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Dry Soils: The Highlands of the Antarctic Dry Valleys and the Defining Environmental Conditions

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1. Introduction

Surface soils are usually wet for at least part of the year. Even in polar regions, where most of the subsurface is ice-rich soil that is perennially frozen (permafrost), the surface layer is warmed by the sun and commonly becomes wet during the summer [e.g., 1]. However, in the high-elevation Dry Valleys of Antarctica, the environmental conditions are sufficiently colder and drier as to produce dry soils [2]. These dry soils are foremost expressed in dry permafrost: that is soil that always has a temperature below freezing, but is free of ice [3,4]. Dry permafrost results when the average frost point of the atmosphere is lower than the average frost point of the ice in the subsurface, thus causing the ice to sublime into the atmosphere and for the ice depth to retreat (deepen). The only known dry permafrost occurs in the high-elevation Dry Valleys of Antarctica, such as University Valley (Figure 1).

In University Valley, the air temperature is always below freezing, with a maximum of -2.9°C recorded in 2010, as measured by the weather station we deployed there. However, the maximum ground surface temperature at the same location was 8.3°C for the same time period (Fig. 2, depth to permafrost ~20 cm, depth to ice-cemented ground 42 cm). Even though the surface temperature exceeded freezing, due to the exceedingly dry atmospheric conditions no liquid water is available and the warm (above-freezing temperatures) soil layer is dry and sublimation dominated. This warm soil layer is similar to an active layer; however, we term this the sublimation-dominated, dry active layer.

This sublimation-dominated active layer is a significant deviation from the common experience of wet active layers, and the lack of liquid water plays an important role in the physical, chemical, and biological processes of the soil.

Figure 1. Dry permafrost, University Valley. The active layer extends to ~20 cm; however, the ground is ice-free and dry to ~45 cm.

In a similar, yet conceptually different scenario, the ice content of the ground itself can adversely affect the availability of liquid water in these same locations where the environmental conditions produce dry permafrost and sublimation-dominated active layers (e.g., University Valley). If the ground becomes ice-cemented to the surface (for example by recurring snow cover [5]), the resulting increase in thermal conductivity and sublimation cooling will keep the ground surface from warming above freezing.

As an example, at University Valley where the depth to permafrost is ~20 cm and depth to ice-cemented ground is more than 40 cm, we measured a maximum surface temperature of about +8°C (as described above, Fig. 2). However, a few hundred meters away where the ground is ice-cemented to the surface, we measured a maximum surface temperature which did not exceed freezing (Fig. 2, 0°C). The sublimation of the ice cools the surface and decreases the depth to permafrost from ~20 cm to effectively zero.

2. Preliminary results

In examining the environmental conditions required for dry soils, we idealize the environmental energy forcing, and examine what parameter space of mean air temperature and yearly and daily temperature variations, wind speeds, humidity, and location on the planet are conducive to these dry sublimation layers.

The cases explored are those of ice-cemented ground to the surface. We ask the question: under what environmental conditions does ice-cemented ground at the surface not melt? We find that in all cases, keeping the surface frozen requires that the air temperature does not exceed freezing. In addition, we find that the wind velocity plays an important role. The wind acts as a coupling between the atmosphere and the ground, thus with increasing wind velocity the ground temperature becomes increasingly similar to the air temperature. This also results in an increased sublimation rate from the ground, as vapour is quickly moved into the dry atmosphere. In cases where the wind velocity is very low, the ground surface can become very warm even with air temperatures which are significantly below freezing. Changes in the atmospheric relative humidity play a minor role, with lower humidities resulting in increased cooling of the ground by sublimation, and thus slightly lower ground temperatures.

3. Summary and Conclusions

In extremely dry and cold conditions, the system may become entirely devoid of liquid water. On one extreme, the subsurface is thoroughly desiccated, and even when the surface warms above freezing there is no water available. On the other extreme, the presence of ice at the surface changes the temperature regime such that the surface temperature never reaches freezing and again no liquid water is available. The lack of liquid water has important consequences for the physical, chemical, and biological processes in these environments. While dry permafrost, and presumably environments which are conducive to liquid water-free surfaces have so far only been found in the high-elevation Dry Valleys of Antarctica, similar conditions may occur in high tropical mountains and in the polar regions of Mars. Current and future work will focus on understanding these environments.

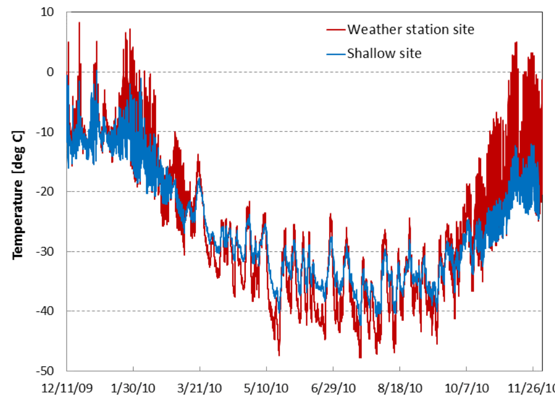

Figure 2. Surface temperatures, University Valley, at the Shallow ice site, with ice-cemented ground to the surface, and the Weather station site where the active layer is ~20 cm.

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