



The **M**ountain **T**errain Atmospheric **M**odeling and **O**bservations (MATERHORN) Program: A Progress Report – Investigator Meeting V

By

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J. P. Hacker, Naval Postgraduate School/NCAR

F. K. Chow, University of California, Berkeley

E. R. Pardyjak, University of Utah

S.F.J. De Wekker, University of Virginia



Principal Investigators:

H.J.S. Fernando

(University of Notre Dame; Pratt)

Eric Pardyjak

(University of Utah)

(S. Whiteman, J. Steenburgh,
Zhaoxia Pu)

Stephan De Wekker

(University of Virginia)

Josh Hacker

(NPS/NCAR)

Tina Katopodes Chow

(Univ. California, Berkeley)

Working Partners:

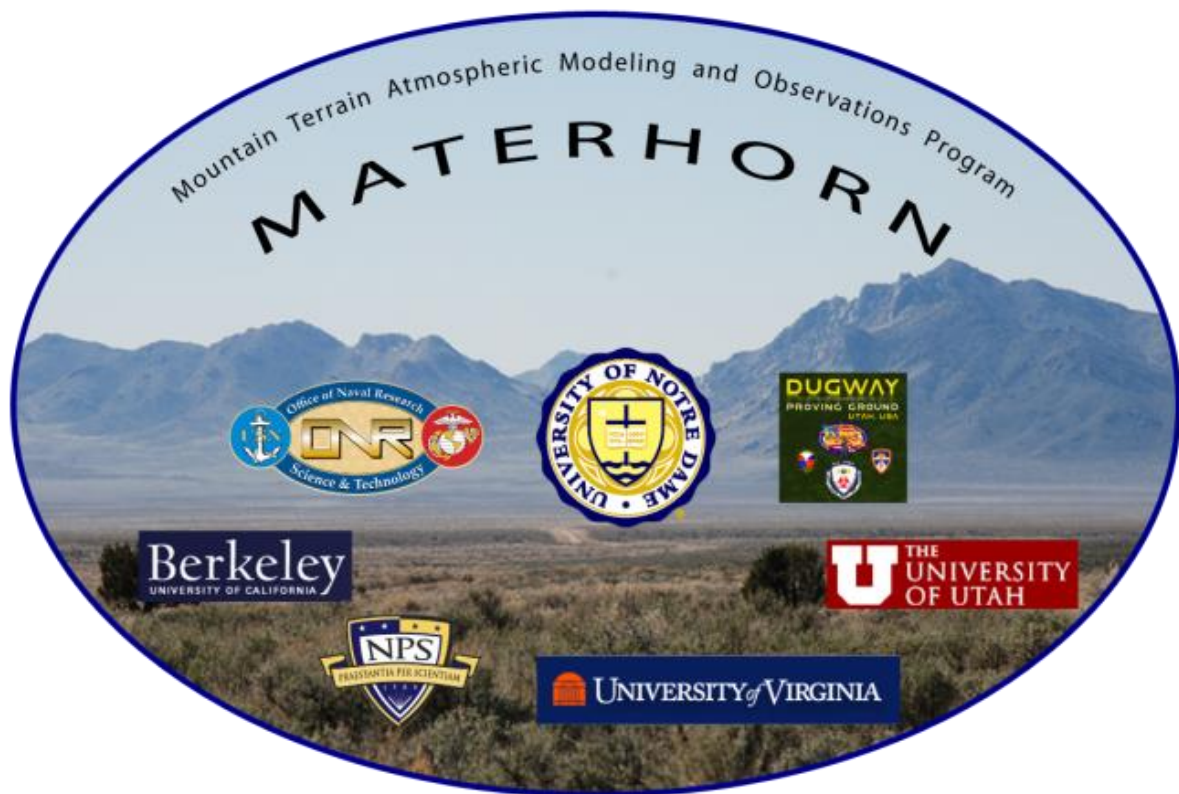
John Pace, Dragan Zajic (DPG)

Jim Doyle (NRL)

Yansen Wang,
Melvin Fenton &
Ed Creegan (ARL)

Julian Hunt (U. London)
Eliezer Kit (Tel Aviv Univ)

Multidisciplinary University Research Initiative MURI



Collaborators

NCAR (Knival, Liu)
NOAA (Grachev, Fairall)
|
Oregon State University
University of Colorado

Semion Sukiriyonski, Beer Sheeva

University of Vienna, Austria
University of Lecce, Italy

École Polytechnique De Montreal, Canada

Acknowledgments

- Advisory Committee – Dave Emmitt, John Pace and Vanda Grubišić for continued support for the group
- Program Managers (Dr. Ron Ferek and Dan Eleuterio)

Acknowledgments

- MATERHORN-Fog Participants from University of Utah, University of Notre Dame and University of Virginia
- ARL (Ed Creegan)
- Environment Canada (Ismail Gultepe, Mike Harwood)
- NCAR – instrumentation (Steve Oncley)
- US Army Dugway Proving Ground – John Pace and Dragan Zajic – continued support

Entering the final period of MURI

10/01/15- 05/31/16
221,077
324,888
141,335
63,903
37,025
788,228

Major accomplishments – Year 4

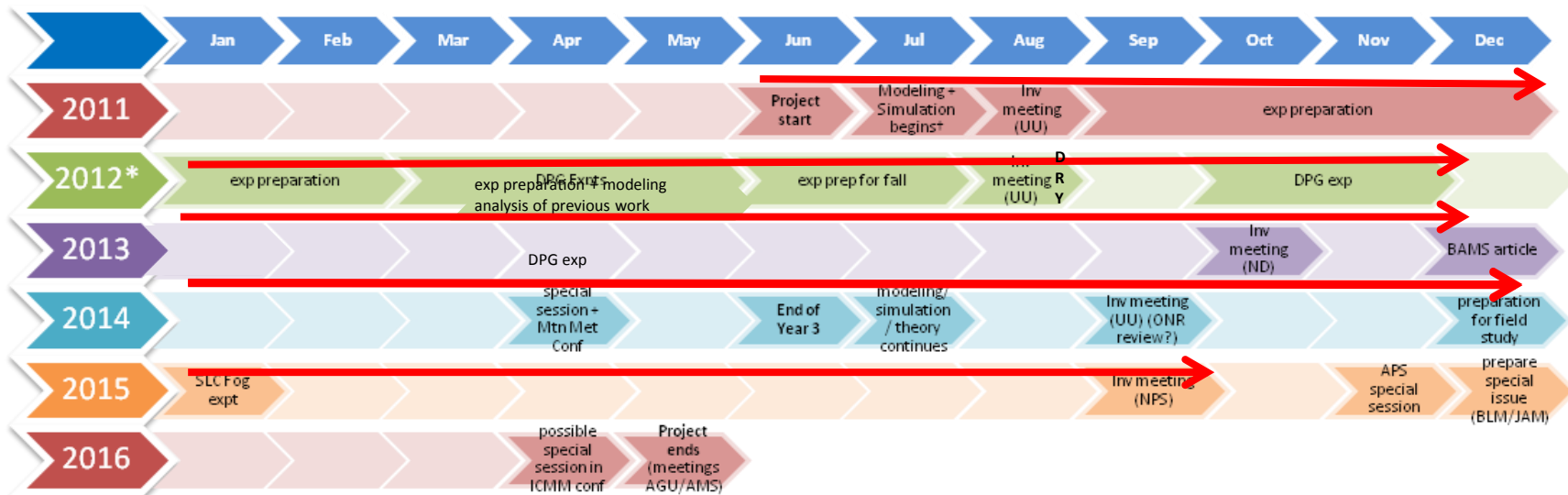
- MATERHORN-FOG – Notre Dame, Utah and Virginia (life cycle of fog events – first in CT)
- BAMS article appearing on November 2015
- So far,
 - 40 papers published or accepted (21 in 2015);
 - 09 submitted (many in preparation);
 - 19 Invited conference presentations (8 in 2015);
 - 07 conference papers (0 in 2015);
 - 124 conference presentations (43 in 2015)
 - 9 Awards and 2 recognitions (4 in 2015)

Summary (End of 4rd year)

- Senior PIs: 11
- Research faculty: ~~4~~, ~~5~~, 5
- Technical staff: ~~8~~, 8
- Post docs: ~~8~~ ~~13~~, 13
- Graduate Students : ~~18~~, ~~22~~, 18 PhD and 9 MS (Total 27)
- Undergraduate Students: ~~13~~ ~~22~~, 25
- Collaborators (proposal): ~~5 (supported 2)~~, 5 (3)
- Collaborators : ~~11~~, 10

(total supported fully or partially: ~~67~~ ~~82~~, 89)

Timeline



25 Aug. - 28 Aug. 2012:

25 Sept. – 25 Oct. 2012:

1 May– 30 May 2013:

Nov 30 – Feb 15 2015:

MATERHORN-X-DRY

MATERHORN-X-FALL

MATERHORN-X-SPRING

MATERHORN-Fog

Organization of Meetings/Special Sessions (8):

- A special AGU Session on Complex Terrain flows was organized by Stephan De Wekker (University of Virginia) and Fotini Chow (UC Berkeley), 2011 Fall Meeting.
- Organized a special session on “Atmospheric Observations in Mountainous Terrain” at the [92nd American Meteorological Society Annual Meeting, January 22-26, 2012](#).
- Organization of special session on “Atmospheric boundary layers in complex terrain and over ice, snow and vegetated surfaces” at the Davos Atmosphere and Cryosphere Assembly (DACA), 8-12 July 2013 by Stephan DeWekker.
- Organized a special session on “MATERHORN Project” 94th AMS Annual Meeting in 2014, Atlanta, 2-6 February, by HJS Fernando, Josh Hacker, Eric Pardyjak, Stephen De Wekker and Tina Chow.
- Organized a special session on “Research on Improving Weather Prediction for Mountain Terrain” at the AGU Fall Meeting, 9-13 December 2013, by Josh Hacker, Eric Pardyjak, Stephen De Wekker and Tina Chow.
- Organized a special session on “Observations, Predictions, and Predictability of the Atmosphere Over Complex Terrain” at the AGU Fall Meeting, 15-19 December 2014 by Josh Hacker, H.J.S. Fernando and Eric Pardyjak.
- Organized a Special session on: Observations and Predictability of the Atmosphere over Complex Terrain (Session ID: 8181), AGU Fall Meeting, 2015 by Eric Pardyjak, Daniel Nadeau, Josh Hacker and H.J.S. Fernando.
- Organized a special session on Complex Terrain Flows, 19th Conference on Applications of Air Pollution Meteorology, American Meteorological Society, 96th Annual Meeting, 2016 (Laura Leo and H.J.S. Fernando).

Special Journal Issues

- AMS Journals – special collection (Zhaoxia Pu as the editor) - afoot
- Boundary Layer Meteorology (Silvana Di Sabatino as the editor) – completed, 9 papers
- Environmental Fluid Mechanics (Eric Pardyjak as the editor)



THE MATERHORN Unraveling the Intricacies of Mountain Weather

BY H. J. S. FERNANDO, E. R. PARDYJAK, S. DI SABATINO, F. K. CHOW, S. F. J. DE WEKKER, S. W. HOCH, J. HACKER, J. C. PACE, T. PRATT, Z. PU, W. J. STEENBURGH, C. D. WHITEMAN, Y. WANG, D. ZAJIC, B. BALSLEY,* R. DIMITROVA, G. D. EMMITT, C. W. HIGGINS, J. C. R. HUNT, J. C. KNEVEL, D. LAWRENCE, Y. LIU, D. F. NADEAU, E. KIT, B. W. BLUMQUIST, P. CONRY, R. S. COPPERSMITH, E. CREEGAN, M. FELTON, A. GRACHEV, N. GUNAWARDENA, C. HANG, C. M. HOCUT, G. HUYNH, M. E. JEGNUM, D. JENSEN, V. KULANDAYELLI, M. LEHNER, L. S. LEO, D. LIBERZON, J. D. MASSEY, K. McENERNEY, S. PAL, T. PRICE, M. SCHIATTI, Z. SILVER, M. THOMPSON, H. ZHANG, AND T. ZSEDEWITS

Comprehensive, multiscale, and multidisciplinary observations allow scientists to discover novel flow physics, address current deficiencies of predictive models, and improve weather prediction in mountainous terrain.

Through woods and mountain passes
the winds, like anthems, roll.

—Henry Wadsworth Longfellow

For centuries, humans have been both fascinated and awed by mountain weather, and its intriguing aberrancy continues to baffle weather forecasters. For instance, a clear morning on a tranquil mountain slope can swiftly change into violent storms within hours while a nearby valley remains calm. The variability of mountain weather spans a wide swath of space-time scales, contributing to a myriad of phenomena that stymie the predictability of mountain weather. Although isolated mountains are rare, about 20% of Earth's land surface is covered by mountainous areas (Louis 1975). Topography less than 600 m in height (<5% of the atmospheric-scale height) is referred to as hills, but demarcations between different topographic features remain ambiguous. Orographic mosaics that incorporate slopes, valleys, canyons, escarpments, gullies, and buttes (also known as complex terrain) cover about 70% of Earth's land surface (Strobach 1991). The majority of the world's urban areas have emerged in complex terrain because

of accompanying water resources. Systematic studies of mountain weather date back to the 1850s, followed by a decline of scientific activity in the early 1900s owing to observational difficulties. A resurgence of research occurred in the midtwentieth century with the advent of aerological networks (Bjerknes et al. 1934) as well as groundbreaking advances of mountain-wave and slope-flow studies (Prandtl 1942; Queney 1948; Long 1953). Vivid applications in areas of urban air pollution (Ellis et al. 2000; Fernando and Weil 2010), dispersion in cities (Allwine et al. 2002), wind energy harvesting (Banta et al. 2013), aviation (Politovich et al. 2011), alpine warfare (Winters et al. 2001), and firefighting (Albini et al. 1982) have burgeoned mountain meteorology, but understanding of flow physics and fidelity of predictions leaves much to be desired. Reviews of relevant past research are found in Taylor et al. (1987), Blumen (1990), Balnes (1998), Belcher and Hunt (1998), Whiteman (2000), Wood (2000), Barry (2008), Fernando (2010), and Chow et al. (2013).

Prompted by applications-driven overarching science questions, in 2011 the U.S. Department of Defense (DoD) funded a 5-yr Multidisciplinary

MATERHORN has four components working symbiotically across institutions and disciplines

Modeling	(MATERHORN-M)
Experiments	(MATERHORN-X)
Technology Development	(MATERHORN-T)
Parameterizations	(MATERHORN-P)

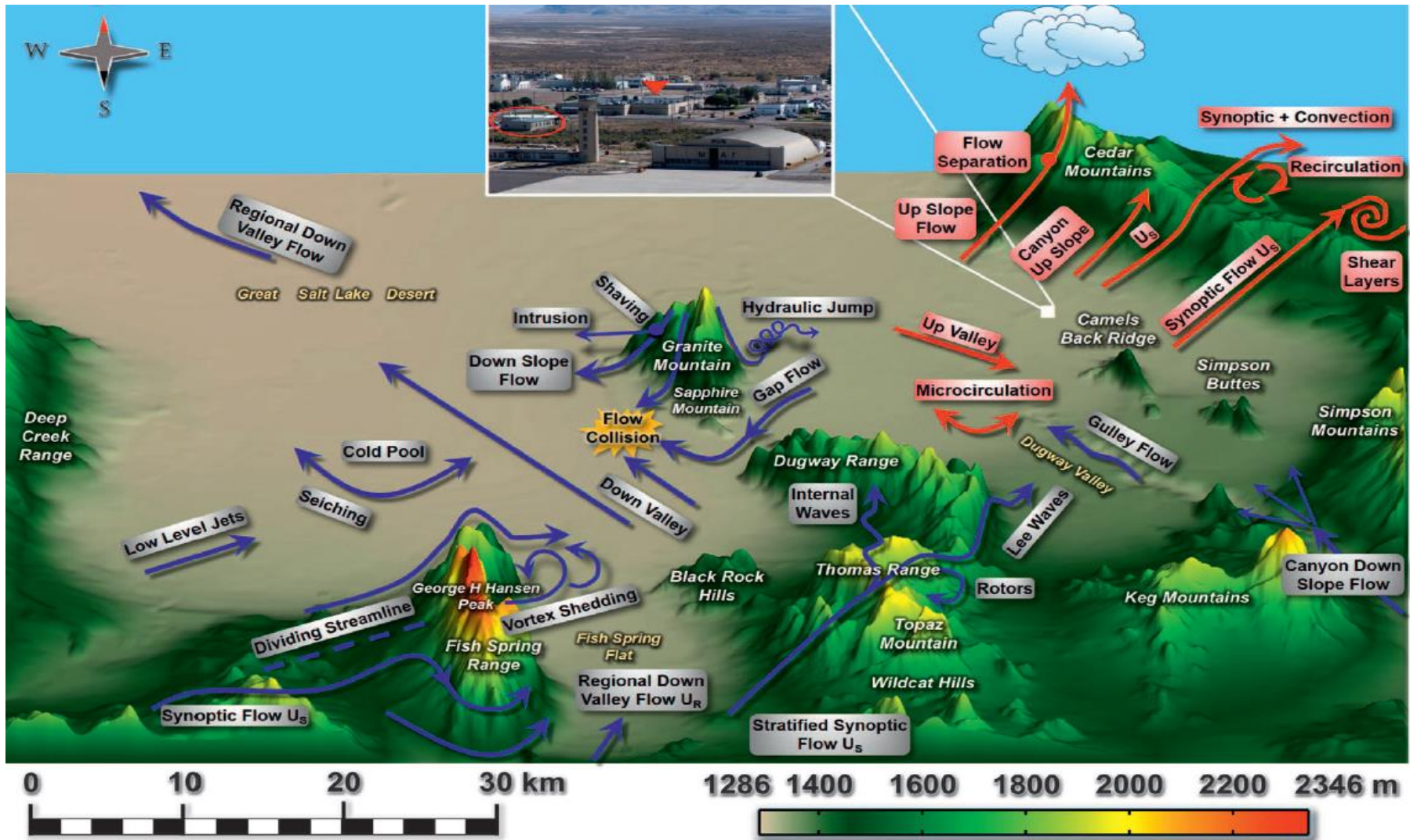


FIG. 1. Physical processes in complex terrain, illustrated on a topographic map of the DPG domain. The spatial and the elevation (shading) scales are shown below. Blue arrows represent nocturnal flows; red arrows represent daytime flows. An arbitrary direction has been used for illustration of synoptic effects (which typically varies from northwest to north to northeast in DPG). Shown in the inset are the control center (red arrow) and Ditto

MATERHORN-X

(Dry, Fall, Spring, Fog)

....Collecting high quality, high space-time resolution, data from the real world

MATERHORN-FOG



Heber Valley

Salt Lake Valley

Nov 30 – Feb 15, 2015



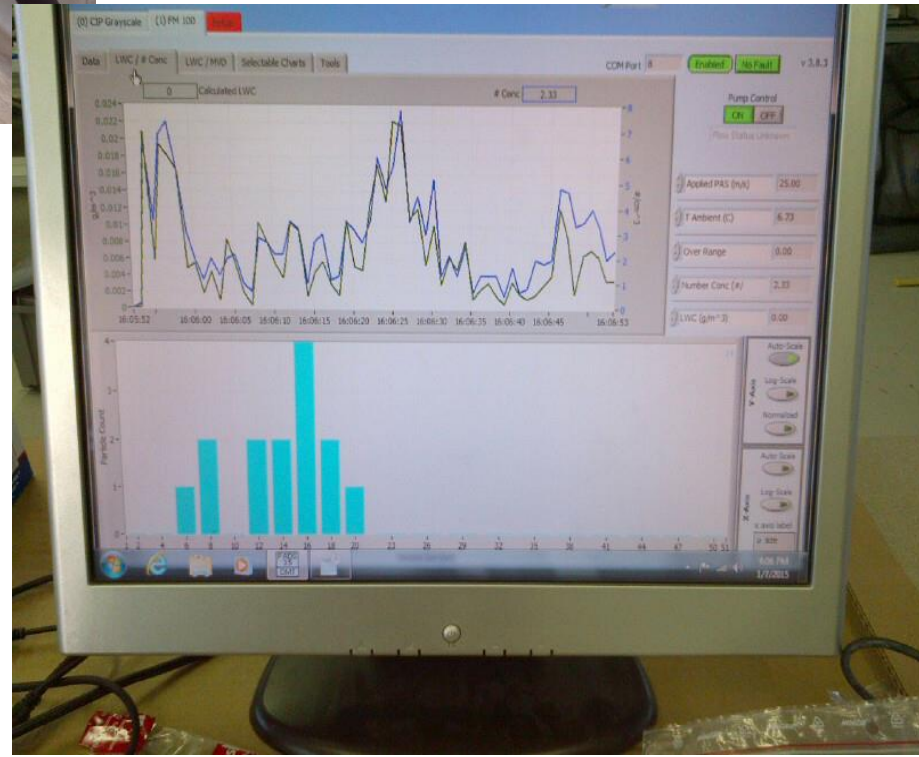


VIPs in action





Radiation measurements/calibrations



Perdigão Field Experiment: May–June 2017

Complex Terrain flow at Microscale with wind engineering applications (NSF – SPO funded)

Lead US Principal Investigators

Harindra Joseph Fernando, University of Notre Dame

Julie K. Lundquist, University of Colorado

Lead EU Investigator:

Jakob Mann, Technical University, Denmark

Contributors:

Robert Banta, NOAA/ETL

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Luciano Castillo, Texas Technical University

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Christopher Hocut, U.S. Army Research Laboratory

Petra Klein, University of Oklahoma

David Knapp, U.S. Army Research Laboratory

Laura Sandra Leo, University of Notre Dame

Jakob Mann, Danish Technical University, Denmark

Steven P. Oncley, National Center for Atmospheric Research

Jose Lahaina Palma, Porto University, Portugal

Eric Pardyjak, University of Utah

Edward Patton, National Center for Atmospheric Research

Marco Princevac, University of California, Riverside

Luis Ribeiro, Bragança Polytechnic Institute



MATERHORN-M

...Improving predictability on
mesoscale

MATERHORN - M

- Numerical experiments examining the impact of regional-scale soil moisture analysis biases on WRF temperature and stability forecasts over the MATERHORN study area – significant improvements in predictions. The recently launched NASA Soil Moisture Active Passive (SMAP) mission may significantly improve forecasts
- A novel method was developed to assimilate near-surface winds and temperatures that have systematic departures from a model.
- Several implementations of the logarithmic drag law for surface momentum and heat fluxes have been tested inside WRF.
- For MATERHORN-Fog, real-time forecasts with WRF were executed by Professor Zhaoxia Pu at high resolution (~1 km horizontal grid intervals), initialized two times per day (at 00 and 12 UTC), which supported the go/no-go decisions for IOPs. After the field programs, the forecast results were evaluated by the University of Utah group.

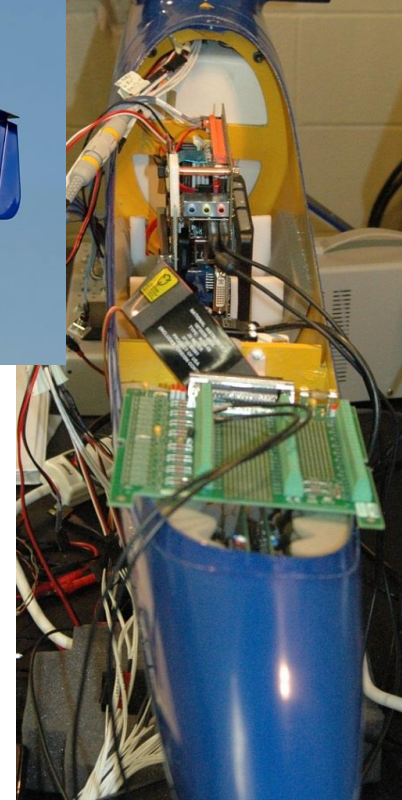
MATERHORN-T

...pushing technological frontiers



MATERHORN - T





- **Unmanned Aerial Vehicle**

- Temperature, humidity, wind velocity
 - Turbulent components (combo probe) up to Kolmogorov
 - Onboard data acquisition
 - Automated flight tracks
 - Fog droplet size distribution (FASS)
-

Triple Lidar deployment

MATERHORN FALL 2012

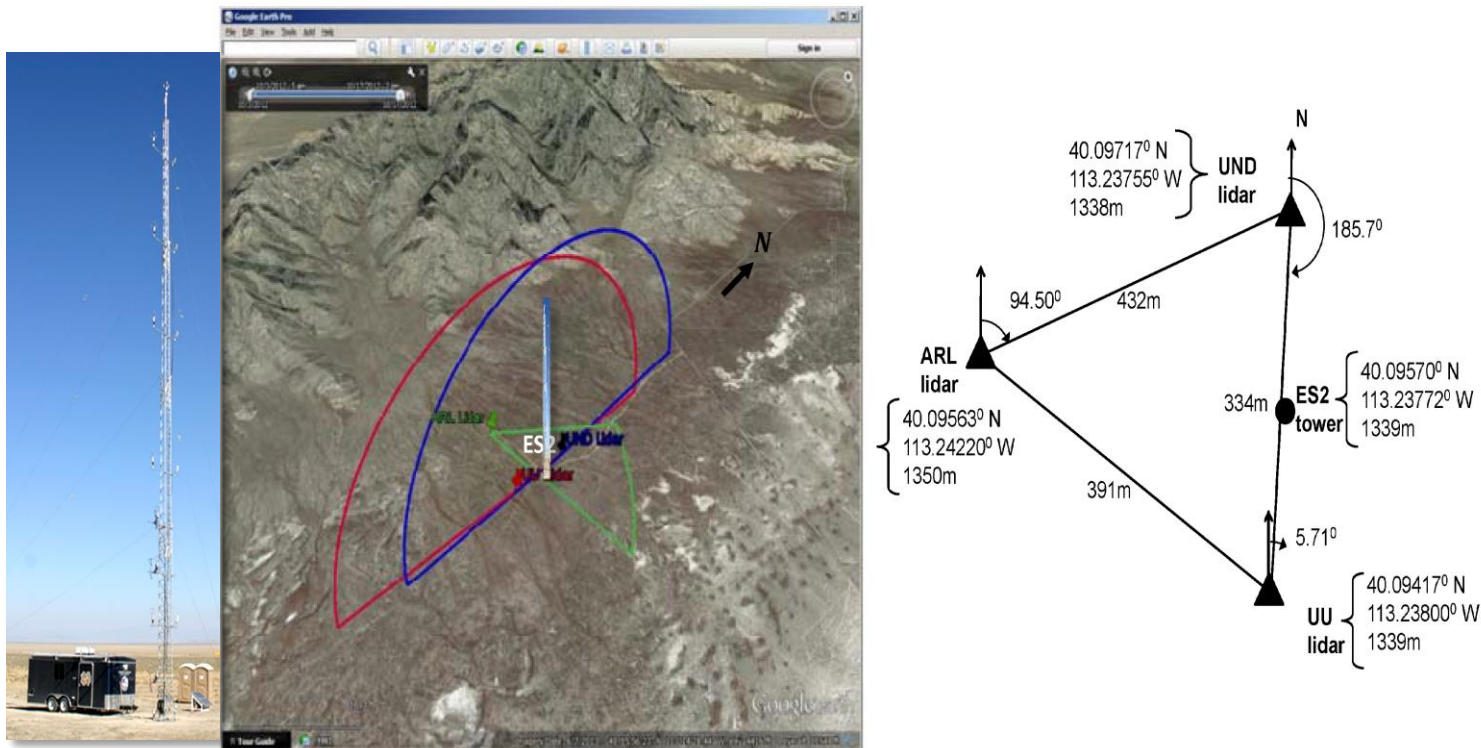
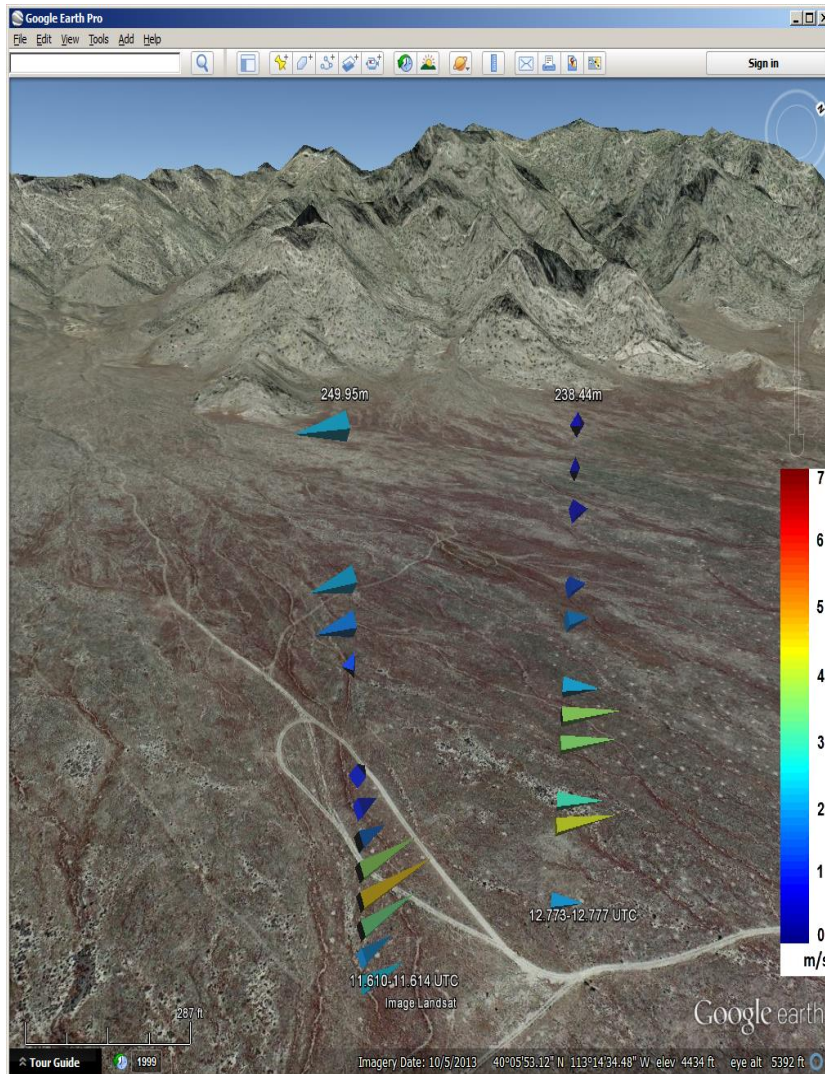


Fig. 3. 7 October 2012 setup of three Doppler wind lidars from ARL (green), UND (blue), and UU (red). The left panel is a 3D depiction of RHI scans from three Doppler wind lidars. The right panel is a latitude, longitude and altitude coordinate for three Doppler wind lidars. Note that a 32 m meteorological tower (ES2) with a 28 m AGL sonic anemometer was located between the UND and UU lidars.

Virtual Tower using Triple Lidar!

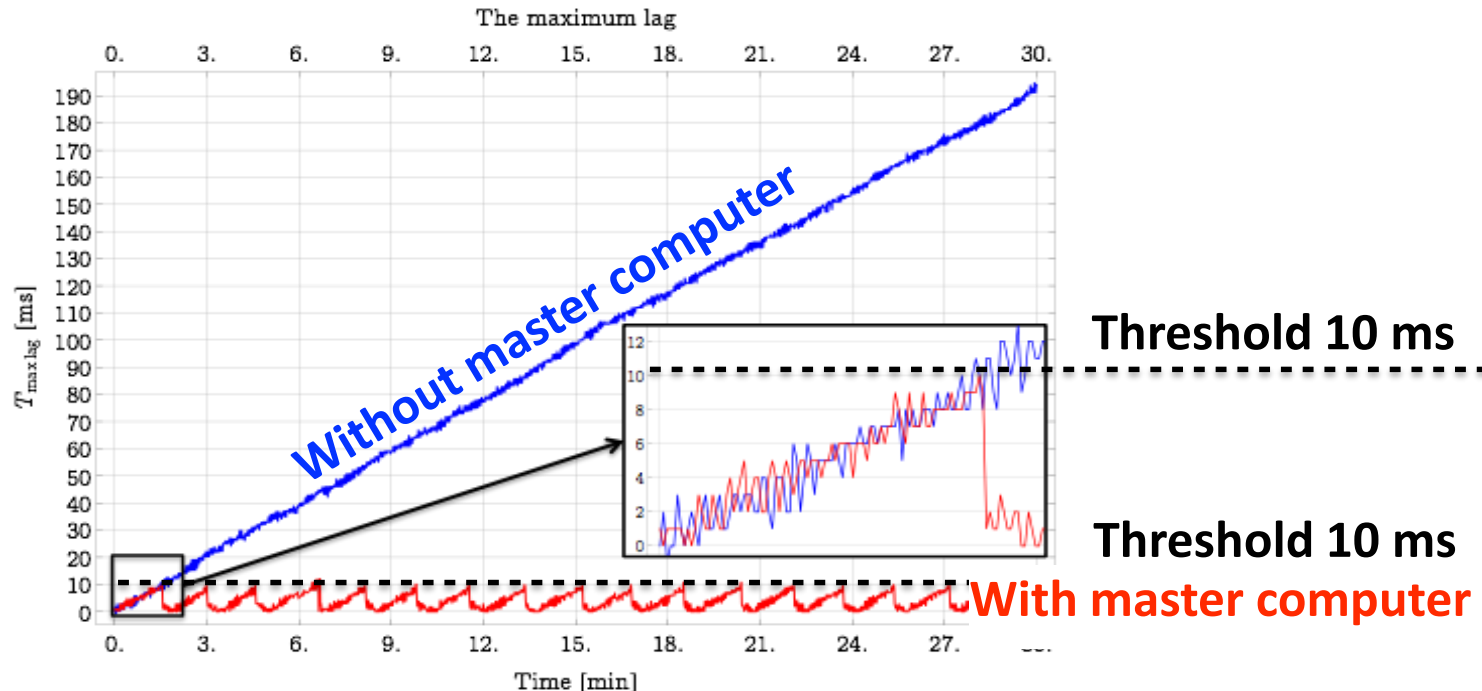


Examples of vertical profile (virtual towers) 3D wind vectors retrieved from coordinated triple Doppler wind lidars scanning on 7 October 2012. The down valley low-level jet was evident in these virtual towers at 11.61 to 12.77 UTC (0537 to 0646 MDT). The horizontal distance between two virtual towers is 134 m.

Notre Dame will soon purchase a Triple Lidar System
– A DURIP Grant/ONR
– First from *Halo Photonics Streamline*®

Long-range WindScanner system

Courtesy: Nikola Vasiljević



- WindScanners coordinated by a remote master computer
- Coordination can be achieved using any type of network
- WindScanners are synchronized
- Arbitrary scanning trajectories
- Measurement rate can be dynamic from one LOS measurement to another
- Distances which the LOS measurements are acquired can be dynamic as well
- **Flexible remote sensing measurement system that can accommodate wide range of atmospheric experiments**

Sonic-hotwire Combo System (2-20 kHz)

- Developed and deployed
- unique turbulence information, dissipation scales
 - Allow myriad of turbulence and multiscale studies



MATERHORN-P

Improve mixing parameterizations
via improved physics

(observations, high resolution
simulations, laboratory experiments)

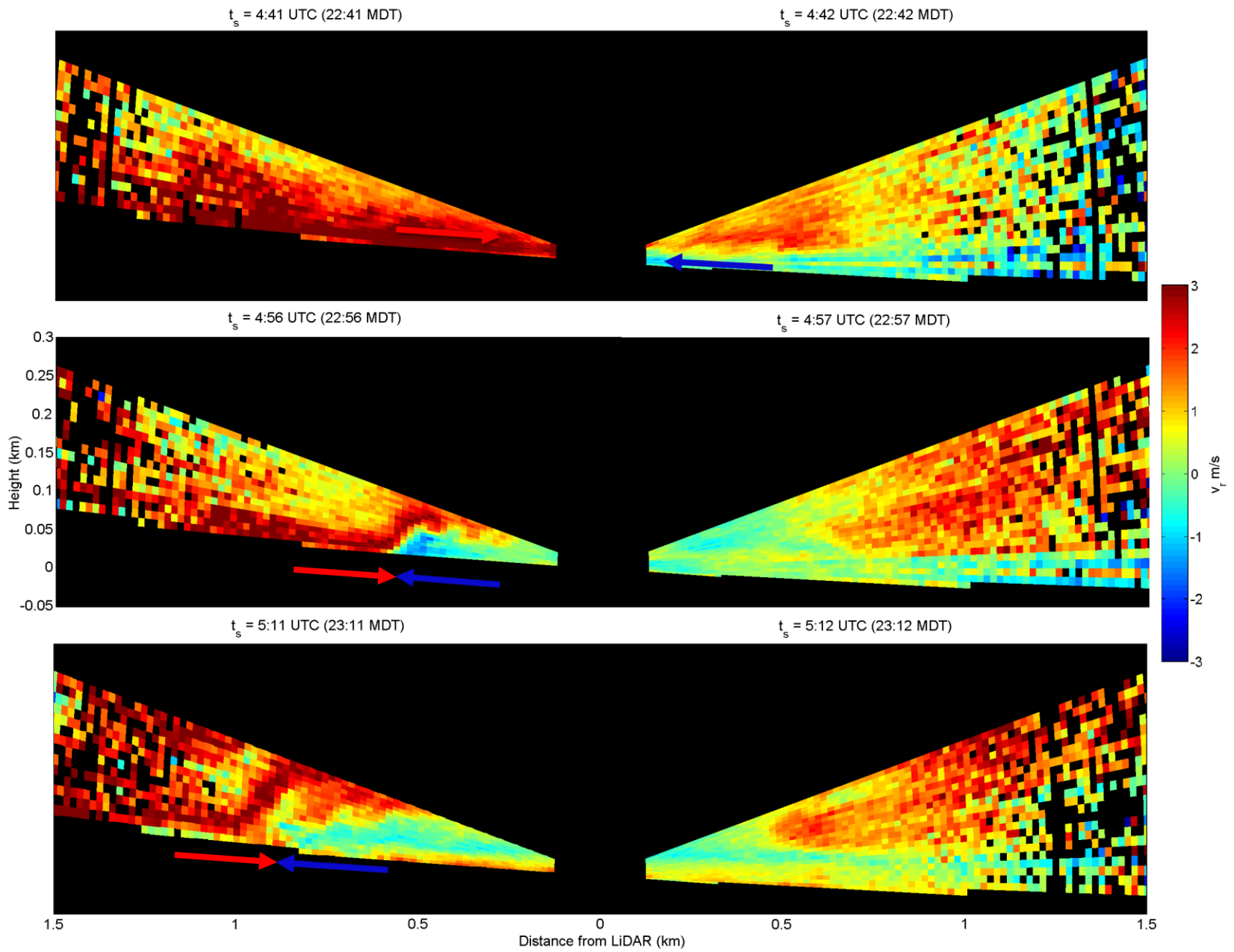
Implement them in models

Progress - Notre Dame Group FY 2015

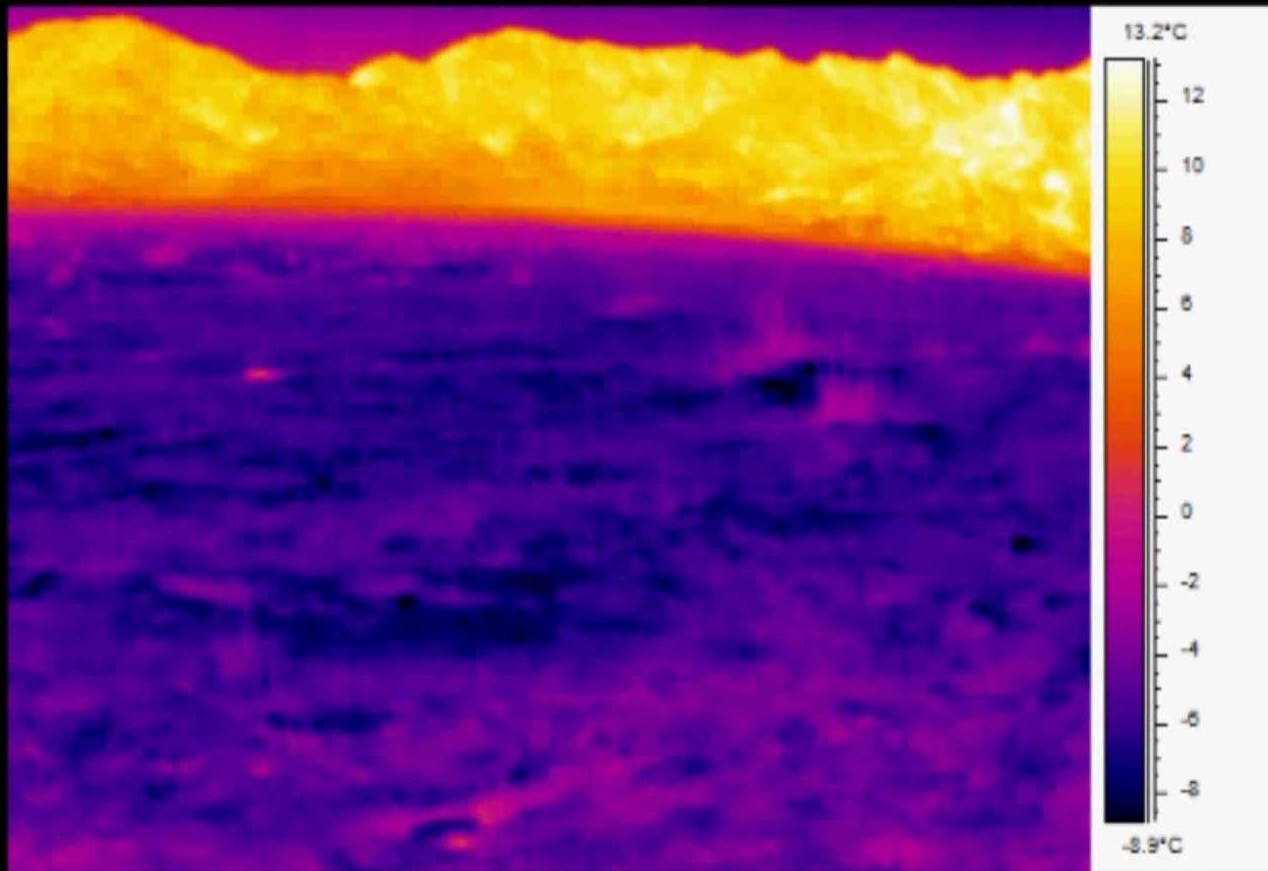
Flow Collisions



East Slope LiDAR - 4:41– 5:11 UTC (22:41 – 23:11 MDT)

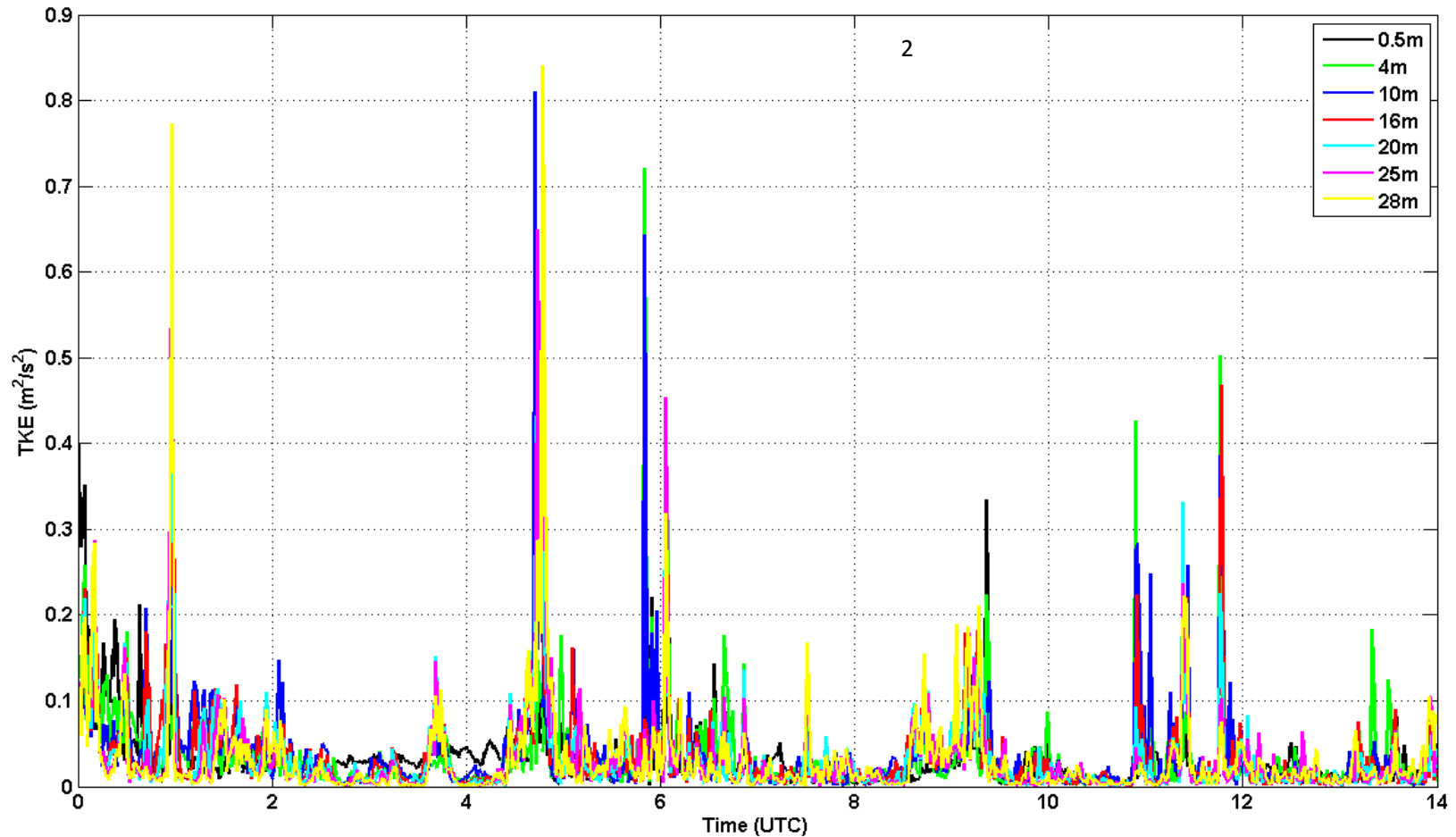


Secondary Collisions



High resolution IR Imaging shows seiche of stratified boundary layer

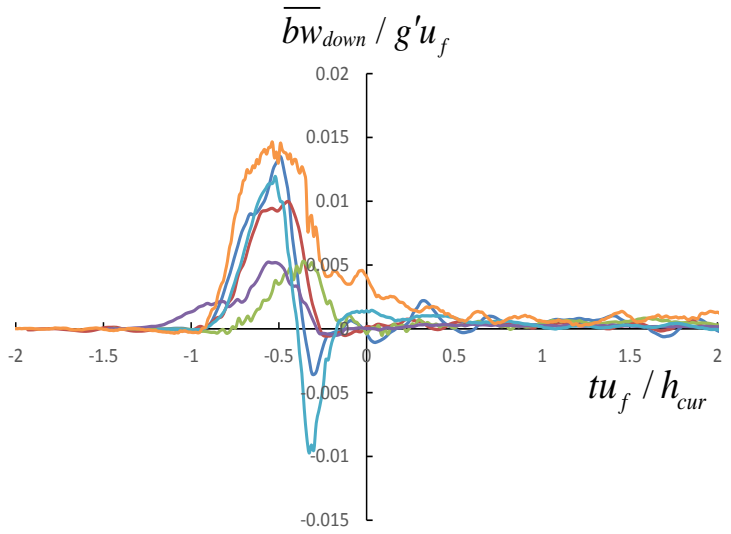
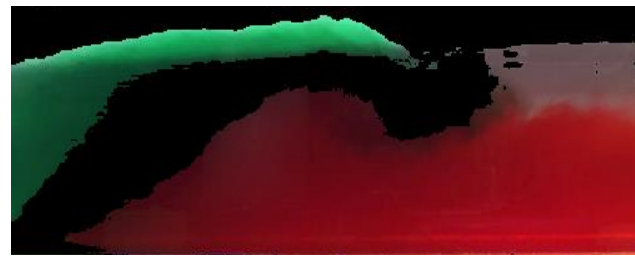
Collision Periods



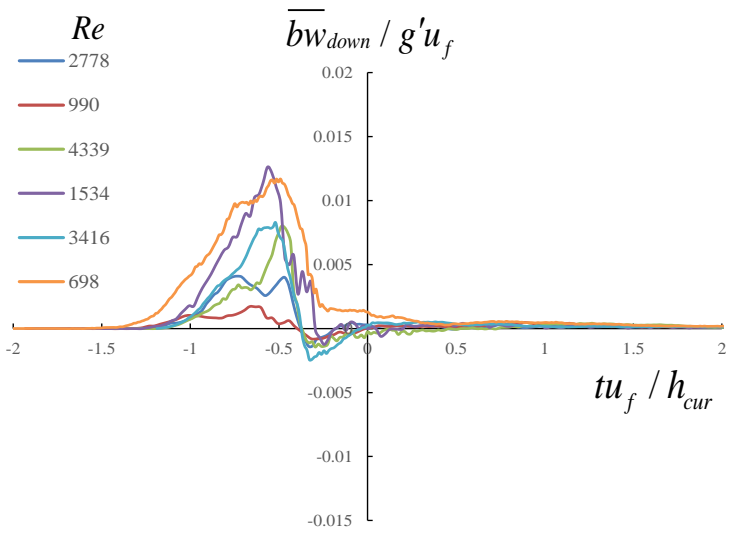
Discernible spikes in TKE when collisions occur

**Secondary Collisions
(Hocut & Hoch)**

$$TKE = \sigma^2 = \frac{1}{2} \left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2} \right)$$



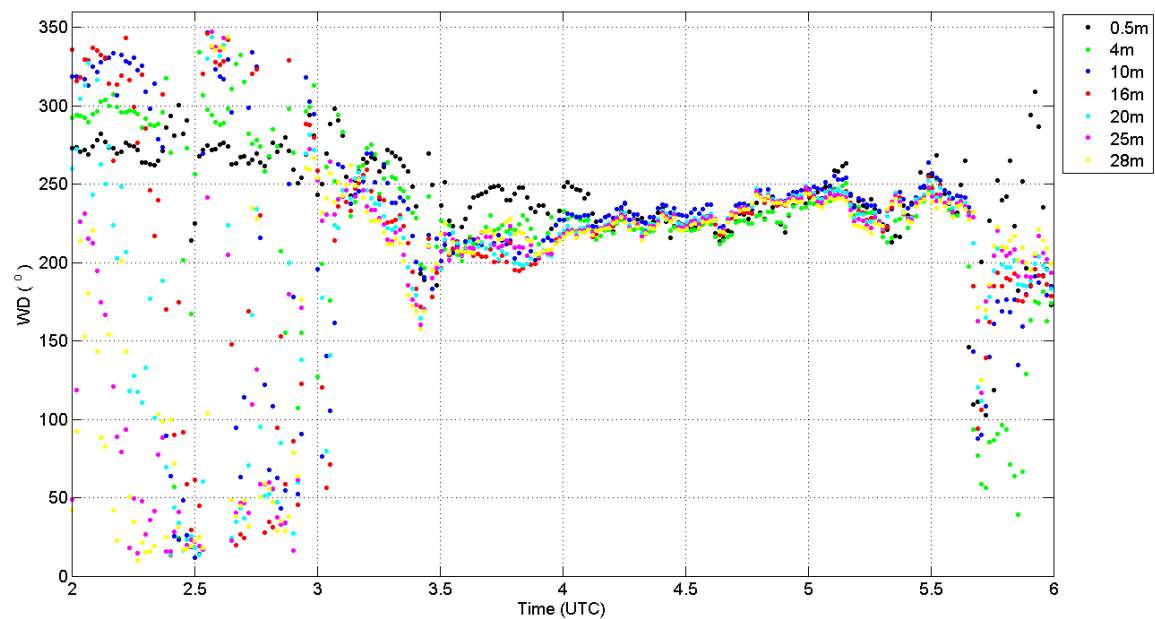
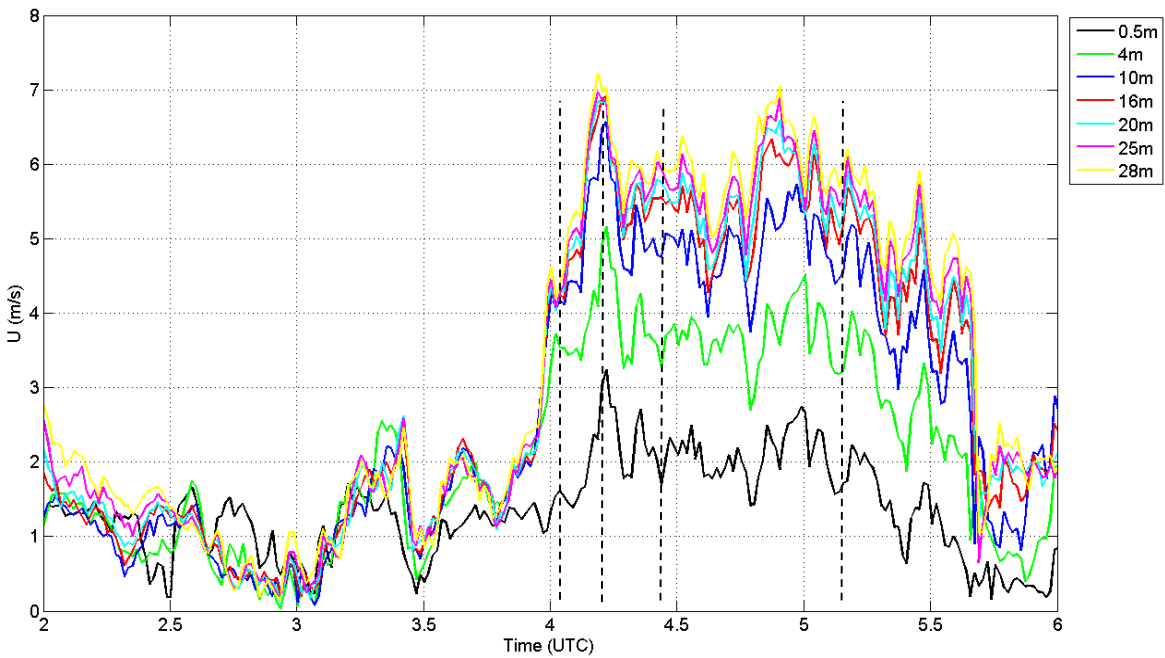
(a) ensemble average method

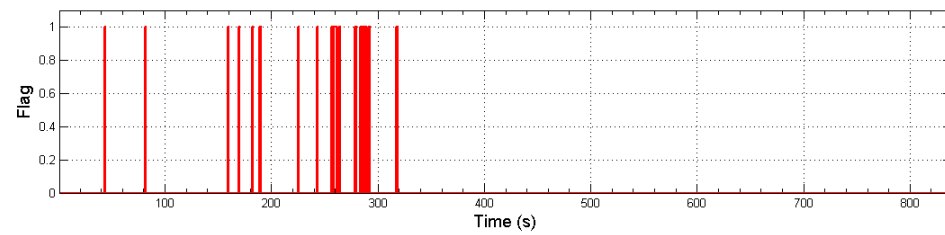
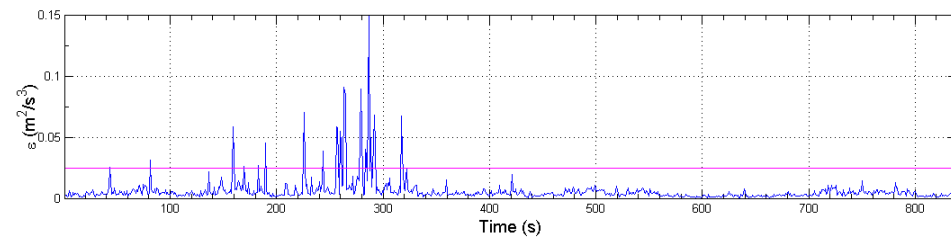
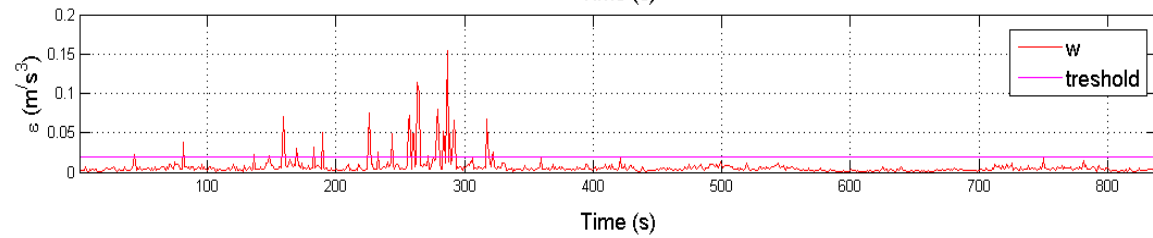
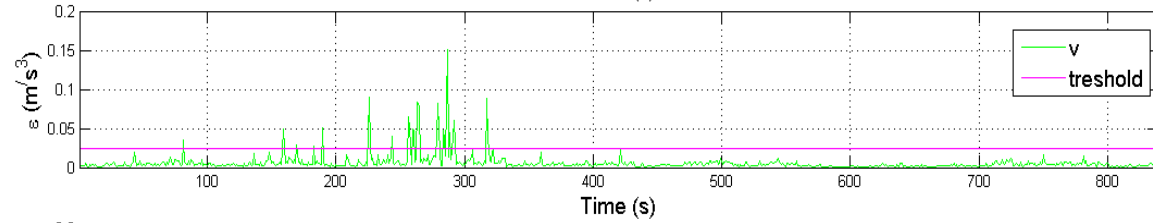
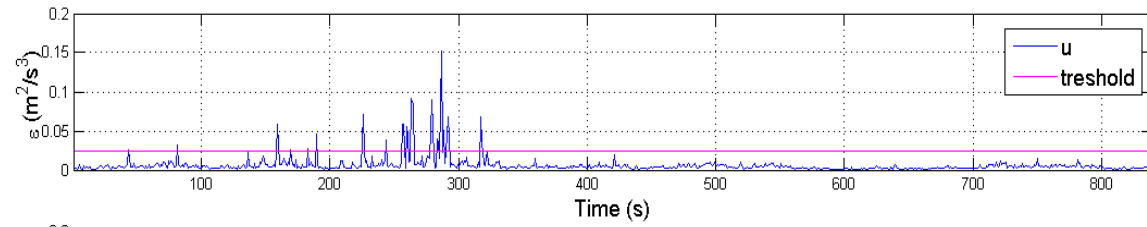


(b) moving average method

Qiang Zhong

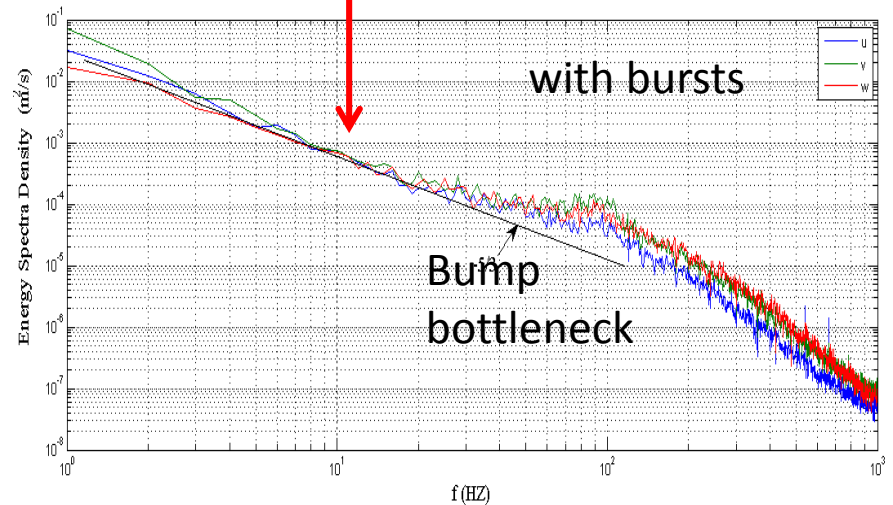
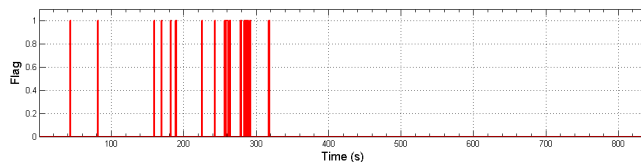
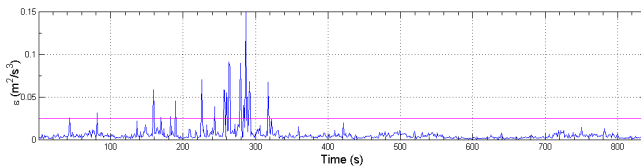
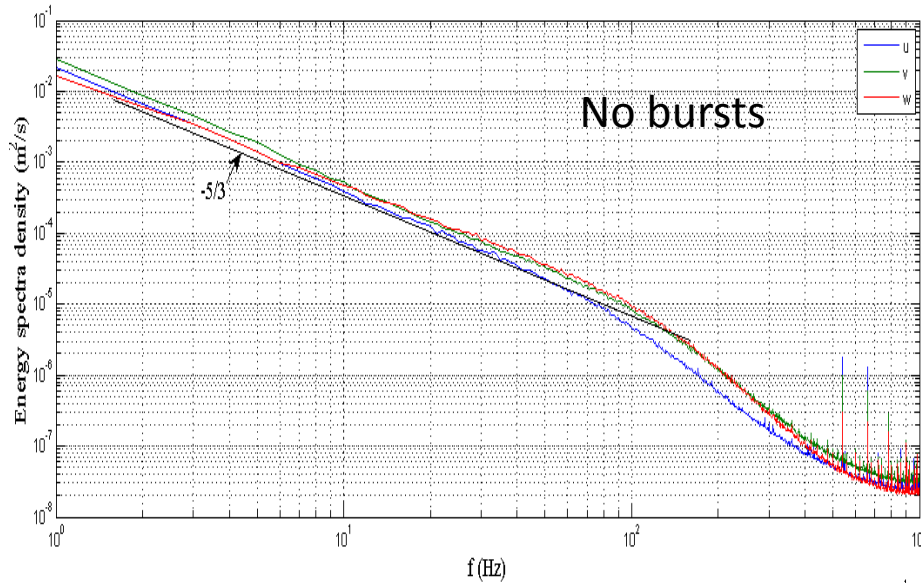
**BURSTING IN THE
STABLE BOUNDARY LAYER –
BOTTLENECK EFFECT**





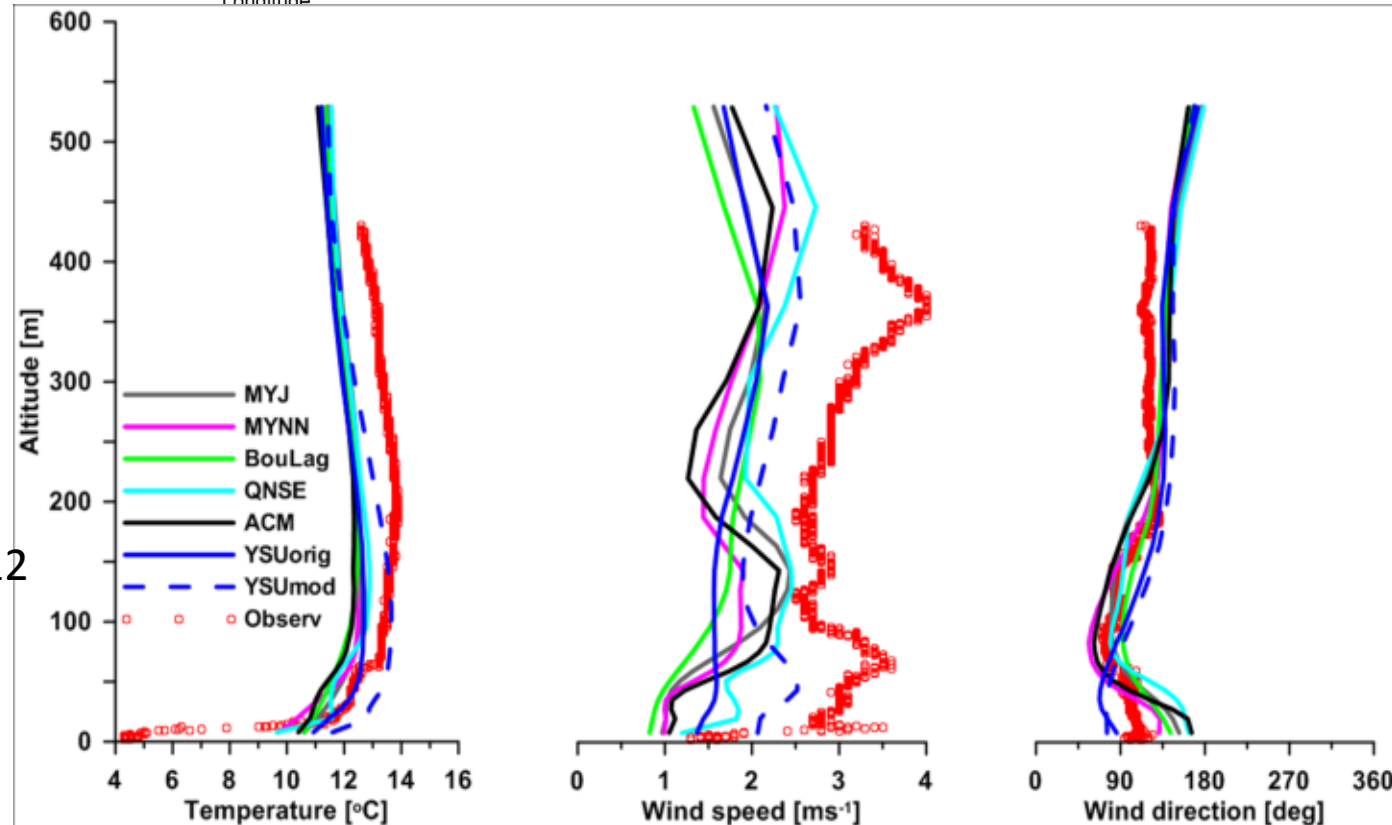
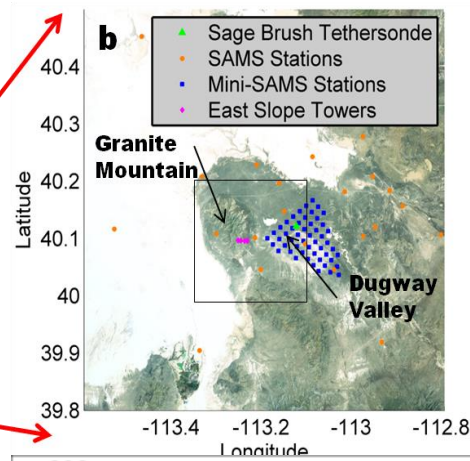
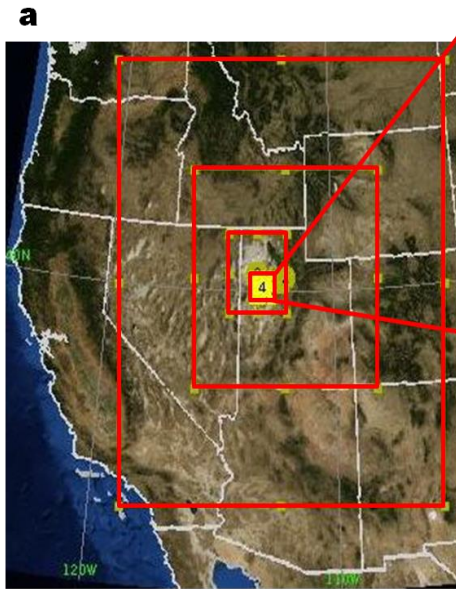
Bursts and no-bursts

Eliezer Kit will present



WRF – 500 m

Reneta Dimitrova
Zachariah Silver



for IOP8, October 18, 2012

Keep unravelling mysteries

www.nd.edu/~dynamics/Materhorn





Thank you