Slope and valley flow interactions in MATERHORN-1

MOUNTAIN TERRAIN ATMOSPHERIC MODELING AND OBSERVATIONS (MATERHORN) PROGRAM

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Outline

1. What is MATERHORN?
   - Components, participants, location and **domain / instrumentation**

2. Initiation of the flows
   - Basin stratification and vorticity development

2. Interactions of flows
   - Collision characteristics

3. Adjustments in the valley

4. Secondary collisions and collision periods

5. Analysis
   - Dimensional analysis, collision types, parameterization and decay time scale

6. Conclusions

7. Ongoing work

What is MATERHORN?

MOUNTAIN TERRAIN ATMOSPHERIC MODELING AND OBSERVATIONS (MATERHORN) PROGRAM

ONR funded DoD multidisciplinary research initiative (MURI) grant to lead multi-institutional efforts

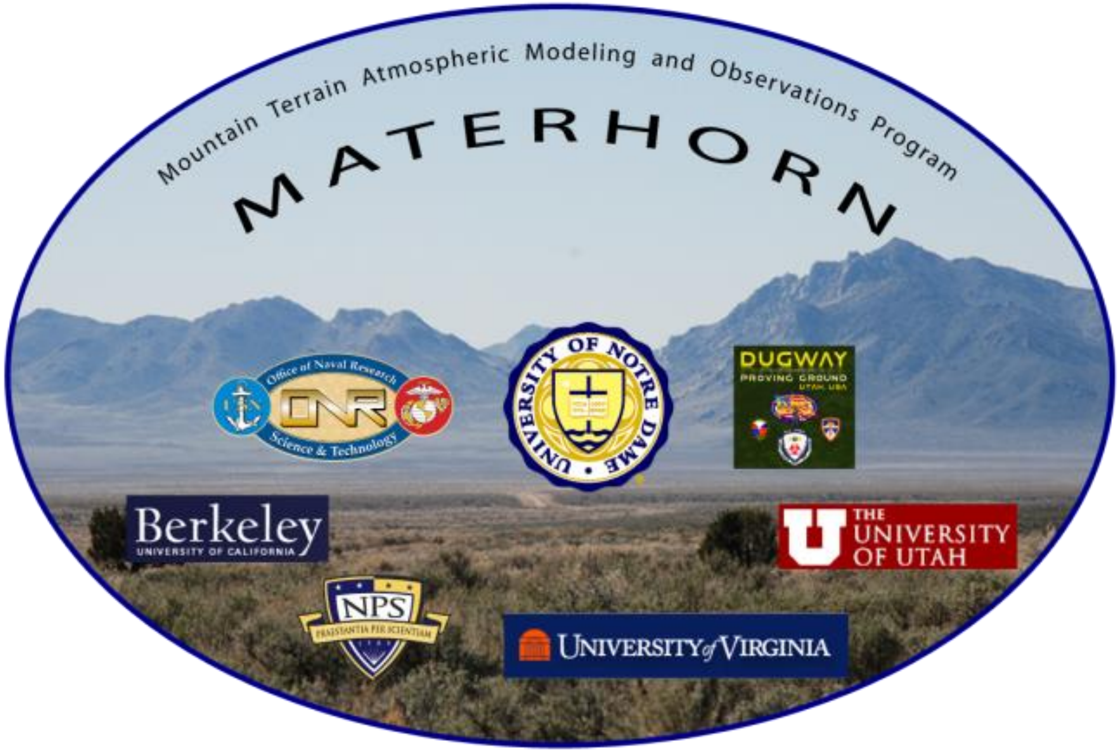
Goals:

Designed to identify and study the limitations of current state-of-the science meso-scale models for mountain terrain weather prediction and develop scientific tools to help realize leaps in predictability

Components:

- MATERHORN-M: Modeling
- MATERHORN-X: Field experiment
- MATERHORN-T: Technology
- MATERHORN-P: Parameterization

Participants



Principal Institutions:

University of Notre Dame

University of Utah

University of Virginia

Navy Postgraduate School

U.C. Berkeley

Partners:

Dugway Proving Grounds

Navy Research Laboratory

Army Research Laboratory

University of London

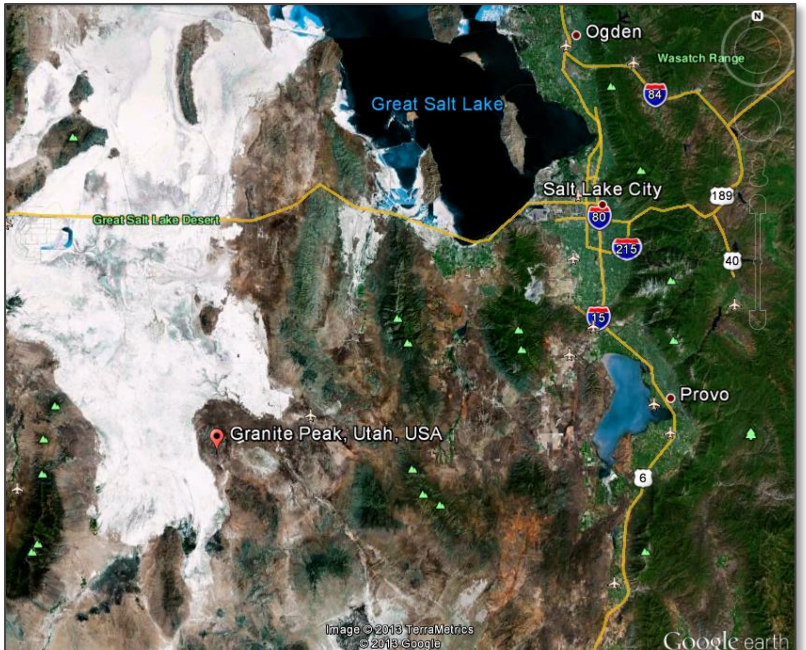
Tel Aviv University

Collaborators:

NCAR
NOAA
Princeton University
Oregon State University
University of Colorado

IIBR, Israel
University of Bergen, Norway
University of Vienna, Austria
University of Lecce, Italy
École Polytechnique De Montreal, Canada

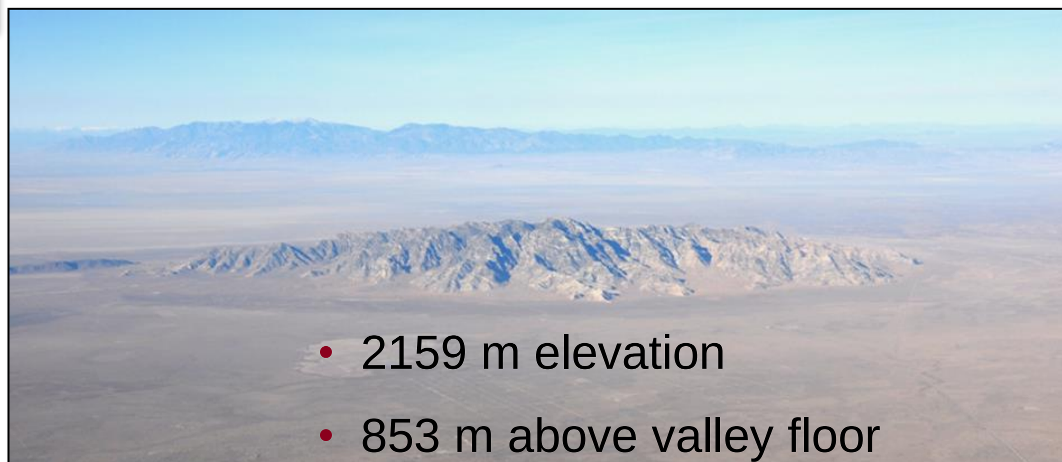
Location



- Dugway Proving Grounds
- 3,700 km^2 of controlled, remote encroachment-free terrain
- 137 km SW of Salt Lake City, UT

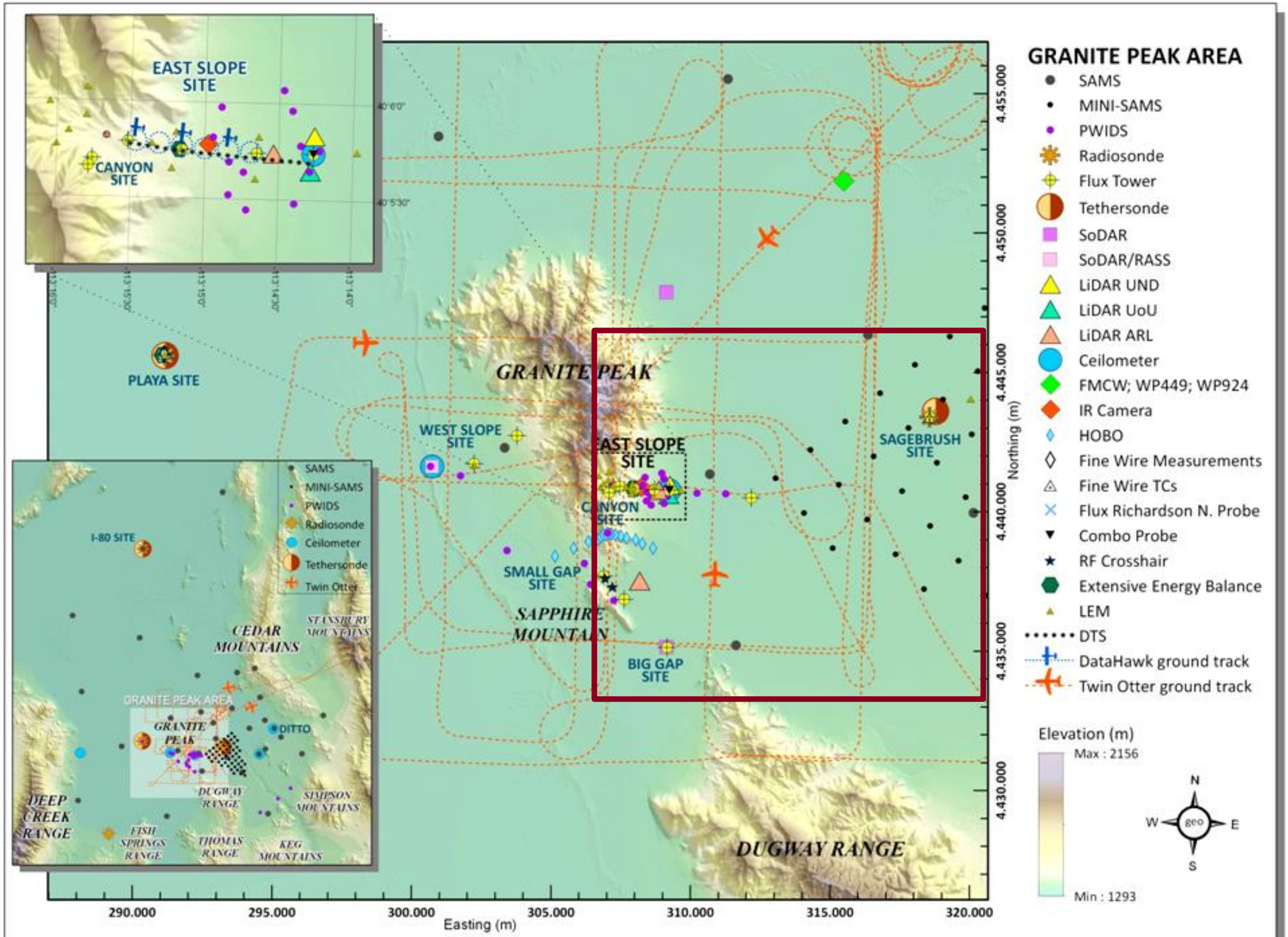
The Granite Mountain Atmospheric Sciences Testbed (GMAST):

"A facility for complex terrain airflow studies"



- 2159 m elevation
- 853 m above valley floor

Domain

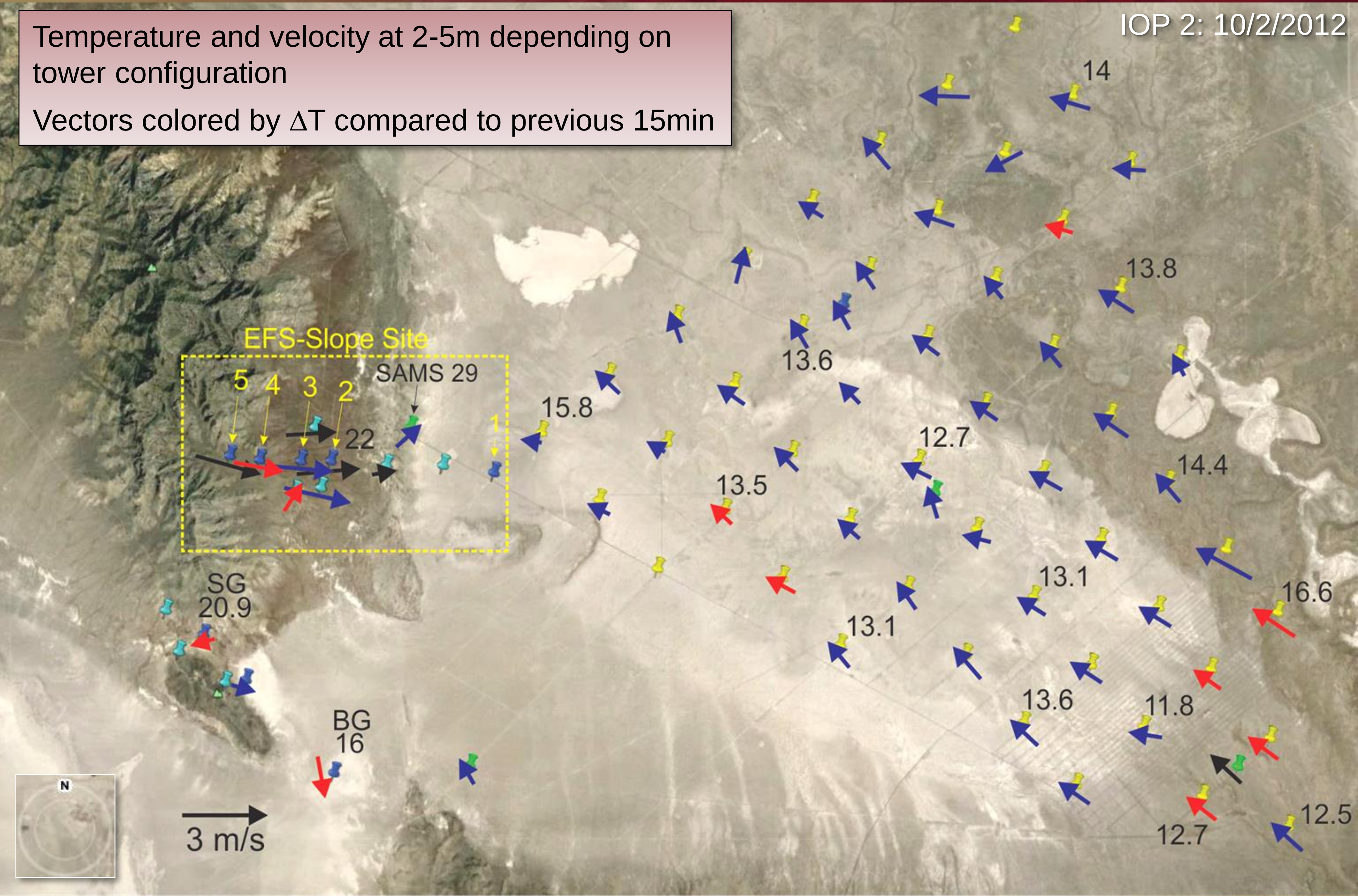


EAST SLOPE SITE
CANYON SITE
PLAYA SITE
GRANITE PEAK
WEST SLOPE SITE
EAST SLOPE SITE
CANYON SITE
SAGEBRUSH SITE
SMALL GAP SITE
SAPPHIRE MOUNTAIN
BIG GAP SITE
DUGWAY RANGE
I-80 SITE
CEDAR MOUNTAINS
GRANITE PEAK AREA
DITTO
DEEP CREEK RANGE
GRANITE PEAK AREA
SAMS
MINI-SAMS
PWIDS
Radiosonde
Flux Tower
Tethersonde
SoDAR
SoDAR/RASS
LiDAR UND
LiDAR UoU
LiDAR ARL
Ceilometer
FMCW; WP449; WP924
IR Camera
HOBO
Fine Wire Measurements
Fine Wire TCs
Flux Richardson N. Probe
Combo Probe
RF Crosshair
Extensive Energy Balance
LEM
DTS
DataHawk ground track
Twin Otter ground track
Elevation (m)
Max : 2156
Min : 1293
290.000
295.000
300.000
305.000
310.000
315.000
320.000
Easting (m)
4.455.000
4.450.000
4.445.000
4.440.000
4.435.000
4.430.000
Northing (m)

Tower Data: 3:30 UTC (21:30 MDT)

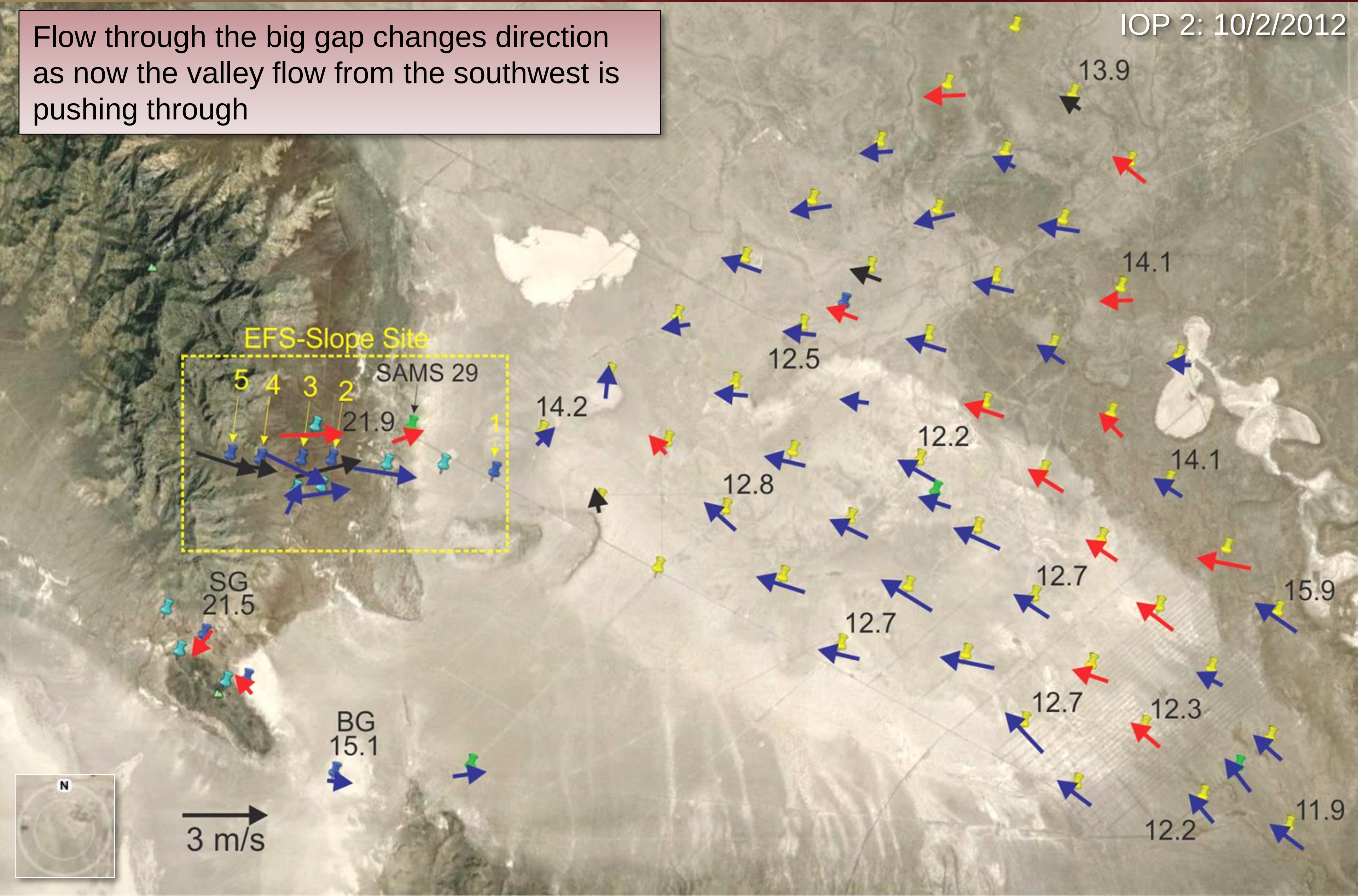
Temperature and velocity at 2-5m depending on tower configuration

Vectors colored by ΔT compared to previous 15min



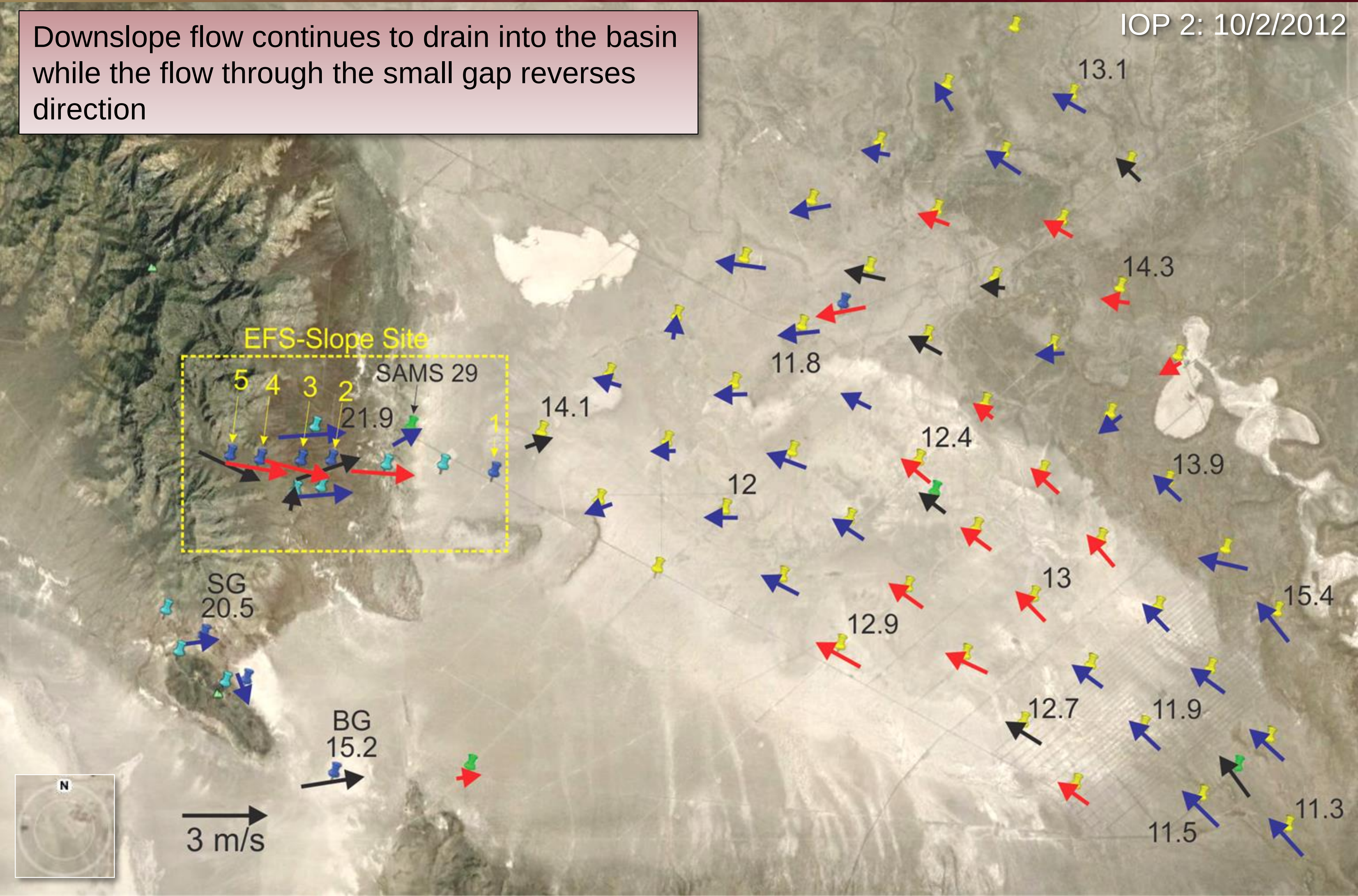
Tower Data: 3:45 UTC (21:45 MDT)

Flow through the big gap changes direction as now the valley flow from the southwest is pushing through



Tower Data: 4:00 UTC (22:00 MDT)

Downslope flow continues to drain into the basin while the flow through the small gap reverses direction

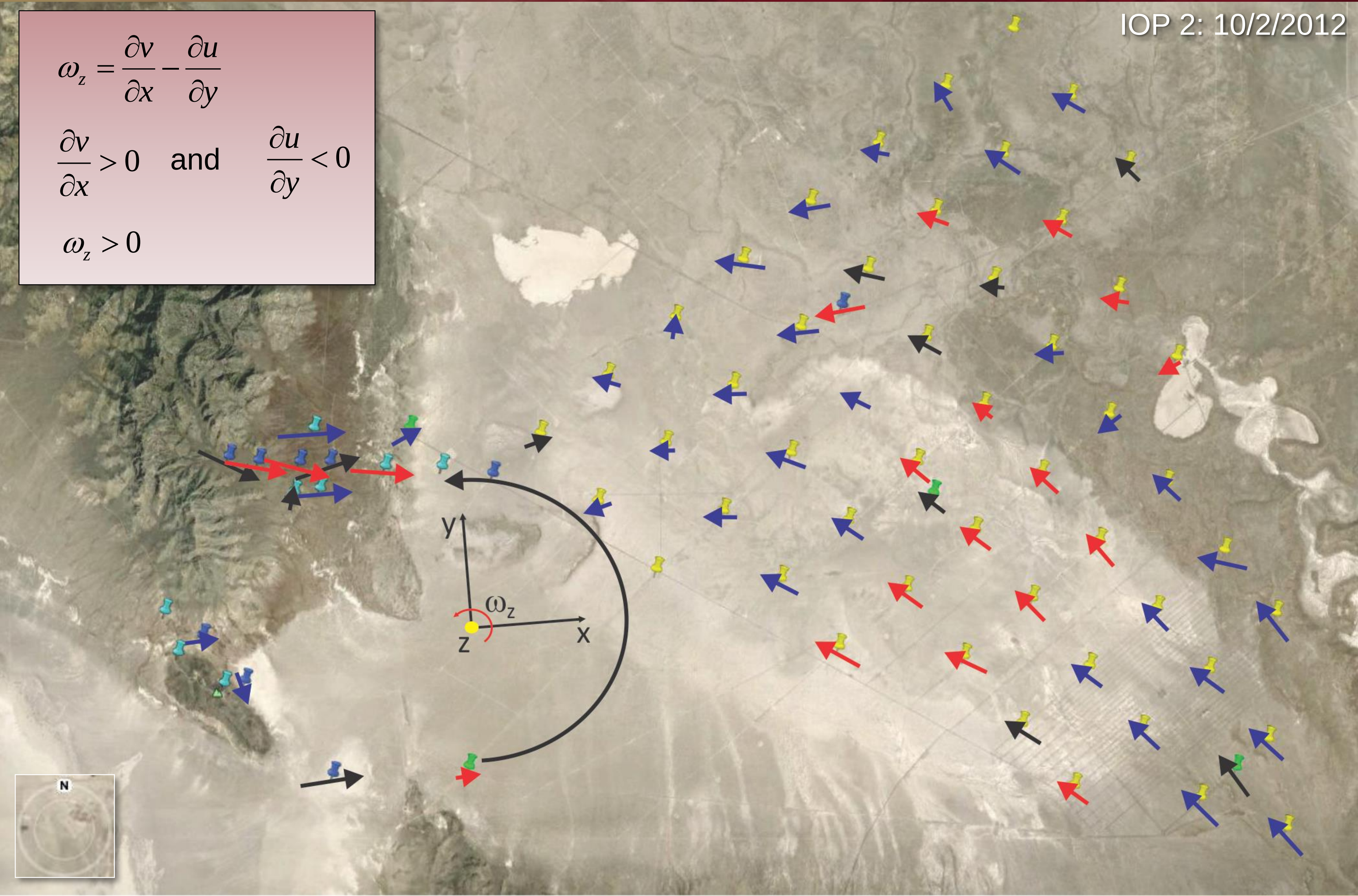


Vorticity Develops

$$\omega_z = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

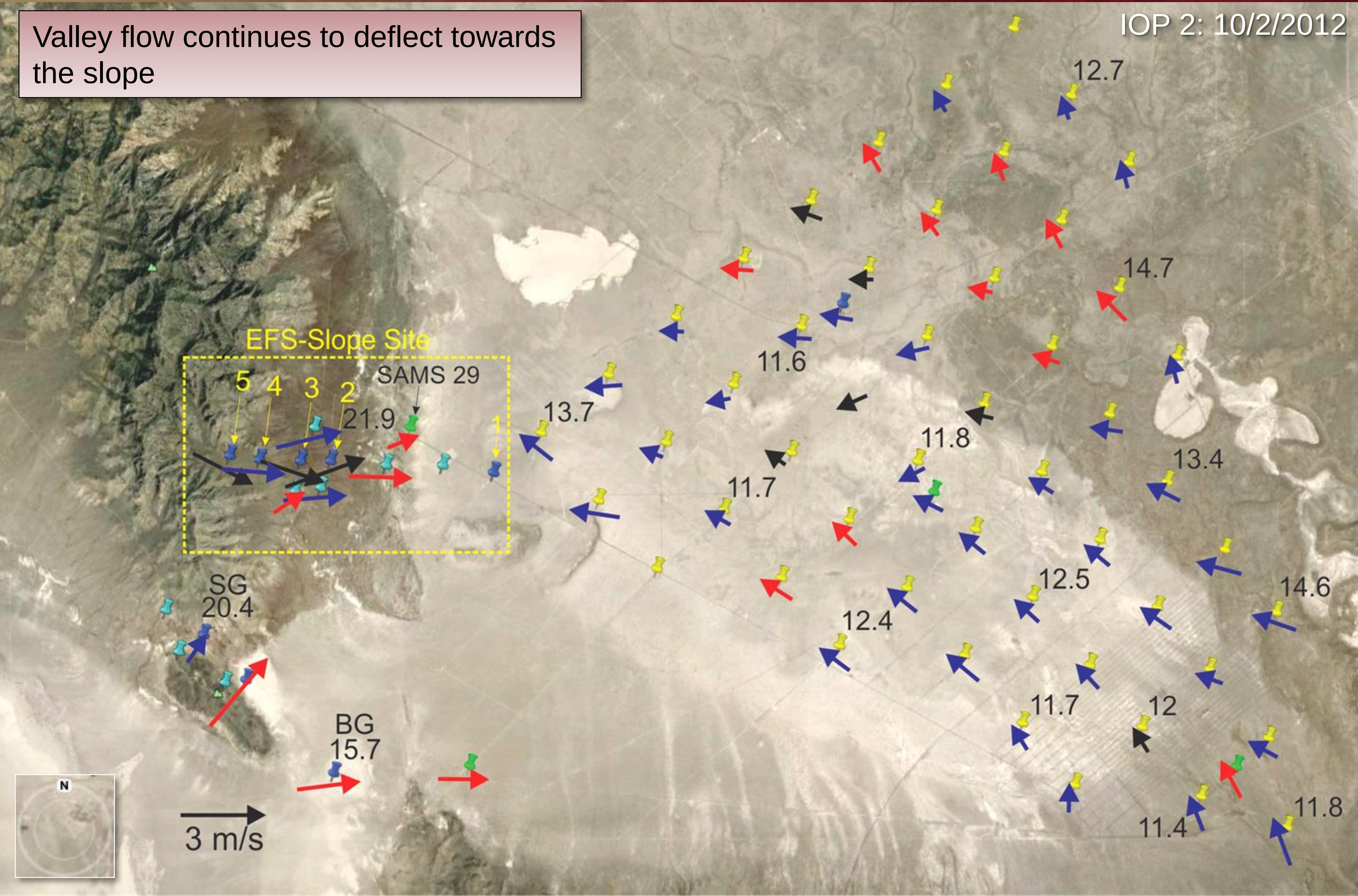
$$\frac{\partial v}{\partial x} > 0 \quad \text{and} \quad \frac{\partial u}{\partial y} < 0$$

$$\omega_z > 0$$



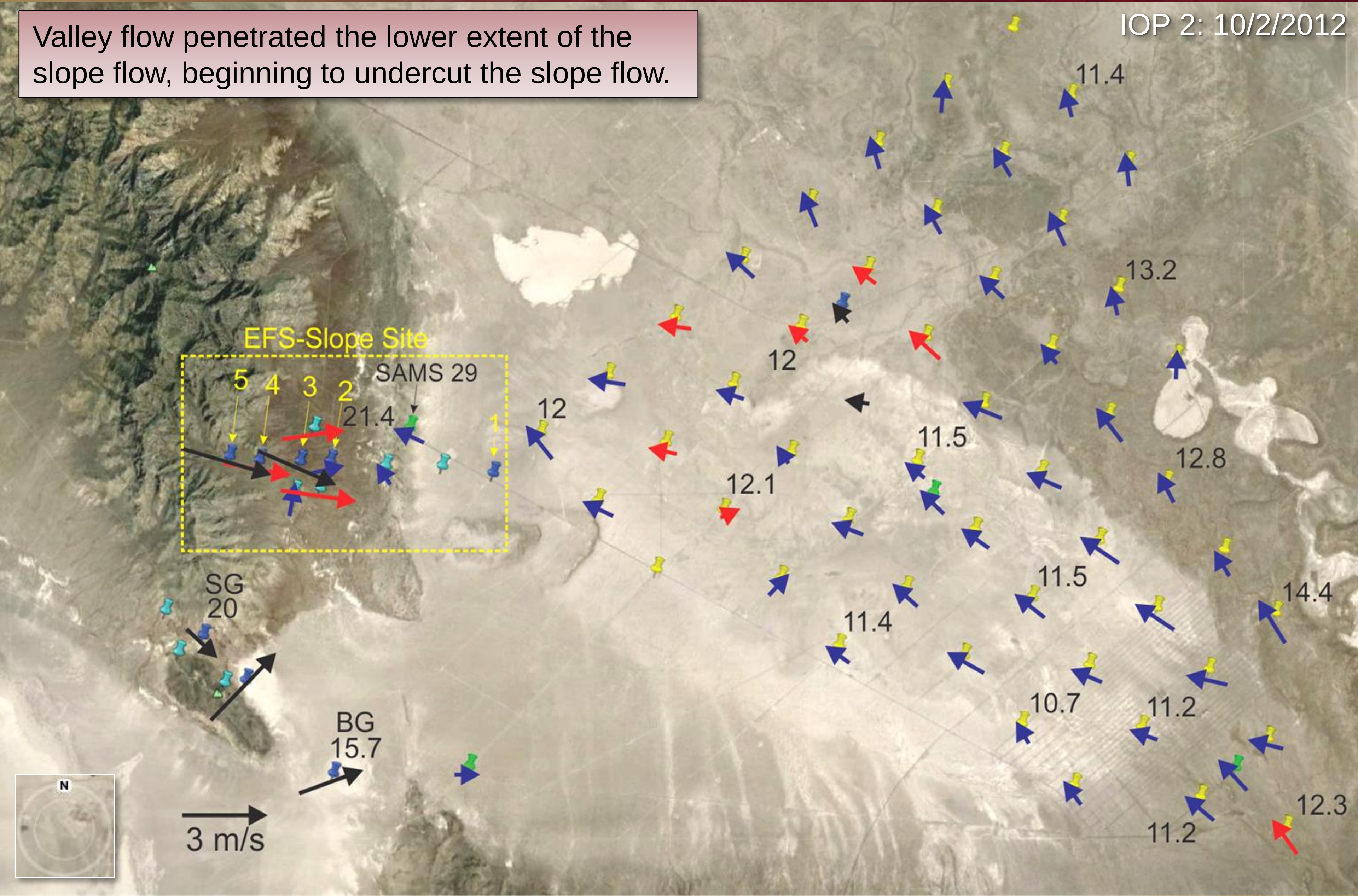
Tower Data: 4:15 UTC (22:15 MDT)

Valley flow continues to deflect towards the slope

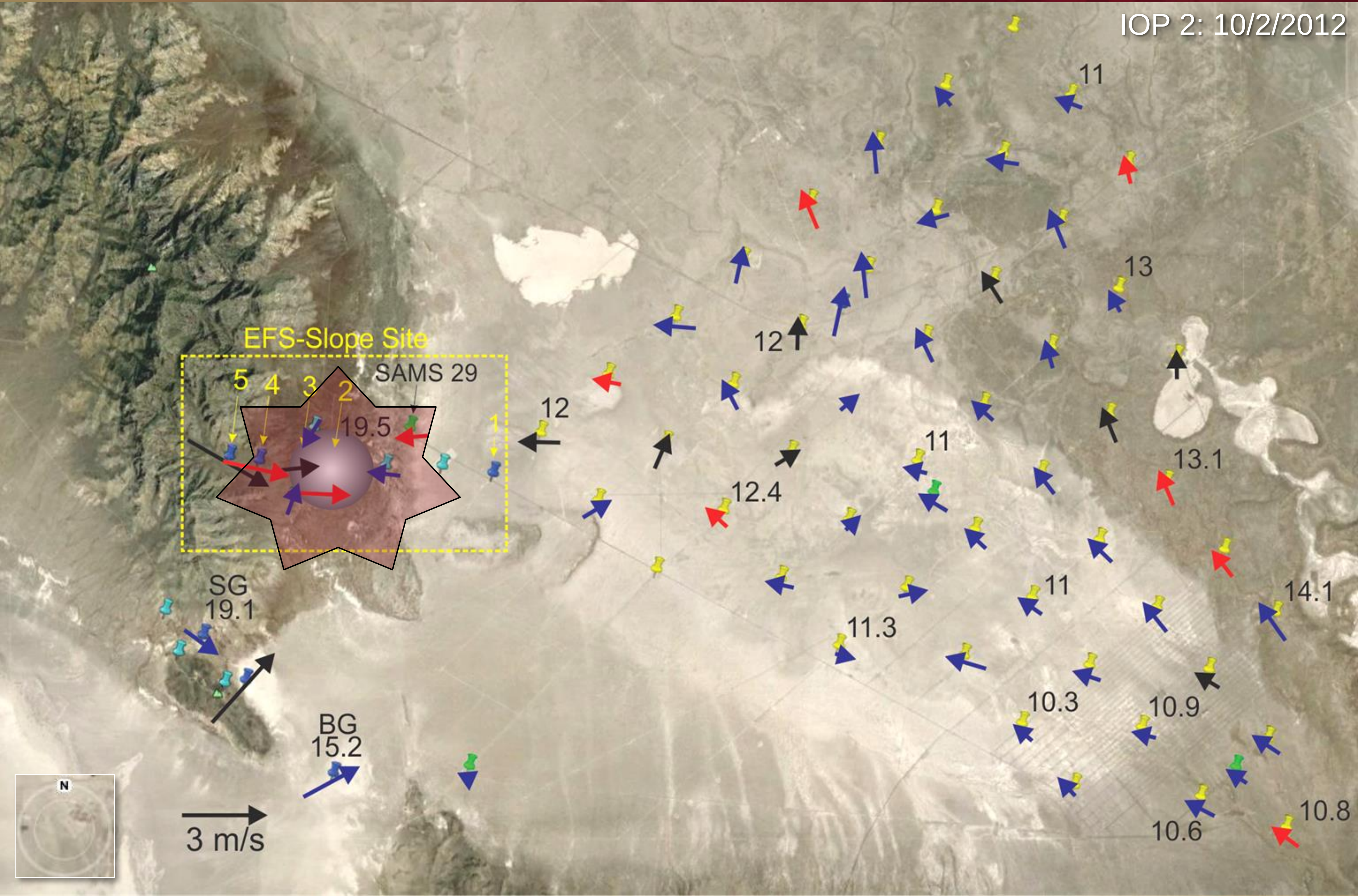


Tower Data: 4:30 UTC (22:30 MDT)

Valley flow penetrated the lower extent of the slope flow, beginning to undercut the slope flow.

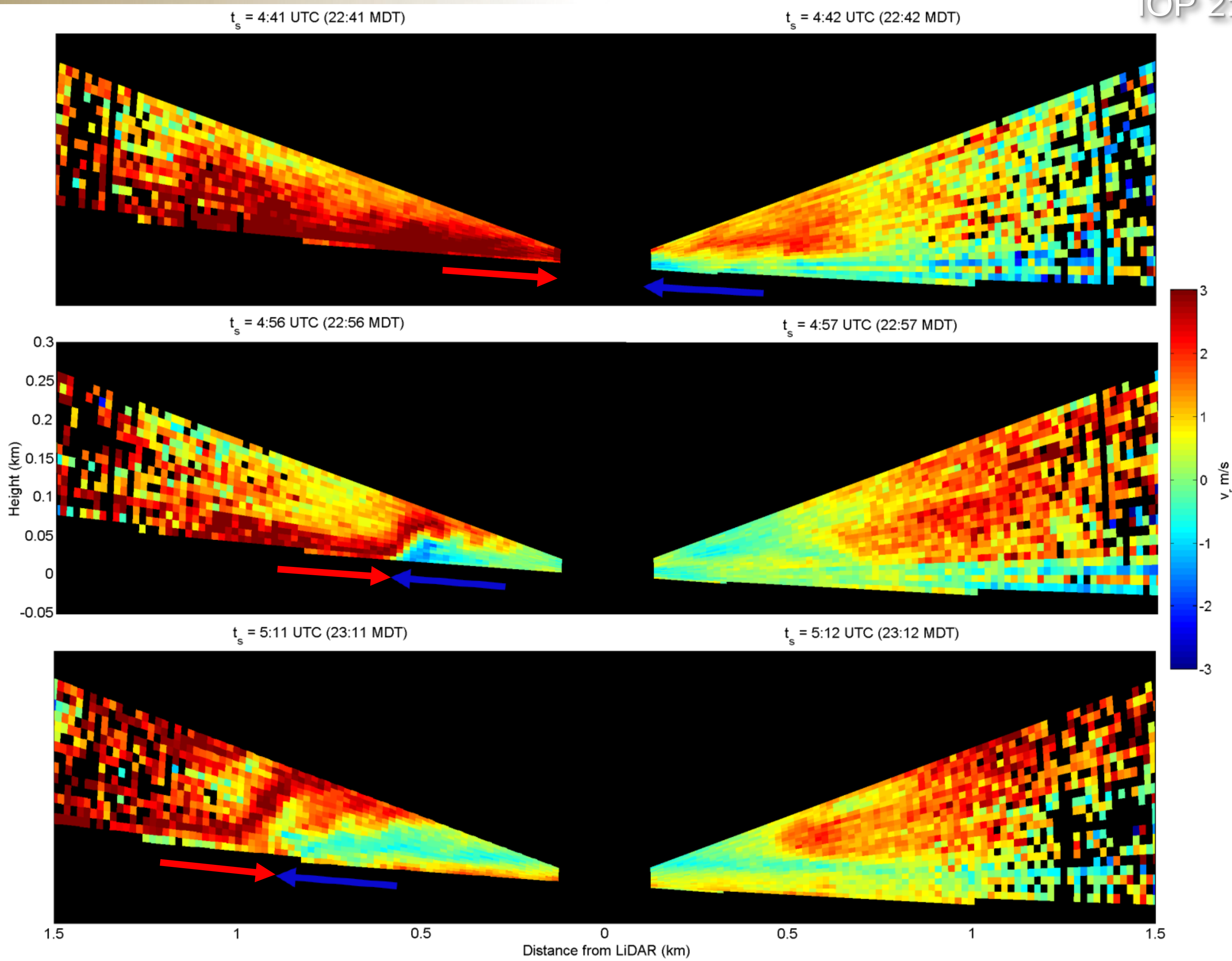


Tower Data: 4:45 UTC (22:45 MDT)

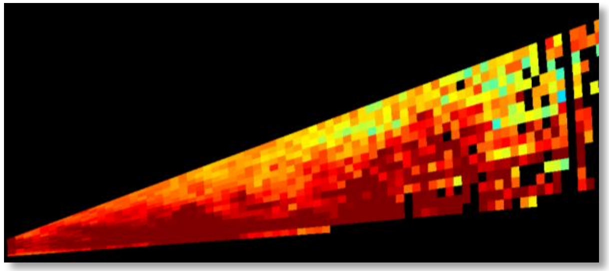


UU East Slope LiDAR

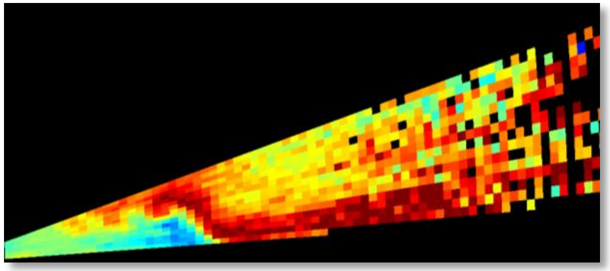
IOP 2: 10/2/2012



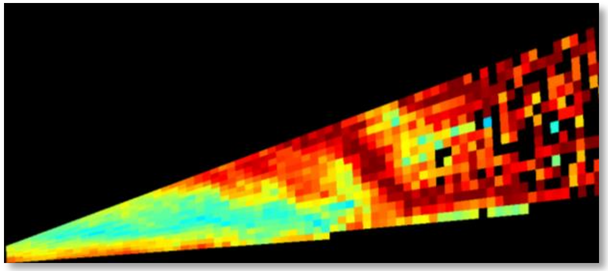
Flows Collide



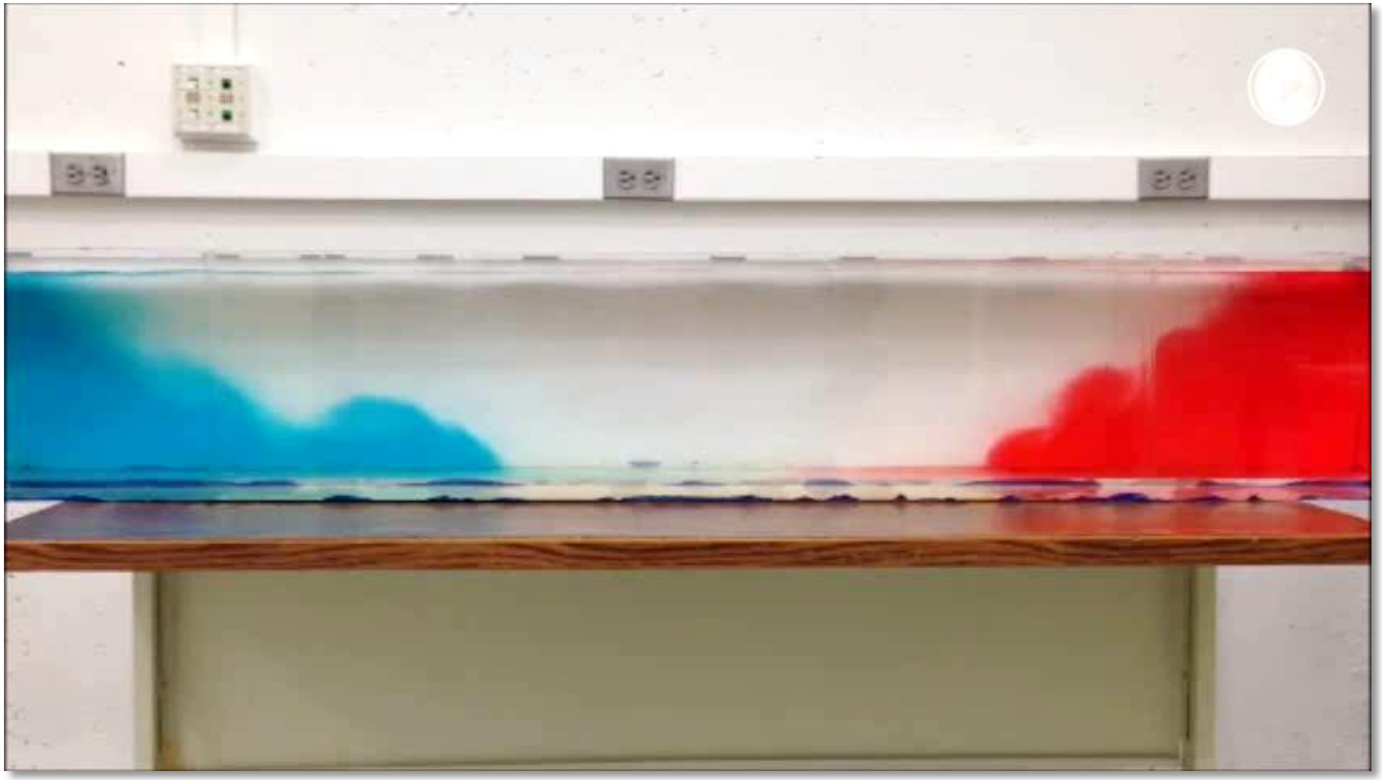
4:41 UTC (22:41 MDT)



4:54 UTC (22:54 MDT)

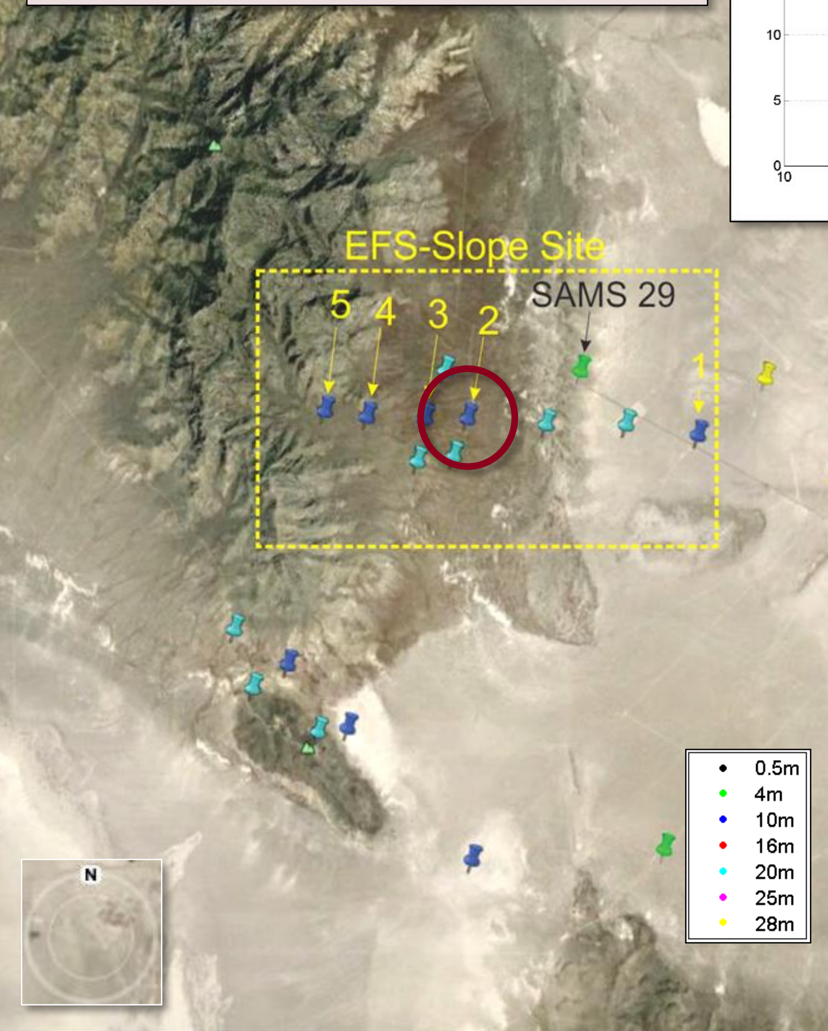


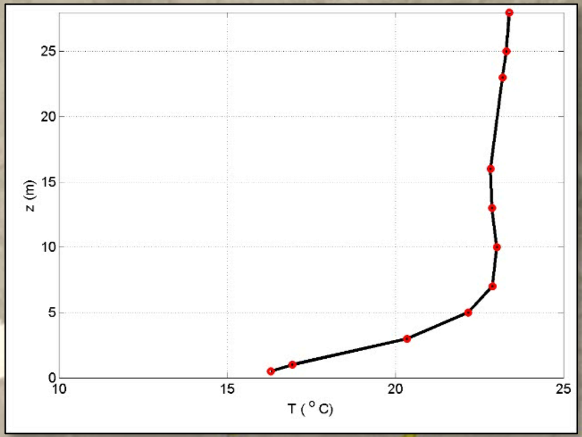
5:11 UTC (23:11 MDT)

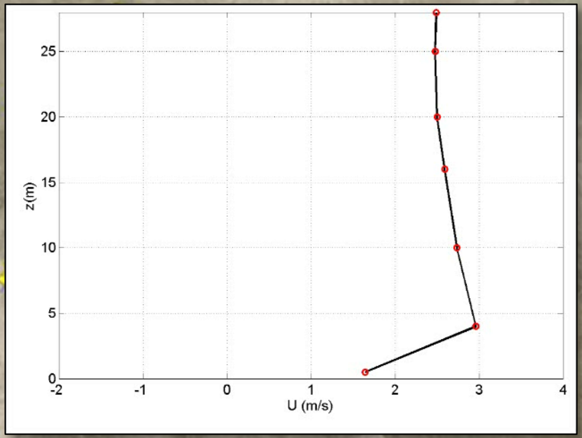


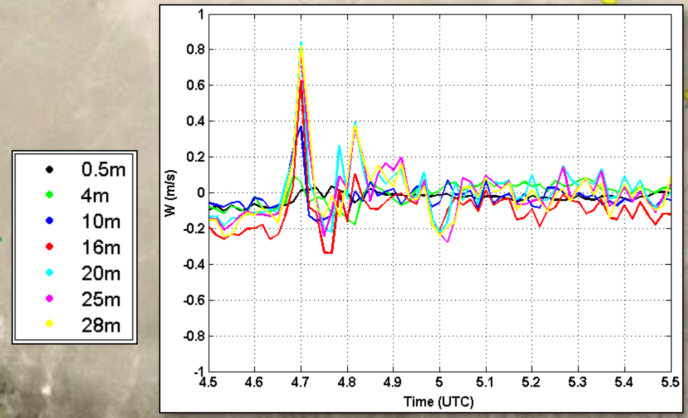
Collision Characteristics

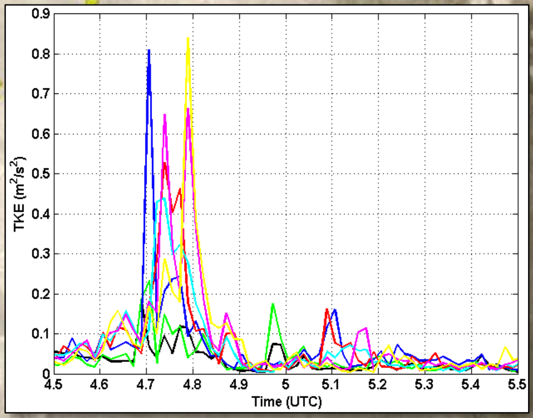
- Rapid drop in temperature
- Destruction of downslope flow
- Strong vertical velocity
- Intense turbulence







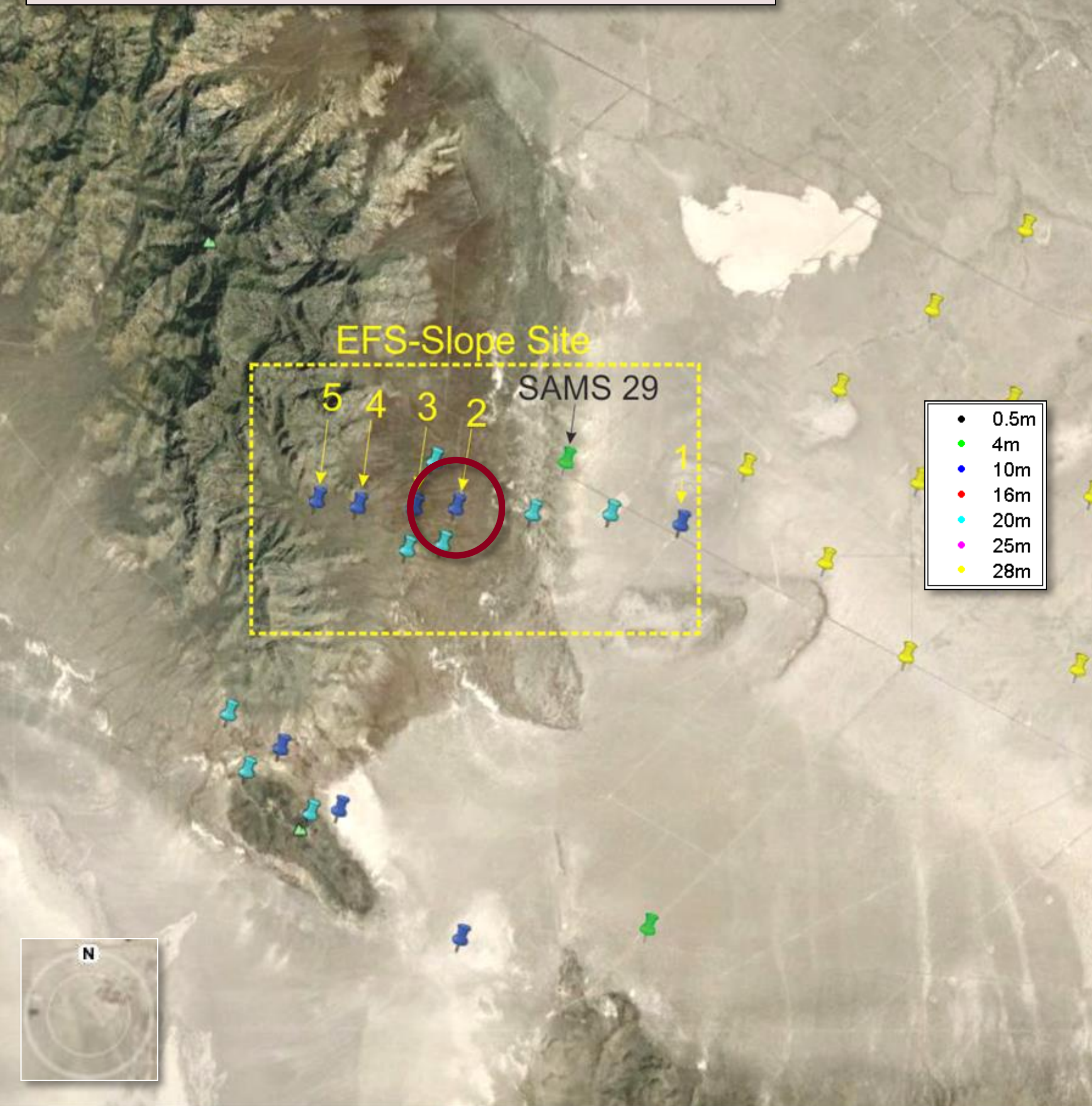


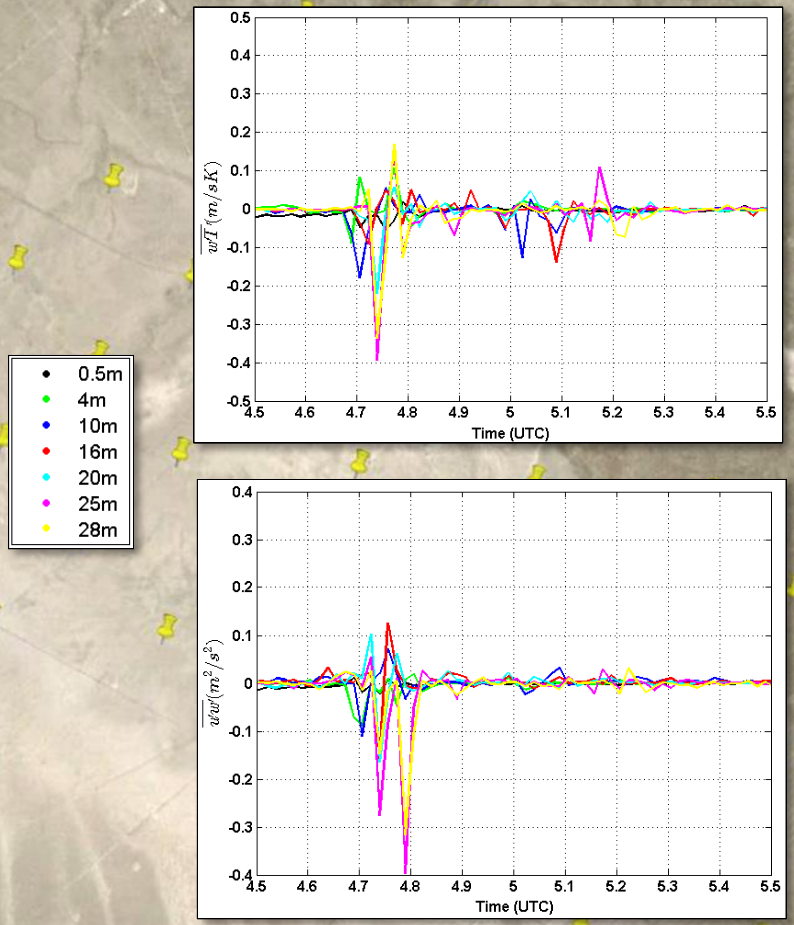


Collision Characteristics

Interaction contributes vigorously to sub-grid heat and momentum transfer

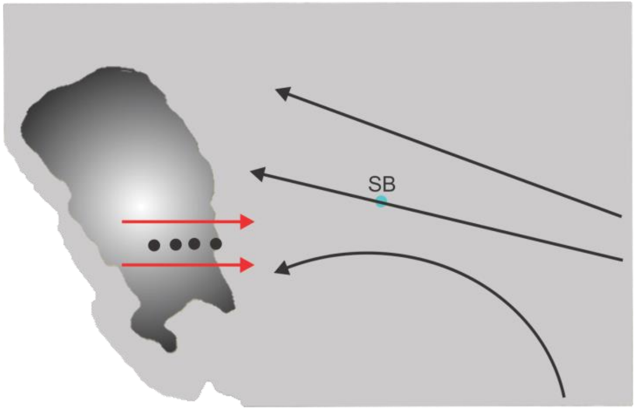
IOP 2: 10/2/2012

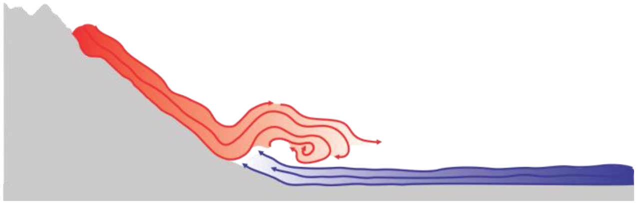


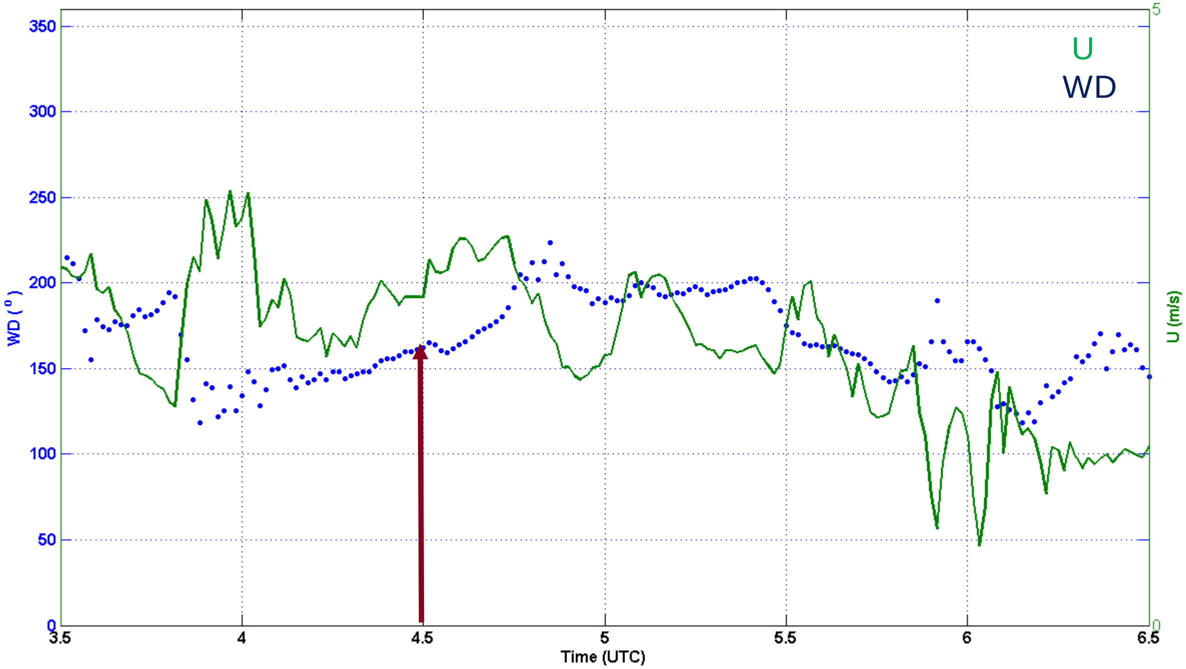


IOP 2: 10/2/2012

Primary Collision



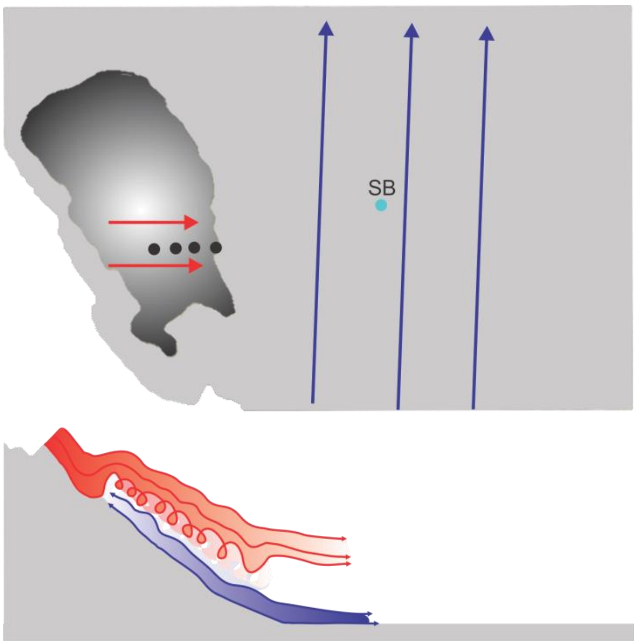


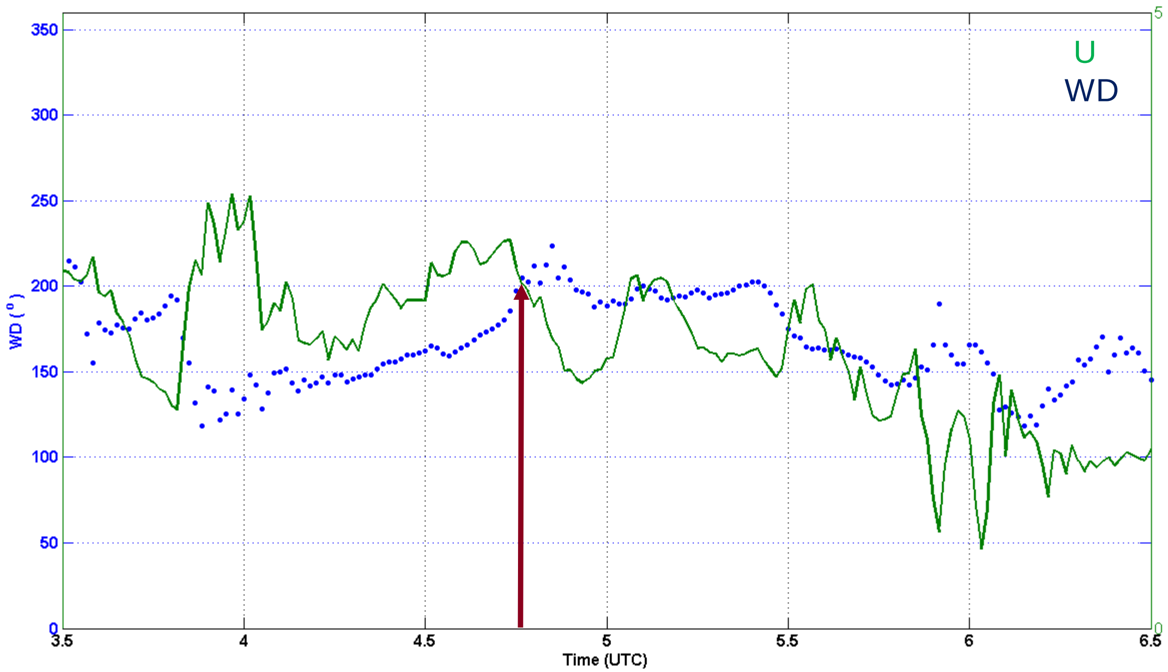


Sagebrush Tower

Adjustments in the Valley

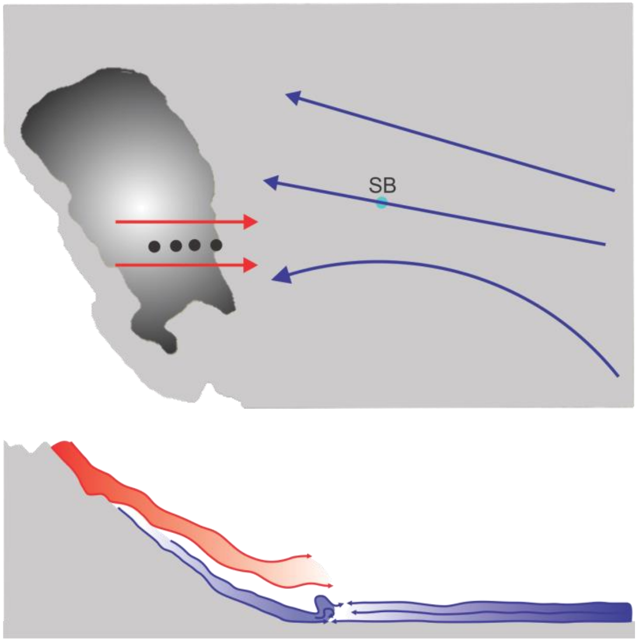
IOP 2: 10/2/2012

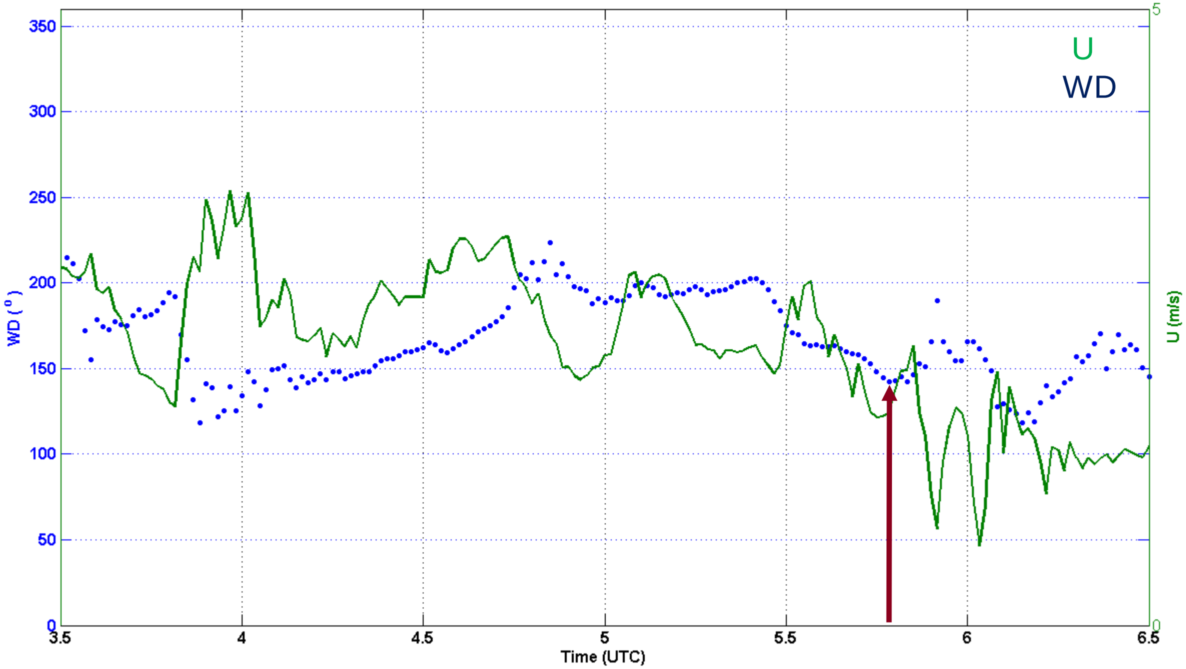




Sagebrush Tower

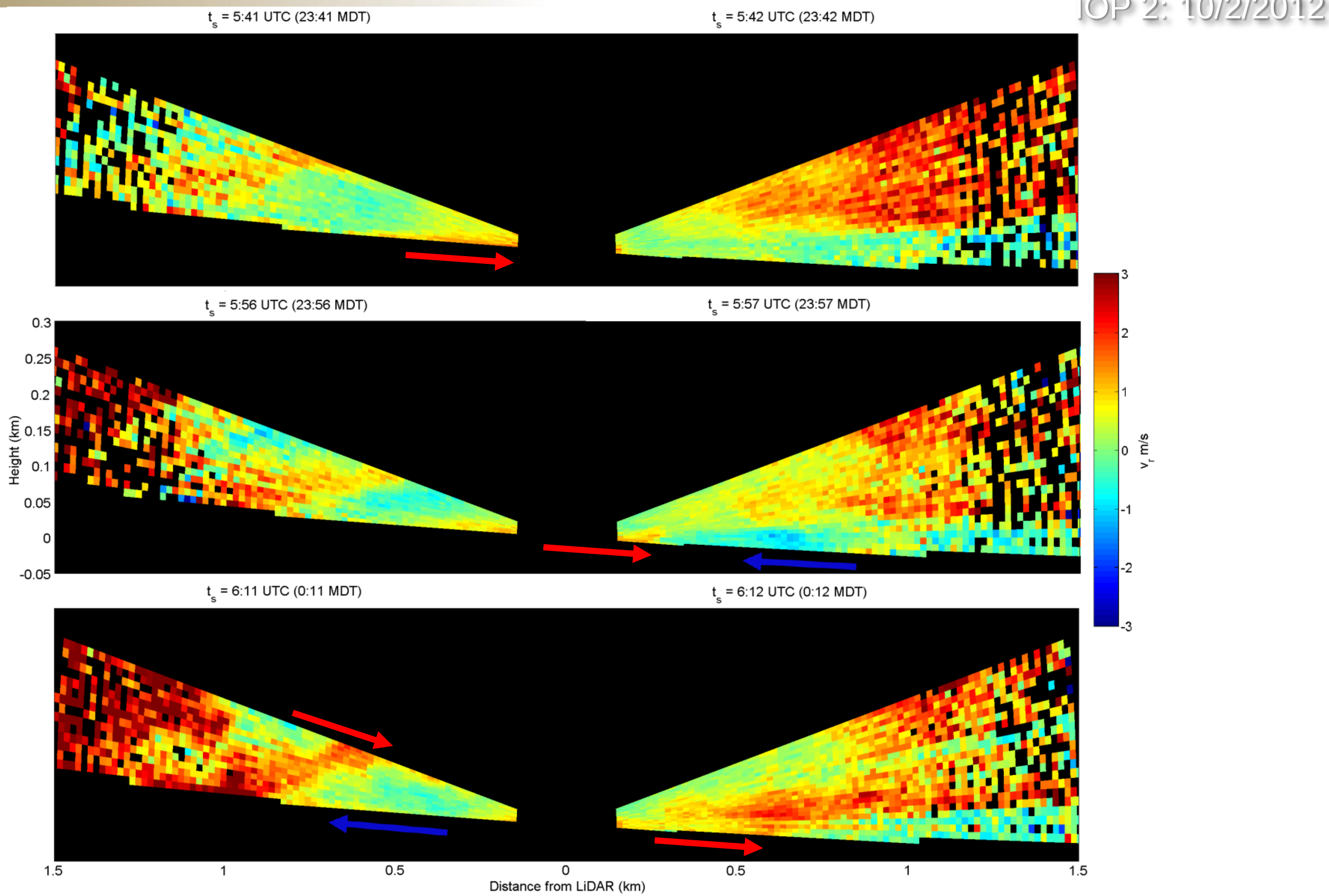
Secondary Collision



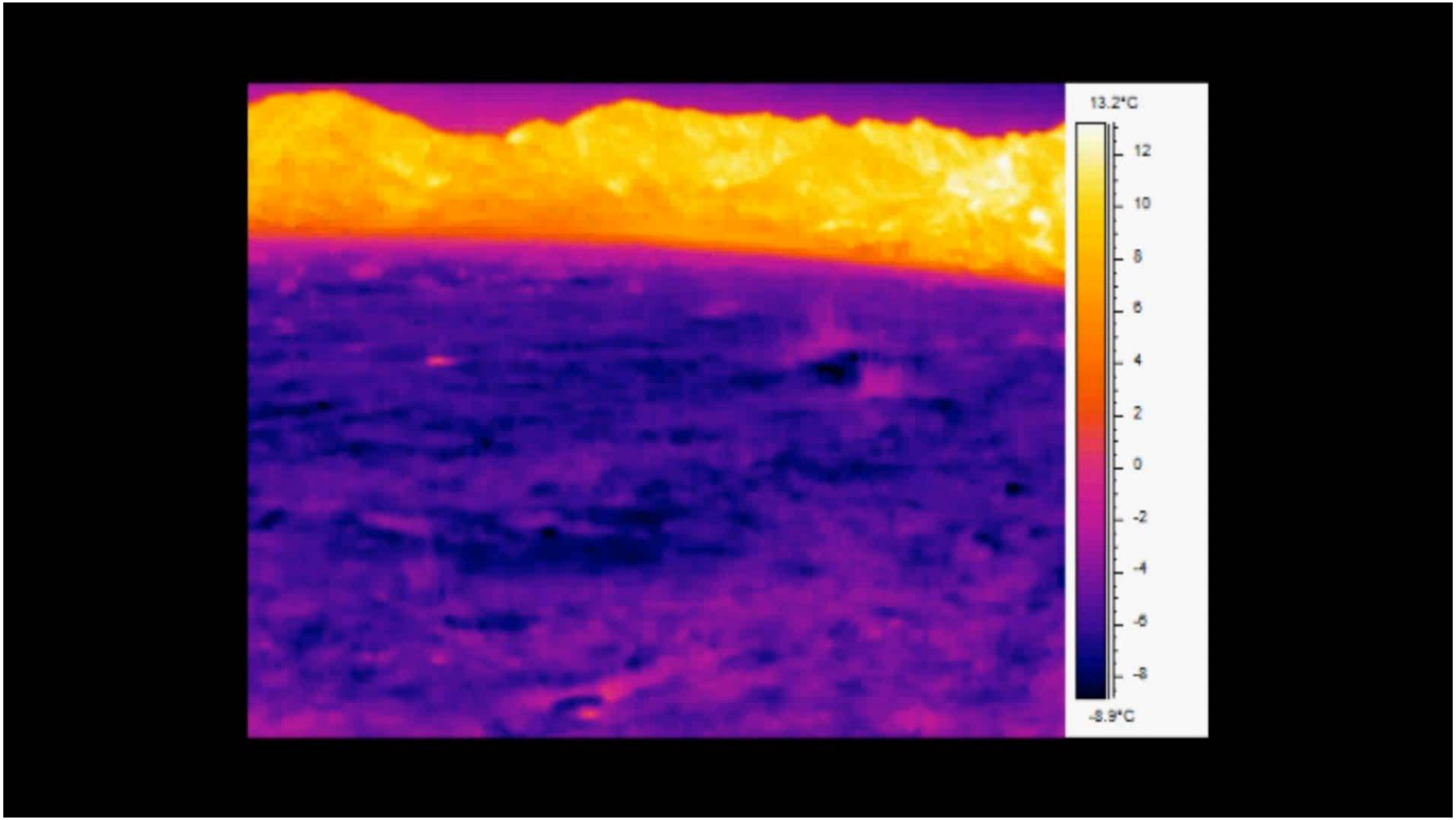


Sagebrush Tower

Secondary Collision

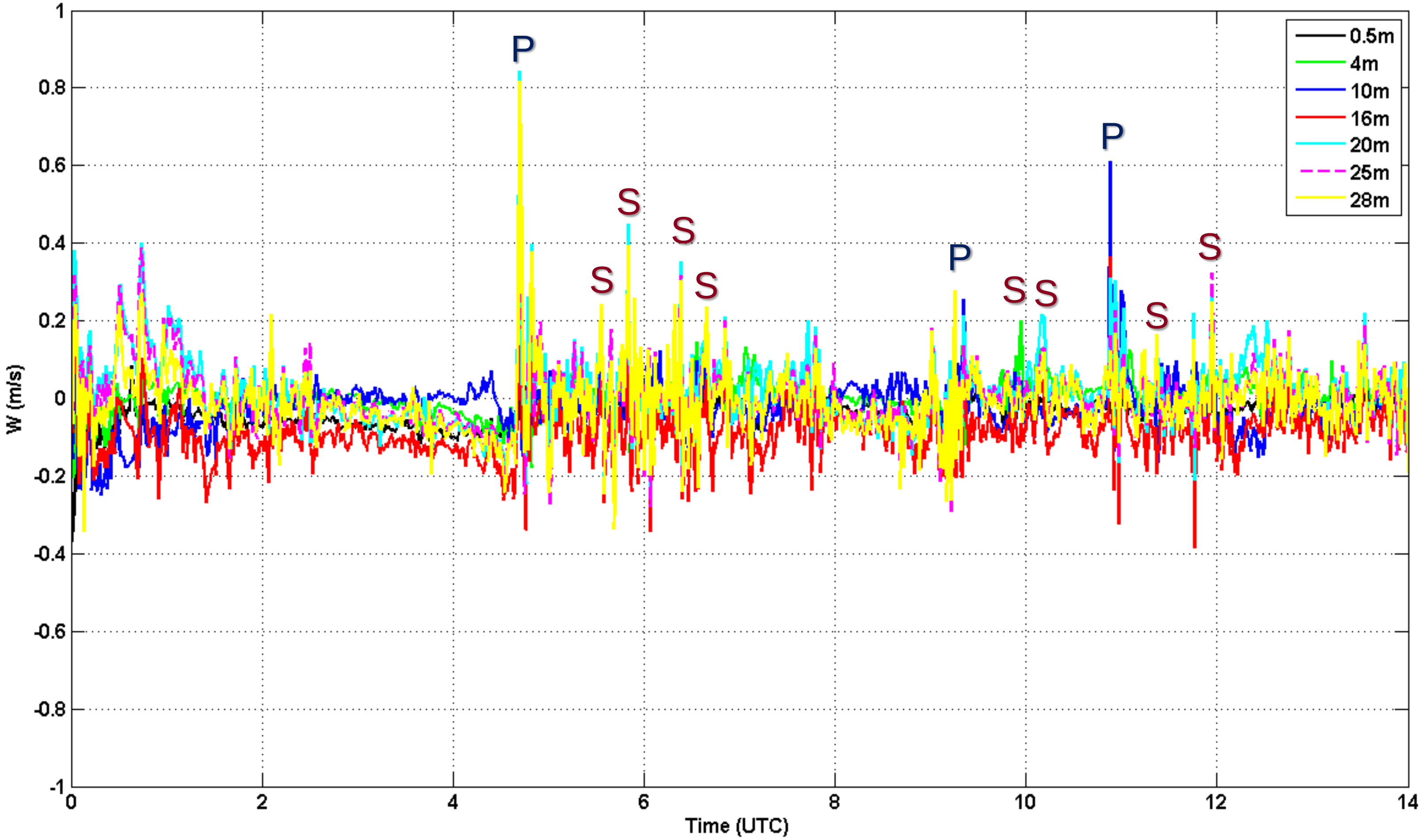


Secondary Collisions



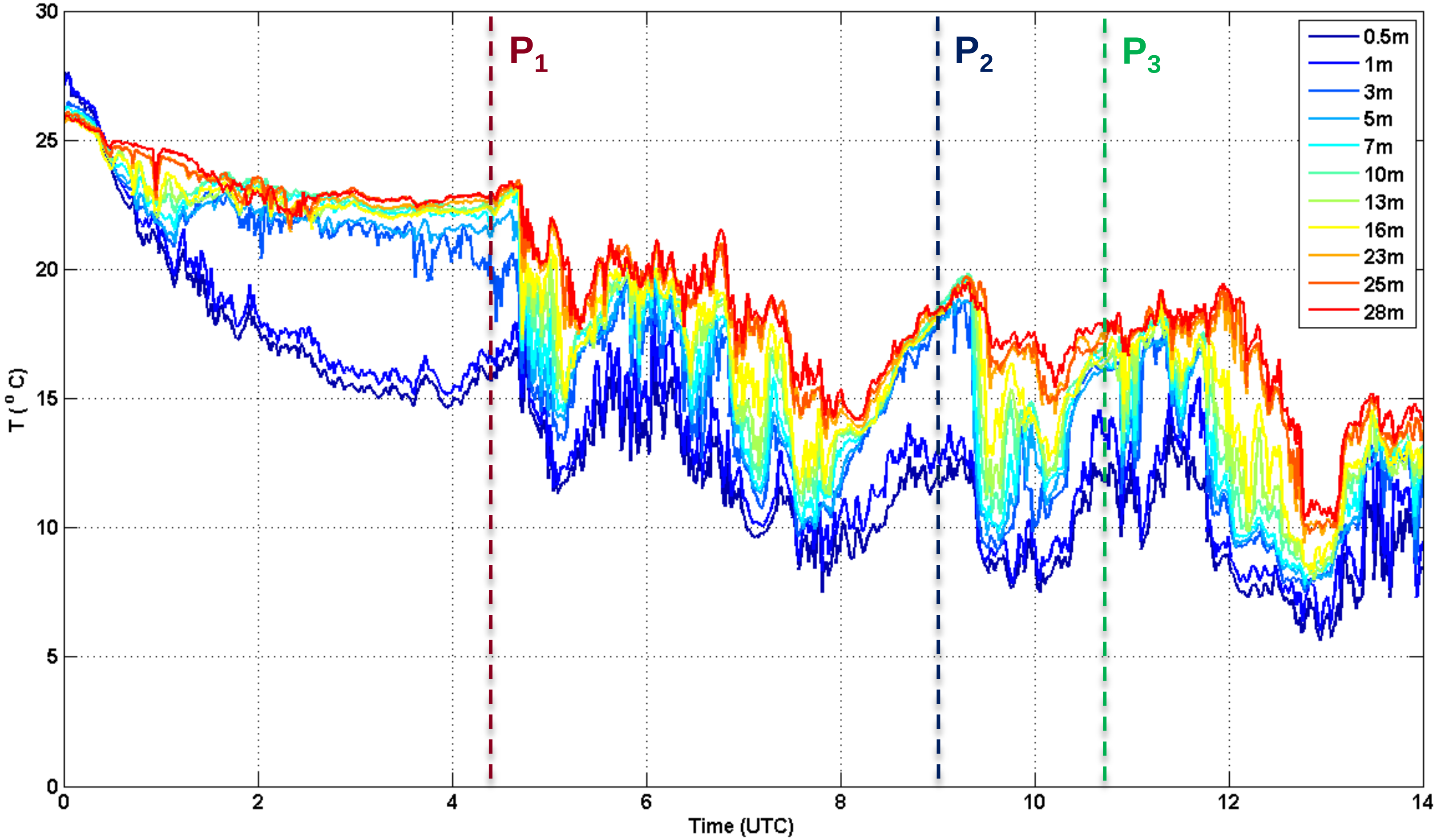
Secondary Collisions

IOP 2: 10/2/2012



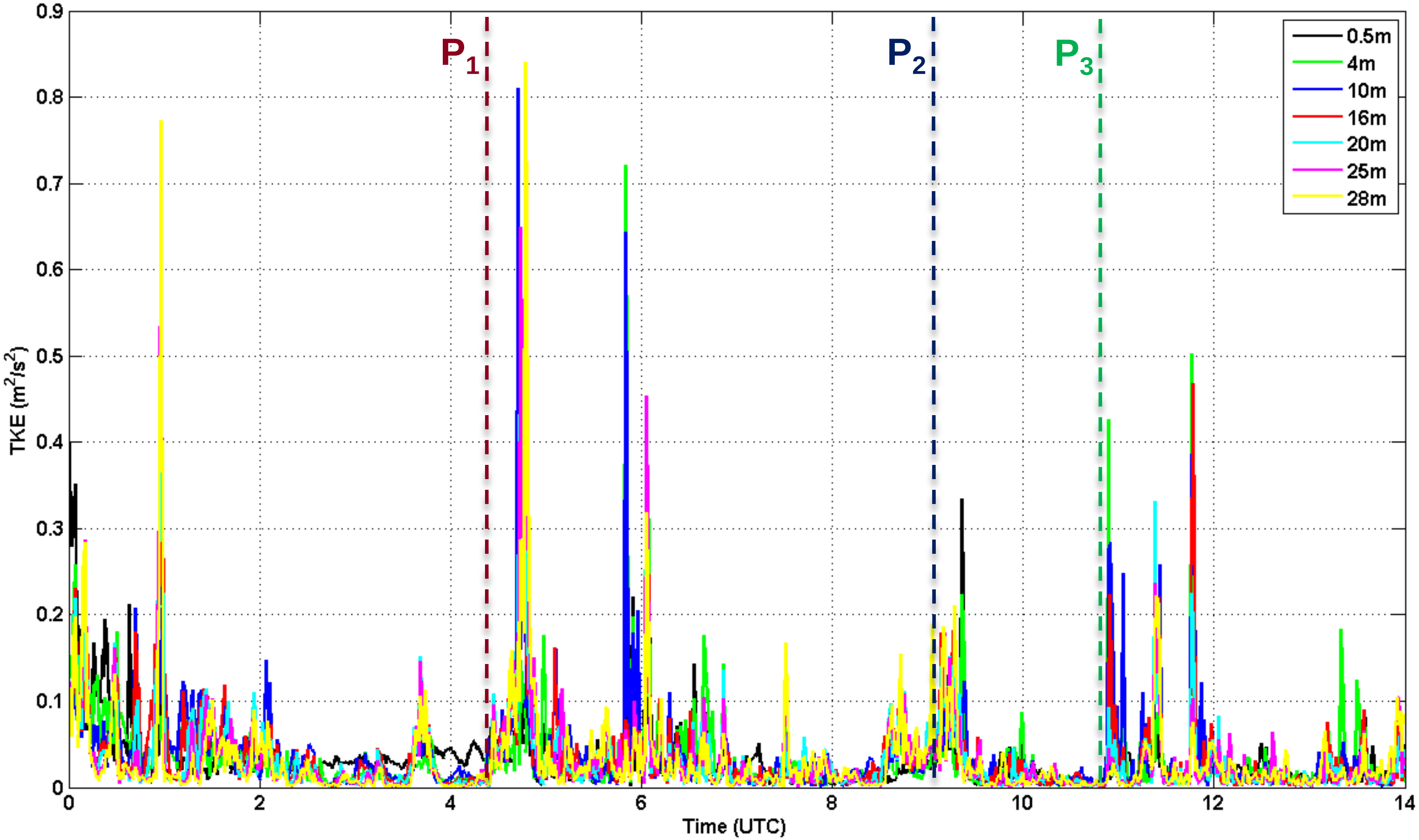
Collision Periods

IOP 2: 10/2/2012



Collision Periods

IOP 2: 10/2/2012

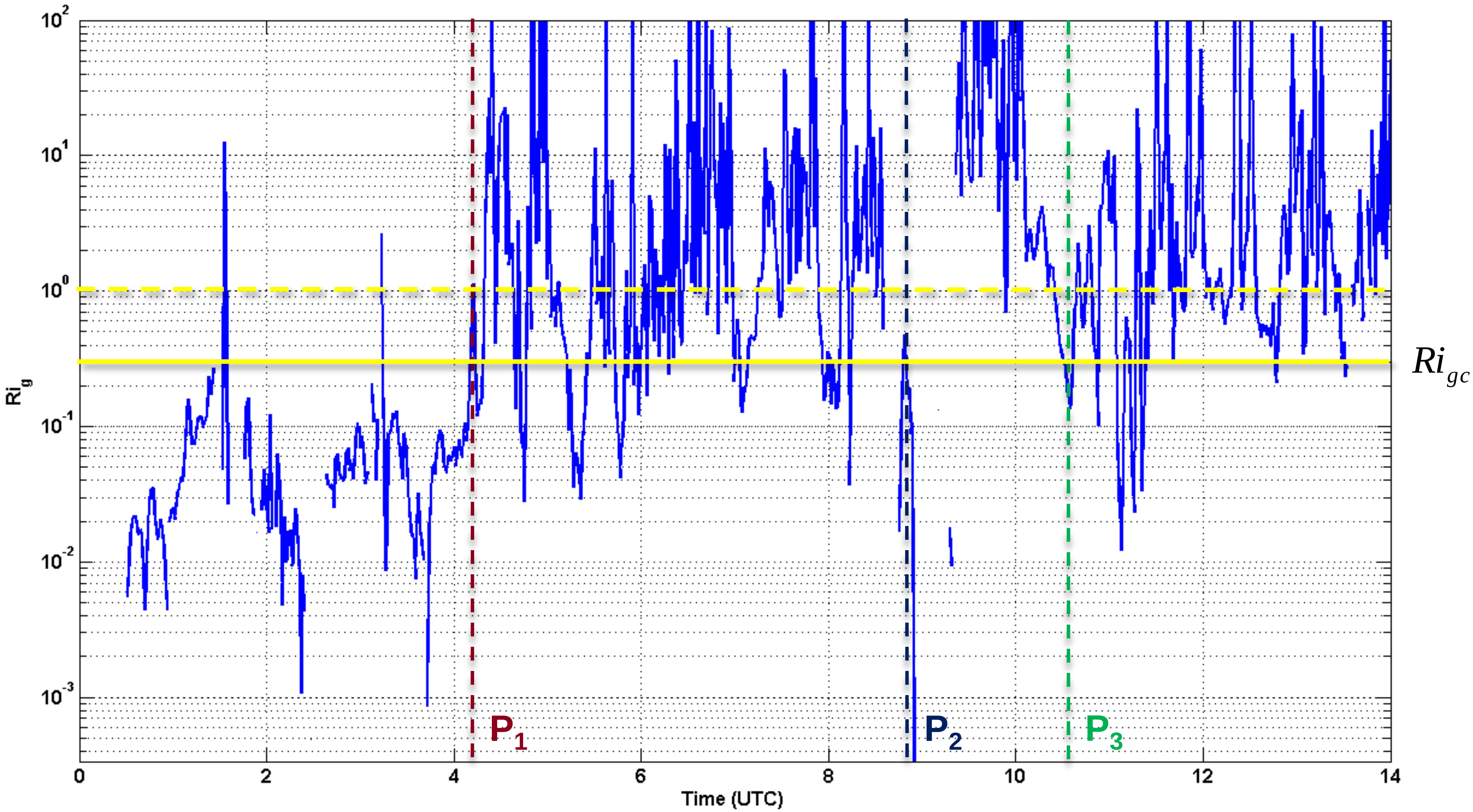


Discernible spikes in TKE when collisions occur

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

Fluxes Correlated to Ri_g?

IOP 2: 10/2/2012



$$Ri_g = \frac{N^2}{\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2} \quad \text{where} \quad N^2 = g\alpha\frac{d\theta}{dz}$$

Dimensional Analysis

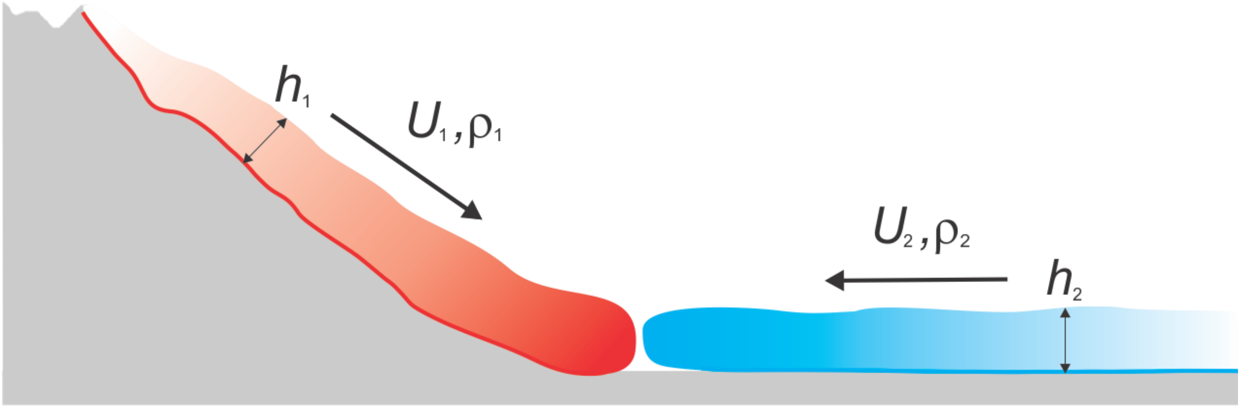
Buoyancy Flux: $\left|\overline{b'w'}\right| = f\left(\Delta b, \Delta U, \Delta h^*\right)$

Buoyancy: $b = g\left(\rho_0 - \rho\right)/\rho_0 \qquad \Delta b = g\left(\rho_2 - \rho_1\right)/\rho_0$

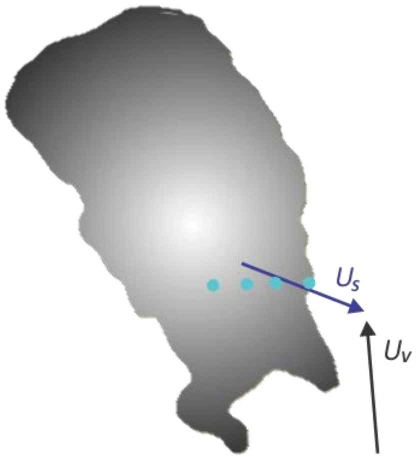
Velocity: $\Delta U = \left(U_1 + U_2\right)$

Height: $h^* = \left(h_1 + h_2\right)/2$

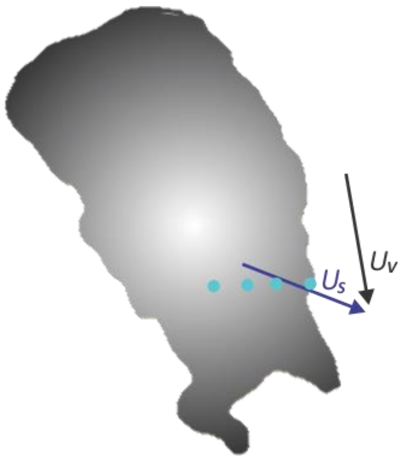
$$\frac{\left|\overline{b'w'}\right|}{\Delta b \Delta U} = f\left(\frac{\Delta b h^*}{\Delta U^2}\right) = f\left(Ri_C\right)$$



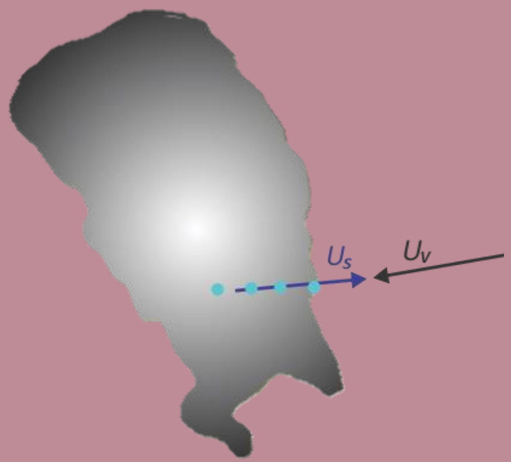
Collision Types



Along slope

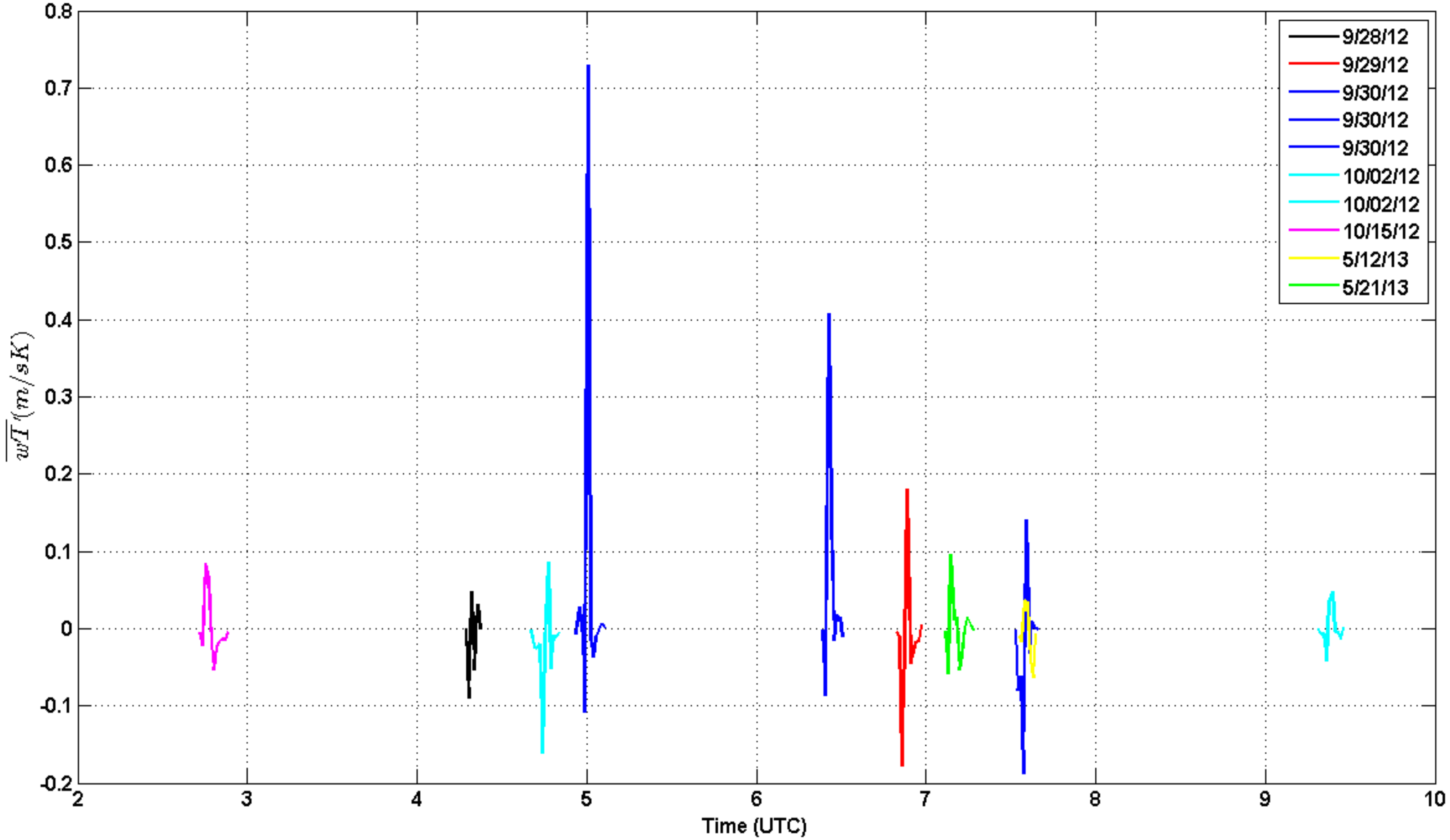


Merging



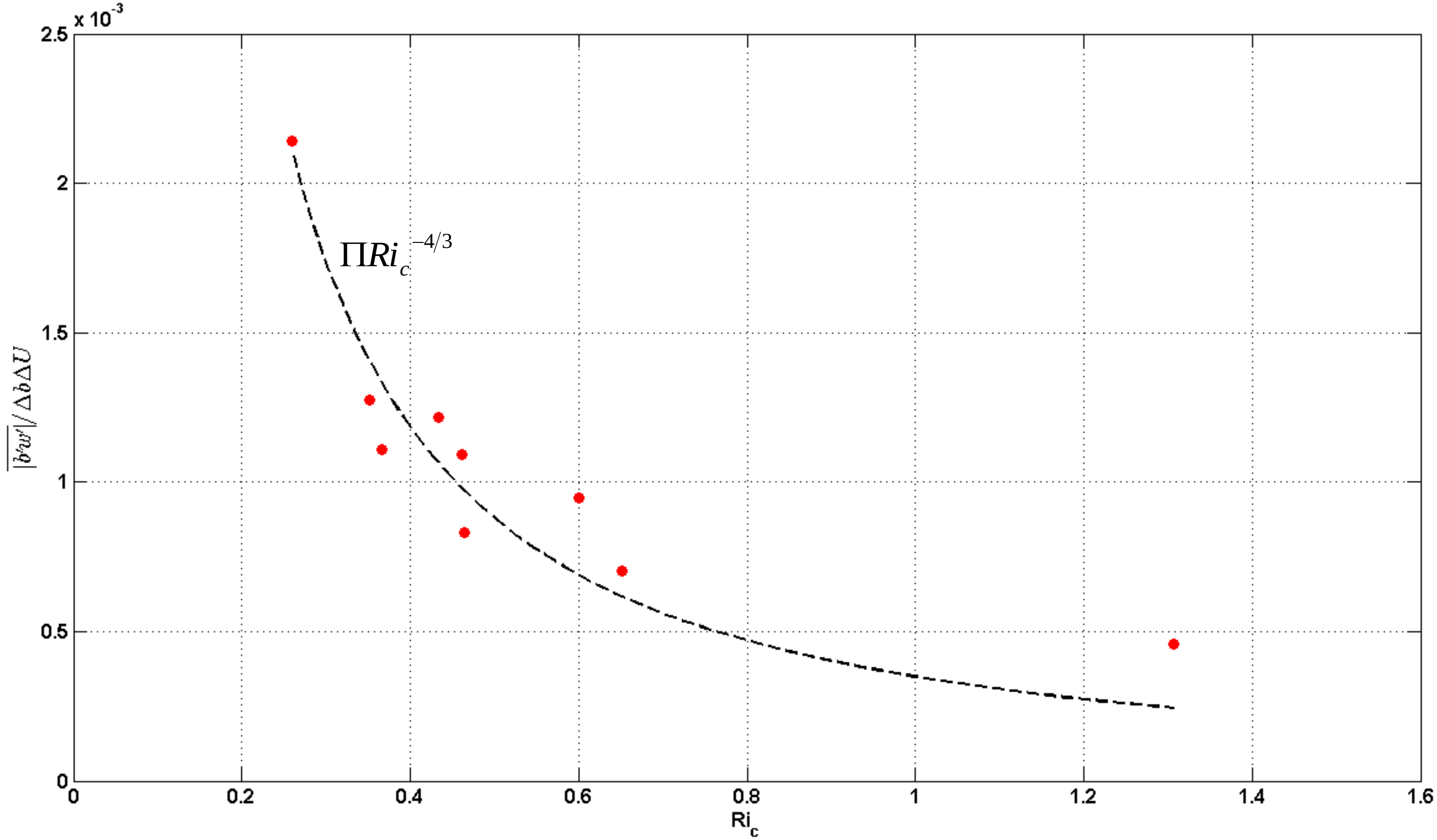
Perpendicular to slope

Vertically Averaged Heat Flux



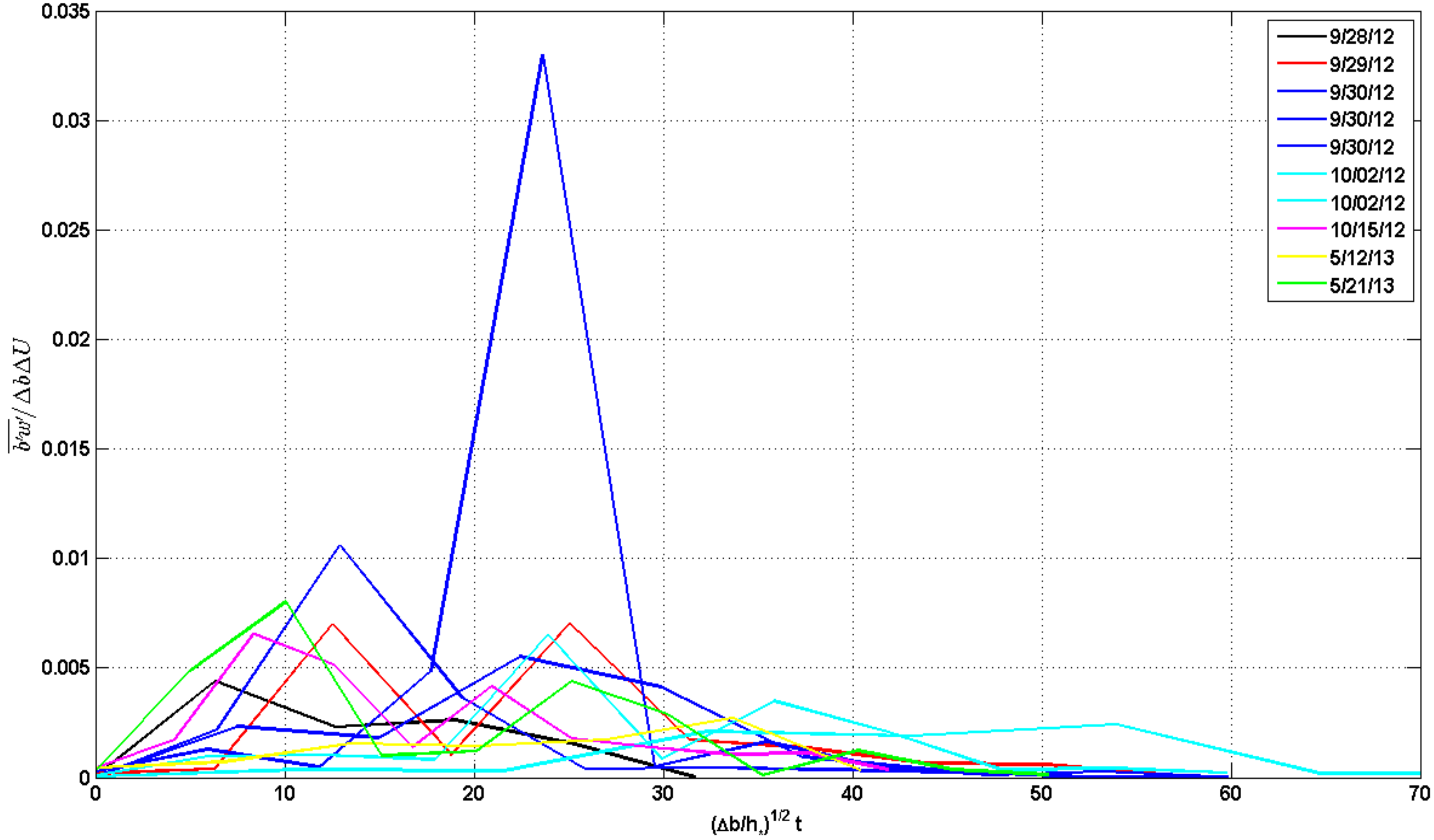
The end of the collision were identified by the time at which the averaged $\overline{w'T'}$ reached 10% of the maximum

Parameterization



$$Ri_C = \frac{\Delta b h^*}{\Delta U^2}$$

Collision Decay Timescale



$$t = \left(\frac{\Delta b}{h^*}\right)^{-1/2}$$

Dies out in ~ 60 buoyancy periods

Conclusions

- During the MATERHORN X quiescent evenings, interactions between downslope and valley flows were identified, each consisting of a series of collisions, sending waves of disturbance throughout the Dugway basin.

- These interactions generated an intriguing set of small scale processes that contribute vigorously to sub-grid heat and momentum transfer.

- Processes include the collision of gravity currents, formation of intense turbulent regions, intrusions and instabilities.

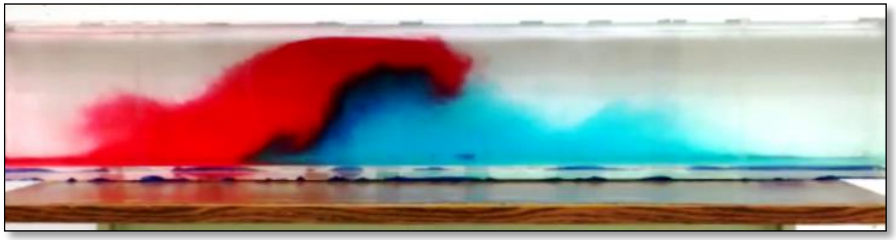
- WRF and other mesoscale models do not account for such sub-grid processes, hence their incorporation is crucial in modeling mountain terrain winds.

Ongoing Work

Laboratory Experiments

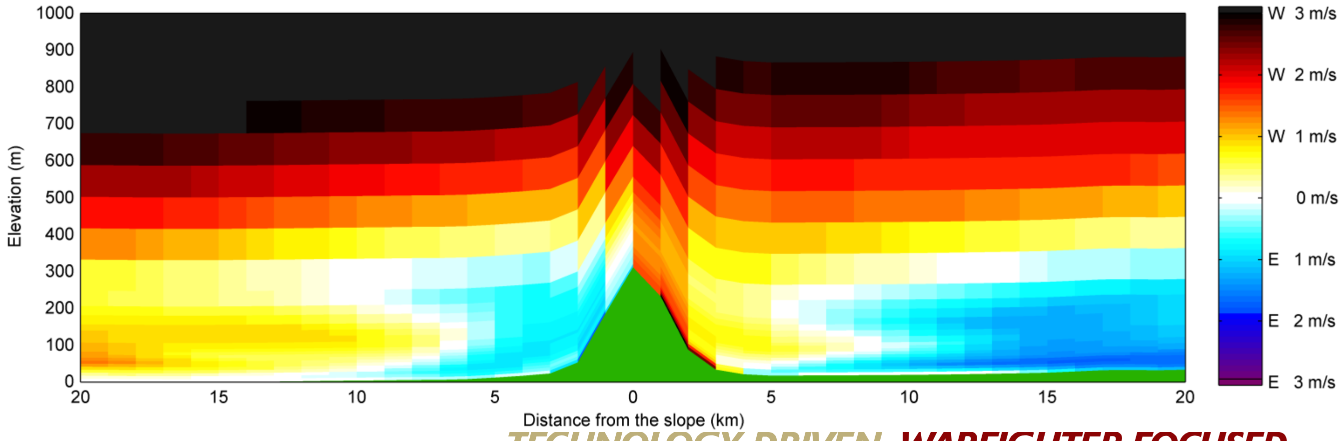
Slope and valley flow tank

Gravity current tank



- Determine the nature of the interactions and the possibility of flow instabilities
- Examine the turbulence near the region of interaction

WRF Modeling



Questions?

www.nd.edu/~dynamics/materhorn/

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