Slope and valley flow interactions in MATERHORN-1

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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
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-art 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
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
The Granite Mountain Atmospheric Sciences Testbed (GMAST):

“A facility for complex terrain airflow studies”

- Dugway Proving Grounds
- 3,700 km² of controlled, remote encroachment-free terrain
- 137 km SW of Salt Lake City, UT

- 2159 m elevation
- 853 m above valley floor
Temperature and velocity at 2-5m depending on tower configuration

Vectors colored by $\Delta T$ compared to previous 15min
Flow through the big gap changes direction as now the valley flow from the southwest is pushing through.
Downslope flow continues to drain into the basin while the flow through the small gap reverses direction.
\[ \omega_z = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \]

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

\[ \omega_z > 0 \]
Valley flow continues to deflect towards the slope.
Valley flow penetrated the lower extent of the slope flow, beginning to undercut the slope flow.
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
Interaction contributes vigorously to sub-grid heat and momentum transfer.
Primary Collision

Sagebrush Tower
Secondary Collision

Sagebrush Tower
Secondary Collisions
Discernible spikes in TKE when collisions occur

\[ TKE = \sigma^2 = \frac{1}{2}(u'^2 + v'^2 + w'^2) \]
Fluxes Correlated to $R_i_g$?

\[ R_i_g = \frac{N^2}{\left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2} \]

where

\[ N^2 = g \alpha \frac{d\theta}{dz} \]
Buoyancy Flux: \[ |b'w'| = f(\Delta b, \Delta U, \Delta h^*) \]

Buoyancy: \[ b = g(\rho_0 - \rho)/\rho_0 \quad \Delta b = g(\rho_2 - \rho_1)/\rho_0 \]

Velocity: \[ \Delta U = (U_1 + U_2) \]

Height: \[ h^* = (h_1 + h_2)/2 \]

\[ \frac{|b'w'|}{\Delta b \Delta U} = f\left(\frac{\Delta bh^*}{\Delta U^2}\right) = f(Ri_c) \]
Collision Types

Along slope

Merging

Perpendicular to slope
The end of the collision were identified by the time at which the averaged $\overline{w'T'}$ reached 10% of the maximum.
\[ \Pi \Delta Ri_c^{-4/3} \]

\[ Ri_c = \frac{\Delta bh^*}{\Delta U^2} \]
Dies out in ~ 60 buoyancy periods
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.
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
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