Boundary-layer phenomena in the vicinity of an isolated mountain: A climatography based on an operational high-resolution forecast system

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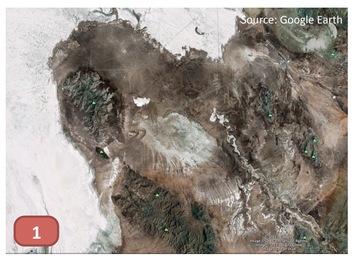
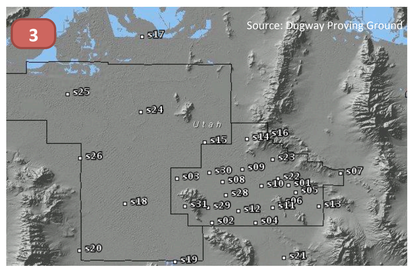
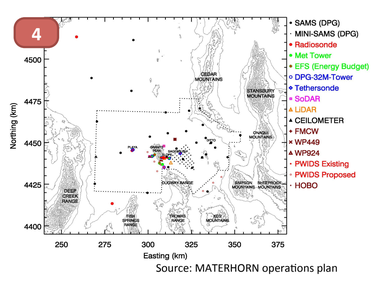
Introduction: Granite Peak and the MATERHORN project

Granite Peak, located in the Dugway Proving Ground (DPG, 1) in western Utah, is an isolated mountain rising ~800 m above the surrounding terrain (2). Flow phenomena occurring in its vicinity may include upslope and drainage winds, local breeze systems, gap flows, dynamically accelerated downslope winds, boundary layer separation and the formation of wakes.





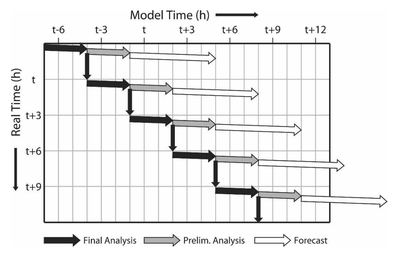


Source: MATERHORN operations plan

During fall 2012 and spring 2013, DPG was the target area of the field campaigns of the MATERHORN project (http://www3.nd.edu/~dynamics/materhorn/). The existing network of Surface Area Mesonet Stations (SAMS, 3) was enhanced with an extensive set of special measurement platforms (4), including a **T**win **O**tter aircraft carrying a **D**oppler **W**ind **L**idar on board (TODWL, Emmitt et al. 2005).

4DWX

Since the 1990s, DPG has used a continuously operating meso-gamma-scale analysis and forecast system (4DWX, 5) developed by the NCAR Research Applications Laboratory (RAL).

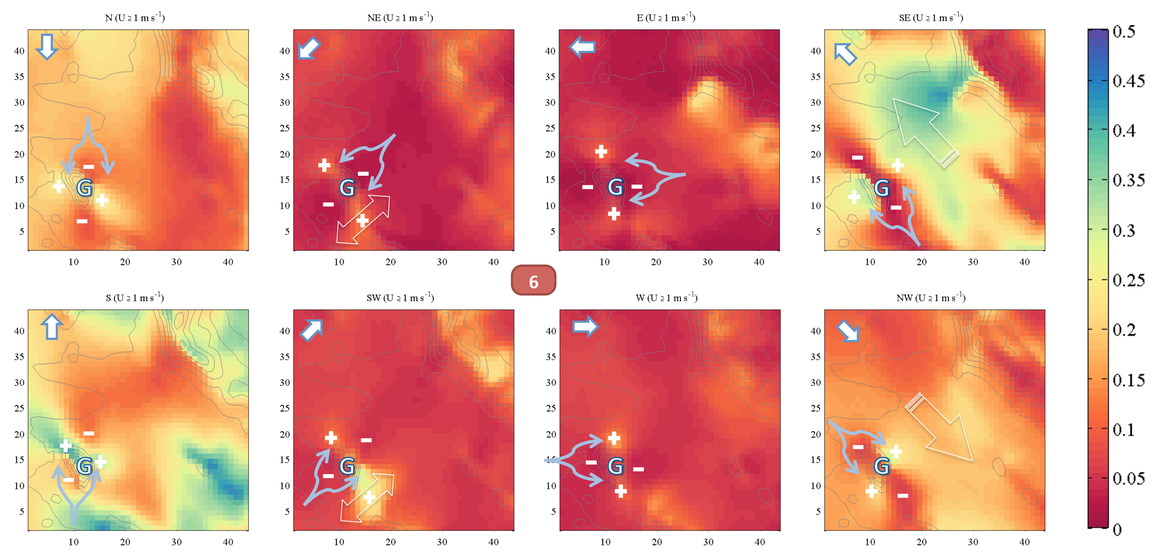


5 The data assimilation and forecast cycle. The ordinate axis is wall clock time, and the abscissa is model time (i.e., the time being simulated during the data assimilation or forecast process). The slope of the arrows indicates the elapsed time associated with the model's execution, but the particular slope shown here is not meant to quantitatively indicate model efficiency. An example follows of the 0800 UTC cycle (real-time t on the ordinate = 0800). The cycle starts at 0820 UTC and generates a 3-h final analysis (horizontal black arrow) from 0400 to 0700 UTC in 20–30 min. Then the model writes a restart file (vertical black arrow) for the next cycle (1100 UTC, $t + 3$ on the ordinate) to start with. The model then continues to produce a preliminary analysis and a forecast for the current cycle, where the real time will be about 1110 UTC by the time the forecast (white arrow) terminates at $t + 36$ h.
Liu et al., 2008

The system is based on WRF, is driven by GFS analyses, runs with a grid spacing of 1.1-km in its innermost domain, applies observational nudging in a three-hour cycle (RTFDDA) and provides weather analyses and forecasts at hourly intervals. "Final analyses" (the black arrows in 5) are considered in the present study.
Key question: **Can 4DWX help planning MATERHORN-X activities?**

Wind climate at DPG

Consider a 3-year set (2010-2012) of 4DWX analyses produced with unchanged model setup.
At every gridpoint, compute frequencies of wind directions from each of 8 quadrants.
The signatures of valley flows, gap flows and flow around Granite Peak (G) are clearly discernible (6).



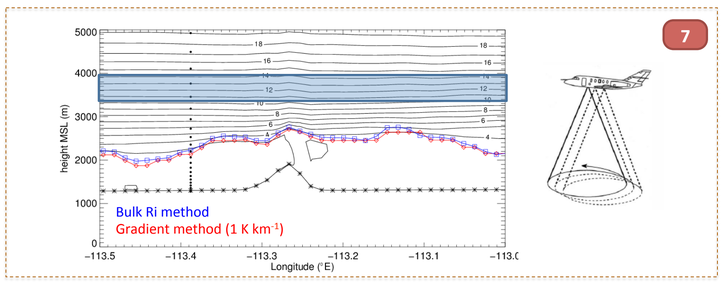
Focus 1: BL depth

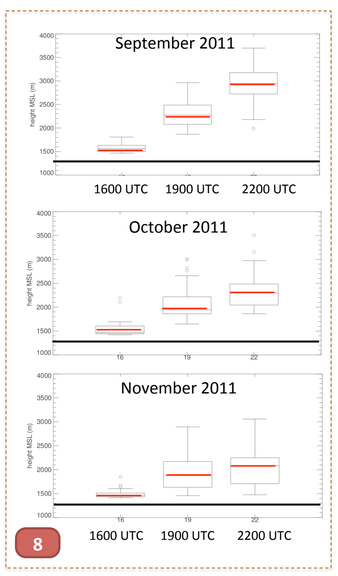
Flying above the entrainment zone is important in order to sample the whole depth of the BL with an airborne lidar. The BL depth can be easily estimated from simulations (7).

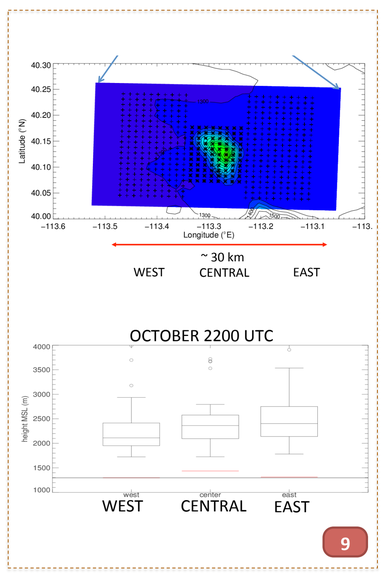
4DWX output shows distinct diurnal and seasonal trends in the BL depth (8). In October, flying at 2500 m MSL is typically sufficient to sample the whole depth of the BL with the TODWL. This is an important element, considering that the Twin Otter has a non-pressurized cabin and hence cannot fly beyond 4000 m MSL.

There is a tendency for the BL to be thicker on the eastern side of Granite Peak (9).

TODWL flight plans during MATERHORN-X in October 2012 were designed based on these considerations.

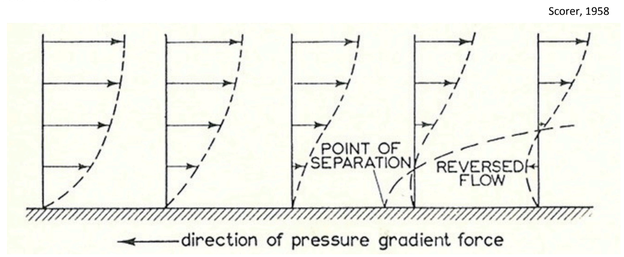




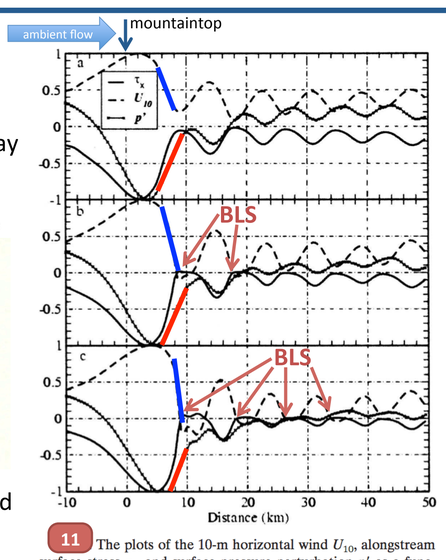


Focus 2: Wave-induced boundary-layer separation (BLS)

The boundary layer may separate from the ground under the action of an adverse pressure gradient force (10). The latter may be caused by the pressure perturbations related to an existing mountain wave.



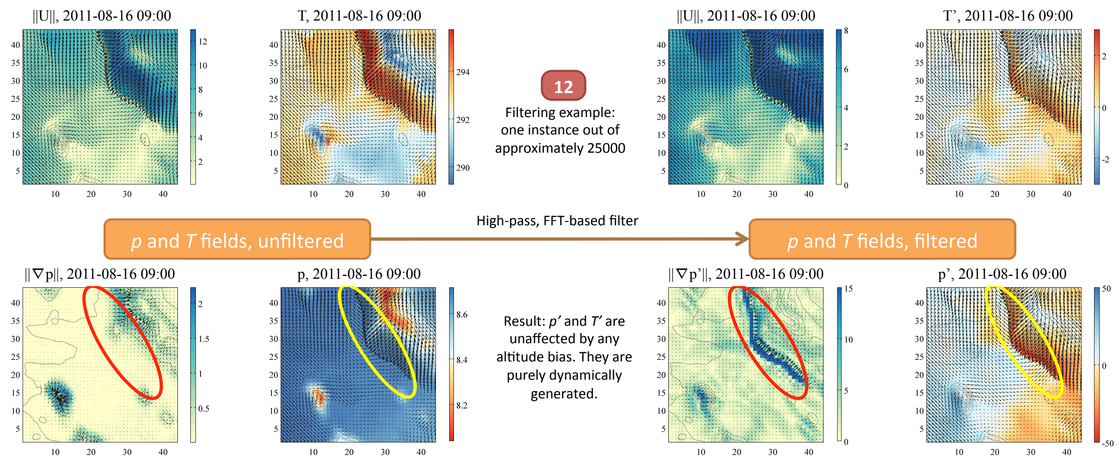
Wave-induced BLS is known to occur in association with trapped lee waves, breaking mountain waves or hydraulic jumps in presence of a strong inversion (Jiang et al. 2007).
The region where BLS occurs features high gradients of near-surface wind speed and perturbation pressure (11).



11 The plots of the 10-m horizontal wind U_{10}, alongstream surface stress τ_x, and surface pressure perturbation p' as a function of horizontal distance derived from the control run with z_o = 0.01 m and h_m = (a) 300, (b) 350, and (c) 400 m. All three variables are normalized by their maximum values.
NOTE - h_m: mountain height.
Jiang et al., 2007

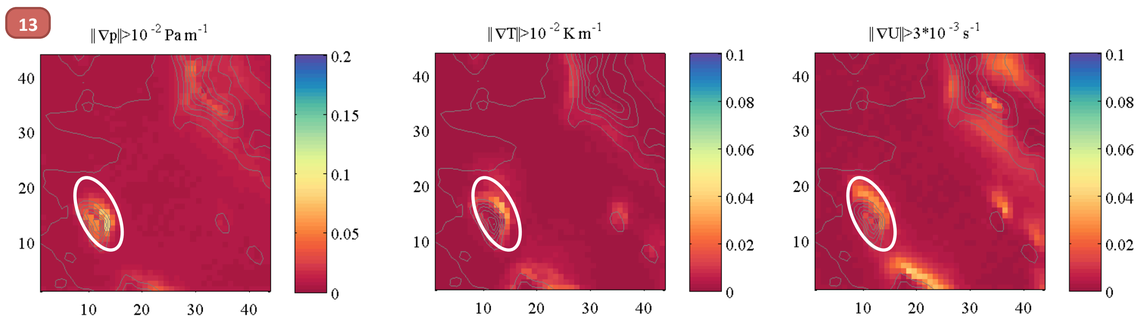
Detecting BLS from 4DWX output

Purpose: Identifying the most favorable locations for BLS in DPG.
Strategy:
1. Consider the 2010-2012 dataset of 4DWX analyses.
2. Extract wind speed (U), pressure and temperature fields at the lowermost model level (~15 m).
3. Treat the p and T field with a high-pass filter (12), to remove the altitudinal dependence and the fingerprint of low-frequency (period > 12 hours) periodic phenomena (e.g., thermally driven flows).
4. Evaluate the magnitude of the horizontal gradients of p', T' and U.



Preferential areas for BLS

Dataset: Maps of the magnitude of the gradients of U, p' and T' (3 yrs, ~25000 hourly samples).
Strategy: Analyze the spatial distribution of the frequency of occurrence of strongest gradients.



Result: The bottom of the NE slope of Granite Peak seems a hot-spot for BLS events (13).
Warning: BLS is not the only mesoscale phenomenon that might be related to strong p', T' and U gradients!

Conclusions

Can operational forecasts with a mesoscale weather model help planning intensive observation periods in the field? Yes.

Example 1: Flying at approximately 2500 m MSL in October (MATERHORN-X Fall field campaign) is generally sufficient to sample the whole depth of the BL.

Example 2: Positioning instruments on the NE slope of Granite Peak might give the best chances for observing BLS and other dynamically forced phenomena (MATERHORN-X spring campaign).

Future efforts

1. Verification of 4DWX forecasts against SAMS data.
2. Signatures of BLS are known. This will enable an automated detection of past case studies from the 4DWX archives.
3. Studying past events will provide insight on the most favorable conditions for dynamically forced flows around Granite Peak.

Research partially supported by the Austrian Science Funds, FWF, through the project P 24726–N27 **STABLEST – Stable Boundary Layer Separation and Turbulence**

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