1. Cover Sheet

Proposal Title: ARM Cloud Aerosol Precipitation Experiment (ACAPEX)

Date submitted: May 1, 2012

Principal Investigator
L. Ruby Leung, Pacific Northwest National Laboratory

Co-Principal Investigators
Kim Prather, University of California at San Diego, Scripps Institution of Oceanography
Marty Ralph, NOAA Earth System Research Laboratory
Danny Rosenfeld, Hebrew University of Jerusalem
Ryan Spackman, NOAA Earth System Research Laboratory, Science & Technology Corporation (STC)

Co-Investigators
Chris Fairall, NOAA Earth System Research Laboratory
Jiwen Fan, Pacific Northwest National Laboratory
Samson Hagos, Pacific Northwest National Laboratory
Mimi Hughes, NOAA Earth System Research Laboratory, CIRES
Chuck Long, Pacific Northwest National Laboratory
Sally McFarlane, Pacific Northwest National Laboratory
V. Ramanathan, University of California, San Diego, Scripps Institution of Oceanography
Steven Rutledge, Colorado State University
Duane Waliser, NASA Jet Propulsion Laboratory
Hailong Wang, Pacific Northwest National Laboratory

Dates of Proposed Deployment of AMF2 and AAF
December 2014 – April 2015

Location of Proposed Deployment of AMF2
Eastern North Pacific Ocean: Repeated Near North-South Transects on NOAA R/V Ron Brown

Location of Proposed Deployment of AAF
Coastal and Inland of Central California

Table of Contents

2. Abstract

The western U.S. receives precipitation predominantly during the cold season when storms approach from the Pacific Ocean. The snowpack that accumulates during winter storms provides about 70-90% of water supply for the region. Understanding and modeling the fundamental processes that govern the large precipitation variability and extremes in the western U.S. is a critical test for the ability of climate models to predict the regional water cycle, including floods and droughts. Two elements of significant importance in predicting precipitation variability in the western U.S. are atmospheric rivers and aerosols. Atmospheric rivers (ARs) are narrow bands of enhanced water vapor associated with the warm sector of extratropical cyclones over the Pacific and Atlantic oceans. Because of the large lower-tropospheric water vapor content, strong atmospheric winds and neutral moist static stability, some ARs can produce heavy precipitation by orographic enhancement during landfall on the U.S. West Coast. While ARs are responsible for a large fraction of heavy precipitation in that region during winter, much of the rest of the orographic precipitation occurs in post-frontal clouds, which are typically quite shallow, with tops just high enough to pass the mountain barrier. Such clouds are inherently quite susceptible to aerosol effects on both warm rain and ice precipitation-forming processes.

This proposal requests the deployment of the DOE ARM Mobile Facility 2 (AMF2) and the ARM Aircraft Facility (AAF) G1 in a field campaign called ARM Cloud Aerosol Precipitation Experiment (ACAPEX), which will take place in December 2014 – April 2015 in conjunction with CalWater 2 – a NOAA field campaign. The joint CalWater 2/ACAPEX field campaign aims to improve understanding and modeling of large-scale dynamics and cloud and precipitation processes associated with ARs and aerosol-cloud interactions that influence precipitation variability and extremes in the western U.S. We propose an observational strategy consisting of the use of land and offshore assets to monitor (1) the evolution and structure of ARs from near their regions of development, (2) long range transport of aerosols in eastern North Pacific and potential interactions with ARs, and (3) how aerosols from long-range transport and local sources influence cloud and precipitation in the U.S. West Coast where ARs make landfall and post-frontal clouds are frequent.

Deployed onboard the NOAA R/V Ron Brown, AMF2 will provide critical measurements to quantify the moisture budget and cloud and precipitation processes associated with ARs, and to characterize aerosols and aerosol-cloud-precipitation interactions associated with aerosols from long-range transport in the Pacific Ocean. The G1 aircraft will probe the clouds that form over the ocean and their transformations upon landfall as well as the orographic effects over the coastal range and the Sierra Nevada. The G1 flights will provide the critical information needed for comparing the simulated and observed processes of the vertical profiles of cloud microstructure, and the resultant precipitation initiation and glaciation. This will allow the development and validation of more realistic simulations that will replicate the aircraft measurements and thus quantify more reliably the entities that cannot be obtained directly by the aircraft measurements to improve understanding and modeling of aerosol-cloud-precipitation interactions.

3. Summary of the Proposed Activity Including Scientific Objectives

This ACAPEX proposal requests the deployment of AMF2 onboard the NOAA R/V Ron Brown in the eastern North Ocean and the AAF G1 for flights over coastal and inland of central California. The overarching objectives of ACAPEX, in conjunction with the NOAA CalWater 2 field campaign, are to provide measurements to:

- Document and quantify the structure and evolution of atmospheric rivers (ARs) and their moisture budgets
- Improve understanding and modeling of the influence of the tropics, including tropical convection and the various intraseasonal modes of variability associated with tropical convection, on extratropical storms and ARs
- Characterize aerosols and microphysical properties and examine aerosol removal processes over the Pacific Ocean
- Improve understanding and modeling of aerosol-cloud-precipitation interactions in clouds transitioning from the maritime regime to the orographic regime

CalWater 2/ACAPEX will address two broad sets of science questions:

- What influences the evolution and structure of AR and its associated cloud and precipitation?
    - To what extent does water vapor in ARs originate from the tropics? What role does tropical convection play in this?
    - What are the roles of air-sea fluxes and ocean mixed layer processes in AR evolution?
    - What are the key dynamical processes that modulate cloud and precipitation from landfalling ARs?
- How do aerosols affect the amount and phase of precipitation?
    - How frequent are aerosols transported across the Pacific and what characteristics make them effective CCN and/or IN? How does cloud processing of aerosols influence the aerosol properties and cloud forming ability?
    - How do aerosols from long-range transport and local sources influence cloud and precipitation over California, in both AR and non-AR conditions?
    - How do aerosols influence cyclogenesis and the thermodynamic development of extratropical cyclones and the coupled atmospheric rivers associated with these storms?
    - How are the aged and new aerosols from local California sources such as those in the Bay Area, Central Valley, and Sacramento eventually removed in the different precipitation systems?

To address the first set of questions, analysis using data from CalWater 2/ACAPEX and numerical modeling will be performed to quantify the AR moisture budgets, evaluate the AR moisture budgets simulated by regional and global models and global reanalyses, assess the contributions to the moisture carried by ARs from different regions and processes, and elucidate the dynamical forcing that provides the linkage between tropical and extratropical processes associated with ARs. In addition, we will combine data of the offshore moisture budget with data from the NOAA Hydrometeorological Testbed over land to investigate how large-scale moisture transport and meteorological conditions influence the occurrence and characteristics of the Sierra Barrier Jet (SBJ), which has been shown to have significant impacts on the spatial distribution of precipitation as ARs make landfall in central California.

To address the second set of questions, we will make use of aerosol and cloud measurements from the G1, NSF/NCAR G-V, NOAA WP-3D, and AMF2, including the single particle mass spectrometer (ATOFMS) with source apportionment on G1, to investigate some leading-edge issues related to aerosol-cloud-precipitation interactions, how they may be vary with aerosols from long-range transport versus local sources, and how aerosols may potentially influence large-scale circulation that modulate AR structure and evolution. The following provides examples of analysis and modeling that will be performed using the wide range of measurements from CalWater 2/ACAPEX.

1) Measurements of aerosol and cloud condensation nuclei (CCN) composition and size distribution as well as ice nuclei (IN) concentration from NSF/NCAR G-V and NOAA WP-3D flying over the east Pacific Ocean will provide an excellent opportunity to examine aerosol properties after processing by the marine environment and investigate how the processed aerosols impact maritime clouds and the large-scale systems such as extratropical cyclones and ARs.

2) Measurements from G1 will be used to document the occurrence of supercooled liquid water and raindrops in different types of clouds. Analysis will be performed using aerosol and cloud microphysical data to elucidate the role of aerosols on the formation and maintenance of supercooled liquid water and raindrops. Numerical modeling with a detailed spectral bin microphysics parameterization will be performed in combination with the data analysis to test different hypotheses of the role of aerosols in precipitation-forming processes.

3) G1 data will be used to investigate the impacts of dust and biological particles on clouds and precipitation. Analysis of vertical profiles of particle numbers from different aerosol species and ice water content will be performed to establish their statistical relationships. The effects of long-range transport of dust and biological particles on precipitation will also be studied using model to understand the potential role of the seeder-feeder mechanism.

4) Parameterizations of aerosol-cloud interactions will be assessed using data from the G1, NSF/NCAR G-V, and NOAA WP-3D. Our focus will be on ice nucleation that plays a critical role in converting liquid to ice in the mixed-phase cloud regime, and on aerosol wet removal and transformation through cloud processing, which can affect long-range transport, spatial distribution and chemical/physical properties of aerosol particles, with important implications to direct and indirect aerosol forcing in climate models.

4. Project Description

4.1 Background and motivation

The western U.S. receives precipitation predominantly during the cold season when storms approach from the Pacific Ocean. The snowpack that accumulates during winter storms provides about 70-90% of water supply for hydropower generation, irrigation, and other uses. However, not all winter storms result in water that can be captured and utilized. Heavy precipitation can lead to floods that are damaging, with little net water gain in reservoirs. On the other hand, reduced precipitation from winter storms or redistribution of precipitation over the complex terrain can have significant implications to water supply year round. Understanding and modeling the fundamental processes that govern the large variability of precipitation in the western U.S. is a critical test for the ability of climate models to simulate clouds and precipitation and to predict the regional water cycle and extremes from intraseasonal to century time scales.

Two elements of significant importance in predicting precipitation variability in the western U.S. are atmospheric rivers and aerosols. Atmospheric rivers (ARs) are narrow bands of enhanced water vapor associated with the warm sector of extratropical cyclones over the Pacific and Atlantic oceans (Zhu and Newell 1998; Ralph et al. 2004; Bao et al. 2006). Some cool season ARs appear to entrain water vapor directly from the tropics (Bao et al. 2006; Neiman et al. 2008; Leung and Qian 2009; Ralph et al. 2011). Because of the large lower-tropospheric water vapor content, strong atmospheric winds and neutral moist static stability, some ARs can produce heavy precipitation by orographic enhancement during landfall on the U.S. West Coast (Ralph et al. 2005, 2006; Neiman et al. 2008) (see Figure 1). Guan et al. (2010) showed that on average 6–7 events per year provided 40% of the total snow water equivalent (SWE) in the Sierra Nevada over a 7-year period studied. For more information on ARs, including a broad list of AR-focused formal publications, please see http://www.esrl.noaa.gov/psd/atmrivers/.

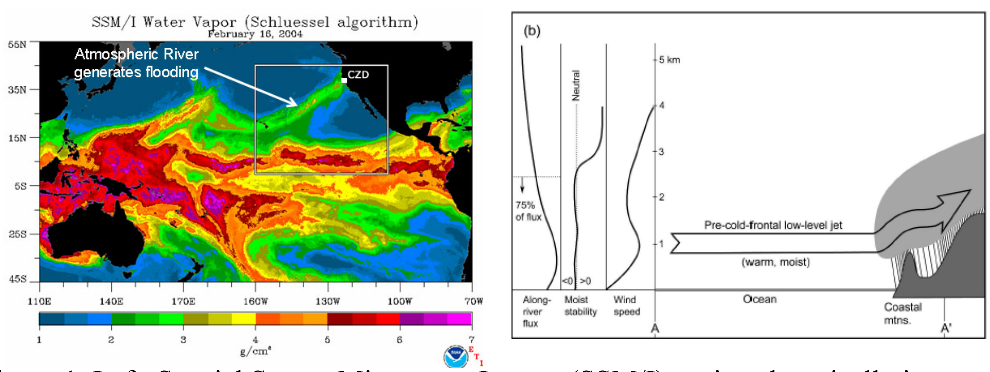

Figure 1. Left: Special Sensor Microwave Imager (SSM/I) retrieved vertically integrated water vapor on February 16, 2004 in which an AR was detected. Right: A schematic showing the vertical profiles of atmospheric moisture flux, moist stability, and wind speed associated with an AR and heavy precipitation as the AR makes landfall on the mountainous west coast.

While ARs are responsible for a large fraction of heavy precipitation in the western U.S. during winter, much of the rest of the orographic precipitation occurs in post-frontal clouds, which are typically quite shallow, with tops just high enough to pass the mountain barrier. In such conditions supercooled cloud water was documented to occur quite regularly in the western side of the orographic clouds over the topographic barrier when the cloud tops were >-15°C to -20°C (Heggli et al. 1983, Reynolds and Dennis 1986). Such clouds are inherently quite susceptible to aerosol effects on both warm rain and ice precipitation-forming processes.

Using observational records, Givati and Rosenfeld (2004) quantified the microphysical effect of anthropogenic aerosols on precipitation in the western U.S. Their study, further supported by the Suppression of Precipitation (SUPRECIP) field campaigns (Rosenfeld et al. 2008), suggests that aerosols that are incorporated in orographic clouds can efficiently slow down cloud-drop coalescence and riming on ice precipitation and therefore, delay the conversion of cloud water into precipitation. As a result, precipitation is redistributed with significant reductions on the upwind slopes and small compensation on the lee side, resulting in a net loss of precipitation and winter snowpack in the mountains.

In an effort to advance the scientific understanding, numerical modeling, and measurements of critical physical processes underlying future changes in water supply and flood risks, a multi-year field experiment CalWater has been formulated to study the AR and aerosol effects on precipitation (http://www.esrl.noaa.gov/psd/CalWater/). CalWater was jointly supported by NOAA and California Energy Commission (CEC). Field experiments were carried out in Jan – Feb 2009 and Jan – Mar 2010 at Sierra Nevada sites that include ground based aerosol and hydrometeorological measurements. In the Dec 2010 – Mar 2011 experiment, the PNNL G1 research aircraft flew between 2 February and 7 March 2011 and documented meteorology, cloud microphysics, and aerosol size and sources/composition in the Sierra Nevada and Central Valley.

The CalWater field experiments have documented important cloud and precipitation processes associated with the ARs and the significant role of the Sierra Barrier Jet (SBJ) in orographic enhancement of precipitation (Neiman et al. 2010; Lundquist et al. 2010). However, much remains unanswered as to the development of ARs and the amount and origin of moisture that is transported by the AR to feed the heavy precipitation in the west coast of the U.S. Previous studies by Mo (1999) and Bond and Vecchi (2003) have linked tropical variability including the Madden-Julian Oscillation (MJO) to precipitation in the western U.S. Matthews and Kiladis (1999) found that enhanced convection over the Indian Ocean associated with MJO can provide favorable conditions for extratropical waves to propagate to the deep tropics and enhance high-frequency convective variability in the central Pacific. In response to the convective heating in the central Pacific, extratropical wave trains can propagate over the Pacific and North America (Jin and Hoskin 1995). Based on a detailed case study, Ralph et al. (2011) indeed found that the phasing of several major planetary-scale phenomena including the MJO and extratropical wave activities led to the direct entrainment of tropical water vapor into the AR that subsequently produced heavy precipitation over the coastal mountain ranges. More recently, Guan et al. (2011) showed that AR timing and frequency and snow water equivalent (SWE) in the Sierra Nevada are significantly augmented when MJO is active over the far western tropical Pacific. However, to what extent tropical-extratropical interactions involving the MJO play a role in ARs and the importance of the tropical and other moisture sources to heavy precipitation as ARs make landfall on the west coast is not known.

The Winter Storms and Pacific Atmospheric Rivers (WISPAR) campaign was a demonstration project of the NOAA dropsonde system on the NASA Global Hawk (GH) unmanned aircraft system. The GH flew three research flights for a total of almost 70 hours in February–March 2011 releasing dropsondes from near 60,000 feet altitude into ARs and mid-latitude cyclones. Dropsonde observations from four different AR transects during this campaign have provided important new information on the structure and evolution of ARs and characterized how well reanalysis data products represent AR conditions (Ralph et al., in preparation). Measurements similar to those collected from WISPAR over multiple years can provide significant information to capture the variability of AR moisture budgets to document the extent tropical-extratropical interactions influence AR timing, frequency, and intensity.

During the 2009 and 2010 CalWater field experiments, comprehensive aerosol chemistry and meteorological measurements documented the potential role of long-range (Asian) dust transport to precipitation in the Sierra Nevada. Comparing two storms with enhanced water vapor associated with AR conditions, Ault et al. (2011) hypothesized that Asian dust transported across the Pacific and incorporated into the upper altitudes of precipitation-producing clouds of a storm increased snowpack compared to the other storm with similar meteorological conditions but lower dust content in precipitation. Augmented by data collected on the G1 aircraft, the 2011 CalWater field experiment further provided important evidence of Asian dust on snowfall in the Sierra Nevada. In addition, the HIAPER Pole-to-Pole Observations (HIPPO) field campaigns measured a comprehensive suite of tracers of the carbon cycle and related species using the NSF/NCAR G-V aircraft during 2009-2011. From several meridional cross sections over the mid-Pacific, the HIPPO data showed episodes of high concentrations of black carbon (BC) from Asian sources (Spackman et al. in preparation) (Figure 2). How Asian aerosols including dust and BC influence precipitation in the western U.S. depends on their composition and concentrations as well as their ability to serve as ice nuclei (IN) and cloud condensation nuclei (CCN) as they are transported across the Pacific.

To fill the above gaps in our understanding and ability to simulate and predict AR and aerosol effects that influence cloud and precipitation, a CalWater 2 field experiment is being proposed by NOAA for 2014/2015 with an offshore focus to quantify the atmospheric water budget in ARs and characterize aerosols from long-range transport over the Pacific Ocean. The proposed ARM Cloud Aerosol Precipitation Experiment (ACAPEX) will deploy the DOE ARM Mobile Facility 2 (AMF2) and the ARM Aircraft Facility (AAF) G1 in conjunction with CalWater 2 observational assets to improve understanding and modeling of large-scale dynamics and cloud and precipitation processes associated with AR and aerosol-cloud interactions that influence precipitation variability and extremes in the western U.S. The G1 aircraft will document the precipitation forming processes and their interactions with aerosols upon landfall of the moist air masses and their impinging on the orographic barriers.

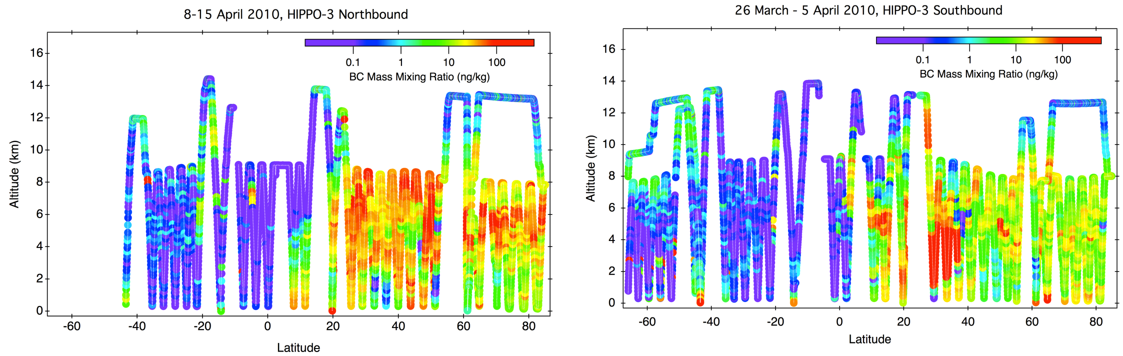

Figure 2. BC mass concentration from HIPPO-3 (NH spring 2010) showing very high loadings of BC-containing aerosol in the remote NH Pacific downstream of Asia during this period. These loadings (100 – 1000 ng/kg) are comparable to those typically observed in the boundary layers of large US cities.

4.2 Objectives and science questions

The overarching objectives of ACAPEX and CalWater 2 are to provide measurements to:

- Document and quantify the structure and evolution of ARs and their moisture budgets
- Improve understanding and modeling of the influence of the tropics, including tropical convection and the various intraseasonal modes of variability associated with tropical convection, on extratropical storms and ARs
- Characterize aerosols and microphysical properties and examine aerosol removal processes over the Pacific Ocean
- Improve understanding and modeling of aerosol-cloud-precipitation interactions in clouds transitioning from the maritime regime to the orographic regime

ACAPEX, in conjunction with CalWater 2, will address two broad sets of science questions:

- What influences the evolution and structure of AR and its associated cloud and precipitation?
    - To what extent does water vapor in ARs originate from the tropics? What role does tropical convection play in this?
    - What are the roles of air-sea fluxes and ocean mixed layer processes in AR evolution?
    - What are the key dynamical processes that modulate cloud and precipitation from landfalling ARs?
- How do aerosols affect the amount and phase of precipitation?
    - How frequent are aerosols transported across the Pacific and what characteristics make them effective CCN and/or IN? How does cloud processing of aerosols influence the aerosol properties and cloud forming ability?
    - How do aerosols from long-range transport and local sources influence cloud and precipitation over California, in both AR and non-AR conditions?
    - How do aerosols influence cyclogenesis and the thermodynamic development of extratropical cyclones and the coupled atmospheric rivers associated with these storms?

- How are the aged and new aerosols from local California sources such as those in the Bay Area, Central Valley, and Sacramento eventually removed in the different precipitation systems?

The above scientific questions are encapsulated by the schematic presented in Figure 3. The figure shows how the remote northern hemisphere Pacific troposphere is a dynamic part of the atmosphere that fosters the rapid development of extratropical cyclones. It also serves as the conveyor of some of the most polluted air masses globally. As shown in Figure 3, the large-scale flow advects anthropogenic and biomass-burning pollution as well as dust from Asia into the central Pacific, a region favorable for the development of storms especially during the cool season. Coastal mountains have important effects on mesoscale circulation and on how aerosols influence clouds and precipitation.

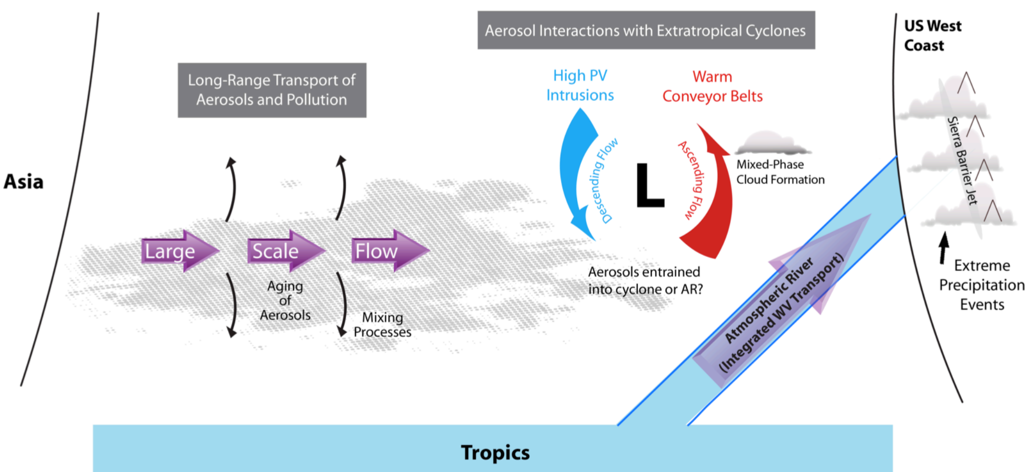

Figure 3. Conceptual framework for CalWater 2 / ACAPEX science objectives. The proposed observational strategy requests airborne and ship-based assets over the central and eastern Pacific complemented by ground-based and aircraft measurements along the U.S. West Coast.

Through data analysis and modeling, measurements collected from ACAPEX and CalWater 2 will be used to improve parameterizations of aerosol-cloud-precipitation interactions and to advance understanding and modeling of extratropical storms that produce heavy precipitation in the western U.S. Advances in these areas will lead to improvements in the predictions of global and regional hydrologic cycle, including droughts and extreme precipitation, and potential changes in the future climate, as well as improve weather forecasts of heavy precipitation distribution, including floods and droughts, in the western U.S.

4.3 Observational strategy

4.3.1 Overarching strategy for the joint CalWater 2/ACAPEX

We propose an observational strategy consisting of the use of land and offshore assets to monitor the evolution and structure of ARs from near their regions of development and long range transport of aerosols in eastern North Pacific and potential interactions between the two, as well as to investigate the interactions between aerosols and cloud/precipitation in the U.S. West Coast where ARs make landfall and post-frontal clouds are frequent. The ACAPEX observations are designed to complement the assets proposed for CalWater 2 in winter 2014-15. *More specifically, we request the deployment of the DOE ARM Mobile Facility 2 (AMF2) and the ARM Aircraft Facility (AAF) G1 for ACAPEX, in conjunction with instruments that will be requested/provided by NOAA for CalWater 2, to study moisture transport by AR and the role of tropical convection and tropical-extratropical interactions on AR development and aerosol effects on cloud and precipitation, respectively. Figure 4 shows a schematic of the overall CalWater 2/ACAPEX observational strategy.*

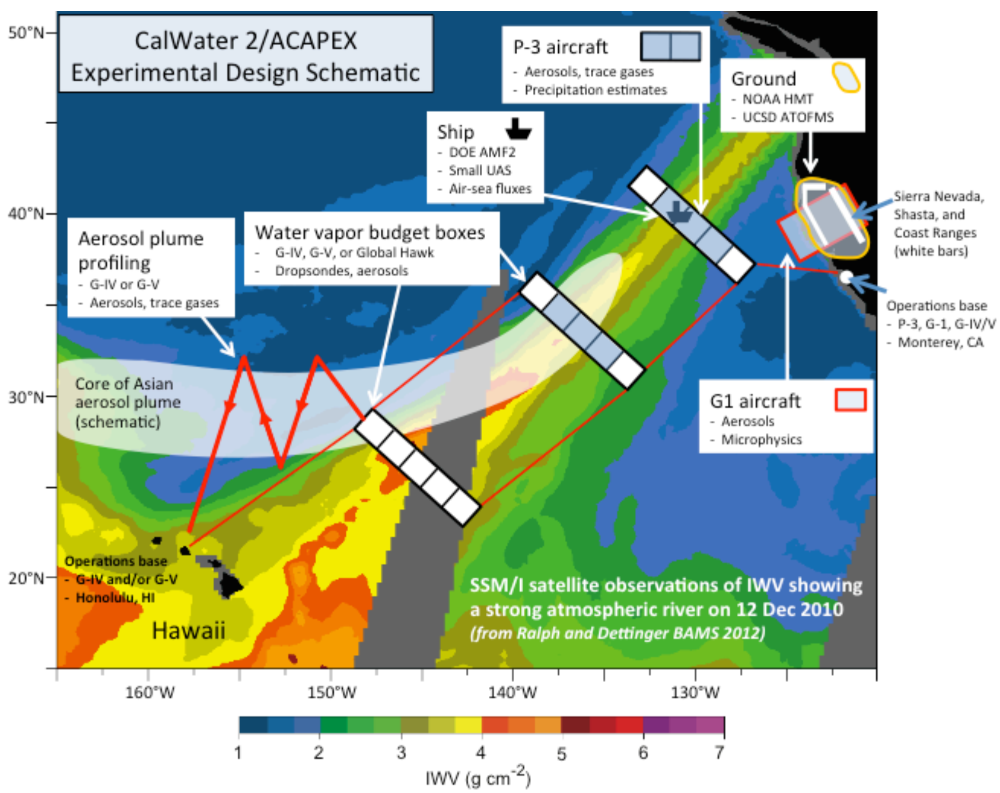

Figure 4. The CalWater 2/ACAPEX observational strategy using high- and low-altitude aircraft platforms, a ship with the AMF2, and a ground-based network including HMT assets and the UCSD /SIO ATOFMS. The aircraft assets include one or two aircraft offshore (NOAA WP-3D, NOAA G-IV, NSF/NCAR G-V, NASA Global Hawk) and the DOE G1 onshore. The experimental design is superimposed on SSM/I satellite observations from a strong AR event discussed in Ralph and Dettinger (2012). An Asian aerosol plume is shown schematically in the context of the AR to conceptually show the sampling strategy for both the AR (transects and water vapor flux boxes) and aerosol (profiling to the north and west of the AR) objectives. During such an AR event, the ship would be vectored along an aircraft transect of an AR to coordinate the observations. As the parent storm moves to the east, the AR would move to the south and east (toward the G1 sampling region in the diagram).

Both CalWater 2 and ACAPEX will also be able to leverage major land-based observations of the water cycle and ARs that are deployed as part of NOAA's Hydrometeorology Testbed (HMT; hmt.noaa.gov) and its legacy network for Enhanced Flood Response and Emergency Preparedness (EFREP) of 93 ground-based observing sites in California (Figure 5). We will also make use of polarimetric radars of the national network that can provide information on hydrometeor types and sizes. Data from six locations (San Francisco, Eureka, Beale Air Force Base, Sacramento, San Joaquin Valley, Reno) in the vicinity of our study region in central California will be particularly useful. The field experiment will occur during the cool season between December 2014 and April of 2015 – giving adequate sampling of a number of MJOs and/or significant tropical-extratropical interactions.

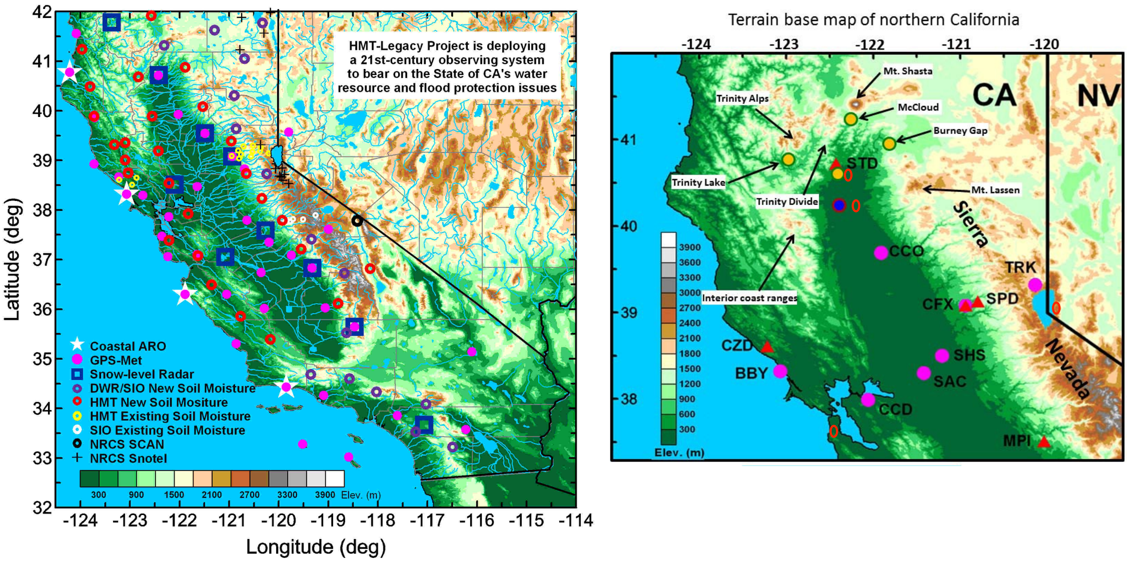

Figure 5. Left panel: A combined >100-site network of state-of-the-art hydrometeorological observations from NOAA's HMT and EFREP that will be in place by the end of Calendar year 2013. Most of the sites shown are already installed and operating as of April 2012. Right panel: The yellow dots mark proposed AROs with wind profiler, surface met and chemistry, and GPS-met. Blue dot marks proposed SkyWater scanning Doppler radar. Purple dots and red triangles are likely HMT ARO or snow-level radar sites. Open red circles show the locations of four polarimetric radars from the National Radar network.

The NOAA R/V Ron Brown will be requested as part of CalWater 2. CalWater 2/ACAPEX will include aircrafts and measurement systems, including AMF2, on board Ron Brown to measure all the water budget components of the AR including air-sea fluxes, atmospheric transport, and cloud and precipitation. The NASA Global Hawk or mid-altitude platform (e.g., NOAA WP-3D or NSF/NCAR G-V) will be deployed to measure thermodynamic and wind profiles using dropsonde observations. The NOAA P-3, with its tail Doppler radar will be used to measure horizontal divergence fields on the scales that drive precipitation and will use the high-spatial resolution reflectivity information to provide spatially extensive precipitation estimates. Small unmanned aircraft systems, Scripps Institution of Oceanography (SIO) UAS, launched and recovered from the ship will be used to observe the air-sea turbulent eddy fluxes of heat and momentum in the marine boundary layer and provide measurements of aerosol optical properties, cloud microphysical quantities, as well as meteorological conditions. Three unmanned aerial vehicles can fly at the same time in stacked formation to sample vertical variability. The AAF G1 aircraft will be deployed in the coastal and inland region of central California to provide measurements of clouds and aerosols. In addition, polar-orbiting observations from CALIPSO and CloudSat (A-Train satellite instruments) and MISR (onboard the Terra satellite) will provide important context for the planned field observations on clouds, aerosols, and precipitation in the region of study.

The overall suite of measurement platforms and instruments for CalWater 2 and ACAPEX is described below.

Aircraft Observations (NOAA, DOE, SIO)

In addition to the DOE G1 and SIO UAS, one to two facilities requests will be made for both high- and low-altitude observations for CalWater 2. Candidate platforms and accompanying payloads for CalWater 2 and ACAPEX are described in Table 1.

Table 1. Proposed Aircraft Observations

Aircraft Platform	Altitude Range (kft)	Location	Theater of Operations	Measurements
NOAA WP-3D	1–22	Coastal CA	Offshore CA	Aerosols (total aerosol in the accumulation/coarse modes, BC mass loadings and size distributions) Microphysics (CCN, IN, cloud water/ice, precipitation spectra Chemical tracers (CO, CO_2, O_3) Horizontal convergence observed by tail Doppler radar
NASA Global Hawk	45–65	Edwards, CA	HI to CA	Dropsondes (P, T, RH, wind speed/direction) HAMSR (T, integrated water vapor)
NSF/NCAR G-V	0.5–45	Coastal CA and/or Honolulu, HI	HI to CA	Aerosols (total aerosol in the accumulation/coarse modes, BC mass loadings and size distributions) Microphysics (CCN, IN, cloud water/ice, precipitation spectra Chemical tracers (CO, CO_2, O_3)
NOAA G-IV	1–45	Coastal CA and/or Honolulu, HI	HI to CA	Dropsondes (P, T, RH, wind speed/direction)
DOE G-1	1–23	Coastal/inland CA	On/Offshore CA	Aerosols (total aerosol number and size distributions, BC mass, dust, scattering/absorption, single particle mass spectrometer) and chemical pollution tracers (CO, O3) Microphysics (CCN, IN, cloud drop size distribution, cloud water/ice content) Atmospheric state (T, P, RH, wind, turbulence)
SIO UAS	Up to 10	Coastal CA	Near Offshore CA	Turbulent eddy fluxes of heat and momentum in MBL Total Aerosols (aerosol absorption coefficient, number concentration, size distribution) Cloud drop concentration Broadband and visible fluxes T, water vapor density and water vapor fluxes

Ship-based Observations (NOAA, DOE)

NOAA instruments:

- Precipitation radars
- Wind profiler
- Radiosonde observations (including tethered)
- Eddy correlation fluxes
- Near-surface meteorology
- Ocean mixed-layer structure, currents, turbulence and surface waves

DOE AMF2:

- Aerosol Observing System (AOS)
- Radar Wind Profiler (RWP)
- Vertically pointing W-band cloud radar
- Ceilometer, micropulse lidar (MPL), and high spectral resolution lidar (HSRL)
- 3-channel microwave radiometer (MWR3C)
- Portable Radiation Measurement Package (PRP2) and sun pyranometer (SPN)
- Atmospheric Sounder by Infrared Spectral Technology (ASSIST) [newer version of the atmospheric emitted radiance interferometer (AERI)]
- Meteorological instruments (MET)
- Bulk aerodynamics fluxes (BAF)

Ground-based Observations (NOAA, UCSD)

NOAA Hydrometeorological Testbed (HMT) and EFREP networks (Coastal and Central California, Figure 4):

- Wind profilers/Atmospheric river observatories (7-8 sites)
- S-band precipitation profilers (3-4 sites)
- Snow-level radars (10 sites)
- SkyWater scanning radar
- National polarimetric radar network (San Francisco, Eureka, Beale Air Force Base, Sacramento, San Joaquin Valley, Reno. See http://radar.weather.gov/)
- Meteorological tower observations
- IWV from GPS-met sites (>30 sites)
- Soil moisture at 10 cm depth (>30 sites)

UCSD: Sugar Pine Reservoir (co-located with NOAA-HMT)—same package as that used in CalWater 2009-2011 at this site:

- Aerosol time-of-flight mass spectrometer for source apportionment of ground-based aerosols to complement G1 measurements
- Aerosol size distributions (10 nm – 10 micron)
- CCN measurements
- Gas phase measurements (O_3, CO, SO_2)
- Aethalometer BC measurements
- Meteorology measurements

- NOAA profilers

To date, all 915-MHz wind profilers and S-band precipitation profilers (S-PROF) deployed for the HMT and CalWater field campaigns have been located in the central and southern portion of the Sacramento Valley (left panel of Figure 4), except for the S-PROF snow-level radar at Shasta Dam. In order to provide crucial observations to directly and continuously monitor the orographic forcing of precipitation in the Lake Shasta region, CalWater 2 plan to deploy four new atmospheric river observatories (AROs), where each ARO includes a 915-MHz wind profiler, a surface meteorological tower, a GPS receiver, and a surface chemistry sampler (right panel of Figure 5). The wind profilers provide hourly averaged vertical profiles of horizontal wind velocity from ~0.1 to 4.0 km above ground with ~100 m vertical resolution and ~1 m s^{-1} accuracy in all-weather conditions (e.g., Carter et al. 1995). In precipitating conditions, the wind profilers can detect the height of the precipitation melting level on an hourly basis using the objective radar bright band detection method of White et al. (2002). The meteorological towers provide 2-min observations of surface wind, temperature, moisture, and pressure, and collocated tipping buckets provide 2 min rainfall measurements with 0.01 inch (~0.25 mm) accuracy. Data collected from GPS receivers in tandem with collocated surface temperature and pressure measurements allow for the retrieval of integrated water vapor (IWV) through the full atmospheric column (e.g., Revercomb et al. 2003; Mattioli et al. 2007). Deployment of the DOE facilities is described in more detail in Section 4.3.2 below.

4.3.2 Objectives and strategies for ACAPEX

<u>AMF2 deployment</u>

The overarching goals of deploying AMF2 in the joint CalWater 2/ACAPEX campaign are two fold: (1) To quantify the moisture budget and cloud and precipitation processes associated with ARs, and (2) to characterize aerosols and aerosol-cloud-precipitation interactions associated with aerosols from long-range transport in the Pacific Ocean.

AMF2 will be deployed on the NOAA R/V Ron Brown, in conjunction with other instruments on board the ship as well as coordinated flights from aircrafts and launching of UAS from Ron Brown as shown in Figure 4. AMF2 will provide profile information, in conjunction with the dropsondes from aircraft and GH, to quantify the AR moisture budget. AMF2 will also provide surface flux measurements, which will be used in conjunction with other surface flux measurements from the ship and UAS measurements of turbulence fluxes to understand the role of air-sea exchange, boundary layer processes, and cloud and precipitation on the moisture budget near the surface and in the boundary layer. Combining these data with satellite measurements of clouds and moisture will provide information to quantify the role of tropical convection and the associated tropical waves on the development of ARs and quantify the evolution of moisture, cloud, and precipitation associated with ARs.

AMF2 will also provide measurements of clouds and aerosols that will be used in conjunction with cloud/aerosol measurements from aircrafts and UAS to characterize aerosols from long-range transport and understand the role of wet scavenging on aerosol characteristics. More details on the instruments requested for AMF2 are provided in Section 7, and research that will be undertaken using the data is described in Section 5.

AAF G1 deployment

The G1 aircraft will probe the clouds that form over the ocean and their transformations upon landfall as well as the orographic effects over the coastal range and the Sierra Nevada. This will include both thermodynamic and aerosol effects. Single particle measurements by ATOFMS (UCSD/SIO) will probe how the sources of aerosols seeding the clouds play a role in impacting cloud microphysics. Thermodynamic effects include the added solar surface heating or radiative surface cooling over land. The daytime solar heating can lead to enhanced convection and mixing with locally emitted aerosols and their precursors. The nighttime surface cooling can lead to decoupling of the surface from the marine air that invades the land, all the way to the Sierra Nevada, keeping the marine microstructure of the clouds undisturbed. Another important thermodynamic feature is the barrier jet, both ahead of the coastal range and the Sierra Nevada.

The G1 flights will focus on the initiation processes of precipitation and glaciation, as the evolution in both time and height provides key information for simulating the processes for the full lifetime of the clouds. Little information can be gained by flying through mature and glaciated cloud systems, because this state of the cloud could have been reached by a large variety of microphysical and thermodynamic processes. Documenting the way by which the cloud reaches this state is critically important, as it determines the precipitation distribution in time and space, as well as the vertical diabatic heating profiles, which couples the cloud and circulation systems.

The flights will provide the critical information needed to address the objective of comparing the simulated and observed processes of the vertical profiles of cloud microstructure, and the resultant precipitation initiation and glaciation. This will allow the development and validation of more realistic simulations that will replicate the aircraft measurements and thus quantify more reliably the entities that cannot be obtained directly by the aircraft measurements.

The G1 aircraft was deployed in the CalWater campaign during Feb – Mar 2011 to collect measurements for investigating aerosol-cloud interactions and their role in precipitation in central California. The instrument package we request is similar to that used in CalWater, including atmospheric states, liquid and total water content, cloud microphysics, aerosols, and gases (see Section 7 for more details), but with the benefit of the operational experience that will make instruments including CCN/IN counter and CVI fully operational in their optimal settings.

CalWater used flight plans with pre-determined trajectory, as shown in Figure 6. We propose to extend the flight plans to about 100 km into the ocean and adding to the pre-determined track several blocks of air space in areas that are not conflicting with major airways. Such blocks will be planned at the areas where clouds of interest occurred in CalWater, including:

- At the foothills and western slope of the Sierra Nevada to the east of Sacramento
- Over the crest to the east of Sacramento
- Over the high terrain of the Yosemite for best cap clouds
- Over the coastal mountains
- Over the ocean near the coast
- Far over the ocean

The flight plans will be prioritized for areas with good coverage of polarimetric radars of the national network for a better determination of the hydrometeor types. Similar to CalWater in spring of 2011, numerical weather forecasts in support of the field campaign will be provided by NOAA and tracers forecasts will be provided by PNNL for planning of the G1 deployment.

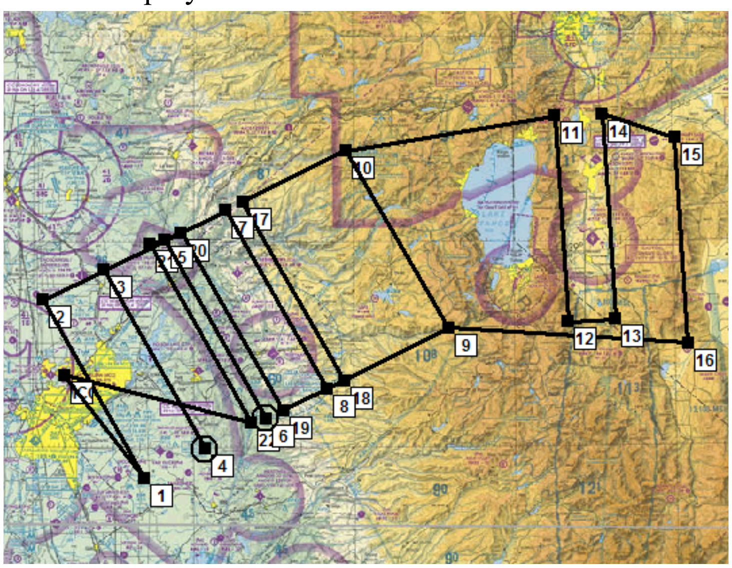

Figure 6. The main orographic flight plan for CalWater in the coastal and foothill areas of central California. The order of the flight plan was along the following points: 1-2-3-4-3-5-6-5-7-8-9-10-11-12-13-14-15-16-9-10-17-18-19-20-21-22-30.

4.4 Science

This section highlights some key findings from CalWater that motivate the CalWater 2/ACAPEX field campaign, and provides more detailed science questions that will be addressed using data collected from the joint CalWater 2/ACAPEX. The deployment of AMF2 will contribute primarily to science questions related to the ARs (Section 4.4.1) and the deployment of AAF G1 will contribute primarily to science questions related to aerosol-cloud-precipitation interactions (Section 4.4.2), but some science questions such as long-range transport of aerosols and potential influence on AR development and cloud and precipitation over land can take advantage of both platforms. More discussions of research that will be undertaken to address specific science questions using data and modeling will be provided in Section 5.

4.4.1 Evolution and structure of ARs

The WISPAR field campaign using the NOAA dropsondes system on the NASA Global Hawk provided unique insight into the performance of current operations reanalysis products on representing the water transport in ARs. Based on 4 flights on WISPAR and two from NOAA's P-3 in earlier experiments, preliminary analyses show that errors in AR water vapor transport range from 0.5-2 million acre-feet/day of equivalent liquid water in individual ARs (Figure 7).

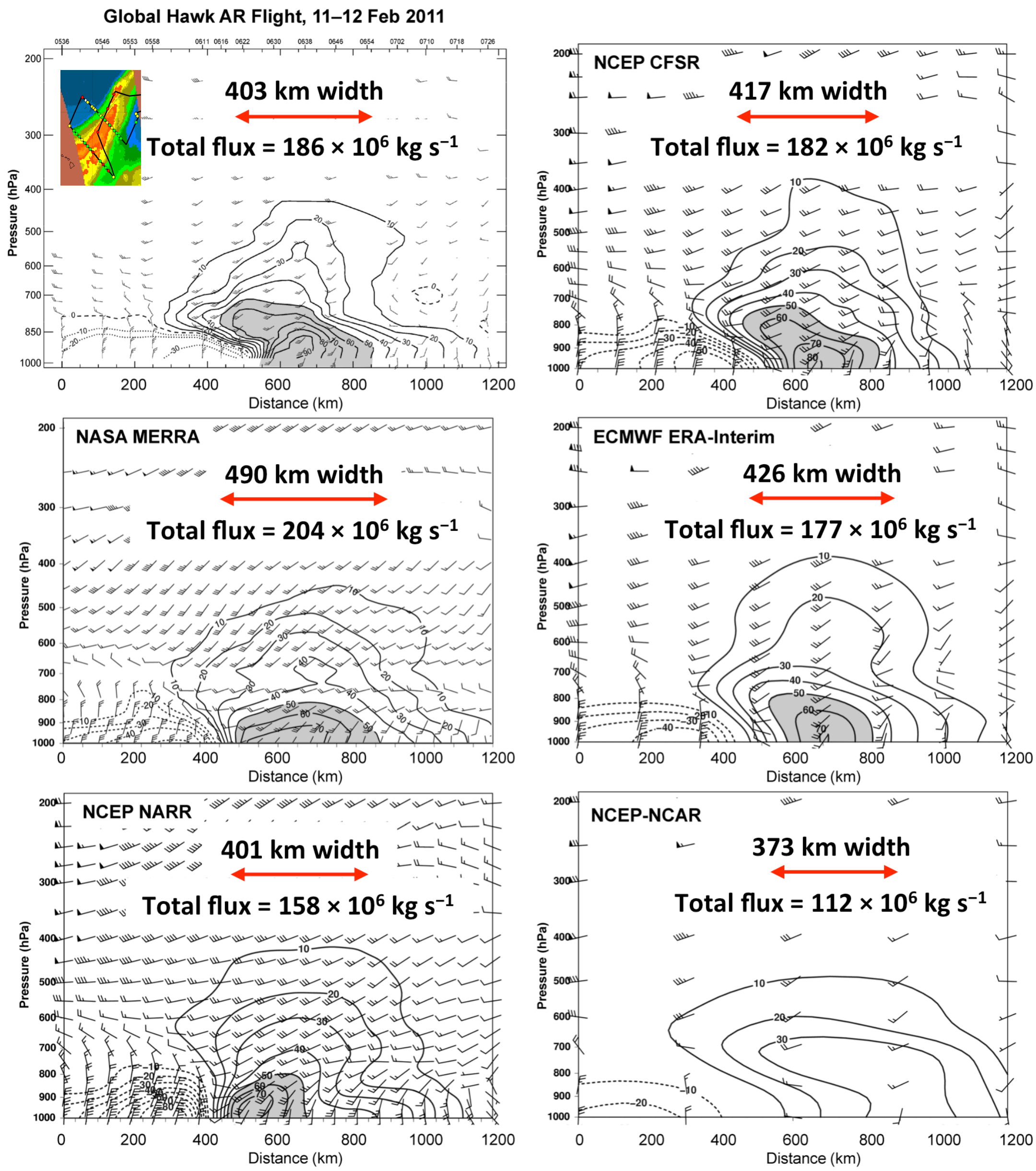

Figure 7. Cross-section showing the dropsonde data through the AR in the inset figure (top left panel) for the first Global Hawk science flight. The contours are along-front WV flux in units of kg m^{-1} s^{-1}. The AR, with a width of about 403 km, provides vertically integrated vapor transport equivalent to 11 times the water flow of the Mississippi River.

To put these results in context, the entire annual flow of the Colorado River averages about 15 million acre feet PER YEAR. Multiply this error by the several ARs present normally on the globe at any one time and then by the number days per year, and it is apparent that this represents a major uncertainty in the representation of the water cycle in state-of-the-art reanalysis (e.g., CFS-R, ERA-Interim, MERRA). This error was 3-4 times worse in the NCEP-NCAR reanalysis. Climate models likely have similar, if not more severe, biases with significant implications on their abilities to simulate moisture transport responsible for heavy precipitation and how heavy precipitation events may change in a warmer climate in many regions worldwide.

The unique observations proposed (see Figure 4), including critical instruments from AMF2 such as the cloud radar, wind/humidity profiler, and microwave radiometer (see Section 7 for more details) would enable the following analyses that will fill gaps in current understanding of AR structure and evolution, especially regarding the water vapor transport budget and the associated cloud and precipitation processes:

- How much water vapor is entrained directly from the tropics and how much of this makes it to the coast and falls as precipitation? What role does tropical convection play in the development of AR and its moisture budget?
- What fraction of rainfall in landfalling ARs results from air-sea fluxes of moisture from the ocean's surface and how much is from horizontal convergence of pre-existing atmospheric water vapor?
- How much rainout occurs in ARs over the ocean, and are the cloud and precipitation processes sensitive to possible influences of Asian aerosols?
- Does "recycling" of atmospheric water via evaporation in virga play a significant role in the AR water vapor transport budget?
- Can mesoscale frontal waves associated with the parent cold front of an AR be detected and if so, can this aid in predictions of AR duration at coastal sites (a critical factor controlling how extreme precipitation will be and where)?
- How does the Sierra Barrier Jet behavior modulate the mesoscale distribution of precipitation, aerosols and their impacts in the mountains near the north end of the Central valley (the primary water supply for northern California)?
- What global weather patterns (e.g., MJO, ENSO, Western Pacific decaying typhoons) affected by tropical convection most influence AR evolution, structure and impacts on the U.S. West Coast?
- Do ARs transport other key atmospheric gases or aerosols besides moisture?

4.4.2 Aerosol effects on cloud and precipitation

Orographic forcing is a unique and dominant mechanism for harnessing water vapor into consumable fresh water in the form of precipitation, snowpack, and runoff. How mountains redistribute the fresh water in time and space is an important aspect of the regional and global water cycle. About 60 – 90% of water resources originate from mountains worldwide. Aerosols, however, have an important role in determining the precipitation properties in orographic clouds. By modulating the amount and phase of precipitation, aerosols can redistribute precipitation spatially, leading to subsequent changes in snowpack, soil moisture, and runoff with important implications to regions that rely on mountain water resources.

Adding aerosols increases the CCN that nucleate more numerous and smaller cloud drops. This slows the drop coalescence and in turn the conversion of cloud water into rain drops. Aerosols can also slow the mixed-phase precipitation forming processes by decreasing the riming and growth rate of ice hydrometeors. Such effects have been demonstrated by a large number of studies using measurements from field campaigns (e.g., Rosenfeld 2000; Hudson and Yum 2001; McFarquhar and Heymsfield 2001; Yum and Hudson 2002; Borys et al. 2003; Andreae et al. 2004; Hudson and Mishra, 2007; Rosenfeld et al., 2008; Saleeby et al. 2008). Slowing the precipitation forming processes in shallow and short lived orographic clouds is expected to cause a net decrease in precipitation amount in the upwind slope of the mountains (Griffith et al. 2005), with some compensation at the downwind slope (Givati and Rosenfeld 2004 and 2005; Jirak and Cotton 2005; Rosenfeld and Givati 2006; Givati and Rosenfeld 2007; Rosenfeld et al. 2007; Cotton et al., 2010). Model simulations supported the hypothesis that adding CCN suppresses orographic precipitation (Lynn et al. 2007). However, adding ice nuclei (IN) to supercooled liquid clouds would increase precipitation. Numerical simulations that show enhancement of mixed-phase precipitation in the presence of aerosols that act as IN support these general trends (Muhlbauer and Lohmann 2009; Lohmann 2002).

In addition to the above processes, recent field campaigns including SUPRECIP and CalWater in central California where aerosol sources are abundant provided further insights on the role of aerosols on cloud and precipitation, and highlighted the presence of supercooled liquid water down to -21^{o}C and supercooled rain down to -12°C in weak convective cloud band associated with a cyclone over the ocean, and in laminar layer cap clouds over the ridge of the high peaks of the Yosemite section of the Sierra Nevada, at temperatures down to -21°C. Analysis of remote sensing data and modeling by Choi et al. (2010) suggests that supercooled liquid droplets can exist at temperatures as low as -40^{o}C and that the variations in the supercooled cloud fraction is negatively correlated with the frequency of dust aerosols. This finding suggests that the seeder-feeder mechanism that greatly enhances precipitation from cold clouds (Houze 1993) can be modulated by the IN concentration.

Indeed long-range transport of Asian dust has been shown to have an impact on air quality in western North American (VanCuren and Cahill 2002). Observational studies have also speculated the impacts of Asian dust through its role as IN on clouds and precipitation that impact snow production (Pratt et al. 2009; Sassen 2002). Using data from the CalWater Early Start campaign (22 February to 11 March 2009), Ault et al. (2011) showed that the presence of Asian dust may have increased precipitation by 1.4 times in an AR event compared to another AR event with similar water vapor transport, but without the presence of dust.

As a follow-on to the measurements in 2009 reported by Ault et al. (2011), one goal of G1 flights in CalWater 2011 was to assess the role of dust and biological particles that had been detected in ground based precipitation samples. Indeed, in the 2011 G1 flights, single particle measurements by Prather et al. (manuscript in preparation) showed the repeated importance of long range transported dust and biological particles from Asia and perhaps even further west impacting upper layer high altitude clouds. Importantly, days when long range transported dust and biological particles were present in the high altitude clouds corresponded with the largest amounts of snowfall on the ground. Such impacts of dust and biological particles were shown to impact a broad range of the mountains through precipitation measurements over a several hundred-mile north-south transect along the Sierras. In general, as shown in 2009 through precipitation measurements, a strong correlation (almost linear) was found between larger snowstorms and high amounts of dust in precipitation sample at ground level. From these measurements we hypothesized that days with extensive precipitation occurred when IN formed in high level clouds by dust/bio particles acted in the seeder feeder mechanism with enhanced riming occurring as IN fell through the lower level orographic marine clouds with large droplets, leading to extensive amounts of precipitation at the ground.

Previous research as well as specific findings described above has answered some old questions, while opening more new ones. Scientific questions that will be addressed using data from CalWater 2/ACAPEX include:

- How frequent is supercooled rain a main precipitation forming process in the CalWater area of interest in the various cloud types? Why was supercooled rain so abundant during CalWater while it was rarely reported earlier?
- How does dust and biological particles influence the occurrence of supercooled rain?
- How can highly marine clouds exist with sustained supercooled water and rain? This directly contradicts extensive reports that clouds glaciate naturally very fast in clouds that form in pristine air with large cloud drops (e.g., Rangno and Hobbs 1988 and 1991).
- How do different added aerosol types change the cloud and precipitation forming processes in maritime, weak convective cloud band over the ocean, and laminar layer cap clouds over the mountain ridges?
- How does wet scavenging (transformation and removal) of aerosols from long-range transport influence their ability to serve as IN and change how aerosols interact with clouds and precipitation over land?
- How well do current cloud microphysical parameterizations capture aerosol-cloud interactions in mixed-phase clouds?
- What are the implications for more accurate simulations of precipitation and modeling of aerosol impacts on precipitation?
- How do aerosols from local sources versus long-range transport affect precipitation phase and spatial distribution?
- What is the role of the Sierra Barrier Jet in aerosol transport and how does this influence cloud and precipitation?

Data to be collected from G1 in the proposed ACAPEX experiment will provide important information to elucidate different mechanisms of how aerosols influence cloud microphysical and precipitation forming processes.

5. Research

5.1 AR dynamics and structure and associated cloud and precipitation

AR dynamics and structure and sources of moisture

Data analysis and modeling will be performed to study the AR moisture budgets, contributions of remote sources to the moisture budgets, and dynamical mechanisms for the remote influence. Our objectives are:

- To document and quantify the moisture budgets of ARs
- To evaluate the AR moisture budgets simulated by regional and global models and global reanalyses
- To assess the contributions from different regions and processes to the moisture carried by ARs
- To elucidate the dynamical forcing that provides the linkage between tropical and extratropical processes associated with ARs

To understand the AR dynamics and structure, and thereby enable improved modeling of AR and the associated cloud and precipitation processes for weather forecasting and climate prediction, we need to improve our understanding of the moisture source of ARs. Recent Lagrangian analysis studies performed by Drummond et al. (2011) suggest that the tropical western Pacific (TWP) warm-pool is the main source of moisture for much of the northern hemisphere precipitation in summer. We hypothesize that this could also be the case for ARs in winter because TWP has little seasonal variability.

We will identify all AR events from the CalWater 2/ACAPEX field campaign and perform detailed analysis of the atmospheric moisture budgets and their evolution, using data from the dropsondes, profilers, as well as air-sea turbulent eddy fluxes in the marine boundary layer, surface flux measurements, and cloud and precipitation to diagnose the moisture tendencies due to advection, turbulence transfer, surface exchange, and cloud microphysical and precipitation processes (see the measurement strategy described in Figure 7). Ensemble simulations will be performed using a regional model such as the Weather Research and Forecasting model (WRF) (Skamarock et al. 2008) and/or a global variable resolution model such as the Model for Prediction Across Scales (MPAS) (Ringler et al. 2011), which is a relatively new dycore in the Community Atmosphere Model (CAM) with high resolution over the region of interest in a weather forecast mode to evaluate how well numerical models can capture the evolution and structure of the ARs in all the cases. In addition, we will also compare the moisture budgets derived from observations with global reanalysis data to assess their skill in capturing the evolution and structure of the ARs and the associated moisture budgets.

To investigate the remote sources and sinks of moisture that influences the ARs, the ensemble simulations that produce more accurate depictions of the AR moisture budgets will be used to provide some insights. More specifically, the divergent moisture flux method of Hagos and Cook (2009) will be applied to the ensemble simulations to identify the relative contributions from various regions to the moisture carried by the ARs. The potential role of intraseasonal variations in TWP heating and the associated subsidence over the eastern Pacific, i.e., variations in the Walker circulation, and the associated subtropical circulations in moisture transport, will be assessed using simulations from both global reanalysis and regional modeling, and satellite data of atmospheric moisture (e.g., AIRS), outgoing longwave radiation, and cloud liquid and ice water paths.

Our analysis will be guided by previous studies that highlighted the role of multi-scale processes in AR development and how it impacts the water cycle of the western U.S. Figure 9 is a conceptual schematic from Ralph et al. (2011) showing the processes involved in generating AR associated heavy precipitation in the west coast. At the large scale, MJO, Kelvin wave, and planetary-scale circulation provide the environments for the development of extra-tropical cyclones. At the synoptic scale, extra-tropical wave packet (EWP) energy dispersion allows tropical moisture to be tapped and transported by the AR. At the mesoscale, frontal wave influences atmospheric stability and development of the Sierra Barrier Jet, and interactions between the AR and the underlying topographical features influence precipitation intensity and spatial distribution.

Since the zonal pressure gradient between cyclonic and anti-cyclonic phases of extratropical wave train creates strong southwesterly wind that could transport moisture from the tropics, an important question remains what mechanisms control the intensity and southward excursion of these wave trains. Tropical intraseasonal variability (Guan et al. 2011) and East Asian cold surge (Jian and Deng 2011) have been proposed as important mechanisms. Furthermore quasi-geostrophic forcing associated with upper level potential vorticity anomalies has been suggested to destabilize the atmosphere by cold air intrusion resulting in lower level cyclonic circulation that enables moisture transports from the Tropics (Knipertz 2006). To shed some lights on the role of these mechanisms, idealized regional model simulations with localized forcing at various latitudes and longitudes and vorticity budget analyses will be used to quantitatively assess their relative impacts of dynamical mechanisms discussed above on the ARs. Regional model simulations with multiple idealized SST patterns of multiple spatial scales will be imposed to assess the roles of phasing and superposition in creating favorable condition of the formation of ARs as proposed by Ralph et al. (2011).

Using the idealized regional model simulations discussed above, we will investigate the phase relationship between the space-time variations in moisture supply and extratropical wave dynamics to assess the existence of modes of tropical variability that allow them to coincide in a manner that promotes the formation of ARs. Insights gained from the idealized experiments will inform our selection of case studies that may highlight conditions favoring different mechanisms. We will then perform data analysis using field data from CalWater 2/ACAPEX and satellite data in combination with numerical simulations to provide further insights on how multi-scale processes involving moisture transport, tropical convection, wave dynamics, and cloud and precipitation on the development and evolution of ARs.

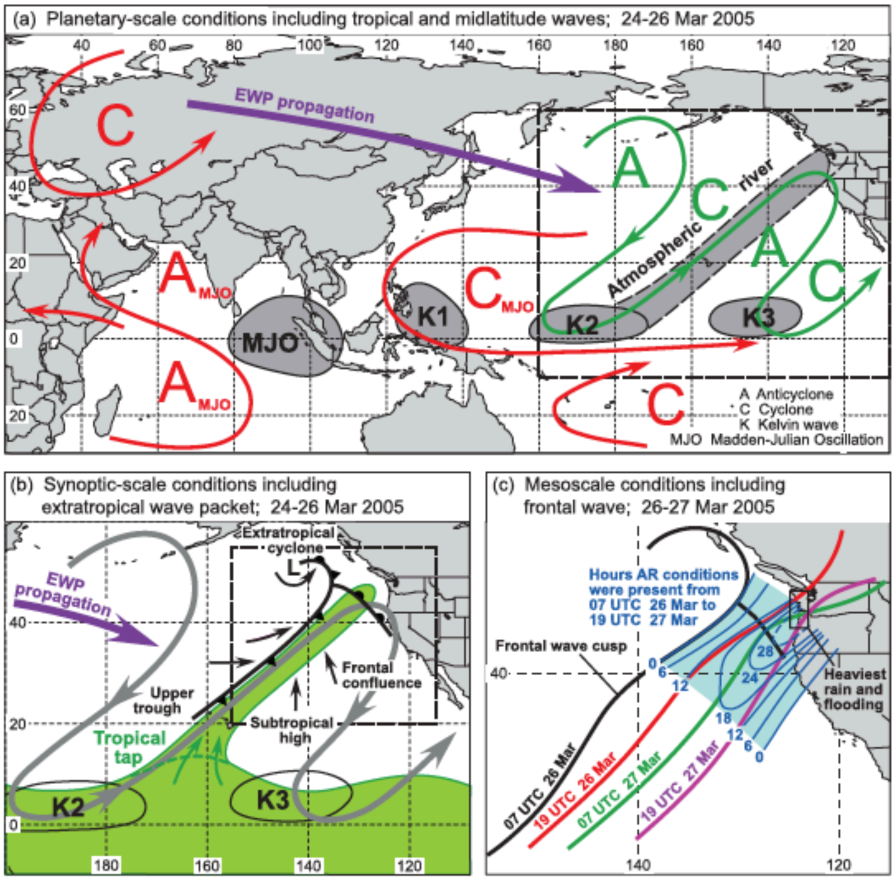

Figure 9. Conceptual schematic for a case study depicting tropical–extra-tropical interactions leading to the extrusion of tropical moisture into an AR over the eastern Pacific on 24–26 Mar 2005. (a) Large-scale depiction of 150-hPa streamline anomalies and the anticyclonic (A) and cyclonic (C) circulation centers. Gray shading depicts coherent cold cloud tops associated with the MJO, three Kelvin waves (K1–K3), and the AR. (b) Regional-scale depiction of the EWP and associated extra-tropical cyclone. Green shading depicts the tropical IWV reservoir and narrow IWV plume associated with the AR, and the green arrows depict the tapping of tropical water vapor into the AR. Kelvin waves 2 and 3 are enclosed with thin, black lines. A frontal isochrone analysis for 26–27 Mar 2005 is shown in (c), with a frontal wave propagating across the eastern Pacific and making landfall in northwestern OR where heavy rain and flooding occurred. The blue isopleths represent the number of hours of AR conditions. Source: Ralph et al. 2011.

Mesoscale distribution of cloud and precipitation

In addition to investigating the offshore AR moisture budget and processes or regions that contribute to the moisture of ARs, we will combine data of the offshore moisture budget with data to be collected from the NOAA HMT over land to investigate the relationships between the large-scale moisture transport and meteorological conditions such as moist static stability and low level jet offshore and the occurrence and characteristics of the Sierra Barrier Jet (SBJ), which has been shown to have significant impacts on the spatial distribution of precipitation as ARs make landfall in central California (Neiman et al. 2010). We will address the following questions:

- What offshore AR characteristics have the most influence on the development and structure of SBJ?

- How does the SBJ behavior modulate the mesoscale distribution of precipitation?

The SBJ is frequently observed over the western slope of the Sierra Nevada during winter (Parish 1982). A cold season regional modeling study (Kim and Kang 2007) suggests that the SBJ and the associated low-level moisture transport may be related with the large-scale circulation over the Eastern Pacific via the Froude number that characterizes the orographic flow. The critical Froude number for the existence of SBJ obtained in that study agrees closely with an earlier observation-based estimate by Kim and Mahrt (1992), perhaps by coincident. If such relationship can be firmly established using more extensive observational data and modeling from CalWater 2/ACAPEX, it can be a useful tool for forecasting local precipitation over the Sierra Nevada, a region of great interests for water resources and flash flooding for California. Wind profilers in the Central Valley and the Sierra foothill regions, in conjunction with the measurements of water vapor can provide a unique opportunity to understand the SBJ and the low-level transport of moisture.

5.2 Aerosol characteristics and interactions with cloud, precipitation, and large-scale circulation

We will make use of aerosol and cloud measurements from NSF/NCAR G-V, NOAA WP-3D, and AMF2, in conjunction with aerosol measurements from DOE G1, including the single particle mass spectrometer (ATOFMS) with source apportionment (Pratt et al. 2011) to investigate some outstanding issues related to aerosol-cloud-precipitation interactions, how they may be differ with aerosols from long-range transport versus local sources, and how aerosols may potentially influence large-scale circulation that modulate the AR structure and evolution.

Aerosol characteristics and effects of cloud processing

Measurements of aerosol and CCN composition and size distribution as well as IN concentration from NSF/NCAR G-V and NOAA WP-3D flying over the east Pacific Ocean will provide an excellent opportunity to examine aerosol properties after processing by the marine environment and investigate how the processed aerosols impact maritime clouds and the large-scale systems such as extratropical cyclones and ARs. Our objectives are:

- To quantify the properties of aerosols from long-range transport
- To investigate how cloud processing influence the abilities of aerosols to serve as CCN and IN
- To estimate how aerosols may influence the large-scale systems

Aerosol wet removal and transformation through cloud processing can affect long-range transport, spatial distribution and chemical/physical properties of aerosol particles, and consequently, direct and indirect aerosol forcing, the estimates of which remain highly uncertain in climate models. Wet scavenging processes followed by aerosol resuspension transform the aerosol, changing the size distribution, mixing state, and composition. Release of scavenged aerosol particles by evaporating cloud and raindrops also redistributes aerosol vertically. The treatment of the resuspension process in models is an integral part of wet removal and cloud processing. However, most current regional and global models neglect the transformation of aerosols by scavenging and resuspension, ignoring some possible feedback mechanisms. These processes remain key sources of uncertainty in global aerosol-climate models.

During the CalWater 2/ACAPEX campaign, extensive measurements will be made by DOE AAF G1, NSF/NCAR G-V, and NOAA WP-3D. We will first perform analysis of aerosol measurements including aerosol number concentrations, size distribution, and chemical composition to characterize the properties of aerosols from long-range transport and local sources statistically. Analysis of CCN and IN will also be performed to link the aerosol properties with CCN/IN concentration and size distribution.

We will also use the aerosol and cloud microphysical measurements along with process modeling to evaluate and improve wet removal processes in global and regional models such as the Community Atmosphere Model (CAM5) (Neale et al. 2010) and the Weather Research and Forecasting (WRF) model (Skamarock et al. 2008). We plan to address the following key science questions:

- Can measurements be used to identify the generic attributes of observed aerosols and clouds that control scavenging, and can we implement those properties in a model so that we can reproduce that behavior?
- How important are the changes to aerosol number, size, mixing state, and vertical distributions through scavenging followed by resuspension in affecting the droplet- and/or ice-nucleating ability of aerosols and precipitating clouds?

We will analyze measurements of chemical properties and size distributions of aerosol particles (particularly, in cloud inflow/outflow, and at various heights from near-surface to cloud top) and cloud/rain drop size distributions from ship-borne, ground-based and/or airborne instruments, and rain intensity (profile) from precipitation radars/profilers. These measurements will be used to derive empirical relationships such as aerosol activation fractions, drop-aerosol collection efficiency and scavenging coefficients that characterize size-dependent nucleation scavenging and impaction/diffusion scavenging. Measurements before, during and immediately after a precipitation event will be used to characterize local below-cloud scavenging. Measurements of clouds and precipitation will also be used to derive spatial and temporal frequencies of precipitation versus precipitating clouds. Observations of meteorological variables (temperature, humidity, pressure, winds, surface fluxes, vertical velocities, boundary-layer turbulence, etc.) will be used to identify uncertainties in the field-derived empirical relationships and to constrain process models.

In addition to wet removal, many other factors/processes can influence aerosol budget and distribution observed in the atmosphere and simulated in a climate model. Whether the climate model can be fed with accurate aerosol sources and can accurately predict clouds and precipitation will definitely affect the evaluation of aerosol wet removal against observations. Given the observational constraints and diagnostics produced from the measurements, detailed process models will be used to bridge this gap by performing the following two types of studies:

1) A cloud parcel model with detailed aerosol and cloud microphysics, taking measured vertical velocities, aerosol size distributions and chemical properties as input, will be used to evaluate the treatment of nucleation scavenging. The parcel model studies will also address the amount of unactivated aerosol within cloud, as not all aerosols enter clouds in an updraft at the cloud base.
2) In cloud-resolving models (i.e., WRF-Chem (Grell et al. 2005)), which have proven useful to simulate more realistic clouds and precipitation, scavenging processes (nucleation, impaction/diffusion, collection, resuspension) can be isolated to determine the importance of individual processes in cloud processing and wet removal of aerosols and, in turn, affecting rain-production and new-particle-formation processes. Scavenging relationships and assumptions plugged into cloud-resolving models will be compared and evaluated against diagnostics derived from field data.

We will conduct detailed model simulations to match the observations. The simulations will be sampled the same way as particular instruments do during the field campaign, to facilitate a fair comparison between model and observations. The detailed models will produce a more complete picture of aerosol wet removal and processing to gain new understanding, which will guide us to improve the current parameterizations in CAM5 and WRF for representing the types of cloud considered here.

To assess how aerosols may influence the large-scale systems, an ensemble of model simulations will be performed with perturbed initial meteorological conditions using aerosol properties derived from the data. Ensemble modeling is important to capture uncertainty in the large-scale conditions. The simulations will be evaluated using atmospheric moisture profile and moisture transport, cloud macrophysical and microphysical properties, and various surface fluxes from the suite of dropsondes, profilers, radars, and surface flux instruments. Sensitivity experiments using different aerosol properties and with perturbed initial meteorological conditions will then be performed to generate an ensemble of simulations for comparison with the simulations constrained by observed aerosol properties to investigate how aerosols entrained into large-scale systems influence their development and evolution. Contrasting cases with extratropical cyclones and atmospheric rivers will provide important insights on aerosol-cloud-climate interactions, with implications to large-scale systems that generate extreme precipitation in the western U.S. Previous studies on aerosol impacts on large-scale circulations are limited to modeling due to the lack of observational data (Fan et al. 2012; Khain et al. 2010; Cotton et al. 2007).

<u>Aerosol effects on coastal and orographic clouds and precipitation</u>

We will address the following science questions related to aerosol impact on clouds and precipitation:

- How does long-range transport of Asian pollution (dust and black carbon) impact cloud properties and precipitation of coastal clouds and orographic clouds in central California?

- How does AR regulate the effects of Asian pollution from long-range transport and local pollution over the Central Valley on orographic clouds and precipitation phase and amount, as well as effects on mountain snowpack?
- What mechanisms are responsible for the formation of the large supercooled droplets observed during the CalWater field campaign in 2011?

Recent field campaigns including SUPRECIP and CalWater in central California where aerosol sources are abundant have provided insights on the role of aerosols on cloud and precipitation that motivated the above questions:

- Aerosols from local sources affect clouds mainly during the afternoon and evening hours, when the solar surface heating induces vertical mixing.
- The air mass that feeds the clouds is often decoupled from the surface and the aerosol sources there, especially during late night and morning hours, when radiative surface cooling stabilizes the boundary layer. This is when marine air reaches the foothills of the Sierra Nevada and produces microphysically marine clouds in that region.
- It has been known for decades that extensive supercooled liquid water (SLW) occurs in the orographic clouds over the Sierra Nevada, especially in the post-frontal clouds (Reynolds et al., 1986 and references therein). But there were no previous reports of supercooled rain, although some was encountered during the SUPRECIP campaign (Rosenfeld et al. 2008). The main region of SLW occurs in orographically triggered convective clouds over the foothills. This SLW was documented in CalWater, in both polluted and pristine air masses.
- While the SLW was reported previously to diminish above the -15°C isotherm, large amounts of SLW were found in CalWater down to -21°C.
- It was found that persistent SLW occurred in clouds that are microphysically highly maritime, i.e., with small concentrations of large cloud drops that coalesce effectively into raindrops. In such cases the rain was highly supercooled (down to -21°C).
- Similar persistent supercooled rain (down to -12°C) was observed in weak convective cloud band associated with a cyclone over the ocean.
- Persistent supercooled rain was found also in laminar layer cap clouds over the ridge of the high peaks of the Yosemite section of the Sierra Nevada, at temperatures down to -21°C.

New measurements from G1 will be used to further document the occurrence of supercooled liquid water and raindrops in different types of clouds. Analysis will be performed using aerosol and cloud microphysical data to elucidate the role of aerosols on the formation and maintenance of supercooled liquid water and raindrops. Numerical modeling using WRF with a detailed spectral bin microphysics parameterization will be performed in conjunction with the data analysis to test different hypotheses of the role of aerosols in the aforementioned processes.

Motivated by Ault et al. (2011) based on results from a CalWater field campaign that showed the potential for Asian dust in impacting precipitation in California, the CalWater campaign in 2011 continued to investigate how dust and biological particles from long range transport may play a role in precipitation amount and phase. Figure 10 shows results from analysis of data collected from the CalWater 2011 campaign. Particle numbers for different species obtained from the single particle mass spectrometer of ATOFMS on G1 were estimated together with ice water content (IWC) by subtracting the liquid water content (LWC) from the total water content (TWC) sampled by the Multi Element Water Content System onboard G1 for each cloud pass, and cloud droplet and ice crystal images collected with a 2D-S (2D-S Stereo Probe, SPEC, Inc.). Figure 10 shows, for a case on February 16, 2011, that in the high altitude clouds (~3500-5000 m ASL), dust and biological particles were frequently coincident with primary ice, suggesting the dust and biological residues served as the IN in these clouds. The top inset shows 2D-S images of unrimed snow surrounded by supercooled droplets. The lower level clouds on these days contained mixtures of dust and biological particles in the same region of the clouds as ice, but as shown in the inset, the ice was rimed based on the 2D-S images. Snow became rimed and grew into graupel, supporting the importance of the seeder-feeder mechanism in this cloud system.

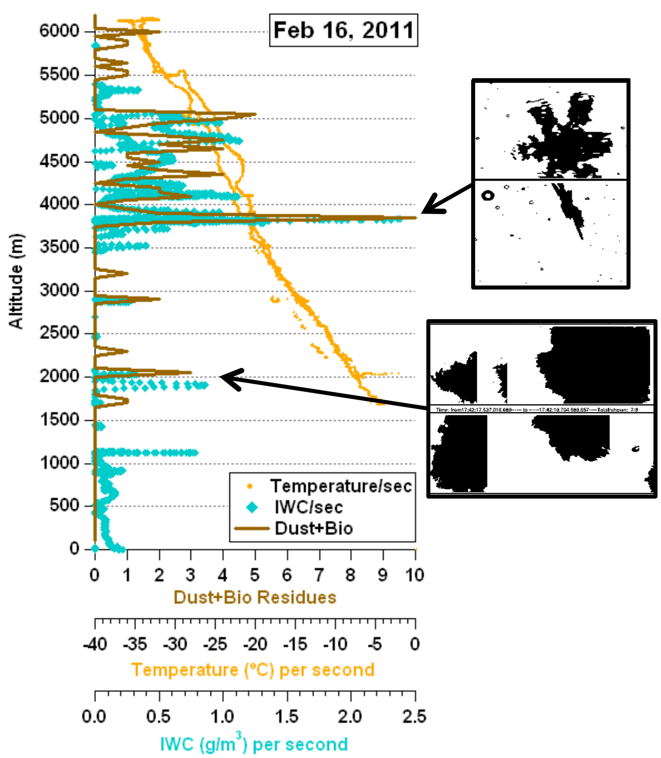

Figure 10. The number of dust and biological (Dust + Bio) particles is summed for 50 m altitude bins and plotted as a function of altitude for the flight on Feb 16, 2011. Also shown are IWC (g/m^3) and temperature (°C) measurements per second. The insets show 2D-S images of cloud droplets and ice crystals at the respective altitudes they were captured.

We will make use of CalWater 2/ACAPEX data to further investigate the impacts of dust and biological particles on clouds and precipitation. Since G1 will have a similar payload as used in the CalWater 2011 field campaign, but deployed over a longer time period, we will potentially yield more samples to perform similar analyses shown in Figure 10 to provide more evidence of the impacts of dust and biological particles on clouds and precipitation. The effects of aerosols from long-range transport will also be assessed using WRF with the spectral bin microphysics parameterization for cases where dust or bio particles are detected. Model simulations of a mixed-phase cloud case with a dust layer during the CalWater campaign in 2011 support the hypothesis that dust particles enhance precipitation by increasing ice and snow formation (Figure 11).

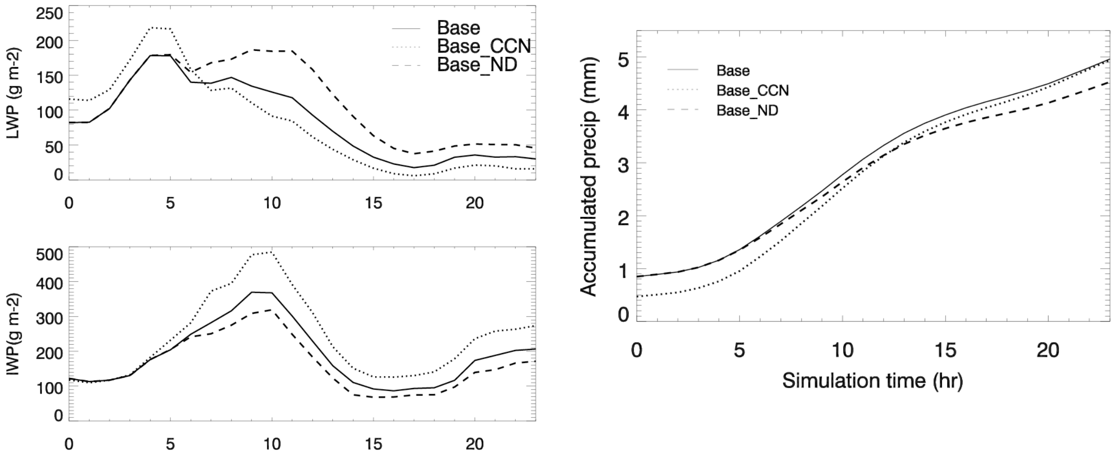

Figure 11. Time series of liquid water path (LWP) (upper left), ice water path (IWP) (lower left), and domain-averaged precipitation (right) for the base run that prescribed CCN, IN, and a dust layer based on measurements (Base) and a simulation in which CCN is increased by 2.5 times (Base_CCN) and a simulation in which the dust layer at 3.5-6.5 km is removed (Base_ND). Simulations were performed using the Weather Research and Forecasting (WRF) model at 2 km resolution with a detailed spectral bin microphysics parameterization.

New data from G1 and the HMT will also enable further investigations of the effects of the SBJ on aerosol transport and the subsequent influence on clouds and precipitation. As discussed in Section 5.1, the SBJ occurs frequently in the eastern foothill of the Sierra Nevada during winter. The SBJ can facilitate local transport of aerosols originating from the coastal urban regions and the agricultural central valley regions along the eastern foothill. This low-level aerosol transport of local origins, combined with the low-level water vapor transport during landfalling AR storms, can play a crucial role in determining precipitation distribution over the Sierra Nevada. Combining offshore characterization of aerosol properties (including the effects of cloud processing) from the NOAA and/or NSF/NCAR aircrafts, UAS, and AMF2, measurements from the HMT that describe the SBJ structure and low-level moisture transport, and observations of aerosol and cloud microphysics from G1 will allow us to separate aerosols originating from local sources from those from long-range transport and study their impacts on the spatial distribution of cloud and precipitation amount and phase.

Data that are critical for addressing the various science questions discussed above are properties of aerosol, CCN, IN, clouds, and surface meteorological measurements (including precipitation). Aircraft data from G1 will be analyzed to obtain composition and size distribution of aerosols and CCN, as well as IN concentration and composition. LWC, IWC, and cloud droplet and ice particle size distribution can be obtained from the cloud probes onboard G1 such as CDP, 2DS and CIP. In addition, cloud properties can be retrieved from the ground- or ship- based radar measurements. To facilitate the comparison of model simulations with radar data, we will also apply a radar simulator to our simulations (Fan et al. 2009) and calculate radar reflectivity, ZDR and Doppler velocity based on model predicted particle size distribution.

We have a strong modeling team to use these data and look into the above science questions after the field campaign. The unique datasets in aerosol-cloud interactions especially dust effects obtained over the region will surely draw many follow-on studies with different models and approaches, because of the importance of the winter precipitation to the water resources over the region.

Parameterizations of aerosol-cloud interactions

Ice nucleation plays a critical role in converting liquid to ice in the mixed-phase cloud regime (between 0 and -38°C), which in turn has important climate consequences. The role of dust from long-range transport serving as IN and influence precipitation in California has been highlighted in previous discussion based on data, analysis, and modeling from CalWater. However, current cloud and climate models generally employ simple temperature- or supersaturation dependent ice nucleation parameterizations (Cooper 1986; Bigg 1953; Meyers et al. 1992). With such parameterizations, the effects of aerosols serving as IN and their subsequent influences on cloud microphysical processes cannot be examined. Recently, a few new parameterizations of heterogeneous nucleation for dust have been developed based on laboratory data that link ice nucleation with dust properties (such as number concentration and surface area) (e.g., Connolly et al. 2009; DeMott et al. 2010; Niemand et al. 2012), but these parameterizations have not been evaluated with field data.

The proposed field experiment will provide excellent field data of dust and biological particles as well as cloud microphysical properties to evaluate the newly developed ice nucleation parameterizations. For example, based on the measured dust and ice number concentrations from G1, we can approximately infer how efficient dust can be nucleated. WRF simulations with the various ice nucleation parameterizations will be performed for selected cases from G1 data to evaluate which parameterization produces results more comparable with the field data for the winter mixed-phase clouds. Sensitivity experiments to assess dust effects cloud properties, precipitation, and radiative forcing will be compared to quantify how uncertainty in ice nucleation parameterizations influences the estimates of dust effects.

In addition, parameterizations for wet removal and cloud processing of aerosols will be evaluated using a range of aircraft data and modeling tools discussed in the subsection "Aerosol characteristics and effects of cloud processing" above.

6. Relevancy to Long-Term Goals of the DOE Office of Biological and Environmental Research

The mission of the ARM Climate Research Facility is to deliver improved climate data and models for policy makers. A major weakness in global climate models is their limitations in simulating the regional hydrological cycle, particularly extremes such as floods and droughts. The west coast of North America presents a specific challenge because of the large precipitation variability and significant implications to water resource management coupled with the growing demand. Although local mountains have a large influence on precipitation, accurately predicting precipitation variability and potential changes in the future requires improved understanding and modeling of atmospheric processes across a wide range of scales. On the intraseasonal time scales, tropical-extratropical interactions involving processes such as the MJO and extratropical wave activities may play an important role in the entrainment of tropical or near-surface moisture by ARs that is a key component of heavy precipitation along the west coast. The IPCC AR4 models show varying degrees of fidelity in simulating AR frequency (Dettinger et al. 2011) and the MJO (Lin et al. 2006), but their ability to correctly simulate the development of ARs and their link to tropical processes including the MJO and the AR moisture transport is not clear because current understanding of these various aspects have not been well quantified by measurements. An additional complicating factor is how aerosols from long-range transport across the Pacific Ocean and local sources may influence clouds and precipitation, leading to changes in frequency and intensity of heavy precipitation, spatial distribution of precipitation, and partitioning between snowfall to rainfall, all with important implications in the western U.S.

The proposed ACAPEX, in conjunction with CalWater 2, will provide the much-needed data over the central/eastern Pacific Ocean to study AR evolution and AR moisture budget and sources, and long-range transport of Asian aerosols, and the potential for interactions between the two and effects on heavy precipitation. The field campaign will also address leading-edge issues related to aerosol-cloud-precipitation interactions in clouds transitioning from the maritime regime to the orographic regime in central California, and how the effects of aerosols may vary for aerosols from long-range transport versus local sources. The data to be collected by AMF2 and G1 as part of ACAPEX, in conjunction with the CalWater 2 aircrafts, UAS, and ship- and ground-based measurements with data analysis and modeling will enable improved understanding and modeling of the targeted processes that play key roles in the water cycle of the western U.S. and regions influenced by similar processes.

7. ACRF Resources Required

We propose to deploy AMF2 and AAF G1 in ACAPEX, in conjunction with other observational platforms from CalWater 2 described in the overall observational strategy in Section 4.3. Detailed information about instruments required for AMF2 and G1 is described below, together with some discussions of how the measurements will be used.

Instrument request for AMF2

This proposal requests the marine deployment of AMF2 with all the included measurement systems (profilers/sounding spectrometers, radars/lidars, surface met, radiometers, eddy correlation, and aerosol observing systems) from December 1, 2014 through April 30, 2015.

The AMF2 instruments for measuring profiles of winds and humidity (RWP and ASSIST) and surface fluxes will provide important information to better quantify the atmospheric and surface water budgets. Lower tropospheric temperature and water vapor profiles can be derived from ASSIST at high vertical (100-250 m) and temporal (~10 min) resolution (Feltz et al. 1998) and used in conjunction with column integrated water vapor from the microwave radiometer and the wind profiles from the RWP to study the evolution of the atmospheric rivers. A C-band Doppler radar is proposed for the ship so the AMF2 observations can be placed in the context of precipitating echoes observed by this radar, which will have an operating range to 150 km. AMF2 cloud radar and lidar measurements in conjunction with satellite remote sensing data and the NOAA precipitation radar, will characterize convection and cirrus clouds associated with propagating wave activity to study tropical-extratropical interactions. Surface energy and water budgets can be determined from the radiation measurement package and bulk aerodynamic fluxes.

To understand aerosol-cloud-precipitation interactions, the aerosol observing system (AOS) and high spectral resolution lidar (HSRL) will be used to characterize the below-cloud aerosol. Following the method of Ghan et al. (2006), the surface cloud condensation nuclei (CCN) measurements can be combined with the lidar extinction profile and water vapor profiles from radiosondes to estimate the CCN at cloud base. This information will be combined with the liquid water path from the 3-channel microwave radiometer (MWR3C) and the cloud radar observations to study the effects of aerosol on drizzle and precipitation formation. These studies will be done in conjunction with the aircraft measurements over the eastern North Pacific Ocean, which will provide comprehensive information about aerosol composition and size distribution as well as cloud microphysical quantities such as CCN, IN, and cloud drop size distribution that can be used to evaluate the AMF2 remote sensing retrievals. In addition, a number of state-of-the-art satellite resources are available via the Earth Observing System's Terra, Aqua and Aura platforms, and the latter two's incorporation, along with a number of other key instruments (e.g. CloudSat, Calipso), into the so-called A-Train. Such data can provide a global and regional scale perspective to augment the field program's more detailed observations.

While all of the AMF2 measurements requested are important to the goals of the campaign, most must be considered critical to the success of the campaign. The vertically pointing cloud radar, MPL, ceilometer, MWR3C, HSRL, ASSIST, RWP, and AOS provide essential measurements that are directly related to the observation of AR and aerosol influences on clouds and precipitation that are the primary focii of the campaign. Thus it is vital that every effort be expended to have these systems be fully functional and operational for this entire deployment.

In addition to the measurements themselves, certain of the ARM programmatic Value Added Products (VAP) are needed to fulfill the campaign objectives. Specifically, the following VAPs are requested as part of this proposal:

- WACR-ARSCL (SWACR-based Active Remotely-Sensed Cloud Locations)
- MICROBASE (Continuous Baseline Microphysical Retrieval)
- MERGESONDE (Merged Sounding)
- MPLCMASK (Cloud mask from Micropulse Lidar)

Instrument request for AAF G1

The table below lists the instruments requested for G1 and the corresponding measurements and PIs. Instruments not a part of ARM (highlighted in blue) will be requested separately by CalWater 2 to be included in the G1 payload.

Instrument	**Measurement**	**PI**
Platform Pos/Vel/Attitude		
Trimble DSM	Position/velocity @ ~10Hz	PNNL
Trimble TANS 10Hz	Pitch/roll/azimuth	PNNL
C-MIGITS	Inertial GPS	PNNL
Atmospheric State		
Rosemount 102 probe	Temperature	PNNL
Rosemount 1201F1	Static pressure	PNNL
Rosemount 1221F2 (3x)	Differential pressure (dynamic, alpha, beta)	PNNL
GE-1011B chilled-mirror hygrometer	Dew-point temperature	PNNL
AIMMS-20	Wind and turbulence	PNNL
Liquid and Total Water Content		
Gerber PVM-100	Liquid water content	PNNL/CIRPAS
CAPS-hotwire	Liquid water content	PNNL/CIRPAS
DMT Cloud Spectrometer and Impactor (CSI)	Total water content	PNNL
SEA total water WCM-2000	Liquid water content, total water content	PNNL/CIRPAS
Cloud Microphysics		
HVPS-3	Cloud droplets size distribution (400-50,000 μm)	PNNL

2DS	Cloud droplets size distribution (10 – 3,000 µm)	PNNL
CIP (part of CAPS)	Cloud droplet size distribution (25-1500 µm)	PNNL/CIRPAS
CDP (part of CSI)	Large aerosol and cloud droplets (2-50 µm)	PNNL/CIRPAS
CAS (part of CAPS)	Large aerosol and cloud droplets (0.5-50 µm)	PNNL/CIRPAS
Aerosol		
UCPC TSI 3025	Total particle concentration (> 3 nm)	PNNL
CPC TSI 3010	Total particle concentration (> 10 nm)	PNNL
PCASP	Aerosol size distribution (100-3000 nm)	PNNL/CIRPAS
UHSAS-A	Aerosol size distribution (55-1000 nm)	PNNL
Fast Cloud Condensation Nuclei (CCN) counter	CCN concentration at various supersaturations	Nenes-GeorgiaTech
ATOFMS	Single-particle mass spectrometer	UCSD/SIO-Prather
Radiance Particle/Soot Absorption Photometer (PSAP)	Aerosol absorption	PNNL
Single-Particle Soot Photometer (SP2)	Single-particle BC-containing mass loadings, size distributions, and coating thicknesses	BNL-Sedlacek
Nephelometer (TSI 3563)	Aerosol scattering	PNNL
CFDC	Ice nuclei concentration	CSU-DeMott
Sample Collection		
Isokinetic inlet	Sample stream of dry aerosol, sizes < 2.5 µm	PNNL
Pumps for aerosol flow	Maintains flow through aerosol inlet and internal plumbing.	PNNL
Counter-flow Virtual Impactor (CVI)	Sample stream of cloud-droplet residuals	PNNL
Cloud Water Collector	Collects cloud water for offline isotope analyses	PNNL/Coplen
Gases		
Thermo Electron 48C	Carbon Monoxide	PNNL
Thermo Electron 49	Ozone	PNNL
Other		
Weather radar	Cockpit display of precipitation returns	PNNL
SEA Data System	Central Data System	PNNL
Iridium Satellite Modem	Limited data link to ground station	PNNL
Radar Altimeter	Altitude above surface	PNNL
TCAS	Traffic Collision and Avoidance System	PNNL
TAWS	Terrain Awareness and Warning System	PNNL
Nose video camera	Forward video images out wind screen	PNNL

8. References

Andreae, M. O., D. Rosenfeld, P. Artaxo, A. A. Costa, G. P. Frank, K. M. Longo, and M. A. F. Silva-Dias, 2004: Smoking rain clouds over the Amazon. *Science,* **303,** 1337–1342.

Ault, A.P., C.R. Williams, A.B. White, P.J. Neiman, J.M. Creamean, C.J. Gaston, F.M. Ralph, and K.A. Prather, 2011: Detection of Asian dust in California orographic precipitation. *J. Geophys. Res*., **116**, D16205, doi:10.1029/2010JD015351.

Bao, J.-W., S. A. Michelson, P.J. Neiman, F. M. Ralph and J. M. Wilczak, 2006: Interpretation of enhanced integrated water vapor bands associated with extratropical cyclones: Their formation and connection to tropical moisture. *Mon. Wea. Rev.*, **134**, 1063-1080.

Bigg, E.K., 1953: The formation of atmospheric ice crystals by the freezing of droplets. *Q. J. R. Meteorol. Soc*., **79**, 510–519.

Bond, N.A., and G.A. Vecchi, 2003: The influence of the Madden-Julian Oscillation on precipitation in Oregon and Washington. *Wea. Forecasting*, **18**, 600-613.

Borys, R. D., D. H. Lowenthal, S. A. Cohn, and W. O. J. Brown, 2003: Mountaintop and radar measurements of anthropogenic aerosol effects on snow growth and snowfall rate. *Geophys. Res. Lett.,* **30,** 1538.

Carter, D.A., K.S. Gage, W.L. Ecklund, W.M. Angevine, P.E. Johnston, A.C. Riddle, J. Wilson, and C.R. Williams, 1995: Developments in UHF lower tropospheric wind profiling at NOAA's Aeronomy Laboratory. *Radio Sci*., **30(4)**, 977-1001.

Choi, Y.-S., R.S. Lindzen, C.-H. Ho, and J. Kim, 2010: Space observations of cold-cloud phase change. *PNAS*, **107**, 11211-11216.

Connolly, P. J., O. Mohler, P. R. Field, H. Saathoff, R. Burgess, T. Choularton, and M. Gallagher, 2009: Studies of heterogeneous freezing by three different desert dust samples. *Atmos. Chem. Phys*., **9 (8)**, 2805–2824.

Cooper W. A., 1986: Ice initiation in natural clouds. Precipitation Enhancement–A Scientific Challenge. *Meteor. Mongr*., **43**, 29–32.

Cotton, W.R., H. Zhang, G.M. McFarquhar, and S.M. Saleeby, 2007: Should we consider polluting hurricanes to reduce their intensity? *J. Wea. Mod*., **39**, 70-73.

Cotton W. R., D. Ward, S. Saleeby, 2010: Aerosol impacts on wintertime orographic precipitation. 13th conference on Clouds Physics.

DeMott, P. J., et al., 2010: Predicting global atmospheric ice nuclei distributions and their impacts on climate. *Proc. Natl. Acad. Sci.*, **107 (25)**, 11 217–11 222.

Dettinger, M. D., 2011: Climate change, atmospheric rivers, and floods in California—A multimodel analysis of storm frequency and magnitude changes. *J. Amer. Water Resour. Assoc.,* **47,** 514–523.

Drumond, A., R. Nieto, and L. Gimeno, 2011: On the contribution of the Tropical Western Hemisphere warm pool source of moisture to the northern Hemisphere precipitation through a Lagrangian approach. *J. Geophys. Res*., **116**, D00Q04, doi:10.1029/2010JD015397.

Fan, J., D. Rosenfeld, Y. Deng, L.R. Leung, and Z. Li, 2012: Potential aerosols indirect effects on atmospheric circulation and radiative Forcing. *Geophys. Res. Lett.,* doi:10.1029/2012GL051851, in press.

Fan, J., M. Ovtchinnikov, J. Comstock, S. A. McFarlane, and A. Khain: 2009: Ice formation in Arctic mixed-phase clouds - Insights from a 3-D cloud-resolving model with size-resolved aerosol and cloud microphysics. *J. Geophys. Res.*, **114**, D04205, doi:10.1029/2008JD010782.

Feltz, W. F., W. L. Smith, R. O. Knutson, H. E. Revercomb, H. M. Woolf, and H. B. Howell, 1998: Meteorological applications of temperature and water vapor retrievals from the ground-based atmospheric emitted radiance interferometer (AERI). *J. Appl. Meteor.,* **37**, 857-875.

Ghan, S.J., T.A. Rissman, R. Elleman, R. A. Ferrare, D. Turner, C. Flynn, J. Wang, J. Ogren, J. Hudson, H. Jonsson, T. VanReken, R.C. Flagan, and J.H. Seinfeld, 2006: Use of in situ cloud condensation nuclei, extinction, and aerosol size distribution measurements to test a method for retrieving cloud condensation nuclei profiles from surface measurements. *J. Geophys. Res.,* **111**, D05S10, doi:10.1029/2004JD005752.

Givati, A., and D. Rosenfeld, 2004: Quantifying precipitation suppression due to air pollution. *J. Appl. Meteorol*., **43**, 1038 – 1056.

Givati, A., and D. Rosenfeld, 2005: Separation between Cloud Seeding and Air Pollution Effects. *J. Appl. Meteor.,* **44,** 1298– 1314.

Givati, A., and D. Rosenfeld, 2007: Possible impacts of anthropogenic aerosols on water resources of the Jordan River and the Sea of Galilee. *Water Resour. Res.,* **43,** W10419.

Grell, G. A., S.E. Peckham, R. Schmitz, S.A. McKeen, G. Frost, W.C. Skamarock, and B. Eder, 2005: Fully coupled "online" chemistry within the WRF model. *Atmos. Environ*., **39**, 6957–6976.

Griffith, D. A., M. E. Solak, and D. P. Yorty, 2005: Is air pollution impacting winter orograhic precipitation in Utah? *J. Wea. Modif.,* **37,** 14–20.

Guan, B., N.P. Molotch, D.E. Waliser, E.J. Fetzer, and P.J. Neiman, 2010: Extreme snowfall events linked to atmospheric rivers and surface air temperature via satellite measurements. *Geophys. Res. Lett*., 37, L20401, doi:10.1029/2010GL044696.

Guan, B., D.E. Waliser, N.P. Molotch, E.J. Fetzer, and P.J. Neiman, 2011: Does the Madden-Julian Oscillation influence wintertime atmospheric rivers and snowpack in the Sierra Nevada? *Mon. Wea. Rev*., doi: http://dx.doi.org/10.1175/MWR-D-11-00087.1.

Heggli, M. F., L. Vardiman, R. E. Stewart, and A. W. Huggins, 1983: Supercooled liquid water and ice crystal distributions within Sierra Nevada winter storms. *J. Clim. Appl. Meteor*., **22**, 1875-1886.

Houze, R.A. Jr., 1993: Orographic clouds, *Cloud Dynamics*, Academic Press, 502-538pp.

Hudson, J. G., and S. S. Yum, 2001: Maritime-continental drizzle contrasts in small cumuli. *J. Atmos. Sci.,* **58,** 915–926.

Hudson, J. G., and S. Mishra, 2007: Relationships between CCN and cloud microphysics variations in clean maritime air. *Geophys. Res. Lett.,* **34,** L16804, 6pp.

Jiang, T., and Y. Deng, 2011: Downstream modulation of North Pacific atmospheric river activity by East Asian cold surges. *Geophys. Res. Lett*., **38**, L20807, doi:10.1029/2011GL049462.

Jin, F.-F., and B.J. Hoskin, 1995: The direct response to tropical heating in a baroclinic atmosphere. *J. Atmos. Sci*., **52**, 307-319.

Jirak, I.L., and W.R. Cotton, 2005: Effect of Air Pollution on Precipitation along the Front Range of the Rocky Mountain. *J. Appl. Meteor.,* **45,** 236-245.
Khain, A., B. Lynn, J. Dudhia, 2010: Aerosol effects on intensity of landfalling hurricanes as seen from simulations with the WRF model with spectral bin microphysics. *J. Atmos. Sci.*, **67**, 365–384. doi: http://dx.doi.org/10.1175/2009JAS3210.1.
Kim, J. and L. Mahrt, 1992: Momentum transport by gravity waves. *J. Atmos. Sci.,* **49,** 735–748.
Kim, J. and H. Kang, 2007: Impact of the Sierra Nevada on low-level winds and water vapor transport. *J. Hydrometrorol*., **8**, 790-804.
Knippertz, P., 2007: Tropical-extratropical interactions related to upperlevel troughs at low latitudes. *Dyn. Atmos. Oceans*, **43**, 36–62.
Leung, L.R., and Y. Qian, 2009: Atmospheric rivers induced heavy precipitation and flooding in the western U.S. simulated by the WRF regional climate model. *Geophys. Res. Lett*., **36**, L03820, doi:10.1029/2008GL036445.
Lin, J. L., G. N. Kiladis, B. E. Mapes, K. M. Weickmann, K. R. Sperber, W. Lin, M. C. Wheeler, S. D. Schubert, A. Del Genio, L. J. Donner, S. Emori, J. F. Gueremy, F. Hourdin, P. J. Rasch, E. Roeckner, and J. F. Scinocca, 2006: Tropical intraseasonal variability in 14 IPCC AR4 climate models. Part I: Convective signals. *J. Clim.*, **19,** 2665-2690.
Lohmann, U., 2002: A glaciation indirect aerosol effect caused by soot aerosols. Geophys. Res. Lett., **29(4)**, 1052, doi:10.1029/2001GL014357.
Lundquist, J.D., J.R. Minder, P.J. Neiman, and E. Sukovich, 2010: Relationships between Barrier Jet Heights, Orographic Precipitation Gradients, and Streamflow in the Northern Sierra Nevada. *J. Hydrometeorol*., **11**, 1141-1156.
Lynn, B., A. Khain, D. Rosenfeld, and W.L. Woodley, 2007: Effects of aerosols on precipitation from orographic clouds. J. Geophys. Res., **112**, doi:10.1029/2006JD007537.
Matthews, A.J., and G.N. Kiladis, 1999: The tropical-extratropical interaction between high-frequency transients and the Madden-Julian Oscillation. *Mon. Wea. Rev*., **127**, 661-677.
Mattioli, V., E. R. Westwater, D. Cimini, J. C. Liljegren, B. M. Lesht, S. I. Gutman, F. J. Schmidlin, 2007: Analysis of Radiosonde and Ground-Based Remotely Sensed PWV Data from the 2004 North Slope of Alaska Arctic Winter Radiometric Experiment. *J. Atmos. Oceanic Technol.*, **24**, 415–431. doi: http://dx.doi.org/10.1175/JTECH1982.1.
McFarquhar, G. M., and A. J. Heymsfield, 2001: Parameterizations of INDOEX microphysical measurements and calculations of cloud susceptibility: Applications for climate studies. *J. Geophys. Res.,* **106,** 28,675–28,698.
Mo, K.C., 1999: Alternating wet and dry episodes over California and intraseasonal oscillations. *Mon. Wea. Rev*., **127**, 2759-2776.
Muhlbauer, A., and U. Lohmann, 2009: Sensitivity Studies of Aerosol-Cloud Interactions in Mixed-Phase Orographic Precipitation. *J. Atmos. Sci.,* **66,** 2517-2538.
Neale, R. B., et al. 2010: Description of the NCAR Community Atmosphere Model (CAM 5.0). *Tech. Note NCAR/TN-486+STR*, Natl. Cent. for Atmos. Res., Boulder, Colo. June.

Neiman, P. J., F. M. Ralph, G. A. Wick, Y.-H. Kuo, T.-K. Wee, Z. Ma, G. H. Taylor, and M. D. Dettinger, 2008: Diagnosis of an intense atmospheric river impacting the Pacific Northwest: Storm summary and offshore vertical structure observed with COSMIC satellite retrievals. *Mon. Wea. Rev.*, **136**, 4398-4420.

Neiman, P.J., E.M. Sukovich, F.M. Ralph, and M. Hughes, 2010: A seven-year wind profiler-based climatology of the windward barrier jet along California's northern Sierra Nevada. *Mon. Wea. Rev.*, DOI: 10.1175/2009MWR3170.1.

Niemand, M., O. Mohler, B. Vogel, et al., 2012: Parameterization of immersion freezing on mineral dust particles: An application in a regional scale model. *J. Atmos. Sci*., in press.

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

Pratt, K.A., P.J. DeMott, J.R. French, Z. Wang, D.L. Westphal, A.J. Heymsfield, C.H. Twoh, A.J. Prenni, and K.A. Prather, 2009: *In situ* detection of biological particles in cloud ice-crystals. *Nature Geoscience*, **2**, 398 – 401, doi:10.1038/ngeo521.

Pratt, K. A., S. M. Murphy, R. Subramanian, P. J. DeMott, G. L. Kok, T. Campos, D. C. Rogers, A. J. Prenni, A. J. Heymsfield, J. H. Seinfeld and K. A. Prather, 2011: Flight-based chemical characterization of biomass burning aerosols within two prescribed burn smoke plumes. *Atmos. Chem. and Phys*., **11**(24), 12549-12565.

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 El Niño winter of 1997/98. *Mon. Wea. Rev.*, **132**, 1721-1745.

Ralph, F. M., P. J., Neiman and R. Rotunno, 2005: 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.

Ralph, F. M., P. J. Neiman, G. A. Wick, S. I. Gutman, M. D. Dettinger, D. R. Cayan, and A. B. White, 2006: Flooding on California's Russian River: Role of atmospheric rivers. *Geophys. Res. Lett.*, **33**, L13801, doi:10.1029/2006GL026689.

Ralph, F. M., P. J. Neiman, G. N. Kiladis, K. Weickman, and D. W. Reynolds, 2011: A multi-scale observational case study of a Pacific atmospheric river exhibiting tropical-extratropical connections and a mesoscale frontal wave. *Mon. Wea. Rev.*, **139**, DOI: 10.1175/2010MWR3596.1.

Ralph, F. M., et al., 2012: Research aircraft observations of water vapor transport in atmospheric rivers and evaluation of reanalysis products. *J. Geophys. Res*., in preparation.

Ralph, F.M., and M.D. Dettinger, 2012: West coast precipitation associated with atmospheric rivers during December 2010. *Bull. Amer. Meteorol. Soc*., DOI:10.1175/BAMS-D-11-00188.1, in press.

Rangno, A. L., and P. V. Hobbs, 1988: Criteria for the development of significant concentrations of ice particles in cumulus clouds. *Atmos. Res*., **21**, 1–13.

Rangno, A. L., and P. V. Hobbs, 1991: Ice particle concentrations and precipitation development in small polar maritime cumuliform clouds. *Quart. J. Roy. Meteor. Soc*., **117**, 207–241.

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

Revercomb, H.E., D.D. Turner, D.C. Tobin, R.O. Knuteson, W.F. Feltz, J. Barnard, J. Bosenberg, S. Clough, D. Cook, R. Ferrare, J. Goldsmith, S. Gutman, R. Halthore, B. Lesht, J. Liljegren, H. Linne, J. Michalsky, V. Morris, W. Porch, S. Richardson, B. Schmid, M. Splitt, T. Van Hove, E. Westwater, and D. Whiteman, 2003: The ARM program's water vapor intensive observation periods. *Bull. Amer. Meteorol. Soc*., DOI: 10.1175/BAMS-84-2-217.

Ringler, T., D.W. Jacobsen, M. Gunzburger, L. Ju, M. Duda and W. Skamarock, 2011: Exploring a Multi-Resolution Modeling Approach within the Shallow-Water Equations. *Mon. Wea. Rev*., DOI: 10.1175/MWR-D-10-05049.1.

Rosenfeld, D., 2000: Suppression of rain and snow by urban air pollution. *Science,* **287,** 1793–1796.

Rosenfeld, D. and A. Givati, 2006: Evidence of Orographic Precipitation Suppression by Air Pollution–Induced Aerosols in the Western United States. *J. Appl. Meteor.,* **45,** 893–911.

Rosenfeld, D., J. Dai, X. Yu, Z. Yao, X. Xu, X. Yang, and C. Du, 2007: Inverse relations between amounts of air pollution and orographic precipitation. *Science,* **315,** 1396–1398.

Rosenfeld, D., W.L. Woodley, D. Axisa, E. Freud, J.G. Hudson, and A. Givati, 2008: Aircraft measurements of the impacts of pollution aerosols on clouds and precipitation over the Sierra Nevada. *J. Geophys. Res*., **113**, D15203, doi:10.1029/2007JD009544.

Saleeby, S.M., W.R. Cotton, D. Lowenthal, R. Borys and M.A. Wetzel, 2008: Influence of Cloud Condensation Nuclei on Orographic Snowfall. *J. Appl. Meteor.,* **48,** 903-922.

Sassen, K., 2002: Indirect climate forcing over the western US from Asian dust storms. Geophys. Res. Lett., **29**, 10.1029/2001GL014051.

Skamarock, W.C., et al. 2008: A Description of the Advanced Research WRF Version 3. *NCAR Technical Note*, NCAR/TN–475+STR, 112 pp.

Spackman, J. R., J. P. Schwarz, R. S. Gao, L. A. Watts, D. W. Fahey, S. C. Wofsy, Black carbon burden in the remote Northern Hemisphere springtime Pacific. *Geophys. Res. Lett*., in preparation.

VanCuren, R. A., and T. A. Cahill, 2002: Asian aerosols in North America: Frequency and concentration of fine dust, J. Geophys. Res., **107(D24)**, 4804, doi:10.1029/2002JD002204.

White, A.B., D.J. Gottas, E.T. Strem, F.M. Ralph, and P.J. Neiman, 2002: An automated brightband height detection algorithm for use with Doppler radar spectral moments. *J. Atmos. Oceanic Technol.*, **19**, 687–697.doi: http://dx.doi.org/10.1175/1520-0426(2002)019<0687:AABHDA>2.0.CO;2.

Yum, S. S., and J. G. Hudson, 2002: Maritime/continental microphysical contrasts in stratus. *Tellus* Ser. A and Ser. B, **54**B, 61–73.

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

9. Biographical Sketches

Principal Investigator

L. Ruby Leung, Pacific Northwest National Laboratory

Co-Principal Investigators

Kim Prather, University of California at San Diego, Scripps Institution of Oceanography
Marty Ralph, NOAA Earth System Research Laboratory
Danny Rosenfeld, Hebrew University of Jerusalem
Ryan Spackman, NOAA Earth System Research Laboratory, STC

Co-Investigators

Chris Fairall, NOAA Earth System Research Laboratory
Jiwen Fan, Pacific Northwest National Laboratory
Samson Hagos, Pacific Northwest National Laboratory
Mimi Hughes, NOAA Earth System Research Laboratory and CIRES
Chuck Long, Pacific Northwest National Laboratory
Sally McFarlane, Pacific Northwest National Laboratory
V. Ramanathan, University of California at San Diego, Scripps Institution of Oceanography
Steven Rutledge, Colorado State University
Duane Waliser, NASA Jet Propulsion Laboratory
Hailong Wang, Pacific Northwest National Laboratory

L. Ruby Leung

Laboratory Fellow, Atmospheric Sciences and Global Change Division
Pacific Northwest National Laboratory, Richland, WA 99352
Email: Ruby.Leung@pnnl.gov; Phone: 509-372-6182

EDUCATION

Chinese University of Hong Kong	Physics & Statistics	B.S. (Honors), 1984
Texas A&M University	Atmospheric Science	M.S., 1988
Texas A&M University	Atmospheric Science	Ph.D., 1991

RESEARCH AND PROFESSIONAL EXPERIENCE

2004-present, Laboratory Fellow, Pacific Northwest National Laboratory, Richland, WA
2004-present, Affiliate Scientist, National Center for Atmospheric Research, Boulder, CO
1999-2004, Staff Scientist, Pacific Northwest National Laboratory, Richland, WA
1992-1999, Senior Scientist, Pacific Northwest National Laboratory, Richland, WA
1991-1992, Postdoc, Pacific Northwest National Laboratory, Richland, WA

SELECTED PROFESSIONAL ACTIVITIES

Fellow of the American Meteorological Society (AMS) and American Association for the Advancement of Science (AAAS)
Chair, Organizing Committee, Workshop on Community Modeling for Long-Term Predictions of the Integrated Water Cycle, September 24 – 26, Washington DC, 2012
Member, US CLIVAR Working Group Committee on Large Scale Circulation Patterns Associated with Extremes, since 2012
Editor, Journal of Hydrometeorology, American Meteorological Society, since 2012
Member, NRC study committee on "A National Strategy for Advancing Climate Modeling", 2011 – 2012
Member, Organizing Committee, First Planning Workshop for Terrestrial Regional North American Hydroclimate Experiment (TRACE), April 18 – 20, 2011, Silver Spring, MD
Member, Department of Energy's Office of Biological and Environmental Research Advisory Committee (BERAC), since 2009/12
Co-organizer, 2009 Japan-America Frontiers of Engineering Symposium, Sponsored by the National Academy of Engineering, November 9 – 11, 2009, Irvine, CA
Organizer, North American Mountain Hydroclimate and Water Resources Workshop, co-sponsored by NOAA and NASA, October 17 – 19, 2007, Boulder, CO
Associate Editor, Journal of Geophysical Research – Atmosphere, since 2007
Chair, Science Panel, NOAA Climate Prediction Program for the Americas (CPPA), 2006 – 2010
Organizer, Workshop on Research Needs and Directions of Regional Climate Modeling Using WRF and CCSM, sponsored by NCAR, March 22-23, 2005, Boulder, CO
Chair, WRF Regional Climate Modeling Working Group, since 2004
Science Advisory Group, GEWEX Americas Prediction Project (GAPP) co-sponsored by NOAA/NASA, 2003 – 2005

Organizer and Program Committee Chair, Workshop on "Regional Climate Research: Needs and Opportunities", co-sponsored by the National Science Foundation and Department of Energy (DOE), April 2001, Boulder, CO

SELECTED PUBLICATIONS

Gao, Y., L.R. Leung, E.P. Salathé, F. Dominguez, B. Njissen, and D.P. Lettenmaier. 2012. "Moisture Flux Convergence in Regional and Global Climate Models: Implications for Droughts in the Southwestern United States." Geophys. Res. Lett., doi:10.1029/2012GL051560, in press.

Zhao, C., X. Liu, and L.R. Leung. 2012. "The Impact of the Desert Dust on the Summer Monsoon System in Southwestern United States." Atmos. Chem. Phys., 12(8), 3717-3731. doi:10.5194/acp-12-3717-2012.

Fan, J., D. Rosenfeld, Y. Deng, L.R. Leung, and Z. Li. 2012. "Potential Aerosols Indirect Effects on Atmospheric Circulation and Radiative Forcing" Geophys. Res. Lett., doi:10.1029/2012GL051851, in press.

Fan, J., L.R. Leung, Z. Li, H. Morrison, H. Chen, Y. Zhou, Y. Qian, and Y. Wang. 2012. "Aerosol Impacts on Clouds and Precipitation in Southeast China – Results From Bin and Bulk Microphysics." *J. Geophys. Res*., 117, D00K36, DOI:10.1029/2011JD016537.

Hagos S, and LR Leung. 2012. "On the Relationship Between Uncertainties in Tropical Divergence and the Hydrological Cycle in Global Models." J. Clim., doi: 10.1175/JCLI-D-11-00058.1.

Hagos, S., and L.R. Leung. 2011. "Moist Thermodynamics of the Madden-Julian Oscillation in a Cloud Resolving Simulation." J. Clim., doi: 10.1175/2011JCLI4212.1.

Hagos, S., L.R. Leung, and J. Dudhia. 2011. "Thermodynamics of Madden-Julian Oscillation in a Regional Model with Constrained Moistening." J. Atmos. Sci., doi: 10.1175/2011JAS3592.1.

Bennartz, R., J. Fan, J. Rausch, L.R. Leung, and A.K. Heidinger. 2011. "Pollution From China Increases Cloud Droplet Number, Suppresses Rain Over the East China Sea." Geophys. Res. Lett., 38, L09704, doi:10.1029/2011GL047235.

Leung LR, M Huang, Y Qian, and X Liang. 2011. "Climate-Soil-Vegetation Control on Groundwater Table Dynamics and its Feedbacks in a Climate Model." *Clim. Dyn.*, doi10.1007/s00382-010-0746-x.

Qian, Y., M.G. Flanner, L.R. Leung, and W. Wang. 2011. "Sensitivity Studies on the Impacts of Tibetan Plateau Snowpack Pollution on the Asian Hydrological Cycle and Monsoon Climate." *Atmos. Chem. and Phy*., 11, 1929-1948.

Leung LR, and Y Qian. 2009. "Atmospheric Rivers Induced Heavy Precipitation and Flooding in the Western U.S. Simulated by the WRF Regional Climate Model." *Geophys. Res. Lett*., 36, L03820, doi:10.1029/2008GL036445.

Leung LR, Y-H Kuo, and J Tribbia. 2006. "Research Needs and Directions of Regional Climate Modeling Using WRF and CCSM." *Bull. Amer. Meteorol. Soc*.,87(12), 1747-1751.

Leung LR, and SJ Ghan. 1998. "Parameterizing Subgrid Orographic Precipitation and Surface Cover in Climate Models." *Mon. Wea. Rev*. 126(12):3271-3291.

Kimberly A. Prather

Distinguished Chair of Atmospheric Chemistry
Department of Chemistry and Biochemistry, University of California, San Diego
9500 Gilman Drive, La Jolla, CA 92093-0314
Tel: (858) 822-5312 Fax: (858) 534-7042
E-mail: kprather@ucsd.edu, http://atofms.ucsd.edu

EDUCATION

University of California, Davis	Chemistry	B. S.	1985
University of California, Davis	Chemistry	Ph.D.	1990
University of California, Berkeley	Chemistry	Postdoctoral Fellow	1990 - 1992

RESEARCH AND PROFESSIONAL EXPERIENCE

2010 - present	Distinguished Chair in Atmospheric Chemistry
2001- present	Professor, Dept. of Chemistry and Biochemistry, Scripps Institution of Oceanography, Univ. of Calif., San Diego
2000 – 2001	Professor, Univ. of California, Riverside
1996 – 2000	Associate Professor, Univ. of California, Riverside
1994 – 2001	Research Associate, Statewide Air Pollution Research Center
1992 – 1996	Assistant Professor, Univ. of California, Riverside

SELECTED PROFESSIONAL ACTIVITIES

- Three existing patents for developments in on-line mass spectrometry: Development of Aerosol Time-of-Flight Mass Spectrometry (ATOFMS) (US Patent 5,681,752), on-line the development of Transportable ATOFMS (US Patent 5,998,215), MALDI-IM-ortho-TOF mass spectrometry with simultaneous positive and negative mode detection (w/ J. Albert Schultz) (US Patent: 7,170,052).
- Spends time with her research group educating the public on climate and air pollution issues by giving lectures at the SIO Birch Aquarium, San Diego Natural History Museum, radio, TV broadcasts (PBS, CNN), local schools. Also works with local schools to reinvigorate science education using environmental measurements. Developing new curriculum for K-6 science education focused on climate and atmospheric chemistry.
- Selected as member of the $PM_{2.5}$ Subcommittee for the U.S. EPA Clean Air Scientific Advisory Committee as well as the National Academy of Sciences Board of Atmospheric Science and Climate (NAS BASC).
- Performs aircraft and land-based field studies worldwide to assist in furthering our understanding of the role of aerosol in climate change and air pollution including Mexico, Asia, India, and the United States.
- PI of CalWater project focusing on aerosol impacts on clouds and precipitation in California. Mission scientist on G1 for CalWater flights in February and March, 2011. Assisted in selection of payload to study aerosol size and composition, cloud microphysics physics, and meteorology.
- Director of NSF Center for Aerosol Impacts on Climate and the Environment (NSF-CAICE). As part of the Center, Prather leads a large education and outreach effort

designed to encourage young K-12 children to become more interested in science at an early age through hands-on inquiry based environmental measurements.

SELECTED PUBLICATIONS

Ault, A. P., C. R. Williams, A. B. White, P. J. Neiman, J. M. Creamean, C. J. Gaston, F. M. Ralph and K. A. Prather (2011). "Detection of Asian dust in California orographic precipitation." Journal of Geophysical Research-Atmospheres **116**.

Creamean, J. M., A. P. Ault, J. E. Ten Hoeve, M. Z. Jacobson, G. C. Roberts and K. A. Prather (2011). "Measurements of Aerosol Chemistry during New Particle Formation Events at a Remote Rural Mountain Site." Environmental Science & Technology **45**(19): 8208-8216.

Pratt, K. A., P. J. DeMott, J. R. French, Z. Wang, D. L. Westphal, A. J. Heymsfield, C. H. Twohy, A. J. Prenni and K. A. Prather (2009). "In situ detection of biological particles in cloud ice-crystals." Nature Geoscience **2**(6): 398-401.

Pratt, K. A. and K. A. Prather (2010). "Aircraft measurements of vertical profiles of aerosol mixing states." Journal of Geophysical Research-Atmospheres **115**: -.

Sullivan, R. C., M. J. K. Moore, M. D. Petters, S. M. Kreidenweis, G. C. Roberts and K. A. Prather (2009). "Timescale for hygroscopic conversion of calcite mineral particles through heterogeneous reaction with nitric acid." Physical Chemistry Chemical Physics **11**(36): 7826-7837.

Moffet, R. C. and K. A. Prather (2009). "In-situ measurements of the mixing state and optical properties of soot with implications for radiative forcing estimates." Proceedings of the National Academy of Sciences of the United States of America **106**(29): 11872-11877.

Gaston, C. J., H. Furutani, S. A. Guazzotti, K. R. Coffee, T. S. Bates, P. K. Quinn, L. I. Aluwihare, B. G. Mitchell and K. A. Prather (2011). "Unique ocean-derived particles serve as a proxy for changes in ocean chemistry." Journal of Geophysical Research-Atmospheres **116**.

Hatch, L. E., J. M. Creamean, A. P. Ault, J. D. Surratt, M. N. Chan, J. H. Seinfeld, E. S. Edgerton, Y. X. Su and K. A. Prather (2011). "Measurements of Isoprene-Derived Organosulfates in Ambient Aerosols by Aerosol Time-of-Flight Mass Spectrometry - Part 1: Single Particle Atmospheric Observations in Atlanta." Environmental Science & Technology **45**(12): 5105-5111.

Moffet, R. C., X. Y. Qin, T. Rebotier, H. Furutani and K. A. Prather (2008). "Chemically segregated optical and microphysical properties of ambient aerosols measured in a single-particle mass spectrometer." Journal of Geophysical Research-Atmospheres **113**(D12).

Sullivan, R. C., S. A. Guazzotti, D. A. Sodeman and K. A. Prather (2007). "Direct observations of the atmospheric processing of Asian mineral dust." Atmospheric Chemistry and Physics **7**: 1213-1236.

Fred Martin Ralph

NOAA/OAR/Earth System Research Laboratory, Boulder, Colorado
325 Broadway R/PSD2, Boulder, Colorado 80305
Marty.Ralph@noaa.gov; 303-497-7099

EDUCATION

1991	Ph.D. in Atmospheric Sciences, University of California at Los Angeles
1987	M.S. in Atmospheric Sciences, University of California at Los Angeles
1984	B.S. in Meteorology, with Highest Honors, University of Arizona

RESEARCH AND PROFESSIONAL EXPERIENCE

2005-present	Chief, Water Cycle Branch of the NOAA/Earth System Research Lab./Physical Sciences Division
2009-present	Research Associate, Scripps Inst. of Oceanography, Climate, Atmos. Sci., and Phys. Ocean. Group
2004-2010	Program Manager, NOAA/Weather & Water/Science, Technology & Infusion Matrix Program
2005-2008	Project Manager, NOAA's Unmanned Aircraft Systems Project
2001-2005	Chief, NOAA/Environmental Technology Lab./Weather & Climate Applications Division
1997-2002	Chief Scientist of the CALJET and PACJET field experiments

SELECTED PROFESSIONAL ACTIVITIES

- 2012, Dept. of Commerce Bronze Medal for rapid response to the Howard Hansen Dam flood risk crisis
- 2010, Fellow of Colorado State Univ./CIRA, Fort Collins, CO
- 2009, NOAA Administrator's Award for leadership of the NOAA Unmanned Aircraft System Program"
- 2008, Elected a Fellow of the American Meteorological Society
- 2007, NOAA/OAR Outstanding Scientific Paper Award, Geophys. Res. Lett., 2006, Vol. 33
- 2011-present, Member, NESDIS/GOES-R Science and Development Executive Board
- 2011-present, Member, Advisory Board, NOAA Steering Group for Precipitation Measurement from Space
- 2011-present, Co-Chair, NOAA's Water Cycle Science Challenge Interagency Workshop
- 2010-present, Member, Council of Fellows, Cooperative Institute for Research in the Atmosphere
- 2010-present, Member, Management Board, Developmental Testbed Center (DTC)
- 2004-present, Chair, NOAA/United States Weather Research Program (USWRP) Executive Committee

SELECTED PUBLICATIONS

Ralph, F. M., P. J. Neiman, G. A. Wick, S. I. Gutman, M. D. Dettinger, D. R. Cayan, and A. B. White, 2006: Flooding on California's Russian River: Role of atmospheric rivers. *Geophys. Res. Lett.*, **33**, L13801, doi:10.1029/2006GL026689.

Wick, G. A., Y. Kuo, F. M. Ralph, T. Wee, and P. J. Neiman, 2008: Intercomparison of integrated water vapor retrievals from SSM/I and COSMIC, *Geophys. Res. Lett.*, **35**, L21805, doi:10.1029/2008GL035126.

Coplen, T. B., P. J. Neiman, A. B. White, J M. Landwehr, F. M. Ralph, and M. D. Dettinger, 2008: Extreme changes in stable hydrogen isotopes and precipitation characteristics in a landfalling Pacific storm, *Geophys. Res. Lett.*, **35**, L21808, doi:10.1029/2008GL035481.

Ralph, F. M., E. Sukovich, D. Reynolds, M. Dettinger, S. Weagle, W. Clark, P.J. Neiman, 2010: Assessment of extreme quantitative precipitation forecasts and development of regional extreme event thresholds using data from HMT-2006 and COOP observers. *J. Hydrometeor.*, **11**, 1288-1306.

Ralph, F. M., P. J. Neiman, G. N. Kiladis, K. Weickman, and D. W. Reynolds, 2011: A multi-scale observational case study of a Pacific atmospheric river exhibiting tropical-extratropical connections and a mesoscale frontal wave. *Mon. Wea. Rev.*, **139**, pp. 1169-1189, doi: 10.1175/2010MWR3596.1.

Dettinger, M.D., Ralph, F.M., Das, T., Neiman, P.J., and Cayan, D., 2011: Atmospheric rivers, floods, and the water resources of California. *Water*, **3,** 455-478.

Ault, A., C. Williams, A. White, P. Neiman, J. Creamean, C. Gaston, M. Ralph, and K. Prather, 2011: Detection of Asian Dust in California Orographic Precipitation. *J. Geophys. Res. – Atmospheres,* **116**, D16205, doi:10.1029/2010JD015351.

Daniel Rosenfeld
Professor, The Hebrew University of Jerusalem, Jerusalem, Israel
Email: Daniel@vms.huji.ac.il; Phone: -972-2-6585821

EDUCATION

1977: B.Sc. degree with distinction in geology at the Hebrew University of Jerusalem, Israel.

1980: M.Sc. degree at the Hebrew University. The subject of the thesis: "Characteristics of Rain Cloud Systems in Israel as Derived from Radar Data and Satellite Images."

1986: Ph.D. at the Hebrew university of Jerusalem. On "The Dynamic Characteristics of Cumuliform Clouds and Cloud Systems and Their Effect on the Rainfall Precipitated by Them."

PROFESSIONAL AND RESEARCH EXPERIENCE

1977-10/1986: Teaching Assistant at the Department of Atmospheric Sciences, Hebrew University of Jerusalem.

11/1986-10/1988: Research Associate with the Universities Space Research Association, at the Severe Storms Branch of the Goddard Space Flight Center, NASA

1988-present: Professor at the Hebrew University of Jerusalem, Israel, Program of Atmospheric Sciences.

Experience as flight scientist in field campaigns for cloud aerosol-precipitation interactions. Selected relevant recent campaigns include:

1988-present: The Israeli rain enhancement project
2-3/2011: CALWATER
Summers of 2009 and 2010: CAIPEEX, India
2-3 of 2005 and 2006: SUPRECIP

SELECTED PROFESSIONAL ACTIVITIES

The Verner Suomi Medal, 17 January 2001, American Meteorological Society, "*for key contributions to remote measurement and interpretation of rainfall, cloud optical properties, and cloud microphysical properties*".

Fellow of the American Meteorological Society, 5 February, 2003

The WMO/UAE Prize for Excellence in Weather Modification, 20 February 2006, *"for contributions to world-wide WM experiments and their advocacy of the aerosol pollution/precipitation link".*

The Schaefer Award, 19 April 2007, Weather Modification Association *"For scientific and technological discoveries that have constituted a major contribution to the advancement of weather modification."*

The Friendship Award, 28 September 2009, the People's Government of China, "*in appreciation to outstanding contribution to the economic construction and society development of Shaanxi Province*", in recognition of the cooperation on cloud-aerosol interactions impacts on weather modification.

1988-2000: Member, Science team of NASA's Tropical Rainfall Measuring Mission satellite.
1996-1999: Member of the American Meteorological Society's committee for Advertent and Inadvertent Weather Modification.
2003-2010: Member of Integrated Land Ecosystem – Atmosphere Processes Study (iLEAPS) science steering committee.
2005: PI for the aircraft field campaign in Texas, aimed at testing the impact of hygroscopic aerosols on precipitation development in convective clouds.
2005-2011: PI for the aircraft field campaign SUPRECIP in February-March 2005 and 2006, continued as CALWATER in 2011, investigating impacts of air pollution on clouds and precipitation in the Sierra Nevada.
2009-2010: Provided scientific guidance to the CAIPEEX cloud physics aircraft campaign in India.
2009-Present: Chair of the American Meteorological Committee for planned and inadvertent weather modification.
2009-present: Member of the Aerosol-Cloud-Precipitation-Climate initiative of iLEAPS, GEWEX and IGAC.

SELECTED PUBLICATIONS

Published more than 137 refereed papers, 8 of them in Science and Nature. H-Factor=39.
Published on the following topics:

Cloud physics: Cloud aerosol interactions impact on precipitation
Weather modification
Remote sensing of cloud and precipitation properties
Nowcasting of severe convective storms
Mitigating hurricanes by seeding with nano-aerosols

Climate Change: Cloud-mediated impact of aerosols on the hydrological cycle
Cloud-mediated impact of aerosols on Earth energy budget
Anthropogenic aerosols invigorating severe convective storms
Mitigating global warming by increasing cloud cover over ocean

J. Ryan Spackman

NOAA Earth System Research Laboratory, Physical Sciences Division
Science and Technology Corporation
Boulder, Colorado, USA
Office: ryan.spackman@noaa.gov, 303-497-7873

EDUCATION

2004 Ph.D., Harvard University, Atmospheric Sciences
1995 Sc.B., Brown University, Honors in Chemistry

RESEARCH AND PROFESSIONAL EXPERIENCE

2011 – 2012 Research Scientist, NOAA Earth System Research Laboratory, Physical Sciences Division, Boulder, Colorado
2011 – 2012 Program Manager, Science and Technology Corporation, Boulder, Colorado
2005 – 2011 Research Scientist, NOAA Earth System Research Laboratory, Chemical Sciences Division, Boulder, Colorado
2004 – 2005 Post-Doctoral Fellow, Harvard University, Cambridge, Massachusetts
1996 – 2004 Research Assistant, Harvard University, Cambridge, Massachusetts
1994 – 1995 Professional Research Assistant, NOAA Climate Monitoring and Diagnostics Laboratory, Boulder, Colorado

SELECTED PROFESSIONAL ACTIVITIES

Dr. Ryan Spackman is a Co-PI and provides expertise on intercontinental transport of pollution in a meteorological context for air quality and climate studies with an emphasis on understanding the role of aerosols in precipitation and improving numerical weather prediction and global aerosol models used for climate prediction. He has over 18 years of airborne science experience in mission coordination, flight planning, and instrumentation operation. He is co-lead mission scientist for the proposed CalWater 2 multi-platform study of precipitation, aerosols, and Pacific atmospheric rivers complementing ACAPEX. During ACAPEX planning and execution, his primary roles will include coordinating the scientific observational strategies between ACAPEX and CalWater 2 missions and leading research derived from the ACAPEX-CalWater 2 observations.

SELECTED PUBLICATIONS

Spackman, J. R., J. P. Schwarz, R. S. Gao, L. A. Watts, D. W. Fahey, S. C. Wofsy, Black carbon burden in the remote Northern Hemisphere springtime Pacific, *Geophys. Res. Lett.*, in preparation.

Ralph, F. M., G. A. Wick, P. J. Neiman, B. J. Moore, J. R. Spackman, M. Hughes, Y. Song, T. Hock, Research aircraft observations of water vapor transport in atmospheric rivers and evaluation of reanalysis products, *J. Geophys. Res.*, in preparation.

Spackman, J. R., J. P. Schwarz, R. S. Gao, L. A. Watts, D. W. Fahey, L Pfister, et al., Seasonal variability of black carbon mass in the tropical tropopause layer, *Geophys. Res. Lett.*, *38*, L09803, 2011.

Spackman, J. R., R. S. Gao, W. D. Neff, et al., Aircraft observations of enhancement and depletion of black carbon mass in the springtime Arctic, *Atmos. Chem. Phys.*, *10*, 9667-9680, 2010.

Schwarz, J. P., J. R. Spackman, R. S. Gao, L. A. Watts, P. Stier, M. Schulz, S. M. Davis, S. C. Wofsy, D. W. Fahey, Global-scale black carbon profiles observed in the remote atmosphere and compared to models, *Geophys. Res. Lett*., *37*, L18812, 2010.

Schwarz, J. P., J. R. Spackman, R. S. Gao, A. E. Perring, E. Cross, T. B. Onasch, A. Ahern, W. Wrobel, P. Davidovits, J. Olfert, M. K. Dubey, C. Mazzoleni, D. W. Fahey, The detection efficiency of the Single-Particle Soot Photometer, *Aerosol Sci. Tech.*, *44*, 612-628, 2010.

Koch, D., M. Schulz, S. Kinne, C. McNaughton, J. R. Spackman, et al., Evaluation of black carbon estimations in global aerosol models, *Atmos. Chem. Phys.*, *9*, 9001-9026, 2009.

Spackman, J. R., J. P. Schwarz, R. S. Gao, et al., Empirical correlations between black carbon aerosol and carbon monoxide in the lower troposphere, *Geophys. Res. Lett*., *35*, L19816, 2008.

Schwarz, J. P., J. R. Spackman, D. W. Fahey, R. S. Gao, U. Lohmann, P. Stier, L. A. Watts, D. S. Thomson, D. A. Lack, L. Pfister, M. J. Mahoney, D. Baumgardner, J. C. Wilson, J. M. Reeves, Coatings and their enhancement of black-carbon light absorption in the tropical atmosphere, *J. Geophys. Res*., *113*, D03203, doi:10.1029/2007JD009042, 2008.

Spackman, J. R., E. M. Weinstock, J. G. Anderson, et al., Aircraft observations of rapid meridional transport from the tropical tropopause layer into the lowermost stratosphere: Implications for midlatitude ozone, *J. Geophys. Res.*, *112*, D12308, 2007.

Weinstock, E. M., J. B. Smith, D. Sayres, J. R. Spackman, J. V. Pittman, N. Allen, J. Demusz, M. Greenberg, M. Rivero, L. Solomon, J. G. Anderson, Measurements of the total water content of cirrus clouds: Instrument details and calibration, *J. Atmos. Oceanic Technol.*, *23*, 1397-1409, 2006.

Christopher W. Fairall

Supervisory Physicist/Chief
Clouds, Radiation, and Surface Processes Division
NOAA Environmental Technology Laboratory Boulder, CO

EDUCATION

Ph.D.,	Solid State Physics, Michigan State University, 1970.
B.S.,	Physics and Mathematics, Florida State University, 1966.

PROFESSIONAL AND RESEARCH EXPERIENCE

1971-1977	Adjunct Professor of Physics, Naval Postgraduate School, Monterey, CA.
1978-1983	Principal Staff Member, BDM Corporation, Monterey, CA.
1982	Visiting Scientist, RISO National Laboratory, Denmark.
1983-1985	Assistant Professor of Meteorology, Pennsylvania State University
1986-1989	Associate Professor of Meteorology, Pennsylvania State University
1989-Pres.	NOAA Earth Systems Research Laboratory, Boulder, CO.

SELECTED PROFESSIONAL ACTIVITIES

Remote Sensing: Ground-based Doppler wind profilers, Sodar and Radar, integrated sounding systems, clear-air turbulence, cloud radiative/microphysical properties.
Air/Sea Interaction: air/sea/ice flux measurements and parameterizations, sea spray, marine and Arctic boundary layers and clouds, particle and gas fluxes.
Boundary Layer Physics: mesoscale interactions, radiative transfer and closure models.
Fellow, Cooperative Institute for Research in Environmental Sciences, 1999
Fellow, American Meteorological Society, elected 2000
NOAA Administrator's Award for Scientific Achievement, 2003
Chair, World Climate Research Program Working Group on Surface Fluxes, 2003-Present
Sverdrup Gold Medal, American Meteorology Society, awarded 2009

SELECTED PUBLICATIONS

Grachev, A.A., E.L Andreas, C. W. Fairall, P.S. Guest, and P.O.G. Persson, 2008: Turbulent measurements in the stable atmospheric boundary layer during SHEBA: ten years after. *Acta Geophysica*, **56**, 142-166.

Fairall, C. W., J. E. Hare, T. Uttal, D. Hazen, Meghan Cronin, Nicholas A. Bond, and Dana Veron, 2008: A seven-cruise sample of clouds, radiation, and surface forcing in the Equatorial Eastern Pacific. *J. Clim*., **21**, 655-673.

Wood, R., K.K. Comstock, C.S. Bretherton, C. Cornish, J. Tomlinson, D.R. Collins, and C.W. Fairall, 2008: Open cellular structure in marine stratocumulus sheets. *J. Geophys. Res.*, **113,** Article Number: D12207, doi:10.1029/2007JD009371.

Serpetzoglou, T., B. A. Albrecht, P. Kollias, and C.W. Fairall, 2008: Boundary layer, cloud, and drizzle variability in the southeast Pacific stratocumulus regime. *J. Clim.*, **21**, 6191-6214.

Weller, R.A., E.F. Bradley, J. Edson, C.W. Fairall, I. Brooks, M.J. Yelland, and R.W. Pascal, 2008: Sensors for physical fluxes at the sea surface: Energy, heat, water, and salt. *Ocean Sci.*, **5**, 327-373, 2008.

Samson Hagos

Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, WA 99352

Email: Samson.Hagos@pnnl.gov; Phone: 509-375-7395

EDUCATION

Ph.D. Cornell University	Atmospheric Sciences	2008
M.S. Cornell University	Atmospheric Sciences	2004
B.S. University of Asmara	Physics	2000

RESEARCH AND PROFESSIONAL EXPERIENCE

2009-present Scientist, Pacific Northwest National Laboratory, Richland, Washington
Dr. Hagos' research focuses on tropical precipitation processes over diurnal, intra-seasonal, seasonal and multidecadal timescales.

2007-2009 Postdoctoral Associate, University of Miami Rosenstiel, School of Marine and Atmospheric Sciences, Miami, Florida
Dr. Hagos worked on problems related to tropical diabatic heating, lifecycle of convection, Madden-Julian Oscillation and monsoon systems.

SELECTED PROFESSIONAL ACTIVITIES

- Refereed articles for *Quarterly Journal of the Royal Meteorological Society*, *Journal of Geophysical Research*, *Journal of Climate*, *Journal of the Atmospheric Sciences*, *Journal of Geophysical Research and Climate Dynamics*.
- Member *American Meteorological Society*, *American Geophysical Union*
- Chaired sessions in the US-DOE Atmospheric Systems Research (ASR) science team meetings.
- Presented an invited talk at workshop on *Sahel climate change* at Columbia University.

SELECTED PUBLICATIONS

Hagos S and LR Leung. 2011. "On the relationship between uncertainties in tropical divergence and the hydrological cycle in global models." *Journal of Climate*, *J. Climate*, **25**, 381–391.

Hagos S and LR Leung. 2011. "Moist Thermodynamics of Madden-Julian Oscillation in a cloud resolving simulation." *Journal of Climate,* 24(21), 5571-5583.

Hagos S, LR Leung, and J Dudhia. 2011. "Thermodynamics of Madden-Julian Oscillation in a regional model with constrained moisture." *Journal of the Atmospheric Sciences,* 68(9), 1974-1989

Hagos SM. 2010. "Building Blocks of Tropical Diabatic Heating." *Journal of the Atmospheric Sciences,* 67(7), 2341-2354.

Hagos SM and C Zhang. 2010. "Diabatic heating, divergent circulation and moisture transport in the African monsoon system." Quarterly Journal of the Royal Meteorological Society, 136(S1), 411-425.

Hagos SM, C Zhang, WK Tao, S Lang, Y Takayabu, S Shige, and M Katsumata. 2010. "Estimates of Tropical Diabatic Heating Profiles: Commonalities and Uncertainties." *Journal of Climate,* 23(3), 542-558.

Mimi Hughes

NOAA ESRL, Water Cycle Branch, PSD,
325 Broadway, Boulder, CO 80305
Email: mimi.hughes@noaa.gov; Phone: (303) 497-4865

EDUCATION

Ph.D. Atmospheric and Ocean Sciences, University of California, Los Angeles, CA, 2008.

M.S. Atmospheric and Oceanic Sciences, University of California, Los Angeles, CA, 2004

B.S. Electrical Engineering (Magna cum laude) and Mathematics (Cum laude), Pennsylvania State University, University Park, PA, 2002

PROFESSIONAL AND RESEARCH EXPERIENCE

2010-pres. Research Scientist, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado

2008-2010 NRC Postdoctoral Research Associate, Water Cycle Branch
NOAA Earth Systems Research Lab, Boulder, CO

2002-2008 Research Assistant, Climate Sensitivity Research Lounge
University of California, Los Angeles, CA

SELECTED PROFESSIONAL ACTIVITIES

Reviewer: Journal of Applied Meteorology and Climatology, Geophysical Research Letters, International Journal of Biometeorology, Journal of the Atmospheric Sciences

Member of the Workplace Advisory Committee in NOAA ESRL's Physical Sciences Division

AMS/AGU Member since 2002

SELECTED PUBLICATIONS

Hughes M, Hall A, and Kim, J (2011) Human-induced changes in wind, temperature and relative humidity during Santa Ana events. *Clim. Change*., 109 (S1), 119-132.

Hughes M and Hall A (2010) Local and synoptic mechanisms causing Southern California's Santa Ana winds, *Clim. Dyn*., 34:847-857 DOI: 10.1007/s00382-009-0650-4.

Hughes M, Hall A, Fovell, RG (2009) Blocking in areas of complex topography and its influence on rainfall distribution, *J. Atmos. Sci*., 66:508-518, DOI: 10.1175/2008JAS2689.1.

Dettinger MD, Ralph FM, **Hughes M**, Das T, Neiman P, Cox D, Estes G, Reynolds D, Hartman R, Cayan D, Jones L (2012) Design and quantification of an extreme winter storm scenario for emergency preparedness and planning exercises in California. *Natural Hazards*, doi:10.1007/s11069-011-9894-5.

Neiman PJ, Schick LJ, Ralph FM, **Hughes M**, Wick GA (2011) Flooding in Western Washington: The connection to atmospheric rivers. *J. Hydrometeor.*, 12:6, 1337-1358

Neiman PJ, Sukovich EM, Ralph FM, **Hughes M** (2010) A Seven-Year Wind Profiler–Based Climatology of the Windward Barrier Jet along California's Northern Sierra Nevada. *Mon. Wea. Rev.*, 138, 1206-1233.

Charles N. Long

Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, WA 99352

Email: Chuck.Long@pnnl.gov

EDUCATION

Ph.D. in Meteorology, May 1996, Penn State University

B.S. in Meteorology, December 1991, with High Distinction, Penn State University

Associate Degree in Letters, Arts and Sciences, December 1989, with Distinction, Penn State University

RESEARCH AND PROFESSIONAL EXPERIENCE

Dec. 1999-present Senior Research Scientist with Pacific Northwest National Laboratory and Site Scientist for the ARM Tropical Western Pacific Program.

SELECTED PROFESSIONAL ACTIVITIES

- 2000 Professor Dr. Vilho Vaisala Award in recognition of the paper entitled "*Ground-Based Remote Sensor Observations during PROBE in the Tropical Western Pacific*"
- Appointed member of the Global Energy Balance Working Group of the International Radiation Commission (IRC) April 2010.
- Editorial Advisory Board Member, The Open Atmospheric Science Journal, Bentham Science Publishers.
- Editorial Advisory Board Member, Open Ocean Engineering Journal, Bentham Science Publishers.
- Member of the international World Meteorological Organization Baseline Surface Radiation Network (BSRN) since 1998. ARM representative to BSRN since 2001. Chair of the BSRN Cloud Parameters Working Group since 2000.
- Invited member of the NSF Facilities Assessment subcommittee on In-Situ Surface and Surface-Atmosphere Exchange (ISSSAE) since 2006.
- Participant in the WMO Global Energy and Water Cycle Experiment (GEWEX) Radiative Flux Assessment, Surface Sub-Group since 2004. Invited Co-Lead Author 2010.

SELECTED PUBLICATIONS

Long, C. N. and T. P. Ackerman, (2000): *Identification of Clear Skies from Broadband Pyranometer Measurements and Calculation of Downwelling Shortwave Cloud Effects*, JGR, 105, No. D12, 15609-15626.

Long, C. N., T. P. Ackerman, K. L. Gaustad, and J. N. S. Cole, (2006): *Estimation of fractional sky cover from broadband shortwave radiometer measurements*, JGR, 111, D11204, doi:10.1029/2005JD006475.

Long, C. N., and Y. Shi, (2008): *An Automated Quality Assessment and Control Algorithm for Surface Radiation Measurements*, TOASJ, 2, 23-37, doi: 10.2174/1874282300802010023.

Long, C. N., and D. D. Turner, (2008): *A Method for Continuous Estimation of Clear-Sky Downwelling Longwave Radiative Flux Developed Using ARM Surface Measurements,* JGR, 113, D18206, doi:10.1029/2008JD009936.

Sally A. McFarlane

Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, WA 99352

Email: Sally.McFarlane@pnnl.gov

EDUCATION

2002 Ph.D., Astrophysical, Planetary, and Atmospheric Sciences, U. Colorado
1999 M.S., Astrophysical, Planetary, and Atmospheric Sciences, U. Colorado
1997 B.A., Physics and Mathematics, Mount Holyoke College (summa cum laude)

RESEARCH AND PROFESSIONAL EXPERIENCE

2009-present Scientist IV, Climate Physics Group, PNNL
2005-2009 Scientist III, Climate Physics Group, PNNL
2002-2005 Postdoctoral Research Associate, Climate Physics Group, PNNL

SELECTED PROFESSIONAL ACTIVITIES

- Chair-elect, 2013 Gordon Research Conference on Radiation and Climate
- Associate Editor, *Journal of the Atmospheric Sciences* (2010 -)
- DOE ARM Tropical Western Pacific Associate Site Scientist (2009 -)
- Science Translator, DOE ASR Cloud-Aerosol-Precipitation Interactions Working Group (2009 - present)

SELECTED PUBLICATIONS

Long, C.N., S.A. McFarlane, A. Del Genio, P. Minnis, T. P. Ackerman, J. Mather, J. Comstock, G.G. Mace, M. Jensen, and C. Jakob, 2012: ARM Resarch in the Equatorial Western Pacific – A Decade and Counting. *BAMS, submitted March 2012.*

Riihimaki, L.D., S.A. McFarlane, and J. M. Comstock, 2012: Climatology and formation of tropical mid-level clouds at the Darwin ARM site. *J. Climate, accepted.*

Zhao, C. and co-authors (including S.A. McFarlane), 2012: Understanding Differences in Current ARM ground-based Cloud Retrievals. *J. Geophys. Res., accepted.*

McFarlane, S.A., K. L. Gaustad, E. J. Mlawer, C. N. Long, and J. Delamere, 2011: Development of a surface spectral albedo product for the ARM Southern Great Plains Central Facility. *Atmos. Meas. Tech.,*4, 1713-1733, doi:10.5194/amt-4-1713-2011.

Varble, A., E.J. Zipser, A.M. Fridlind, A.S. Ackerman, J.-P. Chaboureau, J. Fan, A. Hill, S. McFarlane, J.P. Pinty, B. Shipway, 2010: Evaluation of TWP-ICE cloud resolving simulations using observations. Part I: Precipitation and cloud structure. *J. Geophys. Res.,* 116, D12206, doi:10.1029/2010JD015180.

Mather, J.H., and S.A. McFarlane, 2009: Cloud classes and radiative heating profiles at the Manus and Nauru ARM sites. *J. Geophys. Res.,* 114, D19204, doi:10.1029/2009JD011703.

Wang, W., X. Liu, S. Xie, J. Boyle, and S. A. McFarlane, 2009: Testing ice microphysics parameterizations in NCAR CAM3 using TWP-ICE data. *J. Geophys. Res.,* 114, D14107, doi:10.1029/2008JD011220.

McFarlane, S.A., E. I. Kassianov, J. Barnard, C. Flynn, and T. Ackerman, 2009: Surface shortwave aerosol radiative forcing during the ARM Mobile Facility deployment in Niamey, Niger, *J. Geophys. Res.*, 114, D00E06, doi:10.1029/2008JD010491.

Veerabhadran Ramanathan

Victor Alderson Professor of Applied Ocean Sciences
Distinguished Professor of Climate and Atmospheric Sciences

EDUCATION

B.E., 1965 Annamalai University, India (Engg.)
M.Sc., 1970 Indian Institute of Science, India (Engg.)
Ph.D., 1974 State University of New York at Stony Brook (Planetary Atmospheres)

RESEARCH AND PROFESSIONAL EXPERIENCE

1979-date	Principal Investigator, NASA Earth Radiation Budget Experiment
1982-1986	Senior Scientist, NCAR, Boulder, CO
1985-1988	Affiliate Professor, Colorado State University, Fort Collins, CO
1986-1990	Professor, Department of Geophysical Sciences, U. Chicago, Chicago, IL
1990-date	Victor C. Alderson Professor of Applied Ocean Sciences, and Professor of Climate and Atmospheric Sciences, Scripps Institution of Oceanography, University of California, San Diego, CA
1991-date	Director, Center for Clouds, Chemistry and Climate, Scripps Institution of Oceanography, University of California, San Diego, CA
1996-date	Director, Center for Atmospheric Sciences, Scripps Institution of Oceanography, University of California, San Diego, CA
1998	First K.R. Ramanathan Visiting Professor, Physical Research Lab, India
2004-date	Distinguished Professor of Atmospheric and Climate Sciences, Scripps Institution of Oceanography, University of California, San Diego, CA

RECENT PROFESSIONAL ACTIVITIES

- Elected to the Royal Swedish Academy of Sciences, 2011
- Member, Science Directions Advisory Council, Scripps Institution of Oceanography, 2011-date
- Chair, Pontifical Academy of Sciences "Fate of Mountain Glaciers in the Anthropocene" Report, 2010-2011
- Member, UNEP Black Carbon Advisory Board 2009-2011
- Tyler Prize for Environment with co-recipient Dr. Richard Alley, February 2009
- Zayed Prize for scientific and technological achievements in environment with co-recipient Prof. Jane Lubchenco, June 2008
- Member, Committee for the 2008 Trieste Science Prize, 2008-date
- PNAS Article, Integrated Model Shows that Atmospheric Brown Clouds and Greenhouse Gases have reduced rice harvest in India, recognized as an exceptional paper published in 2006 by the Editorial Board of PNAS, Winner of the Cozzarelli Prize, 2007
- Recognized by the AGU Atmospheric Sciences Section for Bjerknes Lecture, Global Dimming and Its Masking Effect on Global Warming, 2006

PUBLICATIONS

184 Peer Reviewed Publications and 30 publications in books and reports.

Steven A. Rutledge

Professor, Scientific Director, Department of Atmospheric Science, CSU-CHILL
National Radar Facility
Colorado State University, Ft. Collins, CO 80523
Phone: (970) 491-8283

EDUCATION

B.S. (1978)	Physics, University of Missouri - St. Louis, St. Louis, Missouri
Ph.D. (1983)	Atmospheric Science, University of Washington, Seattle, Washington

PROFESSIONAL AND RESEARCH EXPERIENCE

1994 -	Professor of Atmospheric Science, Colorado State University
1999 -2006	Head, Department of Atmospheric Science, Colorado State University
1990-1994	Associate Professor, Colorado State University
1988-1990	Assistant Professor, Colorado State University
1983-1988	Assistant Professor, Oregon State University
1978-1983	Graduate Research Assistant, University of Washington

SELECTED PROFESSIONAL ACTIVITIES

Dr. Rutledge's interests are in mesoscale meteorology, atmospheric electricity, radar meteorology and cloud physics. He is a member of the NASA PMM Science Team. He was Co-chair for the MCTEX Experiment and the STERAO-A Deep Convection Experiment. He was the Lead Scientist for the TRMM-LBA Field Campaign in Brazil and Co-PI for STEPS in 2000. He was a PI for the NAME field experiment radar campaign in 2004. He is a PI for the Deep Convection, Clouds and Chemistry Experiment (DC3) and a PI and member of the Steering Committee for DYNAMO, Dynamics of theMJO. He also serves as the Scientific Director of the CSU-CHILL National Radar Facility. He recently completed terms as Editor for J. Atmos. Sci., member of the UCAR Board of Trustees and Councilor of the AMS. He is a Fellow of the AMS.

SELECTED PUBLICATIONS

S-Band Dual-Polarization Observations of Winter Storms. *J. of Appl. Meteor. and Climatology.* (P. Kennedy and S.A. Rutledge) In press.

Using CASA IP1 to Diagnose Kinematic and Microphysical Interactions in a Convective Storm. *Mon. Wea. Rev*., **138,** 1613-1634. (B. Dolan and S.A. Rutledge).

A Theory-Based Hydrometeor Identification Algorithm for X-band Polarimetric Radars. *Journal of Atmospheric & Oceanic Technology***, 46**, 1196-113. (B. Dolan, and S.A. Rutledge).

Observations of Quasi-Symmetric Echo Patterns in Clear Air with the CSU-CHILL Polarimetric Radar. *Journal of Atmospheric and Oceanic Technology*, **21**, 1182-1189. (Lang, T. J., S. A. Rutledge, and J. L. Stith).

Polarimetric Observations of Hail Formation, *Journal of Applied Meteorology*, **40**, 1347-1366. (P. C. Kennedy, S. A. Rutledge, W. A. Petersen, and V. N. Bringi).

Duane Waliser

Chief Scientist, Earth Science and Technology Directorate
Jet Propulsion Laboratory, Pasadena, CA; Email: Duane.E.Waliser@jpl.nasa.gov

EDUCATION

B.S. Physics	Oregon State University 1985
B.S. Computer Science	Oregon State University 1985
M.S. Physics	University of California, San Diego 1987
Ph.D. Phys. Oceanography	Scripps Institution of Oceanography, UCSD 1992

RESEARCH AND PROFESSIONAL EXPERIENCE

2007 – Present	Adjunct Professor and Fellow, Joint Institute for Regional Earth System Science and Engineering (JIFRESSE), U. California, Los Angles, CA.
2010 – Present	Chief Scientist, Earth Science and Technology Directorate, Jet Propulsion Laboratory, Pasadena, CA.
2007 – 2010	Senior Research Scientist, Water and Carbon Cycle Group, Science Division, Jet Propulsion Laboratory, Pasadena, CA.
2004 – Present	Visiting Associate Faculty, Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA.
2004 – 2007	Principal Scientist, Water and Carbon Cycle Group, Science Division, Jet Propulsion Laboratory, Pasadena, CA.
1999 – 2004	Associate Professor, Institute for Terrestrial and Planetary Atmospheres, Marine Science Research Center, State U. New York, Stony Brook.

SELECTED PROFESSIONAL ACTIVITIES

Co-chair, with Mitch Moncrieff, Science Working Group on the WCRP-WWRP/THORPEX Year of Tropical Convection activity (www.ucar.edu/yotc).

Co-chair, with Matthew Wheeler, WCRP-WWRP/THORPEX Madden-Julian Oscillation (MJO) Task Force (www.ucar.edu/yotc/mjo.html).

Member, National Research Council, National Academy of Sciences study on Intraseasonal and Interannual Climate Predictability, 2009/1 to 2010/9.

Member, Science Advisory Group, International Pacific Research Center (IPRC), University of Hawaii, March 2011-Present.

SELECTED PUBLICATIONS

Waliser, D. E., J. Ridout, S. Xie, and M. Zhang, 2002: Variational Objective Analysis for Atmospheric Field Programs: A Model Assessment, J. Atmos. Sci., 59, 3436-3456.

Waliser, D. E., K. Seo, S. Schubert, E. Njoku, 2007: Global Water Cycle Agreement in IPCC AR4 Model Simulations, Geoph. Res. Let., 34, L16705, doi:10.1029/2007GL030675.

Tian, B. J., **D. E. Waliser**, R. A. Kahn, Q. B. Li, Y. L. Yung, T. Tyranowski, I. V. Geogdzhavev, M. I. Mishchenko, O. Torres, and A. Smirnov, 2008: Does the Madden-Julian Oscillation influence aerosol variability? J. Geophys. Res., doi:10.1029/2007JD009372.

Hailong Wang

Scientist, Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, WA 99352; Email: Hailong.Wang@pnnl.gov

EDUCATION

Ph.D.	University of Illinois, Urbana	Atmospheric Sciences	2007
M.S.	Lanzhou University, China	Atmospheric Sciences	2001
B.S.	Lanzhou University, China	Atmospheric Sciences	1998

RESEARCH AND PROFESSIONAL EXPERIENCE

2009-present Scientist, Pacific Northwest National Laboratory, Richland, WA
Dr. Wang's research focuses on high-resolution modeling of aerosol-cloud-precipitation interactions and on improving earth system modeling of aerosol-cloud processes.

2008-2009 Research Scientist, Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado and NOAA, Boulder, CO
Dr. Wang worked on microphysical and dynamical controls on precipitation and mesoscale cloud structures of marine stratocumulus.

2007-2008 Visiting Fellow, CIRES, University of Colorado and NOAA, Boulder, CO
Dr. Wang was involved in the development and application of the Weather Research and Forecasting model for studies in aerosol-cloud-precipitation interactions.

SELECTED PROFESSIONAL ACTIVITIES

- Member of the American Meteorological Society (AMS) Cloud Physics Committee
- Member of the program committee of the AMS 13th and 14th Conference on Cloud Physics and session chair
- Session convener and chair for the 2011 AGU fall meeting
- Reviewer of journal articles (JAS, ACP, JGR, QJRMS, JAMC, MWR, etc.), research proposals (DOE, NSF and NOAA) and IPCC AR5 draft.

SELECTED PUBLICATIONS

Wang, H., P. J. Rasch, and G. Feingold, 2011: Manipulating marine stratocumulus cloud amount and albedo: a process-modelling study of aerosol-cloud-precipitation interactions in response to injection of cloud condensation nuclei, *Atmos. Chem. Phys.*, 11, 4237-4249, doi:10.5194/acpd-11-4237-2011.

Wang, H., G. Feingold, R. Wood, and J. Kazil, 2010: Modeling microphysical and meteorological controls on precipitation and cloud cellular structures in Southeast Pacific stratocumulus. *Atmos. Chem. Phys.*, 10, 6347-6362, doi:10.5194/acp-10-6347-2010.

Wang, H., and G. Feingold, 2009: Modeling open cellular structures and drizzle in marine stratocumulus. Part II: The microphysics and dynamics of the boundary region between open and closed cells. *J. Atmos. Sci.*, 66, 3257-3275.

Wang, H., and G. Feingold, 2009: Modeling open cellular structures and drizzle in marine stratocumulus. Part I: Impact of drizzle on the formation and evolution of open cells. *J. Atmos. Sci.*, 66, 3237-3256.