MOUNTAIN TERRAIN ATMOSPHERIC MODELING AND OBSERVATIONS (MATERHORN) PROGRAM

ONR FY 2011 MURI TOPIC #7: Improved Meteorological Modeling in Mountain Terrain

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Agency to which the proposal is submitted:
Office of Naval Research (Topic Chiefs: Dr. Ronald J. Ferek and CDR Daniel Eleuterio, PhD)

Principal Investigator:
Professor Harindra Joseph Fernando
Wayne and Diana Murdy Endowed Professor of Engineering & Geosciences
Department of Civil Engineering and Geological Sciences
Concurrent: Aerospace and Mechanical Engineering
University of Notre Dame, Notre Dame, IN 46556
Phone: 574-631-9346; Fax: 574-631-9236
e-mail: Fernando.10@nd.edu
URL: www.nd.edu/~dynamics

MURI Team:
Naval Post Graduate School
University of California, Berkeley
University of Utah
University of Virginia

Current DOD Contracts:
Agency Contact/phone: Office of Naval Research (Dr. Theresa Paluszkiewicz; 703-696-6680)

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1. INTRODUCTION

In spite of laudable progress in orographic meteorology over the past three decades, the gaps in knowledge and technology continue to challenge the fidelity of meso- and smaller scale predictions of weather in mountainous terrain. These challenges are fraught by rapid spatial and temporal variability and intricate dynamics of mountain weather (Barry 2008). About 70% of the Earth's land surface, and more so the urban areas, is characterized by complex topography, and thus atmospheric processes typical of complex-terrain airsheds have been studied extensively in the context of air quality; reviews are given by Blumen (1990), Whiteman (2000), Fernando (2010) and Zardi & Whiteman (2010). Yet the weather in heavily mountainous areas has received less attention, perhaps because of sparse human settlements therein. The more recent U.S. military engagements in mountainous areas, however, have generated a renewed interest on mountain weather (Figure 1), given that war fighting in such terrain - historically referred to as *mountain (or Alpine) warfare* - is one of the most dangerous types of combat (Winters 2001).

Mountain weather is rich in remarkable phenomena, the most fundamental being the slope and valley winds, known as *thermal circulation*, and their modifications by synoptic flows (Figure 2). The salient nocturnal phenomena include downslope (katabatic) flows, pooling in basins, hydraulic jumps, lee waves, rotors, internal-wave radiation and breaking, intrusion formation on the slopes and fog. Upslope (anabatic) flows and their convergence at mountaintops to produce deep convection and secondary flows at terrain and land-cover inhomogeneities are characteristics of daytime flows. Rapidly varying sub-mesoscale phenomena (< a few km, on the order of an hour or less) abound, including (clear air) turbulence, wind gusts, Venturi effects, eddy shedding, pulsating flow through canyons and gaps and lightning. Thus, in mesoscale modeling of mountain weather, the role of sub-grid processes is more crucial than elsewhere.

FIGURE 1: A CH-47 Chinook helicopter delivering troops during operation Anaconda in Afghanistan.

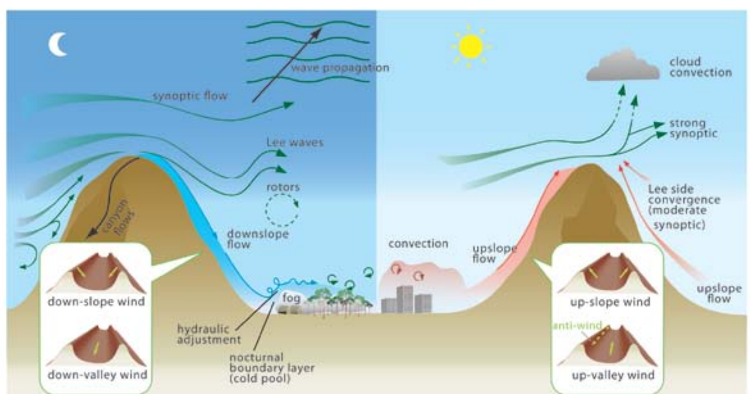


FIGURE 2: Dominant meteorological processes in complex terrain.

A principal element of mountain warfare is meteorological support, which is stymied by weather extremes, steep terrain, incomplete environmental information, intricate logistics, greater uncertainties and higher risks to warfighters. In a recent workshop convened by the ONR/ARO (February 1-2, 2010, Tempe, Arizona), invited presenters from the armed forces identified the most crucial operational issues of mountain weather -- wind speeds and shifts, shear, visibility (turbulence and dust entrainment), moisture and illumination. For example, the recent drought in Afghanistan has created islands of low visibility as a result of dust entrainment under high winds, which has drastically impacted helicopter operations. Recently, the DoD initiated "coordinated" deployment of predator Unmanned Aerial Vehicles (UAV), aircraft with aerial refueling and helicopters, for which mountain weather has been identified as a limiting factor. The UAVs are deleteriously affected by moisture and viable only when the relative humidity is < 30%. Dispersion in complex terrain is also poorly understood, yet its predictions are imperative for protection against chemical or biological attacks and for mapping obscurant pathways. As such, development of reliable Decision Aids for mountain warfare is dependent on the progress in mountain meteorology (Peck 2002). As Col. James Richardson, the commander of the 101st Combat Aviation Brigade, aptly described - "it's the terrain and the weather that will kill you in Afghanistan" (Hames 2009). Herein we propose a multidisciplinary research program - MATERHORN - to study weather phenomena and their predictability in mountain terrain.

In the ONR/ARO workshop, overarching challenges to mountain weather prediction were identified, categorizing them into five groups: core issues, model performance, boundary conditions, model initialization and model validation. The critical elements of each category are summarized in MURI BAA 10-026 and not repeated here; recognizing that a single project cannot handle all, a subset of issues were selected to be addressed in the proposed project.

GOAL: MATERHORN is designed to identify and study the limitations of current state-of-the-science mesoscale models for mountain terrain weather prediction and develop scientific tools to help realize leaps in predictability. It melds four synergistic components working symbiotically:

<u>The Modeling Component (MATERHORN-M)</u> will study the predictability at mesoscale, in particular, the error growth (i.e., the sensitivity to initial conditions at various lead times), and develop meaningful measures of skill relative to appropriate conditional climatologies (i.e., the skill of capturing specific phenomena when they are supposed to appear; e.g., turbulence generation when a Richardson number criterion is satisfied). Sensitivities to input properties and boundary conditions will be investigated. Data assimilation studies will be conducted, and different techniques (e.g., 4DVAR, ensemble Kalman filtering, 3DVAR) will be compared.

<u>The Field Experimental Component (MATERHORN-X)</u> will conduct measurements with unprecedented spatio-tempotal detail to support modeling efforts and process studies. Data from remote sensors, an instrumented UAV and a dense sensor network will be used for model evaluation over many grids and over tens of km. Primarily, the <u>Granite Mountain Atmospheric Science Testbed (GMAST) at the US Army Dugway Proving Grounds (DPG)</u> will be employed, which is the most sophisticated complex terrain test bed in existence. These will follow experiments in the Salt Lake basin to investigate fog-laden complex terrain flows. Archived data from T-REX (Grubišić et al. 2008), VTMX (Doran et al. 2002) and other field experiments (e.g. MeteoDiffusion in Italy; Fernando et al. 2011) will also be used.

<u>The Technology Component (MATERHORN-T)</u> will develop cutting edge technologies to enable some needed, yet currently untenable, meteorological measurements. These include an instrumented UAV, and remote sensors and samplers for moisture measurements.

<u>The Parameterization Component (MATERHORN-P)</u> will employ high resolution simulations with novel modeling and terrain-representation methodologies as well as imaginative laboratory studies to educe and quantify processes intermingled (and hidden) in field observations. Salient processes will be analyzed theoretically and described using conceptual models. Insights so gained will be used to develop sub-grid parameterizations with improved physics. The new parameterizations will be implemented in mesoscale models, and their efficacy will be evaluated using new and archived data taken under diverse mountain weather conditions.

To pursue this goal, we have assembled a multidisciplinary team that includes atmospheric scientists, geophysicists, numerical/theoretical analysts, engineers and applied mathematicians culled from five academic institutions. We have firm commitments from the DPG and Naval Research Laboratory (NRL) for collaboration (§7); non-federal funding has been secured to cover their efforts. The team and their expertise are listed below.

University of Notre Dame (ND) – H.J.S. Fernando (field observations, theoretical and lab models), R. Dimitrova (WRF/MM5, parameterization implementation), P. Dunn (aerosols and fog), J.C.R. Hunt (theoretical analysis), C. Retallack (Lidar), E. Kit (waves and turbulence), T. Pratt (radar remote sensing), M. Zenk (UAV, Pilot) and S. Coppersmith (instrumentation);

Naval Post Graduate School (NPS) – J. Hacker (mesoscale modeling and predictability, ensemble data assimilation DA); Karl Pfeiffer (model set up, data assimilation); Kurt Nielsen (data analysis, model runs); in partnership with J. Doyle (NRL) on modeling and analysis;

University of California, Berkeley (UCB) – F. Chow (Large Eddy Simulations LES, nesting, sub-grid models);

University of Utah (UU) – E. Pardyjak (observations, aerosols), S. Hoch (observations), Z. Pu (DA, ensemble forecasting), J. Steenburgh (modeling) and D. Whiteman (observations); and

University of Virginia (UV) – S. de Wekker (Aerosol Lidar, model evaluation, optimal siting);

The entire team will work with DPG (John Pace). The Army Research Laboratory ARL (Dennis Garvey) has also shown a strong interest in joining the team (approval pending).

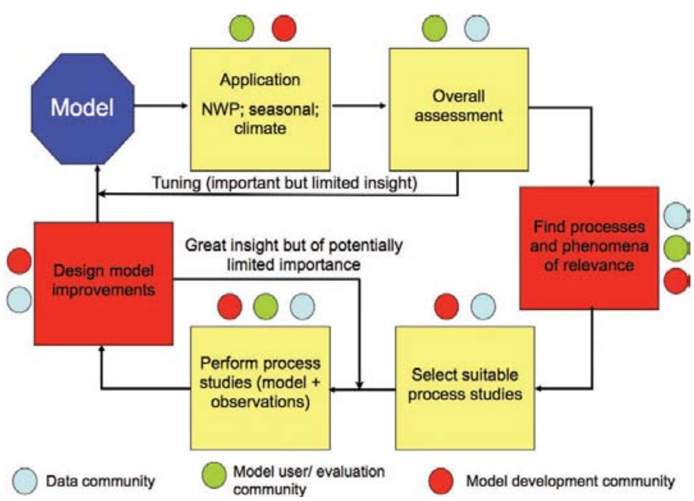


FIGURE 3: A schematic of model development ingredients (Jakob 2010). This general approach will be at the heart of the project, and is described in §2.

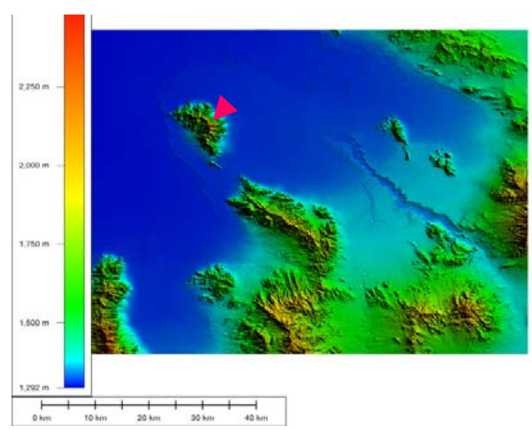


FIGURE 4: The complex terrain of DPG area. Granite mountain is marked by the arrow; GMAST surrounds this mountain.

2. MODEL DEVELOPMENT AND IMPROVEMENT APPROACH

With the project focused on improving mountain weather forecasting, we will pursue novel scientific paradigms and approaches that undergird mesoscale model development. The recent authoritative essay of Jakob (2010) on meteorological model development has identified the key elements of model development and improvement (Figure 3), contributed by three players: (i) the model development and improvement community, (ii) the user and evaluation community, and (iii) the data community. The accelerated model improvement depends on how the three communities cross-fertilize. The upper part of Figure 3 highlights model application and assessment with standard tools. This step helps identify model problems, but often not the root causes. For mountain terrain, there is some consensus on core problems, and an efficient next step would be to concentrate on the rest of the loop (process studies and design of model improvements). For MATERHORN, we have assembled a group of experienced researchers from all three communities who will not only enable near-term model improvements, but will also establish a research framework for future improvements.

Jakob (2010) places a special emphasis on process studies, parameterization development in particular, cogently arguing that realistic representation of momentum, heat and mass transfer is strongly intertwined with improved model performance. A paradigm shift was advocated, with strong emphasis on: (i) connections between model errors and parameterizations (currently they are loosely coupled); and (ii) implementation and testing of new parameterizations (which is unacceptably slow at present). The latter requires working with organizations that host mesoscale models, thus we will work with Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®) and NCAR's Weather Research and Forecasting Model (WRF; Skamarock et al. 2008). WRF forms the backbone of the USAF weather prediction capability.

3. PROPOSED RESEARCH

Improving predictability via understanding of model errors, error growth, predictability limits and limitations of parameterizations will be the focus of the proposed research. Enabling these efforts will be two major field experiments at GMAST (Figure 4), two additional field campaigns in Salt Lake Valley, LES and Reynolds averaged Navier Stokes (RANS) simulations, laboratory studies and theoretical work -- all facilitating model validation, data assimilation and development of physics-based parameterizations. The expertise of the group in these areas and the role of each investigator are summarized in §1 and §5.

Because of the rapid variability in predictions of mountain weather, the model initialization is crucial. Careful studies on initialization techniques (either ensemble or adjoint sensitivities), including sensitivities to land-surface, are required. An instrumented UAV is a part of the project, which will allow, among other benefits, investigation of their efficacy as a future data assimilation platform.

The selection of GMAST was made after careful consideration. First, GMAST is the most densely instrumented complex-terrain test bed available, and with the supplemental instrumentation that we will bring in (§3.2), the field experiments are expected to be unusually comprehensive. Second, DPG has been very enthusiastic of hosting MATERHORN-X, citing mutual benefits (§7). Third, DPG has a high-resolution weather modeling system using WRF and data assimilation, cycling 8 times a day at 1.1km resolution. In addition, a 30-member mesoscale ensemble (15 WRF and 15 MM5) runs continually, cycling 4 times a day at 3.3km resolution. Run by NCAR, this will provide guidance and distributed boundary conditions for numerical investigations. Fourth, the U.S. Intermountain West offers semi-arid terrain analogous to remote areas of DoD interest, including Afghanistan; the weather is modulated by land-surface contrasts, complex topography and intrinsic synoptic variability. The DPG observes thermal circulation flows, terrain-forced flows and turbulence, frontal cyclones, convective systems and dust storms (Rife et al. 2002; Schultz et al. 2002; Schultz & Trapp 2003; Shafer & Steenburgh 2008; West & Steenburgh 2010; Jeglum et al. 2010).

3.1 Modeling and Model Improvements: MATERHORN-M

It is often unclear whether the prediction errors result primarily from initial condition (IC) errors, uncertainty in the large scales or model inadequacy. For significant prediction improvements, we must disentangle various sources of error, preferably using the state-of-the-science modeling platforms. We can then propose and test more optimal observing strategies with current and future observational assets. A combination of basic predictability studies and observation-impact studies, within the framework of well-performing (DA) systems, can address many of these challenges. Previous validation studies highlight some of the key shortcomings of existing modeling systems in semi-arid mountainous regions (e.g., Davis et al. 1999; Rife et al. 2002, 2004; Hart et al. 2004, 2005; Liu et al. 2008a,b). For example, 10-m wind speed and direction forecasts are remarkably poor, and at DPG the mean absolute errors of wind speed and direction are about 2 m s^{-1} and 60-75°, respectively, at only a 12 hour lead time (Rife et al. 2004). Forecast skill is especially poor for non-periodic circulations, at stations where the wind is modulated by sub-mesoscale circulations and when stable or persistent surface-based cold pools (Hart et al. 2005) are present. To address these model inadequacies, we propose four research focus areas for MATERHORN-M, each supported by a mesoscale DA framework over mountainous terrain:

(1) Quantifying spatial and temporal scales of error growth internal to a mesoscale model, and relating them to Initial Condition (IC) uncertainty;
(2) Determining whether the errors can be reduced by improving ICs or whether we are already near the limits of predictability imposed by chaos;
(3) Proposing and testing observations and strategies that will reduce the important IC errors while bringing us closer to predictability limits;
(4) Quantifying and characterizing the importance of model inadequacy in maintaining prediction errors that are not reduced as much as expected.

Results from (1)-(3) form a loop for guiding the study, while (4) is made possible by examining residual errors. The focus will be on combined synoptic and thermal forcing, including fog, high-winds that generate dust, and low-level clouds. Both the existing observations from T-REX and proposed MATERHORN-X (§3.2) will be used, and modeling studies will guide the later phases of observational strategies. By systematically addressing (1)-(4) using observations, DA and a prediction system, we hope to make significant gains in predictive skill.

Existing mesoscale Numerical Weather Prediction (NWP) models and DA systems are mature enough to support this work, and future operational DA systems will almost surely include some characteristics of both ensemble DA and variational DA. The COAMPS functions with either an ensemble DA system (DA Research Testbed, DART) or the Navy's 3DVar (NRL Atmospheric Variational DA System NAVDAS). In either case, observation sensitivity can be computed by direct (for NAVDAS) or approximate (for ensemble methods) adjoint computations of both the model and the DA system. Similarly WRF's adjoint is available, and is fully functional in DART. Ancell & Hakim (2007) elucidated the theoretical equivalence between ensemble sensitivity analysis and adjoint calculations. Because of its relative simplicity, the appeal of flow-dependent covariances for high-resolution Planetary Boundary Layer (PBL) flows, and the ensemble forecasts that result, we will work with DART rather than variational methods. We will concurrently seek external opportunities to compare ensemble and variational methods in mountainous terrain. The COAMPS-DART and WRF-DART will support the areas (1)-(4) at NPS and UU, respectively.

Currently available predictions over DPG will be leveraged to begin investigation while configuring and testing COAMPS-DART and WRF-DART. As mentioned, NCAR runs forecasts with 30 members for the DPG area, with an archive that covers several years. We will use these forecasts to further identify key deficiencies in numerical simulations. In particular, we will concentrate on initialization and simulation of <u>Stable Boundary Layers SBL</u> (i.e., diurnal or persistent cold pools, katabatic winds), including their formation and dissipation, sub-mesoscale circulations, and large-scale (synoptic) circulations (Fernando & Weil 2010).

Short-range ensemble forecasts will be analyzed for error growth internal to COAMPS and WRF, under focus area (1). Ensemble DA produces a set of ICs that are consistent with flow-dependent errors, observations, and observational errors. Differences amongst the ICs quantify IC uncertainty, and have small amplitude compared to forecast error. Predictability can be characterized by quantifying the temporal and spatial evolution of differences between forecasts that ensue from those ICs. The co-evolution of system components can be examined to identify *raison d'être* of predictability maintenance or loss. Hacker (2010) used spectral and co-spectral analysis, in a limited study with pairs of mesoscale simulations, to quantify the importance of land-surface uncertainty to loss of predictability in low-level winds. We will extend those techniques to ensembles, and characterize the relative importance of forcing scales, land-surface properties, topography, fog, low clouds, and large-scale flow; such analyses have never been completed for mountainous terrain. Analysis of IC sets from COAMPS-DART and WRF-DART, using real observations, will be of great importance for model development.

Ensemble sensitivity calculations will then be used to relate the error growth to initial-condition uncertainty under task (1). Reinecke & Durran (2009) used ensemble sensitivity computed from COAMPS and an ensemble DA system to show that downslope winds can be highly sensitive to upstream flow details. A similar result from the COAMPS adjoint is shown in Fig. 5. Upstream cross-barrier (U) wind speed errors smaller than 0.2 ms^{-1} can produce meaningful (one standard deviation) changes in downslope kinetic energy 9 h later.

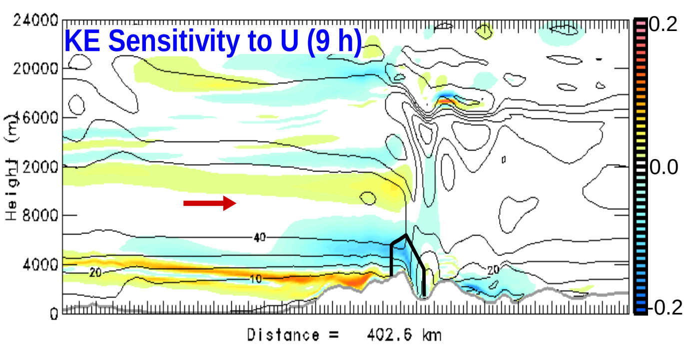


FIGURE 5: An example of a COAMPS adjoint sensitivity calculation for wind normal to the Sierra. The COAMPS adjoint was integrated over a nine hour period to compute the sensitivity of a kinetic energy response function (within the bold black outline) to the cross-barrier (U) wind component.

A corollary is the study of under what conditions topographic and/or land-surface contrasts and large-scale forcing enhance or degrade mesoscale and local predictability. Using the WRF and COAMPS models, we plan to conduct such sensitivity studies, concentrating on the simulation of MATERHORN-X. This will be done by perturbing the key parameters that represent topographic characteristics and land-surface conditions in numerical simulations.

The natural next step is calculation of the impacts of observations on reducing IC uncertainty and subsequent forecast uncertainty in focus area 2. From forecast errors prior to the assimilation of new observations (the innovations), and an adjoint of the DA system, observation impact can be directly quantified without re-running the ensemble forecasts and DA system. The adjoint of the ensemble DA system is approximated with the help of the Kalman gain matrix and analysis error covariance matrix (Ancell & Hakim 2007). The observation impact can be interpreted as forecast uncertainty reduction expected from including additional observations (Pu et al. 1998). Notwithstanding model inadequacy, it can be further interpreted as forecast error reduction.

Results from these types of studies depend on the metric chosen to measure uncertainty. Having a thorough understanding of the important error-growth scales, as described above, will enable intelligent and relevant choices of metrics. One can also consider how the error growth may impact DoD operations in mountainous terrain, and construct metrics to reflect operational sensitivities. Along the way care must be taken to ensure that the relationship between ICs and forecasts is sufficiently linear. Although uncertainty in thermal circulation may be well-approximated by linear techniques over a few hours, fog and low cloud periods may be different. Linearity can be established by re-running a few select cases, testing the impact of observations by assimilating them, and then forecasting forward with the nonlinear model.

New observing strategies with current observational capabilities, or altogether new observation platforms, can be explored relatively cheaply within this framework. Because models and observations are imperfect, field observations must be integrated to determine the extent to which forecast uncertainty reduction correlates with forecast error reduction. Thus under focus area (3) we will consider UAV and surface-based observations of MATERHORN-X, which could be either forward-deployed or fielded upstream. Tethered balloons can also simulate UAV ascents and descents. Also considered will be Lidar observations, given the potential of Lidars for future deployment aboard DoD aircraft. Early in the project, we propose to use aircraft and surface observations from T-REX to provide a data set to test sensitivity results with real data, and to test hypothetical strategies that could be deployed later in MATERHORN-X. Three research aircraft were involved in T-REX, which covered an altitude range from 150m above ground within Owens Valley to 14km MSL, extending from 200km upwind of the Sierra Nevada to about 100km downwind of the Sierra. These observations will be used as a surrogate for UAV observations in the early part of the study. Predictability and sensitivity studies with T-REX data will aid formulation of deployment strategies in the MATERHORN-X second field program. Both sets of observations will feed back into the final analysis and provide critical tests for all of the modeling work described above, completing a loop in focus areas (1)-(3).

Surface networks are of special interest because of the low cost and relative ease of deployment. Ensemble filters have shown promise with surface observations (Hacker & Snyder 2005; Hacker & Rostkier-Edelstein 2007), but have not been tested in mountainous terrain with real observations (Zhang & Pu 2010). We propose to assimilate near-surface, UAV and sounding data collected during MATERHORN-X in conjunction with available satellite data to produce the best possible near surface and boundary layer analysis. The impact of DA on the local and mesoscale predictability will be assessed. In addition, using DA/data denial experiments, optimal observational strategies in terms of the distribution and type of observations will be identified.

Throughout our work, validation of the forecast will be needed. With the data collected during Intensive Operational Periods (IOPs), outputs of WRF and COAMPS will be verified and major deficiencies identified. Through validation and sensitivity results, we expect to determine the relative importance of systematic model error, local forcing uncertainties (e.g., topographic and land-surface characteristics) and analysis uncertainties in the prediction of local atmospheric conditions. These will form the basis of modifications to be proposed for WRF and COAMPS.

Model inadequacies can be identified (focus area 4) via errors remaining after completing a loop through focus areas (1)-(3). Within a cycling ensemble DA system, systematic analysis increments are defined as the mean increment across many DA cycles. The mean increment reveals errors in the model-forecast ensemble covariance, and shows the physical structure of model errors. The approach is conceptually similar to that used by Danforth & Kalnay (2008), although it is more powerful because we have the ensemble covariance to exploit for complicated error structures. We have a greater chance of finding model errors in residual errors after assimilating with the most optimal strategy within focus areas (1)-(3), and thus a better chance of describing the correct error structures to model developers.

3.2 Field Observations: MATERHORN-X

Two field campaigns will be conducted at GMAST in calendar year 2012 to sample a range of surface and synoptic conditions. Based on climatology, the spring is expected to have moist soils and passing synoptic disturbances. In contrast, fall will have drier soils and fewer passing synoptic disturbances. By having these experiments in the same calendar year (but in different fiscal years), some of the equipment may be left at DPG over the summer, thus greatly simplifying logistics. About ten IOPs are planned for each campaign, ranging from calm (thermally forced) to synoptically dominated conditions. A third, smaller field campaign focusing on fog formation will be conducted during the 2013/2014 winter in the Salt Lake Valley near the Great Salt Lake, to be followed by an extensive fog experiment in 2015.

Within the framework of §3.1, observations are designed to: (i) resolve the variations of surface boundary conditions (e.g., radiation and surface energy budgets, moisture availability, surface and subsurface processes) that drive diurnal mountain winds; (ii) study fundamental near-surface exchange processes (e.g., radiative and sensible heat fluxes, advection); (iii) investigate the spatial and temporal variations of PBL in complex terrain; (iv) understand the interactions of flows of different scales (e.g., synoptic, meso and sub-meso scale flows); and (iv) provide data for model evaluation and improvement. The GMAST is characterized by slopes, valleys and playas (Figure 4) that host a full suite of complex-terrain physical processes (Figure 2), allowing studies of broad relevance. The measurements will span from meso-β to Kolmogorov (~1mm dissipation) scales. The available equipment for DPG MATERHORN-X includes the following:

ND: 1 Halo-Photonics Lidar (10km range); 10 sonics; 2 sonic-hotfilm combos; 60m (1) and 10m (2) towers; 1 Sodar/RASS; 1 laser ceilometer; 1 tethered balloon system; 1 Krypton hygrometer; fog aerosol sampling system (FASS); 2 SW/LW/in/out (4-component) radiometers; Unmanned Aerial Vehicle UAV; 2 soil heat flux probes; 1 high-end FLIR® infra-red camera (0.02K resolution); IR thermometers; 2 surface energy balance stations; and smoke visualization.

UU: 40-60 HOBO (temperature) data loggers; 9m (1), 20m (2), 3m (1) towers; 2 mini Sodars; 1 tethered balloon sounding system; 2 rawinsonde sets; 1 Krypton hygrometer; 5 sonics, 2 sensible heat flux hot-wire probes; CO_2 probes; 20 mini-surface skin temperature sensors; 3 SW/LW/in/out (4-component) sets; and Dustracks® for particle concentration.

UV: Leosphere® ALS300 aerosol backscatter lidar.

DPG: 113 Portable Weather Information Data Display Systems (PWIDS); 10 32m (5-level instrumented) towers; 82 10m mini-SAMS stations (sensors at 2,10m; skin IR temperature, soil probing at 4 levels); 2 weather and 1 FM-CW radars; 3 wind profilers; 3 Sodar/RASS; 2 tethered balloon systems; 2 rawinsonde launchers; 1 Lidar; 1 ceilometer; 2 scintillometers and transmissometers; 60+ sonics; 4 energy balance stations; 3 Bowen ratio stations; whole-sky imagers; and quartz thermometers. DPG and UV will conduct data denial studies to recommend the optimal instrumentation density, siting of remote sensors and flight plans for UAV.

A sample instrument placement is shown in Figure 6, which allows sampling of slope, valley and sub-mesoscale flows with unprecedented resolution. The Lidar locations were selected so that our innovative virtual tower technique (Calhoun et al. 2006) can be used, while the upstream Sodar/RAAS measuring the approach flow. This configuration will be adjusted as more is learned from modeling studies. The observational program includes those at local scales (at <u>Extended Flux Sites, EFS)</u> and those that directly cover a range of scales and flow interactions.

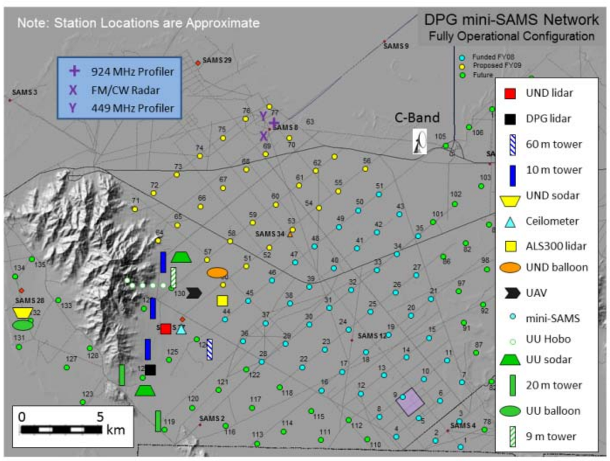


FIGURE 6: The GMAST and placement of selected instrumentation (tentative). Doppler and ALS 300 Lidars will be relocated, as needed.

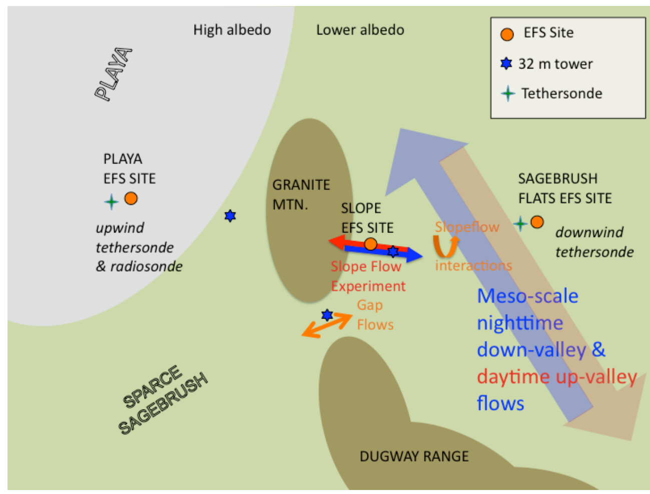


FIGURE 7: Illustration of the locations of the planned sub-experiments at EFS with respect to the terrain features at DPG

3.2.1 Experiments at Extended Flux Sites (EFS): Three heavily instrumented EFS (Figure 7, orange dots) will be developed to investigate: (i) surface energy budgets and fluxes, (ii) internal waves and fine-scale turbulence, and (iii) SBL and <u>Convective Boundary Layer (CBL)</u>. The EFS will exploit several contrasting features, including albedo, roughness, moisture availability and slope angle. These sites will form the *anchor points for model validations* with regard to surface <u>boundary conditions BC</u> and IC.

EFS-Playa will be located on the salt playa west of Granite Mountain. It is characterized by a high albedo, low roughness length and large seasonal variations in albedo and moisture.

EFS-Flats will be located east of the Granite Mountain. Covered by sparse sagebrush-type vegetation, it is highly representative of the land cover found at DPG. This site is expected to be influenced by the nocturnal DPG basin-scale mesoscale drainage flow.

EFS-Slope will be located on the eastern slope of Granite Mountain. Local slope flows are expected to play an important role at this site, which will be embedded into the "slope flow experiment" to be described in (*v*) below.

Each EFS site will consist of an instrumented 10-m meteorological mast. Measurements will include: temperature and relative humidity at 2 and 10 m, 10 Hz velocities and temperatures, momentum and sensible heat fluxes (3D sonics and fine wire thermocouples at 2 and 10 m), CO_2 and water vapor concentrations (Campbell open-path sensor at 10 m for latent heat and CO_2 fluxes), fine-structure temperature profiles (~25 thermocouples up to 10 m, with enhanced vertical resolution near the ground), full radiation budget at 2 m (LW in- and outgoing, SW in- and outgoing), IR surface temperature, soil heat flux, soil moisture and subsurface temperatures.

In addition, a FLIR® IR camera will be deployed at EFS-Slope, facing uphill to investigate the spatial and temporal response of surface temperatures that are important for model validation but not easily obtained with point sensors. Several additional sonics will be placed near the surface of the EFS-Slope site to investigate the formation of *skin flows*, an observed phenomenon (Manins & Sawford 1979a, Thompson 1986; Manins 1992; Mahrt et al. 2001; Soler et al. 2002; Clements et al. 2003) that is unresolved by both LES and mesoscale models. These near-surface EFS measurements will be supported by frequent tethered balloon soundings at the EFS-Playa and EFS-Flats sites as well as by 8 radiosonde launches per IOP from near the EFS-Playa site. The soundings and Sodar/RASS measurements will define the thermodynamic structure of the atmosphere. They are also needed as input for the radiative transfer calculations.

(i) Surface Energy Budget and Flux Experiments

Hypothesis: *The Monin-Obukhov (1954) Similarity Theory (MOST), which assumes horizontal homogeneity and stationarity, while widely used in today's forecast models, needs to be more thoroughly evaluated for mountainous terrain. Alternative formulations may be necessary.*

While some observations suggest that MOST scaling for velocity and temperature variances hold at least at the middle of a wide valley with a flat floor (Moraes et al. 2004; de Franceschi 2004; de Franceschi & Zardi 2009), the need for extensions and/or modifications for other locations such as sloping sidewalls has been expressed (Andretta et al. 2001, 2002; Hunt et al. 2003; van Gorsel et al. 2003a,b; Grisogono et al. 2007). Thus, this experiment will focus on collecting the data necessary to test MOST for CO_2, moisture, heat and momentum fluxes under a variety of conditions typical of mountainous terrain. The dataset will be used to address questions related to modeling of near-surface processes. We hope to capture all sub-grid processes responsible for mass and heat exchanges in the lowest grid cells of current LES models (0-3 m).

The data will help validate existing parameterizations and support the development of new parameterizations. The relative roles of different physical processes (i.e., turbulence, heat, moisture and momentum transport, radiation, subsurface) will be quantified. The role of radiative flux divergence in heating and cooling of the atmospheric surface layer will be evaluated using a state-of-the-art Monte Carlo radiative transfer model (Mayer & Kylling 2005; Mayer 2009; Mayer et al. 2010), with support from near-surface fine-scale temperature profile observations. We will also investigate surface energy budget imbalances, as reported by Oncley et al. (2007) and Rotach et al. (2008). Of particular interest will be transition periods where MOST is highly questionable and alternative formulations may be necessary.

(ii) Fine-scale Turbulence and Transport Experiments (Playa and Slope sites)

Hypothesis**:** *Understanding of fine-scale surface-layer processes (e.g. distorted turbulent eddies, coherent structures, dissipation mechanisms, and small-scale advection) may lead to greatly improved surface heat/mass/momentum/moisture flux parameterizations*.

Under stable conditions, turbulence is typically modeled using flux (Ri_f) and gradient (Ri_g) Richardson number parameterizations (Strang & Fernando 2001a,b; Pardyjak et al. 2002), *viz.*,

$Ri_f = g\alpha \overline{T'w'} / \overline{u'w'} \partial U / \partial z$ and $Ri_g = N^2 / (\partial U / \partial z)^2$, where the symbols have their usual meaning. The $Ri_f - Ri_g$ relationship forms the basis of many geophysical numerical closure models (e.g., Mellor & Yamada 1974). Nevertheless, present understanding of PBL turbulent exchange processes, and hence a knowledge of the above relationship, is poor (Peltier & Caulfield 2003). The data taken during calm IOPs in DPG campaigns will be used test the applicability of existing parameterizations and gain further insights on transport phenomena (Metzger et al. 2007). Measurements will be made ~ 1cm above the ground and in the surface layer (1-10m). Dust and UAV-based fog sampling will also be made, and the results will be interpreted using the measurements of local flow and turbulence.

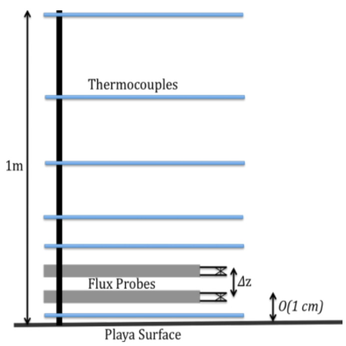


FIGURE 8: A schematic illustrating the placement of the near-surface flux probes within a dense array of thermocouples.

FIGURE 9: The sonic-Hot-film combo (Kit et al. 2010) will probe down to Kolmogorov scale of turbulent kinetic energy dissipation.

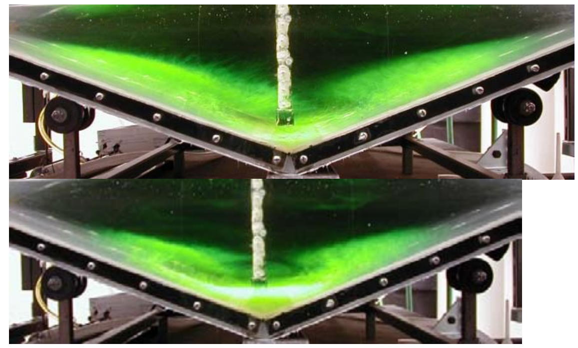


FIGURE 10: A new mechanism of morning breakup of cold pools, involving intrusion formation (Princevac & Fernando 2008). This laboratory observation will be verified during MATERHORN-X.

The near surface experiments will utilize a novel *flux Richardson number probe* (Figure 8). It consists of a pair of hot-wire supports, each of which has a hot-wire x-array for measuring the along-wind and vertical velocity components and a cold wire to measure the temperature, sampling at 1kHz at two heights above the surface separated by a distance Δz ~ 7-10mm. The probe will measure flux divergences of momentum and sensible heat. Also located at 10m above the ground, with a 2m separation vertically, will be two sonic anemometer/hot-film combos developed by the PIs. Here the hot-film and sonic are co-located, with the former responding to the variations of wind measured by sonic via a feedback loop; in-situ calibrations of hot films are performed using the sonic signal via a neural network techniques (Figure 9). These two high-resolution probes will provide unprecedented information that will help improve mesoscale and LES model parameterizations at the first few grid levels. The vertically resolved sensible heat flux observations will allow us to address, for the first time, the relative roles of <u>all</u> known processes involved in the evolution of surface temperature (e.g., diffusion, advection, radiation).

(iii) Stable Boundary Layer (SBL) Evolution Experiments

Hypotheses**:** *Quantification of the evolution of SBL, for example its height and strength (i.e., buoyancy frequency), starting from the evening transition until the morning break up, requires delineation of the physics of two transition processes and processes responsible for the development of nocturnal stable stratification. In particular, understanding of non-equilibrium (evolving) turbulence in SBL will be crucial.*

The transition of CBL to SBL and *vice versa* in complex terrain is poorly understood and <u>not</u> parameterized in mesoscale models (Lee et al. 2006). In addition, existing theories such as

MOST are invalid during transition periods. Yet, transition periods are very important for forecasting the timing of air quality episodes, frost/fog formation and dynamics of trace gas fluxes during time periods of low surface stress (Massman & Lee 2002). Grimsdell & Angevine (2002) and Pardyjak et al. (2009) observed that the evening transition may begin several hours before sunset, concurrent with a rapid collapse of turbulence (Nadeu et al. 2010). Acevedo & Fitzjarrald (1999, 2001) reported, during evening transitions, sudden increases of specific humidity, drops in surface temperature and an abrupt decay in wind velocity. The details of these processes are poorly understood for complex terrain, although some theoretical predictions, adumbrated by sparse experimental evidence, exist (Hunt et al. 2003; Fernando et al. 2011).

Once the evening transition is completed, katabatic flow over slopes can maintain weak but continuous turbulence (vis-à-vis intermittent turbulence over flat terrain) determined by resonant internal-wave breakdown (Princevac et al. 2008). The dynamics of the ensuing turbulence, its co-existence with internal waves and their role in determining stratification in valleys all await detailed studies. Another issue of interest is the breakup of stratification during the morning transition, which can be associated with intrusion formation (Figure 10) and shear waves (Manins 1976) that penetrate over substantial horizontal distances (Princevac & Fernando 2008).

We will monitor the morning/evening transitions in detail at the three EFS sites with the aim of capturing flow physics. Additional information is needed to fully understand the *temporal and spatial* variability of the surface and boundary layer, for which we will use 20 dispersed HOBO/IR sites co-located with DPG PWIDS weather stations. They will be located on transects connecting the plains and slopes on both sides of Granite Mountain, in the gap between Granite Mountain and the Dugway range, and on a transect across the playa-sagebrush-plain interface. The measurements will provide the timing of surface energy budget reversal and the strength and speed of surface-inversion development (evening transition) or evolution of the super-adiabatic sublayer (during morning transition). This will be augmented by IR temperature observations by FLIR® camera for the entire domain to identify temperature fronts (e.g., Fernando et al. 2010).

At three selected sites (bottom of the eastern and western slopes of Granite Mountain and in the gap between Granite Mountain and the Dugway Range; Figure 7), 32-m DGP meteorological towers will be deployed with 8 levels of temperature, relative humidity and horizontal winds. These instruments will allow monitoring the growth of the inversion layer as well as the influence of local drainage flows at the foot of the slopes. The varying evolutions of SBL in two sub-basins separated by Granite Mountain could lead to gap flows due to exchange of cold air between sub-basins, which will be captured by a Lidar. These flows may trigger internal wave activity in basins, for example, seiching (Whiteman et al. 2008). A hydraulics analysis will be conducted on the gap flows as well as on the internal wave field (e.g., see Pratt & Whitehead 2008), which will be compared with data. We will also investigate possible Coriolis effects on valley flows (see Cenedese et al. 2004; Hunt et al. 2005; Fedorovich & Shapiro 2009a,b).

(iv) Unstable Boundary Layer Development and Evolution Experiments

Hypotheses*: A combination of energetic processes (e.g., CBL growth, flow oscillations and flow-convergence at hilltop; Figure 2) determines daytime turbulent fluxes.*

Owing to measurement difficulties, CBL over sloping terrain has not received due focus. As such, many theoretical results remain unverified. For example, theoretical analysis of Schumann (1990) shows that upslope flow over an incline has along-slope oscillations. Hunt et al. (2003) argued that MOST can be valid for upslope flows on gentle inclines, which contrasts the laboratory results of Deardorff & Willis (1987). Several formulations also exist for the upslope flow velocity (Prandtl 1942; Schuman 1989; Kondo et al. 1990; Hunt et al. 2003). There are a handful of field studies, but the measurements are not extensive (Reuten et al. 2005, 2007). In the proposed work, we will extend IOPs in (*iii*) to cover upslope flow, and gather critical data (e.g., CBL height, convection velocity and turbulence statistics) to evaluate extant theoretical concepts. A suite of instruments, including ceilometers, Doppler Lidars, mobile scanning aerosol Lidar (Figure 11), instrumented towers and UAV (Figure 12) will be used. We will observe and quantify flow separation and merger of flows on opposite flanks at the mountain top. This work can be the precursor to a new generation of upslope flow parameterizations.

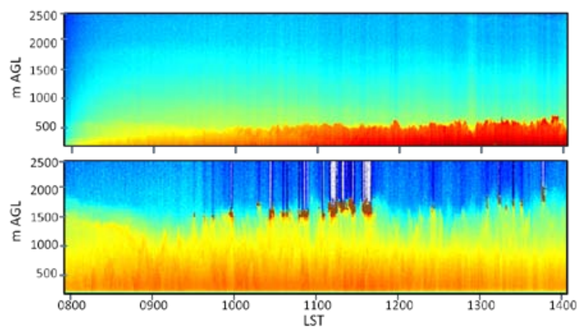


FIGURE 11: UV Aerosol Lidar (Leosphere ALS300) images (staring mode) on two different days. Range Height Indicator (RHI) scans will be performed using elevation ranges from 2 degrees to 90 degrees to provide details on cloud cover, CBL height and aerosol layer structure.

FIGURE 12: (a) Silvertone Flamingo Mark 4 UAV (length 2m; wingspan 4m; Moki 180 gas engine, 5.6 liter fuel tank; payload 15 lbs; 30-90 mph); (b) instrument mounting plan developed in consultation with the manufacturer; (c) on-going UAV instrument development at ND (www.flamingouav.com); see §3.3.2.

(v) Slope Flow Evolution and Interaction Experiments

Hypothesis*: Where terrain inhomogeneities are present, multi-scale thermal circulations are generated. Their interactions create jet-like vertical and horizontal profiles and directional shear within the valley cross section, leading to sustained turbulence.*

Heterogeneities caused by shadow propagation from surrounding terrain, solar insolation on slopes of different orientation and variable land cover lead to cross-valley/slope circulations (Kuwagata & Kimura 1997; Ruffieux et al. 1995; Fernando et al. 2001; Matzinger et al. 2003; Lee et al. 2003; Hoch & Whiteman 2010). Flow separation occurs at canyon mouths, and intermittent wind break-ins to the valleys and slopes may adversely affect UAV operations. Interaction between flows originating at steeper (high elevation) and gentler (foothills) slopes lead to hydraulic adjustments and enhanced mixing. Merger of slope flows with valley flows at the slope bottom produces horizontal shears. When the valley winds get strong enough, horizontal and vertical shears can greatly modify the slope flows or remove them entirely (Doran et al. 1990). These interactions can be quite pronounced, and sensitive to ambient flows (Fitzjarrald 1984; Barr & Orgill 1989). No detailed observations of flow interactions are available, although numerical simulations have provided some useful insights (Doran 1991).

Such complicated interacting flows may be best studied with research grade numerical simulations, but RANS models have been developed for mesoscale simulations on scales larger than the slope flows or for 1D and 2D flows (Weng & Taylor 2003). The insufficient vertical resolutions near the slope and uncertainties in the applicability of turbulence parameterizations have limited their utility. Elegant analyses of the ilk of Manins & Sawford (1979b) are also not viable for three-dimensional interacting flows. The advent of LES techniques has permitted detailed simulations (§3.4.1), but careful observations are sorely needed for testing LES models.

We propose to collect detailed observations of multi-scale thermally driven flow interactions at the EFS-Slope site. Interactions of local slope flows with larger-scale mesoscale drainage flows that form in the entire DPG Basin have been previously reported (Whiteman & Hoch 2010), upon which we will build our work. The slope site has a host of instruments capable of capturing spatial and temporal evolution of surface temperatures and flow interactions. The data will be used to validate new modeling approaches and numerical schemes (§3.4.1). Parallel laboratory experiments will also be conducted for eduction of flow physics, wherein drainage flows from cooled inclines are allowed to merge in and flow down a valley (§3.4.2).

(vi) Synoptic-Thermal Flow Interaction Experiments

Hypotheses*: Interactions between flows of different scales play a crucial role in high frequency variations of mountain weather. Of particular significance is the action of synoptic flows on diurnal thermally driven flows that may produce a cascade of flow structures and turbulence.*

Most previous studies of diurnal mountain wind systems have been deliberately conducted on calm weather days with weak synoptic forcing. Relatively little is known about the influence of synoptic flows on diurnal mountain winds, about dynamically induced channeling within terrain from overlying synoptic flows and about interactions of thermally driven flows with precipitation (Fernando 2010). The pressure gradients that drive synoptic flows are relatively persistent compared to thermal circulation (Whiteman & Doran 1993), yet they interact and change the surface heat flux during the diurnal cycle (Jiang & Doyle 2008) and produce interesting flow structures (Hill et al. 2010). In the proposed work, we will collect data on these multi-scale interactions, to be used as test cases for model evaluation. Some examples are:

Gap Flows: The low point between the Dugway range and Granite Mountain is an excellent site to study dynamically induced channeling from larger scale (synoptic/background) flows onto the valley flow system during both night and day (Zardi & Whiteman 2010). Selected gap-flow data from (*iii*) above can be processed to understand the synoptic flow influence on gap flows.

Mountain Waves and Topographic Effects: External-flow-generated lee and progressive waves interact with thermal circulations and with the surface (Stone & Hoard 1989; Poulos et al. 2000, 2007; Večenaj et al. 2011). Interaction of synoptic and thermal circulations with topography also leads to modulations of the thermal circulations (Mahrt & Larsen 1982; de Wekker 2002). Analysis of MATERHORN-X data using special flow structure interrogation techniques (e.g., Hill et al. 2010) can shed light on processes of different scales, their interaction and evolution.

Vortical Motions: Eddies, large vortices and wakes are expected in the lee of Granite Peak when the Froude number is low. The *horizontal spatial pattern* of these motions will be observed using the DPG meteorological network and Lidar, and upstream flow will be continuously monitored using Sodar. The vertical *structure* of these vortical motions will be measured using Lidar scans and Lidar virtual towers up to 1 km (Calhoun et al. 2006). The results will be compared with those of Brighton (1978) and Hunt & Snyder (1980). The *temporal evolution* will be observable in both surface-based and remote sensing data. Special focus will be on wind fields near the ridgeline, where eddies due to flow separation and hydraulic jumps may cause strong turbulence.

Progressive Gravity Waves: The pressure sensors of the DPG instrument array east of Granite Mountain will be used to investigate the direction, strength, and speed of progressive waves generated by westerly airflow over Granite Mountain. In addition, the Lidar virtual towers will be used to detect shear-driven, nocturnal wave-like flow structures (Newsom & Banta 2003) and ensuing turbulence within the SBL (Princevac et al. 2008). Special emphasis will be given to momentum and scalar transport by a combination of waves and turbulence.

Dividing Streamlines and Coriolis Effects: Theoretical and computational studies (Hunt et al. 2001) show that the strongest Coriolis forces occur over a distance on the order of the Rossby radius upstream of a mountain barrier, while the mean flow is deflected over a distance approximately equal to the mountain width. This upstream blocking distorts synoptic eddies and leads to asymmetric downstream wakes, which may also cause an upscale energy cascade. We will observe these phenomena by moving two scanning Doppler lidars to upstream locations and employing the dual lidar technique to observe flow distortions. For GMAST, typical Rossby deformation radii are ~ 100km and Rossby numbers are ~ 2. Spectra along the flow deformation path will provide information of the upscale transfer of energy.

3.2.2 Fog Formation Experiments in Salt Lake Valley: MATERHORN-X-Fog

Hypothesis: *Radiative cooling, surface moisture, turbulent intensity and turbulent flux divergences determine the radiation fog formation under near-calm conditions.*

As discussed, moisture and fog seriously limit the UAV operations in theater, although they are not considered extreme weather (here fog is defined as moisture conditions that reduce visibility to < 1km over a 50-min window; Glickman 2000). Recent exhaustive reviews by Gultepe et al. (2007) and Haeffelin et al. (2010) identified the continuing challenges for predicting the timing and location of fog formation, the most basic being flow and radiative interactions. Current (deterministic-modeling based) uncertainty of fog predictability is more than 50%, which is considered unsatisfactory. Available short-term predictive models rely on parameterizations of droplet microphysics, aerosols chemistry and dynamics, turbulence, radiation and surface moisture conditions. Complex terrain processes can either aid (cold pools) or suppress (upslope advection) fog, while an increase of turbulence levels facilitates fog formation. Virtually no detailed studies exist on fog formation in complex terrain (Gultepe et al. 2007). We will conduct a pilot experimental study in 2013, followed by a comprehensive experiment in 2015, to understand the life cycle of fog events in complex terrain (i.e. the valley fog; NOAA 1995). Initially we will explore the case of radiation fog that forms on clear calm days in the SBL, which is determined by a balance between radiation and turbulent mixing (Roach et al. 1976). The experiment will take place near the Salt Lake International Airport, where wintertime fog is one of the most challenging forecast problems for National Weather Service (NWS).

Fog in the Salt Lake Basin is generally linked to a variety of mechanisms such as advection, sublimation and radiative flux divergence. The radiative fog changes the role of radiative processes in the lowest 50 m of the atmosphere (Hoch et al. 2007), thus having a feedback on SBL evolution. We will deploy two 32-m towers, instrumented with 10 levels of sonic anemometers; temperature and humidity sensors; long-wave flux probes to measure radiative flux divergence (LW in/outgoing fluxes at 0.5m, 2 m, 20 m levels); 2-3 open-path, fast-response gas analyzers to measure CO_2 and water vapor fluxes; 2 m shortwave radiation balance; ~30 thermocouples for fine temperature structure profiles; tethered balloons; soil heat flux plate; a ceilometers; DF-320 visibility meter (borrowed); subsurface temperature probes; IR sensors for surface skin temperatures; and a high resolution IR camera. In addition, 8 daily radiosoundings (2 from NWS, 6 additional) will provide vertical structure of the atmosphere. As discussed in §3.3, several new technologies will be deployed, including a surface moisture instrument that maps a larger footprint and a moisture sampling instrument carried by the UAV. We will also analyze (now public) data from the 2006/7 winter PARISFOG experiments (Haeffelin 2010) to compare with the new data. We will attempt to develop a theoretical framework for interpreting radiation fog formation data.

3.3. Development of Measurement Technologies: MATERHORN-T

3.3.1 Soil moisture sensing

To measure surface moisture over large footprints, we plan to develop a soil moisture probe based on remote polarimetric sensing, thus addressing the current serious limitation of probing intermediate (meso) scales between limited-scale contact measurement approaches and conventional remote sensing techniques (~ 100km). One recently proposed non-contact approach involves measurement of low-energy cosmic-ray neutrons above the ground, which provides characterizations for areas of 34 hectares and depths up to 30cm. An alternative technology that is being developed by PI Pratt (ND) provides flexible scales, and it is based on radio frequency (RF) polarimetry that exploits time dispersion between the polarization modes. The concept involves polarimetric characterizations derived from bistatic clutter between spatially separated transmitter and receiver systems. The water content in the soil layers imparts changes in the polarimetric response of the clutter, and these changes can be detected through differential polarization detection processing. Initial results from an exploratory testing campaign (Figure 13) illustrate the capability of the sensing technique to detect changes in polarimetric properties of the bistatic clutter before and after the application of water to soil.

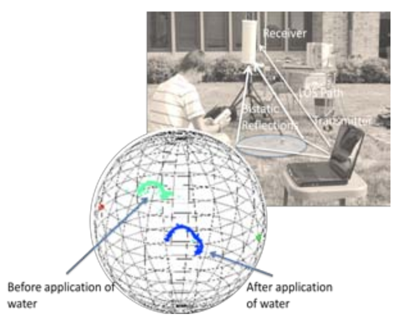


FIGURE 13: Exploratory RF polarimetric sensing test. Note the changes in clutter response due to land surface water.

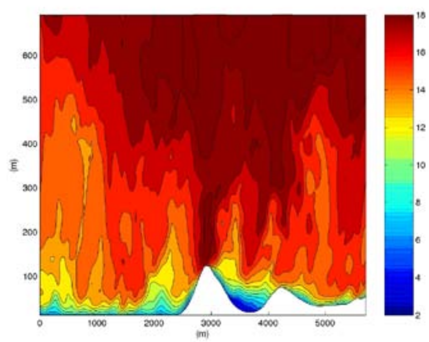


FIGURE 14a: Streamwise velocity over Askervein Hill; computations were conducted using TKE-1.5 closure.

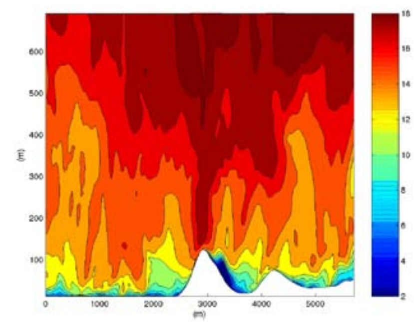


FIGURE 14b: Same as in Figure 14a, but with DRM; this captures the separation in the lee of the hill (Chow & Street 2009).

In the proposed work we will deploy a sensing system using RF equipment, including a digital sampling scope with coherent signal collection capability. The equipment will enable transmission and dual-polarized reception of RF energy that will be used to characterize the area within the bistatic footprint of the system. Data will be processed to characterize the sensed changes, which will be correlated with surface characterizations based on local soil moisture probe measurements (calibration). The operation and performance of the RF polarimetric system will continually be upgraded, potentially including multiple transmitters, additional frequencies as well as upgrades to receiver systems and processing algorithms.

3.3.2 Unmanned Aerial Vehicle (UAV)

Airborne turbulence measurements are more difficult to make and analyze, given the fragility of instrumentation, vibration problems and airspace restrictions. Wind velocity components are retrieved as a difference between absolute airplane motion with respect to a fixed frame of reference and airspeed as indicated by the aircraft (Crawford & Dobosy 1992). These two terms are at least an order of magnitude larger than the difference between them. Thus, high accuracy in the wind velocity components requires quite high accuracy in the original measurements. Airborne measurements are, nonetheless, the most promising tool for analysis of turbulence properties far from the surface in the middle of valley volumes (Rotach et al. 2004; Weigel et al. 2007). The advent of smoothly operating UAVs, development of novel turbulence measurement methodologies by the PIs (Kit et al. 2010) and their on-going miniaturizations (Figure 12c), access to a military airspace at DPG and availability of qualified UAV pilots at ND have afforded an opportunity for MATERHORN to develop and deploy an instrumented UAV. It will have measurement capabilities of three air velocity components, fluctuations sampled at high frequency, mean velocity, humidity, temperature and fog characteristics (§3.3.3). These parameters will be recorded simultaneously, over a range of conditions.

A Flamingo Mark 4 is the UAV model of choice; Figure 12. We have already designed the instruments, considering the payload and geometric restrictions of UAV. The temperature and humidity measurements will be made using thermocouples and a standard humidity sensor. Additional thermocouples will be used to monitor internal temperatures to counter check instrument reliability. The average velocity will be measured using a Pitot tube, a sonic anemometer (in the combo) and UAV GPS avionics. The hot-film/sonic anemometer combo will provide all three turbulent air velocity components (20 kHz, 1mm resolution) via in-situ calibration (Kit et al. 2010; Figure 9). Fog droplets size distribution will be made using the instrument described below. The UAV will be equipped with sensitive accelerometers to detect any vibrations that can influence results. The typical UAV operation mode is an autonomous flight, with average duration of ~ 1 hour, along a predefined flight path. Owing to relatively long flights, the quantity of experimental data will be large, about 2.1 Terabytes per flight, requiring an on-board data storage solution. We have successfully designed such a system with remote control capabilities for initiation/stoppage of data acquisition and controlling data rate.

3.3.3 Suspended moisture instruments

To understand how local turbulence processes are linked to fog droplet growth and evaporation, we will co-sample the fog-related aerosols and turbulence aboard the UAV. This is particularly important given that advanced models use such relationships to predict fog behavior, and that little to no data exists on fog for the three MATERHORN-X sites. Fog literature suggests droplet sizes of order 1-10 μm (Straub & Collett 2002; Moore et al. 2002; Ghosh et al. 2005). Several impact collector designs have been attempted previously, utilizing fog droplet momentum variations based on size as a means of sample sorting. A stationary ground-based stepped chamber system was developed to study fog droplet size distribution with capabilities of analyzing five droplet size ranges (Moore et al. 2002). Similar principles have been utilized to develop systems for use on airborne vehicles (Straub & Collett 2004). All of these designs, however, are too large in scale to be used on a UAV. To meet this challenge, a novel and compact (cylindrical shape, ~ 10 cm diameter, ~ 40 cm length) Fog Aerosol Sampling System (FASS) is proposed here for development that will be UAV deployable. The FASS measures fog aerosol mass concentration (for droplet diameters from ~0.5 to 50 μm), fog aerosol chemical composition (determined post-deployment from collected samples), and sample temperature and pressure. This information, coupled with wind velocity and turbulence intensity measurements, allows fog aerosol characteristics to be related to local wind conditions. Measurements will be made over short (< 15s) intervals, yielding excellent temporal and spatial resolution. The FASS components include an isokinetic sampling inlet, a flow-through impactor with 5 to 10 successive stages (for mass concentration versus size partitioning), a fast-response thermistor and a piezo-resistive pressure transducer (for ambient pressure).

Each successive stage of the impactor collects a progressively smaller droplet size range because of the impactor's aerodynamic partitioning. Each stage consists of three different, overlapping methods that determine fog droplet distribution, thus assuring improved sample accuracy. A similar methodology was used by PI Dunn to sample nuclear aerosols (Dunn et al. 1989). During sampling within a particular stage, the fog aerosol first passes through the gap of an IR emitter/detector pair and then through a fine (~1 μm to 10 μm diameter)-wire impactor (Dunn & Renken 1987). The detector's voltage output is related to the concentration of water vapor that passes through the gap. The wires of the fine-wire impactor collect a small fraction (<1%) of the aerosol droplets. These wires are examined post-deployment to determine the airborne droplet size distribution and chemical content of the droplets. The aerosol then is focused directly onto a moisture-sensitive, variable-dielectric capacitive sensor (~1 cm diameter). Droplets within that stage's specific diameter range collect on the sensor by impaction. The sensor's output is proportional to the amount of moisture collected. The development of FASS involves *a-priori* laboratory calibration using phase-Doppler anemometry and in-draft wind tunnel testing at ND.

3.4 Process Studies and Parameterizations Development: MATERHORN-P

3.4.1 High resolution Large Eddy Simulations (LES)

LES is a powerful tool for research grade simulations. It uses spatially varying filters to realize seamless transitions between grid nesting levels, from meso-β (20-200 km) to topographic canyon scales with 1 m grid spacing. LES is a convenient alternative to the RANS approach used in mesoscale modeling wherein the turbulence model has no direct link to the grid resolution or a filter width. The first complex-terrain LES simulations have been done for upslope flows (Schumann 1990), given that energy containing scales in stable flows are too small to realize adequate separation between resolved and unresolved scales. Recent advances in LES, numerical schemes and computer power now allow simulations of SBL in complex terrain (Skyllingstad 2003; Chow et al. 2006; Axelsen & Van Dop 2008, 2009; Serafin & Zardi 2010a).

We propose the development and testing of a robust universal framework for LES of flow over complex terrain, based on an explicit filtering and reconstruction turbulence modeling approach. Within this framework, PI Chow has developed a dynamic reconstruction model (DRM) that has proven advantageous of simulating turbulence in complex terrain (Chow et al. 2005). Our LES model applies an explicit filtering procedure to the governing flow equations, thereby separating the turbulent stresses into resolvable subfilter scales (RSFS) and subgrid scales (SGS). The RSFS stress is ignored in the traditional LES approach, notwithstanding that it provides valuable information about the nature of turbulent interactions near the grid cutoff for numerical schemes based on finite volumes or finite differences. The SGS portion is modeled using a dynamic eddy-viscosity with a near-wall stress augmentation. The RSFS/SGS explicit filtering and reconstruction procedure proves to be advantageous for SBL simulations, as shown through comparisons with theory and observations (Figure 14a,b). It reproduces similarity theories, is capable of representing intermittent turbulence, especially in cases where traditional LES methods fail (Zhou & Chow 2010a,b), and allows energy backscatter from small to large scales.

The proposed study will expand upon this framework, which so far has been used for idealized cases (viz., periodic boundaries, specified heat fluxes), to real terrain under stable conditions. When combined with MATERHORN-X measurements, our approach will provide an excellent opportunity to study orographic processes such as mountain wakes, gap flows and thermal circulation. We will also use the Immersed Boundary Method to resolve flow around the steep terrain features at GMAST. The proposed studies will be performed using the WRF model that has LES capabilities. We will test the scalability of LES using fine-scale observation data so it can be used from regional to very fine scales. We will investigate microscale turbulence in detail, and educe how they are generated via cascading from the synoptic scale. Nested simulations will be used to refine the grid in the region of interest, down to very fine resolution. In our previous work, 45 km spacing down to 25 m were used, and the finest grid in the proposed work will be ~ 10m (Michioka & Chow 2008). Such nesting will allow understanding of energy transfer amongst different spatio-temporal scales. There is evidence that MOST is invalid under strong stability conditions (Grachev et al. 2008), and we will attempt to formulate alternative scaling based on LES. Simulation results will be checked against data. Insights on key processes and their quantification will help develop sub-grid parameterizations for mesoscale models.

In the last three years of the proposed work, we will transfer knowledge gained from the DPG simulations to Salt Lake Valley, to focus on fog formation. It is well known that atmospheric simulations are highly sensitive to soil moisture (Chow et al. 2006; Ookouchi et al. 1984), and the wealth of data to be collected during MAREHORN-X will be used to verify proposed mesoscale to fine-scale simulations. Soil moisture determines the partitioning between sensible and latent heat fluxes at the land surface, thus affecting moisture and fog formation in the PBL (Maxwell et al. 2007). We will apply our nested LES with DRM to simulate fog formation in SBL. Salient physical processes will be identified, providing guidance for interpreting field data.

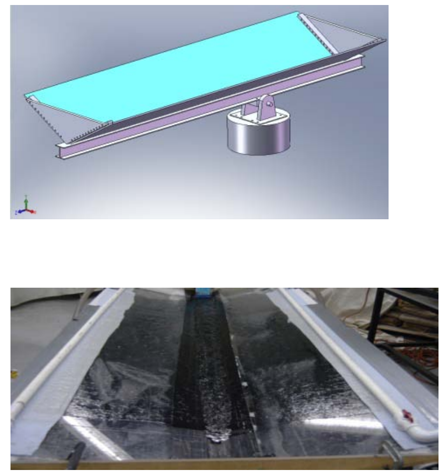
3.4.2 Laboratory Experiments

Inspired by the central role that laboratory experiments have played in revolutionary advances of complex terrain flows [Deardorff & Willis (1987) and Willis & Deardorff (1974) work on convection; Long's (1955) epoch-making experiments on lee waves], MATERHORN will also include a laboratory modeling program. To this end, the ND group will conduct laboratory experiments on (i) hydraulic adjustments on discontinuous slopes (Figure 15a,b), (ii) merger of valley and slope flows (Figure 15c), (iii) interaction of thermal circulation with background (synoptic) flow and (iv) morning and evening transitions. For brevity, the experimental details are omitted here, but are depicted in Figure 15. State-of-the-art flow diagnostic techniques such as particle image velocimetry and laser-induced fluorescence will be used (for example, see Princevac & Fernando 2008). Time permitting, additional process-level studies will be included. The aim is to understand phenomena and develop parameterizations for numerical models.

In simulating atmospheric motions in laboratory tanks, we will build on previous developments. It has been shown that, under suitable conditions, the conservation equations of momentum, mass and buoyancy in the laboratory model are similar to those in the atmosphere. In particular, the counterparts of potential temperature and Exner function in the atmosphere correspond to the specific volume and pressure, respectively, of the experimental tank. The displacement, velocity and temperature fields play similar roles in the atmosphere and in the model (Berman et al. 1995; Chen et al. 1996, 1999). Whenever possible, comparisons will be made between laboratory and field data to evaluate the applicability of low-Reynolds and high-Prandtl number water tank experiments to high Reynolds number atmospheric flows. As pointed out by Snyder et al. (1990, 2002), Merony (1990) and Uehara et al. (2003), the requirements for matching of these parameters can be relaxed if the laboratory flows are to be maintained sufficiently turbulent to satisfy Reynolds number similarity, which we plan to achieve.

FIGURE 15a: Experiments on katabatic and anabatic flows with slope discontinuities. The slopes can be heated or cooled by circulating water via a series of internal passages that help distribute the heat flux uniformly.

(b) The model slopes (e.g. Fig. 15a) are placed in a large glass tank, and state-of-the-art flow diagnostics are used for measurements.



(c) The newly constructed facility for investigating slope and valley flow interactions. This facility can also be modified to study along-valley large-scale flows. Preliminary experiments have shown promising results.

3.4.3 Analytical Studies

We will employ conceptual models and theoretical analyses to quantify complex terrain processes. A unique aspect will be the isolation of salient phenomena, known or to be discovered, and delineation of conditions for their occurrences in a mesoscale grid cell. In this way, the diffusivities within a grid cell can be formulated based on its boundary values, considering plausible phenomena in the cell (i.e., conditional climatologies, §1). For example, a Richardson number can be used to identify the generation of shear turbulence in a grid cell (Monti et al. 2002; Lee et al. 2006). Similarly, criteria will be developed for other processes. A challenge would be to account for the cumulative diffusivity when many processes are present, and the first step would be to use a simple additive rule, as in the ocean model of Large et al. (1994). Obviously this neglects interactions between the processes, to account for which new methodologies will be developed.

We will also pursue analytical models for mesoscale drag effects of mountains under stable conditions, extending previous perturbation analyses of Hunt et al. (2001, 2004) and Orr et al. (2005). For strongly convective conditions, when the mixing height is greater than the mean mountain height, the mesoscale effects can be analyzed by methods dealing with flow over and through a porous region. Our new research will study how thermal circulations interact with these mesoscale processes, for example, in affecting the drag.

The physical processes of thermal adjustment are poorly represented in current mesoscale models (Owinoh et al 2005); they do not consider how convective eddies can help drive the flow rather than slowing it down. Where slopes change rapidly at the mountain tops, in areas where hydraulic jumps occur and other places such as lee slopes where flow separation takes place, the structure of mechanically driven flow undergoes large changes, which need careful theoretical analysis (e.g., Counihan et al. 1974). Buoyancy forces can enhance or suppress flow separation (Lin et al. 1992), which will be studied in the context of drag and wave radiation. During the course of the project, we expect to identify other crucial problems amenable for analysis.

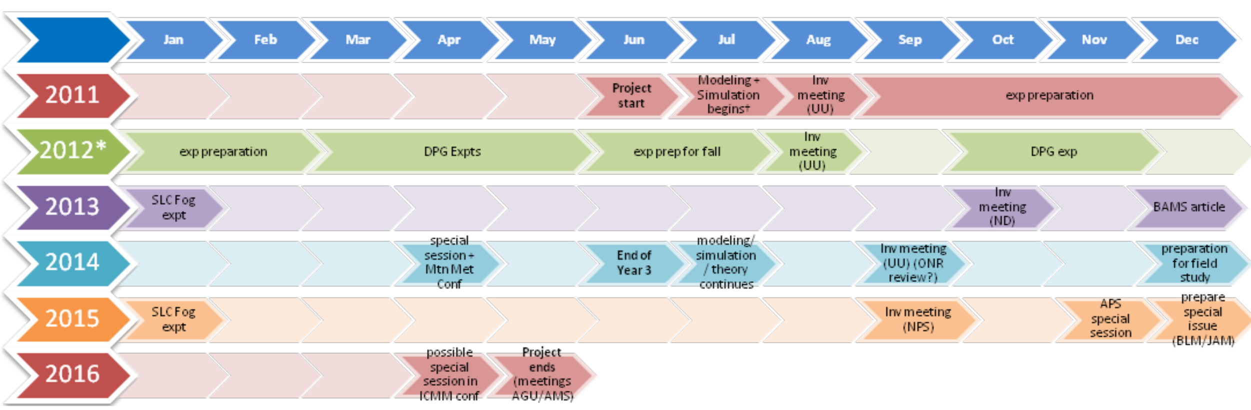
3.4.4 Implementation in Mesoscale Models

The WRF model offers multiple options for parameterization of turbulence in the PBL, based on the so-called "nonlocal K" approach, but validation studies suggest that these models leave much to be desired both in the context of land-surface models and sub-grid parameterizations. It has become evident that different localities have different dominant processes, and the parameterizations ought to have the 'intelligence" to identify these processes and assign a cumulative "eddy diffusivity" as discussed in §3.4.3. Given that WRF offers sub-grid-parameterization implementation facilities, we plan to work with the NCAR WRF group (Dr. Jimy Dudhia) to implement the new developments in WRF. To this end, PI Dimitrova plans an extended visit to NCAR during the third year of the project. Time permitting, similar attempts will be made for COAMPS in consultation with PI Hacker. In our previous work, we have made tangible improvements to the NBL parameterizations of MM-5 model (Lee et al. 2006).

4. PROJECT SCHEDULE, MILESTONES AND DELIVERABLES

The overall project schedule and milestones are given in Table 1. The main items include: the two 2012 DPG experiments; 2013 (pilot) and 2015 Salt Lake Valley fog experiments; preparation periods for experiments; investigator meetings; special sessions in professional meetings (e.g., AMS Mountain Meteorology Conference, International Conference on Mountain Meteorology ICMM, APS Fluid Dynamics Meeting); an article in the Bulletin of the American Meteorological Society (BAMS); and special issues in Boundary Layer Meteorology (BLM) or Journal of Applied Meteorology and Climatology (JAM). The PIs are encouraged to rapidly disseminate new results via reputed journals, books and meetings, individually or as groups.

Table 1 - Timelines of activities



†Modeling & simulations continue to the project end; *****Field year at Dugway Proving Ground

5. MANAGEMENT PLAN

The MATERHORN group will work symbiotically to achieve the overall goal of improving weather prediction in mountain terrain. All personnel involved have either regular or formal visiting appointments with the five MURI institutions. In addition, the group will have close non-MURI collaborators, including University of Lecci, Italy (Silvana DiSabatino), Central Institute for Meteorology and Geodynamics, Vienna (Thomas Haiden), German Weather Service (Meinolf Kossmann) and Ludwig-Maximilians-University (Bernhard Mayer).

A project management plan has been developed for <u>technical aspects</u>, which is depicted in Figure 16. Each MATERHORN component has a group leader; The Project Director (PI Fernando) is responsible for P and T, Pardyjak for X and Hacker for M, selected based on their expertise and commitments. For <u>administrative matters</u>, each institution will have a point of contact: Pardyjak at UU; Hacker at NPS; Chow at UCB; and deWekker at UV. The Project Director will conduct overall supervision and be responsible for ensuring that all project components are progressing as proposed. His other duties include: overseeing regulatory compliance of field studies; timely submission of reports; developing formal arrangements with DPG and NRL; interacting with the Topic Chiefs at ONR; and coordinating monthly and annual meetings of the PIs.

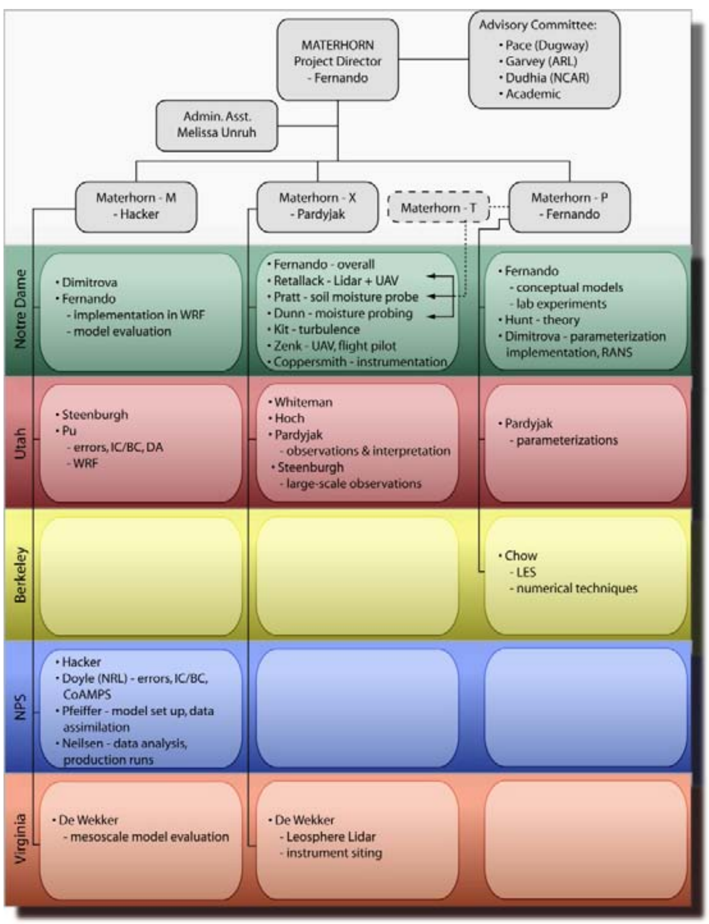


FIGURE 16
Project management structure: The leaders of each project component and the major tasks of each investigator and staff member are listed. Both vertical and lateral interactions will be essential to the success of the project. Dedicated administrative support will be available.

An **advisory group** will be formed to provide annual reviews of the project. Drs. John Pace (DPG), Dennis Garvey (ARL) and Jimy Dudhia (NCAR) have graciously accepted to serve. Two academics are yet to be invited (suggested: Ron Smith, Yale and Steve Mobbs, Leeds).

The integrity of the team will be maintained as follows:

- A project website will be maintained by ND to post the activities, deadlines and research products. New postings will trigger e-mails to project scientists and to ONR topic chiefs. This site will be linked to the password-protected DPG site where data will be stored.
- Monthly teleconferences/webinars will be held to monitor progress. Meetings will be held more frequently, if necessary. Subgroups may also conduct their own meetings.
- Annual project meetings will be held as shown in the timeline of Table 1. ONR topic chiefs will be invited, but they may decide to have separate reviews at locations of their discretion. All PIs, grad students and post docs are required to attend, and the dates will be determined sufficiently in advance to facilitate travel plans of the advisory committee and project personal.
- Summer graduate and undergraduate student (and perhaps senior personnel) exchanges are planned between MURI institutions, NRL and ARL. ARL plans to institute a CRADA with ND.

Qualifications of the Project Director: The PI has extensive experience in handling large-scale complex terrain air quality and meteorology projects. He has successfully directed several field and modeling projects for Arizona Department of Environmental Quality (Lee at al. 2007) and National Science Foundation (Pardyjak et al. 2009), and has been a PI or co-PI of many important meteorological research projects (VTMX, T-REX, CHATS, Joint Urban 2003 and MeteoDiffusion). He is a Fellow of the American Meteorological Society, American Society of Mechanical Engineers and American Physical Society, and an elected member of the European Academy (Geosciences). He will work with an accomplished group of personnel with demonstrated expertise. The resumes of the PI and the team are in §8.

Plans for research training of students: MATERHORN will train 3 post-docs, 9 grad students and 4 undergraduates (Table 2). Graduate thesis topics will be selected to ensure true cross-disciplinary training, covering a suitable combination of topics and tools (theory, field/laboratory experiments and modeling). The aim is to train grad students and post docs with multiple skills, yet rooted in fundamental understanding. Summer exchange visits are planned between MURI institutions and partners. The thesis committees of MURI students will have external examiners from the group. Students will also partake in international/national meetings. The undergrads will participate in field/lab experiments and data processing under the supervision of a PI.

Capital equipment purchases: The UU is requesting funds for the experimental team to construct *EFS* surface energy budget stations (1st year) and for upgrading computer equipment for data storage, reanalysis and simulations (2nd year). The NPS is requesting enhancement of computer power for numerical and field data analysis (in year 2 and option year 2).

Table 2: Human Resources (ND - 1 student match; NPS graduate and UV undergraduate are free)

Category/Institution	ND	UCB	NPS	UU	UV	Total
Regular faculty	2	1	2	3	1	9
Research faculty	2	0	1	2	0	5
Visiting/Adjunct Professors	2	0	0	0	0	2
Staff/Academic Professionals	2	0	0	0	0	2
Post Doctoral Fellows	1	0	1	1	0	3
Graduate Students (PhD)	3	1	1	3	1	9
Undergraduate Students	2	0	0	1	1	4
Total	14	2	5	10	3	34

DOD collaborators: The GMAST field program will rely on the support of DPG group led by John Pace. The UU and ND PIs have visited DPG, had discussions with its technical personnel and conducted a site survey. A preliminary budget was developed for personnel, medics and security for 25 IOP days and for DPG instrumentation deployment. The cost estimate is $110K, which will be paid by non-MURI funds to be cost shared by ND and UU (see commitment letters in the Cost Proposal). DPG will also provide support for field preparation, environmental compliance, and data storage to ensure the longevity of data base beyond the life of MURI.

Another major DOD collaborator is James Doyle from NRL, who will work with the NPS group by sharing a post doc with PI Hacker. Dennis Garvey's group from ARL also has expressed strong interest in participating in the field programs and data analysis.

Advantages to Collaborators and Transitions: At present, DPG is used by the DoD as a diffusion and UAV test bed representative of complex terrain in arid regions. The proposed study will help further characterize meteorology of this test bed. The DPG also has been invited to submit a DTRA phase-II full proposal to conduct a tracer experiment on the southwest side of Granite Mountain. If both proposals are successful, DPG will conduct this study concurrent with MATERHORN-X to cross-fertilize the two experiments. The COAMPS development is directly relevant to Navy, and hence for the NRL Mesoscale Modeling Section headed by Jim Doyle.

Other possibilities: Dr. Dave Emmitt (UV and Simpson Weather Associates) has submitted a proposal to ONR to conduct a meteorological experiment involving Airborne Twin-Otter Doppler Wind Lidar (TODWL); if funded, he plans to deploy it alongside MATERHORN-X.

Data management: The data will be stored in Campbell data loggers, followed by radio transmission to a central station at a dedicated military frequency. DPG will archive all data after QA/QC. A structured database with a pass-word protected web interface will provide access to data by the entire team. The data will be made public two years after the experiments.

Resource Availability: Most of the facilities needed for proposed computations and measurements (§3) are in hand. The GMAST/DPG is fully committed to the project via providing facilities (§9). The UU has ample computer facilities via Linux clusters operated by the Center for High Performance Computing. The PI Chow has a small computer cluster (256 processors) for code development and testing. For computationally expensive production runs, computer allocations will be requested from NCAR or the TeraGrid or from other supercomputing centers. ND has a dedicated research computing facility and a fully fledged Environmental Fluid Dynamics Laboratory for physical modeling and instrumentation storage, maintenance and development (www.nd.edu/~dynamics). An electro-mechanical engineer provides full time technical support for the laboratory. The NPS Meteorology Department is currently installing a 48 processor (Intel Xeon) Linux cluster with InfiniBand networking, for which PI Hacker has direct access. PI de Wekker at UV maintains an aerosol backscatter lidar system (Lesopshere EZ ALS300), and excellent computer support is available to him.

The current **major time commitments** of the PIs are summarized in Table 3.

Table 3: Current and pending support summary

Project name	Sponsor	Funds	Period	Time commitment
Fernando (ND)				
Double Diffusion in the US Petroleum Reserves	Sandia (PI)	Current 370K	10/06-12/10	0.5 mo summer
Up-Scale Influence of Urban Processes	NSF (coPI)	Current $775K	08/09-08/13	0.25 mo summer
Mixing in China Seas and Western Pacific	ONR (coPI)	Current $483K	04/10-03/13	0.25 mo AY
Modeling Particulate Matter in Urban Areas	AzDEQ (PI)	Current $825K	09/07-06/11	0.25 mo summer
Understanding the atmospheric boundary layer	NSF (PI)	Pending 273K	04/11-06/14	0.5 mo summer

Air Sea Interactions in Northern Indian Ocean	ONR (PI)	Pending $213K	01/11-12/12	0.5 mo summer
Thomas Pratt (ND)				
Polarimetric processing techniques for signal detection and recovery	DARPA (PI)	Current $500K	02/10 - 02/11	8 months CY
High-Fidelity Input–Output Polarization Channel Modeling	NSF (PI)	Pending $500K	02/11 - 3/14	1 month/CY
Communication Under Extreme RF Spectrum Conditions (CommEx*)*	DARPA (PI)	Pending $1.5M	03/11 - 03/13	3 months/CY
Patrick Dunn (ND)				
Cavitation Suppression in Piston Fuel Pumps	Honeywell CoPI	Current $572K	08/04- 06/11	1 mo/CY
Fotini Chow (UCB)				
Explicit Filtering and Adaptive Mesh Refinement for LES	NSF (PI)	Current $257,382	09/09–08/12	1 mo summer
CAREER: LES of ABL Over Complex Terrain	NSF (PI)	Current 598K	08/07-07/12	1 mo summer
Atmospheric Modeling for Wind Farm Siting	LLNL (PI)	Current 98K	08/09–12/10	0.25 mo summer
Fully-coupled hydrologic modeling with ensemble data assimilation	NSF (co-PI)	Pending $735,900	09/11–08/16	1 mo summer
A Framework for Regional Climate Simulations	DOE (PI)	Pending $752K	06/11-05/16	1 mo summer
Joshua Hacker (NPS)				
State space analysis of model error	ONR (PI)	Current $890K	01/10-12/13	3 mo summer
Probabilistic Ceiling and Visibility predictions	AFWA (PI)	Current $125K	06/10-05/11	1 mo buyout
-same-	AFWA (PI)	Pending $70K	02/11-01/12	1 mo buyout
Eric Pardyjak (UU)				
Urban designs for air quality and energy efficiency	NSF (PI)	Current $341K	09/08-10/11	0.5 mo summer
Development of a windbreak dust predictive model and mitigation tool	SERDP (PI)	Current $356K	03/01-12/10	1 mo summer
Rotor blade vortex control using surface roughness	KIGAM (PI)	Current $42K	06/10-12/10	1 mo summer
“Poste Rouge” Visiting scientist award	Midi-Pyrén. (PI)	Current $19K	06/11-07/11	2 mo summer
Atmospheric Mercury Monitoring in Utah	EPA (co-PI)	Current $337K	12/08-12/12	0.5 mo summer
Toward understanding the atmospheric boundary layer	NSF (PI)	Pending $276K	04/11-3/14	1 mo summer Year 2 & 3
Steenburgh (UU)				
Mechanisms of Intermountain Cold Front Evolution	NSF (PI)	Current $387K	02/07-01/11	2 mo summer
Orographic Influences on Lake-Effect Precipitation	NSF (PI)	Current $471K	06/10-05/13	2 mo summer
Warning Capabilities for High Impact Weather Events	NOAA/NWS (co-PI)	Current $375K	05/10 - 4/13	0.5 mo summer
Pu (UU)				
On the variable terrains and diurnal variations in data assimilation	NSF (PI)	Current $235K	11/08-10/11	0.5 mo summer
The impact of Aqua satellite multi-sensor data on predicting hurricane intensity change	NASA (PI)	Current $270K	12/07-12/10	0.5 mo summer
Convective clouds over the western Pacific and their relationship to tropical cyclones	ONR (PI)	Current $293K	01/08-12/10	2 mo summer
Assimilating Aqua-Terra satellite multi-sensor data to predict tropical cyclones	NASA (PI)	$389K Pending	12/10-11/13	1 mo summer
Whiteman (UU); Hoch (UU)				
The diurnal evolution of SBL in enclosed basins	NSF (PI)	Current (617K)	01/09-12/11	3.5 month CY (W)
Bingham Mine Cold-Air Pool Structure and Evolution (Whiteman)	Kennecott Copper (PI)	Current $557K	10/10-09/13	2 mo CY (**W**); 4 mo CY (**H**)
Persistent wintertime temperature inversions in the Salt Lake Basin	NSF (PI)	Current $544K	02/10-01/13	2 mo CY (**W**); 0.5 mo (**H**)
De Wekker				
Blue Ridge Mountains - Climate change effects	NPS (Co-PI)	Current $96K	6/10- 5/13	1.0 mo summer
Vegetation-microclimate feedback	NSF (Co-PI)	Current $265K	06/08 –06/11	0.5 mo summer
Numerical simulation of atmospheric CO2 transport over mountainous terrain	NOAA (PI)	Pending $402K	5/2011-5/2014	1.0 mo summer

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7. LETTERS OF SUPPORT

DEC-02-2010 17:55 From: To:914358312594 Page:2/3
2010-12-01 22:30 DPG*COMMAND 4358312594 >> P 2/3

DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY DUGWAY PROVING GROUND
DUGWAY, UTAH 84022-5000

REPLY TO ATTENTION OF:

DEC 0 2 2010

Office of the Commander

Program Managers
Multidisciplinary University Research Initiative Topic - 7
Office of Naval Research
875 North Randolph Street – Suite 1425
Code 03R
Arlington, Virginia 22203-1995

Dear Sir or Madam,

This letter is to confirm that the U.S. Army Dugway Proving Ground (DPG) is endorsing the proposal "Mountain Terrain Atmospheric Modeling and Observations (MATERHORN) Program" submitted to the Multidisciplinary University Research Initiative (MURI) by the University of Notre Dame, Naval Postgraduate School, University of California (Berkeley), University of Utah and University of Virginia. The group of researchers involved represents the topmost expertise in the field of mountain meteorology, drawn from the communities of numerical modeling, field observations, analysis, research computations and laboratory experiments. A unique feature of the program is its approach of melding model improvements, observations, parameterization development and their implementation within a single collaborative program. The MURI group will use the Granite Mountain Atmospheric Sciences Testbed (GMAST) at DPG for a series of experiments. GMAST is a one of a kind test facility in the world with unprecedented density of state-of-the-art meteorological instrumentation. The visiting group also plans to bring in a myriad of their own instrumentation, including a unique unmanned aerial vehicle (UAV), that carries turbulence and fog-measurement probes, to be operated by a certified pilot. There is no doubt that MATERHORN will be one of the best instrumented and planned mountain terrain meteorology programs ever to be conducted.

The benefits to DPG and the Developmental Test Command are wide-ranging. MATERHORN will improve DPG's understanding of airflow patterns over Granite Mountain, enabling more effective chemical, biological, toxic industrial chemical/toxic industrial material, and other testing over this portion of the range. Further benefits will derive from addressing meteorological data assimilation and prediction in complex terrain, which is a major challenge for the Four-Dimensional Weather (4DWX) program and of critical importance to several Developmental Test Command test centers and to Department of Defense operations. Interaction between the DPG Meteorology Division and the visiting scientists will help guide our evaluation of new types of instrumentation for potential use in test support, and will provide opportunities for future collaboration. Finally, this study will expand awareness of DPG and GMAST, potentially leading to new test and research and development activities.

2010-12-01 23:39 00143 >> DPG*COMMAND P 2/3

DPG will provide assistance for data collection, data archiving and instrumentation placement by dedicating several support personnel to provide technical and logistical help as well as to ensure safety and environmental compliance. The DPG Meteorology Division is excited about the possibility of hosting the MATERHORN experiments, interacting with visiting scientists and contributing to the improvement of mountain terrain weather predictions.

The point of contact at DPG is Mr. John Pace, (435) 831-5101.

Sincerely,

William E. King, IV
Colonel, US Army
Commanding

NAVAL RESEARCH LABORATORY
Marine Meteorology Division
7 Grace Hopper Avenue
Monterey, CA 93943-5502

Dr. James D. Doyle
Naval Research Laboratory
7 Grace Hopper Avenue
Monterey, CA 93943-5502
Tel: (831) 656-4716
Fax: (831) 656-4769
E-mail: doyle@nrlmry.navy.mil

15 November 2010

Dear Sir or Madam,

The Naval Research Laboratory Marine Meteorology Division would like to express our desire to collaborate with the *Mountain Terrain Atmospheric Modeling and Observations (MATERHORN) Program* that has been submitted by the P.I. Prof. Harindra Joseph Fernando for consideration for the ONR FY 2011 MURI TOPIC #7: *Improved Meteorological Modeling in Mountain Terrain*. The problem of data assimilation and prediction in complex terrain is a major challenge and of critical importance to Department of Defense for operations. Should the MATERHORN be funded, we would look forward to collaborations with Dr. Fernando and his colleagues on this important problem. In particular, we see important areas of collaboration on the topics of data assimilation and predictability in complex terrain using high-resolution models such as the Navy's COAMPS®, as well as ensemble-based mesoscale data assimilation. We have on-going programs to improve our assimilation of observations in both our global and mesoscale models, which are used for the Navy's operational weather forecasts, as well as programs in the development of ensemble and ensemble-variation hybrid data assimilation methods. We have a new initiative that has just begun aimed at quantifying the predictability of terrain-forced gravity waves and how these impact the stratosphere and middle atmosphere. We anticipate the potential for fruitful collaboration on these topics, particularly with Prof. Hacker of the Naval Postgraduate School (NPS). Prof. Hacker has recently interacted with NRL on ensemble data assimilation and predictability related research, and we would welcome further collaboration in this area. As part of this proposal, Prof. Hacker has proposed for a postdoctoral scientist at NPS to work closely with scientists at NRL on these important topics to further facilitate this collaboration.

The PI of the proposal has assembled a world-class team of scientists, who are among the leaders of mountain and mesoscale meteorology. They propose a well-thought-out and well-organized methodology to address these challenging problems in complex terrain and are well-poised to make significant advancements to the science of mesoscale and mountain meteorology. A particularly strong point of the proposal is the link between basic research and operations, which will promote the training of students in mesoscale modeling and the transition of new ideas into operations. Additionally, the proposed suite of observations will provide a valuable opportunity to evaluate and verify high-resolution models such as COAMPS applied over complex terrain, in regions of interest to the Navy and DoD.

In closing, the *Mountain Terrain Atmospheric Modeling and Observations Program* is poised to make important contributions to the prediction and observations of complex terrain flows and we strongly urge you to support this proposal. Please contact us if you have any questions. Thank you for your consideration.

Sincerely,

JAMES D. DOYLE, Ph.D.
Mesoscale Modeling Section Head

8. CURRICULUM VITAE
University of Notre Dame

Biographical Sketch: Harindra Joseph S. Fernando

Professional Preparation

The University of Sri Lanka	Mechanical Engineering	B.Sc. (Ist Class Hons), 1979
The Johns Hopkins University	Geophysical Fluid Mechanics	M.A., 1982; Ph.D., 1983
California Institute of Technology	Environmental Fluid Mechanics	Post Doctoral, 1983-1984

Appointments

2010-	Wayne and Diana Murdy Endowed Professor of Engineering & Geosciences, University of Notre Dame (Department of Civil Engineering & Geological Sciences; Concurrent Professor – Aerospace & Mechanical Engineering)
1992-2010	Professor, Department of Mechanical and Aerospace Engineering, Arizona State University (Also 1994 - 2009, Director, BOR Center for Environmental Fluid Dynamics; 2007-2010, Professor, Global Institute of Sustainability; 2010- Professor Emeritus)
1988-1992	Associate Professor, Department of Mechanical and Aerospace Engineering, Arizona State University
1990-1991	Senior Visitor, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, England
1984-1988	Assistant Professor, Department of Mechanical and Aerospace Engineering, Arizona State University
1983-84	Post-Doctoral Fellow, Division of Engineering and Applied Sciences, California Institute of Technology (also at the Johns Hopkins University – 3 months)

Publications

Five most closely-related publications:

Fernando, H.J.S. and Weil, J., "An Essay: Whither the SBL? - A Shift in the Research Agenda," *Bulletin of the American Meteorological Society* (BAMS**),** In Press, 2010 (November Issue).

Kit, E., Cherkassy, A., Sant, T. and Fernando, H.J.S., "In-situ Calibration of Hot-film Probes using a Co-located Sonic Anemometer: Implementation of a Neural Network," *Journal of Atmospheric and Ocean Technology*, **27(1)**, 23-41, 2010.

Fernando, H.J.S. "Fluid Dynamics of Urban Atmospheres in Complex Terrain," *Annual Reviews of Fluid Mechanics*, **42**, 365-389, 2010.

Princevac, M. and Fernando, H.J.S., Morning Break-up of Cold Pools in Complex Terrain, *Journal of Fluid Mechanics*, **616,** 99–109, 2008.

Hill, M., Calhoun, R., Fernando, H.J.S., Wieser, W., Dörnbrack, D., Weissmann, M. Mayr, G., and Newsom, R. "Coplanar Doppler Lidar Retrieval of Rotors from T-REX," *Journal of the Atmospheric Sciences*, **67(3)**, 713-729, 2010.

Five other publications:

Zajic, D., Fernando, H.J.S., Calhoun, R., Princevac, M., Brown, M.J. and Pardyjak, E., Flow and Turbulence in an Urban Canyon, *Journal of Applied Meteorology*, In Press.

Fernando, H.J.S., Zajic, D., Di Sabatino, S., Dimitrova, R., Hedquist, B., and Dallman, A., Flow, Turbulence and Pollutant Dispersion in Urban Atmospheres, *Physics of Fluids*, **22**, 051301-19, 2010.

Princevac, M., Hunt, J.C.R. and Fernando, H.J.S. Quasi-Steady Katabatic Winds Over Long Slopes in Wide Valleys," *Journal of the Atmospheric Sciences*, **65 (2)**, 627-643, 2008.

Rotter, J., Fernando, H.J.S. and Kit, E., "Evolution of a Forced Stratified Mixing Layer," *Physics of Fluids*, **19**, 065107 (1-10), 2007.

Choi, Y-J., Hyde, P. and Fernando, H.J.S., “Modeling of episodic particular matter events using a 3-D air quality model with fine grid: Applications to a pair of cities in the U.S./Mexico border” *Atmospheric Environment*, **40**, 5181-5201, 2006.

Synergistic Activities

- I am a Fellow of the American Meteorological Society, American Society of Mechanical Engineers and American Physical Society, and a member of the AGU and also an elected member of the European Academy. I participate in numerous activities of these societies.
- Tempe Five Who Matter - honored by Arizona Republic Newspaper at the yearend (2008) as one of the five Tempe residents who have made a notable difference in the life of the city. This was in recognition of my work on urban heat island measurement, modeling and mitigation.
- Since 1998, I have led several field experiments for the Arizona Department of Environmental Quality (ADEQ) to track and predict the pollutant dispersion in Phoenix in support of the development of a State Implementation Plans (SIP) for EPA (co-chair of the SIP technical modeling group). In 2009, I led a State of Arizona mandated field experiment in South Phoenix to investigate high levels of lead pollution within the area and make recommendations to mitigate the effects.
- I have served on numerous national and international committees, some examples in the NSF Graduate Fellowship (1996-1999), Career (1994, 1999) and Oceanography (1997, 2006) panels, Scientific Committee for Ocean Research (SCOR) Working Group on Double Diffusion (Co-Chair, 1999), AMS Committee on Air Pollution (2000-2003), DOE Biological and Chemical National Security Review Panel (2002)
- I have played a major role in natural disaster related to science and policy, including memberships in the International Tsunami Survey Team (Liu et al. 2005, *Science*, 308), Louisiana Coastal Area Reconstruction Science Board (2006-), AGU Committee on Natural Disasters (2007-8) and EPA NUDAPT Urban Modeling Group (2004-). My work on natural defenses against natural disasters has had significant impacts on public policy (see the reports in *Nature* by Emma Marris 25th Aug, 2005; *20th* Apr, 2006). I was featured in full length articles in New York Times (2007) and 13 other International Newspapers on my tsunami work.
- I serve on the editorial boards of Applied Mechanics Reviews (Associate Editor, 1989-), Theoretical and Computational Fluid Dynamics (Editor, 1997-), Advances in Fluid Mechanics (Associate Editor, 2000-), Non-Linear Processes in Geophysics (Editor, 2010-) and am a founding associate editor of the Journal of Environmental Fluid Dynamics (2000-) and the IAHR Journal of Hydro Environmental Research (2007-). I am a founding member and a Fellow of the International Institute for Infrastructure Renewal and Reconstruction (IIIRR) based in University of Calgary (2005-), Board Member for the Catalan Institute for Water Resources (Spain, 2007-) and Urban Sustainability Committee of the City of Phoenix (2007-9).

Collaborators & Other Affiliations

Collaborators and Co-Editors (past 48 months): S. Di Sabatino (Univ. Lecci), R. Calhoun. A. Mahalov, Huei-Ping Huang (ASU), B. Cushman-Roisin (Dartmouth College), S. Hanna (Harvard School of Public Health), M.Y. Hussaini (Florida State U.), J.C.R. Hunt (U. College London), E. Kit (Tel Aviv U.), P. Monti (Università degli Studi di Roma, Italy), N. Ovenden (Univ. London), A. Mahalov (

Graduate Advisors and Post-Doctoral Sponsors: Professor R.R. Long (Thesis Advisor, retired) and Professor E. J. List (Post-Doctoral Supervisor, retired)

Doctoral Thesis Advisor and Postgraduate-Scholar Sponsor (past 5 years): S. Balasubramanian (Los Alamos Natl. Labs), Yu-Jin Choi (Seoul Urban Development Authority, Korea), Reneta Dimitrova (ND), Suhas Pol (Los Alamos Natl Labs), S. Smirnov (Texas Tech University), P. Monti (University of Rome), C. Shi (Urban Meteorological Institute, Heifei, China), F. Testik (Clemson University), D. Zajic (Los Alamos Natl. labs), Z. Zhao (Univ. South Dakota).

Biographical Sketch: Reneta Dimitrova

Professional Preparation

University of Sofia, Bulgaria	Physics	B.Sc., 1988
University of Sofia, Bulgaria	Meteorology and Geophysics	M.Sc., 1990
Institute of Geophysics, Bulgarian Academy of Sciences	Physics of the ocean, atmosphere and near earth's space	Ph.D., 2002
Central Nantes University, France	Fluid Mechanics Laboratory	Post Doctoral, 2003-05

Appointments

2010-present Research Assistant Professor, University of Notre Dame, Department of Civil Engineering & Geological Sciences, USA

2007 – 2010 Faculty Research Associate, Department of Mechanical and Aerospace Engineering – Center for Environmental Fluid Dynamics, Arizona State University, USA

2005 – 2007 Research Fellow I degree, Bulgarian Academy of Sciences, Geophysical Institute,

2003 – 2005 Postdoctoral Research Fellow, Central Nantes University, Fluid Mechanics Laboratory, France

2002 – 2003 Research Fellow I degree, Bulgarian Academy of Sciences, Geophysical Institute, Bulgaria

1996 – 2002 Research Scientist, Bulgarian Academy of Sciences, Geophysical Institute, Bulgaria

Publications

***Five most closely-related publications**:*

Vardoulakis, S., Dimitrova, R., Richards, K., Hamlyn, D., Camilleri, G., Weeks, M., Sini, J.-F., Britter, R., Borrego, C., Schatzmann, M., Moussiopoulos, N. (2010). Numerical Model Inter-comparison for Wind Flow and Turbulence Around Single-Block Buildings, *Envir. Modeling & Assessment*, DOI: 10.1007/s10666-010-9236-0, accepted for publication

Fernando, H.J.S., Zajic, D., Di Sabatino, S., Dimitrova, R., Hedquist, B., Dallman, A. (2010). Flow, Turbulence and Pollutant Dispersion in Urban Atmospheres, *Physics of Fluids*, **22**, 051301-19

Dimitrova, R., Sini, J.-F., Richards, K., Schatzmann, M., Weeks, M., García, E., Borrego, C., (2009). Influence of Thermal Effects on the Wind Field within the Urban Environment, *Boundary-Layer Meteorology*, **131** (2), 223-243

Dimitrova, R., (2000). Numerical studies of the city heat island", *Bulg. Geoph. J.*, **XXVI(**1-2), 103-113

Dimitrova, R., (2000). Numerical simulation of flow data over two-dimensional hills and valley and comparison with wind tunnel experiment data", *Bulg. Geoph. J.*, **XXV**(1-4), 32-43

Five other publications:

Dimitrova, R., Webb, S., Fernando, H.J.S., Pol, S. (2010). Simulations of double-diffusive convection in narrow container", *Engineering and Computational Mechanics*, EACM-D-10-00027, accepted for publication

Zerefos, Ch., Syrakov, D., Ganev, K., Vasaras, A., Kourtidis, K., Tzortziou, M., Prodanova, M., Dimitrova, R., Georgieva, E., Yordanov, D., Miloshev, N. (2004). Study of the pollution exchange between Bulgaria and Northern Greece, *Int. J. Environment & Pollution*, **22 (**1/2), 163-185

Ganev, K., Dimitrova, R., Syrakov, D., Zerefos, Ch., (2003). Accounting for the meso-scale effects on the air pollution in some cases of large sulfur pollution in Bulgaria or Northern Greece, *Environmental Fluid Mechanics*, **3**(1), 41-53

Dimitrova, R., (2001). Air flows and pollution transport in the Sofia valley under highly stable background conditions", *Bulg. Geoph. J.*, **XXVII** (1-4), 124-136

Dimitrova, R., Ganev, K. (1999). Some examples of the mesoscale topography effects on large scale air pollution transport, *Notes on Numerical Fluid Mechanics*, **73**, 267-274

Synergistic Activities

- The Best Poster Award, Atmospheric Sciences and Air Quality Conference (ASAAQ 2005), San Francisco, CA, 27–29 April 2005
- Team Leader for Environment Impact Assessment - Bulgarian Ministry of the Environment and Waters, License N°1518 / 27.02.2003
- Licensed Environment Impact Assessment expert (Air Quality) - Bulgarian Ministry of the Environment and Waters, License N°1493 / 26.09.2002
- Development of a methodology for determination of traffic emissions and distribution of the pollution concentration in the surface layer - Project funded by the PHARE program, trough the Bulgarian Ministry of the Environment and Waters, contract N° 2750-599U. The results were approved as a national regulatory standard for evaluation of air quality in urban traffic, 2000-2002
- Development of methodology for designing new industrial stacks and calculation of pollution concentration and distribution in the surface layer" - Project funded by the PHARE program, trough the Bulgarian Ministry of the Environment and Waters, contract N° 166-1618. The results were approved as a national regulatory standard for evaluation of the anthropogenic impacts on the air quality, 1997-1998

Collaborators & Other Affiliations

Collaborators and Co-Editors (past 48 months):

H.J.S. Fernando, A. Dallman (University of Notre Dame), B. Hedquist (University of Utah), J.-F. Sini, (Central Nantes University, France), M. Schatzmann (University of Hamburg, Germany), C. Borrego (University of Aveiro, Portugal), S. Di Sabatino (University of Lecci, Italy), M. C. Mammarella, G. Grandoni, P. Fedele (ENEA, Italy), N. Moussiopoulos (Aristotle University of Thessaloniki, Greece), S. Vardoulakis (University of London, UK), R. Britter (University of Cambridge, UK), S. Webb (Sandia National Laboratories), S. Pol (Los Alamos National Laboratory), K. Ganev (Institute of Geophysics, Bulgarian Academy of Sciences), D. Syrakov (National Institute of hydrology and Meteorology, Bulgarian Academy of Sciences)

Graduate Advisors and Post-Doctoral Sponsors:

Professor D. Sirakov (M.Sc. Thesis Advisor, University of Sofia, Bulgaria)
Professor K. Ganev (Ph.D. Thesis Advisor, Institute of Geophysics, Bulgarian Academy of Sciences) Professor J.-F. Sini (Post-Doctoral Supervisor, Central Nantes University, France)

Biographical Sketch: Patrick F. Dunn

Professional Preparation

Ph.D. in Engineering, 12/74, School of Aeronautics, Astronautics and Engineering Sciences, Purdue University.
M.S. in Aeronautics and Astronautics, 8/71, School of Aeronautics, Astronautics and Engineering Sciences, Purdue University.
B.S. in Aeronautical and Astronautical Engineering, 6/70, School of Aeronautics, Astronautics and Engineering Sciences, Purdue University.
Postdoctoral Fellow, 1/75 to 5/76, Department of Physiology and Pharmacology, Duke University Medical Center.

Appointments

1985 to present: Professor, Department of Aerospace and Mechanical Engineering, University of Notre Dame (Associate Professor from 1985 to 1993). Director of Hessert Center for Aerospace Research (1998 to 2002).
1982 to 1985:Mechanical Engineer, Aerosol Program Group Leader, Argonne National Laboratory.
1978 to 1982: Mechanical Engineer, Engineering Division, Argonne National Laboratory.
1976 to 1978: Assistant Mechanical Engineer, Engineering Division, Argonne National Laboratory.

Publications

***Five most closely-related publications**:*

O. V. Kim and P. F. Dunn, Real-Time Direct Charge Measurements of Microdroplets and Comparison with Indirect Methods**,** *Aerosol Science & Technology*, **44**, pp. 292-301, 2010.
O. V. Kim and P.F. Dunn, Direct Visualization and Model Validation of Microsphere Impact and Surface Capture, *Journal of Aerosol Science,* **39**, pp. 373-375, 2008.
A. Ibrahim, P.F. Dunn and M. Qazi, Experiments and Validation of a Model for Microparticle Detachment from Surfaces by Turbulent Air Flow, *Journal of Aerosol Science*, **39**, pp. 645-656, 2008.
O. V. Kim and P.F. Dunn, A Microsphere-Surface Impact Model for Implementation in Computational Fluid Dynamics, *Journal of Aerosol Science*, **38**, pp. 542-549, 2007.
T. Szarek and P.F. Dunn, An Apparatus to Determine the Pull-Off Force of a Conducting Microparticle from a Charged Surface, *Aerosol Science and Technology*, **41**, pp.43-50, 2007.

Five other publications:

R.M. Brach, P.F. Dunn and X. Li, Experiments and Engineering Models of Microparticle Impact and Deposition, *Journal of Adhesion*, Vol. 74, pp. 227-282, 2000.
W. Cheng, P.F. Dunn and R.M. Brach, Surface Roughness Effects on Microparticle Adhesion, *Journal of Adhesion*, **78**, pp. 929-965, 2002.
P.F. Dunn, V.J. Novick and B.J. Schlenger, Nuclear Aerosol Measurement Techniques, Advances in Fluid Mechanics Measurements: *Lecture Notes in Engineering*, Vol. 45, pp. 569-606, Springer-Verlag, New York, 1989.
P.F. Dunn and K.J. Renken, Impaction of Solid Aerosol Particles on Fine Wires, *Aerosol Science and Technology*, 7, pp. 97-107, 1987.

F.R. Kirchner, P.F. Dunn, and C.B. Reed, Toxicologic and Physicochemical Characterization of High-Temperature Combustion Emissions, **2**, pp. 389-400, *Aerosol Science and Technology*, 1983.

Synergistic Activities

- Author of three texts: (*1) Fundamentals of Microparticle Dynamics* (in preparation), Taylor & Francis / CRC; ©2012. (2) *Sensor Fundamentals and Application*, Taylor & Francis / CRC; ©2011. (*3) Measurement and Data Analysis for Engineering and Science,* ISBN: 0072825383, McGraw-Hill Science/Engineering/Math, 1st edition, ©2005; ISBN: 9781439825686, Taylor & Francis / CRC; 2nd edition, ©2010.
- U.S. Patent on nuclear aerosol sampling system: P.F. Dunn, J.E. Herceg, R. Klocksieben, Apparatus for Sampling and Characterizing Aerosols, No. 4,570,494, 1986.
- Reviewer for Journal of Aerosol Science, Aerosol Science & Technology, Journal of Heat Transfer, Journal of Fluids Engineering, International Journal of Heat and Mass Transfer, Physics of Fluids, Experimental Heat Transfer, Experimental Thermal and Fluid Science, Experiments in Fluids, Review of Scientific Instruments.
- Invited PhD External Examination Committee Member, Technical University of Delft, 2009, 2008, and 2003.
- Consulted for Proctor and Gamble, Troutman Sanders LLP, Johnston & Lehman, Numerical Applications, Inc., Illinois Tool Works, Inc., National Aeronautics and Space Administration, Argonne National Laboratory, and Electric Power Research Institute.

Collaborators & Other Affiliations

Collaborators and Co-Editors (past 48 months): Notre Dame Graduate Students and Post-Docs (O.V. Kim, M. Davis, J. Jiménez-Lozano, A. Ibrahim, S. Ghosh, M. Qazi); Notre Dame Faculty (F. Thomas, M. Sen).

Graduate Advisors and Post-Doctoral Sponsors: Professor Paul S. Lykoudis (Thesis and Dissertation Advisor, retired) and Professor George G. Somjen (Post-Doctoral Supervisor, retired)

Doctoral Thesis Advisor and Postgraduate-Scholar Sponsor (past 5 years): O.V. Kim (Univ. of Notre Dame), T. Szarek (Aerovironment), M. Davis (BWI), A. Ibrahim (Cairo University), S. Ghosh (IIT-India).

Biographical Sketch: J.C.R. Hunt, CB, FRS (Official Title: Lord Hunt of Chesterton)
Department of Space and Climate Physics, University College, London

Professional Preparation

Undergraduate: 1955-59, Trinity College, Cambridge, Mechanical Sciences (Engineering), First Class Honors

Postgraduate: 1963-64, Trinity College, Cambridge (Ph.D. awarded 1967)
1964-66, University of Warwick, School of Engineering Sciences

Appointments

1967 Visiting Lecturer, University of Cape Town, South Africa, on Magneto-hydrodynamics
1967 Fulbright travel scholarship to USA to work as Research Associate at the Department of Theoretical and Applied Mechanics, Cornell University, Ithaca, New York, with Professor G.S.S. Ludford
1968-70 Research Officer at the Central Electricity Research Laboratories in the Fluid Dynamics Section, under Mr. D.J.W. Richard
1970-78 University Reader in Fluid Mechanics at the University of Cambridge
1990-98 Professor in Fluid Mechanics at the University of Cambridge
1992-97 Chief Executive & Director General, British Meteorological Office
1997-98 Visiting Professor, Arizona State University, Environmental Fluid Dynamics Program
1998 Fellow, Trinity College, University of Cambridge
1999 Professor of Climate Physics, University College of London
2003- Director, Lighthill Institute of Mathematical Sciences (LIMS)
2007-10 Visiting Professor of Mechanical & Aerospace Engineering, Arizona State University, USA
2010- Visiting Professor, University of Notre Dame, Indiana, USA

Awards and Honors (Since 1990, Selected)

1993 Appointed President of the Institute of Mathematics and its Applications
1992-97 Chief Executive, Meteorological Office, U.K.
1998 Appointed member of the Royal Companion of the Bath, C.B.
2001 Lewis Fry Richardson medal of the European Geophysical Society.
2000 Created as a Baron in the House of Lords (with the title Lord Hunt of Chesterton)

Publications

Five Most Closely Related Publications:

Belcher, S.E. and Hunt, J.C.R., "Turbulent Flow over Hills and Waves," *Ann. Rev. Fluid Mech.*, **30**, 507-538, 1998.

Belcher, S., Zu, D.P. and Hunt, J.C.R., "The Response of a Turbulent Boundary Layer to Arbitrarily Distributed Roughness Change," *Q. J. Roy. Met. Soc.*, **116**, 611-635, 1990.

Hunt, J.C.R., Olafsson, H and Bougeault, P., "Coriolis Effects on Orographic and Mesoscale Flows." (Paper presented at Am. Met. Sci. Jan 1998). *Q. J. Roy. Met. Soc.*, **121**, 601-633, 2001.

Hunt, J.C.R., Orr, A., Rottman, J.W. and Capon, R., 2004. Coriolis effects in mesoscale flows with sharp changes in surface conditions. *Q.J. Roy. Met. Soc.*, **130**(603), 2703-2731.

Hunt, J.C.R., Pacheco, J.R., Mahalov, A., and Fernando, H.J.S., " Effects of rotation on fronts of density currents," *J. Fluid Mech.*, **537**, 285-315, 2005.

Zilitinkevich, S.S., Hunt, J.C.R., Esau, I.N., Grachev, A.A., Lalas, D.P., Akylas, E., Mombrou, M., Fairall, C.W. and Fernando, H.J.S., "The influence of large convective eddies on the surface layer turbulence." *Q.J. Roy. Met. Soc.*, **132**(618), 1423-1456. 2006.

Five Other Publications:

Hunt, Julian (Ed.), London's Environment: Prospects for a sustainable world city. 336 pp. Imperial College Press. 2005.

Hunt, J.C.R., and Synder, W.H., "Experiments on stably and neutrally stratified flow over a model three-dimensional hill," *J. Fluid Mech.*, **96**, 671-701, 1980.

Hunt, J.C.R., Kaimal, J.C., and Gaynor, J.E., "Eddy structure in the convection boundary layer-new measurements and new concepts," *Q.J. Roy. Met. Soc.*, **114**, 821-858, 1988.

Carruthers, D.J.C., Holroyd, R.J., Hunt, J.C.R. and Weng, W.S., "UK-ADMS- a new approach to modeling dispersion in the Earth's atmospheric boundary layer," *J. Wind Eng. & Ind. Aerodyn.*, **52**, 139-153, 1994.

Hunt, J.C.R., 2002. "Floods in a changing climate". *Phil. Trans. Roy. Soc.*, **360**, 1531-1543.

Synergistic Activities

- His work on application of fluid mechanics to atmosphere and oceans has been internationally well received. For example, he was awarded honorary degrees from Salford, Bath, East Anglia, Warwick, Grenoble, and Uppsala. He was elected a Fellow of the Royal Society in 1989 and was awarded the L.F. Richardson Prize of the European Geophysical Society in 2001 and was appointed vice president of the National Society for Clean Air (now Environmental Protection UK) in 2001, and President from 2005 to 2006. He is chairman of Cambridge Environmental Research Consultants Ltd., which is working world wide on air pollution modeling and forecasting; he helped found it in 1986. He is also a Project Advisor for the Global System Dynamics and Policies Project. He was elected a Fellow of the Royal Society in 1989. He was the Chief Executive of the Meteorological Office from 1992-1997, and was created a Baron in the House of Lords (with the title Lord Hunt of Chesterton) in May 2000.
- Since 1978 he has been much involved in the Institute of Mathematics and its Applications (IMA), holding several positions, becoming Vice-President in 1989-1993 and President from 1993-1996. He contributed 3 chapters of the popular Penguin Book on Applications of Mathematics (Ed. C. Bondi, 1991) organised by the IMA that was translated into Japanese. He was an Associate Editor of the Journal of Fluid Mechanics (1978-1999). He was a member of the Council of NERC, the National Environment Research Council, from 1994 to 1996, and for one year chaired the Atmospheric Science Research Committee. During 1998-99 he was a member of the Council of the Royal Society where he was involved in initiatives on prevention of the spread of biological weapons, government policy on data and natural disasters and sustainable development. He organized conferences on these topics and the wider policy issues.
- Since 1998 he was chairman of the Scientific Committee and the RISK Group, an industry-science project for the problems raised by the insurance industry. In 2002 with colleagues at University of London he organized a major conference on 'London's Environment and Future' covering most aspects from science to politics. This has led to further conferences and the publication of a book. In 2001 he became Chairman of the Advisory Committee for the Protection of the Sea Ltd. (ACOPS), a non-governmental organization for international projects on sustainable development set up by Lord Callaghan in 1952, now based in Cambridge. From 2003-2006 he was Director of the Lighthill Institute of Mathematical Sciences, based at University College London. While at the Met Office he was elected to the Executive Committee of the World Meteorological Organization and was active in negotiating new international arrangements for the exchange of data to ensure that National Meteorological Services world-wide can continue to collaborate with each other. At the same time, he encouraged commercial applications of meteorology worldwide.
- He lectured on behalf of the World Meteorological Organization at the UN World Conference on the International Decade for Natural Disaster Reduction in 1994 and on urban problems at Habitat II Conference in Istanbul in 1996. This led to new efforts to improve international warnings for disasters ranging from tropical cyclones to volcanoes. He actively promoted collaboration in Europe and was elected Chairman of the Conference on West European Directors for 1994 -95.
- He was the founding Secretary-General of the European Research Community for Flow, Turbulence and Combustion (ERCOFTAC) in 1988 and was then Chairman of its Scientific Programme Committee from 1990 to 1994.

Biographical Sketch: Charles James Retallack

Professional Preparation

University of New Mexico	Mechanical Engineering	B.S. 2005
Arizona State University	Mechanical Engineering	Ph.D. 2010
University of Notre Dame	Environmental Fluid Dynamics	Post-Doctoral 2010

Appointments

2010 – present	Post-Doctoral Research Fellow, Dept. of Civil Eng., Univ. of Notre Dame
2005 – 2010	Graduate Research Assistant, Dept. of Mechanical Eng., Arizona State U.
2002 – 2005	Undergraduate Research Intern, Sandia National Laboratories

Publications

Five Most Closely Related Publications:

Mondy, L., Rao, R., Lindgren, E., Sun, A., Adolf, D., Retallack, **C.** & Thompson, K. 2010 Modeling coupled migration and settling of particulates in curing filled epoxies. *J. App. Poly. Sci.* (in press).

Retallack, C., Calhoun, R., Fernando, H. J. S., Rayner, K., Stuart, A., Sutton, J. & Hibberd, M. F. 2009 Flow and pollution transport during Wagerup 2006: a case study. *Met. Apps*. **17 (3)**, 269-278.

Mondy, L. A., Retallack, C., Thompson, K., Barney, J., Grillet, A. & Graham, A. L. 2008 On bubbles rising through suspensions of solid particles. *AIChE Journal* **54 (4)**, 862-871.

Hibberd, M., Calhoun, R., Rayner, K., Retallack, C. & Sutton, J. Dispersion model evaluation for Wagerup 2006: near neutral stability and moderate to strong winds. Submitted to *Boundary Layer Meteorology*.

Internal Research Report: Calhoun, R., Retallack, C., Christman, A. & Fernando, H. J. S. 2008 Meteorological Mechanisms and Pathways of Pollution Exposure: Coherent Doppler Lidar Deployment in Wagerup. (Final Research Report). Perth, Australia: Department of Environment and Conservation.
www.dec.wa.gov.au/component/option,com_docman/task.../Itemid,1/

Collaborators and Other Affiliations

Past/Present Collaborators (Last 48 months): R. Calhoun (Arizona State Univ.), H. J. S. Fernando (Univ. of Notre Dame), M. Hibberd (CSIRO), K. Rayner, A. Stuart, J. Sutton (DEC Western Australia)

Graduate and post-doctoral advisors: Professor R. Calhoun (Graduate Advisor, Arizona State Univ.) and H. J. S. Fernando (Post-Doctoral Supervisor, Univ. of Notre Dame)

Biographical Sketch: Eliezer Kit

Professional Preparation

Saint Petersburg Elecrotechnical University (LETI-ETU)	Industrial Electronics	M.Sc., 1964
Latvian Academy of Science	Institute of Physics	Ph.D., 1971

Appointments

1980 - Date Research Engineer, Associate Professor (1987), Full Professor (1995), Head of Department (1998-2002), School of Mechanical Engineering, Tel-Aviv University.

1973 - Date Senior Researcher and Consultant, Acting director (1993 Oct.-1994 Mar., 1997 Oct.-1998 Mar.), Coastal and Marine Engineering Research Institute, Technion

1971 - 1973 Period of unemployment due to pressures pending Aliya (emigration) to Israel

1967 - 1971 Research Associate, MHD Laboratory, Institute of Physics, Academy of Sciences, Latvia

1964 - 1967 Research Engineer, Research Institute for micro-devices, Riga

Visiting Positions (mostly during summer/fall)

2010 - University of Notre Dame

2003 - The Johns Hopkins University

1993, 1995, 1997, 2003, 2006, 2007, 2008, 2009 - Arizona State University

1994 - Delft University of Technology

1988, 1990 - ETH, Zurich

1986 - University of Maryland

1979 - NCSR, South Africa

Publications

Five most closely-related publications*:*

E. Kit and B. Gritz. *In-situ* calibration of hot-film probes using a co-located sonic anemometer: angular probability distribution properties. *Journal of Atmospheric and Oceanic Technology-AMS***,** In Press, 2010.

Kit, E., Cherkassy, A., Sant, T. and Fernando, H.J.S., “In-situ Calibration of Hot-film Probes using a Co-located Sonic Anemometer: Implementation of a Neural Network,” *Journal of Atmospheric and Ocean Technology*, **27(1)**, 23-41, 2010.

S. Beisel, L. Chubarov, I. Didenkulova, E. Kit, A. Levin, E. Pelinovsky, Y. Shokin, and M. Sladkevich The 1956 Greek tsunami recorded at Yafo, Israel, and its numerical modeling. *JGR*, **114**, c09002, 2009.

Dov Zviely, Eliezer Kit, Baruch Rosen, Ehud Galili, Micha Klein Shoreline migrations and beach-nearshore sand balance over the last 200 years in Haifa Bay (SE Mediterranean) ***Geo-Marine Letters***, **29/2**, 93-110, DOI 10.1007/s00367-008-0126-2, 2008.

E. Kit, D. Gerstenfeld, A. Yu. Gelfgat, N.V. Nikitin. Bulging and bending of Kelvin-Helmholtz billows controlled by symmetry and phase of initial perturbation. *Journal of Physics: Conference Series***, 216,** 012019, doi:10.1088/1742-6596/216/1/012019, (2010).

Five other publications:

Kit, E., Wygnanski I. On periodically excited turbulent mixing layer created downstream of a plane chevron partition. *Physica Scripta T,* doi:10.1088/0031-8949/2008/T132/014008, 2008.

Kit, E., Wygnanski I., Krivonosova O., Zhilenko D. and Friedman D. On the periodically excited, plane turbulent mixing layer, emanating from a jagged partition. *Journal of Fluid Mechanics*, **589**, 479–507, 2007.

D. Zviely, E. Kit, M. Klein Patterns of longshore sand transport along the southeastern Mediterranean coast in the Holocene. *Marine Geology*, **238**, 61–73 2007

Rotter, J., Fernando, H.J.S. and Kit, E., "Evolution of a Forced Stratified Mixing Layer," *Physics of Fluids*, **19**, 065107 (1-10), 2007.

Kit E. and Shemer L**.** Spatial versions of the Zakharov and Dysthe deep water gravity waves evolution equations, *J. Fluid Mech.***,** **450**, 201-205, 2001.

Synergistic Activities

- I have been an active researcher on a broad range of problems on experimental fluid mechanics and near-shore oceanography. I have published extensively on experimental investigations of nonlinear water waves, stability and transition phenomena in 3D-mixing layers, vorticity dynamics in turbulent flows and on turbulent entrainment pertinent to the wind-induced mixing in solar ponds and in the ocean. Recently, I became strongly involved in a research dealing with atmospheric physics.
- I have been a university professor for more than twenty years in Tel-Aviv University and for more than thirty five years senior researcher and leading scientist in Coastal and Marine Engineering Research Institute (CAMERI) affiliated to the Technion - Israel Institute of Technology. In 1993-1994 and then in 1997-1998 I was an acting director of CAMERI and I conducted there a great deal of applied research and consulting work in the field of coastal engineering for Israel Port Authorities and for Israel Electric Corporation and other agencies such as Ministry of Environmental Protection, desalination plants etc.
- Since 1992, I am deeply involved in studies of wave climate prediction in the eastern Mediterranean and developed a new approach that became an integral part of any sedimentological model used in Environmental Impact Assessment (EIA) upon request by the Ministry of Environmental Protection of Israel prior to any coastal development. I am also one of the promoters and leaders of an ambitious program to develop a global sedimentological model of the Israeli coast along the eastern Mediterranean.
- I have served on national committees, such as Israel Scientific Foundation (ISF) review panel and just recently (2010) was on the Ministry of Environmental Protection review panel that aimed at selection of the best projects dealing with potential morphodynamic variations caused by climate changes and fast development at the Israeli coast.

Collaborators & Other Affiliations

Collaborators (past 48 months): N. Nikitin (Moscow State University), M. Stiassnie, J Cohen, Y. Agnon (Technion), E. Pelinovsky (Lobachevsky State University of Nizhny Novgorod), Yu. Shokin, L. Chubarov **(**Institute of Computational Technologies, Siberian Branch of the Russian Academy of Sciences), I. Didenkulova (Tallinn University of Technology).

Graduate Advisors and Post-Doctoral Sponsors: Professor A. Tsinober (Thesis Advisor, retired)

Doctoral Thesis Advisor and Postgraduate-Scholar Sponsor (past 5 years): D. Jilenko (Moscow State University), S. Panjabi (Ujjain Engineering College, India), B. Gritz (IAO SB RAS), D. Zviely (University of Haifa), K. Goulitski (Deep Breeze Ltd.), V. Haslavsky (Ph.D. work in progress, Tel Aviv University), E. Miroshnichenko (Ph.D. work in progress, Tel Aviv University).

Biographical Sketch: Thomas G. Pratt

Professional Preparation

University of Notre Dame	Electrical Engineering	B.S. High Honors, 1985
Georgia Institute of Technology, Atlanta, GA	Electrical Engineering	M.S., 1989
Georgia Institute of Technology, Atlanta, GA	Electrical Engineering	Ph.D, 1999

Appointments

2008-Present University of Notre Dame, Research Associate Professor

Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA 30332

2004-2008	Principal Research Engineer
1996-2004	Senior Research Engineer,
1989-1996	Research Engineer II,
1985-1989	Research Engineer I,

Licensure

Professional Engineering License, State of Georgia, 2007-Present

Honors and Awards

- Keynote speaker, Title of Presentation: Multiport Architectures for Communications and Sensor Systems, WAVE 2008 Conference, Dearborn, MI, December 2008.
- Best Paper Award, 15th International Conference on Telecommunications, St. Petersburg, Russia, June 2008. Paper title is `Statistical Modeling and Experimental Verification for Wideband MIMO Mobile-to-mobile Channels in Urban Environments"

Patents and patents pending

- Radio Network Test Analysis System, U.S. Patent US6754487 and European Patent EP1329026
- Systems and Methods for Adaptive Polarization Transmission, Submitted Jan 2008
- Methods for Polarization-Based Interference Suppression, Submitted Jan 2008

Collaborative activity related to the proposal

- Invited presentation, "*Wideband Polarization-Based Interference Suppression*," DARPA Industry Day, September 2010
- Development of Wideband Polarimetric Testbed, University of Notre Dame, 2010
- Development of wideband multichannel collection receiver using software radio platform; The system was used in the conduct of MIMO and full-polarization mobile-to-mobile measurements in both city and interstate environments
- Founding member of the Notre Dame Wireless Institute at the University of Notre Dame.
- Evaluating polarimetric sensing concepts for horticulture applications in collaboration with University of Georgia.

Publications

Refereed Journals

T. Pratt and H. Tapse, "A Statistical Method to Detect Mutually-Independent Identically

Distributed Zero-Mean Bivariate Gaussian Noise Sequences," Submitted to IEEE Signal Processing Letters.

T. Pratt, "Spectrum Sensing with Polarimetric Integration Techniques," Pending submission to IEEE Transactions on Vehicular Technology.

T. Pratt, Y.F. Huang, Z. Gong, and M. Lemmon, " Measures for Subspace Optimization in Centralized MIMO Radar," paper to be published in IEEE Transactions on Aerospace and Electronics Systems, April 2011.

T. Pratt, H. Tapse, B. Walkenhorst, and G. Acosta, "A Modified XPC Characterization for Polarimetric Channels," Pending submission to IEEE Transactions on Aerospace and Electronics Systems (awaiting approval from DARPA).

T. Pratt, B. Walkenhorst, and S. Nguyen, "Adaptive Polarization Transmission of OFDM Signals in a Channel with Polarization Mode Dispersion and Polarization Dependent Loss" IEEE Journal on Wireless Communications, Vol. 8, No. 7, July 2009, pp. 3354-3359.

H. Kang, J. Kwak, T. Pratt, and G. Stuber, "Analytical Framework for Optimal Combining with Arbitrary Power Interferers and Thermal Noise," IEEE Transactions on Vehicular Technology, Vol. 57, No. 3, May 2008, pp. 1564-1575.

T. Pratt, B. Walkenhorst, and H. Kang, "Analysis of Multi-Antenna Architectures for Non-LOS Mobile-to-Mobile Communications in Co-Channel Interference", IEEE Transactions on Vehicular Technology, 2007, Vol. 56, No. 4, Part 2, July 2007, pp. 2168-2179.

G. Stuber, J. Barry, S. McLaughlin, Y. Li; M.A. Ingram, and T. Pratt, "Broadband MIMO-OFDM Wireless Communications," Invited Paper, IEEE Transactions on Communications, Vol. 92, No. 2004, pp. 271-294.

A. Zajic, G. Stuber, T. Pratt, and S. Nguyen, "Wideband MIMO Mobile-to-Mobile Channels: Parametric Statistical Modeling and Experimental Verification." Paper Accepted to IEEE Transactions on Vehicular Technology, June 2008.

Biographical Sketch: Michael A. Zenk

Professional Preparation

Air Force Institute of Technology	Operations Research	M.S., 1989
Loyola University, New Orleans	Pastoral Ministry	M.A., 1987
United States Air Force Academy	Civil Engineering	B.S., 1978

Appointments

2007-present University of Notre Dame, Operations Manager for Airborne Aero-Optics Laboratory
2000-2007 University of Notre Dame, Department Chair and Professor of Aerospace Studies
2000-2007 National Geospatial-Intelligence Agency, Bethesda, MD, Customer Support Executive
1995-2000 95th Flying Squadron, Royal Air Force Base Mildenhall, UK, Commander,
1995-2000 North Atlantic Treaty Organization Defense College, Rome, Italy, Student
1995-2000 45th Flying Squadron, Offutt Air Force Base, Omaha, NE, Director of Operations
1989-1995 United States European Command, Stuttgart, Germany, Staff Officer,
1989-1995 Flying Detachment, Shemya Air Force Base, Alaska, Director of Operations
1989-1995 Strategic Air Command Headquarters, Omaha, NE, Strategic Analyst
1978-1989 Air Force Institute of Technology, Dayton, OH, Student,
1978-1989 46th Flying Squadron, Marquette, MI, Instructor and Evaluator
1978-1989 71st Flying Unit, Marquette, MI, Instructor and Evaluator
1978-1989 8^{th} Flying Training Squadron, Enid, OK, Instructor Pilot

Honors and Awards

Legion of Merit, 2007
Defense Superior Service Medal, 2003
Meritorious Service Medal
Air Medal and Aerial Achievement Medal

Board Involvement

Served on Notre Dame's Faculty Senate, 2004-2005 academic year, member of the Student Affairs Committee
Serve on Congressional military service academies selection committee, 2003 to present
Served on Management Review Level Board; evaluated qualifications of military officers to determine promotion potential
Board of Directors for Military Officer's Association of America's local chapter

Personal and Other Education

Security Clearance: TS SCI
Squadron Officer's School (Air University) 1985
NATO Defense College (Rome, Italy) 1998
Group Commander's Course (Air University) 2001
Executive Flight Safety Course (Air University) 2001
Notre Dame Leadership Certificate 2006

Biographical Sketch: Ronald Scott Coppersmith

Professional Preparation

Michigan Technological University	Electrical Engineering	B.Sc., 1987
Indiana University South Bend	Management Development	Certificate, 2001
Lake Michigan College	Machine Tool Operation	Certificate, 2005

Appointments

2010-	Research Engineer, University of Notre Dame (Department of Civil Engineering & Geological Sciences)
2004-	Adjunct Faculty, Department of Technology, Ivy Tech Community College
2008-2010	Development/Simulation Senior Engineer, Foundation Brake Global Core Engineering, Robert Bosch LLC
2006-2008	Senior Test Engineer/Support to Manufacturing, Actuation Test Engineering, Robert Bosch LLC
1998-2006	Senior Engineering Supervisor, Medium/Heavy Truck Brake Test Engineering, Robert Bosch LLC
1993-1998	Staff Electrical Engineer, ABS Braking Systems, Allied Signal Corporation
1991-1993	Application Engineer, Philips Optical Components and Jukebox Applications, Enco Systems Corporation
1988-1991	Contract Project Engineer, Powertrain and Chassis Controls, Chrysler Motors Corporation
Summer 1986	Student Engineer, FWD Manual Transaxles Div., General Motors Corporation

Publications and Patents (not restricted by corporate confidentiality agreements)

Coppersmith, R. Scott, "Wireless Mobile Robotics - A Wi-Fi-Enabled System with a Mounted Webcam," *Circuit Cellar Magazine*, Circuit Cellar Inc**., 2009 (March Issue 224),** http://www.circuitcellar.com/magazine/224.html

Coppersmith, R. Scott, "A PC-Controlled Light Show—A Parallel-Communication Lighting Board with MIDI Potential," *Circuit Cellar Magazine,* Circuit Cellar Inc.**, 1991 (April/May Issue 20),** http://www.circuitcellar.com/library/toc.asp

Coppersmith, R. Scott, "WIZnet WiFi-PIC-BOT," *Circuit Cellar WIZnet iEthernet Design Contest,* Circuit Cellar Inc**., 2007,** http://www.circuitcellar.com/wiznet/winners/DE/001106.html

Coppersmith, R. Scott, "RaceRollers," *Circuit Cellar Design Stellaris Contest,* Circuit Cellar Inc**., 2006,** http://www.circuitcellar.com/designstellaris2006/winners/DE/LM1742.htm

Coppersmith, R. Scott, "MIDI Laser Show," *Circuit Cellar Microchip 16-bit Embedded Control Design Contest,* Circuit Cellar Inc**., 2007,** http://www.circuitcellar.com/microchip2007/winners/DE/MT2163.html

Coppersmith, R. Scott**, US Patent D355656, "Audio Mixer",The Enco Group, 1995,** http://www.freepatentsonline.com/D355656.html

Synergistic Activities

- I have been working with the Environmental Fluid Dynamics group at University of Notre Dame for six months learning, developing, and operating the meteorological equipment, including setup and operation of a field experiment using a SODAR and RASS system, and a small tower with sonic anemometers and data acquisition systems.
- I have started the construction of a small data acquisition system capable of logging the meteorological data from sonic and hot film anemometers for use in a UAV.
- I have over 20 years of experience working with embedded microprocessor systems and laboratory component testing, data acquisition, data reduction, and embedded systems/PC programming, prototype and fixture design and fabrication, along with test stand design, fabrication and programming.

Collaborators & Other Affiliations

Society of Automotive Engineers (SAE) **–** Member, 19 years

Naval Post Graduate School

Biographical Sketch: Joshua P. Hacker

Professional Preparation

University of California Los Angeles	Atmospheric Sciences	B.S. 1994
University of British Columbia	Atmospheric Sciences	M.Sc. 1996
University of British Columbia	Atmospheric Sciences	Ph.D. 2001

Appointments

9/2009 –Present Associate Professor, Naval Postgraduate School, Department of Meteorology
7/2007 – 9/2009 Scientist II, National Center for Atmospheric Research, Research Applications Lab
1/2004–6/2007 Scientist I, National Center for Atmospheric Research, Research Applications Lab
1/2002–12/2003 Post-Doctoral Fellow, National Center for Atmospheric Research, Advanced Studies Program
7/1995–11/2001 Research Assistant, University of British Columbia, Earth and Ocean Sciences

Publications

Most closely-related publications*:*

Hacker, J., S.-Y. Ha, C. Snyder, J. Berner, F. Eckel, E. Kuchera, M. Pocernich, S. Rugg, J. Schramm, and X. Wang, 2011: The U.S. Air Force Weather Agency's mesoscale ensemble: Scientific description and performance results. *Tellus A.* Accepted for publication.

Hacker, J., 2010: Spatial and temporal scales of boundary layer predictability in response to small-amplitude land-surface uncertainty. *J. Atmos. Sci*., 217-233.

Rostkier-Edelstein, D., and J. Hacker, 2010: The roles of surface-observation ensemble assimilation and model complexity for nowcasting PBL profiles: A factor separation analysis. *Wea. and Forecast.*, in press.

Hacker, J., and D. Rostkier-Edelstein, 2007: PBL state estimation with surface observations, a column model, and an ensemble Kalman filter. *Mon. Wea. Rev.*, **135**, 2958-2972.

Hacker, J., J. Anderson, and M. Pagowski, 2007: Improved vertical covariance estimates for ensemble-filter assimilation of near-surface observations. *Mon. Wea. Rev.*, **135**, 1021-1036.

Hacker, J., and C. Snyder, 2005: Ensemble Kalman filter assimilation of fixed screen-height observations in a parameterized PBL. *Mon. Wea. Rev.*, **133**, 3260-3275.

Five Other Publications:

Hacker, J., C. Snyder, S.-Y. Ha, and M. Pocernich, 2010: Linear and nonlinear response to parameter variations in a mesoscale model. *Tellus A.* Accepted for publication.

Pu, Z., and J. Hacker, 2009: Ensemble-based Kalman filters in strongly nonlinear dynamics. *Adv. Atmos. Sci.*, **26**, 373-380.

Thomas, S., J. Hacker, and J. Anderson, 2009: A robust formulation of the ensemble Kalman filter. *Quart. J. Royal Meteor. Soc.*, **135**, 507-531, DOI: 10.1002/qj.372.

Duane, G. S., and J. Hacker, 2008: Automatic parameter estimation in a mesoscale model without ensembles. *Nonlinear Time Series Analysis in the Geosciences*, R. Donner and S.

Barbosa, Eds., Springer-Verlag, 81-95.
Hacker, J., and D. Rife, 2007: A practical approach to sequential estimation of systematic error on near-surface mesoscale grids. *Wea. and Forecast.*, **22**, 1257-1273.

Synergistic Activities

- North American Lead, THORPEX International Grand-Global Ensemble, Limited Area Models
- Associate Editor, *Monthly Weather Review.*
- Development and maintenance of the Weather Research and Forecast Model (WRF) single-column model (SCM), used by students and researchers world-wide.
- Co-development of the WRF interface with the Data Assimilation Research Testbed (DART) system, used by students and researchers world-wide.
- Recent Peer Reviews: *Geophysical Research Letters, Journal of the Atmospheric Sciences, Journal of Geophysical Research, Journal of Hydrometeorolog, Monthly Weather Review, Quarterly Journal of the Royal Meteorological Society, Tellus A.*

Collaborators & Other Affiliations

Collaborators and Co-Editors (past 48 months):Anderson, Jeff; National Center for Atmospheric Research; Angevine, Wayne; National Oceanic and Atmospheric Administration; Berner, Judith; National Center for Atmospheric Research; Bondell, Howard; North Carolina State University; Delle Monache, Luca; National Center for Atmospheric Research; Eckel, Tony; National Weather Service; Ha, Soyoung; National Center for Atmospheric Research; Hansen, James; Naval Research Laboratory; Kaufman, Cari; University of California Berkeley; Knievel, Jason; National Center for Atmospheric Research; Liu, Yubao; National Center for Atmospheric Research; Pocernich, Matt; National Center for Atmospheric Research; Pu, Zhaoxia; University of Utah; Rife, Daran; National Center for Atmospheric Research; Rostkier-Edelstein, Dorita; Israel Institute for Biological Research; Snyder, Chris; National Center for Atmospheric Research; Stauffer, David; Pennsylvania State University; Thomas, Steven; Zeus Analytics; Weil, Jeff; University of Colorado; Wang, Xuguang; University of Oklahoma

Graduate and post-doctoral advisors: Graduate advisor: Roland Stull, University of British Columbia, Earth and Ocean Sciences; Post-doctoral Advisor: William Cooper (ASP director), National Center for Atmospheric Research

Graduate ***Advisor:*** Dr. Doug McCollor, University of British Columbia, Earth and Ocean Sciences and BC Hydro; Maj. Cedrick Stubblefield, Ph.D. Candidate, Naval Postgraduate School; Capt. William Ryerson, Ph.D. Student, Naval Postgraduate School

Biographical Sketch: Karl D. Pfeiffer

Professional Preparation

University of West Florida	Physics	BS 1988
Air Force Institute of Technology	Computer Science	MS 1994
North Carolina State University	Atmospheric Sciences	PhD 2001

Appointments

7/2010 – Present	Naval Postgraduate School, Visiting Assistant Professor
1/1989 – 9/2010	Air Force Weather officer (retired as Lt Col, 1 Sep 2010)

Related Publications

Laing, A., M. LaJoie, S. Reader, K. Pfeiffer, 2008: The influence of the El Nino—Southern Oscillation on cloud-to-ground lightning activity along the Gulf Coast: Part II: Monthly correlations, *Mon. Wea. Rev.*, **136**, 2544-2556.

Pfeiffer, K.D., M.L. Kaplan, and Y.-L. Lin, 2001: The mesoscale evolution of the early cyclogenesis of the March 1993 Storm of the Century, *Ninth Conference on Mesoscale Processes*, American Meteorological Society, Ft Lauderdale, FL (Aug 2001).

Kaplan, M. L., Y.-L. Lin, J. J. Charney, K. D. Pfeiffer, D. B. Ensley, D. S. DeCroix, and R. P. Weglarz, 2000: A terminal area PBL prediction system at Dallas-Fort Worth and its application in simulating diurnal PBL jets, *Bull. Amer. Meteor. Soc.*, **81,** 2179-2204.

Charney, J.J., M.L. Kaplan, Y.-L. Lin, K.T. Waight, K.D. Pfeiffer, J.A. Thurman, and C.M. Hill, 2000: Wind and temperature verification statistics for the Operational Terminal Area PBL Prediction System at the Dallas-Fort Worth International Airport, *Ninth Conference on Aviation, Range and Aerospace Meteorology*, American Meteorological Society, Orlando, FL (Sep 2000).

Pfeiffer, **K. D**., D.W. Quinn and C.E. Dungey, 1996: A numerical model to predict the fate of jettisoned aviation fuel, *AIAA Journal of Aircraft*, **33**, 352-363.

Recent Synergistic Activities

- Co-principal investigator in Adaptive Architectures for Command and Control (A2C2), a research project investigating information flow and collaborative structure; this project is funded by the Office of Naval Research. The 2011 experiment will use humans participating in a computer-mediated simulation to investigate the impact of uncertain and perishable information (that is, weather forecasts) in the human planning process.
- Principal investigator in Cloud Data Generation System (CDGS) study. This work supports systems engineering studies of platforms affected by clouds, producing both “true” cloud fields and forecasts with controllable quality. The operational application involves assessing the impact of poor forecasts, and the expected return on investment for improving cloud forecast quality.
- Developed geographic projection extensions to the widely used *wgrib* written by Wesley Ebisuzaki (Climate Prediction Center). This code has become part of the new *wgrib2* baseline.

Collaborators & Other Affiliations

Collaborators and Co-Editors (past 48 months): Charney, Joseph (Jay); USDA Forest Service; Dungey, Cliff; Ball Aerospace (Ohio); Ensley, Darrell; US Environmental Protection Agency; Hansen, James; Naval Research Laboratory; Hutchins, Susan; Naval Postgraduate School; Kaplan, Michael L; Desert Research Institute; Kemple, William; Naval Postgraduate School; Kleinman, David; Naval Postgraduate School, University of Connecticut; Lajoie, Mark (Lt Col); Headquarters Air Force; Laing, Arlene; National Center for Atmospheric Research; Lin, Yuh-Lang, North Carolina A&T University; Quinn, Dennis W; Air Force Institute of Technology; Regnier, Eva; Naval Postgraduate School; Thurman, James; US Environmental Protection Agency; Waight, Kenneth T; MESO, Inc.

Graduate and post-doctoral advisors: Graduate advisor: Michael Kaplan, Desert Research Institute; Yuh-Lang Lin, North Carolina Agricultural and Technical University

Graduate ***Advisor:*** Maj (Dr) Brian Belson, Air Force Weather Agency; Maj (Dr) Jungsoo Kim, Republic of Korea Air Force; Lt Col (Dr) Tara Leweling, Headquarters Air Force; Lt Col Rob LeeJoice, PhD Candidate, Naval Postgraduate School; CDR (Dr) John Looney, Naval Postgraduate School; Maj Scott Miller, PhD Candidate, Naval Postgraduate School; Capt William Ryerson, PhD Student, Naval Postgraduate School; Maj Cedrick Stubblefield, PhD Candidate, Naval Postgraduate School; Lt Col Carlos Vega, PhD Candidate, Naval Postgraduate School; Total graduate students advised: 9 PhD, over 50 MS in Information and Atmospheric Sciences

Biographical Sketch: Kurt E. Nielsen

Professional Preparation

University of Oklahoma	Meteorology	MS,1988
University of California, Davis	Atmospheric Science	BS,1985

Appointments

1999-Present	Naval Postgraduate School, Department of Meteorology, Research Associate
1990-1999	Naval Postgraduate School, Department of Meteorology, Meteorologist
1988-1990	Cooperative Institute for Mesoscale Meteorological Studies, Norman, OK, Research Associate

Related Publications

Durkee, P. A., R. E. Chartier, A. Brown, E. J. Trehubenko, C. Skupniewicz, and K. E. Nielsen, 2000: Composite ship track characteristics. *J. Atmos. Sci.*, 57, 2542-2553.

Coakley, J.A., P.A. Durkee, K. Nielsen, J.P. Taylor, S. Platnick, B.A. Albrecht, D. Babb, F.-L. Chang, W.R. Tahnk, C.S. Bretherton, and P.V. Hobbs, 2000: The appearance and disappearance of ship tracks on large spatial scales. *J. Atmos. Sci.*, 57, 2765-2778.

Durkee, P.A., K.E. Nielsen, P.J. Smith, P.B. Russell, B. Schmid, J.M. Livingston, B.N. Holben, C. Tomasi, V. Vitale, D. Collins, R.C. Flagan, J.H. Seinfeld, K.J. Noone, E. Öström, S. Gassò, D. Hegg, L.M. Russell, T.S. Bates, and P.K. Quinn, 2000: Regional aerosol optical depth characteristics from satellite observations: ACE-1, TARFOX and ACE-2 results. *Tellus*, 52B, 484-497.

Nielsen, K. E., R. A. Maddox and S. V. Vasiloff, 1994: The Evolution of Cloud-to-Ground Lightning within a Portion of the 10-11 June 1985 Squall Line. *Mon. Wea. Rev.*, 122, 1809-1817.

MacGorman, D. R. and K. E. Nielsen, 1991: Cloud-to-Ground Lightning in a Tornadic Storm on 8 May 1986. *Mon. Wea. Rev.*, 119, 1557-1574.

Biographical Sketch: James D. Doyle

Professional Preparation

The Pennsylvania State University	Meteorology	1991
The Pennsylvania State University	Meteorology	1986
The University of Wisconsin-Mil.	Atmospheric Science/Mathematics	1983

Appointments

1997-Present	Head, Mesoscale Modeling Section, Naval Research Laboratory, Monterey, CA.
1996	Visiting Research Scientist, European Centre for Medium Range Fcst., Reading, UK.
1993-1997	Research Scientist, Mesoscale Modeling Section, Naval Res. Lab., Monterey, CA.
1992	Postdoctoral Scholar, Global Change Distinguished Postdoc. Fellowship, Penn State.
1991	Research Associate and Instructor, Dept. of Meteorology at Penn. State.
1986	Visiting Research Scientist, National Meteorological Center.
1983-1991	Graduate Research Assistant, Dept. of Meteorology at Penn State.

Awards and Recognition Highlights

2008 Top Navy Scientists and Engineers of the Year Award
AMS Fellow
NRL Alan Berman Outstanding Research Pub. Award: 1996, 2002, 2003, 2004, 2007 (2 awards)
NRL 75th Anniversary Award for Innovation, 1998.

Synergistic Activities

- 10th AMS Mesoscale Processes Conference, 23-27 June 2003 (Conference Co-Chair).
- AMS Mesoscale Processes Committee, 1999-2003 (Chair, 2001-2003).
- Associate Editor, *Monthly Weather Review*, 2003.
- Autonomous Ocean Sampling Network (AOSN) II Executive Team, 2003-2006.
- CenCOOS Science Committee, 2004-2007.
- Editor, *Monthly Weather Review*, 2004-2009. (T-REX Special Issue Editor, 2007-present).
- MAP Gravity Wave Working Group, Chair, 1999-2003.
- MAP U.S. Scientific Steering Committee, 1997-2003.
- Mediterranean Experiment (MEDEX) Scientific Steering Committee, 2000-2004.
- Mesoscale Alpine Programme (MAP) International Scientific Steering Committee, 2003-2005.
- National Unified Operational Prediction Capability Infrastructure Committee, 2008-present.
- NCAR RAL Advisory Board and DTC Science Board, 2010-present
- Subject Matter Editor (Numerical Weather Prediction), *Bull. Amer. Meteor. Soc.*, 2003-2006.
- Terrain-Induced Rotor Experiment (T-REX) Scientific Steering Committee, 2002-present.
- Weather Research Model and Forecasting (WRF) Model Science Board, 2000-2004.

Relevant Publications (94 Peer-reviewed publications over career)

Doyle, J.D., V. Grubišić, W,O.J. Brown, S.F.J. De Wekker, A. Dörnbrack, Q. Jiang, S.D. Mayor, M. Weissmann, 2009: Observations and numerical simulations of subrotor vortices during T-REX. *J. Atmos. Sci.,* **66**, 1229-1249.

Doyle, J.D., and C.A. Reynolds, 2008: Implications of regime transitions for mountain wave breaking predictability. *Mon. Wea. Rev.*, **136**, 5211–5223.
Doyle, J.D., and D.R. Durran, 2007: Rotor and sub-rotor dynamics in the lee of three-dimensional terrain. *J. Atmos. Sci.*, **64**, 4202.
Doyle, J.D., and Q. Jiang, 2006: Observations and numerical simulations of mountain waves in the presence of directional wind shear. *Q.J. Roy. Meteor. Soc.*, **132**, 1877-1905.
Doyle, J.D., C. Amerault, C.A. Reynolds, 2007. Sensitivity analysis of mountain waves using an adjoint model. *Meteorologische Zeitschrift*, **16**, 607-620.
Doyle, J.D., M.A. Shapiro, Q. Jiang, D. Bartells, 2005: Large-amplitude mountain wave breaking over Greenland, **62**, 3106-3126.
Doyle, J.D., 2002: Coupled atmosphere-ocean wave simulations under high wind conditions. *Mon. Wea. Rev*., **130**, 3087-3099.
Grubišić, V., J.D. Doyle, J. Kuettner, S. Mobbs, R.B. Smith, C.D. Whiteman, R. Dirks, S. Czyzyk, S.A. Cohn, S. Vosper, M. Weissman, S. Haimov, S. De Wekker, L. Pan, F.K. Chow, 2008: The Terrain-Induced Rotor Experiment: An overview of the field campaign and some highlights of special observations. *Bull. Amer. Meteor. Soc.*, **89**, 1513-1533.
Jiang, Q., J.D. Doyle, T.H. Haack, M.J. Dvorak, C.L. Archer, M.Z. Jacobson, 2008: Exploring wind energy potential off the California Coast. *Geophys. Res. Letters*, **35**, L20819, doi:10.1029/2008GL034674.
Smith, R.B., J.D. Doyle, Q. Jiang, S.A. Smith, 2007: Alpine wave breaking: Lessons learned from MAP regarding mountain wave generation and breaking. *Q. J. Roy. Meteor. Soc.*, **133**, 917-936. DOI: 10.1002/qj.103.

Collaborators & Other Affiliations

Collaborators and Co-Editors (past 48 months): Clark Amerault (NRL), Nick Bond (U. Washington), Bill Brown (NCAR), Tina Chow (U.C. Berkeley), Steve Cohn (NCAR), Stan Czyzyk (NWS), Stephan DeWekker (U. Virginia), Clive Dorman (Scripps Inst.), Andreas Dörnbrack (DLR, Germany), Dale Durran (U. Wash.), Craig Epifanio (Texas A&M), Vanda Grubišić (U. Vienna), Sam Haimov (U. Wyoming), Shane Mayor (U. Calif., Chico), Peter Janssen (ECMWF), Qingfang Jiang (UCAR), Todd Lane (Monash Univ.), Steve Mobbs (Leeds Univ.), Laura Pan (NCAR), Julie Pullen (Stevens Inst.), Carolyn Reynolds (NRL), Mel Shapiro (NCAR, NOAA), Ron Smith (Yale, Univ.), Sam Smith (UK Metoffice), Joao Teixeira (JPL), Simon Vosper (UK Metoffice), Stuart Webster (UK Metoffice), Martin Weissmann (DLR, Germany), David Whiteman (U. Utah)

Graduate Advisor: Thomas T. Warner (NCAR) (M.S. and Ph.D.)

Post Doctoral Scientists, Contractors and NRL Staff: Clark Amerault (NRL), Brian Billings (NRC Postdoc), Sue Chen (NRL), Sasa Gabersek (UCAR), Tracy Haack (NRL), Eric Hendricks (NRC Postdoc), Richard Hodur (SAIC), Teddy Holt (NRL), Xiaodong Hong (NRL), Qingfang Jiang (UCAR), Hao Jin (NRL), Chi-Sann Liou (NRL), Paul May (CSC), Jason Nachamkin (NRL), Larry Oneill (NRC Postdoc), Alex Reinecke (NRL), Jerry Schmidt (NRL), William Thompson (NRL), Kevin Viner (NRC Postdoc), Shouping Wang (NRL)

University of California, Berkeley

Biographical Sketch: FOTINI KATOPODES CHOW

PROFESSIONAL PREPARATION

Harvard University	Engineering Science (summa cum laude)	B.S. 1998
Stanford University	Civil & Environmental Engineering	M.S. 1999
Stanford University	Civil & Environmental Engineering	Ph.D. 2004
Lawrence Livermore National Laboratory	Atmospheric sciences, post-doctoral researcher	Aug. 2004 – June 2005

APPOINTMENTS

Jul. 2005-present	Assistant Professor, Civil & Environmental Engineering, University of California, Berkeley
Aug. 2004-Jun. 2005	Consulting Assistant Prof., Civil & Environmental Engineering, Stanford

Selected honors and awards: NSF CAREER Award 2007-12; UC Berkeley Hellman Faculty Grant 2007; Postdoctoral Fellowship for Foreign Researchers, Kobe Univ., Japan Society for the Promotion of Science, May-June 2005; National Defense Science and Engineering Graduate Fellowship, 1998-2001; Stanford Graduate Fellowship (Honorary), 1998-2001; Phi Beta Kappa, 1997; Robert C. Byrd Honors Scholarship (U.S. Dept. of Education), 1994-98; National Science Scholarship Program, 1994-96; National Merit Scholarship, 1994-95.

SELECTED PUBLICATIONS (published articles available at http://www.ce.berkeley.edu/~chow)

Zhong, S. and F.K. Chow. 2010. Meso- and fine-scale numerical modeling over complex terrain: parameterizations and applications. In *Mountain Weather Research and Forecasting*, Meteorological Monograph, No. 56, ed. F. K. Chow, S. F. J. De Wekker, B. Snyder, *in press*. Boston: American Meteorological Society.

Lundquist, K.A., Chow, F.K., and J.K. Lundquist. 2010. An immersed boundary method for the Weather Research and Forecasting model. *Monthly Weather Review* **138**(3), 796-817.

Chow, F.K. and R.L. Street. 2009. Evaluation of turbulence closure models for large-eddy simulation over complex terrain: flow over Askervein Hill. *Journal of Applied Meteorology and Climatology* **48**(5), 1050–1065.

Schmidli, J., Poulos, G.S., Daniels, M.H. and F.K. Chow. 2009. External influences on nocturnal thermally driven flows in a deep valley. *Journal of Applied Meteorology and Climatology* **48**(1), 3-23.

Ludwig, F.L., Chow, F.K., and R.L. Street. 2009. Effect of subfilter-scale turbulence models and resolution on resolved velocity structure and momentum fluxes in simulations of neutral boundary layer flow. *Journal of Applied Meteorology and Climatology* **48**(6), 1161–1180.

Michioka, T. and F.K. Chow. 2008. High-resolution large-eddy simulations of scalar transport in atmospheric boundary layer flow over complex terrain. *Journal of Applied Meteorology and Climatology* **47**(12), 3150-3169.

Weigel, A.P., Chow, F.K., and M.W. Rotach. 2007. The effect of steep and complex topography on moisture exchange between the "surface" and the free atmosphere. *Boundary-Layer Meteorology* 125, 227-244.

Chow, F.K., Weigel, A.P., Street, R.L., Rotach, M.W., and M. Xue. 2006. High-resolution large-eddy simulations of flow in a steep Alpine valley. Part I: Methodology and sensitivity studies. *Journal of Applied Meteorology and Climatology* **45**(1), 63–86.

Chow, F.K., Street, R.L., Xue, M., and J.H. Ferziger. 2005. Explicit filtering and reconstruction turbulence modeling for large-eddy simulation of neutral boundary layer flow. *Journal of the Atmospheric Sciences* **62**(7), 2058-2077.

Gullbrand, J. and F.K. Chow. 2003. The effect of numerical errors and turbulence models in LES of channel flow, with and without explicit filtering. *Journal of Fluid Mechanics* **495**, 323-341.

SYNERGISTIC ACTIVITIES

- Developed strategies for grid nesting from mesoscale to sub-kilometer resolution over complex terrain, including choice of turbulence closure and land-surface forcing. Made quantitative comparisons to field data from the MAP-Riviera Project in Switzerland and the Terrain-induced Rotor Experiment in Owens Valley. Explained mechanisms for re-stabilization of valley atmosphere even under strong radiative forcing.
- Developed and tested turbulence models and improved boundary conditions for large-eddy simulation of the atmospheric boundary layer. Demonstrated improved simulations with new velocity reconstruction subfilter-scale turbulence models for flow over flat and complex terrain.
- Editor of new mountain meteorology monograph through the American Meteorological Society (AMS), with 12 invited chapters. Wrote comprehensive chapter on mesoscale numerical modeling over complex terrain. Co-chair of Mountain Weather Workshop in August 2008 to bridge gap between research and forecasting.
- Member of Mountain Meteorology Committee (2006-08) and Boundary Layers and Turbulence Committee (2009-present) of the AMS Scientific and Technological Activities Commission. Served as reviewer for ~10 journal articles for several different journals each year. Gave numerous invited seminars and conference presentations across the country on current research.
- Developed new introductory graduate course on numerical modeling for environmental flows at UC Berkeley. Introduced Matlab as a computational tool here and in an undergraduate fluid mechanics class. Advising four PhD students on various projects for LES of environmental flows. Advised under-represented minority engineering student in 2009 through SUPERB summer program at UC Berkeley. Member of CEE faculty search committees, CEE department curriculum and outreach/enrollment committees.

COLLABORATORS & OTHER AFFILIATIONS

Collaborators: E. Balaras (U. Maryland), S. Chan (LLNL), S. De Wekker (U. Virginia), S. Kollet (U. Bonn), B. Kosović (NCAR), F. Ludwig (Stanford), J. Lundquist (CU Boulder), R. Maxwell (Colorado School of Mines), J. Mirocha (LLNL), T. Michioka (CRIEPI, Japan), M. Rotach (MeteoSwiss), J. Schmidli (ETH Zurich), B. Snyder (Met. Service Canada), R. Street (Stanford), A. Weigel (MeteoSwiss), M. Xue (U. Oklahoma), S. Zhong (Mich. State U.).

Doctoral and post-doctoral advisors: Doctoral advisor: R.L. Street (Stanford); Post-doctoral advisors: B. Kosović and G. Sugiyama (LLNL).

Thesis advisor and Postgraduate-scholar sponsor: M. Daniels (EPFL, Switzerland), L. Goodfriend, K. Lundquist (LLNL), N. Marjanovic, J. Rihani, B. Zhou. T. Michioka (Post-doc, now CRIEPI, Japan). Current Ph.D. candidates: 4; Post-doctoral students being sponsored currently: 0

University of Utah

Biographical Sketch: Eric R. Pardyjak

Professional Preparation

Michigan State University	Mechanical Engineering	B.S., 1994
University of Wisconsin-Madison	Mechanical Engineering	M.S., 1996
Arizona State University	Mechanical Engineering	Ph.D., 2001
Los Alamos National Laboratory	Transport & Dispersion	1999-2001

Appointments

2010- Director of Graduate Studies/Associate Chair, Dept. of Mech. Eng. Univ. of Utah
2009-10 Visiting Professor, École Polytechnique Fédérale de Lausanne, Switzerland
2007- Associate Professor, Dept. of Mechanical Engineering, University of Utah
2007- Adjunct Associate Professor, Department of Atmos. Sciences, University of Utah
2001-07 Assistant Professor, Department of Mechanical Engineering, University of Utah
2006-07 Adjunct Assistant Professor, Department of Atmos. Sciences, University of Utah

Publications

Five most closely related to proposal project:

Nadeau, D.F., E. R. Pardyjak, C. W. Higgins, H. J. S. Fernando, and M. B. Parlange, A simple model for the afternoon and early-evening decay of turbulence over different land surfaces, Boundary-Layer Meteor., under revision, June 2010

Pardyjak, E.R., H.J.S. Fernando, J.C.R Hunt, A.A. Grachev and Anderson, J., A Case Study of the Development of Nocturnal Slope Flows in a Wide Open Valley and Associated Air Quality Implications, Meteorologische Zeitschrift, 18(1), 1-17, 2009.

Pardyjak, E.R., Monti, P., and Fernando, H.J.S. (2002). Flux Richardson number measurements in stable atmospheric shear flows. J. Fluid. Mech. 459, 307-316.

Ramamurthy, R., and Pardyjak, E.R., Toward understanding the behavior of carbon dioxide and surface energy fluxes in the semi-arid Salt Lake Valley, Utah, USA. Atmospheric Environment. In press doi:10.1016/j.atmosenv.2010.09.049

Ramamurthy, P., Pardyjak, E.R., and Klewicki, J.C. (2007). Observations of the Effects of Atmospheric Stability on Turbulence Statistics Deep within an Urban Street Canyon. J. Appl. Meteorol. & Climatology, 46, 2074-2085.

Five other significant publications:

Pataki, D.E., Emmi, P.C., Forster, C.B., Mills, J.I., Pardyjak, E.R., Peterson, T.R., Thompson, J.D., and Dudley-Murphy, E. (2009). An integrated approach to improving fossil fuel emissions scenarios with urban ecosystem studies. Ecological Complexity, 6, 1-14.

Pataki, D.E., Tyler, B.J., Peterson, R.E., Nair, A.P., Steenburgh, W.J. and Pardyjak, E.R. (2005). Can carbon dioxide be used as a tracer of urban atmospheric transport? J. Geophys. Res., 110, D15102.

Holmes, H.A., Pardyjak, E.R., Tyler, B.J., and Peterson, R.E. (2009). Investigation of the Time Evolved Spatial Distribution of Urban PM2.5 Concentrations and Aerosol Composition During Episodic High PM Events in Yuma, AZ. Atmospheric Environment, 43, 4348-4358.

Singh, B., Hansen, B., Brown, M.J., and Pardyjak, E.R. (2008). Evaluation of the QUIC-URB fast response urban wind model for a cubical building array and wide building street canyon. Environmental Fluid Mechanics. 8, 281-312.

Nelson, M.A., Pardyjak, E.R., Brown, M.J., and Klewicki, J.C. (2007). Spectral properties of the wind field within the Oklahoma City Park Avenue street canyon: Part II: Spectra, Cospectra, and Quadrant, Analyses, J. Appl. Meteorol. & Climatology, 46, 2055-2073.

Synergistic Activities

- Collaborative Field Experiments - Pardyjak has worked together with multiple defense agencies from the U.S., Canada, and U.K. as well as National Laboratories and Universities to produce high resolution field experiment data sets used to develop improved understanding and modeling capabilities for agent dispersion in urban areas. Experiments have included the Mock Urban Setting Tests (MUST) at the Dugway Proving Ground, the URBAN 2000 field campaign in Salt Lake City, UT and the JU2003 urban dispersion field campaign in Oklahoma City, OK. Additional field research has been done in the area of transport and dispersion. This work has involved collaboration with multiple universities, National Laboratories and various governmental agencies. Experiments have included: the Swiss Slope Experiment at La Fouly (SELF) investigating the interaction of thermal circulation patterns and turbulent fluxes on steep mountain slopes, Mercury deposition to the Great Salt Lake, the Urban Trace-gas Emission Study (UTES), the Vertical Transport and Mixing Experiment (VTMX), the Phoenix Air-Flow Experiments (PAFEX-I and II), and multiple trans-border air pollution field experiments.
- Multi-disciplinary Research - Pardyjak has collaborated with aerosol chemists, biologists and meteorologists at multiple universities to provide new understanding of reaction, transport and dispersion of pollution. Pardyjak has also worked with members of the Health and Sports Science group at the University of Utah to develop improved experimental measuring techniques.
- Undergraduate Research – Pardyjak has made a strong effort to incorporate undergraduate students into his research program. Since August 2001, Pardyjak has supervised 26 undergraduates working on a variety of environmental fluid mechanics projects. Eleven of the students have continued on to graduate school. Some of these students have also been selected to present their research at the National Conference on Undergraduate Research.

Collaborators & Other Affiliations

Collaborators: J. Steenburgh, J. Veranth, M. Metzger, M. Minor, J. Hollerbach, J. Horel, S. Burian, D. Bowling, C.D. Whiteman, S. Hoch: University of Utah, C. Biltoft: Adiabat Services, D. Pataki: UC-Irvine, D. Nadeau, C. Higgins, M. Parlange: École Polytechnique Fédérale de Lausanne, M. Brown: LANL, P. Kastner-Klein:University of Oklahoma, H.J.S Fernando: Notre Dame, P. Willemsen: University of Minnesota-Duluth.

Graduate and Postdoctoral Advisors: Ph.D. - H.J.S. Fernando, Arizona State University, M.S. - C.J. Rutland, University of Wisconsin – Madison, Postgraduate - M.J. Brown, Los Alamos National Laboratory

Thesis Advisor and Postgraduate-Scholar Sponsor: Current: P. Ramurthy (PhD), B. Singh (PhD), S. Speckart (PhD), B. Addepalli (PhD), T. Booth (MS), C. Nielson (MS); Graduated: H. Holmes (PhD), S. Kulkarni (PhD), A. Gowardhan (PhD/MS), M. Nelson (PhD), N. Bagal (MS), P. Ramurthy (MS), C. Neslen (MS), B. Singh (MS), M. Deaver (MS), A. Uzma (MS), T. Falvaloro (MS), T. Dwyer (ME), J. Kiran (MS), H. Oldroyd (MS), C. Allen (MS); Total: 8 Ph.D., 13 M.S.

Biographical Sketch: Sebastian W. Hoch

Professional preparation

ETH Zurich, Switzerland,	Diploma in Natural Sciences, 1999
ETH Zurich, Switzerland,	Ph.D. Natural Science, 2006

Professional affiliations

2009 - present	University of Utah, Atmospheric Sciences	Research Assistant Professor
2006–2009	University of Utah, Atmospheric Sciences	Research Associate

Appointments

Dr. Hoch has been a research assistant professor in the Atmospheric Sciences Department at the University of Utah since July 2009. He specializes in complex terrain, radiative transfer and boundary layer meteorology, meteorological field studies and instrumentation, and is co-teaching instrumentation classes and field courses. He has investigated thermally driven flows and stable boundary layer development and evolution in and around Arizona's Meteor Crater, the Owens Valley, near canyon exits in the Wasatch Mountains, at Utah's Dugway Proving Grounds, and in Utah's Kennecott open pit copper mine. His special interests are radiative transfer and the topographic influences on radiation and energy budgets. He conducted observations of radiative flux divergence on the Greenland Ice Sheet and inside Arizona's Meteor Crater and is modeling radiative heating and cooling in complex terrain using a Monte Carlo radiative transfer model. Dr. Hoch was a member of the ETH Greenland Summit Expedition (2000-2002) and was a participant and radiative experiment designer in the Meteor Crater Experiment (METCRAX 2006). He led a follow-on meteorological experiment at the Meteor Crater in 2009. His postdoctoral studies at the University of Utah were financed by a Swiss National Science Foundation fellowship for prospective researchers under the working title “Radiative effects on cold air pool evolution”. As a co-principal investigator for the Army research Office, he conducted parametric simulations of the effects of valley and basin terrain on radiative transfer.

Publications

Hoch, S. W., C. D. Whiteman, and B. Mayer, 2010: Radiative cooling within idealized valleys and basins modeled with a 3D radiative transfer model. *J. Appl. Meteor. Climat*. In preparation.

Lehner, M., C. D. Whiteman, and S. W. Hoch, 2010: Diurnal cycle of thermally driven cross-basin winds in Arizona's Meteor Crater. *J. Appl. Meteor. Climatol*. In press.

Haiden, T., C. D. Whiteman, S. W. Hoch, and M. Lehner, 2010: A mass-flux model of nocturnal cold air intrusions into a closed basin. *J. Appl. Meteor. Climatol.* In press.

Whiteman, C. D., S. W. Hoch, M. Lehner, and T. Haiden, 2010: Nocturnal cold air intrusions into Arizona's Meteor Crater: Observational evidence and conceptual model. *J. Appl. Meteor. Climatol.*, **49**, 1894-1905.

Hoch, S. W., and C. D. Whiteman, 2010: Topographic effects on the surface radiation balance in and around Arizona's Meteor Crater. *J. Appl. Meteor. Climat.*, **49**, 1114-1128.

Mayer, B., S. W. Hoch, and C. D. Whiteman, 2010: Validating the MYSTIC three-dimensional radiative transfer model with observations from the complex topography of Arizona's Meteor Crater. *Atmos. Chem Phys.*, **10**, 8685-8696. doi:10.5194/acp-10-8685-2010.

Whiteman, C. D., S. Hoch, and G. Poulos, 2009: Evening temperature rises on valley floors and slopes: Their causes and their relationship to the thermally driven wind systems. *J. Appl. Meteor. Climat.*, **48**, 776-788.

Whiteman, C. D., A. Muschinski, S. Zhong, D. Fritts, S. W. Hoch, M. Hahnenberger, W. Yao, V. Hohreiter, M. Behn, Y. Cheon, C. B. Clements, T. W. Horst, W. O. J. Brown, and S. P. Oncley, 2008: METCRAX 2006 – Meteorological experiments in Arizona's Meteor Crater. *Bull. Amer. Meteor. Soc*., **89**, 1665-1680.

Hoch, S. W., P. Calanca, R. Philipona and A. Ohmura, 2007: Year-round observations of longwave radiative flux divergence in Greenland, 2007. *J. Appl. Meteor. Climat.*, **46**, 9, 1469-1479, doi: 10.1175/JAM2542.1

Stohl, A., E. Andrews, J. F. Burkhart, C. Forster, A. Herber, S. W. Hoch, D. Kowal, C. Lunder, T. Mefford, J. A. Ogren, S. Sharma, N. Spichtinger, K. Stebel, R Stone, J. Ström, K. Tørseth, C. Wehrli, K. E. Yttri, 2006: Pan-Arctic enhancements of light absorbing aerosol concentrations due to North American boreal forest fires during summer. *J. Geophys. Res.*, **111**, D22214, doi:10.1029/2006JD007216

Dissertation

Hoch, S. W., 2006: Radiative flux divergence in the surface boundary layer. A study based on observations at Summit, Greenland. ETH Dissertation 16194. http://e-collection.ethbib.ethz.ch/cgi-bin/show.pl?type=diss&nr=16194

Synergistic Activities

- Internship at CMDL, NOAA, 1997, supervised by Dr. E. G. Dutton
- Univ. of Utah. Dept. of Engineering: Invited seminar, 2006
- Member, Amer. Meteor. Soc (2006-present), Europ. Geophys. Union (2004-present)

Collaborators & Other Affiliations

Collaborators: Behn, M. (U. Mass.-Amherst), Brown, W. (NCAR), Cheon, Y. (U. Mass.-Amherst), Clements, C. B. (San Jose State), Fritts, D. (CORA, Boulder), Haiden, T. (ZAMG), Hahnenberger, M. (U. Utah), Hohreiter, V. (U. Mass.-Amherst), Horst, T. (NCAR), Kossmann, M. (DWD, Germany), Lehner, M. (U. Utah), Lund, T. (CORA, Boulder), Mayer, B. (U. Munich), Muschinski, A. (U Mass-Amherst), Ohmura, A. (ETH Zurich, Switzerland), Oncley, S. (NCAR), Philipona, R. (MeteoSwiss, Switzerland), Poulos, G. (Clipper Wind Power), Savage, L. (Mich. State U.), Stohl, A., NILU, Norway, Whiteman, C. D. (U. Utah), Yao, W. (Mich. State U.), Zhong, S. (Michigan State U.)

Graduate Advisor: Prof. Dr. Atsumu Ohmura, ETH Zurich, Switzerland

Postdoctoral Advisor: Dr. C. David Whiteman, University of Utah

Biographical Sketch: Zhaoxia Pu

Professional preparation

Ph.D., 1997, Meteorology, Lanzhou University (Thesis research completed at NCEP, USA)

Professional Appointment

2010- present Associate Professor, Department of Atmospheric Sciences, University of Utah
2004- 2010 Assistant Professor, Department of Atmospheric Sciences, University of Utah
2000- 2004 Associate Research Scientist, Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County. Worked at NASA Goddard Space Flight Center, Greenbelt, MD
1998-2000 Research Scientist, Universities Space Research Association. Worked at NASA Goddard Space Flight Center, Greenbelt, MD
1997-1998 UCAR Postdoctoral Fellow at Environmental Modeling Center, NCEP/NOAA, Camp Springs, MD.

Selected Publications

(Prof. Pu was authored on 1 translated book and over 40 peer-reviewed journal articles)

Ma, M., Z. Pu, S. Wang and Q. Zhang, 2010: Characteristics and numerical simulations of extremely high atmospheric boundary layer heights over a arid region in northwest of China. *Boundary Layer Meteorology*, (Conditionally accepted).

Pu, Z., and L. Zhang, 2010: Validation of AIRS temperature and moisture profiles over tropical oceans and their impact on numerical simulations of tropical cyclones, *J. Geophs. Res.-Atmosphere*, (in press)

Snyder, A., Z. Pu, and C. A. Reynolds, 2010: Impact of stochastic convection on ensemble forecasts of tropical cyclone development. *Mon. Wea. Rev.*, (In press).

Snyder, A., Z. Pu and Y. Zhu, 2010: Predictability of the east Atlantic tropical cyclone genesis in NCEP global ensemble: Case studies during NASA African monsoon multi- disciplinary analyses. *Wea. Forecasting*, 25, 1397-1411.

Pu Z, X. Li and J. Sun, 2009: Impact of airborne Doppler radar data assimilation on the numerical simulation of intensity changes of Hurricane Dennis near a landfall. *J. Atmos. Sci.*, **66**, 3351-3365.

Pu, Z., J. Hacker, 2009: Ensemble-based Kalman filters in strongly nonlinear dynamics. *Advances in Atmos. Sci.*, **26**, 373-380.

Li, X. and Z. Pu, 2008: Sensitivity of numerical simulation of early rapid intensification of Hurricane Emily (2005) to cloud microphysical and planetary boundary layer parameterizations. *Mon. Wea. Rev.*, 136, 4819-4838

Pu, Z., X. Li, C. Velden,S. Aberson, W. T. Liu, 2008: Impact of aircraft dropsonde and satellite wind data on the numerical simulation of two landfalling tropical storms during TCSP. *Wea. Forecasting* 23, 62-79

Pu, Z.-X., and E. Kalnay, 1999: Targeting observation with the quasi-inverse linear and adjoint NCEP global models: performance during FASTEX. *Q. J. Roy. Meteorol. Soc.*, **125**, 3329-3338.

Pu, Z.-X., S. J. Lord, and E. Kalnay, 1998: Forecast sensitivity with dropwindsonde data and targeted observations. *Tellus*, **50A**, 391-410.

Pu, Z.-X., E. Kalnay, J. Sela, and I. Szunyogh, 1997: Sensitivity of forecast error to initial conditions with a quasi-inverse linear method. *Mon. Wea. Rev.*, **125**, 2479-2503

Field Program Participation

2008/Aug-Sep. Mission support scientist, International TPARC/TCS08 field program, Monterey Operational Center.

2005-6 Research Co-Investigator, NASA African Monsoon Multidisciplinary Analyses (NAMMA) and NASA Tropical Cloud System Processes (TCSP) field programs

1997/Jan-Feb Participant, international FASTEX field program. Performed real time targeting experiments with adjoint and quasi-inverse linear methods of NCEP global model

Courses Taught

Atmos 6500/5500 Numerical Weather Prediction
Atmos 5110 Dynamic Meteorology
Atmos 5000/3100 Introduction to Atmospheric Sciences

Synergistic Activities

Member of American Meteorological Society (AMS) since 1994
Fellow of Royal Meteorological Society (RMS) since 2010
Associate Fellow of Royal Meteorological Society (RMS) 1997-2010
Member of American Geophysical Union (AGU) since 1998

Selected Professional Services

2010-present Member, American Meteorological Society annual meeting oversight committee

2006-present Member, American Meteorological Society (AMS) Weather Analysis and Forecasting Committee

2010-2011 Co-chair (with Carolyn Reynolds), upcoming AMS 24nd conference on weather and forecasting and 20th conference on numerical weather prediction, January 23-27, 2011, Seattle, WA.

2006-2007 Associate Editor, *Monthly Weather Review*

2007 Co-chair (with John Horel), AMS 22nd conference on weather and forecasting and 18th conference on numerical weather prediction, June 25-29, 2007, Park City, UT,

Selected Honors and Awards

2006 Early Career Scientist Assembly Visiting Research Award, NCAR

2000 Outstanding Achievement Award**,** Code 912, Laboratory for Atmospheres, NASA Goddard Space Flight Center

1993 1st prize for science and technology advancement and outstanding young meteorologist, Chinese Meteorological Society, Gansu Chapter

Biographical Sketch: W. James Steenburgh

Professional Preparation

The Pennylvania State University	Meteorology	B.S. 1989
University of Washington	Atmospheric Sciences	Ph.D. 1995

Appointments

2005 – present	Chair, Dept. of Atmospheric Sciences (formerly Meteorology), Univ. of Utah
2006 – present	Professor, Dept. of Atmospheric Sciences, University of Utah
2001 – 2006	Associate Professor, Dept. of Meteorology, University of Utah
2002	Visiting Professor, University at Albany, State University of New York
2002	Head, Mesoscale Modeling Group, 2002 Olympic Winter Games
1995 – 2001	Assistant Professor, Dept. of Meteorology, University of Utah
1995	Research Associate, Dept. of Atmospheric Sciences, University of Washington
1989 – 1995	Research Assistant, Dept. of Atmospheric Sciences, University of Washington
1988	Intern Meteorologist, National Weather Service, Albany, NY

Publications

Five publications most closely related to the proposed project:

Steenburgh, W. J., D. M. Schultz, B. Snyder, and M. Meyers, 2010: Bridging the gap between operations and research to improve weather prediction in mountains regions. Mountain Weather and Forecasting, Meteor. Monogr. Amer. Meteor. Soc., in review. [Available at http://www.inscc.utah.edu/~steenburgh/papers/gap.pdf].

Steenburgh, W. J., C. R. Neuman, G. L. West, and L. F. Bosart, 2009: Discrete frontal propagation over the Sierra-Cascade Mountains and Intermountain West. *Mon. Wea. Rev.*, **137**, 2000-2020.

Cheng, W. Y. Y., and W. J. Steenburgh, 2007: Strengths and weaknesses of MOS, running-mean bias removal, and Kalman filter techniques for improving model forecasts over the western U. S. *Wea. Forecasting*, 22, 1304-1318.

Cheng, W. Y. Y., and W. J. Steenburgh, 2005: Evaluation of surface sensible weather forecasts by the WRF and Eta models over the western United States. *Wea. Forecasting*, **20**, 812-821.

Hart, K. A., W. J. Steenburgh, and D. J. Onton, 2005: Model forecast improvements with decreased horizontal grid spacing over fine-scale Intermountain orography during the 2002 Olympic Winter Games. *Wea. Forecasting*, **20**, 558-576.

Five other significant publications:

West, G. L., and W. J. Steenburgh, 2010: Life cycle and mesoscale frontal structure of an Intermountain cyclone. *Mon. Wea. Rev.*, **138**, 2528-2545.

Jeglum, M. E., W. J. Steenburgh, T. P. Lee, and L. F. Bosart, 2010: Multi-reanalysis climatology of Intermountain cyclones. *Mon. Wea. Rev.*, **138**, 4035-4053.

Shafer, J. C., and W. J. Steenburgh, 2008: Climatology of strong Intermountain cold fronts. *Mon. Wea. Rev.*, **136**, 784-807.

Steenburgh, W. J., 2003: One hundred inches in one hundred hours – evolution of a Wasatch Mountain winter storm cycle. *Wea. Forecasting*, **18**, 1018-1036.

Steenburgh, W. J., D. M. Schultz, and B. A. Colle, 1998: The structure and evolution of gap outflow over the Gulf of Tehuantepec, Mexico. *Mon. Wea. Rev.*, **126**, 2673-2691.

Synergistic activities

Societal service: Lead Author, *Climate Science and Utah: The Scientific Consensus*. Report to Utah Gov. Jon Huntsman, 2007.

Professional service: Chair, UCAR/Unidata User Committee 2003-2006; Member 1998-2006

Development of curricular materials and pedagogical methods:

Co-author, two chapters of the forthcoming *AMS Mountain Weather and Forecasting Monograph* (Meyers and Steenburgh 2009; Steenburgh et al. 2009).

Orf, L. G. Lackman, C. Herbster, A. Krueger, E. Cutrim, T. Whitaker, J. Steenburgh, and M. Voss, 2007: Models as educational tools. *Bull. Amer. Meteor. Soc.*, **88**, 1101-1104.

Steenburgh, W. J., 2004: Dynamics and microphysics of cool-season orographic storms. COMET Meteorological Education & Training (MetEd) Program Webcast. http://deved.meted.ucar.edu/norlat/orographic/index.htm.

Collaborators and other affiliations

Collaborators and co-editors: Lance Bosart (University at Albany), Brian Colle (SUNY-Stony Brook), Elen Cutrim (Western Michigan), Chris Herbster (Embry-Riddle), David Kingsmill (NOAA/ESRL), Anton Krueger (University of Iowa), Gary Lackman (NC State), Neal Laird (Hobart and William Smith Colleges), Mike Meyers (NOAA/NWS), John Monteverdi (San Francisco State), Amit Nair (University of Utah), Leigh Orf (Central Michigan), Eric Pardyjak (University of Utah), Diane Pataki (UC-Irvine), Richard Peterson (University of Utah), David Schultz (FMI-Finland), Brad Snyder (MSC/Canada), Bonnie Tyler (University of Utah), Michael Voss (San Jose State), Tom Whitaker (University of Wisconsin)

Graduate and postdoctoral advisors: Clifford F. Mass (University of Washington)

Thesis advisor and postgraduate scholar sponsor: W. Cheng (NCAR), J. Cox (Garrad Hasan), J. Shafer (Lyndon State), G. West (University of British Columbia), K. Hart (Air Force Academy), R. Grandy (Utah Department of Environmental Quality), A. Siffert (ACE USA), D. Onton (NOAA/NWS), T. Blazek (US Air Force), S. Halvorson (Dugway Proving Grounds), K. Cook (NOAA/NWS), C. Neuman (NOAA/NWS), M. Jeglum (Dugway Proving Grounds), T. Alcott (University of Utah), K. Yeager (University of Utah), J. Massey (University of Utah)

Biographical Sketch: C. David Whiteman

Professional Preparation

Colorado State University	Physical Science, with high distinction	B.S., 1968
University of Michigan	Meteorology	M.S., 1970
Colorado State University	Atmospheric Science	Ph.D., 1980

Appointments

2005 –	Research Professor, Dept. of Atmospheric Sciences (formerly Meteorology), Univ. of Utah
1980 – 2005	Senior Research Scientist, DOE's Pacific Northwest National Laboratory (PNNL)

He served as an adjunct professor of Environmental Science at Washington State University, serves on various national and international committees, and has taught short courses on mountain meteorology and scientific writing. He has been a visiting scientist, professor or fellow at Austria's Central Institute for Meteorology & Geodynamics, at Switzerland's Paul Scherrer Institute, and at the Universities of Freiburg, Vienna, Canterbury, Berne, Munich, and Innsbruck. Before working at PNNL he was a presidential intern at NOAA's Environmental Research Laboratory, an Air Force weather officer, and a meteorological technician.

Publications

Five recent publications:

Whiteman, C. D., S. W. Hoch, M. Lehner, and T. Haiden, 2010: Nocturnal cold air intrusions into Arizona's Meteor Crater: Observational evidence and conceptual model. *J. Appl. Meteor. Climatol.*, **49**, 1894-1905.

Hoch, S. W., and C. D. Whiteman, 2010: Topographic effects on the surface radiation balance in and around Arizona's Meteor Crater. *J. Appl. Meteor. Climat.*, **49**, 1114-1128.

Mayer, B., S. W. Hoch, and C. D. Whiteman, 2010: Validating the MYSTIC three-dimensional radiative transfer model with observations from the complex topography of Arizona's Meteor Crater. *Atmos. Chem Phys*., **10**, 8685-8696. doi:10.5194/acp-10-8685-2010.

Schmidli, J., B. Billings, F. K. Chow, J. Doyle, V. Grubišić, T. Holt, Q. Jiang, K. A. Lundquist, P. Sheridan, S. Vosper, S. F. J. de Wekker, C. D. Whiteman, A. A. Wyszogrodzki, and G. Zängl, 2010: Intercomparison of mesoscale model simulations of the daytime valley wind system. *Mon. Wea. Rev*. In press.

Lehner, M., C. D. Whiteman, and S. W. Hoch, 2010: Diurnal cycle of thermally driven cross-basin winds in Arizona's Meteor Crater. *J. Appl. Meteor. Climatol*. In press.

Five other significant publications:

Zardi, D., and C. D. Whiteman, 2010: Diurnal Mountain Wind Systems. Chapter 2 in: Mountain weather research and forecasting (Chow, F. K., S. F. J. DeWekker, and B. Snyder (Eds.)). *Meteor. Monogr.* To be published by Amer. Meteor. Soc., Boston, MA. Accepted.

Whiteman, C. D., 2000: *Mountain Meteorology: Fundamentals and Applications*. Oxford University Press, New York, 355pp.

Whiteman, C. D., 1990: Observations of Thermally Developed Wind Systems in Mountainous Terrain. Chapter 2 in Atmospheric Processes Over Complex Terrain, (W. Blumen, Ed.),

Meteorological Monographs, **23**, no. 45. American Meteorological Society, Boston, Massachusetts, 5-42.

Haiden, T., C. D. Whiteman, S. W. Hoch, and M. Lehner, 2010: A mass-flux model of nocturnal cold air intrusions into a closed basin. *J. Appl. Meteor. Climatol.* In press.

Whiteman, C. D., A. Muschinski, S. Zhong, D. Fritts, S. W. Hoch, M. Hahnenberger, W. Yao, V. Hohreiter, M. Behn, Y. Cheon, C. B. Clements, T. W. Horst, W. O. J. Brown, and S. P. Oncley, 2008: METCRAX 2006 – Meteorological experiments in Arizona's Meteor Crater. *Bull. Amer. Meteor. Soc.*, **89**, 1665-1680.

Synergistic Activities

AMS Fellow; AMS Certified Consulting Meteorologist #187; Head, AMS Mountain Meteorology Committee, 2006-2009; Head, UU Mountain Meteorology Group; Editor, *Journal of Applied Meteorology* (1998-2000); Member, American, German and Austrian Meteorological Societies; Chester L. Cooper Mentor of Year Award, PNNL (2003); Fitzner-Eberhard Lab Director's Award for Outstanding Contributions. to Science and Engineering Education (2001); instructor for mountain meteorology & technical writing short courses in the U.S., Germany, Austria, New Zealand, Switzerland & Italy. Co-chair, AMS 14th Conf. on Mountain Meteorology, Aug-Sep 2010, Lake Tahoe area, CA.

Collaborators and Other Affiliations (last 48 months):

Collaborators and Co-Editors: Baumann, K. (ZAMG, Vienna), Behn, M. (U. Mass.-Amherst), Bian, X. (USFS, E. Lansing), Bica, B. (ZAMG), Billings, B. (NPS), Brown, W. (NCAR), Cheon, Y. (U. Mass.-Amherst), Chow, F. K. (UC-Berkeley), Clements, C. B. (San Jose State), Cohn, S. (NCAR), Czyzyk, S. (NWS-Las Vegas), De Wekker, S. F. J. (U. Virginia), Dirks, R. (NCAR), Dorninger, M. (U. Vienna), Doyle, J. (NPS), Eisenbach, S. (U. Vienna), Fritts, D. (CORA, Boulder), Fu, P. (Lanzhou U., China), Grubisic, V. (U. Vienna), Haiden, T. (ZAMG), Hahnenberger, M. (U. Utah), Haimov, S. (U. Wyoming), Hoch, S. (U. Utah), Hohreiter, V. (U. Mass.-Amherst), Holt, T. (NCAR), Holzer, A. (U. Vienna), Horel, J. (U. Utah), Horst, T. (NCAR), Jiang, Q. (NPS), Kossmann, M. (DWD, Germany), Kuettner, J. (NCAR), Lehner, M. (U. Utah), Li, J. (Michigan State U.), Lundquist, K. (UC-Berkeley), Mayer, B. (U. Munich), Mobbs, S. (U. Leeds, UK), Mursch-Radlgruber (BOKU, Vienna), Muschinski, A. (U Mass-Amherst), Oncley, S. (NCAR), Pan, L. (NCAR), Pospichal, B. (U. Vienna), Poulos, G. (Clipper Wind Power), Savage, L. (Mich. State U.), Schmidli, J. (ETH, Zurich), Sheridan, P. (UK Met Office), Smith, R. (Yale), Snyder, B. (Environ. Canada), Steinacker, R. (U. Vienna), Vosper, S. (UK Met Office), Weihs, E. (BOKU, Vienna), Weissmann, M. (DLR), Wyszogrodzki, A. (NCAR), Yao, W. (Mich. State U.), Zängl, G. (DWD, Germany), Zhong, S. (Michigan State U.)

Graduate and Postdoctoral Advisor: Dr. Thomas B. McKee, Colorado State University, retired

Thesis Advisor and Postgraduate-Scholar Sponsor: Thesis advisor: M. Hahnenberger, M. Farley-Chrust, M. Lehner, R. Atherton, D. Martinez-Villagrassa, B. Adler;

Graduate student committee member: C. Stephan, G. Last, K. J. Allwine, C. B. Clements, S. F. J. De Wekker, A. Weigel, J. A. Cox, D. T. Myrick, J. Sriramasamudram, E. Crosman.

Post-doctoral scholars sponsored: (S. F. J. De Wekker, Markus Furger, S. W. Hoch)

University of Virginia

Biographical Sketch: Stephan Franz Joseph de Wekker

Professional Preparation

University of Wageningen, Wageningen, Netherlands, Atmospheric Science, MS, 1996
University of British Columbia, Vancouver, Canada, Atmospheric Science, PhD, 2002

Appointments

2006 – present	University of Virginia, Assistant Professor
2004 – 2006	National Center for Atmospheric Research, USA, Postdoctoral Fellow
2003 – 2004	Pacific Northwest National Laboratory, USA, Postdoctoral Fellow
2003	Paul Scherrer Institute, Switzerland, Postdoctoral Fellow
1997 – 2002	University of British Columbia, Canada, Graduate Research Assistant

Selected refereed publications

Schmidli, J., B. Billings, F.K. Chow, **S.F.J. De Wekker**, J. Doyle, V. Grubisic, T. Holt, Q. Jiang, K. A. Lundquist, P. Sheridan, S. Vosper, C. D. Whiteman, A. Wyszogrodzki, G. Zangl: Intercomparison of mesoscale model simulations of the daytime valley wind system. Submitted to Monthly Weather Review, 2010, in press.

De Wekker, S.F.J., and S. D. Mayor, 2009: Observations of atmospheric structure and dynamics in the Owens Valley of California with a ground-based, eye-safe, scanning aerosol lidar. J. Appl Meteor. Climat. 48, 1483–1499.

De Wekker, S.F.J. A. Ameen, G. Song, B.B. Stephens, A.G. Hallar, and I. McCubbin, 2009: A preliminary investigation of boundary layer effects on daytime atmospheric CO2 concentrations at a mountaintop location in the Rocky Mountains. Acta Geophysica 57, 904-922.

Doyle, J.D., V. Grubišić, W,O.J. Brown, **S.F.J. De Wekker**, A. Dörnbrack, Q. Jiang, S.D. Mayor, M. Weissmann, 2009: Observations and numerical simulations of subrotor vortices during T-REX. J. Atmos. Sci., 66, 1229-1249.

De Wekker, S.F.J., 2008: Observational and numerical evidence of depressed convective boundary layer heights near a mountain base. J. Appl Meteor. Climat. 47, 1017–1026.

De Wekker, S.F.J. and C.D. Whiteman, 2006: On the timescale of nocturnal boundary layer cooling in valleys, basins, and over plains. J. Appl. Meteor. Climat., 45, 813–820.

De Wekker, S.F.J., D.G. Steyn, J.D. Fast, M.W. Rotach, and S. Zhong, 2005: The performance of RAMS in representing the convective boundary layer structure in a very steep valley. Env. Fluid Mech. 5, 35-62.

De Wekker, S.F.J., D.G. Steyn, and S. Nyeki, 2004: A comparison of aerosol layer- and convective boundary layer structure over a mountain range during STAAARTE '97. Bound.-Layer Meteor. 113, 249-271.

Kossmann, M., U. Corsmeier, **S.F.J. De Wekker**, F. Fiedler, R. Vögtlin, N. Kalthoff, H. Güsten, and B. Neininger, 1999. Observations of handover processes between the atmospheric boundary layer and the free troposphere over mountainous terrain. Contrib. Atmos. Phys., 72, 329-350.

De Wekker, S.F.J., S. Zhong, J.D. Fast, and C.D. Whiteman, 1998: A numerical study of the thermally driven plain-to-basin wind over idealized basin topographies. J. Appl. Meteor., 37, 606-622.

Synergistic activities

1. Serves as Co-editor of a monograph on Mountain Meteorology to be published by the American Meteorological Society (AMS). Served as Member of the AMS committee on Mountain Meteorology. Served as co-organizer of the Mountain Weather Workshop that was held in Whistler, BC, 5-8 August 2008.

2. Participated in many national and international meteorological field programs, including the Terrain-Induced Rotor Experiment (T-REX), the Airborne Carbon in the Mountains Experiment (ACME), the Joint urban experiment 2003, the MAP-Riviera field campaign (Switzerland), IMADA field campaign (Mexico) and the REKLIP field campaign (Germany).

3. Visited several research institutions from 1 week to multiple months to start and/or enhance collaborative activities in and outside the US. Research institutes visited include Central Institute of Geodynamics and Meteorology (ZAMG), Vienna, Austria, Institute for Atmospheric and Climate Science ETH, Zürich, Switzerland, Paul Scherrer Institute, Villigen, Switzerland, NOAA Environmental Technology Laboratory, Boulder, USA, Pacific Northwest National Laboratory, Richland, USA.

4. Served as instructor at Advanced Study Program colloquium in 2007 on regional Biogeochemistry and as a lab instructor at ASP colloquium in 2009 on Exploring the Atmosphere: Observational Instruments and Techniques.

5. Currently advising two PhD students, two Masters students, and three undergraduate students on various projects related to mountain and boundary layer meteorology. Regularly inviting foreign scientists to work in my research group.