DOWNSLOPE WINDS AND MELTING EVENTS IN THE ANTARCTIC DRY VALLEYS AND ON MARS. K. E. Scanlon and J. W. Head, Department of Geological Sciences, Brown University, Providence, RI 02912 USA. <kathleen_scanlon@brown.edu>

Introduction. When climatological temperature and humidity hover near the boundaries of habitability, transient, localized or small-magnitude atmospheric processes can effect large changes in biological activity. A summer foehn wind in the terrestrial Mars analogue environment of the Antarctic Dry Valleys may raise temperatures only locally and only by one or two degrees, but where ice is present and summer mean temperatures are near the melting point, this could be more than sufficient to cause ice to melt and a dormant ecosystem to reactivate. Such events can be difficult to resolve explicitly in a global circulation model or identify from orbit, but observations of their magnitude and effects in analogue environments can be combined with remotely sensed observations of water ice availability, insolation geometry, and climatological atmospheric conditions to expand the set of places believed to have been potentially habitable in Mars's past. We are investigating the effects of foehn winds on meltwater production in the Antarctic Dry Valleys and whether foehn or katabatic winds could have caused melt production on Mars. Insight into whether and where small-scale atmospheric processes could have created habitable microenvironments on Mars could expand the range of locations to search for signs of past or present life.

Downslope winds. A mesoscale feature of particular interest in the Dry Valleys is the dry, warm, fast, and intermittent downslope wind. These winds have historically been referred to as katabatic, a term which describes any downslope wind but particularly refers to winds that arise due to the gravitational, downslope acceleration of dense air masses formed by radiative cooling on glaciers or mountains [1]. Buoyancy-forced katabatic winds are warm due to adiabatic compression as they accelerate downslope. Foehn winds flow over topographic ridges, typically but not necessarily losing moisture due to adiabatic cooling as they ascend, and increasing in potential temperature due to latent heat of condensation and the drawdown of higher potential temperature air from above forced by mountain waves or blocking [2]. Recently, it has been convincingly argued that the Dry Valleys' downslope winds are foehn [3] because (a) the valleys are not sites of katabatic convergence, (b) the reversal in background wind direction with height associated with downslope wind events in the Dry Valleys is characteristic of foehn dynamics, (c) lenticular clouds are present during downslope wind episodes, implicating mountain wave activity, and (d) downslope wind episodes are associated with trans-mountain winds forced by cyclones in the Amundsen Sea.

The winds often raise local temperatures by tens of degrees temporarily and by smaller amounts for days afterwards [1, 2]. Since they can raise local temperatures above zero in the summer, they may play an important role in the generation of meltwater and hence habitable zones. However, since they also involve the rapid movement of very dry air they may instead cause evaporation of meltwater, or ice ablation and sublimation instead of melt [4]. At least one season of above-average downslope wind activity also experienced much higher than average meltwater fluxes in streams and lakes [5], but no published work has yet demonstrated a case-by-case correspondence between foehn events and liquid water activity.

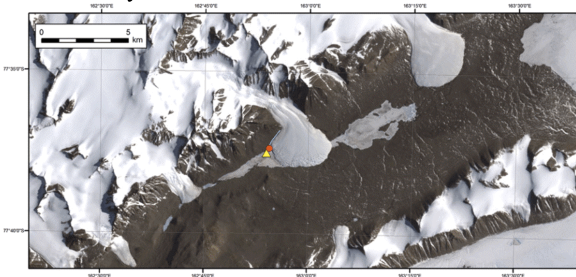

__Figure 1.__ Projected Landsat image of Taylor Valley showing the location of Andersen Creek (cyan line) and the Lake Hoare (yellow triangle) and Andersen Creek (red circle) LTER stations [6].

Preliminary investigation of the foehn-melt relationship. Criteria [3, 7] for diagnosing the onset of a foehn episode in the Dry Valleys are (a) wind speed above 5 m/s, (b) a westerly component in the wind direction, (c) a near-surface atmospheric warming rate of at least 1°C/hour, and (d) a near-surface atmospheric drying rate of at least -5% relative humidity / hour. As a precursor to a formal investigation of the relationship between individual foehn and melting events, we identified foehn episodes between December 3, 2006 and January 20, 2007 at the Lake Hoare LTER meteorology station [8] and the adjacent Andersen Creek LTER hydrology station [9] (**Figure 1**). This time period was chosen for the near-continuous availability of good quality data from the hydrology station.

Flow in Andersen Creek over this time period (blue curve, **Figure 2**), when smoothed with a one-day rolling average to remove diurnal effects (thick black curve, **Figure 2**) and ignoring a brief period of missing data, peaks nine times. All peaks are simultaneous with maxima in the one-day rolling average of insolation (net shortwave radiation, thick green curve, **Figure 2**) but five of the tallest six peaks immediately follow the beginning of a foehn episode (red shading, **Figure 2**) and the sixth occurs during a foehn episode and when background temperatures (not shown) are still elevated after the previous episode. Insolation is not significantly higher for these peaks than for the shorter flow peaks.

This correspondence is worthy of further investigation. In order to build a statistically meaningful relationship, we are testing for enhanced flow following foehn in all years of the publicly available Lake Hoare / Andersen Creek dataset, as well as other creeks short enough that discharge is unlikely to be confounded by meteorological effects felt at the melt source but not the nearest weather station. We are also examining the effects on small gullies [10], where evaporation effects could potentially be more important than in larger streams.

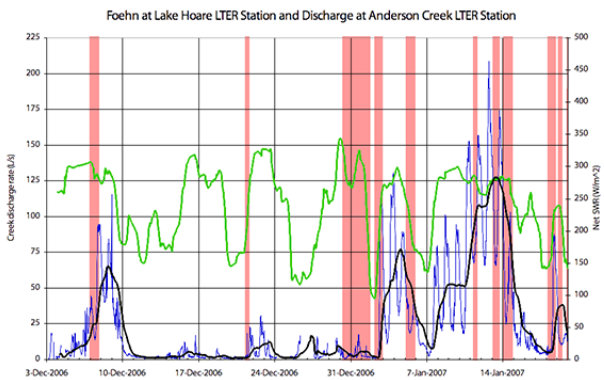

Figure 2. *Insolation (moving average in green, right y-axis), Andersen Creek discharge rate (blue, left y-axis; moving average in black) and foehn events (red shading) from 12/3/06 - 1/20/07.*

Applicability to Mars. Mesoscale climate model (MCM) simulations at Valles Marineris and Olympus Mons have shown that katabatic winds can warm the base of these features by up to 20°C [11,12]. Because of the process that generates them, katabatic winds on Mars necessarily occur at nighttime or at the poles, in background temperatures far colder than 20° below freezing. They are therefore unlikely candidates to cause melting in the present-day martian climate.

The mechanism that causes foehn events, while it occurs only in certain dynamical circumstances, has no such necessary spatial or temporal limitation. Terrestrial downslope windstorms occur [13] when a critical level (for a mountain wave, the level of background wind reversal) or deep flow across a mountain causes mountain wave breaking, and/or when the atmosphere is more stable at mountain level than aloft. For a reasonable range of martian near-surface background flow profiles, an idealized analytical model shows that the obstacle height required to produce a foehn event increases rapidly as the Brunt-Väisälä frequency N decreases [14]. Therefore, and because the martian surface is stably stratified (has large, real N) at night but near-neutral or unstable during the day (small or imaginary N, respectively), [14] predicts foehn events only at night. However, in a time-dependent, two-dimensional, numerical model that can represent both vertical and diurnal variations in background flow, the strongest surface winds were seen in the afternoon [15]. Rather than temperature effects, modeling of downslope windstorms on Mars has so far focused on the wind acceleration, which could explain how dust is lifted on Mars when GCM winds are typically too weak to do so [14, 15, 16] and which could pose hazards to spacecraft during entry, descent and landing [e.g. 16, 17]. In two-dimensional models of downslope wind episodes [15], however, isentropes are displaced sharply downward on the lee-side, which we hypothesize could warm the surface enough to melt ice under certain background climate conditions, despite the dryer air and smaller lapse rate on Mars.

Using idealized ridge topography in a three-dimensional martian mesoscale climate model [11], we are exploring parameter space in obstacle height, background flow profile, orbital and spin-axis parameters, atmospheric CO_2 content (within Amazonian values [18]), and insolation geometry in order to determine the magnitude of warming possible under the range of martian topographic and recent climate conditions.

Conclusion. A preliminary case study indicates that foehn episodes seem to have a positive effect on meltwater availability in the Antarctic Dry Valleys. A broad statistical survey of foehn events and other factors is required before firm conclusions can be reached on the magnitude and robustness of effects in the ADV. Ice melt by foehn is also plausible on Mars, and we are working to determine the magnitude of warming possible and how common such events could have been throughout the Amazonian by exploring a range of parameters using a three-dimensional MCM. In the future, we will also investigate these processes on Early Mars. The presence of a surface temperature lapse rate on Early Mars simulations with a thicker CO_2 atmosphere [19, 20] indicates that katabatic winds could have been more effective at melting ice in the distant past: cold air masses forming at the top of a volcano (or in the southern highlands) would reach much warmer ground at its base, and the thicker atmosphere could communicate its heat to the surface more effectively.

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