizontal moisture gradient can impact the horizontal distribution of static stability in such a way as to lead to convergence between blocked and unblocked flow yielding enhanced uplift (Rotunno and Ferretti 2003; Galewsky and Sobel 2005). Colle (2004) provided evidence, using idealized two-dimensional simulations of the MM5 that orographic precipitation can extend upstream of a wide barrier under stably stratified conditions when a mountain wave tilts upstream with height and has a large vertical wavelength. Recent results from IMPROVE suggest that a series of narrow ridges upstream of the crest can enhance precipitation by forcing gravity waves, which can enhance accretional riming growth above the narrow ridges (Garvert et al. 2006). This behavior occurs at scales of 10-20 km in both the cross-barrier flow and in the along-barrier component of the flow.

Houze and Medina (2005) suggested that turbulence within a layer of strong shear along the windward slope could enhance precipitation growth and fallout over this region. Convection is also common within orographic precipitation. Kirshbaum and Durran (2005) showed that a more dominant quasi-stationary mode of convection parallel to the mean low-level wind direction develops when the convection is initiated by topographic roughness.

Additionally, orographic processes can locally decrease precipitation. For example, as air passes over high terrain and begins to descend, condensed water that has not already fallen to the ground will begin to evaporate. In many cases, this process will limit the total precipitation that falls. It follows that the patterns of descent are almost as important as the patterns of ascent. If there is a background of static stability in the atmosphere, these patterns will tilt upwind relative to the terrain.

Comprehensive, multi-scale 3-D wind and precipitation structure observations (Sec. 7) will document the characteristics and evolution of frontal systems and their associated rainbands as they approach and pass over the windward side of the Sierra. The observations will also be used to motivate and evaluate modeling studies of orographic modification processes.

4. What are the key spatial scales of vertical motions and their association to the dominant microphysics processes? Are intermittent or steady-state processes more directly responsible for the observed high precipitation efficiency and high spatial variability of orographic precipitation?

Results from previous field experiments and modeling studies (Sec. 3) have yielded a plethora of orographic enhancement mechanisms at different spatial and time scales. Question 4 relates to the spatial and temporal scales of vertical motions responsible for precipitation variability over the windward slope. The spatial distribution of precipitation at the surface is a result of a complex superimposition and interaction of microphysical and kinematic processes. Untangling the superposed processes requires close integration and analysis of the planned field observations and modeling studies.

Comprehensive and consistent observations of the resulting 3-D precipitation and wind structures (Sec. 7) will follow the same observation plan for each IOP (Sec. 7.15). The details of the environment and storm structure are expected to vary from storm to storm. Consistent storm-to-storm observations will provide a foundation for analysis of differences and similarities in precipitation growth processes among storms. A combination of linear and regional forecast models (Sec. 6) will be used to decompose the influence of specific processes and determine which subsets are most important to the resulting complex distribution of precipitation over the Sierras. Modeling studies will be used to constrain storm characteristics that cannot be directly observed and to test the sensitivity of the spatial distribution and intensity of precipitation to specific aspects of the microphysics parameterization. Iterative model sensitivity tests and comparison of model output to observed fields also provide methods of refining the numerical-model microphysics parameterization.

5. How can improved representation of the distribution and variability of atmospheric parameters (temperature, winds, fluxes, precipitation) enhance hydrologic prediction of runoff and improve parameterization schemes used in hydrologic models?

The American River Basin, at a range of elevations from 300 to 3000 m, is representative of many basins on the western slope of the Sierra Nevada (Dettinger et al., 2004). Precipitation varies greatly with elevation, from about 800 mm yr^{-1} at Auburn (400 m) to over 1600 mm yr^{-1} at Blue Canyon (1700 m) (Jeton et al., 1996). Whether the precipitation falls as rain or snow is critical to hydrological applications. About two-thirds of annual runoff originates as winter rainfall, and one-third originates as spring snowmelt (Dettinger et al., 2004). Floods typically occur as a result of multi-day heavy winter rain events, when large amounts of warm moist air arrive from the tropics via atmospheric rivers (Neiman et al. 2007). In the west-coast mountains, particularly warm storms result in floods primarily because rain falls at higher elevations and over a much larger contributing area for runoff than during a typical storm. Continuous snow depth observations, using an array of 100 ultra-sonic depth sensors, will provide the back-bone for SHARE ground validation of local-scale snow distribution patterns.

As the rain-snow line rises from 800 m to 2800 m (a common range for the melting level in California winter storms), the fraction of total basin area contributing to runoff increases from 25% to 100%, resulting in up to 4 times as much runoff with a constant rain rate across the basin. The contribution of snowmelt to runoff during a warm storm is generally a secondary factor but can provide up to 1/3rd of the total input to a river network, as observed in the Oregon flood of February 1996 (Taylor 1997). Snowmelt varies widely between storms and locations and is caused primarily by the sensible heat flux (Marks et al. 1998). In addition to resolving precipitation across the basin, SHARE will measure wind fields through the complex terrain and fluxes at three elevations. SHARE will also use new sensor technology to densely sample near-surface air temperature across the basin. The intensive observations generated through SHARE provide a unique opportunity to investigate how small scale variability of precipitation, snowdepth, temperature, and winds in complex terrain impact the amount of precipitation of each type (rain vs. snow), snowmelt, and consequently total basin runoff. These data will also permit examination of whether bulk flux parameterizations developed for flat terrain (Monin and Obukov 1954) should be used in complex terrain, and if not, under what conditions alternatives should be employed.

2.3 Broader impacts

The motivation and significance of this project goes beyond the science issues outlined in the last section. Knowledge obtained about orographic precipitation and air mass transformation associated with the Sierra Nevada mountains may be applicable to other major north-south oriented mountain ranges such as the Andes in South America.

Physical processes to be studied in SHARE are focused on the time scales of individual storms and seasons. The air mass transformation investigations and their impact on regional precipitation patterns have upscale ramifications to regionalization of precipitation climate (Guirguis and Avissar, 2007). Longer time-scale hydrologic issues will also benefit from knowledge gained in SHARE. For example, improvements in the representation of physical processes in storm-scale hydrologic models will be applicable to hydrologic models that focus on intra- and interseasonal scales.

Understanding the fine-scale precipitation structures over a topographic barrier is also important for hydrological modeling. For example, Westrick et al. (2002) illustrated that the streamflow forecasts over the Washington Olympics and Cascades were sensitive to the observed and simulated precipitation distributions on the ridge and valley scale. Ralph et al. (2003) also showed that the peak river flows during CALJET were highly sensitive to the exact location of the windward enhancements and rain shadows. Understanding of the fine-scale precipitation structures over a barrier is also useful for geological studies of local debris-flows and to study the erosion rates for uniform precipitation versus highly variable precipitation. For example, Anders et al. (2004)

suggested that the Olympic Mountains would be 500 m higher if the precipitation was uniform.

SHARE will also have large societal impacts, spanning issues associated with public safety, commerce, and human resources development. Knowledge gained from the project will contribute to the improvement of tools used by operational forecasters for warnings of floods and other severe weather that may endanger lives and property. This knowledge also has relevance to several sectors of the western U.S. regional economy, such as freshwater management (quality and quantity), commercial transportation, fisheries, and recreation. The American River flows into Folsom Reservoir (drainage area of 4,740 km2), which mitigates flood damage for approximately 400,000 people and $37 billion worth of property in the city of Sacramento, California (Shamir et al. 2006). While still undersampled, the American River is one of the most heavily-instrumented watersheds in the mountain ranges of the U.S. west coast, making it an ideal laboratory to gain process-oriented understanding that can be applied to less well-studied basins across the region. Human resources development will also be a major outcome of SHARE. One form of this broader impact will come from meteorological and hydrological field observation training for undergraduate and graduate students. Classroom training modules derived from knowledge gained during SHARE will also be developed.

3. How SHARE builds on previous work

3.1 Legacy from previous orographic field projects

Orographic enhancement of precipitation in the western states of the U.S. has been studied in several previous field programs. The Cascade Project (Hobbs et al. 1973; Hobbs 1975), examined orographic airflow and microphysics. Aircraft data and two-dimensional trajectory modeling showed that ice particle growth by riming was an important process and much of the riming growth occurred in the lowest kilometer above the terrain. Precipitation processes in the Sierra Nevada Mountains along California's eastern border were first studied in the Sierra Cooperative Pilot Project (SCPP), which used ground-based radar and aircraft in situ sensors to document airflow and microphysics (Reynolds and Dennis 1986). These studies successfully documented some of the terrain-enhanced barrier winds (Parish 1982; Marwitz 1983, 1987) and microphysical structures over the terrain (e.g. Heggli and Rauber 1988; Rauber 1992). In addition, the datasets have been utilized to compare with two- and three-dimensional simulations of the precipitation and microphysics above the Sierras (e.g. Meyers and Cotton 1992; Colle and Zeng 2004; Grubišic et al. 2005).

The mesoscale flow and precipitation structures of storms approaching the west coast of the U.S. from the Pacific were studied in the Coastal Observations and Simulation with Topography (COAST) experiments in December 1993 and 1995 (Bond et al. 1997) and in the California Land-Falling Jets (CALJET) and Pacific Land-Falling Jets (PACJET) experiments in 1998 and 2000-2002, respectively (Ralph et al. 1999; Neiman et al. 2002, 2005). In COAST, airborne Doppler data were obtained to show the formation of barrier flows and the modification of frontal systems approaching the coastal mountain ranges (Colle and Mass 1996; Braun et al. 1997; Colle et al. 1999, 2002; Yu and Smull 2000). CALJET and PACJET datasets, particularly airborne Doppler radar and ground-based profiling radars, have also been used to document flow modification by coastal orography (e.g., Ralph et al. 2003; Neiman et al. 2004; Neiman et al. 2006). In addition, these datasets have been used to characterize "atmospheric rivers", narrow channels of horizontal water vapor flux that were associated with flooding in the coastal mountains. About a third of the coastal orographic precipitation observed during CALJET and PACJET was shown to be dominated by liquid-phase precipitation processes (White et al. 2003; Neiman et al. 2005). On average, roughly twice the normal precipitation fell when winter-storms exhibited atmospheric river attributes (Neiman et al. 2007). Generalizing beyond the California field experiments, James and Houze (2005) examined a 2-year climatology of radar data obtained at Eureka, on the northern California coast. In addition to the archetypal windward enhancement on the larger barrier scale and on the smaller scale of individual peaks of terrain, their study of 61 days with major rainfall events found that windward enhancement often occurred both upstream and over the first peak of terrain.

Orographic enhancement of precipitation has also been investigated recently for other barriers of different dimensions. Baroclinic storm systems passing over a wide barrier, the Alps, were documented during autumn 1999 in the Mesoscale Alpine Programme (MAP, Bougeault et al. 2001, Rotunno and Houze 2007). The flow from the Mediterranean varied from stable to slightly unstable in these cases. In the less stable cases (nearly moist neutral) the air easily rose directly over the mountains in an “up-and-over” fashion, while the more stable cases had upstream flow first rising over a low-level layer of cold air (Rotunno and Ferretti 2003; Medina and Houze 2003). In both types of flow, small-scale cellularity enhanced the precipitation on the windward side of the Alps. In the less stable up-and-over cases, strong enhancement occurred over the individual (~10 km horizontal scale) peaks on the windward side (Medina and Houze 2003; Houze and Medina 2005). In the more stable cases, a shear layer bounded the top of the lower cold layer, and turbulent cellular updrafts (~1-3 km in horizontal scale) were observed associated with the shear layer (Houze and Medina 2005).

The Intermountain Precipitation Experiment (IPEX) provided an opportunity to examine precipitation processes over a relatively narrow barrier within the intermountain west. IPEX collected Doppler radar and microphysical data around the narrow (half width = 5 km) Wasatch Mountains of northern Utah in February 2000 using the NOAA P-3 aircraft as well as two mobile Doppler radars (Schultz et al. 2002). This steep barrier resulted in low-level flow blocking below mid-mountain on 12 February 2000 (Cox et al. 2005), which resulted in precipitation enhancement extending 20-30 km upstream of the barrier. Colle et al. (2005a) used high-resolution model simulations of this event to illustrate the importance of the Great Salt Lake and upstream terrain in modifying the blocked flow structures. Shafer et al. (2005) described non-classical frontal structures that developed as a baroclinic wave moved across the Sierras and approached northern Utah. Cox et al. (2005) used ground-based and aircraft radar to show the evolution of the precipitation structures over the Wasatch on 12 February 2000. Even though the surface precipitation was predicted to within 10-20% in the 1.33-km MM5 for this event, the model overpredicted the cloud water over the Wasatch by 40-50% and underpredicted the snow by 40% (Colle et al. 2005a). This result suggests that the model obtained fairly accurate surface precipitation forecasts for possibly the wrong microphysical reasons aloft. Modifying the slope intercept in the assumed particle-size distribution for snow to include more snow crystals at colder temperatures helped to improve the snow forecast aloft.

The IMPROVE II (Improvement of Microphysical PaRameterization through Observational Verification Experiment II) field program investigated frontal systems passing over the Oregon Cascades during the winter rainy season in the Pacific Northwest (Stoelinga et al. 2003). This experiment employed the NOAA P-3 and University of Washington Convair-580 aircraft , the NCAR S-Pol radar measurements, the NOAA/ETL S-Prof vertically pointing S-band radar, and ground-based particle sampling to observe properties of the precipitation on scales ranging from synoptic to a few km. The IMPROVE data showed that as the central region of the frontal cloud systems pass over the Cascades, a barrier scale vertically propagating gravity wave affects the vertical motion and cloud structure at upper levels over the windward slope (Garvert et al. 2006). This is consistent with the idealized modeling results of Colle (2004) and Smith and Barstad (2004), which showed that the precipitation structures aloft are largely determined by the gravity-wave structure above the barrier. Previous observational studies of gravity waves had focused on precipitation enhancement aloft over the crest and immediate lee (Bruintjes et al. 1994) or with supercooled water over windward ridges (Reinking et al. 2000). At lower levels a shear layer forms over the windward slopes in connection with the low-level flow being retarded or partially blocked (Medina et al. 2005). Similar to MAP stable cases mentioned above, cellular overturning occurs in the shear layer, and the small-scale updraft cells evidently form pockets of supercooled water, allowing the snow particles in the baroclinic cloud system to grow rapidly by riming (Houze and Medina 2005).

Air mass transformation objectives have not previously been the focus of a formal field program but two activities in the southern hemisphere have demonstrated the feasibility of the approaches proposed for SHARE. The Southern Alps Experiment (SALPEX) in New Zealand (Wratt et al. 1996; Sinclair et al. 1997; Falvey and Beavan 2002) succeeded in quantifying the amount of precipitation “spill-over” to the leeward side, tested the impact of GPS-integrated WV observation on model initialization, and verified the role of added precipitation observations to river discharge predictions. Work in the southern Andes south of 40°S by Smith and Evans (2006) used isotope analysis of streamwater and sapwater to determine a drying ratio of about 50%. The total cloud delay time (time for conversion and fallout) was estimated to be about 1700 seconds.

3.2 What makes SHARE unique?

SHARE builds on previous orographic field studies and incorporates several unique elements. By addressing a broad range of scales simultaneously using aircraft and surface-based sensors, we can study the interactions of the multi-scale kinematic and microphysical processes of orographic precipitation and the associated large-scale air mass transformation as integrated components for the first time.

Although significant progress has been made in our understanding of orographic precipitation and microphysics with these recent field studies, much work remains. Each of the mountain ranges where previous studies have been conducted have had their limitations in terms of making future progress in this area. All mountain barriers have fine-scale 3-D structure. The geometry of a particular large-scale barrier geometry can make certain processes easier to study than others. For example, in order to understand the microphysical interaction time scales for growth, a simple barrier geometry is ideal, and the Sierras offer a particularly good large-scale 2-D barrier geometry for the further pursuit of these studies. In contrast, the concave large-scale geometry of the Alps is well suited for study of localized circulations and convergence (Lin et al. 2001; Chiao et al. 2004).

A dynamically wide barrier, such as the Sierras, with a series of windward ridges and valleys is needed to capture the full spectrum of dynamical processes on orographic precipitation, from upstream blocking to gravity waves. The upstream blocking and barrier jet generation over the Cascades and coastal range is not as significant as the Sierras, and the Wasatch is primarily a single ridge and cannot be used to study upstream gravity waves off windward ridges. The Sierras is also higher and wider than the Cascades, which allows the barrier to generate a significant orographic cloud even in the absence of a baroclinic trough (Meyers and Cotton 1992; Colle and Zeng 2004). Therefore, an important question to address for a wide barrier, such as the Sierras, is determining the contribution of the precipitation over the windward slope from baroclinic processes versus upslope flow. Shallow systems are often mostly orographic whereas deep systems usually contain both orographic and baroclinic elements. Separating rainfall contributions by storm morphology (e.g. White et al. 2003) can aid in distinguishing the contributions of baroclinic processes and upslope flow. A wide barrier (~100 km scale), such as the Sierras, also allows time for snow particles over the windward slope to grow and fall out near the crest; therefore, the full time history of microphysical growth can be documented over the Sierras. Finally, the average freezing level over the Sierras during the cool season is around 2 km, about 2/3 up along the windward slope. This allows for a wide spectrum of microphysical processes to be documented, from liquid-phase collision/coalescence at low levels, to cold microphysical growth processes of riming and vapor deposition at higher elevations.

Dropsonde measurements of atmospheric river characteristics over the ocean have been made in past field projects (Ralph et al. 2005a) but have not previously been coupled to the large-scale airmass transformation over land or to time-varying properties of orographic precipitation enhancement.

NCAR S-POL will have a similar role in SHARE as it had in MAP and IMPROVE, namely to document the shear structures and 3-D hydrometeor fields over the windward slope. The Wyoming King Air will focus on documenting precipitation processes and variability within the ice layer using a combination a cloud radar and in situ measurements of cloud and precipitation particles. The University of Wyoming King Air (WKA) flight tracks for collection of in situ microphysics measurements (EDO, Fig. 7.9-1a,b) are similar to those of the Convair-580 during IMPROVE II. The addition of the cloud radar adds an important enhancement relative to IMPROVE II allowing the WKA to measure the small-scale reflectivity and wind variability along the vertical and horizontal planes along which it is flying (EDO, Fig. 7.9-1c).

Although a rich microphysical and surface precipitation data set was gathered in SCPP (Meyers and Cotton 1992; Rauber 1992), limited Doppler wind data was available above the barrier and the information that was available was single Doppler (Marwitz 1987). Several recent studies have shown the feasibility of using the tail Doppler radar from the NOAA P-3 to obtain winds over within complex terrain (Sec. 7.8, Colle and Mass 1996; Bousquet and Smull 2003; Garvert et al. 2005b; Smull et al.

2005). These winds are important to put the microphysics in context with the evolving dynamics over the barrier. As a mobile platform, the P-3 has the advantage of being able to sample winds in otherwise inaccessible areas on the Sierra slope. Dual-Doppler wind information from a pair of Doppler on Wheels (DOW) radars (Sec. 7.12) will provide fine-scale wind information near the mouth of the American River basin and immediately upstream of the Sierras, the latter being particularly important for examining the evolution of the barrier jet. The wind information from the P-3 and the DOWs will be embedded within a coarser-scale wind field derived from operational radars and S-POL (Sec. 7.7). The combination of operational and research radars to derive 3-D wind fields will utilize similar techniques to those employed in MAP (Bougeault et al. 2001; Georgis et al. 2000, 2003), including automatic velocity dealiasing (James and Houze 2001). The operational radars can provide nearly continuous information on the 3-D wind field over the Sierra slope when echo is present. These types of 3-D wind data were not available in the SCPP and provide the opportunity to analyze the joint interaction of the 3-D microphysics and kinematics in orographic precipitation. Aircraft microphysics and radar data are more meaningful when they can be placed within a larger spatial and temporal scale context. Opportunities in recent orographic field projects to compare the observed volumetric microphysics and kinematics field over the duration of the storm have been limited, with Georgis et al. (2003) a notable exception.

Another unique feature of SHARE is the proposed temperature/RH sensor mini-network (EDO, Sec. 7.6.4) to obtain a detailed mapping of the surface temperature, which can be used to make inferences about precipitation type (rain vs. snow) and snow melt in close coordination with other detailed atmospheric measurements. In combination with the stream-depth sensors, these data will help clarify the basin response to small-scale kinematic and precipitation variability.

The proposed multiscale observational network makes SHARE unique compared to previous orographic field programs. For the first time, windward slope small-scale precipitation variability observations will be embedded within large-scale water vapor budget observations. As part of this multi-scale approach, SHARE will feature sampling upstream and downstream of the Sierra crest in addition to observations on the windward slope during the same storm.

4. Synergy with NOAA hydrometeorology and hydrology (see EDO)

5. Regional precipitation and atmospheric river climatology

5.1 Climatology data

The northern California rainfall climatology shown in Fig. 5.1-1 illustrate the frequency of daily rain totals exceeding 0.5 in at 352 Cooperative Observer Program (COOP) stations for December and January. Plots for different thresholds (0.25, 0.75, and 1.0 in) have similar patterns (not shown). The February climatology has a similar pattern but an overall slightly lower frequency of daily rain events exceeding 0.5 in (not shown) as compared to December and January. The data sets were obtained from the archive at the Western Regional Climate Center (www.wrcc.dri.edu/summary/Climsmcca.html and www.wrcc.dri.edu/summary/Climsmnca.html). Most stations began collecting data in the 1940s so the climatology represents up to 60 years

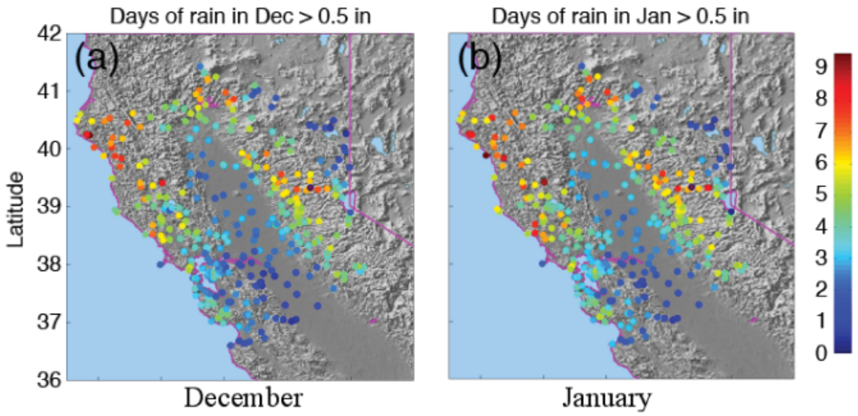

Figure 5.1-1 Average monthly frequency of daily precipitation > 0.5 in/day based on COOP data sets for December and January.

of information with different specific time periods for each station. The monthly days of rain > 0.5 in at each plotted COOP site were averaged for each month over the entire recorded history of each station ending in 2005 (www.wrcc.dri.edu/cgi-bin/sod_xtrmts1x.pl?04). Orographic enhancement of rainfall is evident over both the coastal and Sierra mountains.

Table 5.1. Atmospheric River Days: # of events/ # of days with river intersecting the CA coast / # of days with atmospheric river in the offshore domain.

Year	December	January	February	March	Winter total
1997-1998	5/6/10	10/14/21	10/13/15	5/9/11	30/42/57
1998-1999	4/4/7	7/8/11	9/12/18	5/6/10	24*/30/46
1999-2000	2/3/3	8/10/12	7/10/15	5/6/10	22/29/40
2000-2001	5/7/8	4/4/6	5/7/9	6/8/10	20/26/33
2001-2002	9/16/19	4/8/12	3/5/7	3/3/7	19/32/45
2002-2003	8/11/17	6/11/14	2/3/4	7/9/12	23/34/47
2003-2004	9/12/15	7/9/13	3/5/6	1/1/2	20/27/36
2004-2005	3/3/4	5/5/8	4/5/8	4/6/9	16/19/29
2005-2006	10/13/17	3/5/6	2/3/5	3/5/8	18/26/36
Mean	6.1/8.4/11.1	6.0/8.2/11.4	5.0/7.0/9.9	4.3/5.9/8.8	21.4/29.5/41.0
Minimum	2/3/3	3/4/6	2/3/4	1/1/2	16/19/29
Maximum	10/16/19	10/14/20	10/13/18	7/9/12	30/42/57

*One atmospheric river spanned across two months; hence there is one extra count in the monthly columns.

Climatology information on atmospheric rivers for 1997-2006 is presented in Table 5.1. There is considerable year-to-year and month-to-month variability in the number of atmospheric rivers intersecting the California coast. In an average year, 7-8 atmospheric rivers intersect the California coast per month for December-February. The average number of atmospheric rivers intersecting the California coast drops to 6 in March.

5.2 Optimal time frame for operations

Based on information in Sec. 5.1, Dec. and Jan. are best suited for SHARE operations. Using this climatological information and logistical constraints, we propose SHARE operations for the 50-day period from 3 December – 22 December 2008 (20 days), and 3 January – 1 February 2009 (30 days) with a holiday break between 23 Dec and 2 Jan. The climatologies of precipitation and atmospheric rivers suggest we should plan for 12 Intensive Observation Periods (IOPs) during SHARE. To be successful, SHARE requires observational resources from both NSF and NOAA. The NOAA HMT program is scheduled to transition to the east coast starting winter 2009-2010. A delay of SHARE would jeopardize access to needed NOAA resources.

6. Modeling

6.1 Atmospheric mesoscale modeling

6.1.1 Modeling background

SHARE real-time forecasts in support of field operations and post-project research simulations will utilize both the Fifth Generation Penn State / NCAR Mesoscale Model (MM5, Grell et al. 1994) and Weather Research and Forecasting (WRF) model (Skamarock et al. 2005). WRF is a fully compressible nonhydrostatic model designed for simulation with a horizontal resolution of 1-10 km, which builds upon the strengths of the MM5. As in MM5, WRF includes several different boundary layer, convective, and microphysical parameterizations. Four-dimensional nudging-based data assimilation (Stauffer and Seaman 1990) is now included in the WRF modeling system; therefore, the NCEP analyses used for initialization can be improved via FDDA of surface and upper-air observations.

In order to investigate precipitation processes in SHARE there are several sophisticated bulk microphysical parameterization (BMP) schemes available in WRF, such as the Thompson (Reisner) (Reisner et al. 1998; Thompson et al. 2004), NASA-Goddard scheme (Tao and Simpson 1993), and NCEP mixed-phase schemes, such as WSM-3 (Hong et al. 2004) and Ferrier (Ferrier et al. 2002). For example, the Thompson et al. (2004) BMP is a mixed-phase BMP similar to those found in state-of-the-art cloud-resolving models, with five hydrometeors categories (cloud water, cloud ice, rain, snow, and graupel), as well as predicted number concentrations of cloud ice and snow. The Thompson BMP will be the primary BMP for the microphysical evaluation and process studies as this BMP is currently considered to be the most advanced. Based on previous field project data, the Thompson scheme has recently been updated to include a variable snow density based on temperature, non-spherical ice particle assumptions, and gamma size distributions (G. Thompson 2006, personal communication). In addition, the scheme is being modified to include double moment capabilities. Other double moment schemes are also being implemented into WRF in 2007, such as Morrison et al. (2005) and Lynn et al. (2005).

The MM5 and WRF BMPs have been evaluated during previous orographic field studies, such as IMPROVE (Garvert et al. 2005c) and IPEX (Colle et al. 2005a). These BMPs have also been verified recently with surface precipitation gauges over the central Sierras from the Sierra Cooperative Pilot Project (Grubisic et. al 2005; Colle and Zeng 2004). Grubisic et. al. (2005) found that the most sophisticated scheme in MM5 (Reisner2 or early version of Thompson) could realistically simulate the precipitation distribution at 4.5-km grid spacing, but all schemes produced overprediction over the windward slope and lee of the Sierras. These biases are similar to that obtained for IMPROVE (Garvert et al. 2005c), so SHARE will provide a useful dataset to explore these BMP deficiencies.

6.1.2 SHARE model setup and analysis

It is important to obtain the best mesoscale forecast for operations and research simulations; therefore, both the WRF and MM5 will be run operationally in a 5 member ensemble configuration at 4-km grid spacing centered on the Sierra IOP region to obtain a 48-h forecast during SHARE. A horizontal grid resolution of 4-km has been shown adequate for resolving the Sierra precipitation distribution (Grubisic et al.2005). This ensemble effort will be led by the Colle and Yuter groups using a few Linux cluster computers, in which different initializations and physics will be run for the 0000 and 1200 UTC cycles (Table 6.1). For the planetary boundary layer, the MRF (Hong and Pan 1996), YSU (Hong et al. 2006) and Mellor-Yamada-Janic (Janic 2002) schemes will be run, while the Kain-Fritsch2 (Kain 2004), Grell (Grell 1993), and Betts-Miller (Betts and Miller 1986) will be utilized for the convective schemes in the 36- and 12-km domains. Two short-wave radiation schemes (Eta and Dudhia) and the RRTM long-wave scheme will be applied (Lacis and Hansen 1974; Dudhia 1989; Mlawer et al. 1989). The ensemble forecasts will be displayed on a centralized web page for both field operations and preliminary research runs, and will be available for input into hydrological applications.

Since the model predictions over the Pacific can include large initial condition uncertainty, an important first step for the research simulations is to determine those operational 4-km ensemble MM5 and WRF members that yielded the best forecast of wind, moisture, and stability upstream (west) of the Sierras using the observed soundings. Some members will be rerun using the 6-h Global Forecast System (GFS) model analyses and field observations in the MM5 and WRF four dimensional data assimilation package, which helped many IMPROVE simulations (Garvert et al. 2005). Specifically, the upstream moisture analysis will be improved dramatically with the curtain of dropsondes over the Pacific. After confidence is gained in the best ensemble member, the orographic process studies can be completed and the microphysical aspects of the simulations can be evaluated. For the microphysical validation, simulated reflectivity fields will be calculated and checked against radar-observed reflectivities, and model precipitation fields will be compared with surface precipitation measurements. Predicted mixing ratios and particle number concentrations for each hydrometeor type will be verified by aircraft measurements, and the assumed particle size distributions will be tested. Over a larger volume of precipitating cloud, dominant hydrometer types will be derived from S-Pol polarimetric radar data.

After the WRF model simulations have been compared to observations, and key discrepancies in the simulated microphysical fields have been identified, sensitivity tests will be performed on various assumptions and components of the BMP to improve the simulated microphysics. IMPROVE airborne in situ data of snow size distributions found that the slope intercept was dependent on temperature and associated ice crystal type (Woods 2005). As a result, the Thompson scheme has been rewritten to include some habit dependency for the snow intercepts, ice density, and mass-diameter relationships. Recent field data has also found that the snow size distribution may not always follow an exponential

Table 6.1 Ensemble members run at 36-, 12- and 4-km grid spacing for SHARE.

Ensemble Members ICs/ BCs-Model	PBL	Microphysics	Convective Parameterization (36 and 12-km)	Radiation
GFS-WRF	YSU	Thompson	Kain-Fritsch2	Dudhia-RRTM
NAM-WRF	MYJ	WSM-3	Grell	Eta-RRTM
NOGAPS-WRF	MYJ	Thompson-double-moment	Betts-Miller-Janic	Dudhia-RRTM
CMC-WRF	YSU	Ferrier	Kain-Fritsch2	Eta-RRTM
GFS-MM5	MRF	Reisner1	Kain-Fristch2	Dudhia-RRTM

curve as given in most BMPs (Colle et al. 2005, Yuter et al. 2006). SHARE will collect additional data on snow size distributions aloft using aircraft probes and at the surface using disdrometers in order increase the sample size and range of conditions upon which the relationships in the Thompson scheme are based. SHARE will also test the newly implemented gamma size distribution in the Thompson scheme for storms in the Sierras. Recent simulations for IMPROVE cases with these changes have shown reduction in some of the snow overprediction problems aloft (G. Thompson, personal communication 2006). SHARE will also help quantify the impact of using double moment BMPs within WRF.

A climatology of the 3D precipitation structures and microphysical processes over the terrain from WRF will be compared to in situ aircraft and radar data. This will help determine the relationship between the southerly barrier jet, gravity waves over the transverse west-east ridges and crest, and the precipitation production over the barrier. As in Garvert et al. (2007), additional model simulations will be completed without the windward ridges (smooth topography) in order to document the local impact of the ridges, while a water-ice budget around a particular windward ridge or the full barrier, as in Colle and Zeng (2004), will help quantify the microphysical impacts of the terrain. The model climatology of precipitation forecasts will also reveal environmental conditions and locations of persistent over- and under-predictions. SHARE will relate the precipitation errors for particular IOPs, as verified using the surface, aircraft, and radar observations, to the microphysical processes aloft by using spatial composites of microphysical processes and backward trajectories starting at the location of the error. The trajectory will be calculated to determine the microphysical processes aloft following the movement/fallout of hydrometeor mixing ratio within the BMP. For example, a trajectory can be started at the surface in the lee and integrated backwards in time and space using model data saved at 10 minute intervals and time-interpolated to 2 minutes. Below the freezing level the trajectory uses the fall speed of rain if no snow or graupel is present, and a mass-weighted fall speed when there is mixed-phase precipitation below the freezing level.

SHARE IOP and storm-total composites of the model spatial precipitation structures above the Sierra will also be compared with ground-based radar. In particular, the frequency and intensity of precipitation rate will be compared between the model and radar cross sections across the barrier. The longer-term IOP verification will help place the specific case study verification results in the context of the overall model biases in precipitation across the barrier during the SHARE experiment.

6.2 Quasi-analytic atmospheric modeling

In addition to the full numerical mesoscale models (MM5 and WRF), quasi-analytical models can be used to test hypotheses and determine bulk properties of an orographic precipitation system. A good example is the linear downscaling model (LDM) of Smith and Barstad (2004). This model uses observed or predicted water vapor fluxes, along with the fine-scale terrain distribution, to predict the spatial distribution of precipitation and the total drying ratio. By optimizing the “cloud time delays” in the model against data, the average cloud properties can be deduced. The LDM has been tested in the Alps, Wasatch, and California coastal ranges (Barstad and Smith 2005), in Oregon (Smith et al. 2005, Smith 2006), and in the southern Andes (Smith and Evans 2007).

6.3 Hydrological Modeling

Temperature, precipitation, and wind fields will be used to run a full energy-balance snow model over the basin (the snow component of the Distributed Hydrologic-Soil Vegetation Model, DHSVM, Wigmosta et al. 1994), and model results will be compared with measurements. Data deprivation studies will be conducted to determine which locations and parameters are most crucial to monitor and which can be estimated. The modeled flux will be compared with measured flux to determine how well the bulk parameterization scheme works in storms in complex terrain.

7. Experimental design and observation systems

7.1 Overview and mapping of objectives to facilities

The geographic layout of planned SHARE facilities is presented in Figs. 7.1-1 and 7.1-2 (next page). Figure 7.1-1 shows the instrumentation within the large-scale surface network that extends from the northern California coast eastward into Nevada. Figure 7.1-2 shows the details of the small-scale surface network embedded within the large-scale network. The small-scale network is centered on the American River basin and extends from the Sacramento Valley to just east of the Sierra crest. The proposed aircraft tracks for the NCAR HIAPER, NOAA P-3, and University of Wyoming King Air are shown in Secs. 7.2, 7.8, and 7.9 in the EDO. The mapping of observation facilities (EDO, Secs. 7.2-7.15) to the SHARE scientific objectives (Secs. 2 and 4) is shown in Table 7.1 (in the EDO). Table 7.1 also groups the instrumentation by their mode of temporal sampling and primary spatial scale.

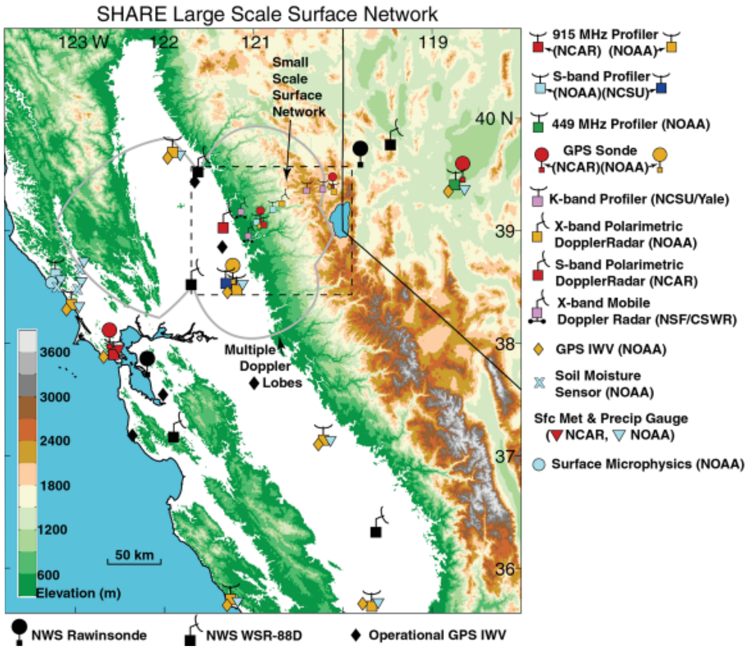

Figure 7.1-1 Map of northern California showing planned observation facilities for SHARE. The small-scale surface network is shown in more detail in Fig. 7.1-2.

SHARE will use a combination of passive microwave satellite data, aircraft dropsondes, upper-air soundings and Global Positioning System (GPS) integrated water vapor (IWV) sensors to characterize the horizontal and vertical distribution of the moisture flux associated with atmospheric rivers crossing over the California coast and the subsequent modification of the air mass as it moves inland and over the Sierra Mountains. The satellite passive microwave and GPS IWV provide vertically integrated estimates of water vapor over ocean and land respectively. The vertically integrated information is helpful but by itself insufficient to address our scientific objectives. In situ sampling is required to obtain the needed vertical distribution of water vapor. Dropsondes from the NCAR HIAPER will be used over ocean and remote land areas while upsondes will be used within inhabited areas.

Existing operational weather resources in northern California (shown in black in Figs. 7.1-1 and 7.1-2) will be augmented by NOAA and NSF facilities for SHARE. Utilization of the operational WSR-88D radars at Davis and Beale augmented by the S-POL radar will permit over-determined dual-Doppler retrieval (Sec. 7.7) of the horizontal wind field over the central portion (3-lobed gray outline in Fig. 7.1-1) of the large-scale SHARE network. Wind profilers along the coast, within the central valley and along the windward slope will provide detailed information on the vertical structure of the wind (Sec. 7.5). The combination of these assets will provide unprecedented documentation of the 3-D wind field as frontal systems move onshore and interact with the barrier jet. A S-band profiler at the coast provides measurements of the precipitation structure upstream of the Sierra. These are needed to help distinguish between variability among frontal precipitation structures and orographic modification by the Sierra.

SHARE will utilize a suite of observations to characterize the 3-D precipitation and kinematic fields over the Sierra slope centered on the area of the American River basin. Aircraft have the ability to sample otherwise inaccessible areas over the mountainous slope while ground-based assets can monitor selected areas more continuously. NOAA P-3 Doppler radar will characterize the 3-D wind field from echo top to near the surface along the Sierra slope (EDO, Sec. 7.8). The Wyoming King Air radar will make detailed measurements of the vertical and horizontal variability of precipitation above the melting layer and will obtain in situ microphysics through the depth of the storm to cloud edge (EDO, Sec. 7.9). The primary focus of NOAA X-POL is to map near-surface precipitation (EDO, Sec. 7.10). The primary focus of NCAR S-POL is to observe a high spatial and time resolution 60° sector of shear and 3-D hydrometeor types over the slope and to serve as part of over-determined dual Doppler network (EDO, Sec. 7.11). The pair of DOWs will make high spatial resolution dual-Doppler wind measurements within lobes extending about 50-km range SW-NE from the two radar sites (EDO, Sec. 7.12). S-band profilers along the windward slope will provide detailed information on reflectivity and vertical air velocity characteristics within orographically enhanced precipitation (EDO, Sec. 7.13.1) while the Ku-band profilers serve a similar function in the weaker precipitation near the crest and on the lee (EDO, Sec. 7.13.2). Barrier parallel transects of precipitation measurements (EDO, Sec. 7.6.3) complement other surface precipitation measurements within the small-scale network.

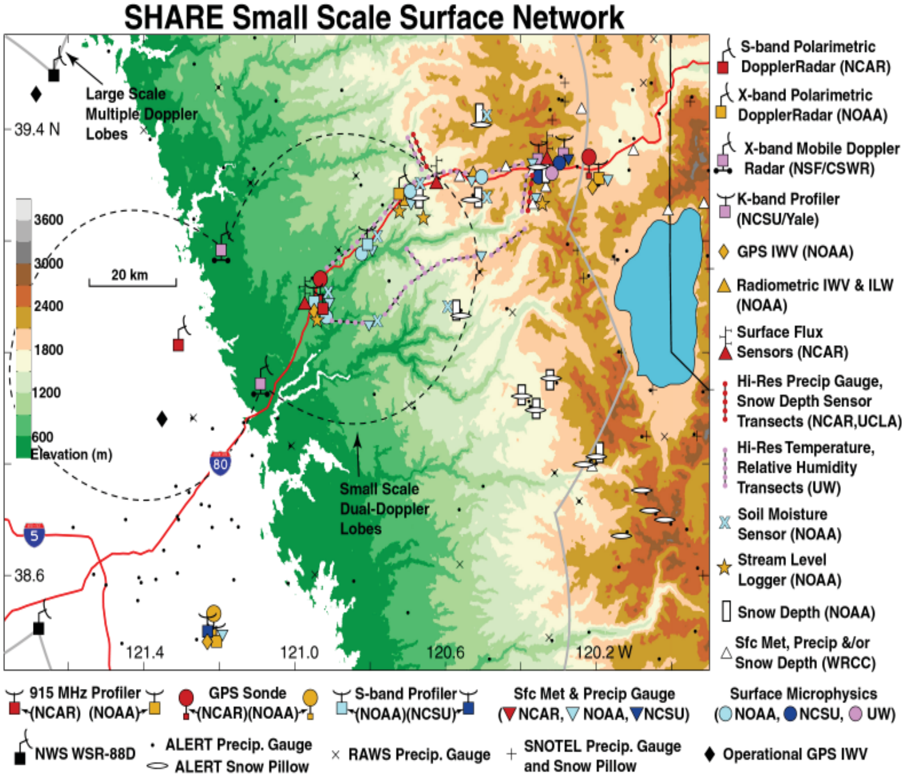

Figure 7.1-2 Small-scale surface network of observation facilities centered on the American River Basin.

7.2–7.13 Experimental design of specific observing systems (see EDO)

7.14 A typical IOP (see EDO)

8. Project and data management

The SHARE Science Steering Committee (SSC) has requested the NCAR Earth Observing Laboratory (EOL) to provide specific assistance in areas related to project planning, field operations support and data management. Detailed descriptions of these issues can be found in section 8 of the EDO.

9. Education plan

9.1 University student training in preparation for field activities

Target audience: graduate/undergraduate students **Timing:** Prior to and during field phase: An organized approach will be a more efficient means of educating field participants on the scientific motivations and goals of SHARE. Small group hands-on training will still be required for specific instrument operations such as upper-air sounding launches. Content would have two main parts. 1)

Orographic precipitation overview for the Sierra Nevada range, including mechanisms for upward motion, microphysics, orographic impact on 3-D wind structures, etc. Background information on research questions that will be investigated during SHARE. 2) Instrumentation overview, including principles of operation and interpretation.

9.2 Development of online case studies of field data

Target audience: university researchers, graduate students, and NWS Science Operations Officers **Timing:** After field phase: Overview of synoptic/mesoscale aspects of cases, data available, and applications to goals of SHARE. Unidata is a potential collaborator in terms of online access. An example of an online case study that uses observational data extensively to demonstrate how forecasters deal with winter phenomena is COMET's "Blowing Snow, Baker Lake, Nunavut, Canada, 4-10 Feb 2003" (www.meted.ucar.edu/norlat/snow/blowingsnow_case).

9.3 Web-based training modules on orographic precipitation

Target audience: University students **Timing:** After field phase: Emphasis on the research output of SHARE efforts after the project. These modules would deal with SHARE key questions. An example of this type of approach of using extensive observational data in a training module context can be found in COMET's "Mountain Waves and Downslope Winds" (www.meted.ucar.edu/mesoprim/mtnwave/index.htm). COMET has many other examples at their meted.ucar.edu site.

9.4 K-12 outreach

Target audience: K-12 students **Timing:** During field phase: Presentations about SHARE science at local schools by PIs and graduate students. Emphasis on a few simple themes from SHARE of general interest to students living in northern California. Potential topics include: what happens to moist air when it goes up over a mountain and down the other side, how weather radars can see inside a storm, and why some storms cause floods.

10. Results from prior NSF support

David Kingsmill: PI on ATM-9901688 and ATM-0432951 ("Studies of Convection Initiation and Evolution"). The two primary objectives of this project were to (1) determine the kinematic, dynamic, and thermodynamic fields associated with the development of horizontal shearing instabilities along boundary-layer convergence zones (boundaries) and the role of these instabilities in convection initiation and (2) characterize the kinematic, dynamic, and thermodynamic structures associated with boundary collisions and the effect they have on convection initiation and evolution. These objectives were addressed through analysis of observations from the 1991 CaPE experiment and the 2002 IHOP experiment. Analyses focused on examination of bore formation from colliding boundaries and quantifying the characteristics of mesocyclones along gust fronts, cold fronts, and drylines. Publications from this work are listed in the PI biography.

Sandra Yuter: PI on ATM-0121963 ("Scales and Characteristics of Convective Processes in Orographic Precipitation"). Analysis of vertically pointing S-band radar and disdrometer datasets to improve understanding of the details of precipitation growth in orographic precipitation and the characteristics of coexisting rain, snow, and wet snow within the melting layer. ATM-0544766 ("Average and Variability Characteristics of Orographic Precipitation at Multiple Scales"). Analysis of all storms occuring over several winter seasons in Portland, OR area using volumetric NWS operational radar data and regional forecast model ouput provided by collaborating PI B. Colle. Findings to date indicate that independent of any microphysical parameterization errors that there are errors in the model's 3D kinematic representation of the storms. These kinematic errors manifest in various ways in the resulting modeling precipitation fields. This work will extend and refine results from previous orographic field programs based on case studies. Publications from these projects are listed in the PI biography.

References cited

Anders, A. M, G. H. Roe, and D. R. Durran, 2004: Conference notebook: Orographic precipitation and the form of mountain ranges. *Bull. Amer. Meteor. Soc.*, **85**, 498-499.

Barstad, I. and R. B. Smith, 2005: Evaluation of an orographic precipitation model. *J. Hydrometeorology,* **6**, 85–99.

Betts, A. K., and M. J. Miller, 1986: A new convective adjustment scheme. Part I: Observational and theoretical basis. *Quart. J. Roy. Meteor. Soc.*, **112**, 677-692.

Bond, N. A., C. F. Mass, B. F. Smull, R. A. Houze, Jr., M.-J. Yang, B. A. Colle, S. A. Braun, M. A. Shapiro, B. R. Colman, P. J. Neiman, J. E. Overland, W. D. Neff, and J. D. Doyle, 1997: The Coastal Observation And Simulation with Topography (COAST) experiment. *Bull. Amer. Meteor. Soc.*, **78**, 1941-1955.

Bougeault, P., P. Binder, A. Buzzi, R. Dirks, R. A. Houze Jr., J. Kuettner, R. B. Smith, R. Steinacker, and H. Volkert, 2001: The MAP Special Observing Period. *Bull. Amer. Meteor.Soc.*, **82**, 433-462.

Bousquet, O., and B. F. Smull, 2003: Airflow and precipitation fields within deep Alpine valleys observed by airborne Doppler radar. *J.Appl. Meteor.*, **42**, 1497-1513.

Braun, S. A., R. Rotunno, and J. Klemp, 1999: Effects of coastal orography on landfalling cold fronts. Part I: Dry, inviscid dynamics. *J. Atmos. Sci.*, **56**, 517–533.

Braun, S. A., R. A. Houze, Jr., and B. F. Smull, 1997: Airborne dual-Doppler observations of an intense frontal system approaching the Pacific northwest coast. *Mon. Wea. Rev.*, **125**, 3131-3156.

Browning, K. A., 1990: Organization of clouds and precipitation in extratropical cyclones. *Extratropical Cyclones: The Erik Palmen Memorial Volume*, C. W. Newton and E. Holopainen, Eds., Amer. Meteor. Soc., 129-153.

Bruintjes, R. T., T. L. Clark, and W. D. Hall 1994: Interactions between topographic airflow and cloud precipitation development during the passage of a winter strom in Arizona. *J. Atmos. Sci.*, **51**, 48-67.

Buzzi, A., N. Tartaglione, and P. Malguzzi, 1998: Numerical simulations of the 1994 Piedmont flood: Role of opography and moist processes. *Mon. Wea. Rev.*, **126**, 2369-2383.

Carlson, T. N., 1980: Airflow through midlatitude cyclones and the comma cloud pattern. *Mon. Wea. Rev.*, **108**, 1498–1509.

Chen, S.-H., and Y.-L. Lin, 2005: Effects of the basic wind speed and CAPE on flow regimes associated with a conditionally unstable flow over a mesoscale mountain. *J. Atmos. Sci.*, **62**, 331-350.

Chiao, S., Y.-L. Lin, and M. L. Kaplan, 2004: Numerical study of the orographic forcing of heavy precipitation during MAP IOP-2b. *Mon. Wea. Rev.*, **132**, 2184-2203.

Chu, C.-M., and Y.-L. Lin, 2000: Effects of orography on the generation and propagation of mesoscale convective systems in a two-dimensional conditionally unstable flow. *J. Atmos. Sci.*, **57**, 3817-3837.

Colle, B. A., and C. F. Mass, 1996: An observational and modeling study of the interaction of low-level southwesterly flow with the Olympic Mountains during COAST IOP 4. *Mon. Wea. Rev.*, **124**, 2152-2175.

Colle, B. A., and C. F. Mass, 2000: The 5-9 February 1996 flooding event over the Pacific Northwest: Sensitivity studies and evaluation of the MM5 precipitation forecasts. *Mon. Wea. Rev.*, **128**, 593-617.

Colle, B. A., B. F. Smull, and M.-J. Yang, 2002: Numerical simulations of a landfalling cold front observed during COAST: Rapid evolution and responsible mechanisms. *Mon. Wea. Rev.*, **130**, 1945-1966.

Colle, B. A., C. F. Mass, and B. F. Smull, 1999: An observational and numerical study of a cold front interacting with the Olympic Mountains during COAST IOP5. *Mon. Wea. Rev.*, **127**, 1310-1334.

Colle, B. A., and Y. Zeng, 2004: Bulk microphysical sensitivities within the MM5 for orographic precipitation: Part I, the Sierra 1986 event. *Mon. Wea. Rev.*, **132**, 2780-2801.

Colle, B. A., 2004: Sensitivity of orographic precipitation to changing ambient conditions and terrain geometries: An idealized modeling perspective. *J. Atmos. Sci.*, **61**, 588-606.

Colle, B. A., J. B., Wolfe, W. J. Steenburgh, D. E. Kingsmill, J. A. Cox., and J. C. Shafer, 2005a: High resolution simulations and microphysical validation of an orographic precipitation event over the Wasatch Mountains during IPEX IOP3. *Mon. Wea. Rev.*, **133**, 2947-2971.

Colle, B. A., M. Garvert, J. Wolfe, and C. F. Mass, 2005b: The 13-14 December IMPROVE event: Part III: Microphysical budgets and sensitivities for the 13-14 December IMPROVE event. *J. Atmos. Sci.*, **62**, 3535-3558.

Cox, J. A., W. J. Steenburgh, D. E. Kingsmill, J. C. Shafer, B. A. Colle, O. Bousquet, B. F. Smull, and H. Cai, 2005: The kinematic structure of a Wasatch Mountain winterstorm during IPEX IOP3. *Mon. Wea. Rev.*, **133**, 521-542.

Dettinger, M. D., Cayan, D. R., Meyer, M. K., and Jeton, A. E., 2004. Simulated Hydrologic Responses to Climate Variations and Change in the Merced, Carson, and American River Basins, Sierra Nevada, California, 1900–2099. *Clim. Change*, **62**, 283–317.

Doswell, C. A., C. Ramis, R. Romero, and S. Alonso, 1998: A diagnostic study of three heavy precipitation episodes in the western Mediterranean region. *Wea. and Forecasting*, **13**, 102-124.

Doyle, J. and R. B. Smith, 2003: Mountain waves over the Hohe Tauern: Influence of upstream diabatic effects. *Q. J. Roy. Meteor. Soc.*, **129**, 799-823.

Dudhia, J., 1989: Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model. *J. Atmos. Sci.*, **46**, 3077-3107.

Falvey, M., and J. Beavan. 2002: The impact of GPS precipitable water assimilation on mesoscale model retrievals of orographic rainfall during SALPEX'96*. *Mon. Wea. Rev.*, **130**, 2874–2888.

Ferrier, B., Y. Jin, Y. Lin, T. Black, E. Rogers, and G. DiMego, 2002: Implementation of a new grid-scale cloud and rainfall scheme in the NCEP Eta model. *Preprints, 13th NWP, AMS*, 280-283.

Galewsky, J., and A. Sobel, 2005: Moist dynamics and orographic precipitation in northern and central California during the New Year's flood of 1997. Mon. Wea. Rev., 133, 1594–1612.

Garvert, M. F., B. A. Colle, and C. F. Mass, 2005a: The 13–14 December 2001 IMPROVE-2 event. Part I: Synoptic and mesoscale evolution and comparison with a mesoscale model simulation. *J. Atmos. Sci.*, **62**, 3474–3492.

Garvert, M. F., B. F. Smull, and C. F. Mass, 2005b: Mountain wave structures occurring within a major orographic precipitation event. Part I: Evaluation of mesoscale model simulations. Paper J8J.6, Proceedings, *Joint 11th Conf. on Meso. Processes* and *32nd Conf. on Radar Meteor.*, Albuquerque, Amer. Meteor. Soc., 7 pp.

Garvert, M. F., C. Woods, B. A. Colle, M. Stoelinga, P. V. Hobbs, and C. F. Mass, 2005c: The 13-14 December IMPROVE event: Part II, Evaluation of the cloud and precipitation structures in the MM5. *J. Atmos. Sci.*, **62**, 3520-3534.

Garvert, M., B. F. Smull, and C.F. Mass, 2007: Multiscale mountain waves influencing a major orographic precipitation event. *J. Atmos. Sci.*, in press.

Georgis, J.-F., F. Roux, and P. H. Hildebrand, 2000: Observation of precipitating systems over complex orography with meteorological Doppler radars: A feasibility study. *Meteor. Atmos. Phys.*, **72**, 185-202.

Georgis, J. F., F. Roux, M. Chong, and S. Pradier, 2003: Triple Doppler radar analysis of the heavy rain event observed in the Lago Maggiore region during MAP IOP 2b. *Quart. J. Roy. Meteor. Soc.*, **129**, 495–522.

Grell, G. A., 1993: Prognostic evaluation of assumptions used by cumulus parameterizations. *Mon. Wea. Rev.*, **121**, 764-787.

Grell, G. A., J. Dudhia, and D. R. Stauffer, 1994: A description of the fifth-generation Penn State/ NCAR mesoscale model (MM5). NCAR Tech. Note TN-398+STR, 122 pp. [Available from UCAR Communications, P.O. Box 3000, Boulder, CO 80307.]

Grossman, R. L., and D. R. Durran, 1984: Interaction of low-level flow with the Western Ghats Mountains and offshore convection in the summer monsoon. *Mon. Wea. Rev.*, **112**, 652-672

Grubišic, V., R. Vellore, and A. Huggins, 2005: Quantitative precipitation forecasting of wintertime storms in the Sierra Nevada: Sensitivity to the microphysical parameterization and horizontal resolution. *Mon. Wea. Rev.*, **133**, 2834-2859.

Guirguis, K. J., and R. Avissar, 2007: The precipitation climatology of the western United States. Part I. Raingauge and satellite data analysis. *J. Hydrometeor*. submitted.

Heggli, M. F., and R. M. Rauber, 1988: The characteristics and evolution of supercooled water in wintertime storms over the Sierra Nevada: A summary of microwave radiometric measurements taken during the Sierra Cooperative Pilot Project. *J. Appl. Meteor*., **27**, 989-1015.

Hobbs, P. V., R. C. Easter, and A. B. Fraser, 1973: A theoretical study of the flow of air and fallout of solid precipitation over mountainous terrain: Part II. Microphysics. *J. Atmos. Sci*., **30**, 813–823.

Hobbs, P. V., 1975: The nature of winter clouds and precipitation in the Cascade Mountains and their modification by artificial seeding. Part I: natural conditions. *J. Appl. Meteor*., **14**, 783-804.

Hong, S.-Y., and H.-L. Pan, 1996: Nonlocal boundary layer vertical diffusion in a medium-range forecast model. *Mon. Wea. Rev*., **124**, 2322-2339.

Hong, S-Y., J. Dudhia, and S-H. Chen, 2004: A revised approach to ice microphysical processes for the bulk parameterization of clouds and precipitation., *Mon. Wea. Rev.*, **132**, 103-120.

Houze, R. A., Jr., P. V. Hobbs, P. H. Herzegh, and D. B. Parsons. 1979: Size distributions of precipitation particles in frontal clouds. *J. Atmos. Sci*, **36**, 156–162.

Houze, R. A., Jr., C. N. James, and S. Medina, 2001: Radar observations of precipitation and airflow on the Mediterranean side of the Alps: Autumn 1998 and 1999. *Quart. J. Roy. Meteor. Soc*., **127**, 2537-2558.

Houze, R. A. Jr., and S. Medina, 2005: Turbulence as a mechanism for orographic precipitation enhancement. *J. Atmos. Sci*., **62**, 3599-3623.

Janic, Z. I., 2002: Nonsingular Implementation of the Mellor-Yamada Level 2.5 Scheme in the NCEP Meso model. NCEP Office Note No. 437, 61 pp.

James, C. N., and R. A. Houze, Jr., 2001: A real-time four-dimensional Doppler dealiasing scheme. *J. Atmos. Oceanic Technol*., **18**, 1674-1683.

James, C. N., and R. A. Houze, Jr., 2005: Modification of precipitation by coastal orography in storms crossing northern California. *Mon. Wea. Rev.*, **133**, 3110–3131.

Jeton, A. E., M. D. Dettinger, and J. L. Smith, 1996: Potential effects of climate change on streamflow, eastern and western slopes of the Sierra Nevada, California and Nevada. USGS Water-Resources Investigations Report 95-4260, 44 pp.

Kain, J. S., 2004: The Kain–Fritsch convective parameterization: An update. *J. Appl. Met*., **43**, 170–181.

Kirshbaum, D. J., and D. R. Durran, 2005: Atmospheric factors governing banded orographic convection. *J. Atmos. Sci*., **62**, 1463-1479.

Lacis, A. A., and J. E. Hansen, 1974: A parameterization for the absorption of solar radiation in the earth’s atmosphere. **J. Atmos. Sci**., **31**, 118-133.

Lackmann, G. M., and J. R. Gyakum, 1999: Heavy cold season precipitation in the Northwestern United States: Synoptic climatology and an analysis of the flood of 17-18 January 1986. *Wea. Forecasting* , **14**, 687-700.

Lin, Y.-L., S. Chiao, T.-A. Wang, M. L. Kaplan, and R. Weglarz, 2001: Some common ingredients for heavy orographic rainfall. *Wea. Forecasting*, **16**, 633-660.

Lynn, B. H., A. P. Khain, J. Dudhia, D. Rosenfeld, A. Pokrovsky, and A. Seifert, 2005: Spectral (Bin) microphysics coupled with a mesoscale model (MM5): Part 1: Model description and first results. *Mon. Wea. Rev*., **133**, 44-58.

Marks, D., J. Kimball, D. Tingey, and T. Link, 1998. The sensitivity of snowmelt processes to climate conditions and forest cover during rain-on-snow: a case study of the 1996 Pacific Northwest flood. *Hydrol. Process*. **12**, 1569-1587.

Marwitz, J. D., 1983: The kinematics of orographic airflow during Sierra storms. *J. Atmos. Sci*., **40**, 1218-1227.

Marwitz, J. D., 1986: A comparison of winter orographic storms over the San Juan Mountains and the

Sierra Nevada. *Precipitation Enhancement – A Scientific Challenge*. Meteorological Monographs, No. 43, Amer. Meteor. Soc., 109-113.

Marwitz, J. D., 1987: Deep orographic storms over the Sierra Nevada. Part I: Thermodynamic and kinematic structure. *J. Atmos. Sci.*, **44**, 159-173.

Medina, S., and R. A. Houze, Jr., 2003: Air motions and precipitation growth in Alpine storms. *Quart. J. Roy. Meteor. Soc.*, special MAP issue, **129**, 345-371.

Medina, S., B. F. Smull, R. A. Houze Jr. and M. Steiner. 2005: Cross-barrier flow during orographic precipitation events: Results from MAP and IMPROVE. *J. Atmos. Sci.*, **62**, 3580–3598.

Meyers, M. P., and W. R. Cotton, 1992: Evaluation of the potential for wintertime quantitative precipitation forecasting over mountainous terrain with an explicit cloud model. Part I: Two-dimensional sensitivity experiments. *J. Appl. Meteor.*, **31**, 26–50.

Mlawer, E. J., S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A. Clough, 1997: Radiative trans-fer for inhomogeneous atmosphere: RRTM, a validated correlated-k model for the long-wave. *J. Geophys. Res.*, **102**(D14), 16663-16682.

Monin, A. S., and A. M. Obukhov, 1954: Basic laws of turbulent mixing in the atmosphere near the ground. *Tr. Akad. Nauk SSSR Gofiz. Inst.*, 24, 163-187.

Morrison, H., J. A. Curry, and V. I. Khvorostyanov, 2005: A new double-moment microphysics parameterization for the application of cloud and climate models, Part I: Description. *J. Atmos. Sci.*, **62**, 1678-1693.

Neiman, P. J., F. M. Ralph, A. B. White, D. E. Kingsmill, and P. O. G. Persson, 2002: The statistical relationship between upslope flow and rainfall in California's coastal mountains: Observations during CALJET. *Mon. Wea. Rev.*, **130**, 1468-1492.

Neiman, P. J., P. O. G. Persson, F. M. Ralph, D. P. Jorgensen, A. B. White, and D. E. Kingsmill, 2004: Modification of fronts and precipitation by coastal blocking during an intense landfalling winter storm in Southern California: Observations during CALJET. *Mon. Wea. Rev.*, **132**, 242-273.

Neiman, P. J., G. A. Wick, F. M. Ralph, B. E. Martner, A. B. White, and D. E. Kingsmill, 2005: Wintertime nonbrightband rain in California and Oregon during CALJET and PACJET: Geographic, interannual, and synoptic variability. *Mon. Wea. Rev.*, **133**, 1199-1223.

Neiman, P. J., F. M. Ralph, A.B. White, D. D. Parrish, J. S. Holloway, and D. L. Bartels, 2006: A multiwinter analysis of channeled flow through a prominent gap along the northern California Coast during CALJET and PACJET. *Mon. Wea. Rev.*, **134**, 1815-1841.

Neiman, P. J., F. M. Ralph, G. A. Wick, J. D. Lundquist, and M. D. Dettinger, 2007: Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the west coast of North America based on eight years of SSM/I satellite observations. *J. Hydrometeorology*, submitted.

Parish, T. R., 1982: Barrier winds along the Sierra Nevada mountains. *J. Appl. Meteor.*, **21**, 925–930.

Ralph, F. M., P. J. Neiman and T. L. Keller, 1999: Deep-tropospheric gravity waves created by leeside cold fronts. *J. Atmos. Sci.*, **56**, 2986–3009.

Ralph, F. M., and Coauthors, 1999: The California Land-Falling Jets Experiment (CALJET): Objectives and design of a coastal atmosphere-ocean observing system deployed during a strong El Nino. Preprints, *Third Symp. on Integrated Observing Systems*, Dallas, TX, Amer. Meteor. Soc., 78-81.

Ralph, F. M., P. Neiman, J., D. Kingsmill, O. Persson, A. White, E. Strem, E. Andrews, and R. Antweiler, 2003: The impact of a prominent rain shadow on flooding in California's Santa Cruz Mountains: A CALJET case study and sensitivity to the ENSO cycle. *J. Hydrometeor*, **4**, 1243-1264.

Ralph, F. M., P. J. Neiman, and G. A. Wick, 2004: Satellite and CALJET aircraft observations of atmospheric rivers over the eastern North Pacific Ocean during the winter of 1997/98. *Mon. Wea. Rev.*, **132**, 1721-1745.

Ralph, F. M., R. M. Rauber, B. F. Jewett, D. E. Kingsmill, P. Pisano, P. Pugner, R. M. Rasmussen, D. W. Reynolds, T. W. Schlatter, R. E. Stewart, S. Tracton and J. S. Waldstreicher, 2005b: Improving short-term (0–48 h) cool-season quantitative precipitation forecasting: Recommendations from a USWRP Workshop. *Bull. Amer. Meteor. Soc.*, **86**, 1619–1632.

Ralph, F. M., P. J. Neiman, and R. Rotunno, 2005a: Dropsonde observations in low-level jets over the northeastern Pacific Ocean from CALJET-1998 and PACJET-2001: Mean vertical profile and atmospheric-river characteristics. *Mon. Wea. Rev.*, **133**, 889-910.

Rauber, R.M., 1992: Microphysical structure and evolution of a Sierra Nevada shallow orographic cloud system. *J. Appl. Meteor.*, **31**, 3-24.

Reinking, R. F., J. B. Snider, and J. L. Coen, 2000: Influences of storm-embedded orographic gravity waves on cloud liquid water and precipitation. *J. Appl. Meteor.*, **39**, 733-759.

Reisner, J., R. M. Rasmussen, and R. T. Bruintjes, 1998: Explicit forecasting of supercooled liquid water in winter storms using the MM5 mesoscale model. *Quart. J. Roy. Meteor. Soc.*, **124**, 1071-1107.

Reynolds, D. W., and A. S. Dennis, 1986: A review of the Sierra Cooperative Pilot Project. *Bull. Amer. Meteor.Soc.*, **67**, 513-523.

Rotunno, R., and R. Ferretti, 2001: Mechanisms of intense Alpine rainfall. *J. Atmos. Sci.*, **58**, 1732–1749.

Rotunno, R., and R. Ferretti, 2003: Orographic effects on rainfall in MAP cases IOP 2B and IOP 8. *Quart. J. Roy. Meteor. Soc.*, **129**, 373-390.

Rotunno, R., and R. A. Houze, Jr., 2007: Lessons on orographic precipitation from the Mesoscale Alpine Programme, *Q. J Roy. Meteor. Soc.*, **133**, in press.

Schultz, D. M., W. J. Steenburgh, R. J. Trapp, J. Horel, D. E. Kingsmill, L. B. Dunn, W. D. Rust, L. Cheng, A. Bansemer, J. Cox, J. Daugherty, D. P. Jorgensen, J. Meitin, L. Showell, B. F. Smull, K. Tarp, and M. Trainor, 2002: Understanding Utah winter storms: The Intermountain Precipitation Experiment. *Bull. Amer. Meteor. Soc.*, **83**, 189-210.

Shafer, J. C., W. J. Steenburgh, J. A. Cox and J. P. Monteverdi, 2005: Terrain influences on synoptic storm structure and mesoscale precipitation distribution during IPEX IOP3. *Mon. Wea. Rev.*, in press

Shamir, E., T. M. Carpenter, P. Fickenscher, and K. P. Georgakakos, 2006. Evaluation of the National Weather Service Operational Hydrologic Model and Forecasts for the American River Basin. J. Hydrologic Engrg., 11, 392-407.

Sinclair, M. R., D. S. Wratt, R. D. Henderson, and W. R. Gray, 1997: Factors affecting the distribution and spillover of precipitation in the Southern Alps of New Zealand: A case study. *J. Appl. Meteor.*, **36**, 428-442.

Skamarock, W. C., and Coauthors: 2005: *A Description of the Advanced Research WRF*. Version 2 [www.wrf-model.org/wrfadmin/publications.php].

Smith, R. B., 1979: The influence of mountains on the atmosphere. *Adv. Geophys.*, **21**, 87-230.

Smith, R. B., 2006: Progress on the theory of orographic precipitation, in S. D. Willett, N. Hovius, M. T. Brandon, and D. M. Fisher eds., Tectonics, Climate and Landscape Evolution: Geological Society of America Special Paper 398, Penrose Conference Series, p. 1-16, doi 10.1130/2006.2390(01).

Smith, R. B., and I. Barstad. 2004: A linear theory of orographic precipitation. *J. Atmos. Sci.*, **61**, 1377–1391.

Smith, R. B., I. Barstad, and L. Bonneau, 2005: Orographic precipitation and Oregon's climate transition. *J. Atmos. Sci.*, **62**, 177-191.

Smith R. B., and J. P. Evans, 2006: Orographic precipitation and isotope fractionation over the southern Andes. *J. Hydrometeor.*, submitted.

Smith, R. B., Q. Jiang, M. G. Fearon, P. Tabary, M. Dorninger, J. D. Doyle, and R. Beniot, 2003: Orographic precipitation and air mass transformation: An Alpine example. *Quart. J. Roy. Meteor. Soc.*, **129**, 433-454.

Smull, B. F., M. F. Garvert, and C. F. Mass, 2005: Mountain wave structures occurring within a major orographic precipitation event. Part I: Analyses of airborne Doppler radar data. Paper J8J.5, Proceedings, *Joint 11th Conf. on Meso. Processes* and *32nd Conf. on Radar Meteor.*, Albuquerque, Amer. Meteor. Soc., 5 pp.

Stauffer, D. R., and N. L. Seaman, 1990: Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic-scale data. *Mon. Wea. Rev.*, **118**, 1250–1277.

Steiner, M., O. Bousquet, R. A. Houze Jr., B. F. Smull, and M. Mancini, 2003: Airflow within major Alpine river valleys under heavy rainfall. *Quart. J. Roy. Meteor. Soc.*, **129**, 411-431.

Stoelinga, M. T., P. V. Hobbs, C. F. Mass, J. D. Locatelli, B. A. Colle, R. A. Houze Jr., A. L. Rangno, N. A. Bond, B. F. Smull, R. M. Rasmussen, G. Thompson, and B. R. Colman, 2003: Improvement of Microphysical Parameterization through Observational Verification Experiment (IMPROVE). *Bulletin of the American Meteorological Society*, **84**, 1807-1826.

Tao, W. K., and J. Simpson, 1993: Goddard Cumulus Ensemble Model. Part I: Model description. *TAO*, **4**, 35–72.

Taylor, G. H., 1997: The great flood of 1996. Oregon State University Report, Oregon State University. [Available from Oregon Climate Service, Oregon State University, Strand Ag Hall, Room 316, Corvallis, OR 97331.]

Thompson, G., R. M. Rasmussen, and K. Manning, 2004: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part I: Description and Sensitivity Analysis. *Mon. Wea. Rev.*, **132**, 519-542.

Westrick, K. J., P. Storck, C. F. Mass, 2002: Description and evaluation of a hydrometeorological forecast system for mountainous watersheds. *Wea. Forecasting*, 17, 250-262.

Wigmosta, M.S., L. W. Vail, D. P. Lettenmaier, 1994. A distributed hydrology-vegetation model for complex terrain. *Water Resour. Res.*, **30**, 1665-1679.

White, A. B., P. J. Neiman, F. M. Ralph, D. E. Kingsmill, and P. O. G. Persson, 2003: Coastal orographic rainfall processes observed by radar during the California Land-Falling Jets Experiment. *J. Hydrometeor.*, **4**, 264-282.

Woods, C. P., 2006: The study of snow particles in Pacific Northwest winter precipitation: Observations and mesoscale modeling. Ph.D. dissertation, University of Washington, 214 pp. [Available from the University of Washington, Department of Atmospheric Sciences, Box 351640, Seattle, WA 98195.]

Wratt, D. S., R. N. Ridley, M. R. Sinclair, H. Larsen, S. M. Thompson, R. Henderson, G. L. Austin, S. G. Bradley, A. Auer, A. P. Sturman, I. Owens, B. Fitzharris, B. F. Ryan and J.-F. Gayet, 1996: The New Zealand Southern Alps Experiment. *Bull. Amer. Meteor. Soc.*, **77**, 683–692.

Yu, C.-K., and B. F. Smull, 2000: Airborne observations of a land-falling cold front upstream of steep coastal orography. *Mon. Wea. Rev.*, **128**, 1577-1603.

Yuter, S. E., D. Kingsmill, L. B. Nance, and M. Löffler-Mang, 2006: Observations of precipitation size and fall speed characteristics within coexisting rain and wet snow. *J. Appl. Meteor*., conditionally accepted.

Zhu, Y., and R. E. Newell, 1998: A proposed algorithm for moisture fluxes from atmospheric rivers. *Mon. Wea. Rev.*, **126**, 725-735.

PI: Sandra E. Yuter

a. Professional Preparation

Brown University	Geology-Physics/Mathematics	B. S., 1983
University of Washington	Atmospheric Sciences	Ph. D., 1996

b. Appointments

2005-	Assistant Professor, Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, NC
2004-05	Research Associate Professor, Department of Atmospheric Sciences, University of Washington, Seattle, WA
1999-04	Research Assistant Professor, Department of Atmospheric Sciences, University of Washington, Seattle, WA
1996-99	Research Scientist, Mesoscale Group, Department of Atmospheric Sciences, University of Washington, Seattle, WA
1988-90	Software Engineer III, Research Data Program, National Center for Atmospheric Research, Boulder, CO
1986-88	Technical Marketing Engineer, Graphics Division, Symbolics Inc., Los Angeles, CA
1983-86	Member of Technical Staff, Data Systems Laboratory, TRW Defense Group, Redondo Beach, CA

c. Publications

(i) Most closely related to proposed project

Colle, B. A., and S. E. Yuter, 2007: The impact of coastal boundaries and small hills on the precipitation distribution across southern Connecticut and Long Island, NY. *Mon. Wea. Rev.*, in press.

Hagen, M. and S. E. Yuter, 2003: Relation between radar reflectivity and rainfall rate during the MAP-SOP. *Quart. J. Roy. Meteor. Soc.*, **129**, 477-493.

Yuter, S. E., and R. A. Houze, Jr., 1995: Three-dimensional kinematic and microphysical evolution of Florida cumulonimbus, Part II: Frequency distributions of vertical velocity, reflectivity, and differential reflectivity. *Mon. Wea. Rev.*, **123**, 1941-1963.

Yuter, S. E., and R. A. Houze, Jr., 2003: Microphysical modes of precipitation growth determined by vertically pointing radar in orographic precipitation during MAP. *Quart. J. Roy. Meteor. Soc.*, **129**, 455-476.

Yuter, S. E., D. Kingsmill, L. B. Nance, and M. Löffler-Mang, 2006: Observations of precipitation size and fall speed characteristics within coexisting rain and wet snow. *J. Appl. Meteor. Climo.,* **45**, 1450–1464.

(ii) Other significant publications

Comstock, K., S. E. Yuter, R. Wood, and C. S. Bretherton, 2007: The three-dimensional structure and kinematics of drizzling stratocumulus. *Mon. Wea. Rev.,* conditionally accepted.

Yuter, S. E., and R. A. Houze, Jr., 1998: The natural variability of precipitating clouds over the western Pacific warm pool. *Quart. J. Roy. Meteor. Soc.*, **124**, 53-99.

Yuter, S. E., and R. A. Houze, Jr., 2000: The Pan American Climate Studies Tropical Eastern Pacific Process Study. Part I: ITCZ region. *Bull. Amer. Meteor. Soc.*, **81**, 451-481.

Yuter, S. E., R. A. Houze, Jr., E. A. Smith, T. T. Wilheit, and E. Zipser, 2005: Physical characterization of tropical oceanic convection observed in KWAJEX. *J. Appl. Meteor.*, **44**, 385-415.

Zeng, Z., S. E. Yuter, R. A. Houze, Jr. and D. E. Kingsmill, 2001: Microphysics of the rapid development of heavy convective precipitation. *Mon. Wea. Rev.*, **129**, 1882-1904.

d. Synergistic Activities

Involvement of undergraduates in research activities: Over the past 7 years, the PI has trained and supervised eleven undergraduate research assistants (including 3 women) to work with her on various research activities including field studies and observational data processing.

Development of comprehensive web sites which serve as a community data reference and archives for PACS TEPPS (http://www.atmos.washington.edu/gcg/MG/tepps), KWAJEX (http://www.atmos.washington.edu/kwajex), and EPIC SC (http://www.atmos.washington.edu/epic).

Extensive field project experience:

2004	HYDROMET 2004: California, Disdrometer scientist
2003	PACJET 2003: California, Disdrometer scientist
2001	IMPROVE II: Oregon, Disdrometer scientist
2001	EPIC Stratocumulus Study: Southeastern Pacific, Senior Scientist
1998-99	KWAJEX: Kwajalein, Marshall Islands, Project Science Coordinator
1997	PACS TEPPS: Tropical eastern Pacific, Chief Scientist
1995	COAST II: Washington, Aircraft flight planning and mission summary preparation
1993	COAST: Washington, Aircraft radar scientist and cloud physics scientist
1992-93	TOGA-COARE: Honiara, Solomon Islands, Aircraft radar scientist and cloud physics scientist
1991	CaPE: Florida, Doppler and dual polarization radar scientist, aircraft scientist, scan coordinator
1988-90	Several field projects in Denver, CO area related to demonstration of Terminal Doppler Weather Radar (TDWR) and nowcasting for the FAA

e. Collaborators and Other Affiliations

(i) Collaborators

Paulo Artuxo, University of Sao Paulo
Aaron Bansemer, NCAR
Len Barrie, WMO, Switzerland
Darrel Baumgardner, Universidad Nacional Autonoma de Mexico
Chris Bretherton, University of Washington
Stacy Brodzik, University of Washington
Robert Cifelli, Colorado State University
Brian Colle, State Univ. of New York at Stony Brook
Kimberly Comstock, University of Washington
William Cotton, Colorado State University
Timothy Downing, University of Washington
Chris Fairall, NOAA ESRL
Bart Geerts, University of Wyoming
Martin Hagen, DLR, Germany
Julie Haggerty, NCAR
Andrew Heymsfield, NCAR
Christopher Holder, North Carolina State University
Daniel Horn, North Carolina State University
Robert Houze, University of Washington
George Kiladis, NOAA ESRL
David Kingsmill, University of Colorado
Alexi Korolev, Sky Research Inc. Canada
John Kwiatkowski, George Mason University
Dennis Lettenmaier, University of Washington
Martin Löffler-Mang, University of Applied Science, Saarbrücken, Germany
Ulricke Lohmann, ETH, Zurich
Brooks Martner, NOAA ESRL
Amanda MacLeod, University of Oregon
Matthew Miller, North Carolina State University
Louisa Nance, NCAR
Paul Neiman, NOAA ESRL
Steve Nesbitt, University of Illinios
M. Jordan Payne, North Carolina State University
Walt Petersen, University of Alabama
Greg Poulos, NCAR
F. Martin Ralph, NOAA ESRL
Art Rangno, University of Washington
Steven Rutledge, Colorado State University
Courtney Schumacher, Texas A&M
Yolande Serra, NOAA PMEL
Eric Smith, NASA GSFC
Ron Smith, Yale University
Brad Smull, University of Washington
Adam Sobel, Columbia University
James Steenburgh, University of Utah
Matthias Steiner, NCAR
Jeff Stith, NCAR
John Stout, George Mason University
Abby Swann, University of California, Berkeley
Catherine Spooner, North Carolina State University
Didier Tanré, CNRS, Lille, France
Taniel Uttal, NOAA ESRL
Robert Weller, WHOI
Allen White, NOAA ESRL
Thomas Wilheit, Texas A&M University
Christopher Williams, NOAA ESRL
Robert Wood, University of Washington
Edward Zipser, University of Utah

(ii) Graduate Advisor: Robert Houze, University of Washington

(iii) Thesis Advisor: 4 graduate students advised. Co-advisor to Ph. D. student Kimberly Comstock, University of Washington; Advisor to M.S. students: Christopher Holder, M. Jordan Payne, and Matthew Miller, North Carolina State University

David E. Kingsmill

Research Scientist III
Cooperative Institute for Research in Environmental Sciences , University of Colorado
UCB 216, Boulder, Colorado, 80309
Tele: (303) 497-4593; FAX: (303) 497-6101
Email: David.Kingsmill@colorado.edu

a. Professional Preparation:

University of California, Los Angeles	Atmospheric Sciences	B.S., 1984
University of California, Los Angeles	Atmospheric Sciences	M.S., 1987
University of California, Los Angeles	Atmospheric Sciences	Ph.D., 1991
National Center for Atmospheric Research	Atmospheric Sciences	1991-1993
University of Washington	Atmospheric Sciences	1993-1996

b. Appointments

2004-present	Research Scientist III, Cooperative Institute for Research in Environmental Sciences, University of Colorado
2003-2004:	Associate Research Professor, Division of Atmospheric Sciences, Desert Research Institute
1996-2003:	Assistant Research Professor, Division of Atmospheric Sciences, Desert Research Institute
1993-1996:	Research Associate, Department of Atmospheric Sciences,, University of Washington
1991-1993:	Postdoctoral Fellow, Advanced Study Program, National Center for Atmospheric Research
1985-1991:	Research Assistant, Department of Atmospheric Sciences, University of California, Los Angeles

c. Publications

(i) Most relevant to the proposed project

Kingsmill, D. E., P. J. Neiman, F. M. Ralph, and A. B. White, 2006: Synoptic and topographic variability of northern California precipitation characteristics in landfalling winter storms observed during CALJET. *Mon. Wea. Rev.*, **134**, 2072-2094.

Yuter, S. E., D. E. Kingsmill, L. B. Nance and M. Loffler-Mang, 2006: Observations of precipitation size and fall speed characteristics within coexisting rain and wet snow. *J. Appl. Meteor.*, **45**, 1450-1464.

Colle, B. A., J. B. Wolfe, W. J. Steenburgh, D. E. Kingsmill, J. A. W. Cox and J. C. Shafer, 2005: High resolution simulations and microphysical validation of an orographic precipitation event over the Wasatch Mountains during IPEX IOP3. *Mon. Wea. Rev.*, **133**, 2947-2971.

Cox, J. A. W., W. J. Steenburgh, D. E. Kingsmill, J. C. Shafer, B. A. Colle, O. Bousquet, B. F. Smull, and H. Cai, 2005: The kinematic structure of a Wasatch Mountain winter storm during IPEX IOP3. *Mon. Wea. Rev.*, **133**, 521-542.

White, A. B., P. J. Neiman, F. M. Ralph, D. E. Kingsmill and P. O. G. Persson, 2003: Coastal orographic rainfall processes observed by radar during the California Land-falling Jets experiment. *J. Hydrometeor*, **4**, 264-282.

(ii) Other significant publications

Friedrich, K., D. E. Kingsmill, and C. R. Young, 2005: Misocyclone characteristics along Florida gust fronts during CaPE. *Mon. Wea. Rev.*, **133**, 3345-3367.

Kingsmill, D. E., S. E. Yuter, A. J. Heymsfield, P. V. Hobbs, A. V. Korolev, J. L. Stith, A. Bansemer, J. A. Haggerty and A. L. Rangno, 2004: TRMM Common Microphysics Products: A tool for evaluating spaceborne precipitation retrieval algorithms. *J. Appl. Meteor.*, **43**, 1598-1618.

Kingsmill, D. E. and N. A. Crook, 2003: An observational study of atmospheric internal bore formation from colliding density currents. *Mon. Wea. Rev.*, **131**, 2985-3002.

Kingsmill, D. E., and R. A. Houze, Jr., 1999: Kinematic characteristics of air flowing into and out of precipitating convection over the west Pacific warm pool: An airborne Doppler radar survey.. *Quart. J. Roy. Meteor. Soc.*, **125**, 1165-1207.

Kingsmill, D. E., 1995: Convection initiation associated with a sea-breeze front, a gust front and their collision. *Mon. Wea. Rev.*, **123**, 2913-2933.

d. Synergistic activities

Associate Editor, *Monthly Weather Review*, 2006-present
Member, AMS Committee on Mesoscale Meteorology, 2005-present.
Member, NSF Observing Facilities Advisory Panel, 2002-2005, Chair 2004-2005.
UCAR Members' Representative, 1998-2003
Field project experience:

2003-2007	HMT, Northern California, Operations director and radar scientist
2005	Atmospheric Rivers, Vicinity of Hawaiian Islands, P3 chief scientist
2002	IHOP, U.S. Central Plains, Radar and radiometer scientist
2001	PACJET, Coastal California, Operations director, P3 chief scientist, cloud microphysics scientist
2000	IPEX, Utah, Cloud microphysics and radar scientist
1999	KWAJEX, Kwajalein Atoll, Cloud microphysics scientist
1998	CALJET, Coastal California, Cloud microphysics scientist
1995	MCTEX, Northern Australia, Radar scientist
1992	RAPS, Northeast Colorado, Forecaster and storm interceptor
1991	CaPE, Central Florida, Scan coordinator, radar scientist, cloud photographer
1989	ERICA, Northwest Atlantic, Radar scientist
1984	BASIN, Southern California, Sounding technician

e. Collaborators and Other Affiliations

(i) Collaborators

Edmund Andrews, USGS
Aaron Bansemer, NCAR ESSL
Olivier Bousquet, McGill University
Brian Colle, SUNY Stony Brook
Justin Cox, University of Utah
Andrew Crook, NCAR ESSL
Cyrille Flamant, Institut Pierre-Simon Laplace
Katja Friedrich, MeteoSwiss, Switzerland
Bart Geerts, University of Wyoming
Julie Haggerty, NCAR EOL
Andrew Heymsfield, NCAR ESSL
Robert Houze, University of Washington
Brian Jewett, University of Illinois
David Jorgensen, NOAA NSSL
Alexei Korolev, Sky Tech Research
Martin Loeffler-Mang, University of Saarbrücken
Brooks Martner, University of Colorado, CIRES
Sergey Matrosov, University of Colorado, CIRES
Louisa Nance, NCAR DTC
Hanne Murphey, UCLA
Paul Neiman, NOAA ESRL
Ola Persson, University of Colorado, CIRES
Paul Pisano, USDOT
Greg Poulos, NCAR EOL
Paul Pugner, USACE
Art Rangno, University of Washington
Marty Ralph, NOAA ESRL
Roy Rasmussen, NCAR RAL
Robert Rauber, University of Illinois
David Reynolds, NOAA NWS
Tom Schlatter, NOAA ESRL
Jason Shafer, University of Utah
Ron Smith, Yale University
Brad Smull, University of Washington
Jim Steenburgh, University of Utah
Matthias Steiner, Princeton University
Ronald Stewart, McGill University
Jeff Stith, NCAR EOL
Mark Stoelinga, University of Washington
Eric Strem, NOAA NWS
Doug Wesley, UCAR COMET
Jeff Waldstreicher, NOAA NWS
Roger Wakimoto, NCAR EOL
Allen White, University of Colorado, CIRES
Gary Wick, NOAA ESRL
Justin Wolfe, SUNY Stony Brook
Carl Young, Desert Research Institute
Sandra Yuter, North Carolina State University

(ii) Graduate and Postdoctoral Advisors

Graduate Advisor: Roger Wakimoto, NCAR EOL

Postdoctoral Sponsors: Jim Wilson, NCAR EOL and Robert Houze, University of Washington

(iii) Thesis Advisor and Postgraduate-Scholar Sponsor

M.S. Thesis Advisor: Todd Hennings, University of Nevada, 1997-2000; Mariana Potcoava, University of Nevada, 2001-2002; Carl Young, University of Nevada, 2002-2003

Postdoctoral Sponsor: Huaqing Cai, NCAR RAL, 2001-2002; Katja Friedrich, MeteoSwiss, 2004-2005

Section I: Facilities, Equipment and Other Resources

Summary of Proposed Observing Systems for SHARE (Part I)

NSF Deployment Pool Observing Facilities (requests for all facilities are yet to be submitted)

Observing Facility	No.	PI(s)	Sponsor	Facility Contact	Est. Deploy. Cost
UWyo King Air w/Cloud Radar,In Situ Microphysics (96h)	1	Geerts, Colle, Kingsmill	NSF Dep. Pool	Rodi	$400K
[1]NCAR S-band Polarimetric Doppler Radar (S-POL)	1	Houze, Colle, Yuter	NSF Dep. Pool	Vivek	$460K
NCAR Integrated Surface Flux Facility	3	Poulos, Lundquist	NSF Dep. Pool	Cohn	$147K
NCAR G-V (HIAPER) w/ Dropsonde System (71h, no lee drops)	1	Smith, Neiman	NSF Dep. Pool	Stith	$490K
Dropsondes for G-V Deployment (no lee drops)	444	Smith, Neiman	NSF Dep. Pool	Stith,Cohn	$445K
[2]NCAR G-V (HIAPER) w/ Dropsonde System (50h, lee drops)	1	Smith, Neiman	NSF Dep. Pool	Stith	$438K
[2]Dropsondes for G-V Deployment (lee drops)	290	Smith, Neiman	NSF Dep. Pool	Stith, Cohn	$332K
NCAR ISS-Profiler,GAUS,SfcMet,Precip (100 upsondes each site)	2	Steenburgh, Poulos, Smith	NSF Dep. Pool	Cohn	$388K
NCAR GAUS (100 upsondes each site)	2	Steenburgh, Poulos, Smith	NSF Dep. Pool	Cohn	$235K

[1] K_a-band capability of S-POL would be useful, but is not essential for project objectives

[2] Items in yellow are relevant if deployment of dropsondes in lee of Sierra Nevada is deemed feasible

Total Estimated Deployment Cost to NSF for Deployment Pool Observing Facilities (does not include lee drops option) $2565K

Observing Facilities deployed with NSF support (proposals for deploying these facilities are yet to be submitted)

Observing Facility	No.	PI(s)	Sponsor	Facility Contact	Est. Deploy. Cost
DOW X-band Mobile Doppler Radars (base+deployment costs)	2	Kingsmill, Yuter	NSF/CSWR	Wurman	$415K
[3]DOW X-band Mobile Doppler Radars (only deployment costs)	2	Kingsmill, Yuter	NSF/CSWR	Wurman	$245K
Precip. Gauge Transects (5 gauges each transect)	2	Poulos, Steenburgh	NSF/NCAR	Poulos	$77K
Snow Depth Sensor Network (100 sensors)	1	Molotch	NSF Grant to UCLA	Molotch	$50K
S-band Profiler	1	Yuter, Houze	NSF Grant to NCSU	Yuter	$5K
K-band Profilers	2	Yuter, Smith	NSF Grants to NCSU/Yale	Yuter, Smith	$5K
Autonomous Surface Microphysics	2	Yuter, Kingsmill	NSF Grant to NCSU	Yuter	$2K
Manual Surface Microphysics	1	Stoelinga	NSF Grant to UW	Stoelinga	$98K
Micro-Temperature Sensors	300	Lundquist	NSF Grant to UW	Lundquist	$20K
Field Project Support, Data Management	--	--	NSF	Moore	$310K

[3] Item in yellow is relevant if CSWR proposal to NSF for base support of DOW's is funded

Total Estimated Deployment Cost to NSF for Non-Deployment Pool Observing Facilities (does not include $245K DOW line item) $982K

Summary of Proposed Observing Systems for SHARE (Part II)

NOAA Research Observing Facilities (Programmatic commitments in place; request for NOAA P3 yet to be submitted)

Observing Facility	No.	PI(s)	Sponsor	Facility Contact	Est. Deploy. Cost
NOAA P3 w/ Tail Radar,In situ Microphysics	1	Kingsmill, Neiman, Smull	NOAA STI	Ralph	$500K
915 MHz Profilers w/ GPS IWV, SfcMet., Precip.	7	Kingsmill,Steenburgh,Smith	NOAA HMT, IOOS, Wx-Clim, CCOS	Ralph	$360K
449 MHz Profiler w/ GPS IWV, SfcMet., Precip.	1	Kingsmill,Steenburgh,Smith	NOAA HMT	Ralph	$80K
S-band Profilers w/ SfcMet, Precip	3	Kingsmill, Houze, Yuter	NOAA HMT, Wx-Clim	Ralph	$170K
X-band Polarimetric Doppler Radar (XPOL)	1	Kingsmill	NOAA HMT	Ralph	$300K
GPS IWV, SfcMet	2	Kingsmill	NOAA HMT, Wx-Clim	Ralph	$10K
Radiometric IWV&ILW w/ SfcMet., Precip.	2	Kingsmill	NOAA HMT	Ralph	$40K
GPS Sonde Site (100 sondes)	1	Kingsmill,Steenburgh,Smith	NOAA HMT	Ralph	$95K
Soil Moisture, SfcMet., Precip.	10	Kingsmill	NOAA HMT	Ralph	$40K
Autonomous Sfc. Microphysics, SfcMet, Precip.	5	Kingsmill, Yuter	NOAA HMT	Ralph	$25K
Stream Level Loggers	4	Kingsmill, Lundquist	NOAA HMT	Ralph	$20K
Snow Depth Sensors	4	Kingsmill, Molotch	NOAA HMT	Ralph	$10K
Total Estimated Deployment Cost Contribution from NOAA for Research Observing Facilities					**$1650K**

Operational Observing Systems within the SHARE domain

Observing Facility	No.	Sponsor
NWS WSR-88D Doppler Radars	5	NOAA NWS
NWS Rawinsondes.	2	NOAA NWS
GPS IWV	5	CA DOT,USACE,DOD
ALERT Precip. Gauges	492	State/Regional/Local Agencies
SNOTEL Precip. Gauges	26	USDA
RAWS Precip. Gauges	196	USFS,BLM
Surface Met, Precip and/or Snow Depth Sensor Sites	26	Western Regional Climate Center

Notes on Observing System Table

1. A listing as PI on an observing system implies a commitment to participate in overseeing field deployment of the system and data processing of measurements for archival and use by the wider group of SHARE PIs.

2. Two options for the NCAR G-V (HIAPER) are included. The first option assumes that dropsondes in the lee of the Sierra Nevada will not be feasible to deploy and is associated with a two circuit offshore deployment strategy. The other option (in yellow) assumes that dropsondes in the lee of the Sierra Nevada will be feasible to deploy and is associated with one circuit of a combined offshore and leeside Sierra Nevada deployment strategy.

3. Two options for the Doppler on Wheels are included. The first option assumes that funds for both base and deployment costs are required while the second option assumes that only deployment costs would be required with the base costs covered by an independent facility proposal submitted to NSF by the Center for Severe Weather Research (CSWR), PI Joshua Wurman.

4. Flight hours were estimated as follows, equivalent of 12 IOPs with:
HIAPER- 5.9 hour mission per IOP = 71 hours total for SHARE (no lee drops)
HIAPER- 4.2 hour mission per IOP = 50 hours total for SHARE (lee drops)
UWKA- two 4 hour missions per IOP = 96 hours total for SHARE
NOAA P-3 – 8 hour mission per IOP = 96 hours total for SHARE

5. The difference between the deployment costs for 915 MHz profilers between NCAR (ISS-profiler) and NOAA is primarily a result of different staffing assumptions.

6. The Ka-band capability of S-POL would be useful but is not essential for project objectives.

Section J: Special Information and Supplementary Documentation

The current SHARE Scientific Steering Committee consists of the following members:

Co-Chair: David Kingsmill, University of Colorado	Co-Chair: Sandra Yuter, North Carolina State University
Brian Colle, Stony-Brook University-SUNY	Robert Houze, University of Washington
Bart Geerts, University of Wyoming	Jessica Lundquist, University of Washington
Paul Neiman, NCAR ESRL	Greg Poulos, NCAR EOL
Ronald Smith, Yale University	Brad Smull, University of Washington
James Steenburgh, University of Utah	

This section contains information on planned research activities for SHARE by members of the Steering Committee and a small group of additional PIs who bring specialized skills and expertise to the program. The pages are ordered alphabetically by the last name of the lead PI on each one page description.

Brian Colle	Stony-Brook University-SUNY	The impact of terrain-forced gravity waves on the precipitation distribution and microphysics over the Sierras
Bart Geerts	University of Wyoming	A study of the interaction between the fine-scale terrain structure and precipitation processes, mainly by means of airborne cloud radar and in situ observations
Vanda Grubišić	Desert Research Insitute	A study of the dynamics and microphysics of the precipitating generating processes in the Sierra Nevada wintertime storms
Robert Houze, Bradley Smull, and Socorro Medina	University of Washington	Small-scale processes contributing to orographic modification of frontal precipitation
David Kingsmill	University of Colorado	Orographic precipitation process studies though integrated kinematic and microphysics observations along the Sierra Nevada
Yuh-Lang Lin	North Carolina State University	Interaction of atmospheric river and barrier jet and its impacts on the orographic precipitation over the northern California Sierra mountain ranges
Jessica Lundquist	University of Washington	Rain and snow in complex terrain: Improving hydrological modeling through intensive observations
Noah Molotch, Roger Bales, Steven Margulis and Robert Rice	University of California, Los Angeles	Quantifying controls on snow distribution in the Sierra Nevada using ground-based and remotely sensed observations within an ensemble Kalman smoother
Paul Neiman	NOAA/ESRL	Precipitation characteristics associated with atmospheric rivers
Ronald Smith	Yale University	Water vapor flux and drying ratio
James Steenburgh and Greg Poulos	University of Utah and NCAR	Joint interactions between frontal systems, blocked flow and flow over traverse ridges in the storm-scale morphology of alpine precipitation
Mark Stoelinga and John Locatelli	University of Washington	Observations and modeling of the characteristics of falling and accumulating snow in the Sierra Nevada mountains
Sandra Yuter	North Carolina State University	Multi-scale kinematics and microphysical mechanisms of orographic precipitation

PI: **Brian A. Colle**
Institute for Terrestrial and Planetary Atmospheres, Stony Brook University / SUNY

The impact of terrain-forced gravity waves on the precipitation distribution and microphysics over the Sierras

Orographic precipitation depends on a number of complex dynamical and microphysical processes, which have been explored recently using field data from MAP over the Alps, CALJET over coastal southern California, IPEX over the Wasatch Mountains of Utah, and IMPROVE2 over the Oregon Cascades. Most of the investigations on moist dynamical impacts on orographic precipitation have focused on the impact of flow blocking (Rotunno and Ferretti 2003; Medina and Houze 2003; Neiman et. al. 2002; Cox et al. 2005) and windward shear layers and associated turbulence (Houze and Medina 2005). Terrain-induced gravity waves also impact the distribution of orographic precipitation (Colle 2004; Smith and Barstad 2004), but this mechanism has received much less attention using field data (Garvert et al. 2007).

The Sierras offer a unique opportunity to study the impact of terrain-induced gravity waves at a variety of scales. One question is how the depth and upstream extent of the Sierra orographic cloud depends on the terrain-induced gravity wave over the crest? For example, a large vertical wavelength (favored under strong flow and/or weak N) can develop a deep orographic cloud, which may enhance the seeder cloud aloft. In addition, the southerly barrier jet can interact with the numerous transverse (west-east) ridges along the Sierra windward slope. Based on recent idealized simulations (Colle 2007), it is hypothesized that the vertical motions associated with these gravity waves from these ridges can locally increase the cloud water and riming growth processes, which significantly increases the precipitation efficiency and removal of moisture by the Sierras. The observed circulations and microphysics collected over these ridges will also be used for verification of bulk microphysical parameterizations (BMPs) in the WRF model.

We propose to investigate the gravity waves over the Sierras and their impact on the observed and simulated microphysics (c.f. Section 2.2, Questions 3 and 4). A pair of Doppler on Wheels radars (Section 8.12) will provide dual-Doppler wind information near the mouth of the American River basin and immediately upstream of the Sierras. Meanwhile, the NOAA P-3 tail radar will sample the airflow around the narrow ridges as well as aloft over the windward slope and lee. The WSR-88D and S-Pol radars will provide continuous coverage of the precipitation structures. The along-barrier P3 legs and cross-barrier King Air transects will help relate gravity waves to microphysical variations aloft. As in the PIs previous IMPROVE work, the microphysical data combined with surface precipitation gauge transects across transverse ridges will be used for model BMP validation and development. Stony Brook will run the WRF model operationally during SHARE, which will be available for field operations.

The three-year budget below supports the research efforts of the PI and a graduate student.

	Field Year (1)	*Non-Field Years (2)*	**Total**
Salaries & Benefits	$40,000	$50,000	
Travel (including per diem)	$10,000	$3,000	
Equipment	$10,000	0	
Publications	$0	$5,000	
Materials and Supplies	$2,000	$2,000	
Indirect costs	$28,600	$33,000	
Total	$89,600	$93,000	**$275,600**

PI: Bart Geerts, University of Wyoming

A study of the interaction between the fine-scale terrain structure and precipitation processes, mainly by means of airborne cloud radar and in situ observations

[**topic of interest**] We propose to participate in SHARE to study cloud microphysical and dynamical characteristics of orographic precipitation enhancement at a *very high resolution*. Both deep frontal disturbances and precipitation in weakly-forced, shallower upslope flow regimes will be examined. The emphasis is on precipitation enhancement in the mixed-phase region. We plan to examine how topography affects precipitation growth over a range of horizontal scales, down to ~100m, under a variety of wind and stability profiles, and to explore the microphysical processes controlling this growth. The airflow field ([along-track, vertical], or vertical only) will be depicted mainly in vertical slices from cloud top to the terrain by means of a high-resolution Doppler airborne cloud radar. The airborne vantage point enables a description of the reflectivity and flow field to within tens of meters above the ground. Of particular interest is precipitation growth within the turbulent PBL over complex terrain, which has been hypothesized to be significant (Medina and Houze 2005, Rotunno and Houze 2006). Our interest in PBL processes has been spurred by recent airborne radar measurements over a range in Wyoming.

[**objectives**] Our objectives mainly relate to SHARE Science Objectives #3 and #4, in particular we aim to: (a) to relate the vertical airflow field, mainly at close range to the terrain, in sections across the main Sierra range and across the much smaller transverse ridges on the Sierra upwind slope, to flight-level measurements of particle size distributions, amount of riming, and LWC; (b) to improve and use a hydrometeor type discrimination scheme based on close-range polarization measurements from the side-looking radar antenna and in situ 2D particle data; and (c) to quantify the effect of PBL turbulence and mountain waves on cloud microphysical processes. We further hope to forge ties with a high-resolution cloud-resolving numerical modeling group.

[**facilities needed**] This project will primarily employ the UW King Air with all cloud probes and the basic thermodynamic, moisture and kinematic probes. The key instrument on the King Air will be the 95 GHz Doppler Wyoming Cloud Radar (WCR). The combination of in situ cloud data and proximity radar data constitutes a unique, powerful synergy for cloud process studies. This project will also employ surface precipitation measurements, because airborne in situ observations in the PBL are difficult, and reflectivity and dual-Doppler velocity data from various scanning ground-based radars, mainly to place the WCR data in a spatially larger context.

[**sponsor and budget**] A proposal will be submitted to NSF/ATM for approximately $410,000 for three years (FY09, 10, 11). This includes full field phase participation for two people, and two 12-month, 3-year PhD-level graduate assistantships.

	Year 1 (incl. field work)	*Years 2 & 3*	**Total**
Salaries (PI + 2 PhDs)+ fringe	$75,000	$165,000	$240,000
Travel (including per diem)	$14,000	$5,000	$19,000
Equipment + other direct costs	$10,000	6000	$16,000
Tuition	$8,000	$16,000	$24,000
Indirect Costs	$40,095	$71,280	$111,375
Total	$147,095	$263,280	**$410,375**

PI: **Vanda Grubišić**
Division of Atmospheric Sciences, Desert Research Institute, Reno, NV

A study of the dynamics and microphysics of the precipitation generating processes in the Sierra Nevada wintertime storms

This is a primarily modeling study designed to explore several aspect of the dynamics and microphysics of the precipitation generating processes in the Sierra Nevada. The main subject to be examined concerns the role of sub-ridge scale terrain features in controlling the precipitation generating processes and spatial and temporal distribution of precipitation. The modeling study by Grubišić et al. (2005) showed that wintertime storms in the Sierra Nevada produce a characteristic filamentary spatial pattern of precipitation on the upwind Sierra slopes, in which individual filaments of maximum precipitation of 20-30 km in width are oriented perpendicular to the NW-SE oriented Sierra crest in a predominantly SW flow. Through combined use of high-resolution model simulations with the MM5 and WRF models and available kinematic and microphysical observations that will be obtained in the SHARE field campaign, we propose to investigate to what degree is this spatial distribution conditioned by the interaction of the Sierra barrier jet with transverse ridges superimposed on the nearly two-dimensional NW-SE oriented Sierra ridge, as hypothesized in Grubišić et al. (2005), or is due to even smaller scale orographic elements at the upstream edge of the upwind Sierra slope that might trigger convective instability within the Sierra orographic cloud (Kirshbaum et al. 2006) and lead to the formation of orographic rainbands parallel to the mean flow. The key measurements provided by SHARE that will facilitate this study are radar data and high-resolution satellite imagery showing the existence of banded structures within orographic clouds, detailed kinematic and thermodynamic documentation of the larger scale upstream environment, kinematic and microphysical measurements over the orographic cloud region, and dense surface measurements of precipitation accumulations for, respectively, dynamical insight into the region of interest and model verification.

The underlying strong link in SHARE between documentation of the large-scale environment related to atmospheric rivers and precipitation-generating processes over the Sierra Nevada offers a unique opportunity to examine the impact assimilation of moisture data from the upstream profiling systems (dropsondes, rawinsondes, GPS IW, aircraft soundings) has on high-resolution forecasts of orographic precipitation. There is sufficient evidence from other mountainous regions that assimilation of moisture field significantly improves precipitation forecasts (Falvey and Beavan 2002; Durcrocq et al. 2002). We propose to examine and quantify this effect on predictions of in cloud water and ice quantities as well as surface precipitation in the Sierra Nevada obtained by common bulk microndphysical schemes.

The anticipated budget for three-years would support research efforts of the PI, part time research associate, and one graduate student.

Item	*Field Year*	*Year 2*	*Year 3*	*Total*
Salaries and Benefits	$49,281	$51,744	$54,330	$155,355
Travel	$22,000	$2,000	$2,000	$26,000
Other Direct Costs	$1,248	$3,777	$3,811	$8,836
Grad Student Total	$25,506	$25,924	$26,760	$78,190
Indirect Costs	$57,840	$49,232	$51,272	$158,344
Total	$155,875	$132,677	$138,174	$426,726

PIs: **Robert A. Houze, Jr., Bradley F. Smull, Socorro Medina**
Department of Atmospheric Sciences, University of Washington, Seattle, WA

Small-scale processes contributing to orographic modification of frontal precipitation

Precipitation fallout when frontal systems pass over the windward slopes of mountain barriers is often a quick and efficient process. Particles growing in this unique environment must achieve appreciable size quickly if they are to fallout locally. One of the fascinating aspects of orographic enhancement in baroclinic precipitation systems encountering mountain ranges is the quickness and efficiency with which the additional moisture condensed by orographic lifting is transferred to precipitation-sized particles once the moist airstream is subjected to the orographic uplift. The additional water condensed by the terrain-induced vertical motions is converted to precipitation rapidly enough for most or all of the precipitation resulting from the orographic lifting to fall out on the lower windward slopes. This research seeks insight into the mechanisms that allow the orographically condensed water to be converted so quickly to precipitation. This work will build on the results of MAP and IMPROVE II, which have made initial inroads into this process by observing the passage of baroclinic systems over the Alps and Cascades. The basic mechanisms appeared to be the same in the Alps and Cascades, although the differences in upstream stability, incident wind strength, shear, and barrier height lead to variations in the degree to which the basic processes were active in these two locales. SHARE provides a venue to test the ideas that emerged from MAP and IMPROVE II, and an opportunity to specifically tailor the measurements to understand the basic processes in more detail and support their critical evaluation in numerical simulations.

In MAP and IMPROVE II we have found that upstream stability, flow strength and shear lead to two characteristic, contrasting regimes of flow and precipitation production over the topography. When the upstream stability is weak the flow rises readily over the terrain and maximum particle growth occurs over the first peak of terrain and over each subsequent secondary small-scale ridge in the corrugated topography. Growth of particles by riming and coalescence in the enhanced upward flow over each ridge contributes to the rapid formation and fallout of precipitation. With greater upstream stability, orographically modified flow becomes increasingly sheared at low levels over the terrain. Turbulence within this shear layer may further contribute to growth of particles by aggregation and riming and thus to the rapid fallout of precipitation. In our most recent analysis of IMPROVE II data we are finding that these processes vary significantly with respect to the part of the synoptic-scale storm system passing over the mountain barrier.

SHARE will advance our understanding of these processes, important aspects of which are still working hypotheses. The required observations are S-Pol multi-polarization and dual-wavelength data, vertically pointing precipitation radar data and soundings at several positions relative to the barrier, and airborne Doppler radar data. Dual-wavelength radar observations at X and K_a bands will identify layers in which orographically generated ascent generates additional condensate and precipitation growth via riming and coalesence. The vertically pointing and S-band scanning radar will identify predominant ice particle types, probable growth mechanisms, and fine-scale air motions intrinsic to the orographic enhancement. The aircraft radar will identify shear layers that lead to precipitation enhancing turbulence and map detailed air motions within valleys. Well placed soundings are essential to evaluate the stability associated with fine-scale processes.

The proposed work will directly address SHARE objectives related to determining the key scales of vertical motions and their relation to the dominant microphysics processes responsible for precipitation enhancement over the hydrologically sensitive west-facing slopes of the Sierras.

Our proposed work on SHARE will be incorporated into Professor Houze's NSF supported research on orographic precipitation in midlatitudes and tropics. If the SHARE initiative goes forward, we will either request a SHARE supplement to an existing grant or include SHARE in a new orographic precipitation proposal. Which course of action will depend on the timing of SHARE. The following numbers reflect only the cost of SHARE-related research as part of our larger orographic research project. The primary costs of our SHARE activities will be salary and travel for the principal participants. The principal personnel will be PI Houze, Co PIs Dr. B. Smull & Dr. S. Medina, Research Engineer S. Brodzik (Research Engineer), and 1 graduate student.

	Field Year 1	*Years 2 & 3*	**Total**
Salaries & Benefits (Houze—0.5 mo., Smull—3 mos., Medina—6 mos., grad student—12 mos., Brodzik—3 mos.)	95,443	202,491	297,933
Travel (assume 2 mos. in field & 1 meeting/yr, all for 4 people)	53,100	9,000	62,100
Tuition (one grad student)	8,851	19,603	28,454
Indirect Costs (56%)	83,184	118,435	201,619
Total	240,577	349,529	**590,106**

PI: **David Kingsmill**

Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder
Email: David.Kingsmill@colorado.edu

Orographic Precipitation Process Studies through Integrated Analysis of Kinematic and Microphysical Observations along the Sierra Nevada

The spatial distribution of orographically enhanced precipitation results from a complex superposition of and interaction between microphysical and kinematic processes. Previous observational studies focusing on orographic precipitation processes have addressed both issues, but rarely with comparable emphasis. For example, a rich microphysical dataset was collected during the Sierra Cooperative Pilot Project (SCPP field program, including extensive in situ and radiometer observations. However, SCPP kinematic datasets were much more limited, with only two-dimensional cross-sections of airflow derived from single-Doppler radar and airborne in situ kinematic observations. In contrast, kinematic observations from the MAP field experiment were relatively good, with three-dimensional wind fields derived from airborne and ground-based radars whereas detailed microphysical datasets were very limited, with some inferred microphysics from polarimetric radar but almost no in situ observations. More recently, datasets collected during the IMPROVE II field experiment have approached a better microphysical-kinematic balance. However, there were some notable limitations to the kinematic datasets. Airborne Doppler radar provided three-dimensional wind fields but with relatively coarse time resolution and incomplete coverage of entire events. Alternatively, the lone ground-based Doppler radar provided continuous coverage, but only with radial velocities, a kinematic context that is insufficient to adequately represent the complex, three-dimensional airflows forced by orography. The SHARE field program is designed to overcome these limitations to kinematic observations while also providing detailed microphysical observations. This combination will allow a temporally continuous multi-scale investigation of airflow structures along and across the barrier and how they relate to characteristics of the precipitation microphysics.

Analyses in this proposed research project will focus on examining the co-evolving kinematic and microphysical structures embedded within orographic precipitation observed in the Sierra Nevada during SHARE. This work will directly address SHARE objectives dealing with the key spatial and temporal scales of vertical motion and associated microphysical processes. Critical observing systems for this work include the two DOW Doppler radars making up the high-resolution dual-Doppler domain, the NOAA P-3 with its airborne dual-Doppler and in situ microphysics, the Wyoming King Air with its in situ microphysics, the NOAA XPOL and NCAR SPOLKa polarimetric radars for inferred microphysics, and the surface-based in situ microphysics sensors. The PI has extensive experience in the analysis of ground-based and airborne multiple-Doppler datasets as well as analysis of airborne and surface-based microphysics datasets. He will lead and coordinate the deployment of the DOWs and will collaborate principally with Dr Yuter on field observation analysis and with Dr. Colle on applying observational results to numerical model applications.

Anticipated budget for three years, starting August 2008 (does not include DOW deployment costs).

	Year 1 (Field Year)	*Year 2*	*Year 3*	*Total*
Salaries+Benefits (PI, MS Analyst, Outreach Coordination)	$90,000	$84,000	$87,000	$261,000
Travel (incl. per diem)	$24,000	$8,000	$8,000	$40,000
Publications	$0	$6,000	$12,000	$18,000
Other Direct Costs	$12,000	$2,000	$2,000	$16,000
Indirect Costs	$32,760	$26,000	$28,340	$87,100
Total	$158,760	$126,000	$137,340	**$422,100**

PI: **Yuh-Lang Lin**, Department of MEAS, North Carolina State University, Raleigh, NC

Interaction of atmospheric river and barrier jet and its impact on the orographic precipitation over the northern California Sierra mountain ranges

Moisture transported by the atmospheric river from the southwest of the coastal range of northern California is well known as the major source of orographic precipitation in the area, but the dynamics of the interaction the atmospheric river with barrier jet along the coastal range and its impacts on orographic precipitation is still not well understood. This interaction may change the direction, speed, moisture flux, and spatial structure of the atmospheric river, which, in turn, will change some flow parameters, in particular the Froude number (Chu and Lin 2000), CAPE (Chen and Lin 2005), moisture flux and low-level jet structure. This may significantly change the formation and propagation of orographically induced convective systems and the amount and distribution of precipitation over the northern California Sierra mountain ranges. Prof. Lin has unique experience in participating in orographic rain related field experiments (e.g. MAP and TAMEX), developing theories, and conducting numerical experiments of flow and weather systems passing over mesoscale mountain ranges (see http://mesolab.meas.ncsu.edu for more information and references). His participation in the proposed SHARE project will help understand the prediction and basic dynamics of orographic precipitation generated in a rather complicated environment. Prof. Lin proposes to: (a) classify the precipitation patterns based on storm tracks and investigate the mechanisms for the orographic precipitation over the Sierra Nevada and coastal ranges; (b) conduct both real-case (to be identified from the field experiment) and idealized numerical experiments using WRF model to help answer the second key question regarding the interaction of atmospheric river, barrier jet, and frontal system (Sec. 2.2), and (c) estimate the spatial distribution and amount of orographic precipitation based on ingredient argument (Lin et al. 2001) to help prove the overarching hydrometeorology hypothesis (Sec. 4 – Hydrometeorology). Data collected by SHARE proposed facilities, such as upper-air soundings, wind profilers, rain gauges, Doppler radars, aircrafts, etc., during the SHARE field experiment are essential to Prof. Lin's proposed research. In particular, the observed upstream sounding, wind pattern, water vapor, hydrometeors upstream and over the mountain ranges are essential in providing the initial data for the model, in verifying the model results, and in helping understand the dynamics from the real-world point of view.

In summery, the proposed work will directly address the second SHARE objective related to the understanding of the interaction of atmospheric river and the barrier jet and its impacts on orographic precipitation and the estimation of distribution of orographic precipitation from the ingredient point of view. Both will help understand the dynamics as well as the prediction of orographic rain over northern California Sierra mountain ranges.

Three year budget (supplement to the PI's regular NSF grant on orographic rain)

	Field Year (1)	*Non-Field Years (2)*	**Total**
Salaries & Benefits	$38,941	$79,799	**$118,740**
Travel (including per diem)	$4,500	$4,500	**$9,000**
Equipments	$5,000	$0	**$5,000**
Other Direct Costs	$9,975	$19,950	**$29,925**
Indirect Costs	$21,478	$41,767	**$63,245**
Total	$79,894	$146,016	**$225,910**

PI: **Jessica D. Lundquist**
Co-PIs: Andrew W. Wood, Alan Hamlet, Dennis P. Lettenmaier
All at: Department of Civil and Env. Engineering, University of Washington, Seattle, WA 98195

Rain and snow in complex terrain: Improving hydrologic modeling through intensive observations

In the maritime mountain ranges of western North America, the most dramatic floods of the past century have been caused by warm rain-on-snow events, and coastal basins spanning a wide range of elevations, such as the North Fork of the American River Basin in California, are extremely sensitive to these events (Kattelman 1997; Osterhuber 1999). While there is a need to forecast these events accurately, mixed rain and snow processes are one of the largest sources of errors in hydrologic models (Shamir et al. 2006). The intensive observations generated through SHARE provide a unique opportunity to investigate hydrologic processes associated with mixed rain and snow in complex terrain. In addition to resolving precipitation across the basin, SHARE will measure wind fields through the complex terrain, fluxes at three elevations, and snow depth in a variety of settings.

Temperature is the primary variable for distinguishing between rainfall and snowfall (US Army Corps of Engineers 1956) and for estimating snowmelt in hydrologic models (Anderson 1976). Thus, an accurate description of temperature across the basin is a crucial first step to improving hydrologic forecasting. We propose to deploy approximately 300 small, low-cost, self-recording temperature/relative humidity sensors (Maxim i-buttons) along the elevational gradients of two road transects and along three river transects down and up the slopes of the river canyons. The instruments will be hung in trees to provide radiative shielding and to keep them above snow level. This technique has proven reliable when compared to standard climate-quality monitoring stations ($R^2 \approx 98\%$).

Temperature, precipitation, and wind fields will be used to run the Distributed Hydrologic-Soil Vegetation Model (DHSVM, Wigmosta et al. 1994), which has a complete energy-balance snow model and has been proven to work in complex terrain. Modeled snow properties will be compared with snow measurements and modeled discharge will be compared with measurements at the basin outlet and at 4 interior basin locations. Data deprivation studies will be conducted to determine which locations and parameters are most crucial to monitor and which can be estimated. The modeled flux will be compared with measured flux to determine how well the bulk parameterization scheme works in storms in complex terrain.

The three-year budget supports 2 months of PI/co-PI salaries and 1 graduate student, each year.

	Field Year (1)	Years 2 & 3	Total
Salaries + benefits	$60,000	$60,000	$180,000
Travel (incl. per diem)	$10,000	$2,500	$15,000
Acquisition/Deployment of Microsensor Network	$20,000		$20,000
Publications		$5000	$10,000
Tuition	$8,000	$8,000	$24,000
Indirect Costs	$40,000	$33,000	$106,000
Total	$138,000	$106,000	$355,000

PI: **[1]Noah Molotch; Co-PI's: [2]Roger Bales, [1]Steven Margulis, and [2]Robert Rice**
[1]Civil and Environmental Engineering, University of California, Los Angeles
[2]School of Engineering, University of California, Merced

Quantifying controls on snow distribution in the Sierra Nevada using ground-based and remotely sensed observations within an ensemble Kalman smoother

Spatial and temporal distribution of precipitation is perhaps the largest source of uncertainty in our understanding of hydrological processes and in forecasting runoff and flood potential. The mechanisms and spatial and temporal distribution of snow and the changes to these distribution patterns due to climatic forcing will potentially impact precipitation type as well as the spatial and temporal distribution of snowmelt. The objective of this research is to understand physiographic controls on snow distribution in the North Fork of the American River basin, and to separate the roles of large-scale airmass transformations versus local-scale topography and landcover. Unprecedented ground-based and remotely sensed snowfall measurements from SHARE will be used to characterize inter- and intra-storm variability in snow accumulation patterns. Continuous snow depth observations, using an array of 100 ultra-sonic depth sensors, will provide the back-bone for SHARE ground-truth validation and to realize local-scale snow distribution patterns. To estimate snow distribution at the basin scale, leveraged Moderate Resolution Imaging Spectroradiometer snow cover products from a NASA Regional Earth Applications Solutions project will be assimilated into a spatially distributed snowpack mass balance model using an ENsemble Kalman Smoother (ENKS); in which the ground-based and airborne SHARE data will be used to evaluate error covariance structure. Three contributions will be obtained: 1) the continuous record of ground-based snow observations is unprecedented at the basin scale with respect to the spatial density and varied terrain to be represented. Observations will enable diagnosing drivers of spatial snow depth variability and will serve a suite of interests in the hydrology and meteorology science communities, 2) SHARE provides unmatched information on orographically induced flow dynamics at a variety of scales, allowing us to evaluate the sensitivity of local-scale snow accumulation patterns to storm structure and associated impacts on ENKS error covariance structure; and 3) the ground-based snow depth measurement clusters and SHARE Doppler radar data provide an unparalleled metric to determine the utility of the ENKS, extending the transferability of SHARE data to hydrologic applications in other regions and time periods.

The advanced techniques and understanding obtained under this research will have broad implications for management of water and other mountain resources. Better, more-accurate snowpack measurement is of great immediate interest to water resource managers, who are being called upon to allocate variable supplies in the face of increasing demand. Projections of snowpack conditions as climate warms compound the need for understanding physiographic controls on snowfall and snow distribution. Reducing uncertainty in these hydrologic predictions will enable mitigation of impacts through informed environmental policy and efficient resource management.

On 1 December 2006 a proposal will be submitted to the National Science Foundation, Hydrologic Sciences Program, requesting the following support:

	year 1 (field year)	years 2 &3	Total
Salaries, Benefits & Tuition (Molotch, Margulis, Rice, PhD Student)	65,000	130,000	195,000
Travel (including per diem for Molotch, Rice, student	10,000	2200	12,200
Equipment	50,000	0	50,000
Indirect Costs	40,875	72,049	112,924
Total	**165,875**	**204,249**	**370,124**

PI: **Paul J. Neiman**
NOAA/Earth System Research Laboratory, Boulder, CO 80466

Precipitation Characteristics Associated with Atmospheric Rivers

The pre-cold-frontal low-level jet (LLJ) in land-falling extratropical cyclones approaching the West Coast of the United States each winter plays a critical role in transporting water vapor into the coastal mountains, resulting in orographic enhancement of precipitation. The LLJ, which resides at approximately 1 km MSL, represents the lower-tropospheric component of a deeper corridor of concentrated water vapor content and transport in the pre-cold-frontal environment (Ralph et al. 2004, 2005). Because these corridors tend to be quite narrow (<1000 km wide) relative to their length scale (>2000 km), and yet are responsible for almost all of the meridional water vapor transport at midlatitudes (Zhu and Newell 1998), they are referred to as atmospheric rivers. Most (~75%) of the water vapor transport within these rivers occur within the lowest 2.5 km of the atmosphere. In an effort to obtain a quantitative relationship between landfalling atmospheric rivers and precipitation characteristics in northern California, we will explore the relationship between integrated water vapor (IWV) content measured by global positioning system (GPS) units in several of northern California’s lowland locations and rain intensity recorded in the downstream mountains, both generally and within atmospheric rivers. Calculations of bulk horizontal water vapor flux will be performed by combining observations of IWV and upslope flow measured by the GPS and collocated wind profiler, and a statistical connection will be established between the bulk fluxes and rain intensity in the downstream mountains. In addition, we will attempt to link the bulk microphysical characteristics of rainfall (i.e., brightband versus nonbrightband rain) measured by vertically pointing S-band radars to transient atmospheric rivers traversing northern California.

The proposed work will directly address SHARE objectives related to the characteristics of landfalling atmospheric rivers and their impact on precipitation microphysics.

PI: **Ronald B. Smith**
Department of Geology and Geophysics, Yale University, New Haven, CT

Water Vapor Flux and Drying Ratio

The PI has worked in mountain meteorology for about 30 years. Recently, he has worked on the subject of orographic precipitation with particular attention to:

- The role of gravity waves controlling the pattern of forced ascent
- Testing a linear theory of orographic precipitation and determining the physical “delay times” in clouds
- The role of smaller scale terrain elements in controlling precipitation patterns (Where is the cut-off?)
- The physical nature of spill-over and the foehn wall, where condensed water that has not precipitated evaporates back into the vapor state.
- Testing the hypothesis relating precipitation rate to horizontal water vapor flux
- Developing complementary methods for estimating the Drying Ratio; including stable isotopes, GPS, dropsonde curtains, and models.

Three recent/current Yale projects have laid a foundation for studies of water vapor flux and drying ratio in SHARE. Isotope data from Oregon*, Patagonia** and Northern California suggest drying ratios between 30% and 50%. Due to the range of terrain scales in these mountains, their drying ratios are sensitive to the characteristic time for clouds to produce precipitation. Data from all three regions are consistent with cloud delay times in the range of 1200 to 2000 seconds. Key questions relate to the validity of the isotope DR estimates, the role small scale terrain, the role of embedded convection and the speed of evaporation over lee slopes. (*JAS 2005, **JHM 2007)

All of these issues can be studied using the proposed observational system in SHARE. During the field phase, the PI will be directly involved with: installing the Yale K-band vertically pointing radar, flying on the HIAPER, monitoring lee slope spill-over, measuring water vapor fluxes, and collecting water samples for isotope analysis.

The PI has recently been awarded three years of funding from NSF (December 2005 to November 2008) to study the role of mountains on climate, including orographic precipitation studies in Patagonia, Europe and N. California. According to current projections, this funding may expire just before the SHARE field phase. Either a new grant or supplemental funds may be sought to cover extra costs associated with the SHARE field program (see below). Additional three year funding will be needed to support data analysis and modeling.

Supplement budget for SHARE field phase

Item	*Cost*
Travel (including per diem and car) 3 people	$18,000
Gauges, Loggers, power, expendables	$ 8,000
Isotope Analysis	$10,000
Indirect Costs	$21,000
Total	$55,000

PIs: **W. James Steenburgh* and Gregory S. Poulos**$^+$
*Department of Meteorology, University of Utah, Salt Lake City, UT
$^+$National Center for Atmospheric Research, Earth Observing Laboratory, Boulder, CO

Joint interactions between frontal systems, blocked flow, and flow over traverse ridges in the storm-scale morphology of alpine precipitation

Prior research shows that the development of flow-orthogonal/barrier-parallel jets by topographic blocking upstream of mountain barriers (e.g., the Alps, Rockies, Sierra Nevada, and Coastal Ranges of western North America) influences the development and distribution of orographic precipitation. Less well understood is how such topographic blocking, and its influence on precipitation processes and rates, is affected by diabatic processes, turbulence, and interactions with frontal systems. In addition, the small spatial-scale variability of precipitation across transverse ridges under either cross- or along-ridge flow is a source of interest and frustration for those trying to understand the detailed physics of precipitation generation and fallout over complex terrain (Colle et al. 1999, Poulos et al. 2002).

We therefore propose to investigate how the joint interactions between frontal systems, blocked flow and flow over traverse ridges control the development and distribution of orographic precipitation over and upstream of the windward slope of the Sierra (c.f. Section 2.2, Questions 2 and 3). The proposed comprehensive and geographically-focused SHARE field assets provide a superb correlative dataset for examining the temporal evolution of these phenomena and their interactions at the mesoscale. Since complex terrain precipitation gradients are seldom measured with sufficient density or at the relevant topographic scale such that their development can be assessed, we propose to deploy two meso-γ-scale precipitation transects. The fine-scale precipitation transects across traverse ridges at two elevations (see Section 7, mixed precipitation and snow), combined with other SHARE measurements, would be used to investigate the processes responsible for barrier-normal and parallel hyper-gradients of precipitation. Kinematic and thermodynamic profiles collected by the ISS, GAUS and other profiling systems will be used to document the modification of fronts traversing the Sierra Nevada, particularly on the windward slopes where the blocking of landfalling cold fronts retards narrow cold-frontal rainbands and may also lead to differential temperature advection, and the generation or enhancement of potential instability (Smith 1984; Shafer et al. 2005). SHARE's DOWs will enable dual-Doppler analysis of the evolution of blocked flow and associated precipitation enhancement under evolving large-scale flow (Cox et al. 2005). The NOAA P-3 tail radar will sample winds in otherwise unsampled areas, enabling a complete view of the horizontal and vertical structure of blocking effects over the entire windward Sierra slope.

This 3 yr budget supports research by PI Steenburgh and a post-doc (none required for Poulos).

	Field Year (1)	*Non-Field Years (2)*	**Total**
Salaries & Benefits	$70,000	$70,000	
Travel (including per diem)	$20,000	$6,000	
Equipment	$10,000	0	
Publications	$0	$3,000	
Materials and Supplies	$3,000	$2,000	
Indirect costs	$51,000	$40,000	
Total	$154,000	$121,000	**$396,000**

PIs: **Mark T. Stoelinga and John D. Locatelli**
Department of Atmospheric Sciences, University of Washington, Seattle, WA

Observations and Modeling of the Characteristics of Falling and Accumulating Snow in the Sierra Nevada Mountains

Field experience and research results obtained from the IMPROVE field project (carried out in the Pacific Northwest in 2001) have pointed toward the importance of the details of snow particles and associated microphysical processes in the development of precipitation associated with winter-time cyclonic storms and orographic environments. However, snow particles are generally represented in simplistic ways in the bulk microphysical schemes that mesoscale models use to develop cloud and precipitation hydrometeors and produce quantitative precipitation forecasts at the ground.

To address this deficiency, we have begun an NSF-supported observational and modeling study to better understand and quantify the characteristics of falling snow particles in an orographic environment. That study involves long-term ground observations of the properties of falling and accumulating snow particles during two winters in the Washington Cascade Mountains (2006/2007 and 2007/2008). The measurements of falling snow particles will focus on particle size distributions and fall speeds as a function of particle habit type. The observations will also include measurements of the depth and density of accumulating snow as a function of particle habit, which will provide important information for forecasting snow depths and avalanche hazard. In addition to the observational component of this study, we are continuing to develop and test our snow habit prediction scheme within the Thompson bulk microphysical scheme used in WRF and MM5.

The SHARE field project, proposed for the Sierra Nevada Mountains during December 2008—January 2009, introduces an opportunity for us to augment our observational data set in a manner that would be mutually beneficial to our research goals and the broader goals of the SHARE project. SHARE would benefit from our participation by gaining a suite of surface-based microphysical observations (size distribution and fall speed from a video disdrometer, microscope observations of particle habit, precipitation rate measurements, and the depth and density of accumulating snow) that help to elucidate microphysical processes in the all-important lowest 1-2 km above the terrain, a region that cannot be sampled by aircraft due to minimum safe altitude restrictions. The combination of our surface observations and SHARE's airborne in situ and remotely sensed microphysical measurements above and upwind of the surface site would allow for a complete description of the microphysical history of particles falling through the depth of the storm system, rather than just the final result at the ground. Furthermore, observations of snow characteristics at a barrier with a significantly a different profile and upstream climatology than those of the Cascades will improve the variety of our snow data set.

Three year budget estimate (all numbers in $1000s).

	Field Year	*Non-Field Years*		
	(1)	*(2)*	*and (3)*	**Total**
Salaries	24	37	73	134
Travel (including per diem)	31	5	5	41
Equipment	5	0	0	5
Services, Supplies, Publications	4	5	5	14
Tuition	1	7	12	20
Indirect Costs	33	26	47	106
Total	**98**	**80**	**142**	**320**

PI: **Sandra E. Yuter**
North Carolina State University, Raleigh, NC

Multi-scale kinematic and microphysical mechanisms of orographic precipitation

Recent field programs (MAP, IPEX, IMPROVE II) have documented evidence for a wide variety of small-scale orographic precipitation enhancement mechanisms including gravity waves over the windward slope (Colle 2004; Garvert et al. 2007), shear layers (Houze and Medina 2005), and upward motion associated with individual small scale peaks in terrain (Medina and Houze 2003, Smith et al. 2003, Garvert et al. 2005). Comparisons of observations with model output have revealed large underestimates and overestimates of surface precipitation depending on the environmental and topographic setting (Colle et al. 2005, Garvert et al. 2005) indicating that these errors are not endemic to the model parameterizations but rather situation dependent. Previous studies were unable to determine the relative importance of different mechanisms of orographic enhancement which has implications for understanding and modeling the basic physics of orographic precipitation spatial variability.

The multi-scale radar observing network of SHARE provides the opportunity address objectives related to SHARE Questions 3 and 4 (Sec. 2, SPO) with rigor and detail. The combination of the coarser scale dual Doppler winds and precipitation pattern information from the combination of the WSR-88D radars and S-POLKA, with the finer scale microphysics and kinematic observations by S-POLKA, the DOWs, the NOAA P-3, the University of Wyoming King Air, and the vertically pointing radars (S-band and Ku-band) will yield a unique combination of simultaneous detailed measurements and their larger scale context. Particularly important to determining the relative importance of different orographic mechanisms are their role in creation versus enhancement versus diminishment of small convective cells. Tracking of individual cells with the coarse scale radar network prior to and subsequent to the cell's intersection with the domain of a fine-scale observation resource will provide information to aid in resolving the steady-state versus intermittent nature of precipitation enhancement processes. The divergence field derived from large scale 3D wind field will aid in determining the evolution of windward slope upward and downward motions detected by the NOAA P-3 radar and DOWs. Downward motions (where existing condensed water can evaporate) may play as important a role as upward motions (where additional water condenses) in determining the pattern of small scale precipitation variability. Additionally, surface based disdrometer data will be analyzed to document particle size distributions and to determine to what degree signatures of particular microphysics processes are present.

The relative importance of a particular orographic mechanism can be examined by first closely coordinating model and observation analysis to determine that the simulations are realistic as well as plausible and subsequent testing of the sensitivity of the 3D model fields to particular orographic mechanisms. In close collaboration with B. Colle, computers at NCSU will host 1-2 of the ensemble model members (Sec. 6.1, SPO). Key collaborations for the proposed work are with D. Kingsmill and R. Houze (radar observation analysis) and B. Colle and Y. L. Lin (model ensemble, evaluation of model output and sensitivity testing of orographic mechanisms within regional models).

Includes field phase costs for PI, instrument engineer, 2 grad students, and 1 undergrad hourly and non-field support for PI, 2 grad students, and 2 undergraduate hourlies.

	Field Year	*Year 2*	*Year 3*	**Total**
Salaries	$71,419	$77,858	$80,568	$229,845
Travel (incl. per diem)	$35,000	$3,500	$3,500	$42,000
Other Direct Costs (incl. pubs)	$10,355	$9,200	$9,611	$29,167
Tuition	$14,828	$15,569	$16,348	$46,746
Indirect Costs	$53,716	$41,657	$43,093	$138,465
Total	$185,318	$147,784	$153,120	**$486,222**