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Ice dynamics in hyperarid soils of Victoria Valley, Antarctica: Results from process-based models and isotopic tracers

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Most soils in the hyperarid Dry Valleys of Antarctica are ice-cemented within 30 cm depth. This is puzzling because soils with ice cement range in age from tens of thousands to possibly millions of years yet sublimation models predict that these soils should be rid of ice to several meters depth within a few thousands of years. To improve our understanding of ice stability, we followed two approaches: (1) updating existing vapor diffusion models to more fully incorporate environmental and soil conditions including snow cover; and (2) utilizing stable isotopes to develop quantitative models of ice/water dynamics in frozen soil. We conducted a case study on soils in Victoria Valley where surface age is $\sim$10 Ka and ice cement occurs at 0.22 m depth. Ice stability was investigated using high-resolution climate and soil temperature data from 2002 to 2005, and data on stable isotopes in ice and soil geochemistry along a 1.6 m soil profile. According to an enhanced vapor diffusion model constrained by humidity, and air and soil temperature, ice sublimates at an average rate of 0.22 mm a^{-1}, which corresponds to an ice recession of $\sim$1.3 mm a^{-1} for soil with 10% ice content. According to the model, most ice is lost as water vapor to the atmosphere during the austral summer; however, 0.1 to 0.03 mm a^{-1} of water vapor diffuses downward into the soil and contributes to the ice cement. One of the additional constraints in the model is the influence of snow cover. According to our enhanced model, snow cover prevents the loss of water vapor during the summer and has the potential to substantially reduce annual ice loss.

Ice/water dynamics in frozen soil were investigated by analyzing stable isotopes (δ^{18}O

& δD) along a 1.6 m depth profile in the ice cement. The data reveal a deuterium excess (–13 to –77 permil) with the greatest enrichment of heavy isotopes at top of the ice cement and decreasing with depth forming a concave-shaped curve. This isotopic profile is modeled by the advection-dispersion of heavy isotope-enriched water into the ice-cement and allows the infiltration rates to be quantified in soils of known age. Advection-dispersion is likely to occur because these soils contain considerable amounts of unfrozen water due to high salt concentrations. The isotopic composition of the upper ice-cement is consistent with snow melt water that has been 90% evaporated. The upper ice cement may be up to 10% unfrozen during the summer according to geochemical modeling. Based on the unfrozen water content and surface age, the best fit of the advection-dispersion equation to the isotopic values is an average of 0.7 mm a^{-1} of brine percolating into the ice-cemented soil. The advection-dispersion model suggests that Victoria Valley ground ice forms or is stabilized due to infiltration of snowmelt water. According to the evaporation model, an average snow melt of 7 mm a^{-1} occurs with 90% of the melt water evaporating and only the remaining 10% infiltrating. Snow melt water infiltration is further supported by field observation, moisture probe data, and salt leaching.

Both the sublimation and advection-dispersion model suggest that summer snow events are important environmental conditions that control ice stability. There is a need for field data on the timing and duration of snow cover, and the formation of snowmelt water, to develop more realistic estimates of the effect of snow on the annual sublimation rates.