Observations and modeling of boundary layer processes in complex terrain

Stephan De Wekker
University of Virginia

Mark Sghiatti (MS student, August 2013)
Nevio Babic (PhD student, August 2014)
Ross Palomaki (MS student, August 2015)
Nathan Rose (MS student, August 2015)
Michael Van Den Bossche (post-doc, January 2014)
Sandip Pal (post-doc, February 2013 – August 2015)

+ collaborators:

Stefano Serafin (University of Vienna)
Dave Whiteman, Sebastian Hoch, Matt Jeglum (University of Utah)
Dave Emmitt (Simpson Weather Associates)
Jason Knievel (NCAR)
Jim Doyle (Naval Research Laboratory)

MATERHORN meeting
7 October 2015
University of Notre Dame

Summary of FY 15 activities

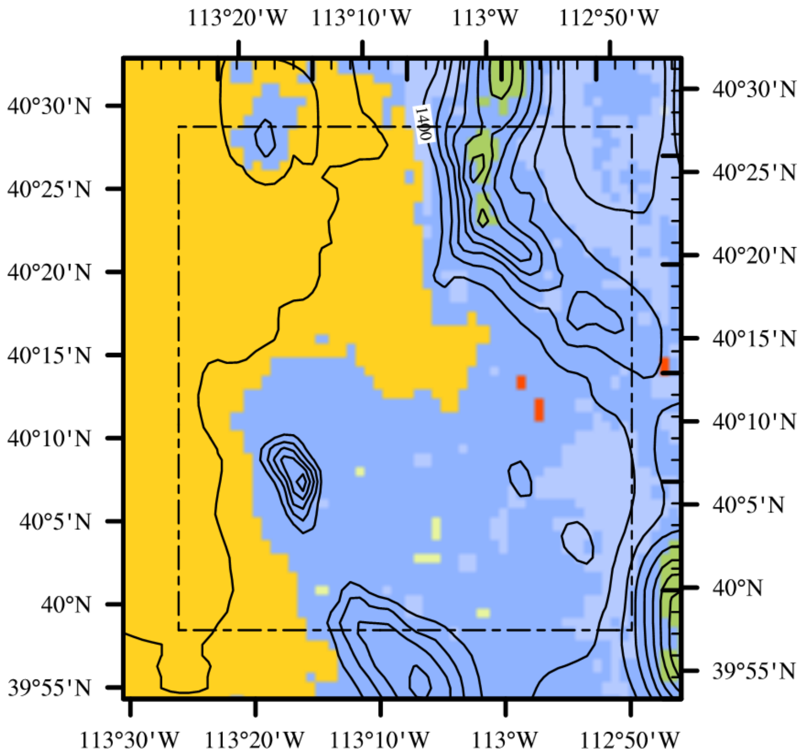
- Analyzing spatial variability of winds, ABL height, and turbulence kinetic energy using airborne Twin Otter Doppler Wind Lidar, airborne in-situ measurements, and a network of surface stations
- Analyzing two years of 4DWX output to investigate ABL height climatology and nocturnal boundary-layer processes over the MATERHORN investigation area
- Investigating the effects of non-stationarity in turbulence time series on the flux-variance functions in Monin-Obukhov similarity theory
- Investigating the relative contribution of complex topography and land-surface heterogeneity on the spatial variability in PBL height using idealized large-eddy-simulations
- Developing an unmanned aerial system consisting of a quad-copter and meteorological sensors for collecting vertical profiles of temperature, humidity, and wind (using tilt algorithm)
- Deploying 6 weather stations in MATERHON-FOG to collect 1 Hz measurements of wind, temperature, humidity, and pressure

1) climatography of daytime atmospheric boundary layer heights around Granite Mountain

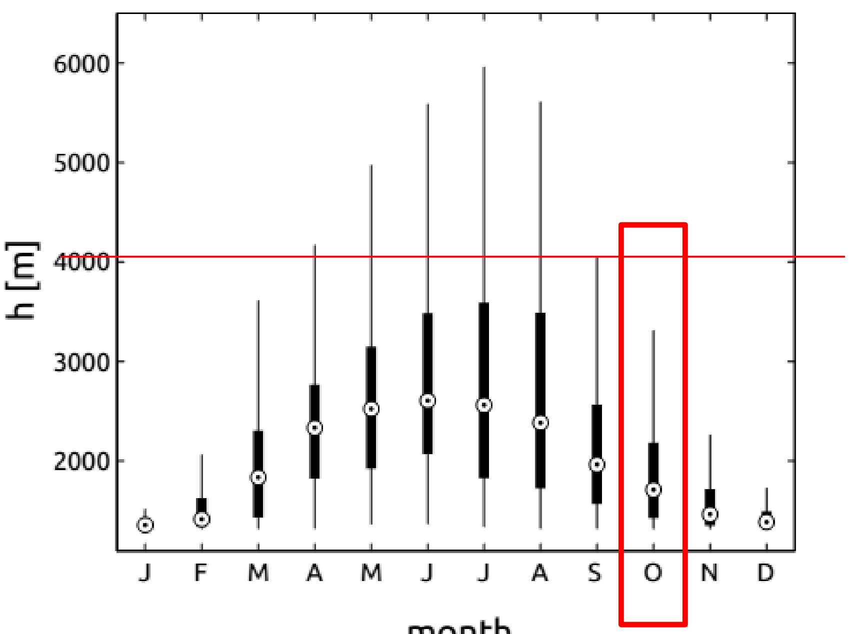
- What are typical ABL heights around Granite Mountain?
- What is the spatial variability of ABL heights and how is variability related to surface type differences and orography?
- How well does an operational forecast model at high resolution simulate the ABL heights?

Climatography: typical ABL heights from 4 DWX

4DWX: Operational forecast model for Dugway Proving Ground. Inner domain size of 60x60 grid points



Seasonal cycle of ABL height



Two years of 4DWX output (1 July 2012 to 30 June 2014) were used in this study.

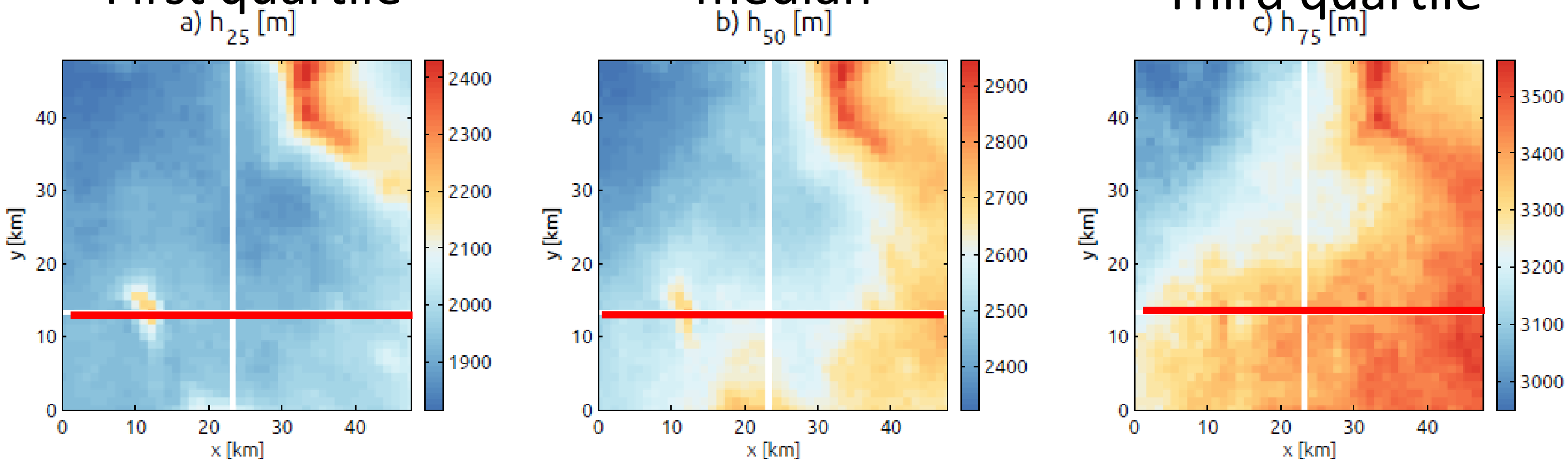
climatography: spatial ABL height variability

Daytime output from April to October

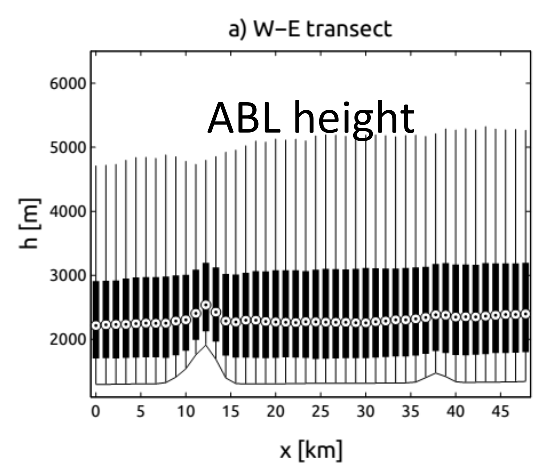
First quartile

median

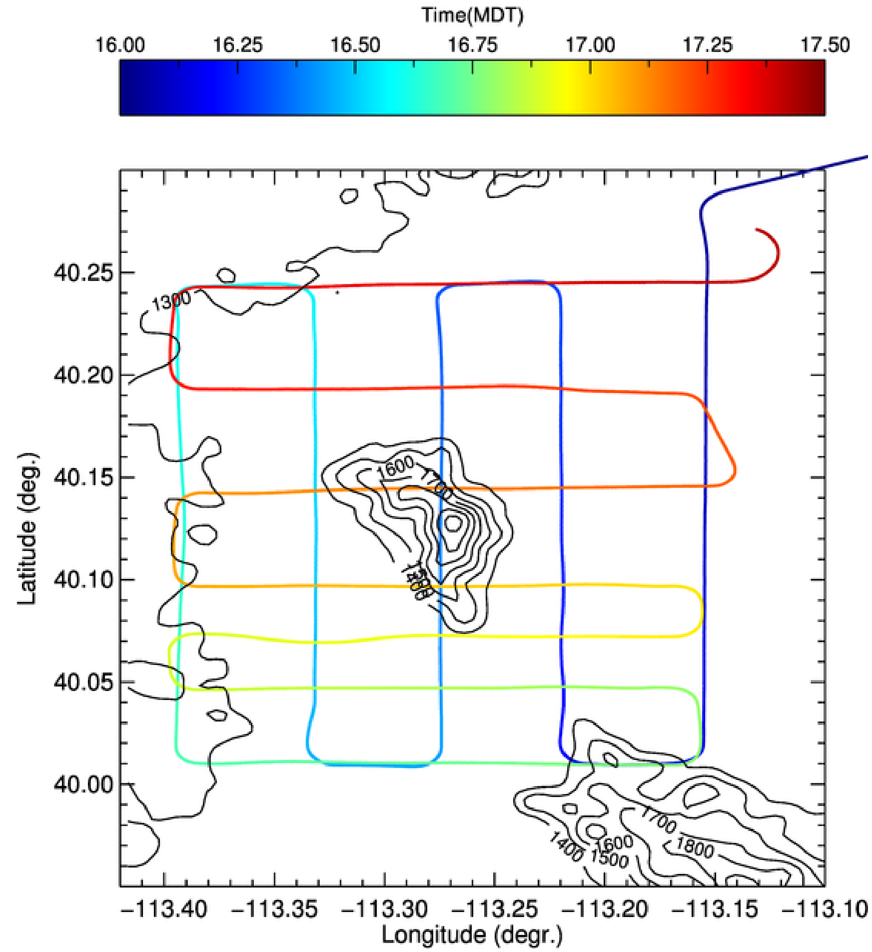
Third quartile



Gradual increase of ABL height from west (playa) to east (sagebrush), and from north to south



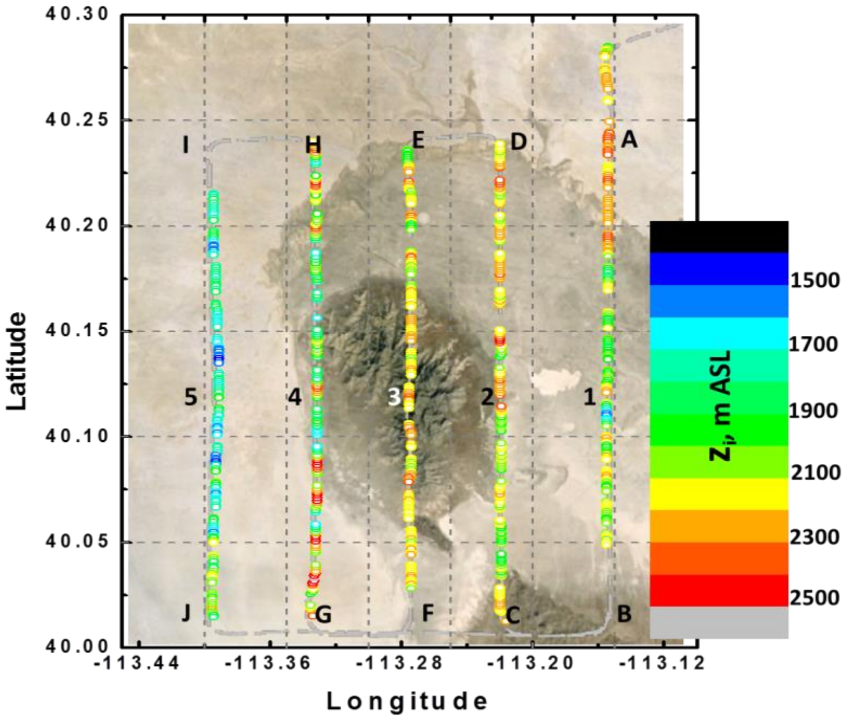
Twin Otter Doppler Wind Lidar Measurements

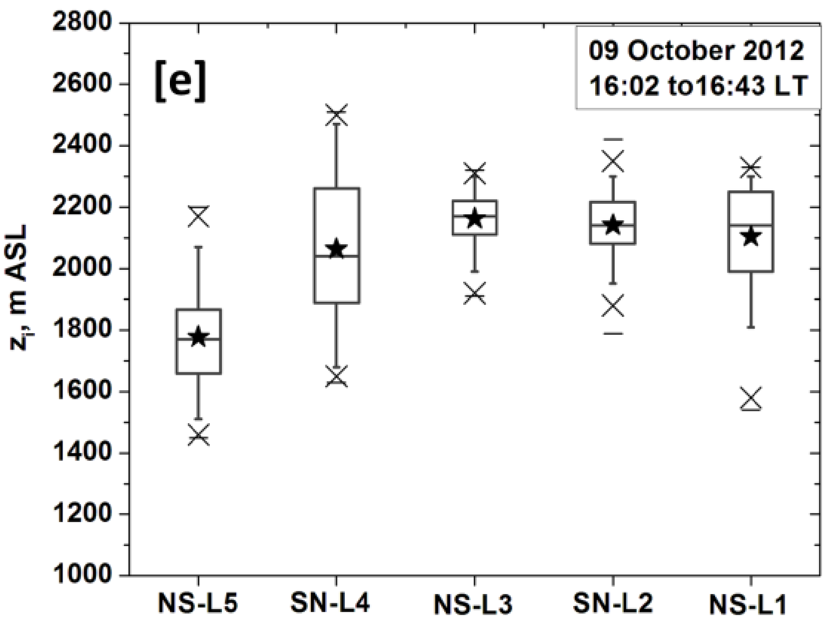


Typical TODWL flight pattern at 4 km MSL

Spatial ABL height from airborne Doppler lidar

Example: Afternoon 9 October 2012

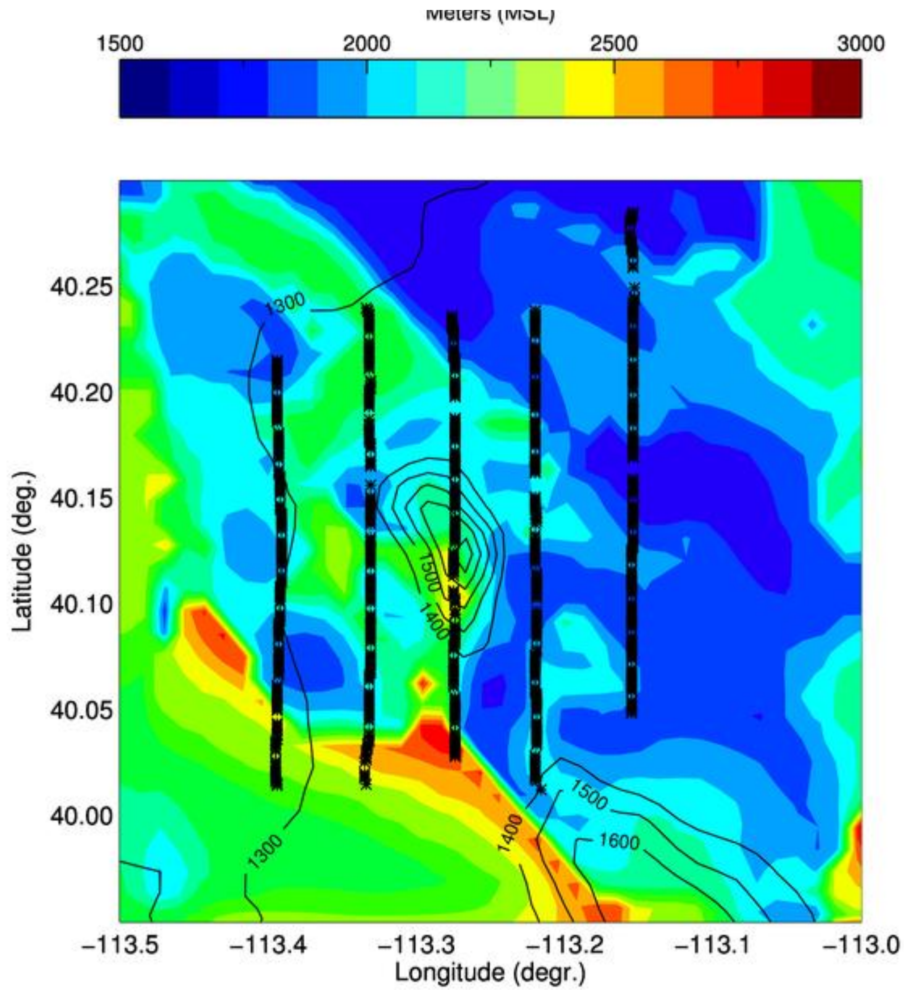




ABL height larger on the eastern side (sagebrush plain) than on the western (playa) side

Comparison of ABL heights from 4DWX simulations and from observations

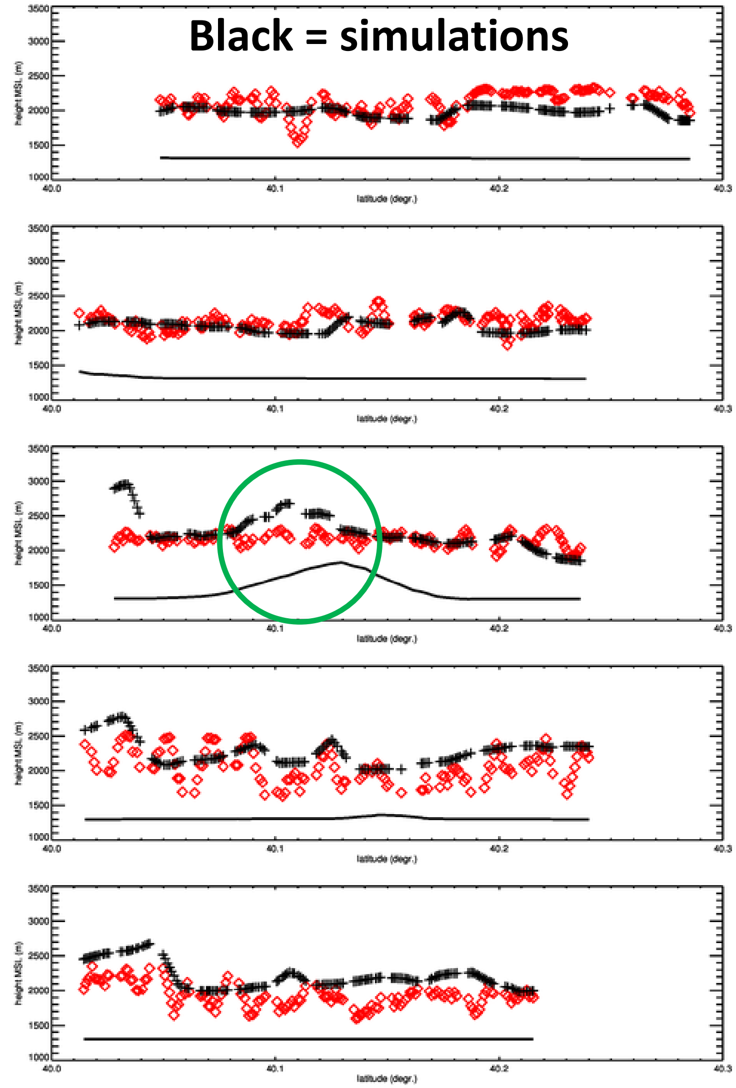
ABL height in meters (MSL) from 4DWX



9 October 2012, 23 UTC

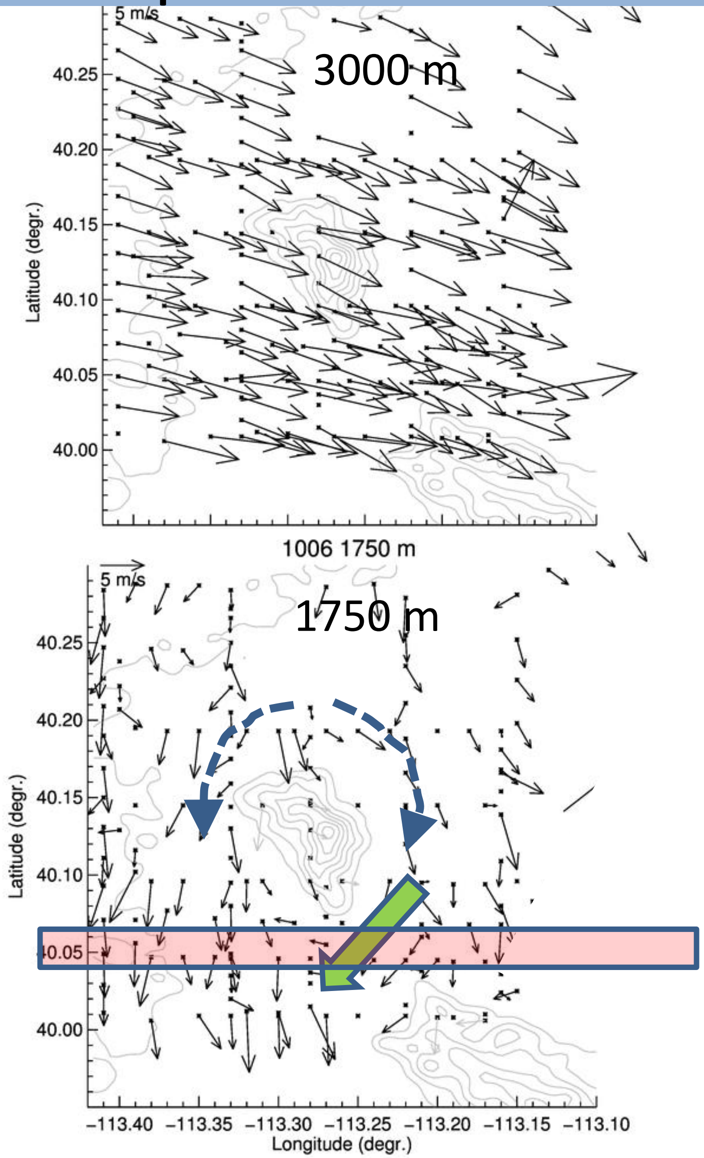
Red = observations

Black = simulations



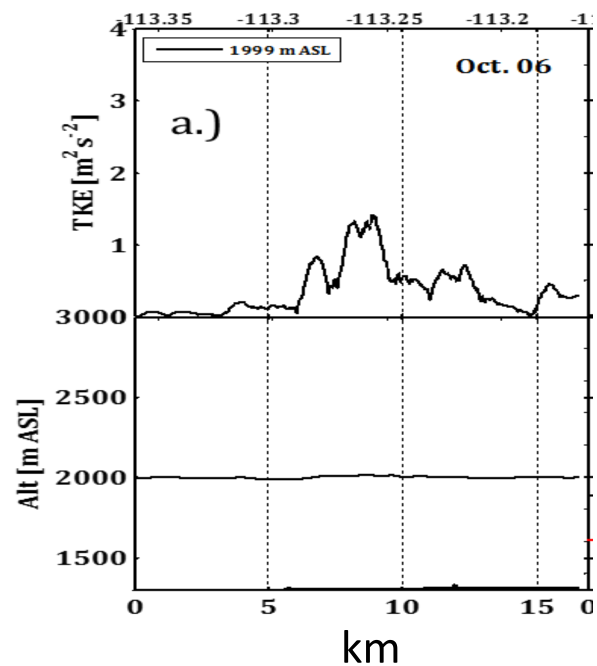
2) Spatial wind and turbulence structure from airborne data

wind pattern 06 Oct 2012



Twin Otter in situ measurements

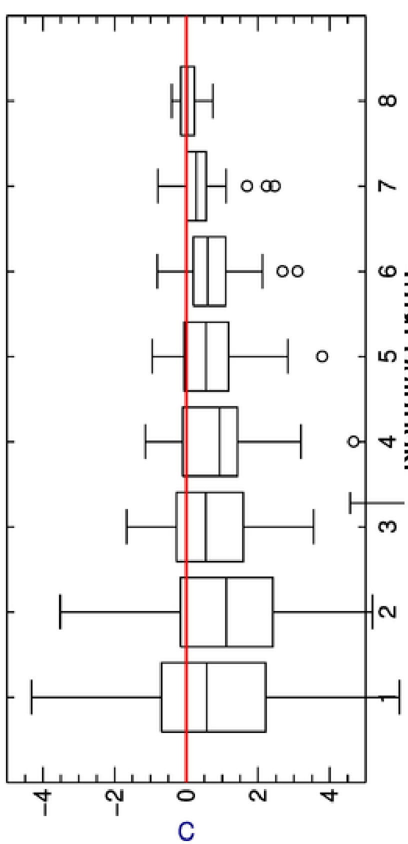
TKE along flight leg in gap at ~ 700m AGL

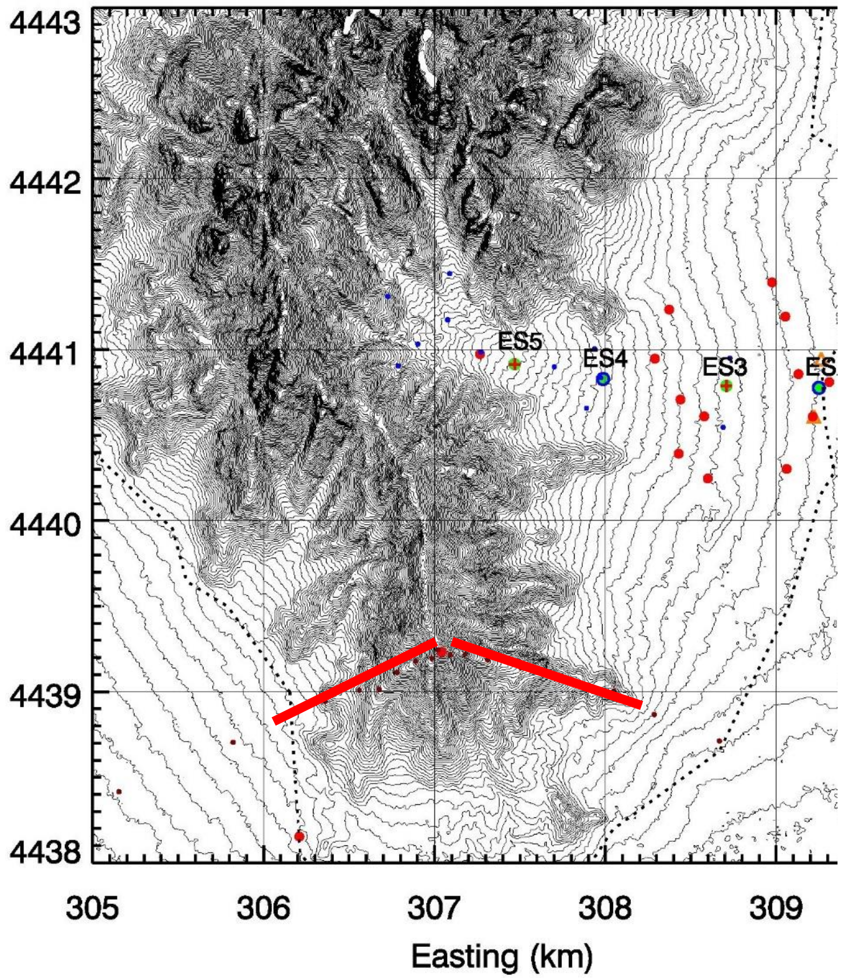


3) gap winds and differential ABL development on western and eastern side of Granite Mountain

nighttime

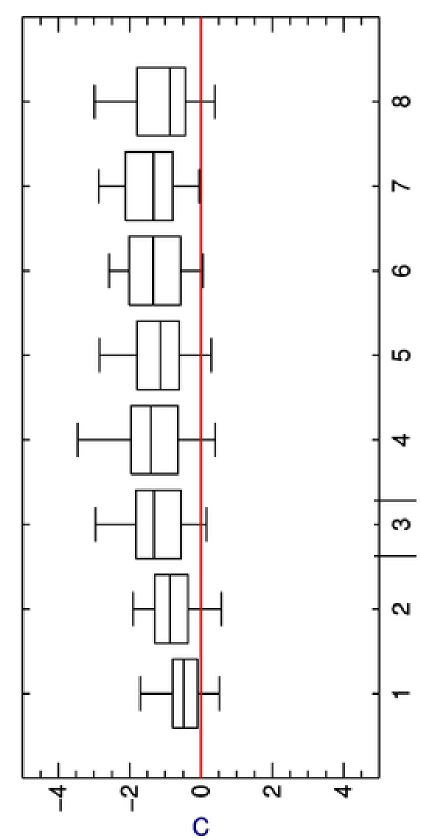
WESTERN SIDE COLDER





daytime

EASTERN SIDE COLDER



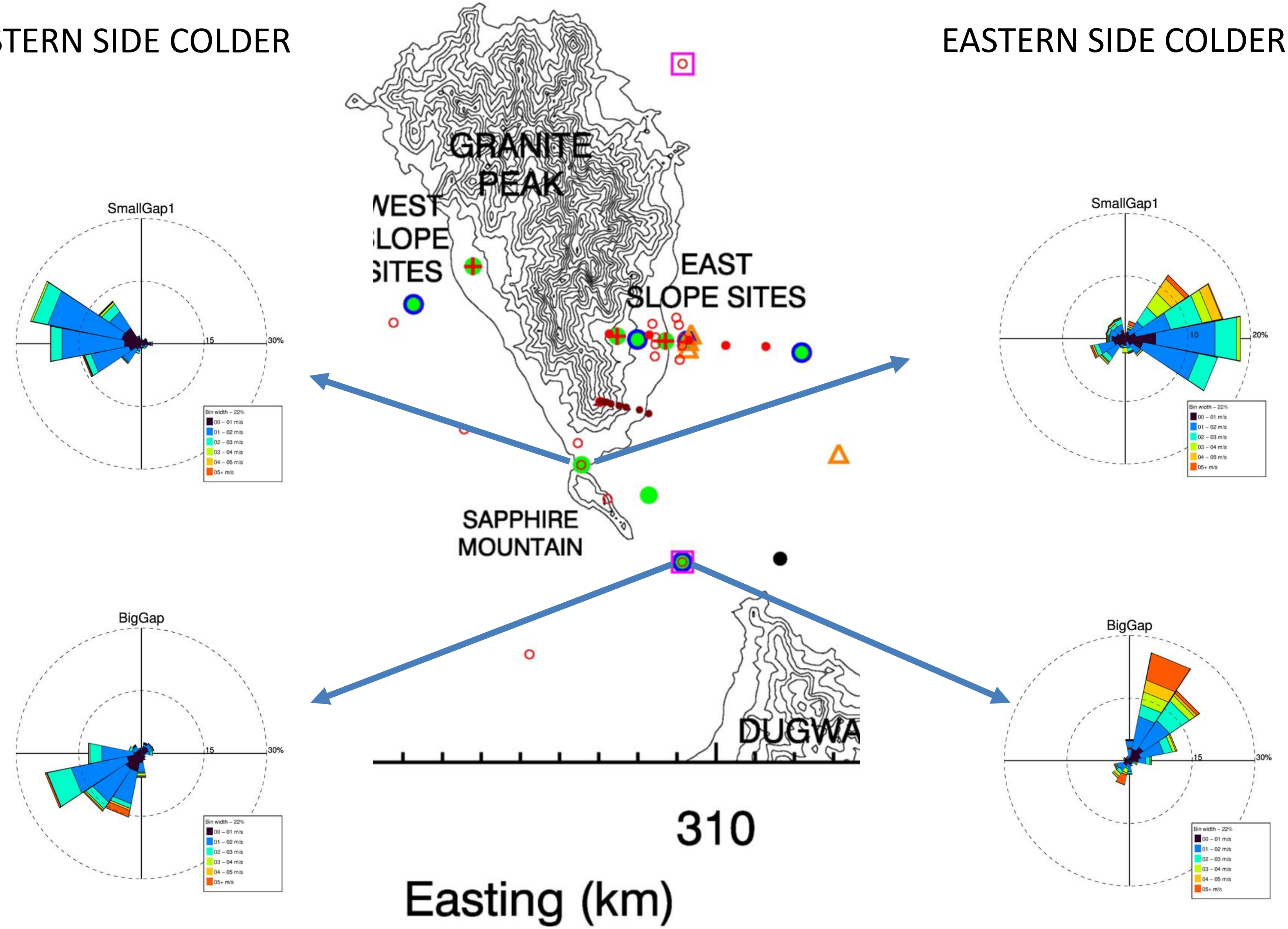
Thermally driven gap winds

nighttime

WESTERN SIDE COLDER

daytime

EASTERN SIDE COLDER



4) an algorithm to determine winds from the attitude of a hovering multi-rotor copter.

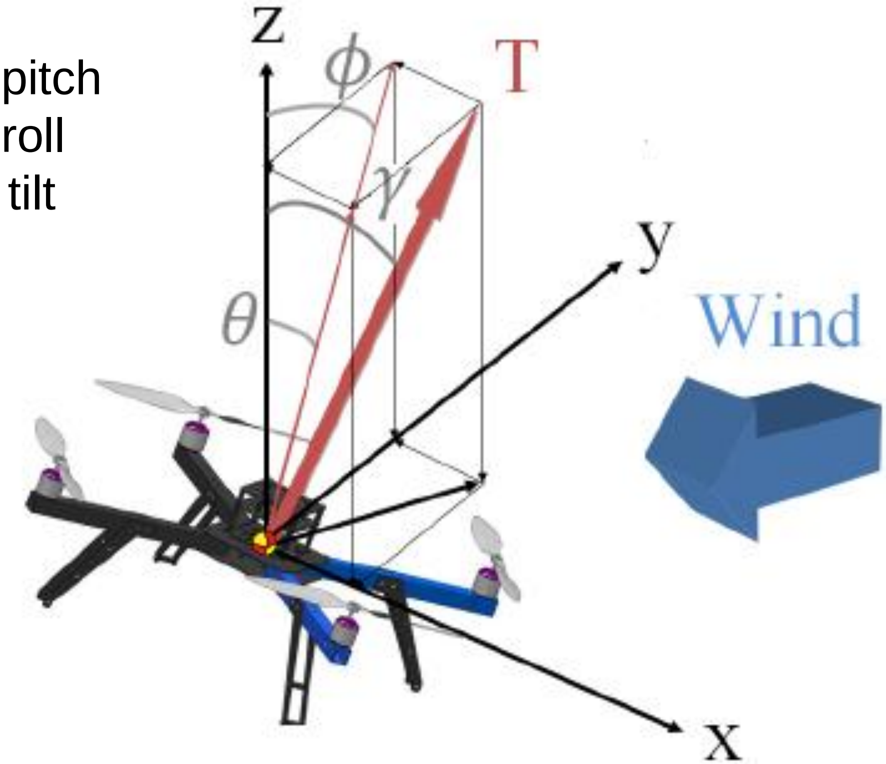
Three main forces act on the quadrotor system. These three forces are:

thrust ***T***,

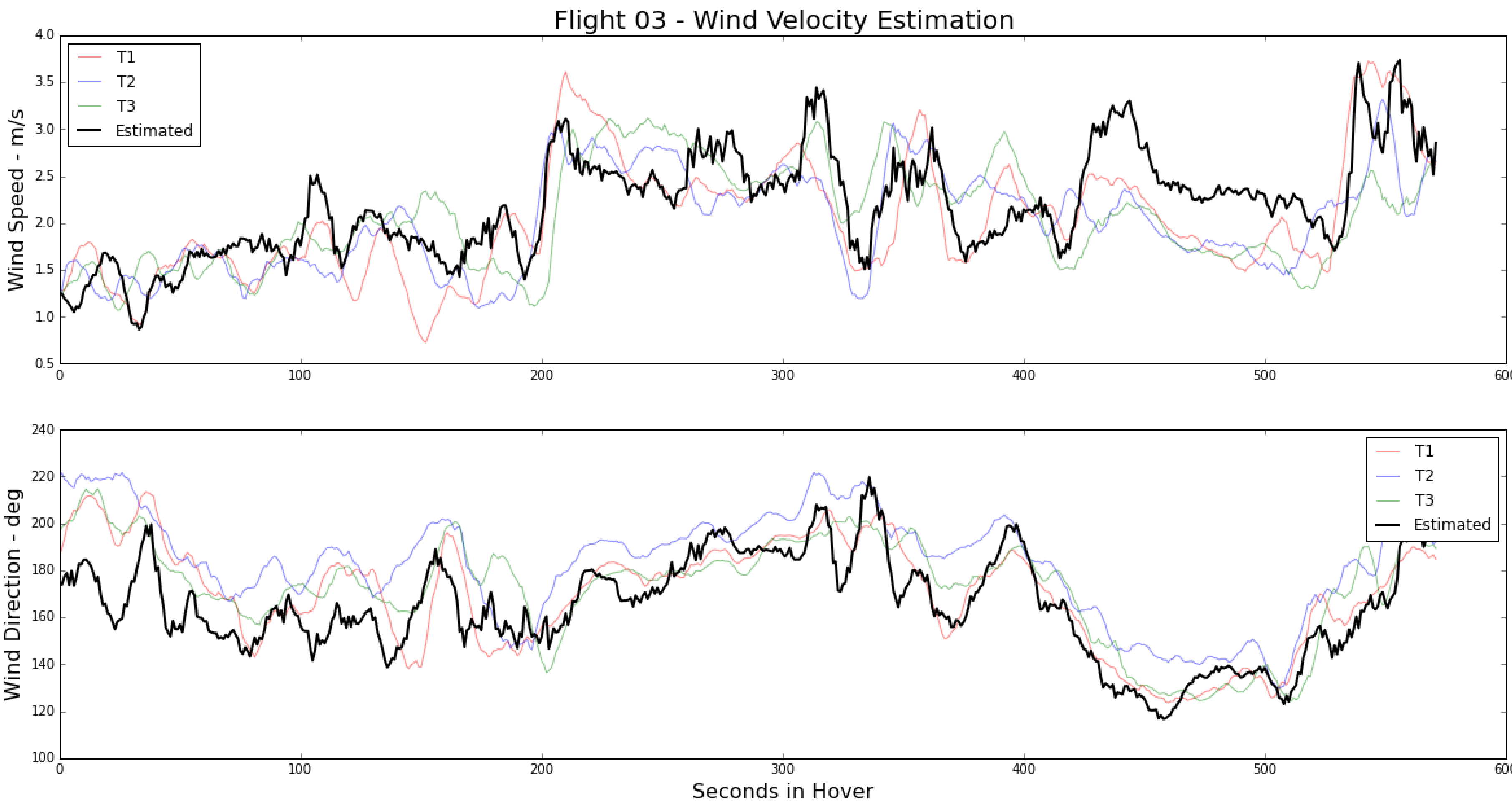
drag ***D***, and

gravitational force, ***G***

ϕ = pitch
θ = roll
γ = tilt



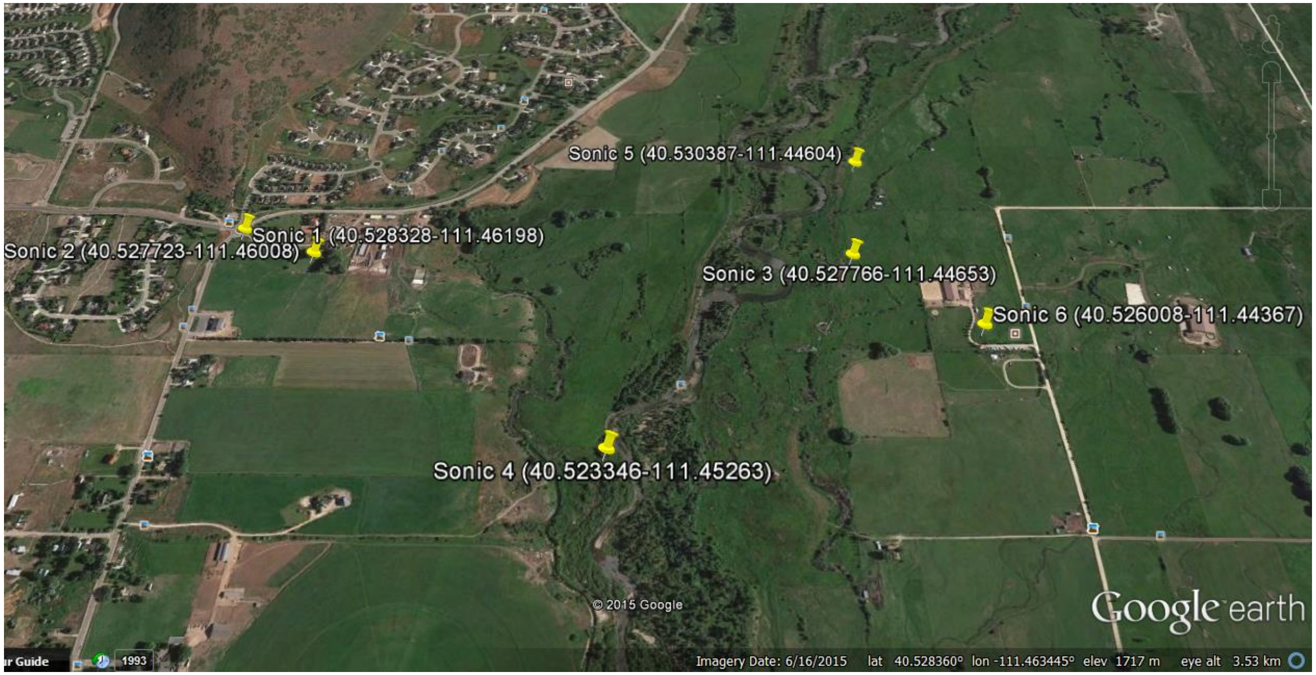
Preliminary results



-> deployment in MURI-CASPER this month

5) Deployment of 6 weather stations during MATERHORN-FOG

Wind, temperature, humidity, pressure at 1 Hz



published/submitted MATERHORN related papers in 2015

- Serafin, S., S.F.J. De Wekker, and J. Knievel, 2015: A mesoscale model-based climatography of nocturnal boundary-layer processes over the complex terrain of north-western Utah. Boundary-Layer Meteorology. DOI 10.1007/s10546-015-0044-6

- Vecenaj, Z. and S.F.J. De Wekker, 2015: Determination of non-stationarity in the surface layer during the T-REX experiment, Quarterly Journal of the Royal Meteorological Society. DOI:10.1002/qj.2458

- Babic, N, Z. Veccenaj, H. Kozmar, K. Horvath, S.F.J. De Wekker, B. Grisogono, Turbulent fluxes of momentum and heat during strong winter Bora wind events. Accepted for publication in Boundary-Layer Meteorology, September 2015.

- Babic, N., Z. Vecenaj, and S.F.J. De Wekker, Flux-variance similarity in complex terrain and its sensitivity to different methods to treat non-stationarity. Accepted for publication in Boundary-Layer Meteorology, October 2015

- Pal, S. S.F.J. De Wekker, and G.D. Emmitt, Investigation of the Spatial Variability of the Convective Boundary Layer Heights over an Isolated Mountain: Selected Cases from the MATERHORN-2012 Experiment. Submitted to Journal of Applied Meteorology and Climatology, September 2015

- De Wekker, S.F.J., and M. Kossmann: Convective boundary layer heights over mountainous terrain: A review. Submitted to Front. Earth Sci, August 2015.

- De Wekker, S.F.J., S. Serafin, J.C. Knievel, 2015: A mesoscale model-based climatography of daytime atmospheric boundary layer heights over complex terrain. 33rd International Conference on Alpine Meteorology (ICAM), 31 August 2015 - 4 September 2015, Innsbruck, Austria.

- Serafin, S., and S.F.J. De Wekker, 2015: A factor-separation study of convective boundary layer development over non-uniform land use and topography. 33rd International Conference on Alpine Meteorology (ICAM), 31 August 2015 - 4 September 2015, Innsbruck, Austria.

- Pal, S., T.R. Lee, S.F.J. De Wekker, 2015: On the combined impact of boundary layer height, near-surface meteorological conditions and nocturnal CO concentration on CO diurnal cycle patterns at a low mountaintop site: A case study using simultaneous lidar and in-situ observations. 33rd International Conference on Alpine Meteorology (ICAM), 31 August 2015 - 4 September 2015, Innsbruck, Austria.

- De Wekker, S.F.J., 2015: Investigating the boundary layer structure in a valley using an instrumented multi-rotor copter. 33rd International Conference on Alpine Meteorology (ICAM), 31 August 2015 - 4 September 2015, Innsbruck, Austria.

- Sghiatti, M., S. Pal, G.D. Emmitt, S.F.J. De Wekker, 2015: The nature of turbulence in the atmospheric boundary layer over an isolated mountain during the Mountain Terrain Atmospheric Modeling and Observations Program. 33rd International Conference on Alpine Meteorology (ICAM), 31 August 2015 - 4 September 2015, Innsbruck, Austria.

- De Wekker, S.F.J., 2015: Development of an autonomous multi-rotor copter for vertical profiling in the atmospheric boundary layer. 3rd annual meeting of the International Society for Atmospheric Research Using Remotely piloted Aircraft (ISARRA), Norman Oklahoma, USA, 20-22 May 2015.

- Sherman, T., R. Palomaki, N. Rose, G. Guadagni, D. Chestnut, S.F.J. De Wekker, 2015: Wind estimation in the lower atmosphere using a multi-rotor copter. 3rd annual meeting of the International Society for Atmospheric Research Using Remotely piloted Aircraft (ISARRA), Norman Oklahoma, USA, 20-22 May 2015.

- Etts, D., Jr., M.Rossi, R. Nzaou, R. Zhu, G.C. Lewin, S.F.J. De Wekker, 2015: Development of an autonomous multi-rotor copter for collecting atmospheric data near the ground. IEEE Systems and Information Engineering Design Symposium (SIEDS'15), 24 April 2015. Charlottesville, VA), p. 120 – 124, 10.1109/SIEDS.2015.7116958

- Pal, S., S.F.J. De Wekker, M. Sghiatti, and G. D. Emmitt, 2015: Investigation of the Spatial Variability of the Atmospheric Boundary Layer Heights over an Isolated Mountain: Selected Results from the MATERHORN-2012 Experiment. 17th Symposium on Lidar Atmospheric Applications, 4-8 January 2015, Phoenix, AZ.

Outlook summary

Continued efforts on:

- Spatial variability of winds , PBL height, and PBL turbulence
- idealized large-eddy-simulations
- assimilation of wind profiles from the airborne Doppler wind lidar in WRF/4DWX
- Surface layer/boundary layer similarity theory
- Multi-rotor copter measurements

New efforts on:

- MATERHORN case study simulations using COAMPS-EDMF
- Ground-based/airborne Doppler lidar intercomparison