# WATER BUDGETS OF MARTIAN RECURRING SLOPE LINEAE.

R.E. Grimm[1], K.P. Harrison[1], and D.E. Stillman[1]. [1]Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80302 (grimm@boulder.swri.edu, dstillman@boulder.swri.edu, harrison@boulder.swri.edu).

**Introduction:** Flowing water, possibly saline, has been suggested to cause seasonally reappearing, incrementally growing, dark streaks on steep, mostly equator-facing slopes on Mars [1]. We quantitatively modeled these recurring slope lineae (RSL) as isothermal water flows in thin surficial layers (1-10 cm) driven by gravity and capillary suction, with a headwall source and loss to evaporation. Constraints include flow length and duration as well as likely ranges in hydraulic conductivity and evaporation rate. Allowing for liquid water to exist for only several hours per day, we find that RSL seasonally require several $m^3$ per m of source headwall and therefore can recur hundreds of times for adjacent $H_2O$ reservoirs just 100-m wide and several meters thick. This is consistent with local metastable ice as the RSL source.

**Observations**: Stillman et al. [2] show that RSL are dark and lengthen from $L_s$ = 252º±7º to 314º±12º but then do not lengthen yet remain dark through $L_s$ 16º±14º. This could be interpreted as RSL reaching a steady state (input balanced by evaporation) at $L_s$ 314º and then the flow cuts off at $L_s$ 16º. Here we focus on an alternative interpretation in which sources cease around $L_s$ 314º but capillary or adsorbed water keeps RSL dark during drying as far as $L_s$ 16º. This requires much less water.

Thermal Emission Spectrometer data indicate that RSL start lengthening when maximum daily surface temperatures reach 297±5 K and they stop lengthening at 289±9 K. Thus RSL growth does not occur when maximum daily surface temperatures are below freezing. Because water-saturated soil will be >273 K to a depth of several cm for several hours per summer day, there is no need to invoke brines—and the concentrations of low-eutectic salts necessary to generate them.

**Model:** A three-phase $H_2O$ model including unsaturated flow and binary gas diffusion is necessary to fully simulate RSL under our specified conditions. We have such a model [3] but chose to begin with a simpler simulation, focusing on the liquid flow and parameterizing freezing and vapor transport. We used the Variably Saturated Flow code [VSF: 4]. Boundary conditions are illustrated in **Figure 1**. The layer thickness $h$ could be unconsolidated over consolidated material; more likely it is a sublimated zone overlying previously emplaced ice [5]. We used the capillary suction parameters derived for the regolith analog JSC-Mars-1 [6] as a reference, but we treated the saturated hydraulic conductivity $k$ as an independent variable. The inferred hydraulic conductivity for JSC-Mars-1 is comparable to a silty sand. A range of loss rates $w$ was chosen following [7-9]. Real time was taken to be 4x model time to approximate RSL that are frozen for ¾ of a sol (we derived 6 hours per sol of partial melting to a depth of 10 cm from Ls = 252 º to 314º).

**Results and Multivariate Regression**: We performed individual VSF runs for 27 different combinations of $h$, $k$, and $w$. We examined the output flow length $L$, water input $V$, ratio of evaporation to storage $\Lambda$, and time until the flow slowed by 90% as equilibrium between input and evaporation was approached. We then used the Buckingham pi theorem to form nondimensional groups for multivariate regression, which allowed the VSF runs to be extrapolated to any conditions. We eliminated models for which the flow length is <50 m after 60 sols or the flow reaches equilibrium in that time. A minimum $w$ was imposed such that residual ice in the RSL can sublimate in the "off-season" to make way for next year's flow. This was computed by integrating an Arrhenius weighting of surface temperatures over the entire year, and comparing the RSL seasonal loss at $w$ to the entire off-season. An activation energy 0.65±0.1 eV can be derived from loss curves published by [7-9].

Under these constraints, acceptable model solutions for $h = 5$ cm are $w \approx 0.1$ mm/hr, $k$ >10x JSC-Mars-1, $V \approx 3$ $m^3$/season per m of headwall, and $\Lambda \approx 10$ (**Figure 2**). Modest evaporative loss can be enforced by a dust layer overlying hydraulically conductive sand. The total seasonal volume of water that has passed through the RSL may greatly exceed the visible footprint.

**Source Zone and Recurrence**: We assume RSL sources are local, say up to ~100 m from the headwalls. If the equivalent source thickness is just 5 m (pure $H_2O$ layer or ~20 m of pore $H_2O$) and RSL cover ~50% of headwalls, then several hundred flow recurrences can be sustained at each RSL site (Fig. 2). This is consistent with relict, metastable ground ice as the source, in which water vapor is cold-trapped by outcropping bedrock and subsequently melted [2]. However, the reservoir size implies that observed RSL have been active for only $10^2$–$10^3$ years or have been only intermittently active since ground ice was recharged more than $10^5$ years ago. The latter is supported by unusually warm conditions in the past thousand years and the sensitivity of RSL to temperature, as evidenced by enhancement following the MY 28 dust storm.

This work was supported by NASA MFR. We thank Tim Michaels for input on surface temperatures.

**References:** [1] McEwen, A. et al., (2011) *Science 333*, 740-743. [2] Stillman, D.E. et al., this volume. [3] Grimm, R. and S. Painter (2009) *GRL*, doi:10.1029/2009 GL041018. [4] Thoms, R.B. et al. (2006) *USGS TM 6-A18*. [5] Kreslavsky, M.A and J.W. Head (2009) *Icarus 201*, 517. [6] Dinwiddie, C. and H. Sizemore (2008) *LPSC XXXIX*, #2394. [7] Mellon, M.T. et al. (2004) *Icarus 169*, 324. [8] Bryson, K.L. et al. (2008) *Icarus, 196*, 446. [9] Altheide, T. et al. (2009) *EPSL 282*, 69.

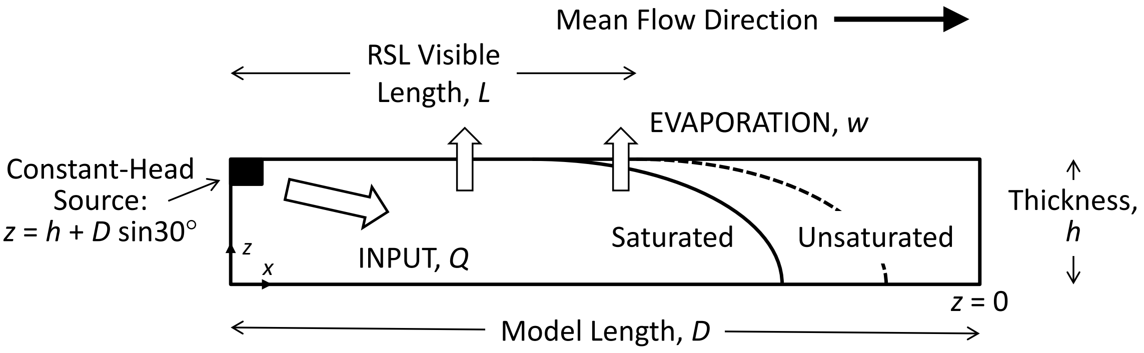

**Figure 1**. Conceptual model for RSL: flow occurs in a thin layer and length is controlled by the balance between water input and water evaporated. Model is implemented as a two-dimensional flow in a domain of length *D* and thickness *h*. The sides and bottom are impermeable: the last represents either bedrock or a saturated frozen sublayer. The source is a constant-head cell that allows variable input *Q*. Dashed line indicates partial saturation at which surface darkens, causing the visible RSL. Evaporation *w* acts across the top of the domain, for simplicity on the visible RSL only. Flow is driven by a 30° topographic gradient and by capillary suction calculated for the surficial analog material JSC-Mars-1. Note that capillary forces must wick water to and along the surface, else flow front would exist almost entirely in the subsurface between the source and toe.

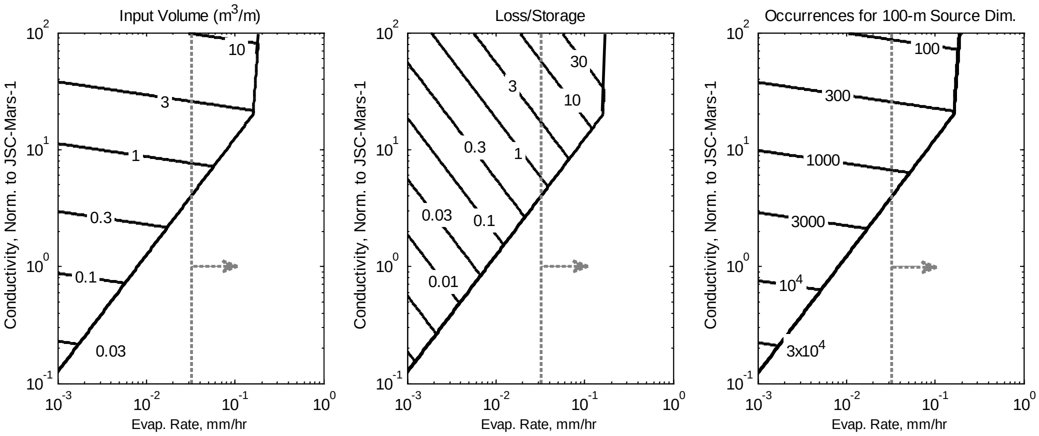

**Figure 2**. Results of unsaturated-flow model in 5-cm layer and inferences for source properties. Models that fail to produce minimum-length RSL (50 m) or come to equilibrium too quickly (<60 sols) are excluded. Dashed line is approximation to the minimum average evaporation rate during RSL season such that off-season sublimation will completely remove previous subsurface $H_2O$. Furthermore, hydraulic conductivity cannot greatly exceed that expected for sand, ~10x JSC-Mars-1. This leaves a restricted range of acceptable models: evaporation rate ~0.1 mm/hr , seasonal water volumes a few m$^3$ per m of headwall, evaporated volume several times that remaining in the RSL, and assumed 5-m x 100-m source zone capable of sustaining several hundred seasonal recurrences. See text for details.