Wind and turbulence structure in the boundary layer around an isolated mountain: airborne measurements during the MATERHORN field study

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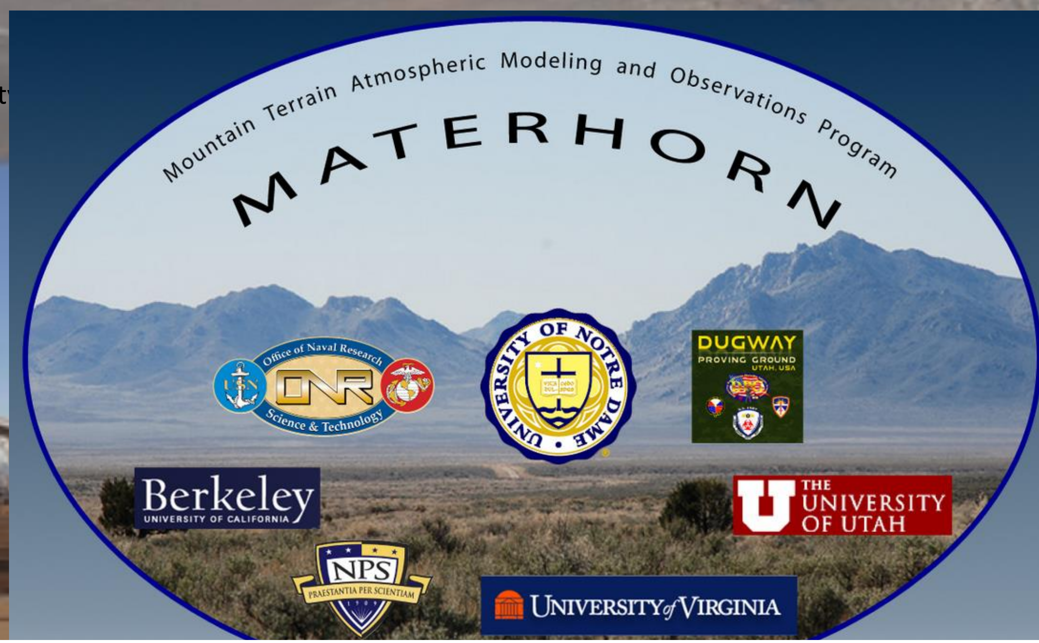
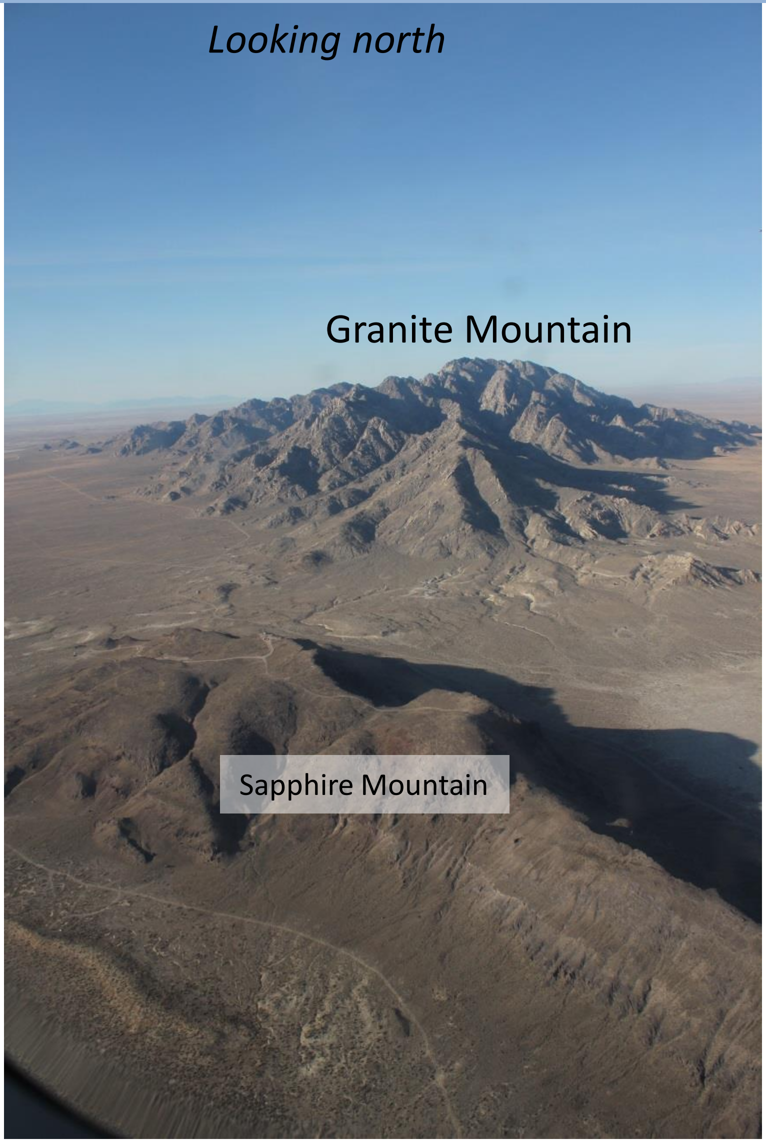


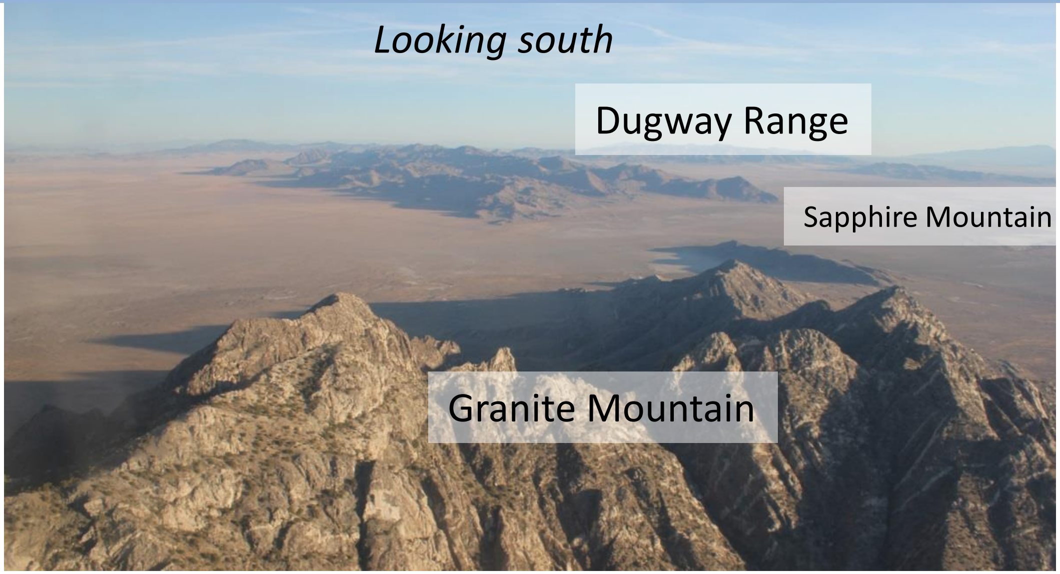
MATERHORN-X
MATERHORN-M
MATERHORN-P
MATERHORN-T

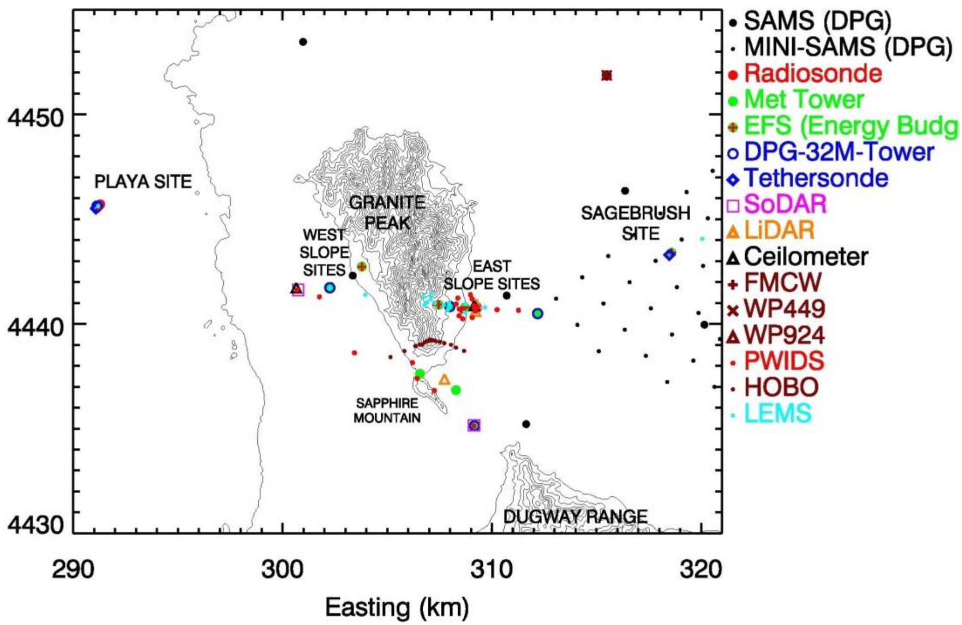
DACA 13, Davos
10 July 2013

http://www3.nd.edu/~dynamics/materhorn/index.php

MATERHORN FIELD SITE

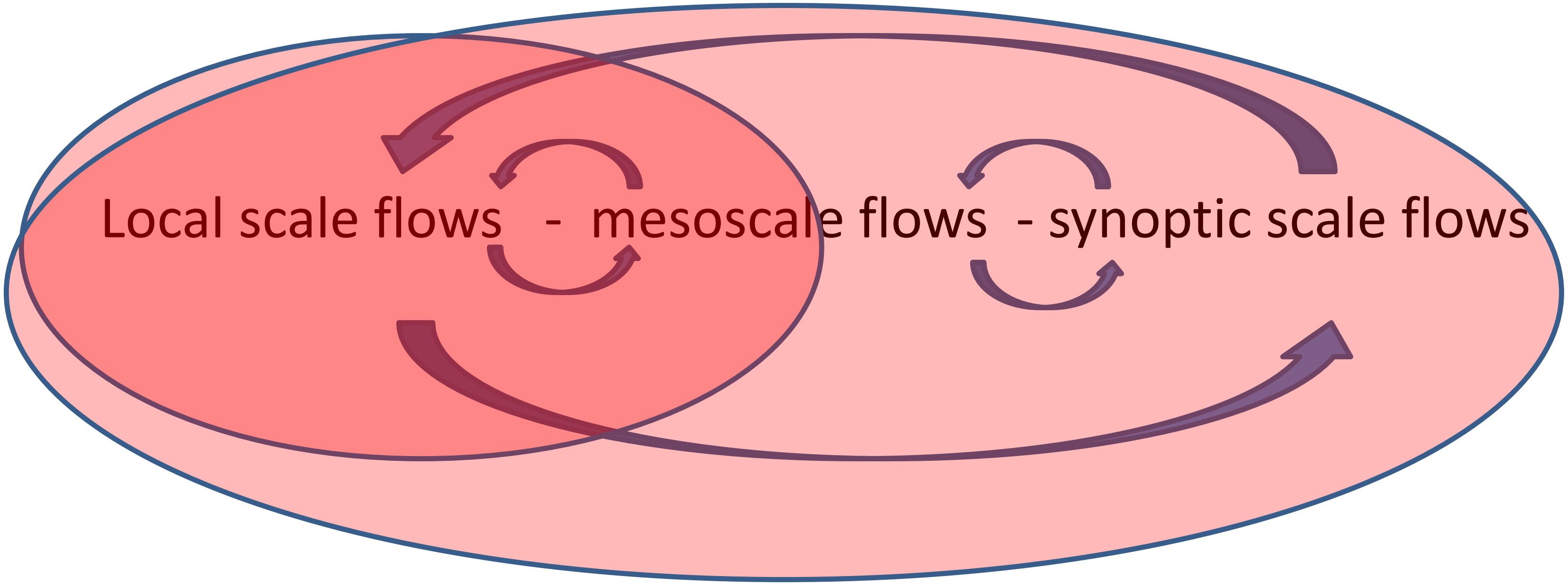






Motivation for airborne measurements

Multi-scale flow interaction



- To capture interaction between mesoscale and synoptic scale flows, wind measurements at high spatial resolution over horizontals distances of at least a few tens of km are required.

-> *airborne Doppler wind lidar measurements* can provide these measurements

Twin Otter Doppler Wind Lidar

TODWL (Twin Otter Doppler Wind Lidar) has been operated since 2002 by CIRPAS (Center for Interdisciplinary Remotely Piloted Aircraft Studies), a part of the Naval Postgraduate School, Monterey, CA.

2 µm coherent detection

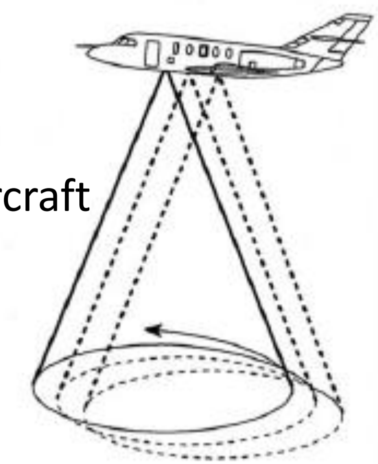
side door mounted scanner

Range: 0.3 – 21 km depending upon aerosols

Accuracy: < 0.10 m/s in three components

conical scans below the aircraft

azimuth angle steps of 30°



TODWL data products

- Downward conical scans (12 point step stare)
  - Off-nadir angle of 20 -30 degrees
  - 20 -25 seconds for full 360 scan (~ 1 - 1.2 km)
  - U,V,W with 50 m vertical resolution
  - SNR (aerosols)
- Downward stare (nadir samples)
  - 5 seconds between conical scans
  - W with 50 m vertical resolution
  - SNR (aerosols)
- Forward stare

Additional Twin Otter Measurements, e.g. *in situ* fluxes, meteorological variables, surface temperature, particle counts

Objectives of MATERHORN- airborne measurements

Provide MATERHORN with high resolution wind data at the mesoscale that provide the background information needed to interpret the many surface-based remote sensing and *in-situ* observations collected around Granite Mountain

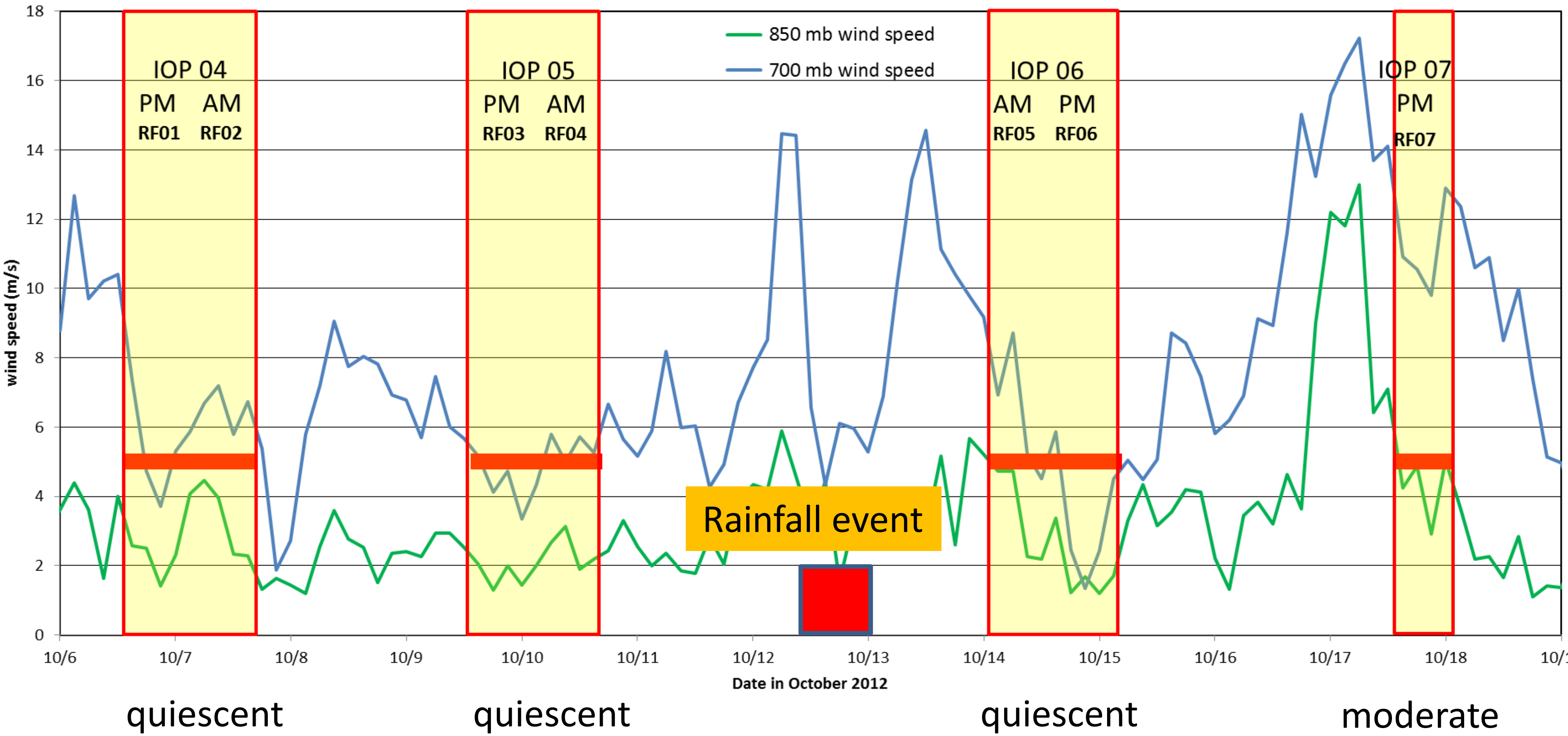
Investigate spatial PBL structure and interaction of boundary layer flows with Granite Mountain

Investigate the benefit of assimilating airborne lidar data in forecasting models and its impact on mesoscale predictability.

Evaluate Eddy Diffusivity Mass Flux parameterization over land in the presence of organized structures (convective rolls) – separating vertical fluxes of heat and mass by turbulence and organized sub-meso/meso-scale structures

MATERHORN-X Fall - airborne

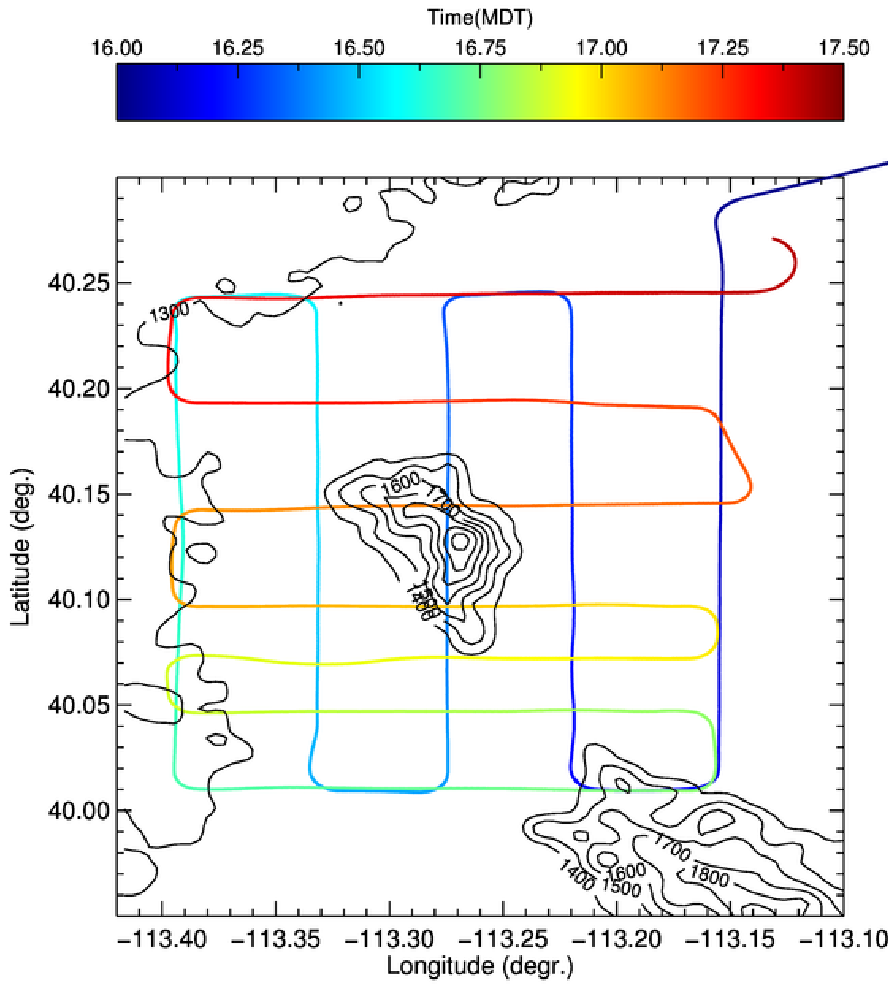
- Twin Otter in Utah between 5 October and 18 October, 2012, participated in 4 IOPs
- Missions lasted ~ 4 hours
- 7 research flights yielded ~3000 wind profiles between surface and 3400 m MSL



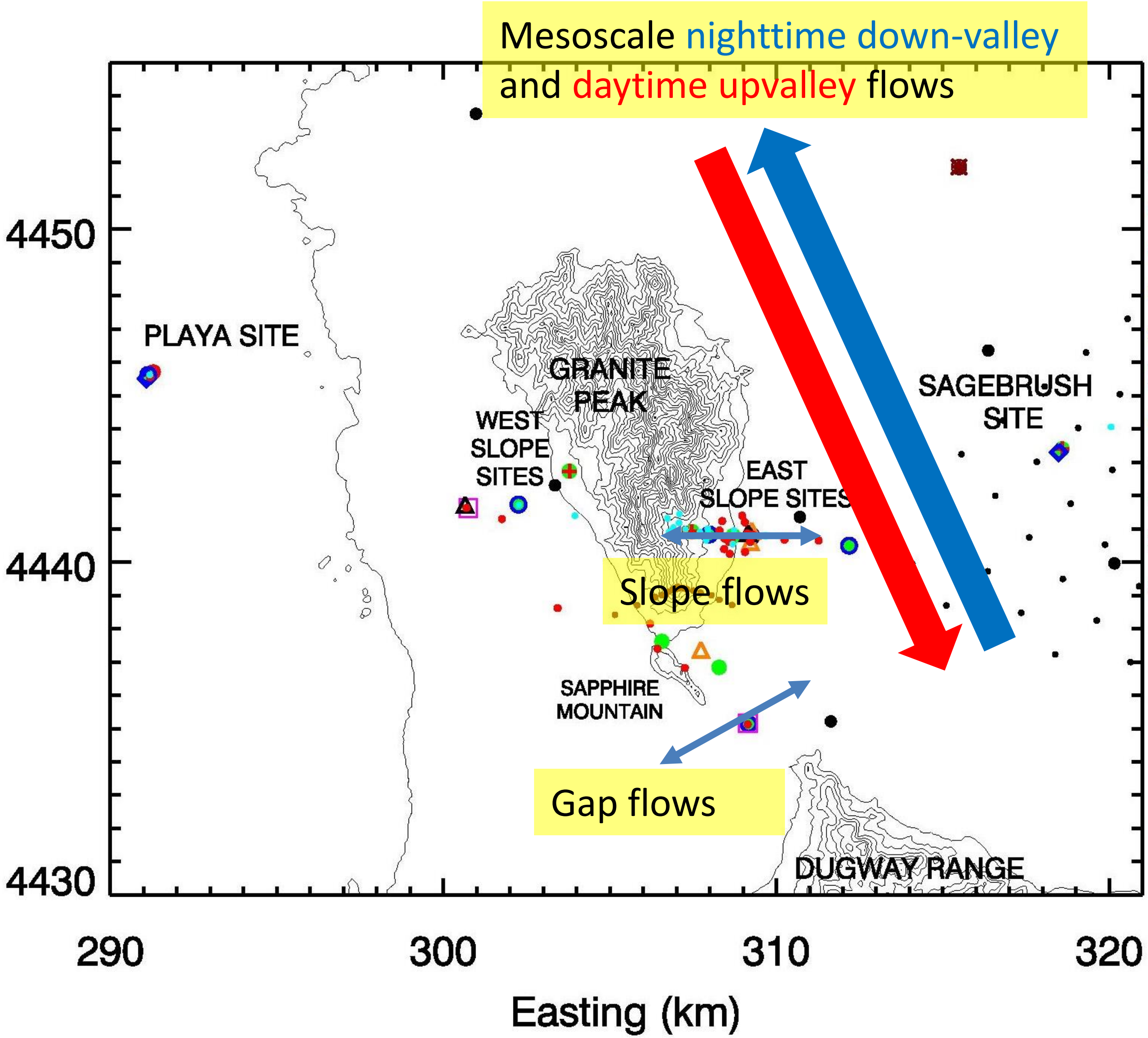
Example Flight pattern 09 October 2012

Afternoon flight (RF03)

- Aircraft was based out of Salt Lake City ~ 20 minute to Granite Mountain
- Climb to ~ 4 km MSL (~1500 m above Granite Peak)
- North-south and east west legs of ~20-30 km
- Low level flights



Expected surface flow patterns

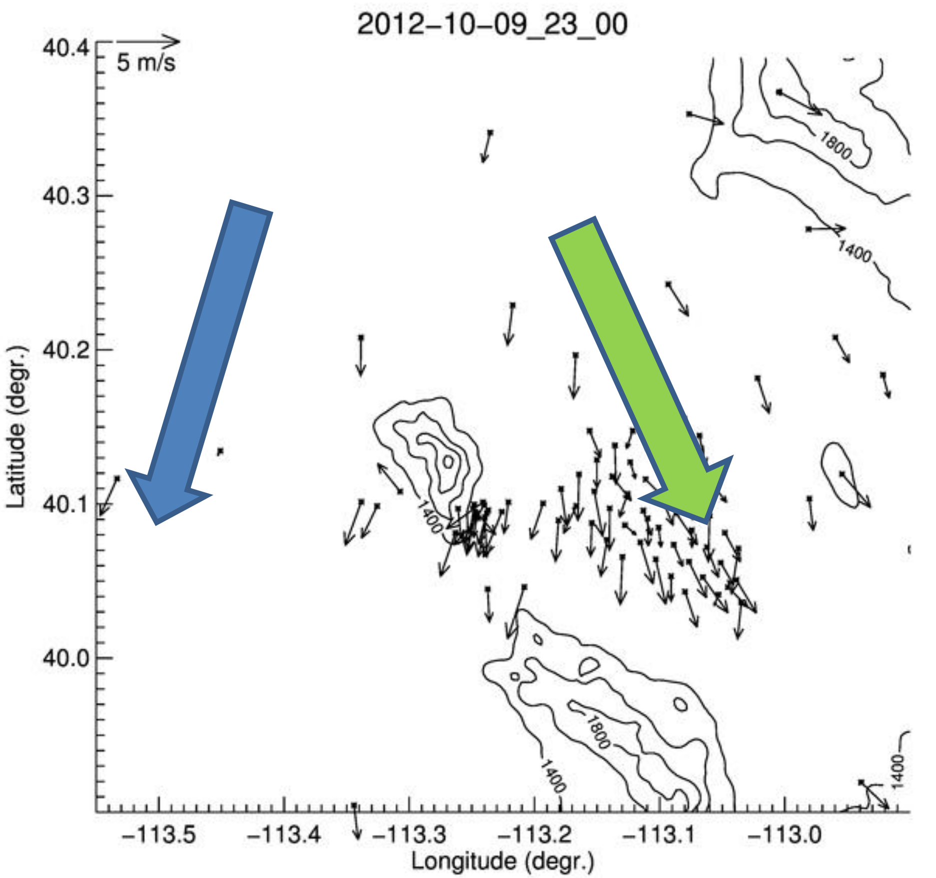


Example 09 October 2012, afternoon

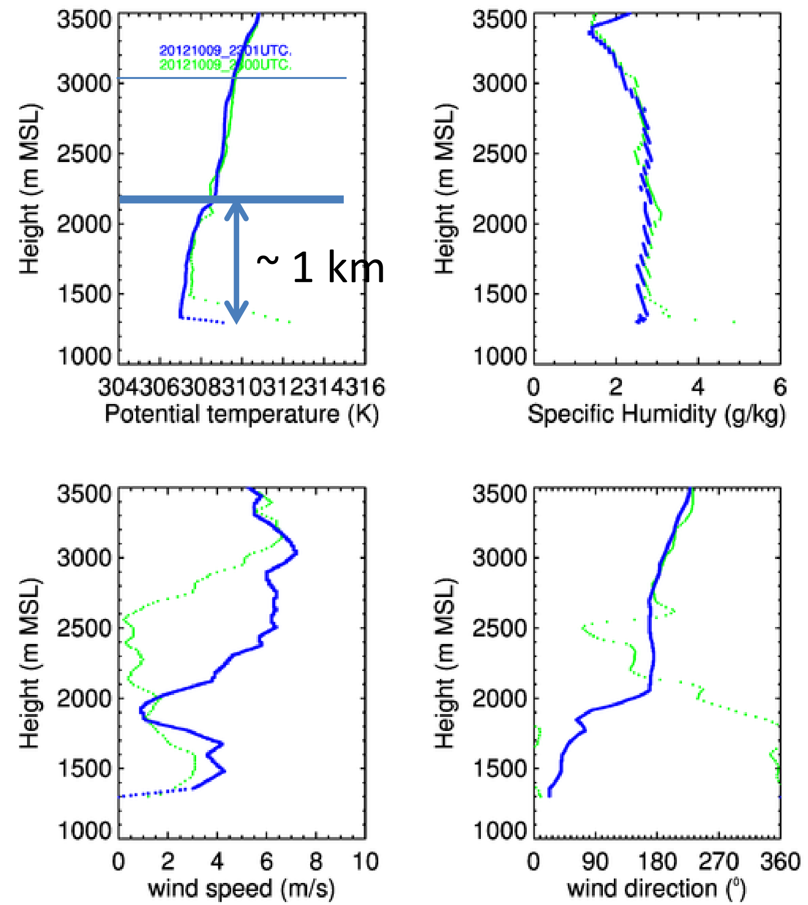
1700 LT

Playa site = blue

Sagebrush site = green

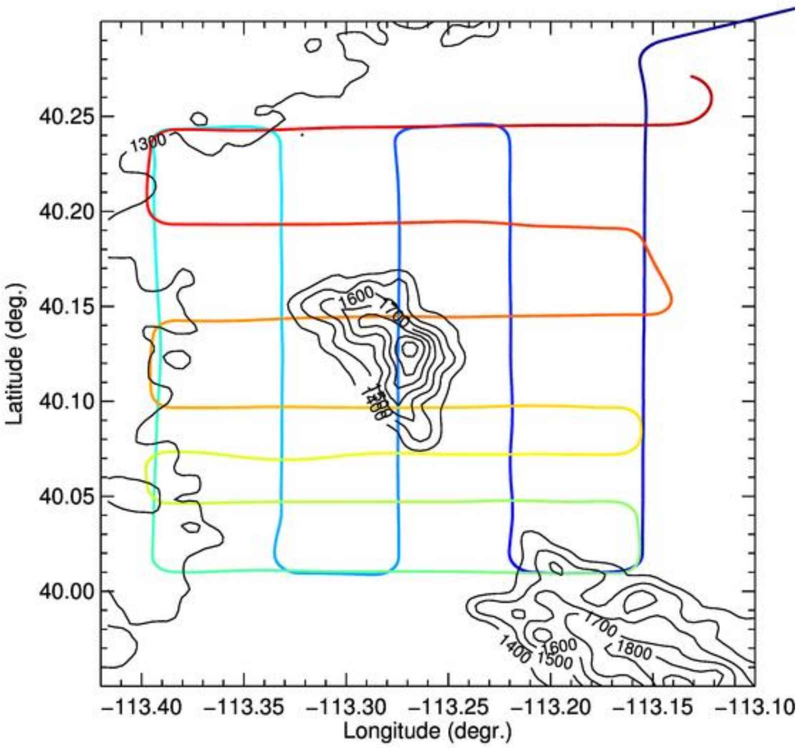


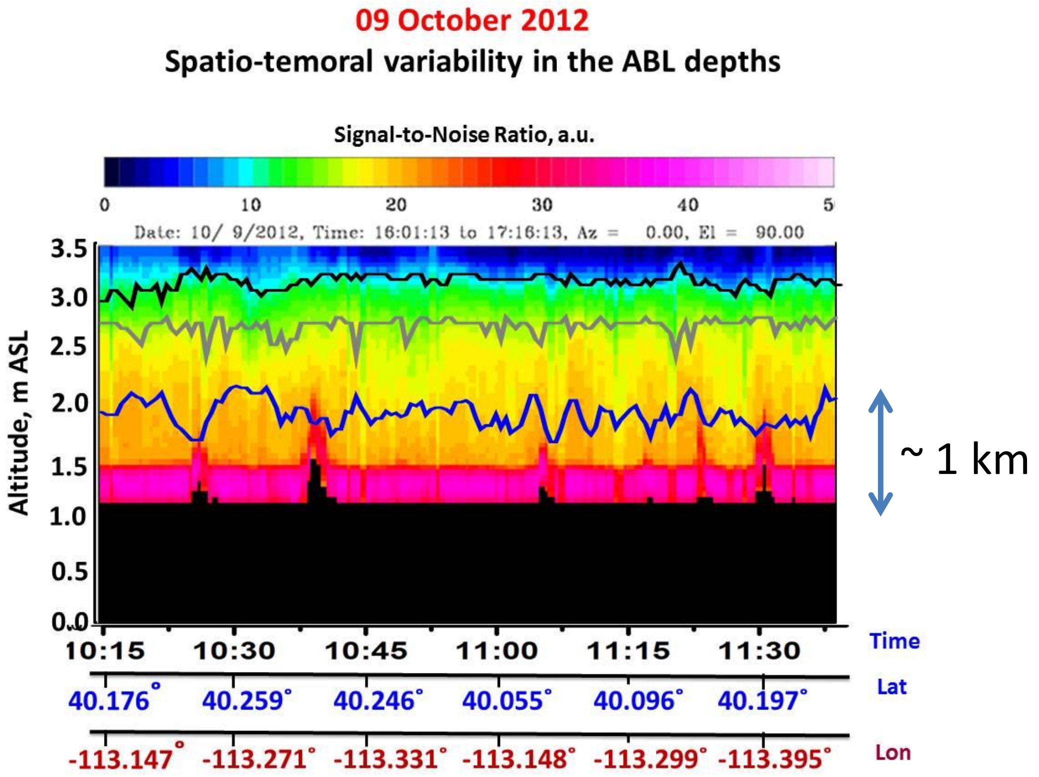
Surface observations



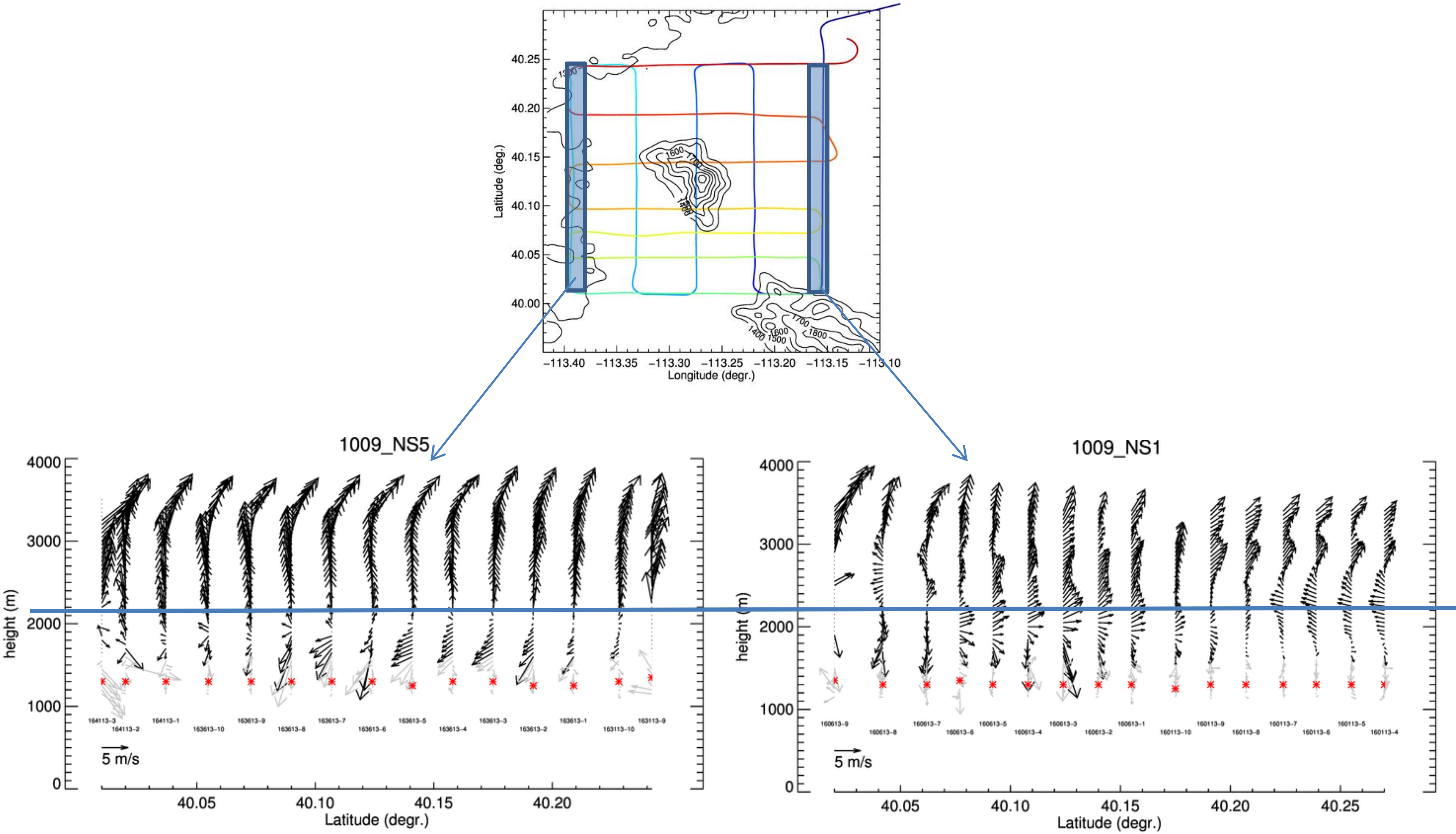
Radiosonde observations

Aerosol structure and PBL height 09 October





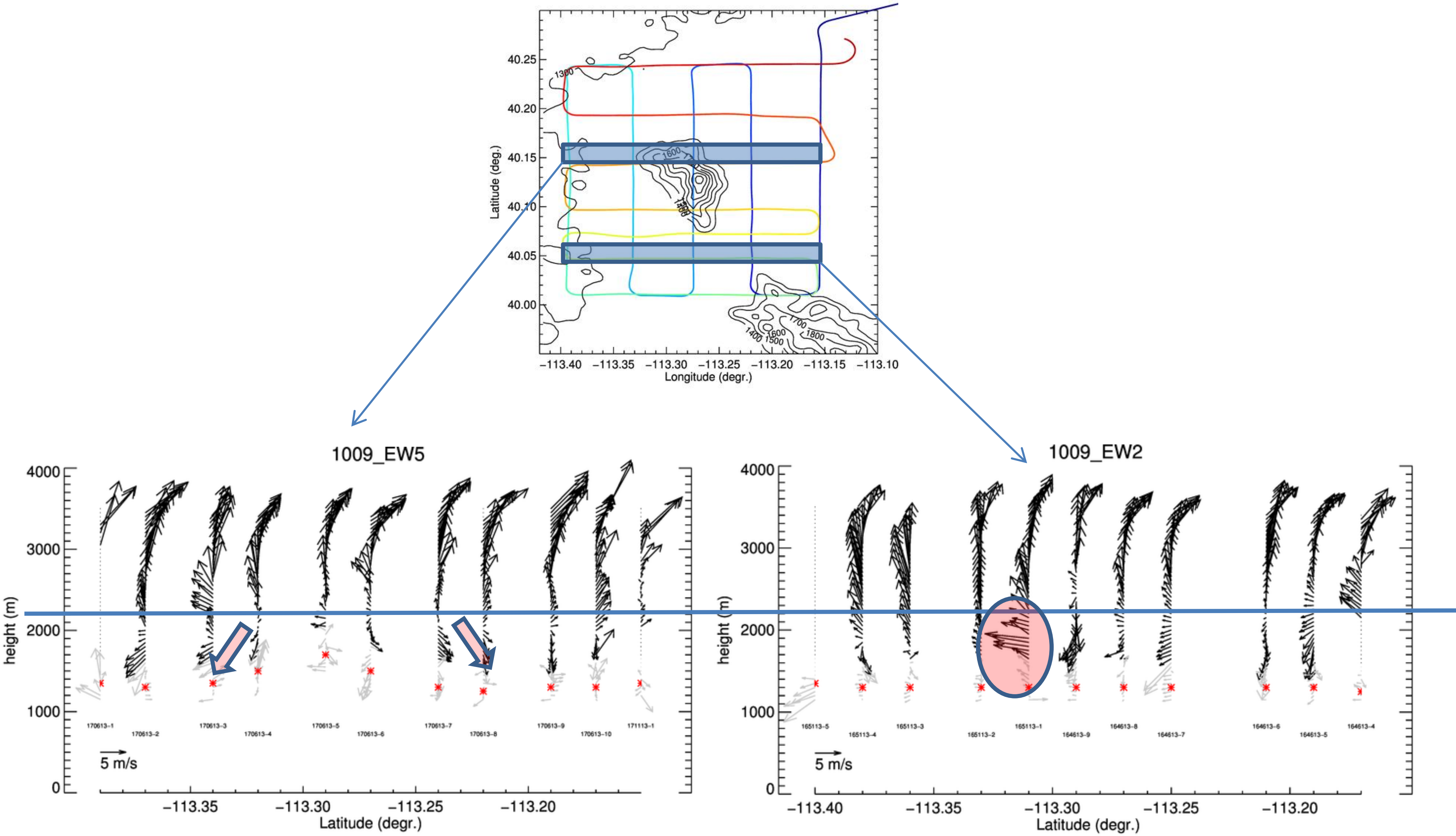
wind profiles for N-S legs 09 October 2012



Northerly ‘mesoscale’ upvalley flows more pronounced and deeper over Playa

Spatial structure in large scale flows aloft. Flows above 2500 m much stronger over Playa

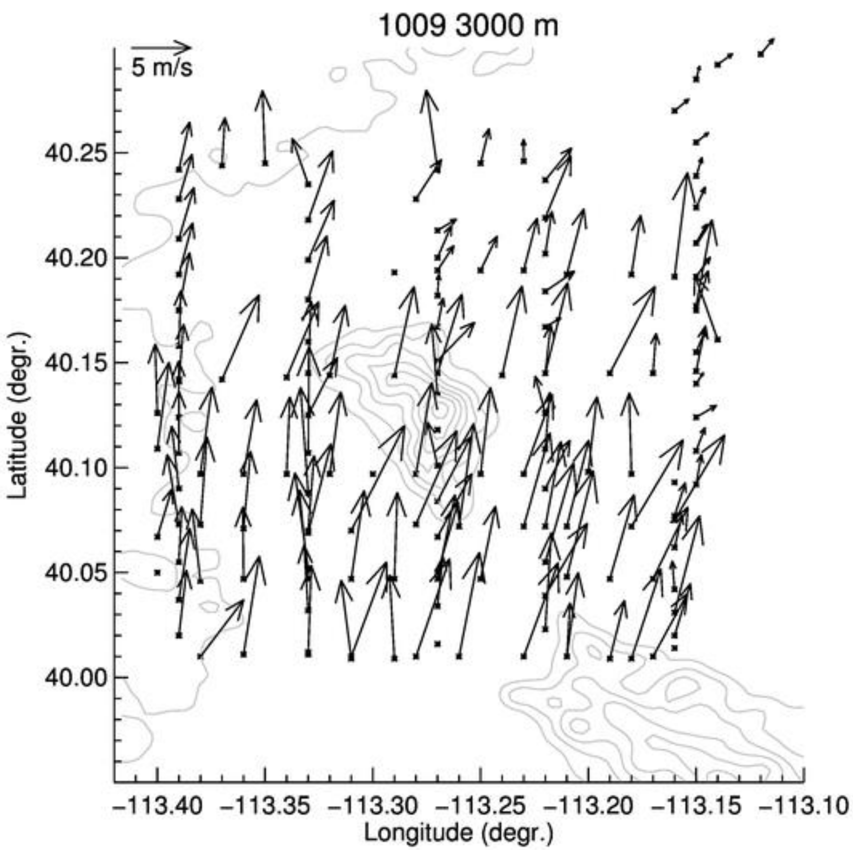
wind profiles for E-W legs 09 October



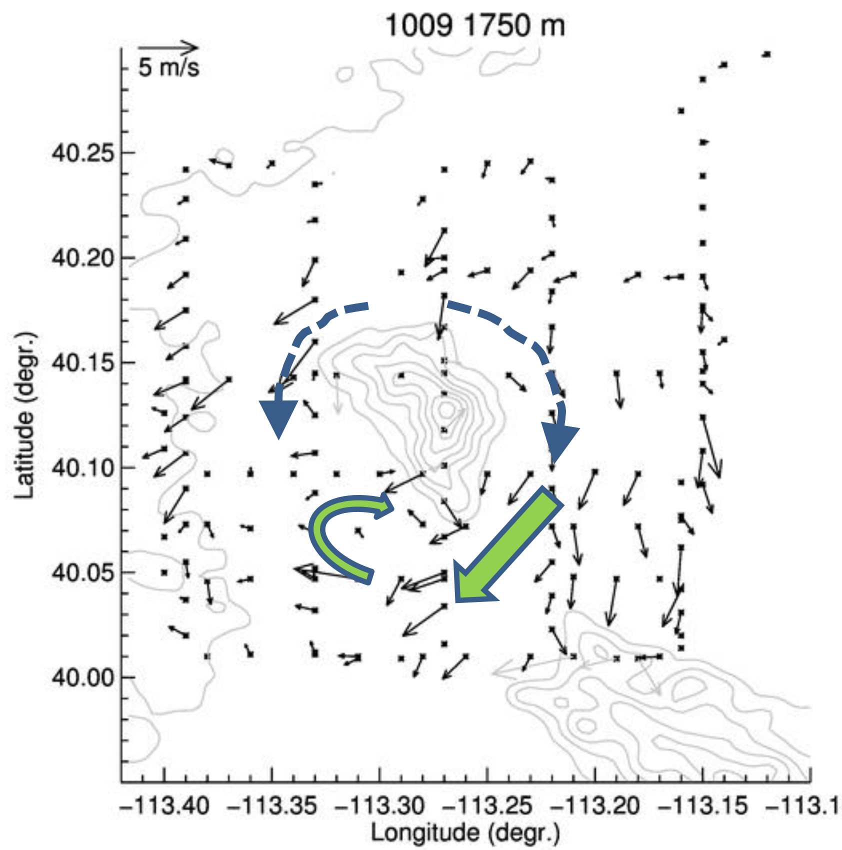
Flow around Granite Mountain and channeling through southern gap

wind pattern 09 October 2012

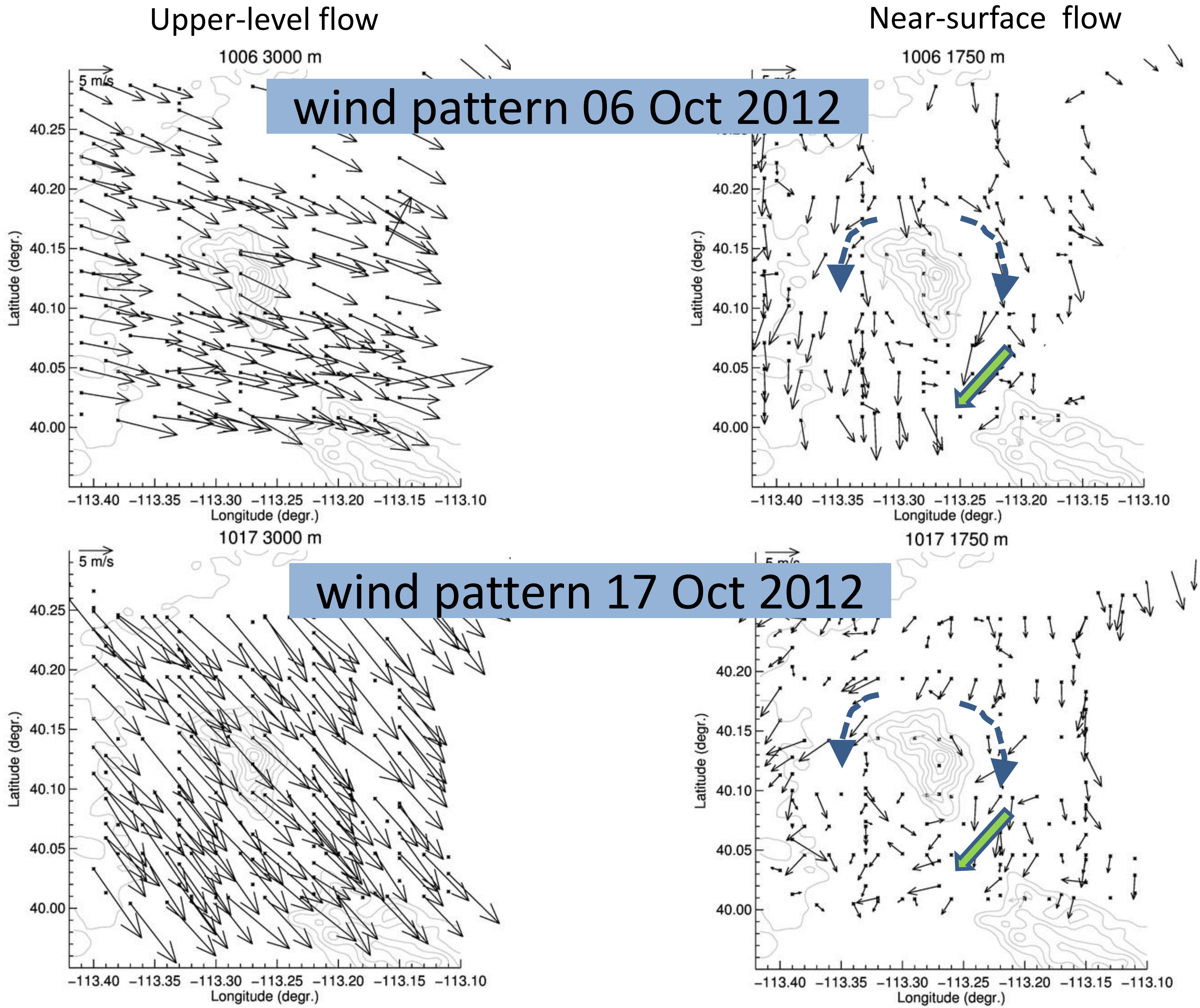
Upper-level flow



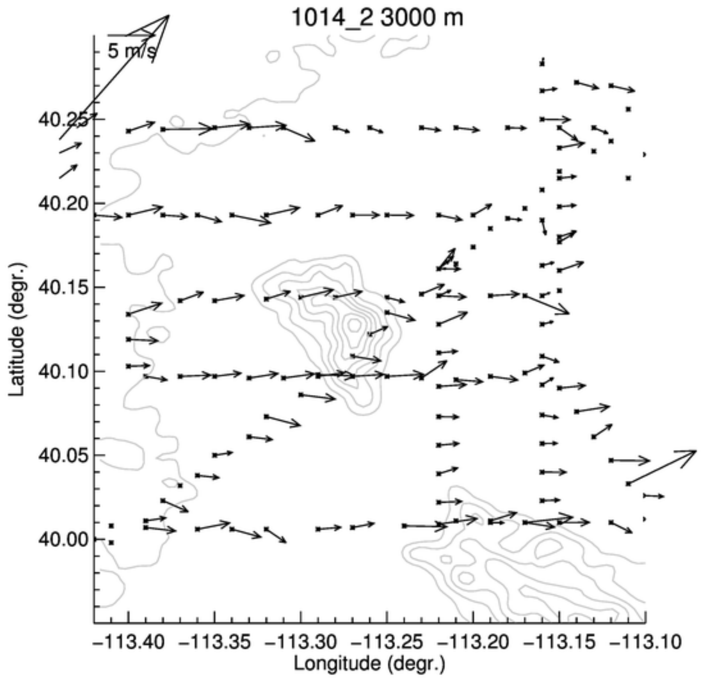
Near-surface flow

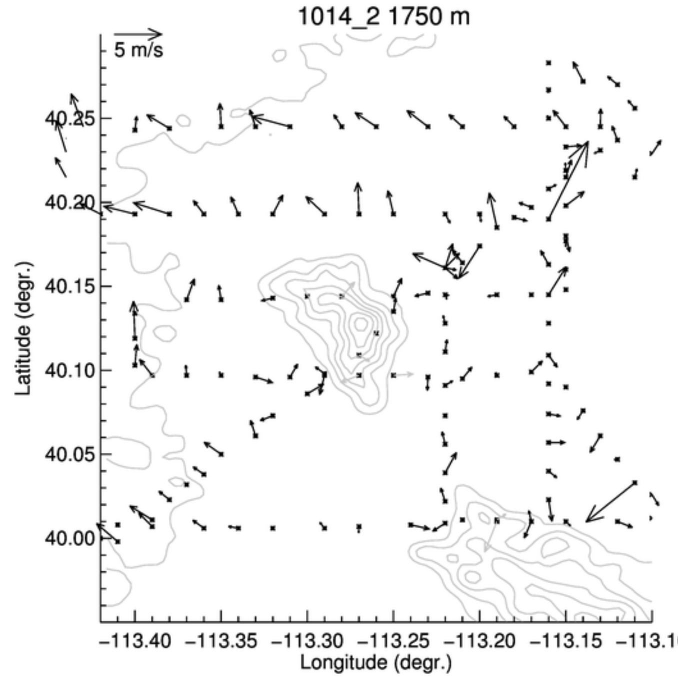


OTHER AFTERNOON EXAMPLES?


Upper-level flow
Near-surface flow
wind pattern 06 Oct 2012
wind pattern 17 Oct 2012
1006 3000 m
1006 1750 m
1017 3000 m
1017 1750 m
5 m/s
Latitude (degr.)
Longitude (degr.)
40.25
40.20
40.15
40.10
40.05
40.00
−113.40 −113.35 −113.30 −113.25 −113.20 −113.15 −113.10

wind pattern 14 Oct 2012

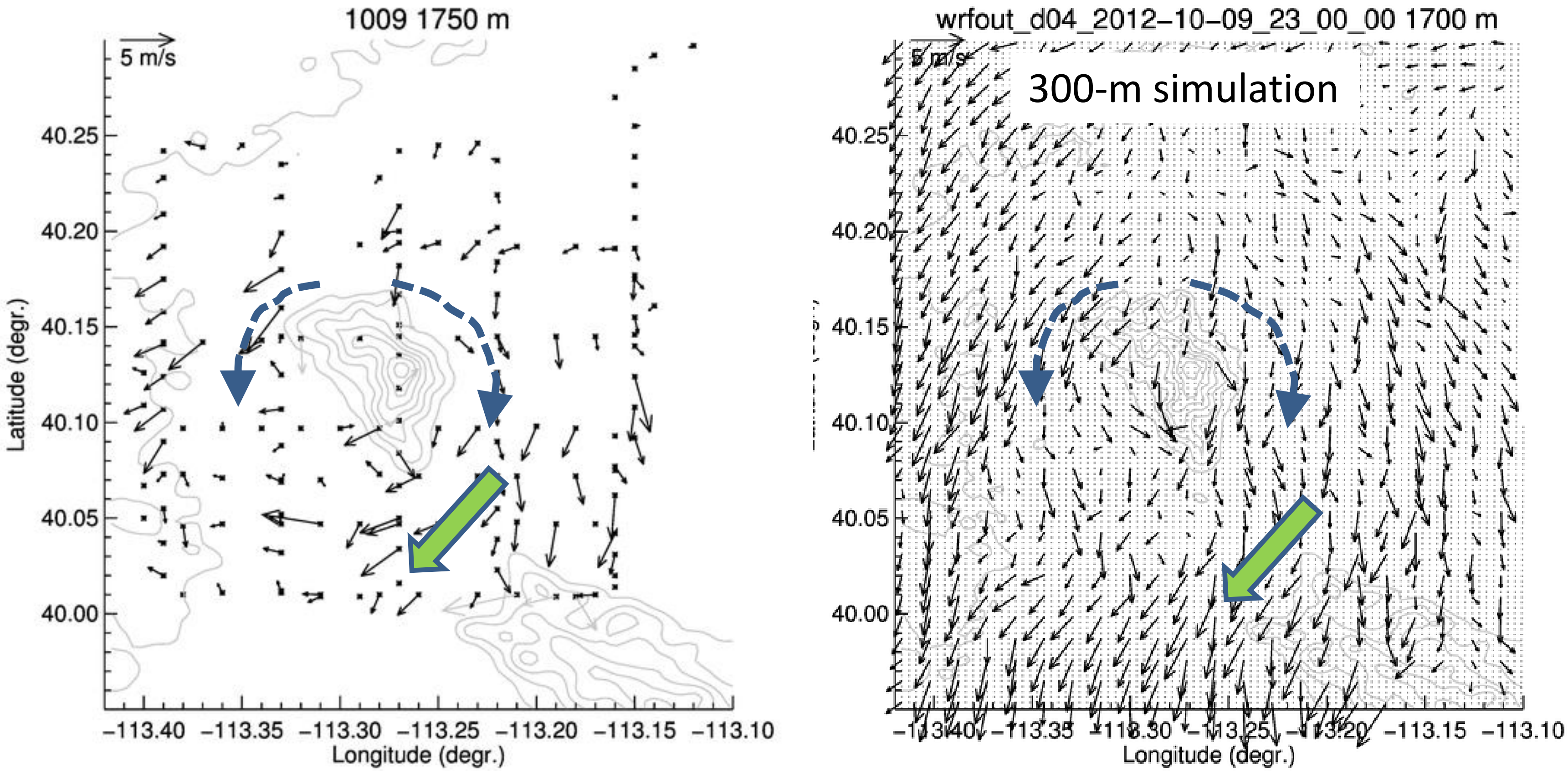




DOWNVALLEY/UNDETERMINED ?

This situation occurred 2 days after rainfall event!

Preliminary example of comparison with Very Large Eddy Simulation (VLES), now operational for Dugway Proving Ground



Courtesy of Yubao Liu, NCAR

Summary

- 7 successful research fights were conducted during MATERHORN-X collecting data during 4 afternoons and 3 mornings in quiescent to moderate synoptic conditions
- Started an investigation of spatio-temporal variability of PBL structure and flow interaction with Granite Mountain
- Typical PBL depth around 1000 m AGL corresponding to height of Granite Peak – large spatial variability
- recurring pattern of northerly thermally driven upvalley flows flowing around Granite mountain with channeling through gap. One afternoon flight after a rainfall event deviates from this pattern -> importance of surface forcing appears obvious
- Very Large Eddy Simulation modeling at 300 m horizontal resolution – shows promising results

Outlook:

vertical velocities,

in-situ aircraft measurement, (fluxes!),

organized convective structures/thermal and interaction with flows,

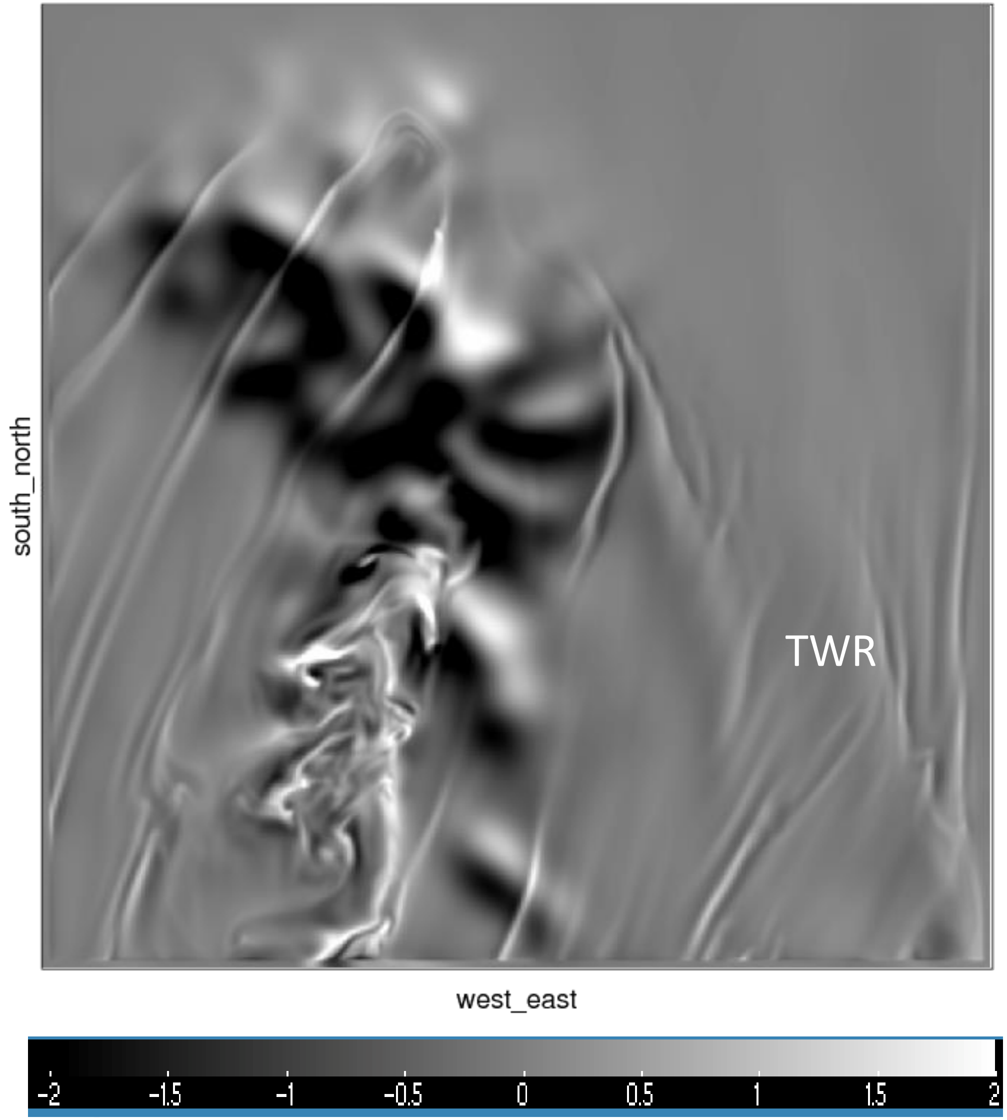
assimilation of wind data from airborne Doppler lidar data in WRF,

LES simulation at 30-m planned for select cases

etc.

Acknowledgments: This research is funded by grants from the Office of Naval Research, the Army Research Office, and the National Science Foundation.

Flow around/over Granite Mountain: Morning Transition

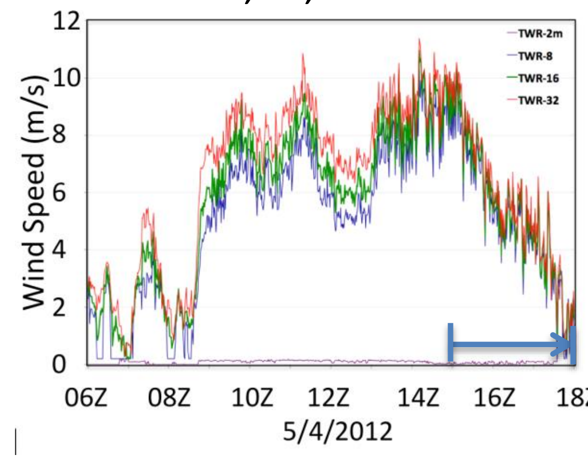


Current Time: 445
Current bottom_top_stag: 2
Frame 1 in File wrfout_d06_2012-05-04_14:50:00

D6 (DX=33m)
W (m/s)

Animation from 14:50 – 17:50 UTC 4 May 2012; Every 2 minutes

TWR 8,16,32m Wind



Courtesy of Yubao Liu, NCAR

Multi-scale flows and boundary layer structure during the morning transition period: a case study from the MATERHORN field study

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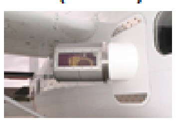
INTRODUCTION

- We studied the atmospheric boundary layer structure and dynamics during the morning transition period of one intensive observational period of the Mountain Terrain Atmospheric Modeling and Observations (MATERHORN) field experiment at Dugway Proving Ground (an army test range in Utah, USA) in Fall 2012
- We use high-resolution data from an airborne Doppler lidar, three ground-based Doppler lidars, in-situ measurements from an unmanned aerial vehicle, and high resolution numerical simulations.

DATA

Twin Otter Doppler Wind Lidar (TODWL)

2μm coherent detection (CTI MAG1A) 2 mJ ; 500 Hz



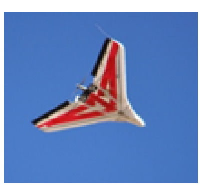
10 cm two axis scanner, side door mounted Range: .3 – 21km depending upon aerosols Accuracy: ~ 0.10 m/s in three components

Obtaining Wind Data

Radial (or line-of-sight – LOS) velocities and aerosol backscatter are obtained at 30 degree intervals (step-stare method) so that 12 radial velocity profiles are obtained for one full rotation. The radial velocities are fit to a sine wave to determine the u, v and w components of the wind.

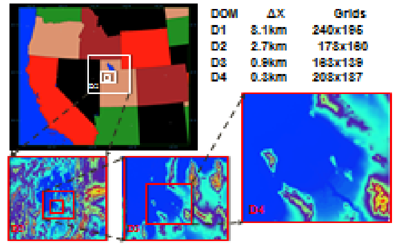
Ground-based Doppler Wind Lidar

DataHawk unmanned aircraft



Wingspan: 1 m
Weight: ~700 gm
Payload: ~ 80 gm
Electric propulsion
Duration: about 40 min.
Rear folding propeller
11-16 m/s airspeed
Power: 40-min lifetime battery
Cost: ~ $600
Autonomous flight control with user supervision, real time changes in flight profile
Flight termination mode prevents fly-away and conflict with other air traffic

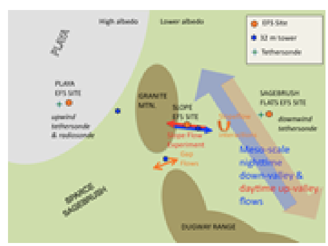
MODELING



DOM	ΔX	Grids
D1	8.1km	240x196
D2	2.7km	178x180
D3	0.9km	163x139
D4	0.3km	208x187

Since the 1990s, DPG has used a continuously operating meso gamma scale analysis and forecast system (4DWX) developed by the NCAR Research Applications Laboratory(RAL). The system is based on WRF, is driven by GFS analyses, runs with a grid spacing of 1.1km in its innermost domain, applies observational nudging in a three hour cycle (RTFDDA) and provides weather analyses and forecasts at hourly intervals. Since May 2012, the system is also running operationally in a very large eddy simulation mode with a grid spacing of 300 m in the innermost domain.

MATERHORN

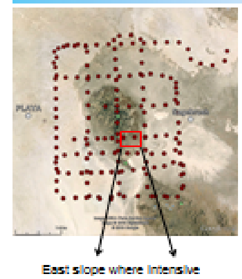


The MATERHORN Field study was conducted at the US Army Dugway Proving Grounds from 25 September through 21 October, 2012

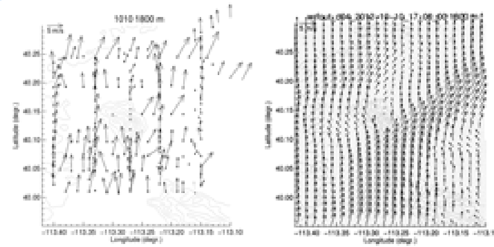
The field study consisted of ten 24-hour long IOPs
5 Quiescent (700mb winds < 5ms⁻¹)
4 Moderate (700mb winds 5-10ms⁻¹)
1 Transitional (dry cold front passage)
6 "Nighttime" IOPs (1400LT start)
2 "Daytime" IOPS (0200LT start)
1 "Mini-IOP" (1200LT-2000LT)
1 "Super-IOP" (0500LT-1200LT+1day)
2 Precipitation Events (Sept 24, Oct 12)

In this poster, we are focusing on the morning transition period of IOP 05 on 10 October 2012, which was classified as a quiescent nighttime IOP.

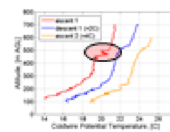
RESULTS



East slope where intensive ground-based observations were made, including those from DataHawk and ground-based Doppler Lidar.

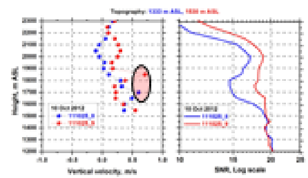


Flight pattern on 10 October 2012 (left), and the observed (middle) and simulated (right) wind pattern at 1800 m MSL at 1700 UTC. Flows were generally from the south-southwest at about 5 m/s. The southwesterly flow acceleration through the gap is evident in both the observed and simulated wind field.

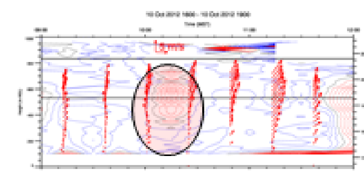


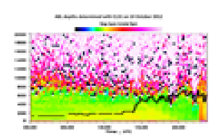
DataHawk observations (left) show evidence of an "overturning" event at about 500 m AGL.

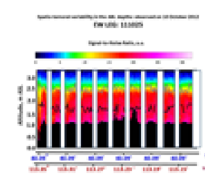
Airborne Doppler lidar observations (right) show increased upward vertical velocities at this location.



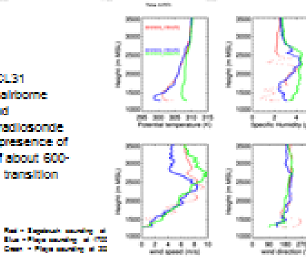
Ground-based Doppler lidar observations (right) also show increased upward vertical velocities at this location. Contour lines of vertical velocity are drawn every 0.1 m/s with red upward and blue downward motions







Aerosol observations from a CL31 ceilometer (top left) and from airborne Doppler lidar (bottom left), and thermodynamic profiles from radiosonde launches (right), indicate the presence of convective boundary layers of about 600-800 m deep after the morning transition period.



CONCLUSIONS

Observations from simultaneous deployment of multiple ground-based and airborne in-situ and remote sensors, and from simulations at very high resolution reveal a consistent picture of the flow pattern and boundary layer structure during a morning transition period in the MATERHORN field experiment. We are performing a detailed analysis of the model simulations to understand the processes underlying the "overturning" event and the spatio-temporal variability in convective boundary layer height.

Acknowledgments: This research is supported by the Office of Naval Research, the Army Research Office , and the National Science foundation