



The Mountain Terrain Atmospheric Modeling and Observations (MATERHORN) Program (2011-2016)

By

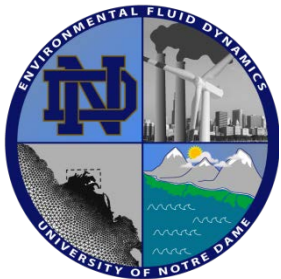
H.J.S. Fernando, Univ. of Notre Dame

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



ONR FY 2011 Multidisciplinary University Research Initiative (MURI)

TOPIC #7:

Improved Meteorological Modeling in Mountain Terrain

Topic Chiefs:

Dr. Ronald J. Ferek and Dr. Daniel Eleuterio (ONR)

Additional support:

Army Research Office
(Dr. Gordon Videen and Dr. Walter Bach)

Air Force Weather Agency
through ARL

www.nd.edu/~dynamics/Materhorn

Principal Investigators:

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(University of Utah)

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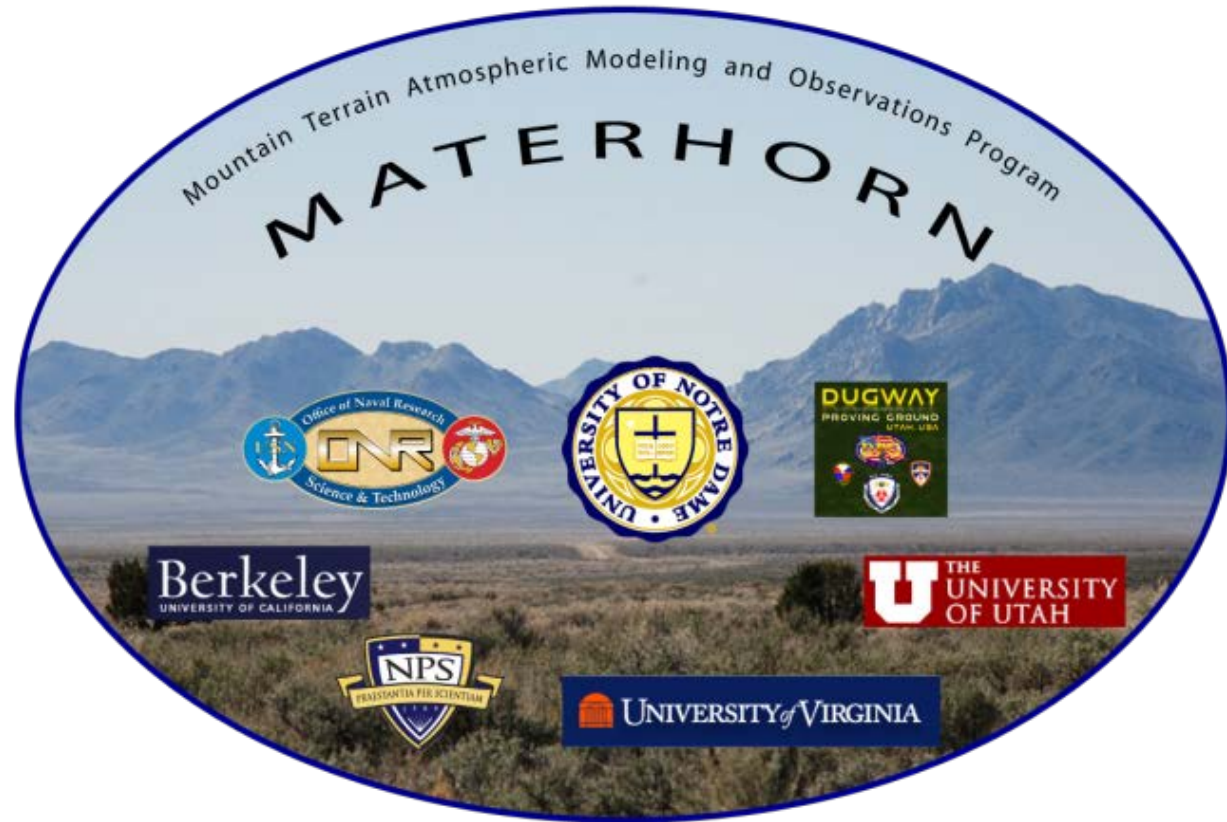
Melvin Fenton &

Ed Creegan (ARL)

Julian Hunt (U. London)

Eliezer Kit (Tel Aviv Univ)

Multidisciplinary University Research Initiative MURI



Collaborators

NCAR

NOAA

Simpson Weather Associates

Oregon State University

University of Colorado

IIBR, Israel

University of Bergen, Norway

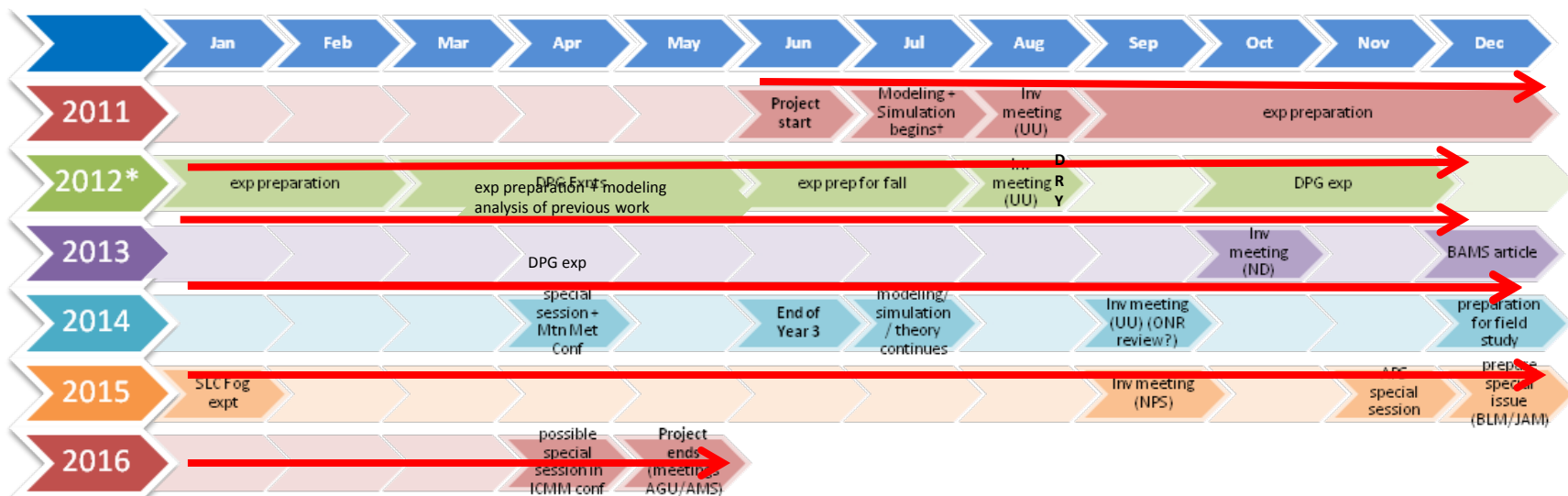
University of Vienna, Austria

École Polytechnique De Montreal, Canada

University of Lecce, Italy

Timeline

Reports available upon request
or
visit www.nd.edu/~dynamics/Materhorn



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

Some Scientific Barriers.....

(1) Near-surface atmospheric wind and temperature predictions in complex terrain

– poor

(2) Accurate measurements of *model relevant* parameters (soil properties, surface energy balance) – lean

(3) Near-surface temperature forecasts - very sensitive to soil moisture

(4) Holistic (multi-scale) observations of large to small-scale processes – rare

Barriers

- Ultra high-resolution (50 m horizontal or finer) simulations have been nearly impossible over complex terrain
- Issues remains on turbulence closure modeling, terrain representation and numerical methods (What is the best? – e.g., terrain-following vs. immersed boundary method)
- Nocturnal predictions are not satisfactory -- unknown physical processes?

Volume 96 Number 11 November 2015

BAMS

Bulletin of the American Meteorological Society

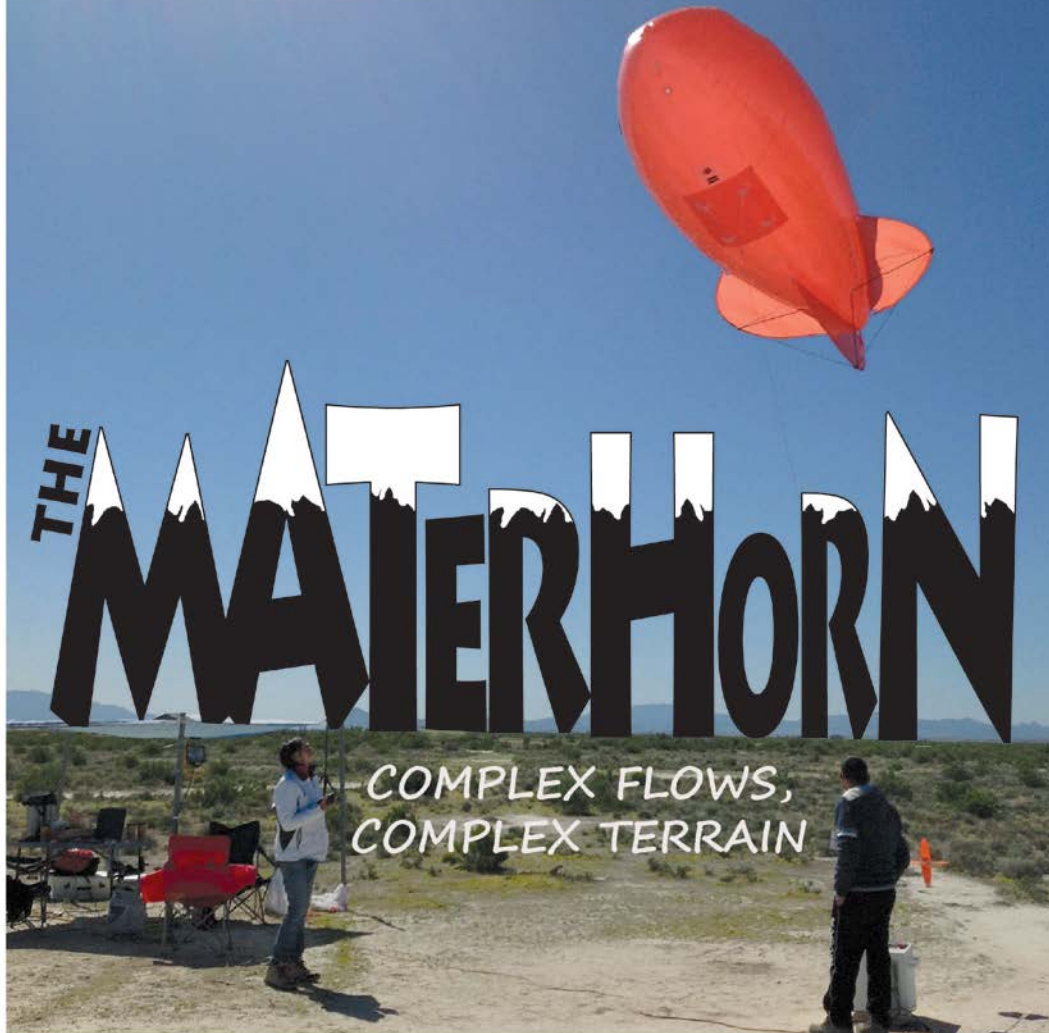
THE EL NIÑO THAT WASN'T

REMOTE SENSING OF SNOWFALL

IMPROVING WIND FORECASTS

Mountain Terrain Atmospheric Modeling and Observations Program

*Bulletin of the American
Meteorological Society*, 96
(11), 2015. doi:
<http://dx.doi.org/10.1175/BAMS-D-13-00131.1>



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 WKKER, 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. KULANDAYELU, 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. ZSEDOVITS

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

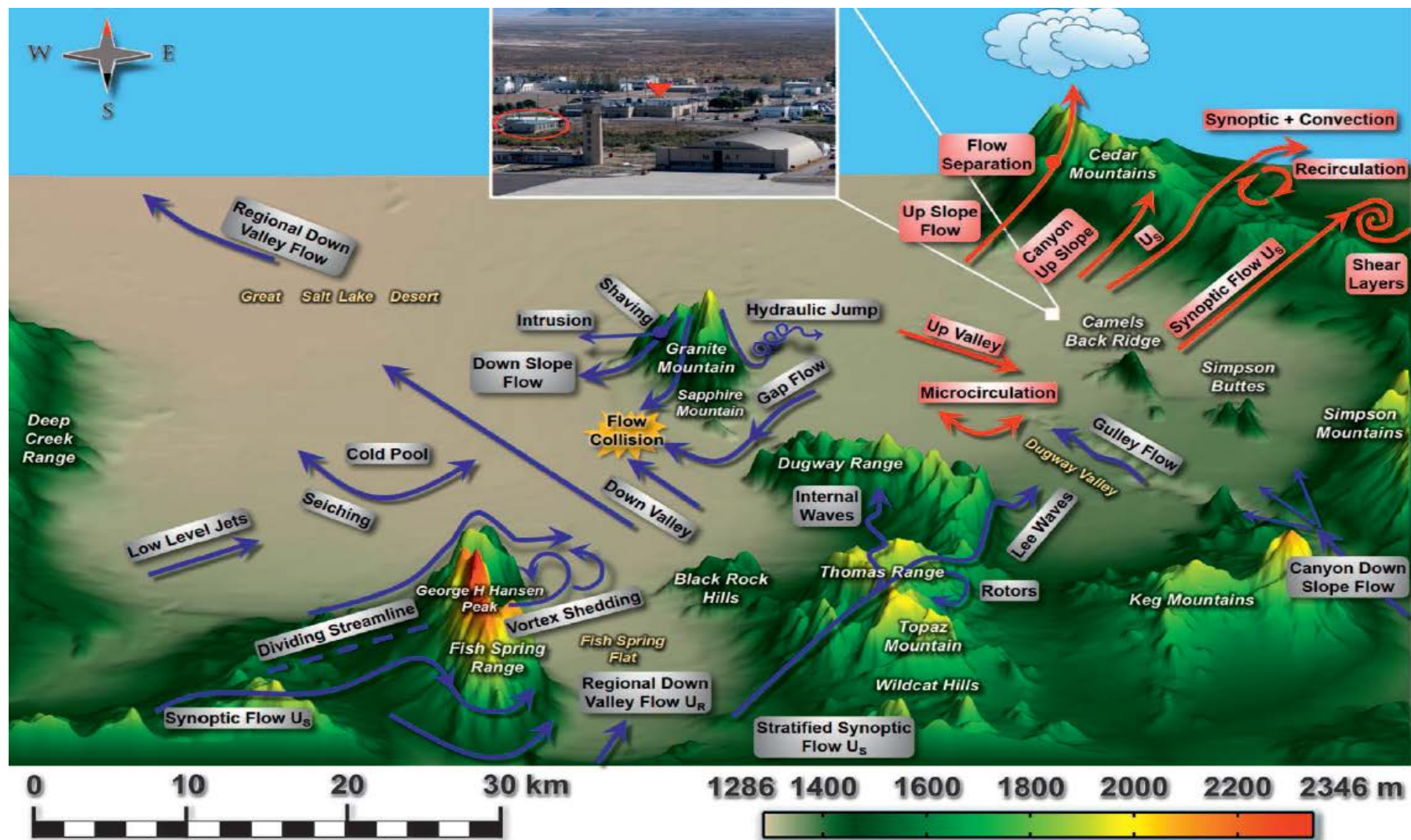


FIG. 1. Physical processes in complex terrain, illustrated on a topographic map of the DPG domain. The spatial and the elevation (shading) scales are shown below. Blue arrows represent nocturnal flows; red arrows represent daytime flows. An arbitrary direction has been used for illustration of synoptic 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 has four components working symbiotically across institutions and disciplines

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

MATERHORN Fall and Spring

Granite Mountain Atmospheric Science Test bed (GMAST)

US Army Dugway Proving Ground (1252 sq. miles)

Calm Winds (FALL) – October 1 - 31, 2012

Synoptic Winds (SPRING) – May 1-30, 2013

10 Intensive Operational Periods IOPs each (24-36 hrs)

5 Intensive Operational Locations IOLs

~ 50 TB Data from MATERHORN 1 and 2

MATERHORN - Fog

November 30 2014 – January 20, 2015

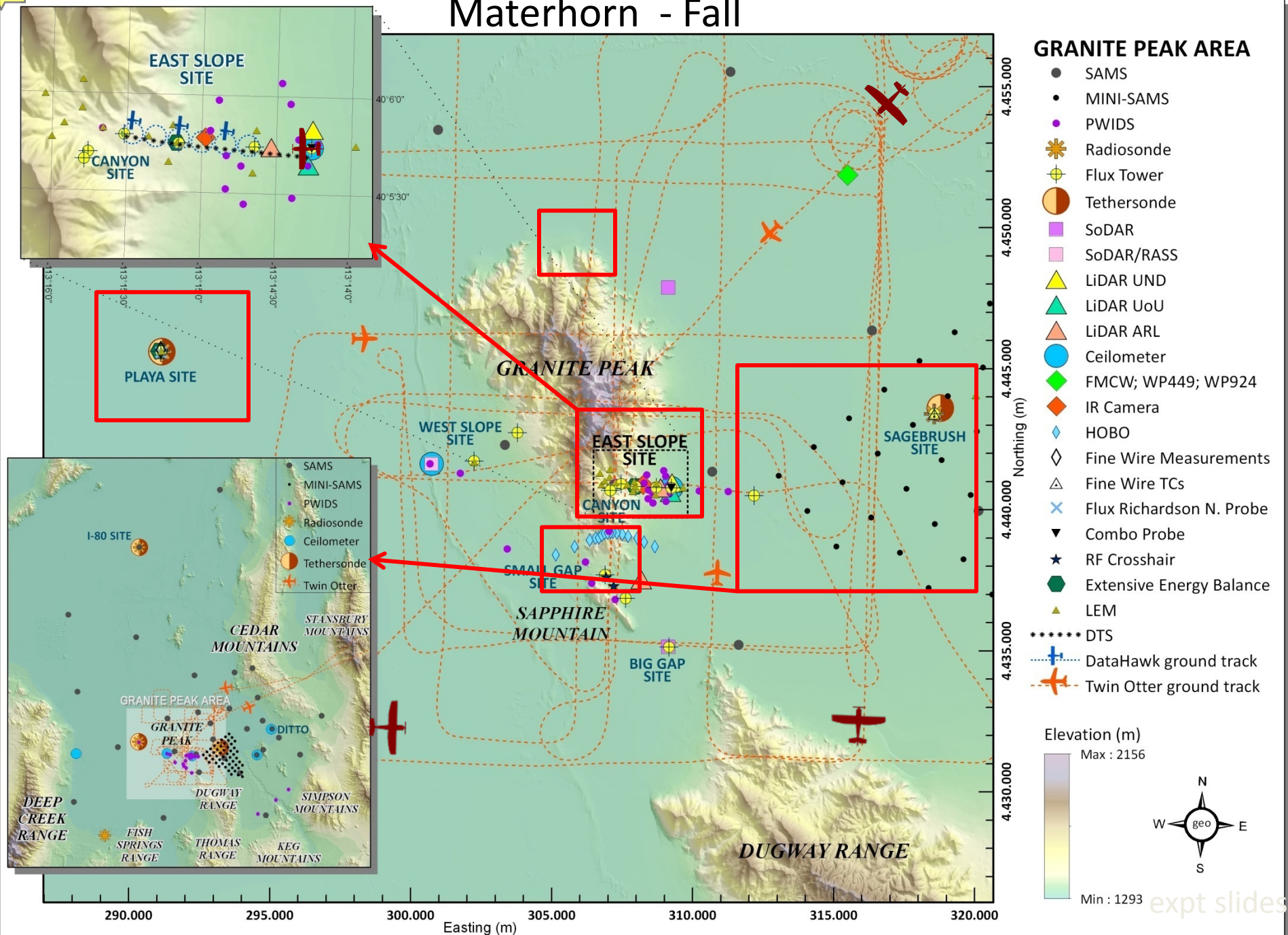
10 IOPs

2 Locations

Heber Valley and Salt Lake Valley

Canada Environment joined in the effort

Materhorn - Fall



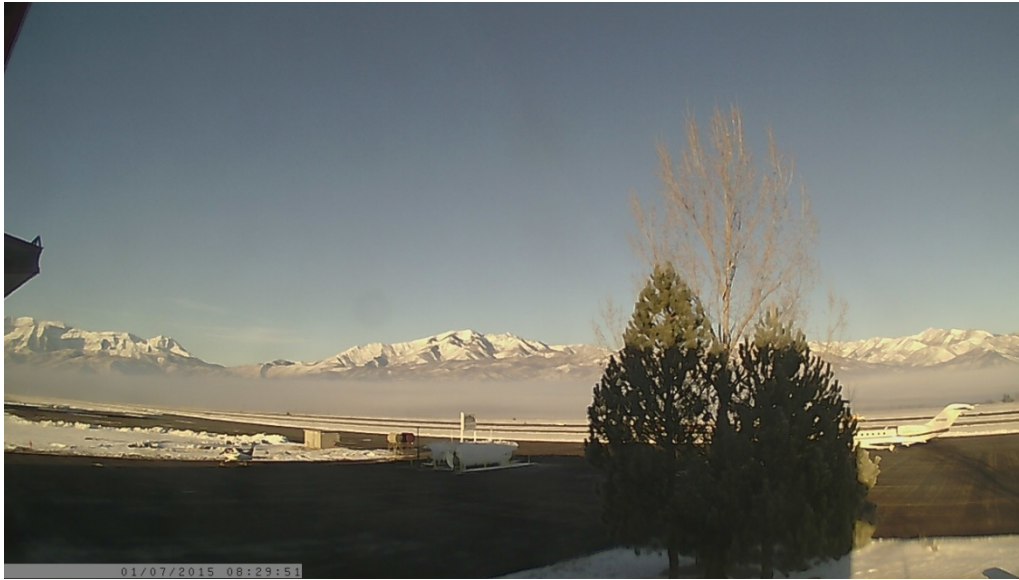
Granite Mountain

Test Bed [GMAST]

US Army Dugway Proving Ground



MATERHORN-FOG



Heber Valley

Salt Lake Valley

Nov 30 – Feb 15, 2015





- Radiosondes
- Full radiation budget
- Flow and turbulence
- Particle counters
- Visibility
- Nephelometer
- Camera
- Temp and RH
- Lidars and MWR

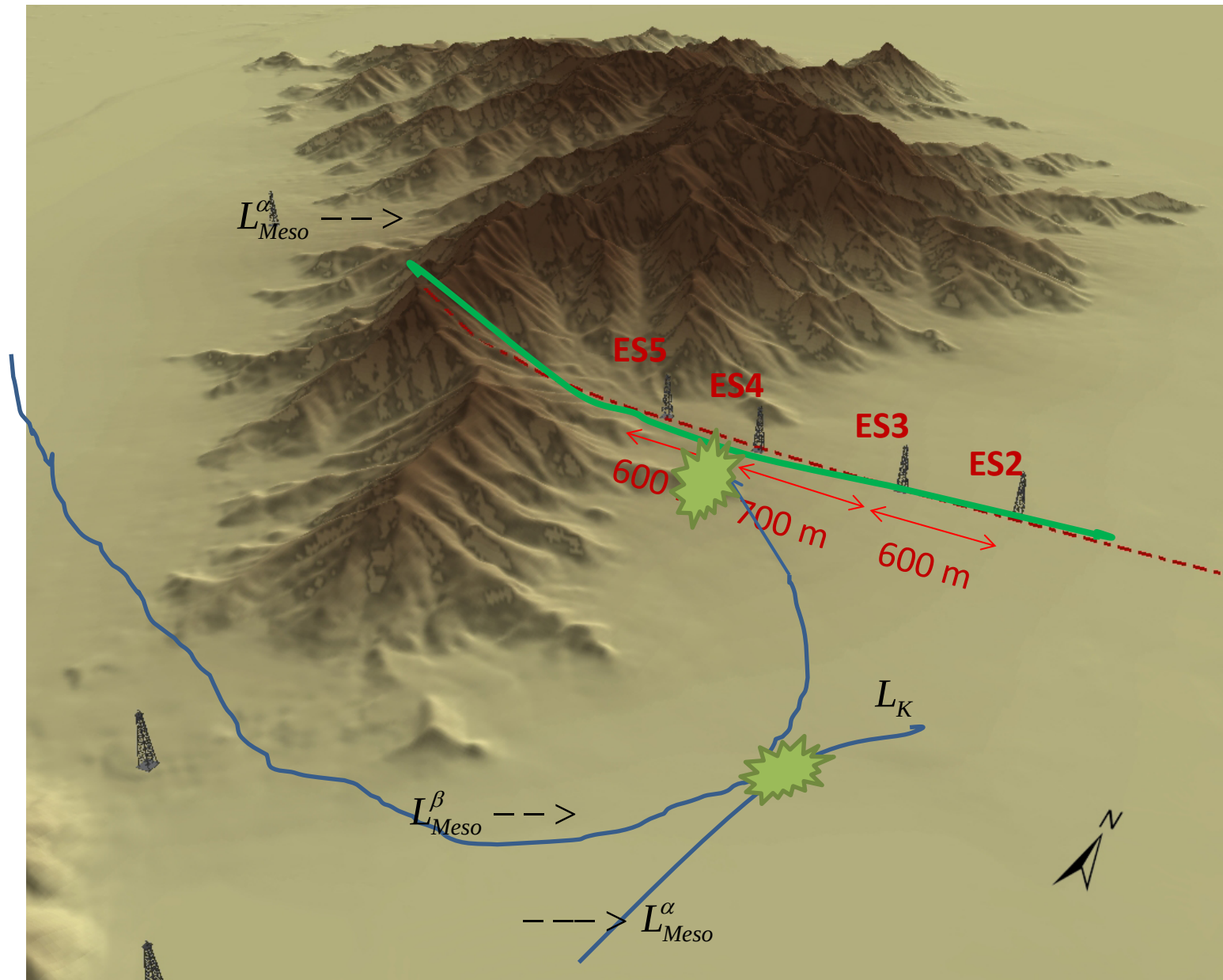


Gultepe, I., Fernando, H.J.S., Pardyjak, E., Hoch, S.W., Silver, Z., Creegan, E., Leo, L.S., P, Z., de Wekker S., Hang, C., Mountain Ice Fog: Observations and Predictability" *Pure and Applied Geophysics*, Revision submitted.

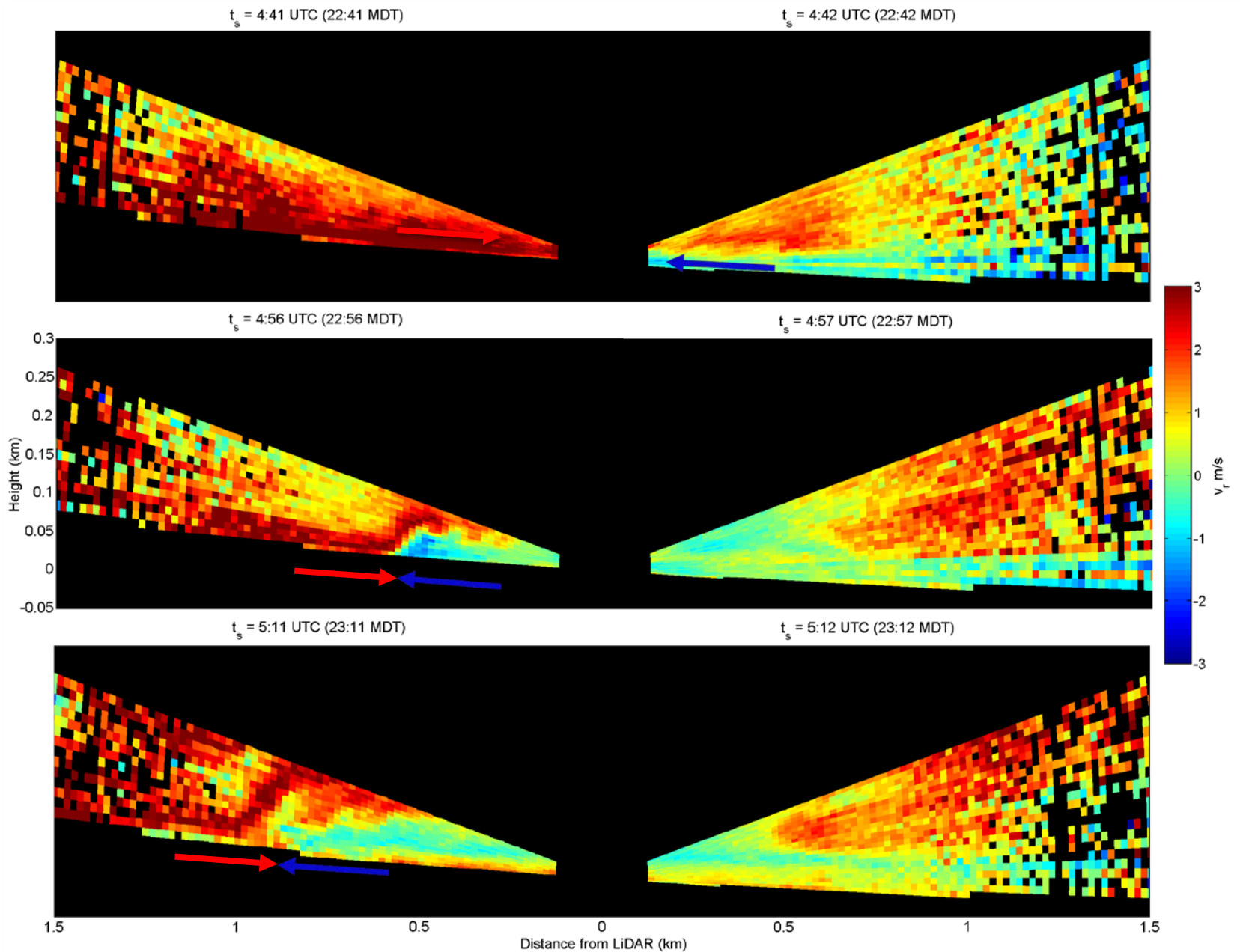
MATERHORN-X Results

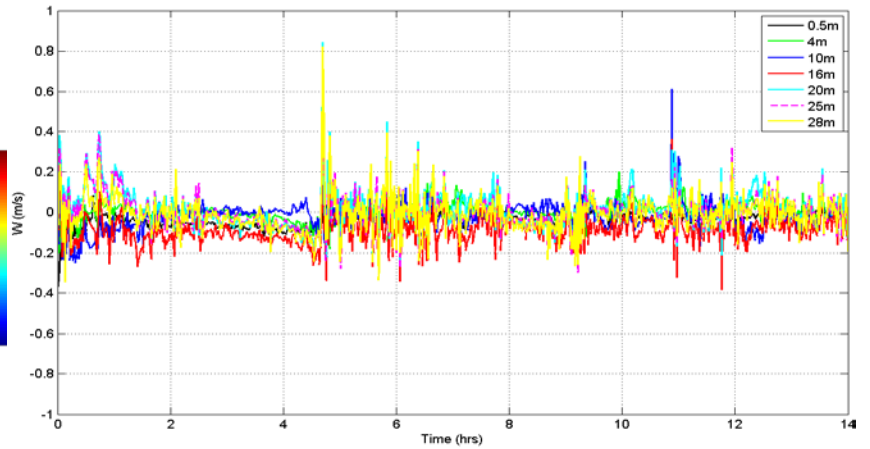
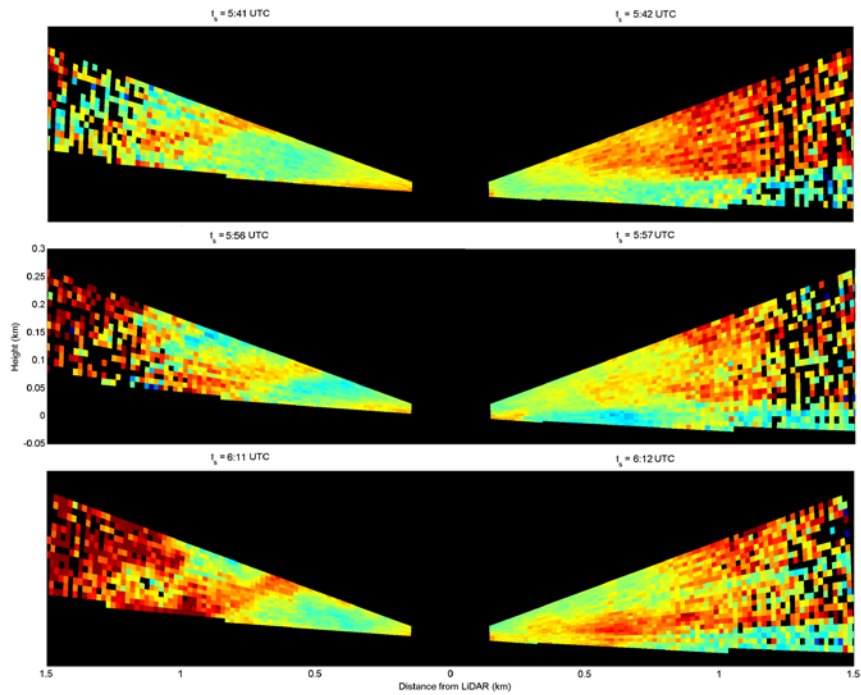
- An example

Flow Collisions

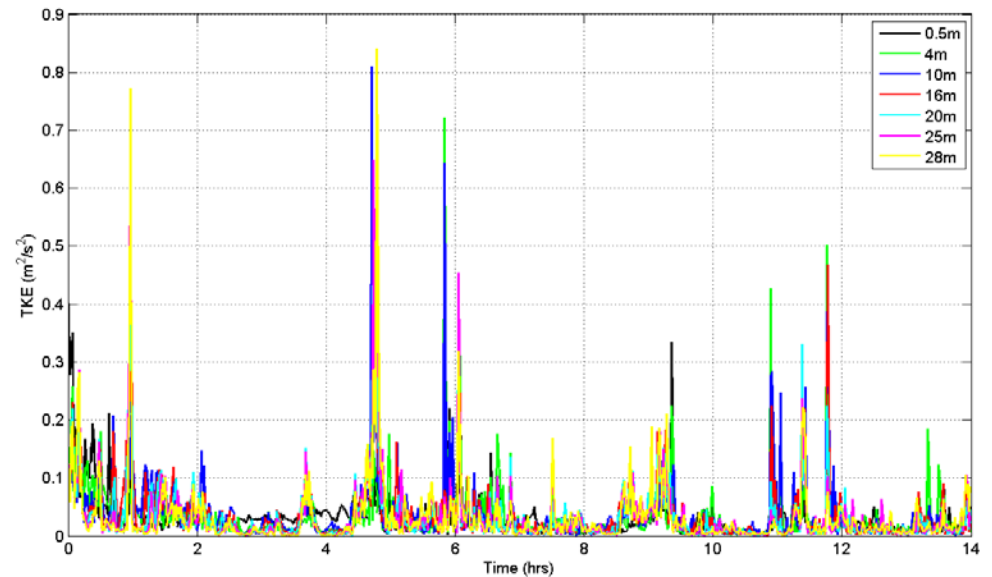


East Slope LiDAR - 4:41– 5:11 UTC (22:41 – 23:11 MDT)

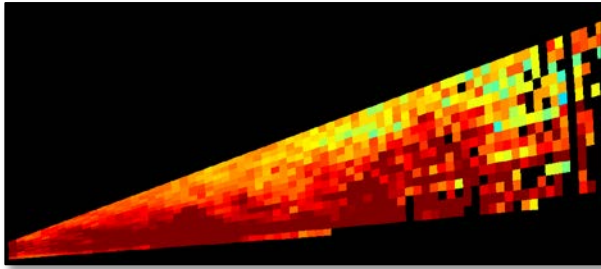




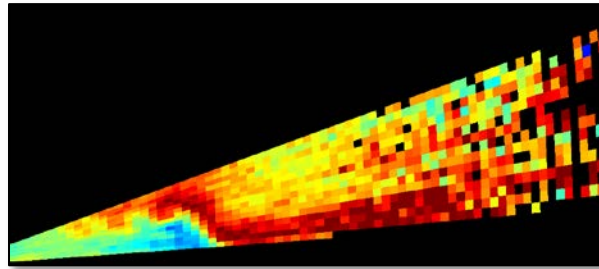
Secondary Collisions



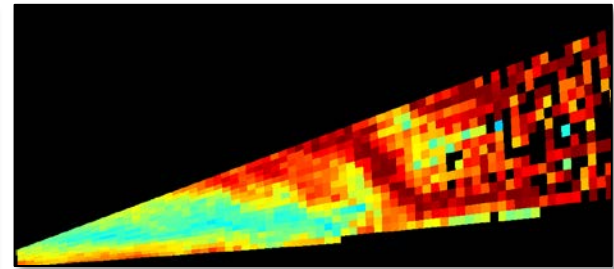
Gravity Currents Collide



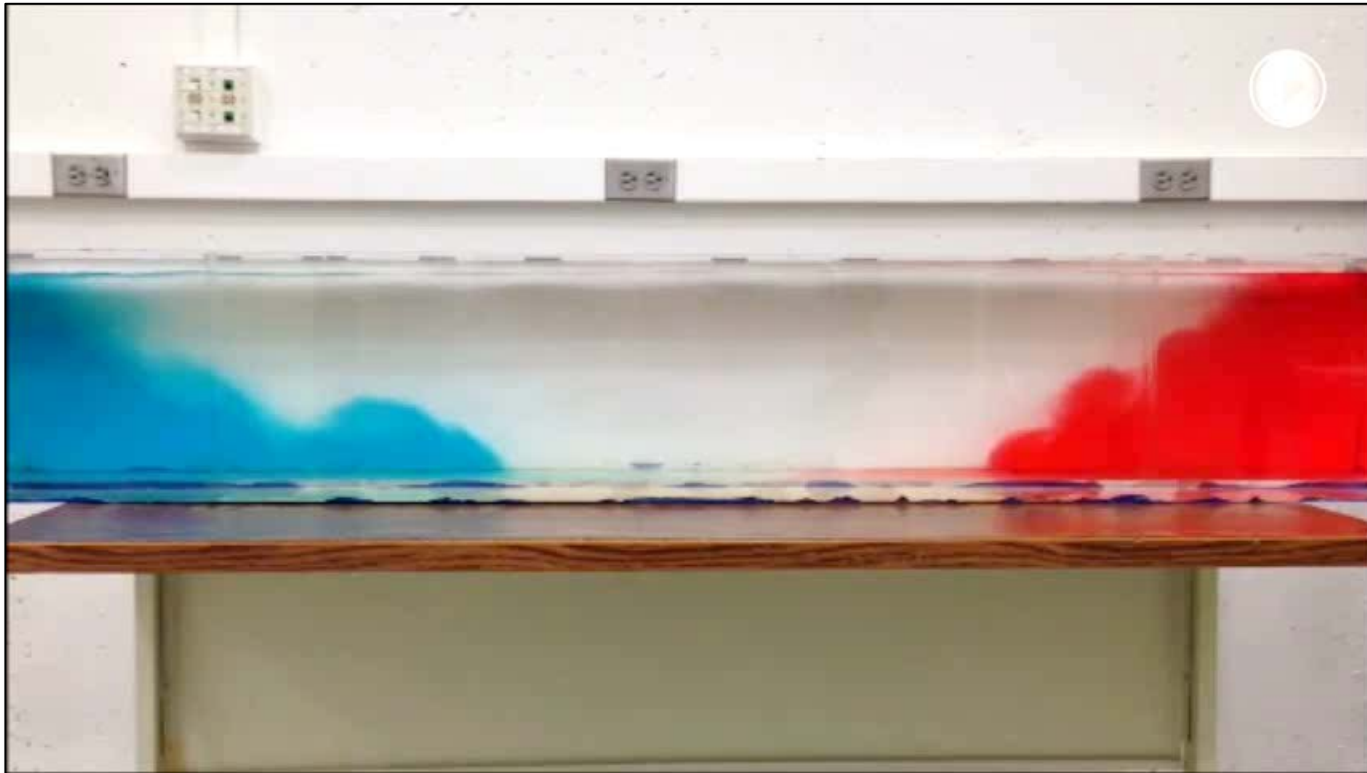
4:41 UTC (22:41 MDT)



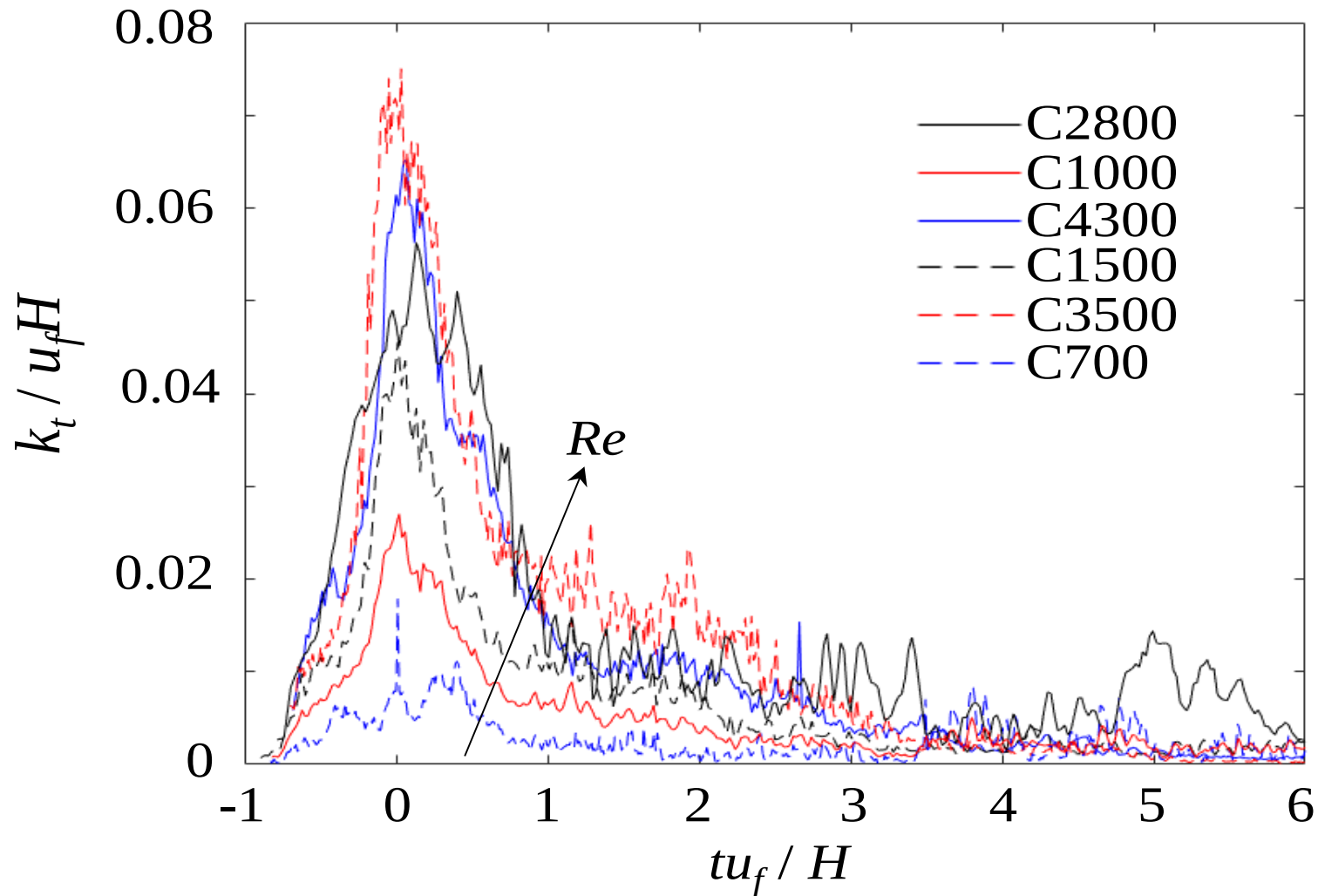
4:54 UTC (22:54 MDT)



5:11 UTC (23:11 MDT)



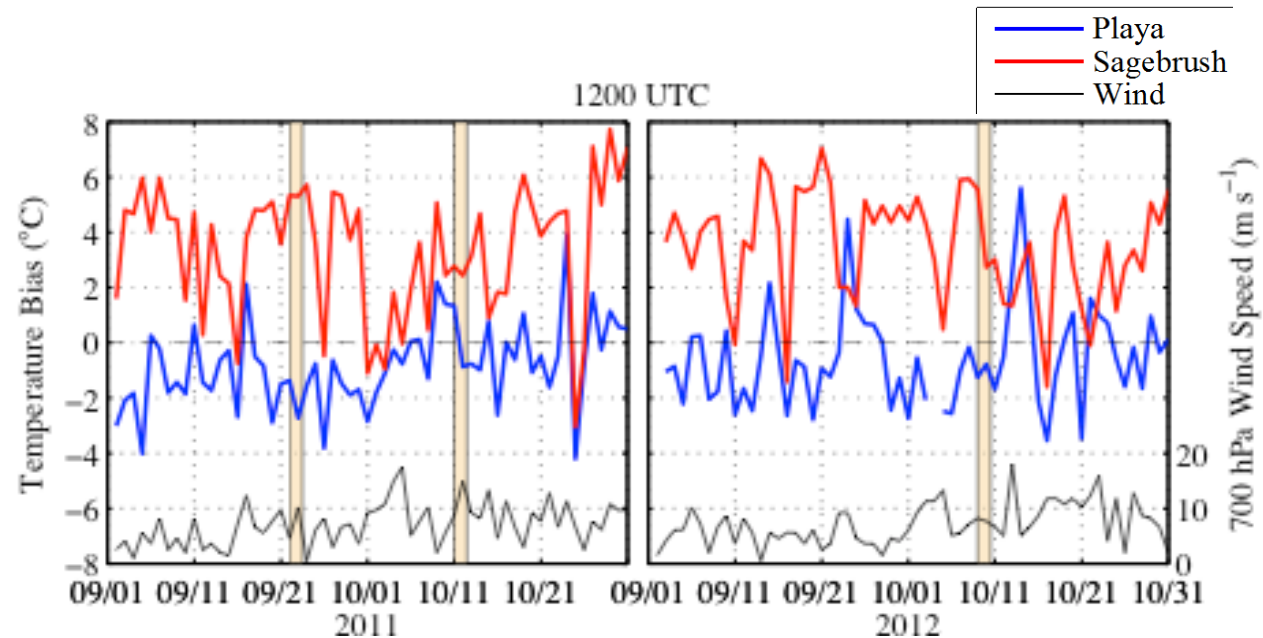
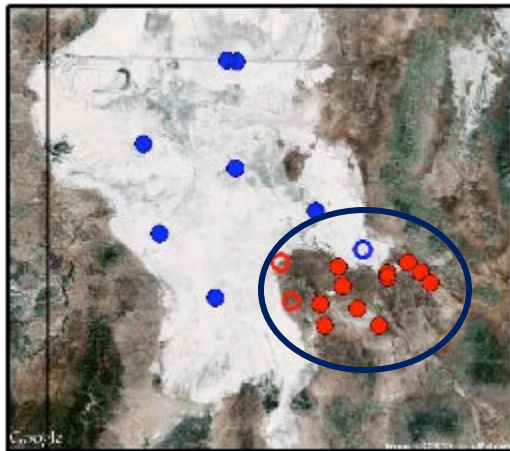
Eddy Diffusion Coefficient for Modelers



MATERHORN-M

...Improving predictability on
mesoscale

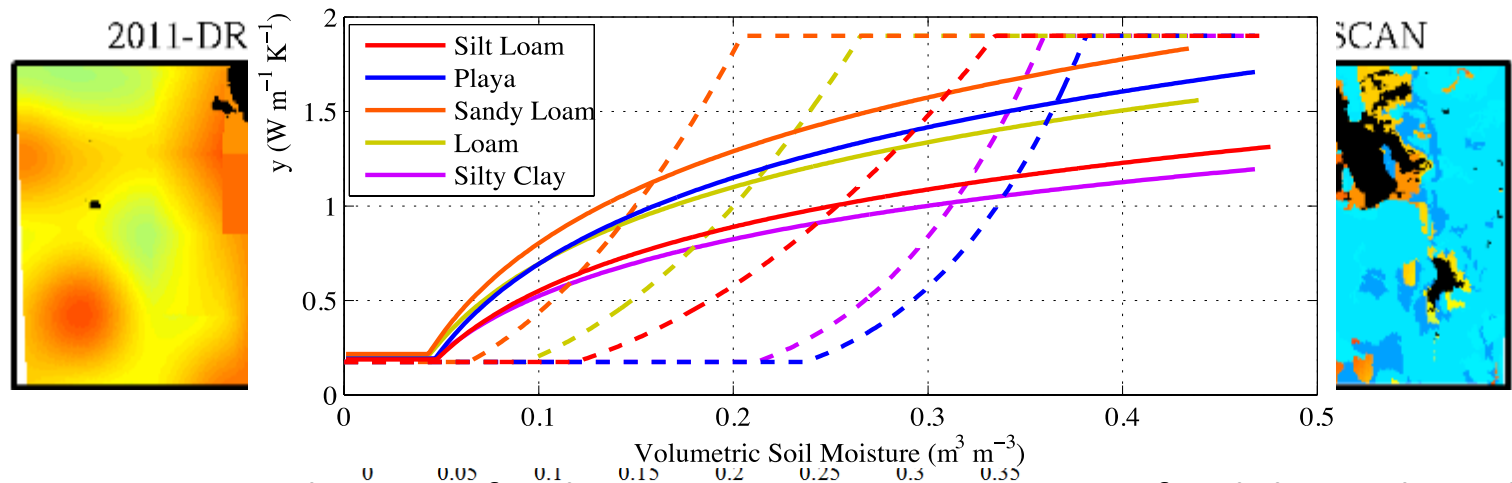
Example - Improving Surface Forecasts



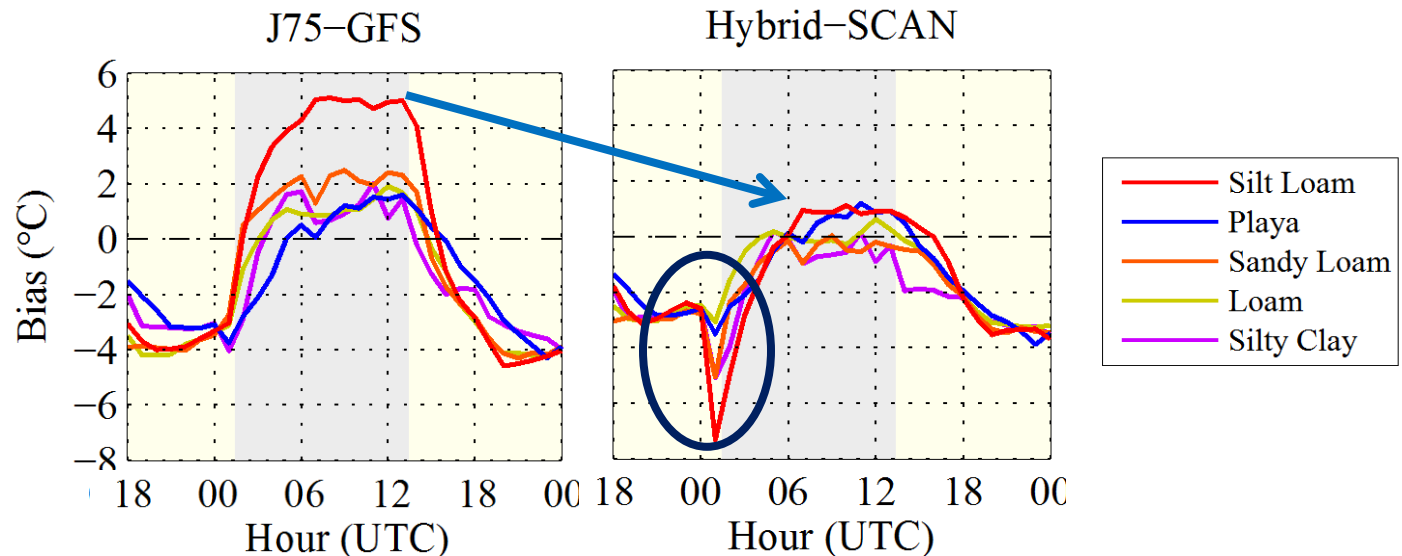
Issue: Atmospheric models (e.g., WRF) are too warm at night over the sagebrush region at DPG (systemic)

Implications: Poorly simulated NBL -> errors in the prediction of near-surface winds and turbulence, dust emissions and transport, etc.

Example - Findings and Advances



Error Sources: Initialization of soil moisture; Parameterization of soil thermal conductivity



Advances: Improved initialization and parameterization of soil characteristics

Remaining Challenge: Improving soil moisture analyses in data sparse regions

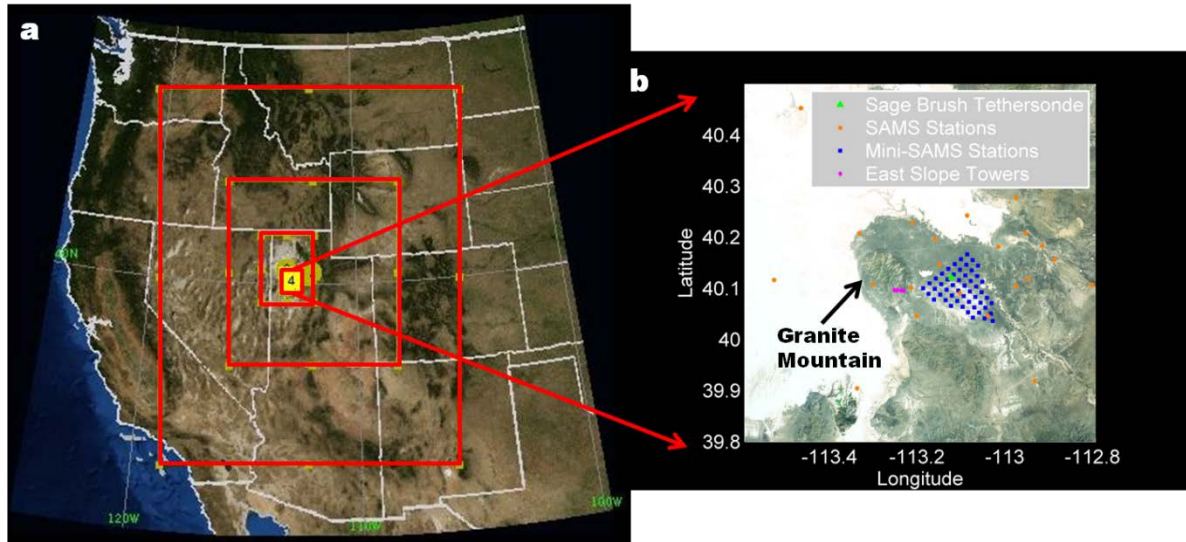
MATERHORN-P

Improve mixing parameterizations
via improved physics

(observations, high resolution
simulations, laboratory experiments)

Implement them in models

Evaluation of PBL Schemes in WRF using MATERHORN Data (started with Massey et al. surface properties)

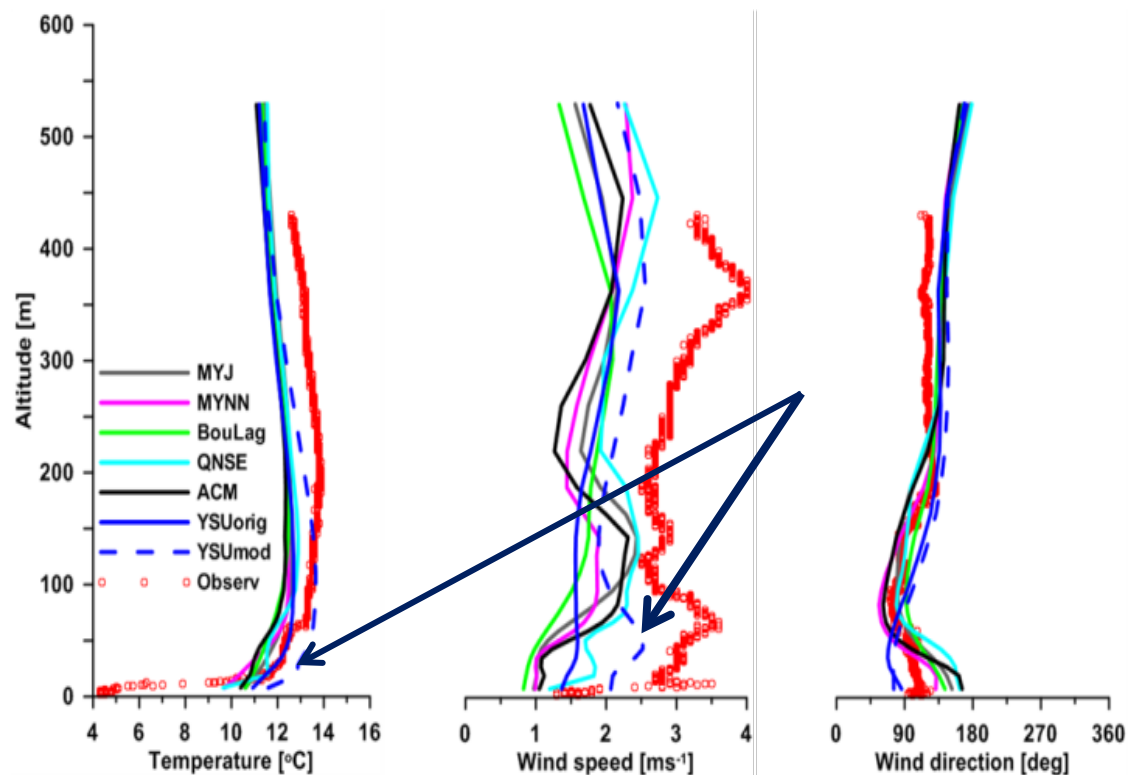


*Dimitrova et al.
BLM, 2016*

- Yonsei University - YSU (Hong et al. 2006)
- Asymmetric Convective Model - ACM2 (Pleim, 2007a)
- Mellor-Yamada-Janjic - MYJ (Janjic, 1990)
- Mellor-Yamada Nakanishi and Niino Level 2.5 – MYNN (Nakanishi and Niino, 2006)
- Bougeault and Lacarrere - BouLac (Bougeault and Lacarrere, 1989)
- Quasi-Normal Scale Elimination - QNSE (Sukoriansky et al. 2005)

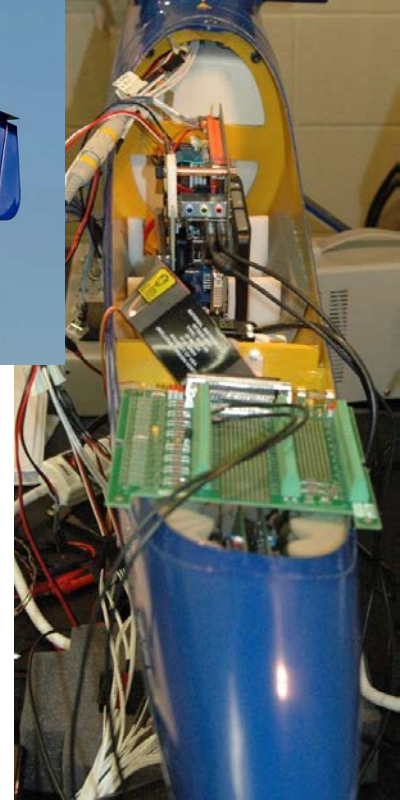
$$\text{YSU Modified} \quad K_m = 0.34 Ri_g^{-0.02} \sigma_w^2 \left| d\vec{V} / dz \right|^{-1} \quad K_h = 0.08 Ri_g^{-0.49} \sigma_w^2 \left| d\vec{V} / dz \right|^{-1}$$

Vertical profile comparison between different PBL schemes and tethered-balloon soundings at SB site, IOP 8



MATERHORN-T

...pushing technological frontiers

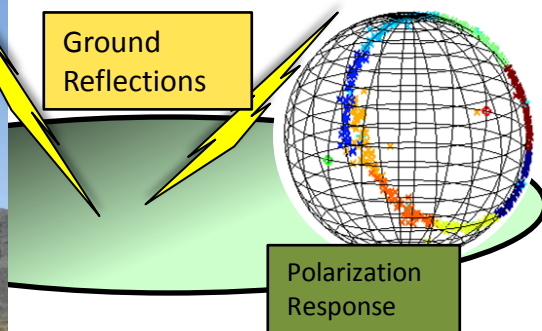


• Unmanned Aerial Vehicle

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



System deployed on tower near east slope of Granite Mountain

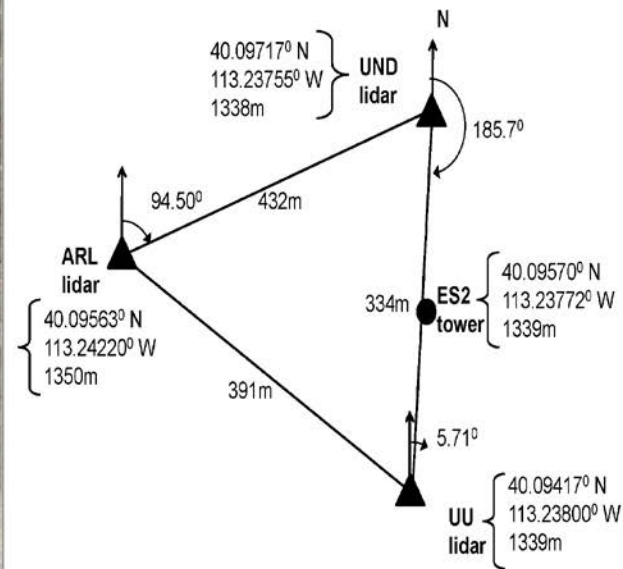
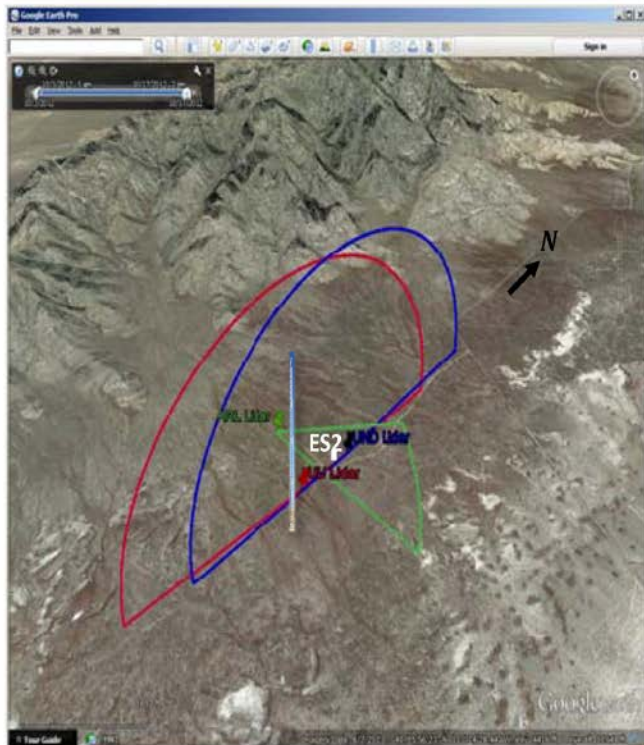


• Designed, Constructed and Deployed three-frequency sensor systems to collection RF polarimetric data – for moisture (RF Cross-wires)

- Extensive data, two MATERHORN sites, moisture calibration
- Developed theoretical electromagnetic modeling
- Field Research Vehicle (DURIP)

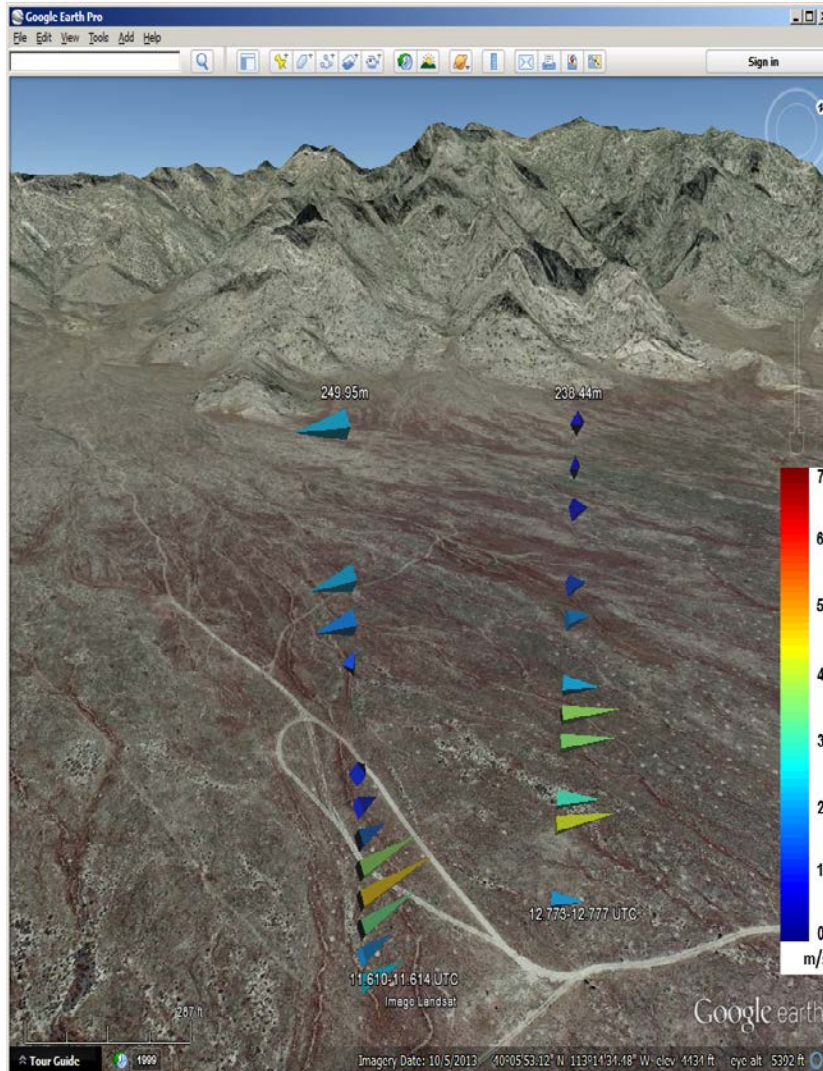
Triple Lidar deployment

MATERHORN FALL 2012



Wang, Y., Creegan, E., Felton M., Huynh, G., Hocut, C., Fernando, H.J.S., Hoch, S., Whiteman, C.D., "Triple Doppler wind lidar observations during the MATERHORN field project" *Journal of Applied Remote Sensing*, 10(2), 026015 (2016).

Virtual Tower using Triple Lidar!



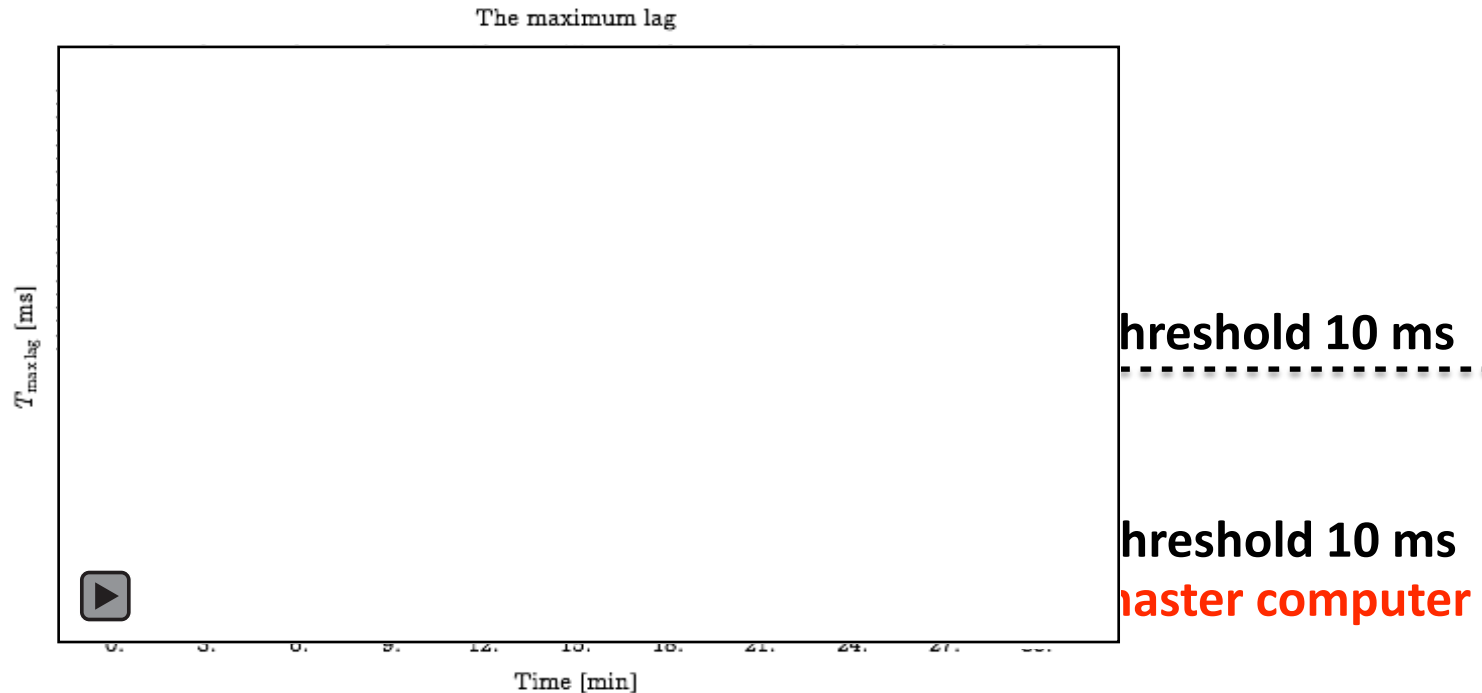
Examples of vertical profile (virtual towers) 3D wind vectors retrieved from coordinated triple Doppler wind lidars scanning on 7 October 2012. The down valley low-level jet was evident in these virtual towers at 11.61 to 12.77 UTC (0537 to 0646 MDT). The horizontal distance between two virtual towers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

Notre Dame will 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**

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)

Major accomplishments – Year 4

- 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)

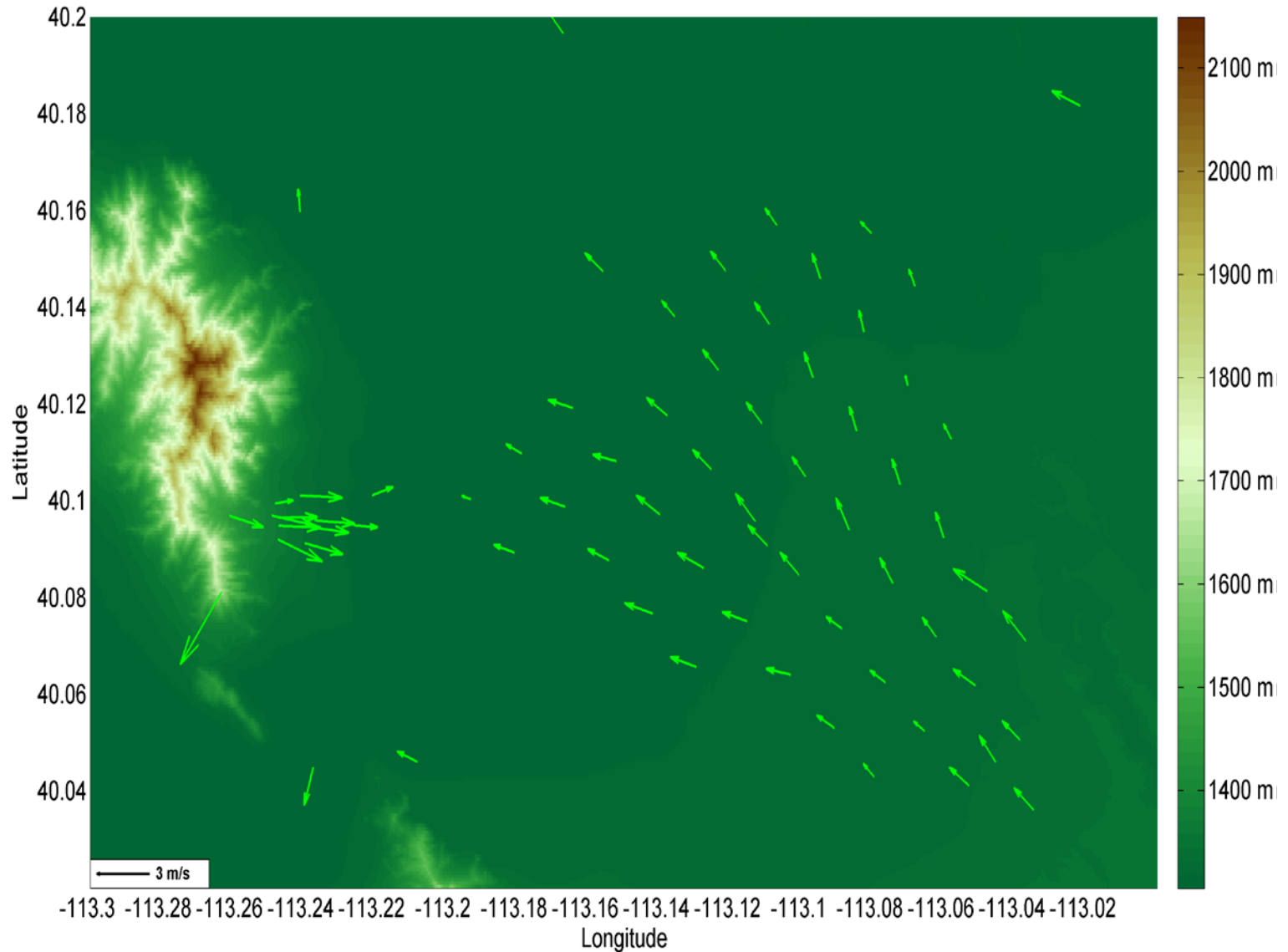
- Senior Pls: 11
- Research faculty: 4 , ~~5~~, 5
- Technical staff: ~~8~~, 8
- Post docs: ~~8~~ ~~13~~, 13
- Graduate Students : ~~18~~, ~~22~~, 18 PhD and 9 MS (Total 27)
- Undergraduate Students: ~~13~~ ~~22~~, 25
- Collaborators (proposal): ~~5 (supported 2)~~, 5 (3)
- Collaborators : ~~11~~, 10

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



Thank you

Proper Orthogonal Decomposition of Velocity Vectors



10/19/2012 21:59 MDT

10/19/2012 03:59 UTC

Ex: Immersed boundary method (IBM) development

