INSIGHTS INTO MARS SUBSURFACE ICE DISTRIBUTION AND POSSIBLE RECENT CHANGES IN STABILITY FROM STUDIES IN THE MARS-LIKE, HIGH-ELEVATION DRY VALLEYS OF ANTARCTICA. M. M. Marinova[1,2], C. P. McKay[2], J. L. Heldmann[2], D. Lacelle[3], A. F. Davila[2,4], W. H. Pollard[5], D. T. Andersen[4]; [1]BAER Institute (margarita.m.marinova@gmail.com), [2]Space Sciences Division, NASA Ames Research Center, [3]Dept. of Earth Sciences, University of Ottawa, [4]SETI Institute, [5]Dept. of Geography, McGill University.

Introduction: Ice, both on Earth and Mars, can serve as a record of climatic conditions. Both in the mid-latitudes on Mars and in the Mars-like, high-elevation Dry Valleys of Antarctica, ice-cemented ground is present, yet current observed climatic conditions argue that it should not be there, or at least not at the depths at which it is observed [1]. If not currently stable, this ice may be a remnant of recent, different climatic conditions. Current models for both planets are able to reproduce subsurface ice distributions in most cases, but in cases where they cannot, we may be able to learn about current or recent climate conditions by examining the importance of the pertinent physical parameters (e.g., snow cover, better albedo and emissivity models, more exact sensible and latent heat calculations). Here we use meteorological and ice distribution data collected in the high-elevation Dry Valleys of Antarctica to better understand what parameters are important for ice stability in this Mars-like environment.

Site description: The high elevation Dry Valleys of Antarctica are extremely dry and cold, and represent one of the best Mars analogues on Earth. Of particular interest is the presence of dry permafrost, that is, soil which always has a temperature below 0°C, but does not contain any water [2,3]. On Mars dry permafrost is the norm, and its presence has been shown by climate data, the Viking Landers, and the Phoenix Lander. On Earth, however, the high-elevation Dry Valleys (> ~1600 m) are so far the only known location to have dry permafrost, and thus they represent a unique environment on Earth and a compelling location for Mars analogue studies.

University Valley is at an elevation of ~1750 m in the Dry Valleys of Antarctica. It has a small glacier at the head of the valley, and the valley slopes gently towards the mouth (fig. 1). We have been extensively studying this valley, including deploying instrumentation to measure the environmental conditions. The measured air temperature in 2010 was always below freezing, with a maximum of -2.9°C; the maximum soil surface temperature at the same location was 8.3°C. This low air temperature together with the low humidity provide conditions in which liquid water is not available, and any transient liquid water due to snow melt is short-lived and does not percolate into the ground (based on measurements and field observations). These features further show this to be an appropriate Mars analogue, and provide constraints on the availability and movement of water. University Valley is a location where subsurface ice cementation is the result of vapour diffusion into the ground [e.g., 4], and the stability of the subsurface ice is determined by the atmospheric temperature and humidity and the subsurface temperature profile.

Figure 1. University Valley as seen from the ledge near the mouth of the valley. The weather station was located near the center of the valley. Approx. size: 0.8 km wide, 1.5 km long.

Some locations on Mars, such as the tropics, have a sufficiently low atmospheric vapour pressure that any ice that is present in the subsurface is expected to sublime away – at these locations subsurface ice is not stable. The high elevation Dry Valleys, including University Valley, experience similar conditions: using the measured atmospheric vapour density and measured temperature profile with depth, we do not expect subsurface ice to be stable in University Valley for the current climatic conditions. That is, the average vapour density of the atmosphere is lower than the average vapour density that would be present over ice at any depth, and thus any subsurface ice should sublime into the atmosphere. Estimates of the sublimation rate for nearby valleys was 0.4 - 0.6 mm/yr [1]; given the current depth of about 40 cm to ice-cemented ground in University Valley, if the ground had been saturated with ice to the surface it would still take only 2500 yrs for the ground to become desiccated to a depth of 1 m. This timescale is much shorter than the > 100 kyr since the last major alpine glaciation in the McMurdo Dry

Valleys [5,6], suggesting that observed depth to ice-cemented ground must effectively be at equilibrium with the current environmental conditions.

This simple observation shows that both on Earth and on Mars, there are locations where models suggest that subsurface ice should not be present, yet it is. In both cases the presence of the ice suggests that either different environmental conditions prevailed in the recent past (where recent has different timescales for Earth and Mars), or that the climate has remained constant but our models do not take into account all pertinent factors. Here we use data collected in these Mars-like, high-elevation Dry Valleys to directly assess the stability of the ice-cemented ground, develop a model of its stability, and use the collected data to validate the model.

Field data and ice stability measurements: Climate data was collected by deploying a weather station in the middle of the valley (fig. 2), and subsurface temperature and humidity sensors at the weather stations and 3 more locations in the valley. Currently data is available for one year starting Dec. 4, 2009; measurements were taken every 30 min. This data can be directly used to determine the stability of the ice, as well as quantify the movement of water vapour into and out of the ground.

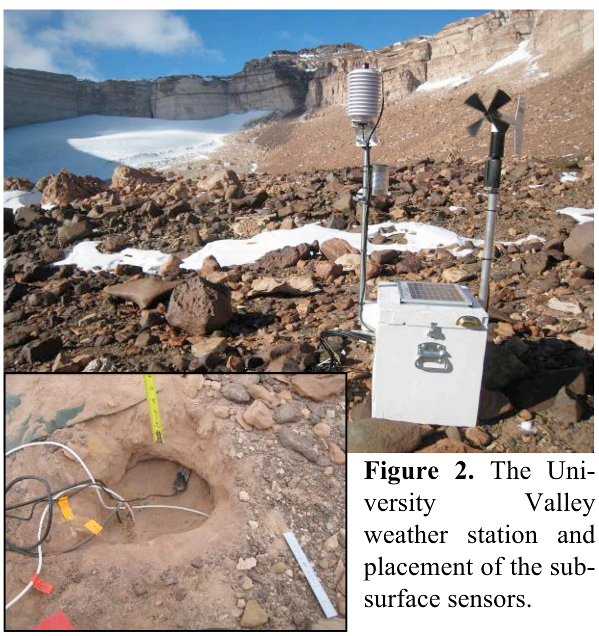

Figure 2. The University Valley weather station and placement of the subsurface sensors.

The atmospheric measurements that were taken include temperature and humidity, wind speed and direction, and solar insolation (fig. 3). In the subsurface, humidity and temperature probes at a variety of depths, including into the ice-cemented ground, provide a direct measurement of the vapour density at each location as well as the temperature profile with depth.

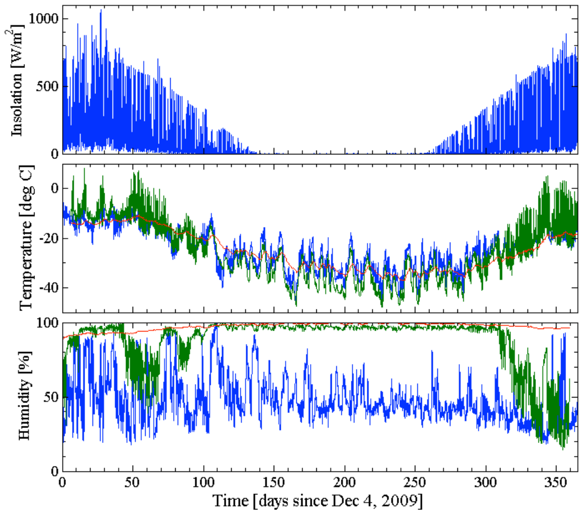

Figure 3. Solar insolation, temperature, and humidity data from University Valley. In panels (b) and (c) the colour represents the depth of measurement: air (blue), surface (green), and at the ice-cemented ground interface (red).

The water vapour density was computed directly using the measured humidity and temperature (fig. 4). Here we assume that the change in vapour density with depth is linear, and we compute the instantaneous fluxes. We compute the rate of ice removal from the subsurface using the atmospheric conditions and the current ice table depth of 42 cm at the weather station (fig. 5); the expected rate of ice-cemented ground retreat is 0.24 mm/yr (assuming 40% porosity, using the method described in [1]). This rather fast retreat rate would suggest that subsurface ice should not be present, and certainly not at the current shallow depths (42 cm of ice retreat would occur in ~1750 years at the current environmental conditions).

The fast sublimation rate as calculated between the ice and the atmosphere suggests that there is a mechanism by which the subsurface ice is stabilized and thus effectively does not see the dry atmosphere at all times. We can look into this effect by calculating the vapour flux between the ice-cemented ground and the surface temperature and humidity sensors. This surface sensor is sensitive to any boundary effects, as well as snow cover. Episodic snow cover has been suggested as a possible stabilizing factor for subsurface ice [7].

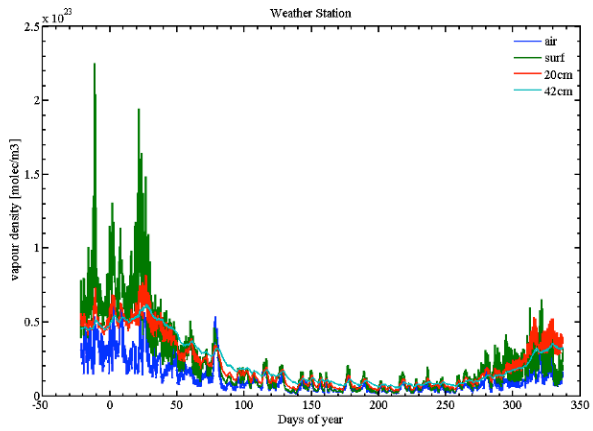

Figure 4. Water vapour density as measured at the University Valley weather station for the atmosphere, surface, 20 cm depth, and 42 cm depth (the ice-cemented ground interface). Time is shown as days in 2010 (data starts Dec 4, 2009). Note that for the majority of the year the atmospheric vapour density is lowest, thus indicating net movement of water vapour from the ground into the air; however, the surface vapour density for the first part of the year is highest, suggesting that something such as snow or other boundary effects is elevating the water availability there compared to the atmosphere. This elevated water availability will result in a net movement of vapour from the surface to the drier subsurface, and disconnects the icy subsurface from the dry atmosphere.

The calculated vapour flux between the ice-cemented ground and the surface results in an ice retreat rate of ~0.002 mm/yr. This rate is over 100 times smaller than was predicted by the atmospheric vapour pressure calculations, and suggests the subsurface ice is stable on the timescale of local climate change [5,6]. Thus it certainly appears that snow cover, perhaps together with other boundary effects, has an important stabilizing effect on the ice-cemented ground and must be taken into account in any modeling efforts. While the high-elevation Dry Valleys are a hyper-arid environment, with an estimate precipitation of less than 10 mm/yr, snow that is blown in from the polar plateau is likely to play an important role, and examination of the surface humidity sensor versus atmospheric data suggests that at least in the vicinity of the University Valley weather station the ground was snow-covered over 70% of the year. Note that snow cover is often heterogenous for these hyper-arid locations, and thus can also be an important factor in the variability in the depth to ice-cemented ground [8]. A single measurement of either snow over or depth to ice-cemented ground is not expected to be representative of the whole valley. Nonetheless, this is the measurement at a location where the ice-cemented ground is at a depth of 42 cm, and suggests snow cover or boundary effects to be important at least at this location.

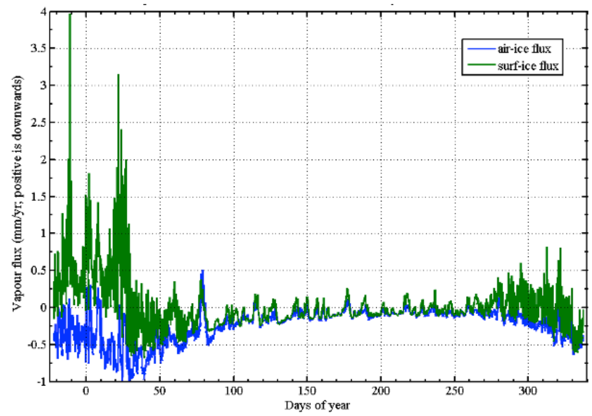

Figure 5. The water vapour flux, as calculated from the vapour densities. Negative values are removal of ice from the subsurface, while positive values are adding to the ice table and thus making it shallower. Note that based on atmospheric measurements the depth to ice-cemented ground is increasing year-round, while surface data shows that the subsurface ice does not see the atmosphere, but instead the surface conditions are different and prevail: ice is deposited into the ground in austral summer and the vapour flux direction is highly variable in spring and late summer.

Modeling: The stability of the subsurface ice can also be calculated for an arbitrary set of environmental conditions by modeling the availability of energy and water vapour in the surface and subsurface. Based on the measurements made at University Valley, we can determine some of the key parameters necessary for this modeling, such as the subsurface thermal diffusivity, surface albedo and emissivity, and availability of solar radiation. In addition, the model can be validated by forcing the model with measured parameters such as solar insolation, wind speeds, and air temperature, and comparing the calculated subsurface conditions to those measured in the field. This modeling effort is especially useful in determining the sensitivity of the system to changes in the parameters. While the modeling is still underway, a pattern that has consistently emerged is the importance of wind. Higher wind speeds, above about 4 m/s, result in effective mixing and energy transport within the boundary layer and thus the surface temperature becomes very similar to that of the atmosphere. Since the air temperature at these locations is always below 0°C, while the surface can warm up significantly during low-wind periods, the wind speed appears to be an important factor in determining whether liquid water would be present at a given location.

Relevance to Mars' recent climate: The high-elevation Dry Valleys of Antarctica are a great analogue to Mars: their hyper-arid and cold climate produce an environment which is devoid of liquid water and has dry permafrost – soil which is always cryotic (T < 0°C), but its pores are not filled with ice. Both of these conditions are analogous to the environment seen on Mars. Also as seen on Mars, atmospheric conditions suggest that the subsurface ice at these locations should not be stable yet it is found there. Measurements of atmospheric and subsurface conditions show that the surface availability of water vapour is significantly higher than that seen in the atmosphere and may be controlling the stability of the ice-cemented ground. That is, the ice-cemented ground feels the conditions prevalent at the soil surface rather than the atmospheric conditions. This suggests that an effect such as snow cover is affecting the surface boundary layer, and should be taken into account by modeling efforts. Initial energy balance modeling efforts also suggest that the wind speed is very important, as it determines the energy transfer between the surface and atmosphere and thus the temperature gradient that can be sustained between the two. Strong winds effectively bring the surface temperature to that of the atmosphere. In locations where the air temperature is below (but near) freezing, the presence or lack of wind could be the difference between the presence or lack of liquid water.

References:

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