SUBLIMATION-DOMINATED ACTIVE LAYERS IN THE HIGHLANDS OF THE ANTARCTIC DRY VALLEYS AND IMPLICATIONS FOR OTHER SITES.
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Introduction: The subsurface in polar regions is commonly characterized by a permafrost soil layer whose temperature never exceeds 0°C, overlain by an active layer which undergoes a seasonal cycle above and below 0°C. In most cases on Earth, an ample surface or atmospheric water supply results in a permafrost layer which is saturated with ice, and a wet active layer which can provide seasonal liquid water [e.g., 1]. The presence, or lack, of seasonal liquid water has important implications for chemical processes, including weathering, the movement of salts, subsurface ice stability, and biological activity.

A periglacial location which significantly deviates from this cold, but seasonally wet, regime is the high elevations of the Dry Valleys of Antarctica [2]. Due to the extreme dryness, a dry permafrost layer is often present: that is, soil that is always frozen (cryotic) but is not ice-cemented [3,4]. Ice-cemented ground does commonly exist below this layer of dry permafrost, and exchanges with the atmosphere via vapor transport (or diffusion). The dry permafrost layer is more than 50 cm thick at the mouth of the valley. The extreme cold and dryness may result in a situation where the presence of ground ice in the shallow subsurface acts as a buffer to maintain subsurface temperatures below 0°C. However, if the temperatures become warm enough, the ice sublimates before melting and essentially retreats into the subsurface, forming an overlying dry permafrost layer. In either case, the top of the ice-cemented ground does not reach above-zero degrees Celcius temperatures, and as such the surface active layer does not experience the activity of liquid water, but instead processes in this dry active layer are dominated by the movement of vapor. We term this dry active layer a 'sublimation-dominated active layer'. A defining requirement for this condition may be that these locations have air temperatures with zero degree days above freezing. Here we use the term 'frozen' to denote temperatures below 0°C, regardless of the material's water content.

Field observations from the upper Dry Valleys, specifically University Valley in the Beacon Valley region, are used to describe, characterize, and model sublimation-dominated active layers, and by extension in high alpine regions and on Mars.

Site description. University Valley (fig. 1), part of the Quatermain Mountains in the upper Dry Valleys, is adjacent to the polar plateau, and at an elevation of about 1730 m (77°S 51.8', 160°E 43'). With an average annual temperature of about -25°C and an average humidity of about 50%, University Valley is one of the coldest and driest rocky areas on Earth. These conditions combine to give (1) an area that has zero degree days above freezing, (2) the presence of dry permafrost, and (3) no long-lived liquid water (except possible briny waters). Air temperatures are always below 0°C, however, the surface may reach above-zero temperatures due to direct solar heating. Due to the extremely dry conditions, these valleys have a dry permafrost layer: that is a layer of soil whose temperature never exceeds 0°C but which is not filled with ice. This dry permafrost layer is present since ice is not stable to the surface; the depth to the underlying ice-cemented ground can vary significantly based on surface and subsurface conditions as well as snow recurrence within the valley [5,6].

Figure 1. The University Valley site. The depth to ice-cemented ground is shallowest near the small glacier (where the shallow climate station site is located) and increases in depth towards the mouth of the valley. The complete meteorological station is located about a third of the way down the valley. © Dale Anderson

Data collection. The University Valley site was instrumented with multiple climate data stations in December 2009 and the data were retrieved after one year of data collection (Dec. 2010). A complete weather station was deployed about a third of the way down the valley, where the depth to ice-cemented ground is 42 cm. Air sensors measure temperature, humidity, wind speed and direction, and solar radiation. Temperature and humidity sensors were also deployed in the subsurface at 10 cm intervals, up to a depth of 49 cm, which is 7 cm into the ice-cemented ground. In addition, three subsurface climate stations were deployed throughout the valley to capture the thermal and vapor propagation in three depths to ice-cemented ground: shallow (4 cm), medium (22 cm), and deep (36 cm). These stations provide data on the actual temperatures and humidities reached at the surface and at various depths in the subsurface, allowing us to evaluate the behavior of a liquid-free (e.g., sublimation-dominated) active-layer.

Modeling. Data collected by the weather station is used to model the subsurface conditions in the Valley, allowing us to evaluate the conditions under which no liquid water is present. Data from the weather station and the subsurface climate stations provide insights into the thermal conductivity and diffusivity properties of the subsurface material, as well as validation for the modeling results.

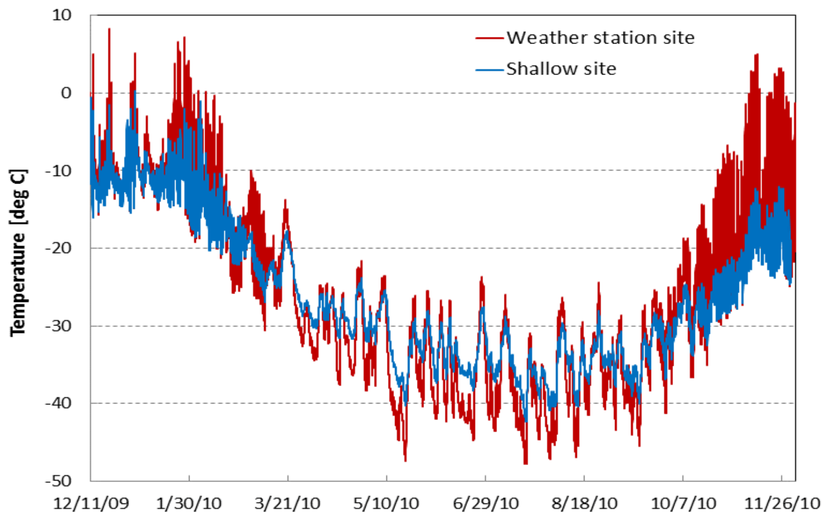

Figure 2. Surface temperature data at the shallow depth to ice-cemented site, and weather station site. Note that the highest temperature reached at the shallow ice site is 0°C.

Results: Field observations in University Valley, in the early summer, indicate a cold and dry landscape where sublimation is prominent. Sublimation is apparent in the snow and ice removal around rocks, unevenness of ice ponds, and removal of snow under very low temperatures (<-20ºC). During sunny days, snow on dark rocks was observed to generate very small amounts of melt; however, this melt appeared to evaporate within a few minutes, and before water moving down the rock could reach the ground.

Data collected from University Valley shows the range of conditions that are present in the valley depending on the local subsurface conditions. At the weather station site, where the depth to ice-cemented ground is 42 cm, the maximum air temperature was -3°C (fig. 2), while a maximum surface temperature of +8°C was reached. This solar heating of the surface translated into subsurface positive temperatures, which reached only to a 10 cm depth; thus the ice-cemented ground, which is at 42 cm, did not melt at any point and reached maximum summer temperatures of -11°C.

At the shallow ice site, with a depth to ice-cemented ground of 4 cm, the maximum surface temperature reached was 0°C and was reached only once during the summer (fig. 2). This result shows that (1) there was no melting at the site, and (2) the ice-content of the subsurface has significantly affected the thermal conductivity, and thus the maximum temperature reached by the surface. A surface snow cover, up to a few centimeters, likely helps to dampen the effect of solar heating due to its lower albedo and low thermal conductivity; however, from field observations, the surface snow sublimes away completely by the early summer and as such it is the effects of the subsurface properties that primarily determine the thermal variations for the majority of the warm months.

Implications: The climate and subsurface system exemplified in University Valley represents a unique mode of operation in extremely dry and cold environments where liquid water is not present due to zero degree days above freezing, subsurface ice buffering the effects of solar heating, and the ice-cemented ground retreating into the subsurface due to changes in stability conditions. The importance of this regime is in the change in chemical processes with the lack of liquid water, and has implications for the viability of biological activity in these extreme environments, and the ice stability, ice distribution, and water cycle on Earth and Mars. Understanding of the University Valley system, including its ice stability and water cycle, will allow us to extend this work to other terrestrial environments, such as high alpine, equatorial environments on Earth, as well as Mars.

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