JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

An Astroecological Approach for Planetary Protection Operations at Mars

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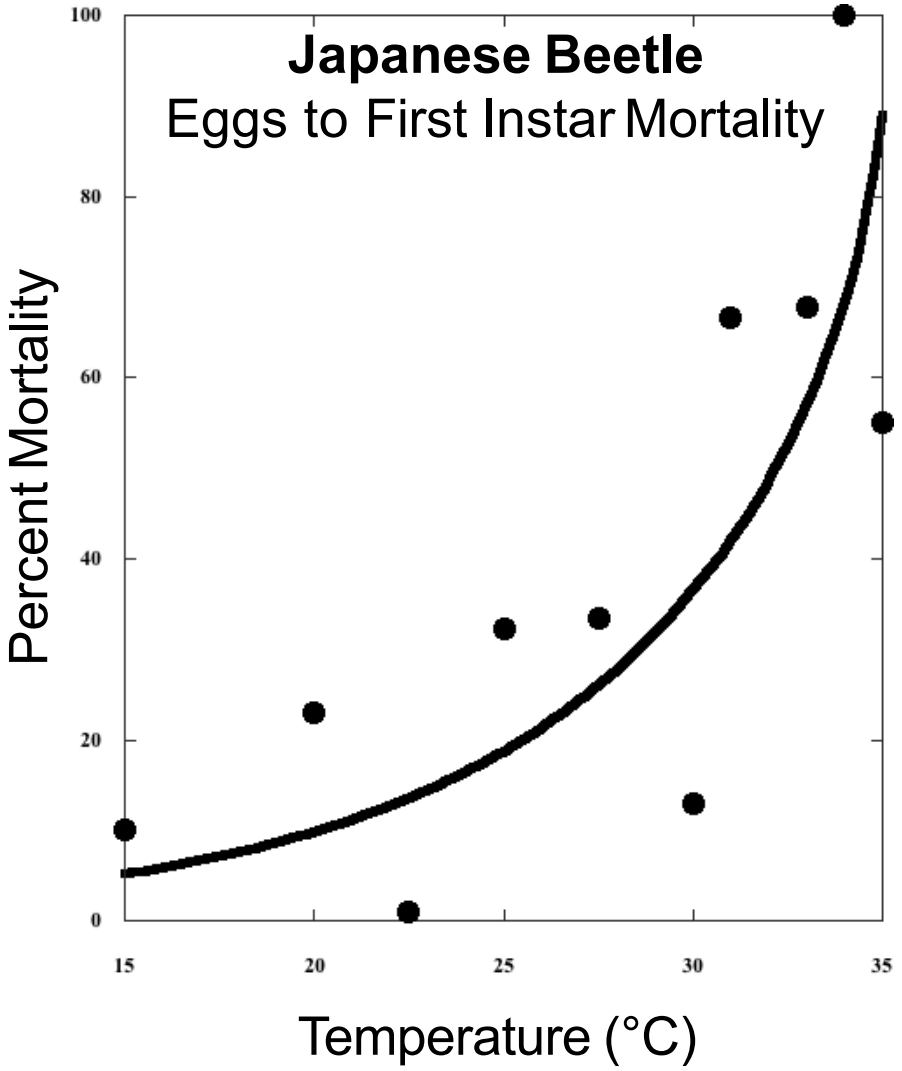
Habitat Suitability Index Models

- **Habitat Suitability Index (HSI) models** are an ecological framework that quantifies the ability of an environment to support a species or model organism.
  - Is organism specific
  - Relies on species-environment relationships (e.g., temperature tolerances)
  - Acknowledges diversity in tolerance across an organism
- Méndez et al. (2021) propose HSIs for analysis of planetary habitability
- Meurer et al. (2024) advocates for HSIs and “Astroecology”

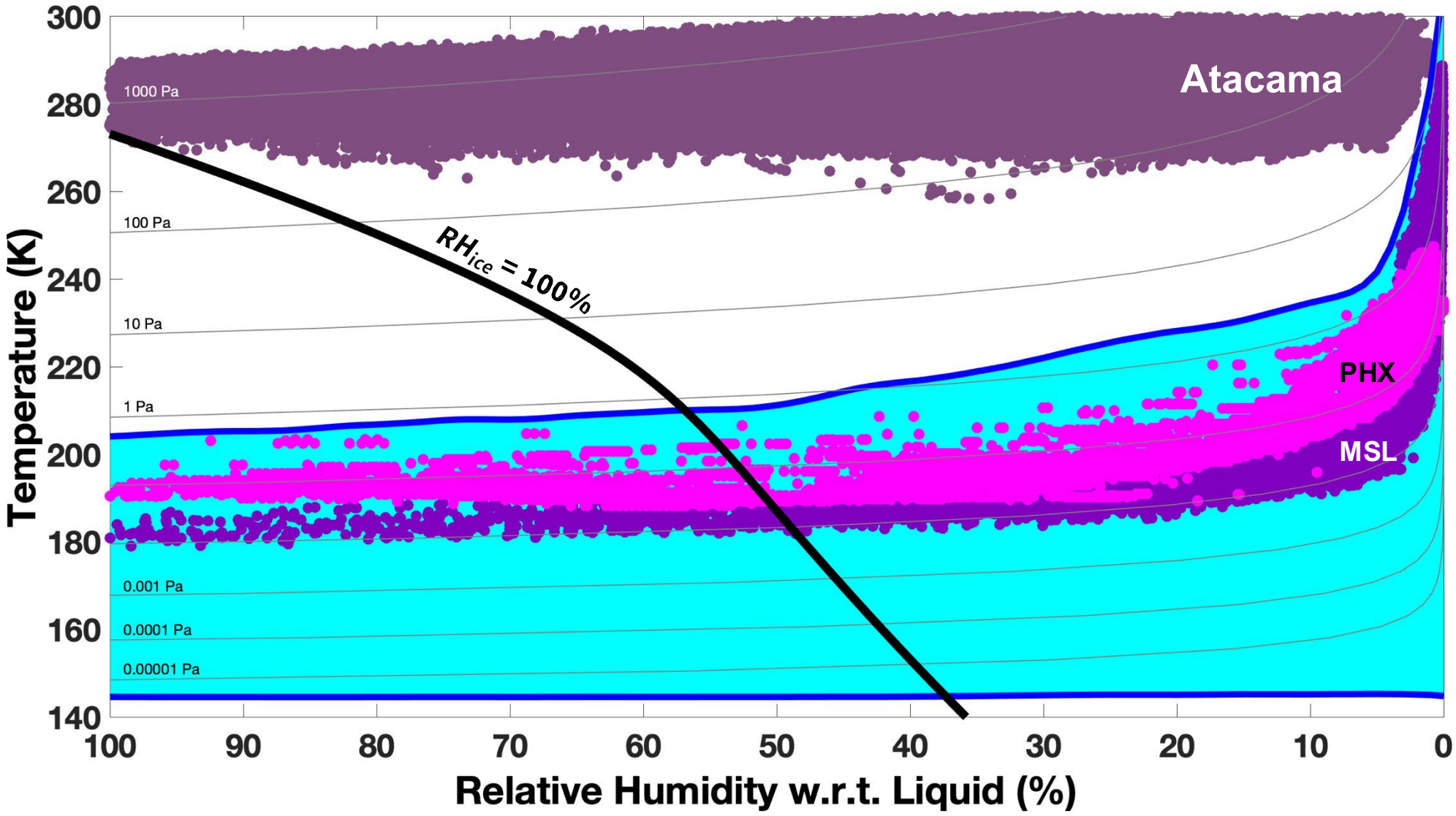


Credit: Petty, Rivera-Valentín, Steinkraus (2011) SBESA

HSI Model Workflow

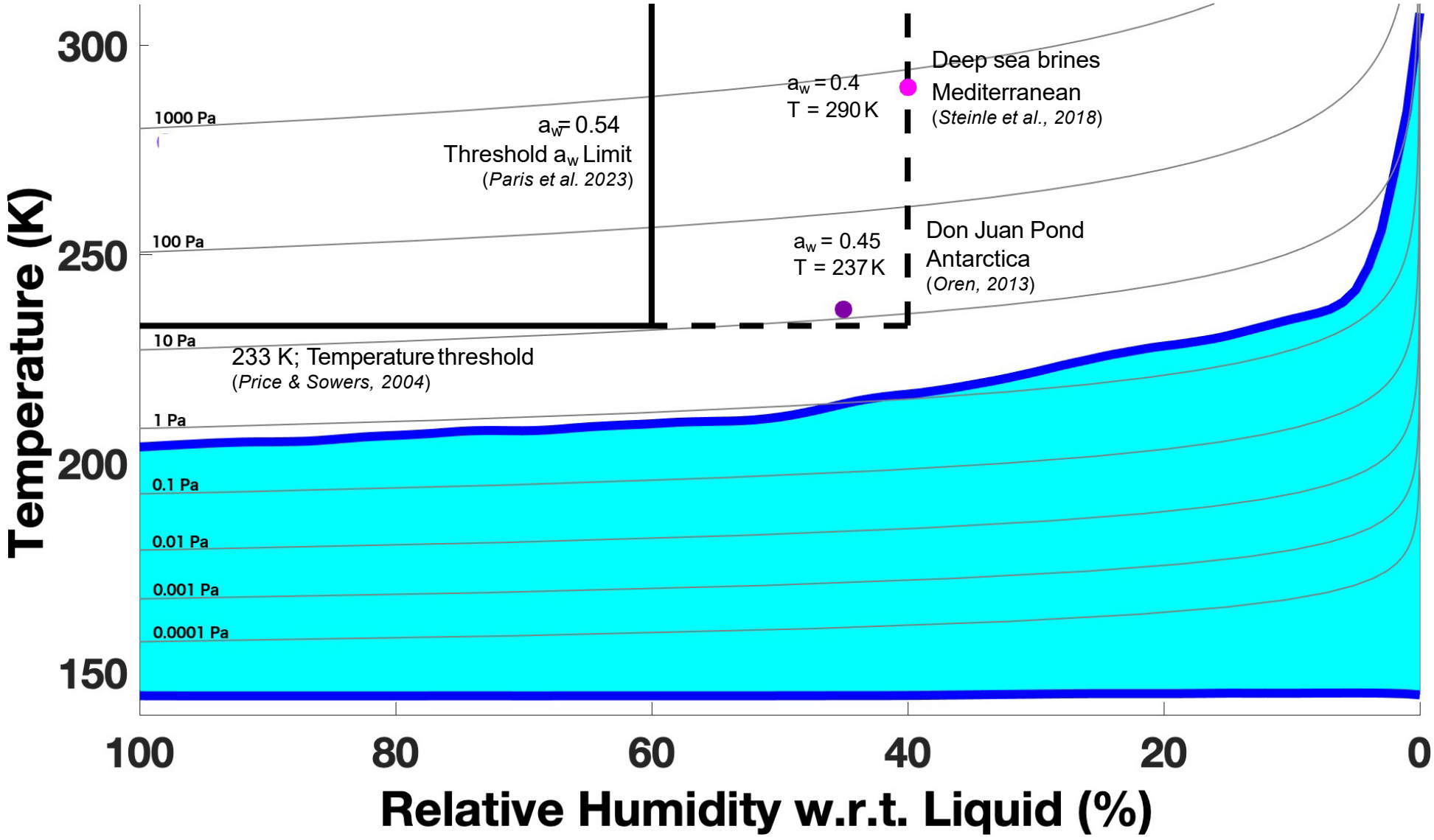
- **Model Development:**
  - Identify environmental parameters that are linked to species mortality and/or development
  - In planetary protection, we typically consider liquid availability, temperature, and water activity
- **Calibration:**
  - Ensure the model is applicable to the environment of interest
  - HSIs typically range from 0, the most unfavorable environment, to 1, the most favorable/optimum
- **Verification / Validation:**
  - Compare model prediction to an observable that quantifies species mortality / activity / development

Mars Climate Context



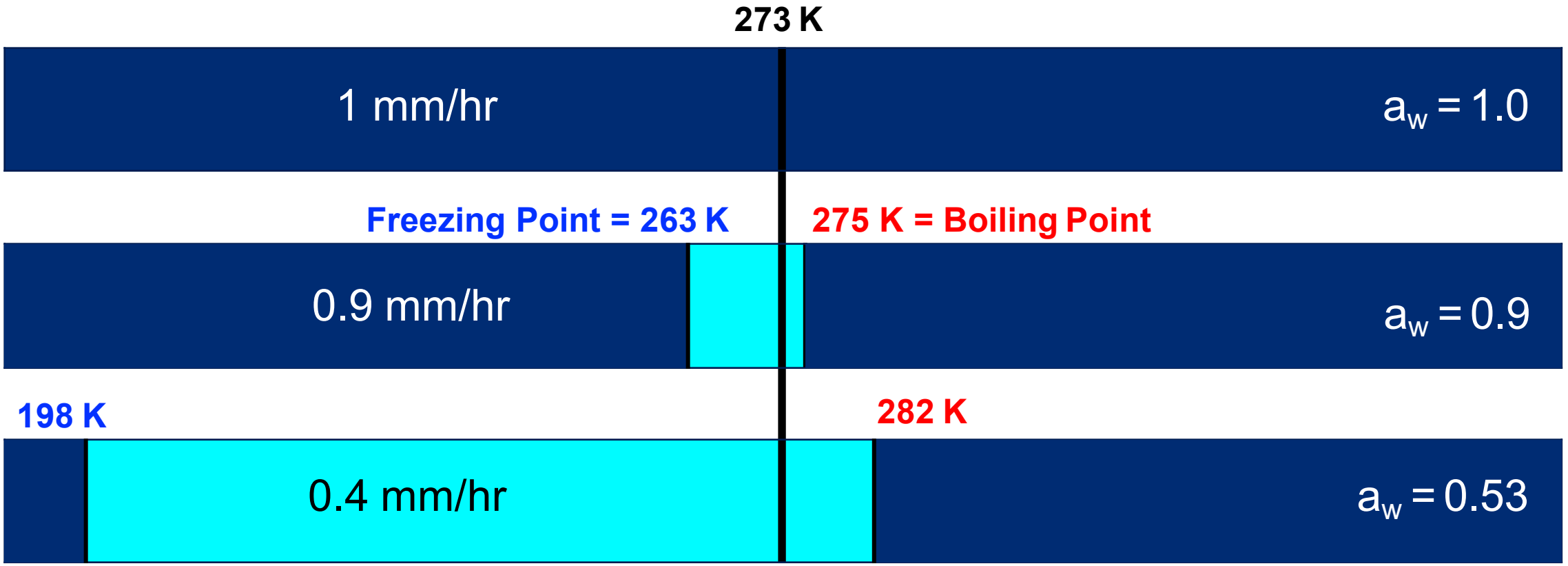
Key:
Mars Conditions
Phoenix
MSL
Atacama

Species-Environment Relationships



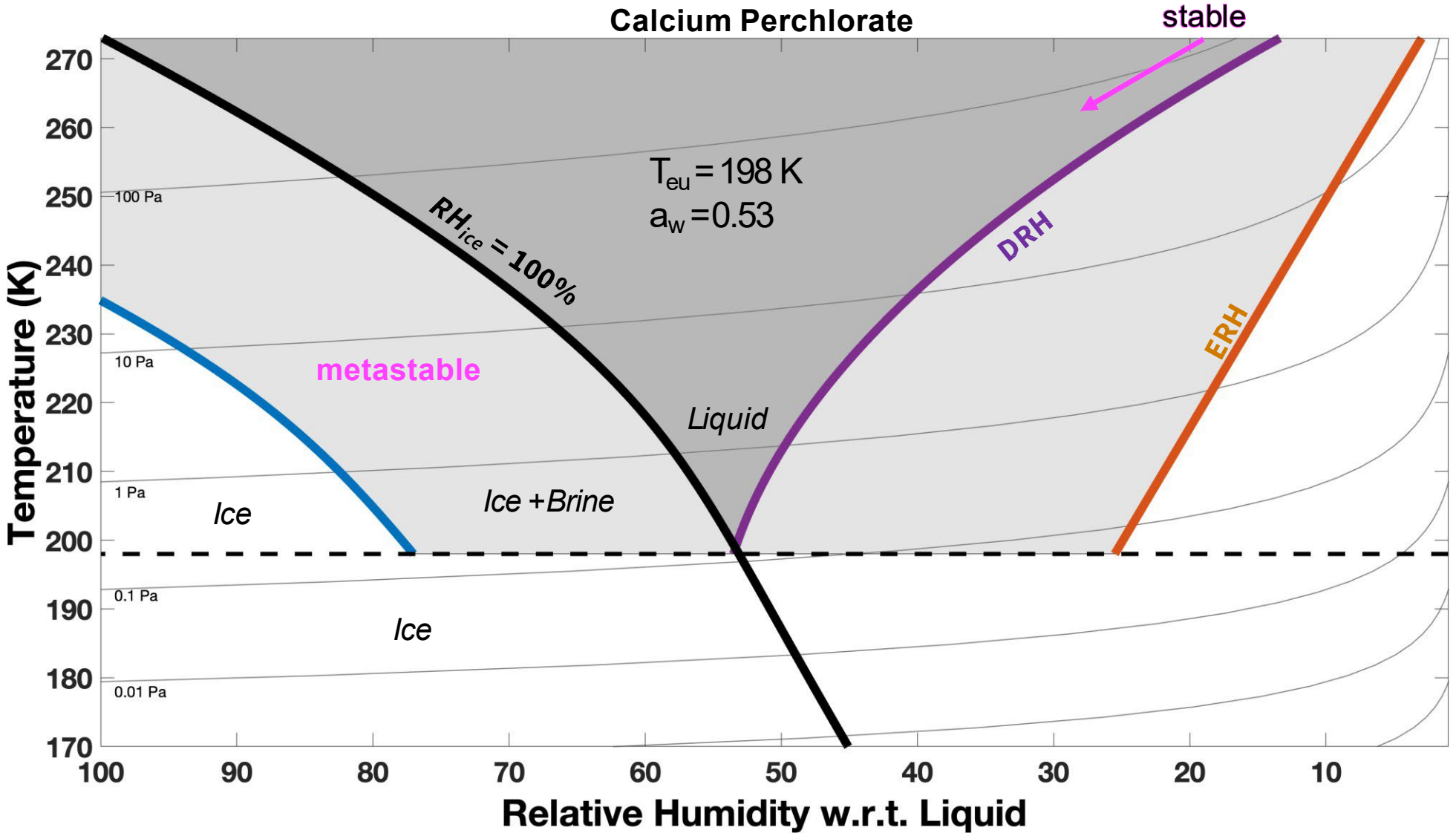
Note that at equilibrium $a_w = (RH_L/100)$

Environment-Brine Relationships



Note that at equilibrium $a_w = (RH_L/100)$

Phase Diagram - Deliquescence

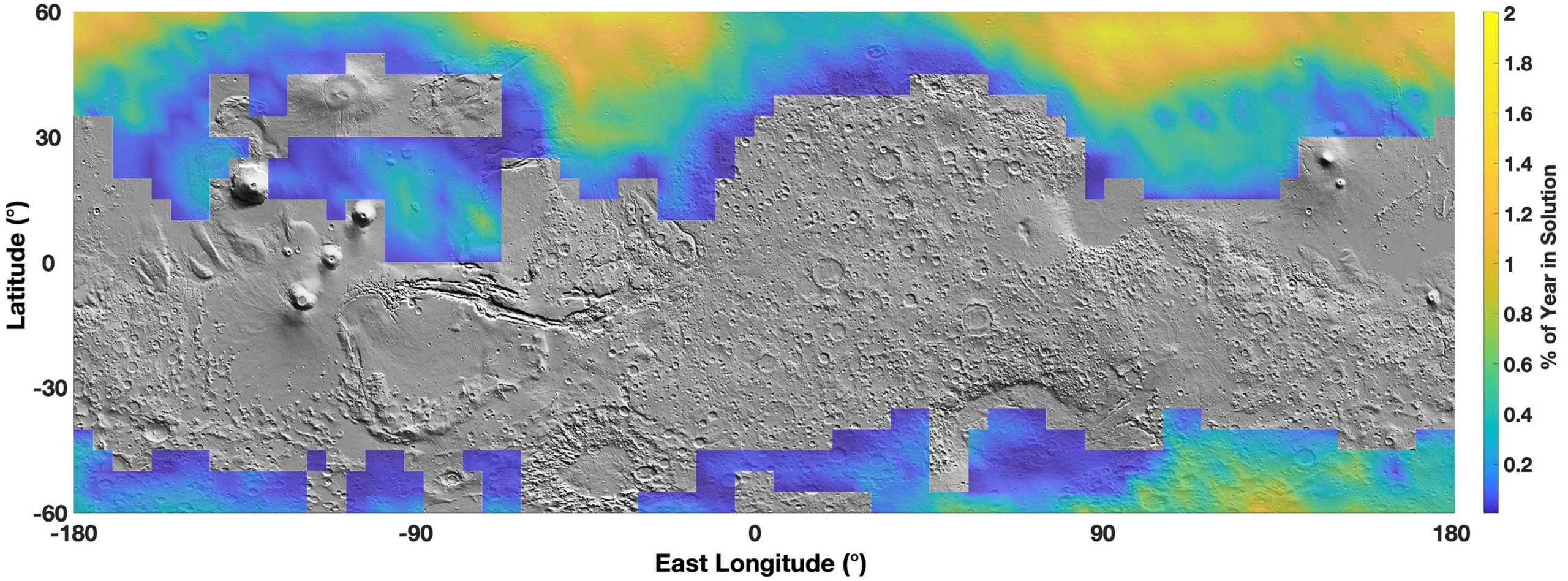


DRH = Deliquescence Relative Humidity

ERH = Efflorescence Relative Humidity

Deliquescence on Mars

Modeled Distribution of Calcium Perchlorate Brines formed through Deliquescence on Present-day Mars



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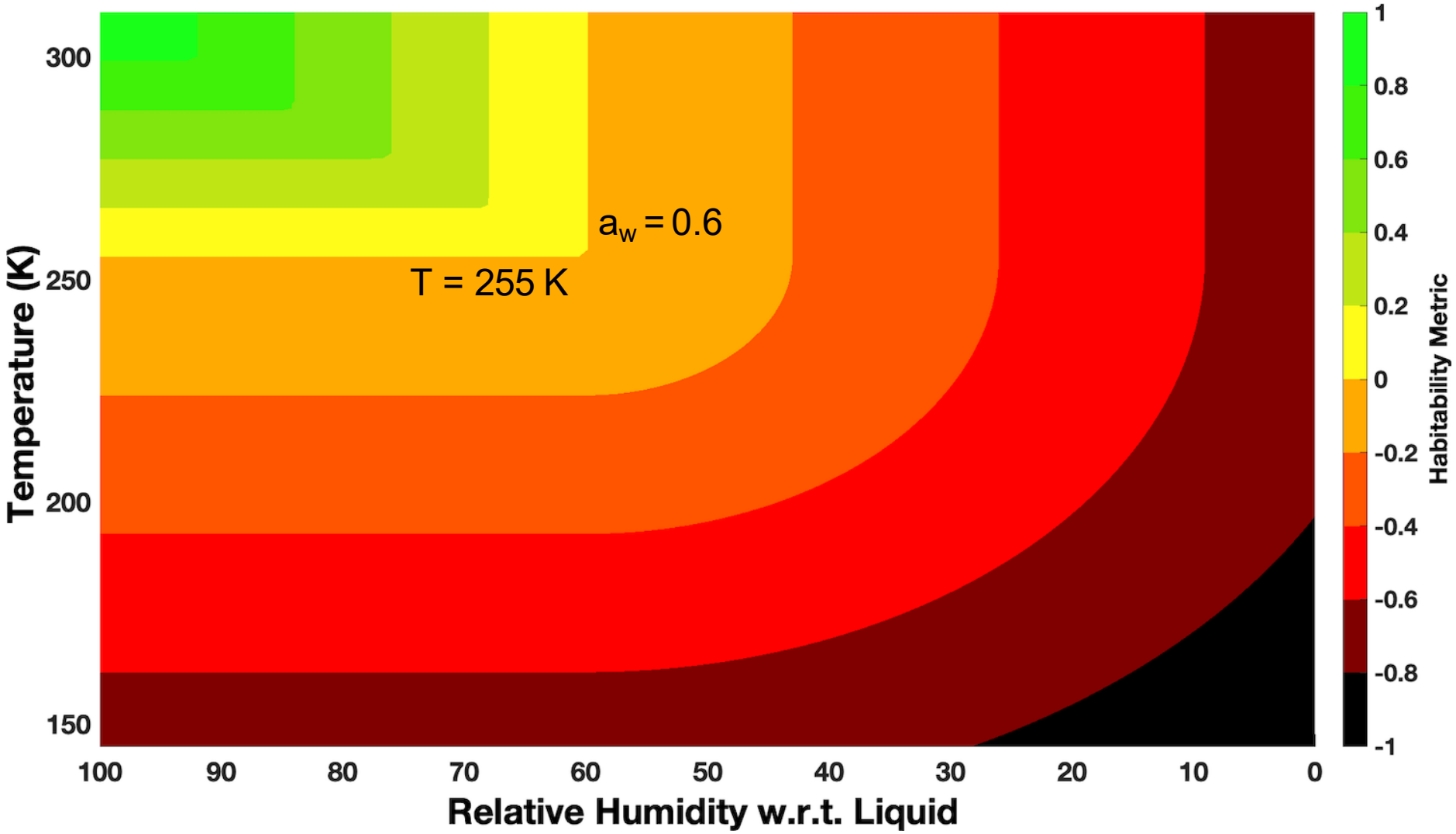
Credit: Rivera-Valentín et al. (2020) Nature Astronomy

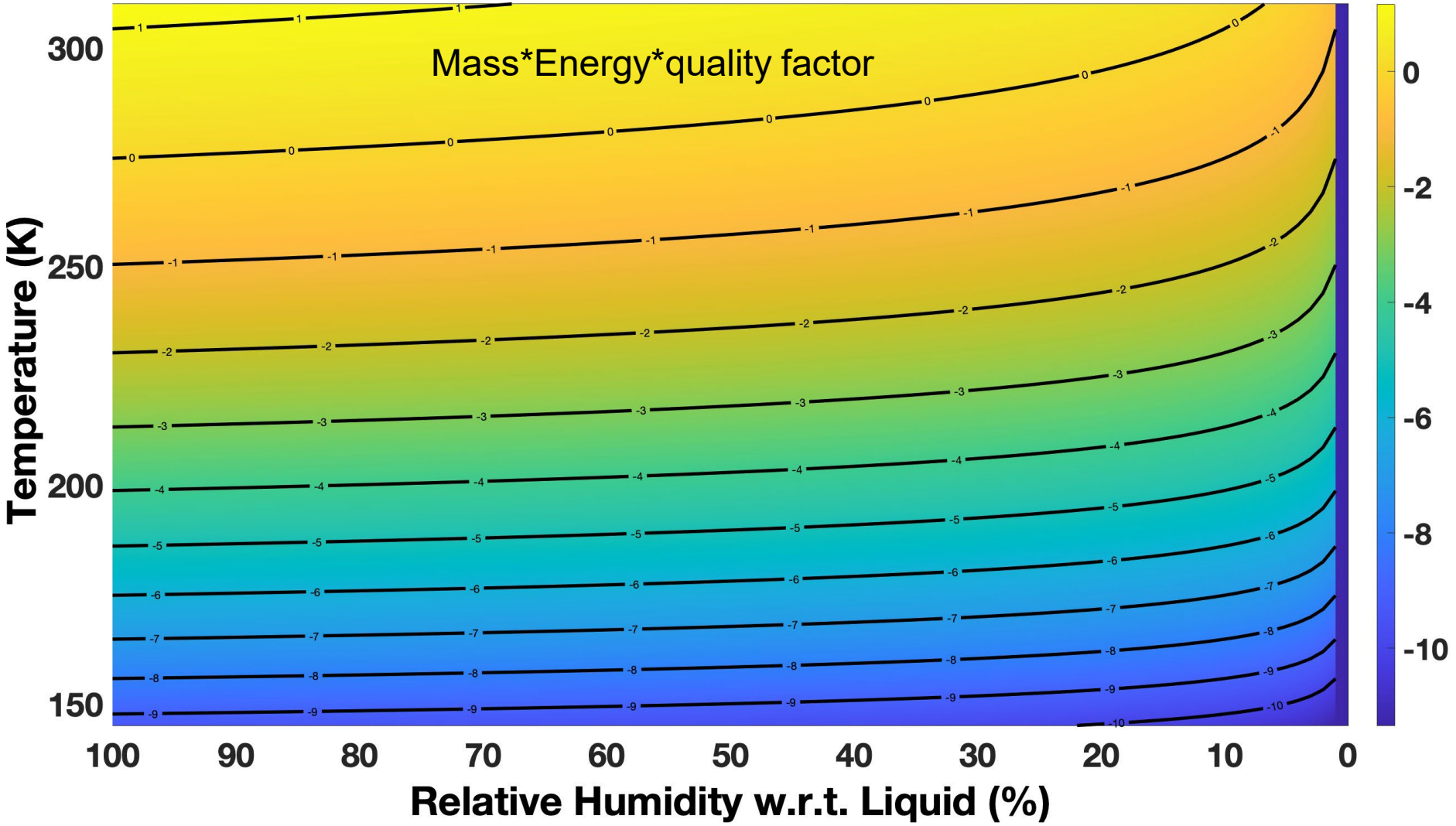
Mars Aqueous Habitat Suitability Index (MAHSI)



- Distance-based metric informed by planetary protection limits
- Relies on T and relative humidity, which at equilibrium relates to water activity a_w
- Brine-centered metric

Rivera-Valentín et al., submitted to PSJ

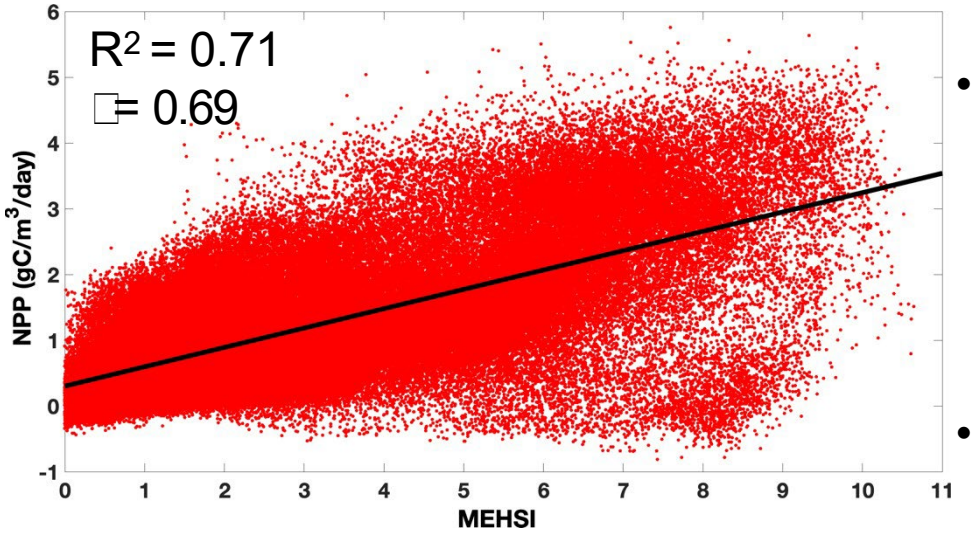
Mass-Energy Habitat Suitability Index (MEHSI)

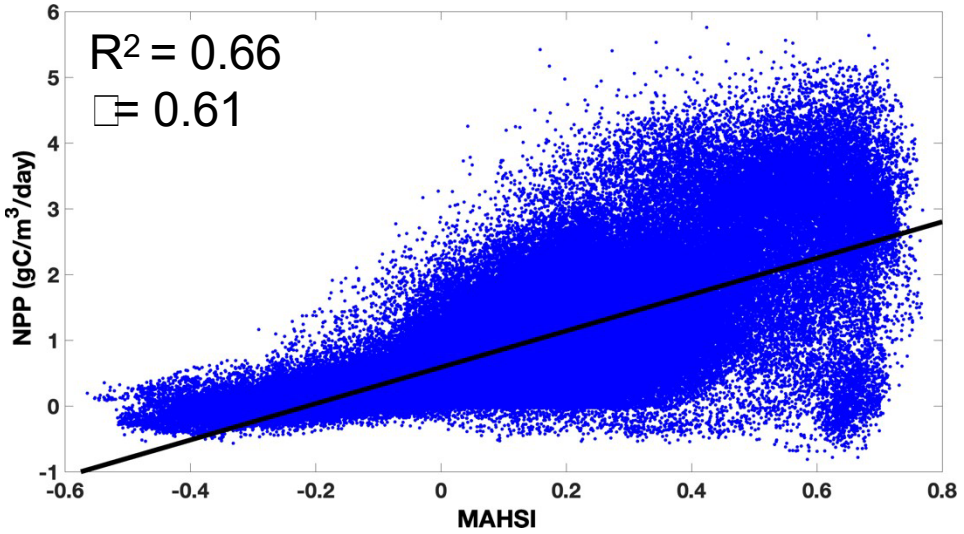


- Follows the work by Méndez et al. (2021)
- Considers bioavailable "mass" and "energy"
- Ratios with respect to a terrestrial environment, and so is a form of a similarity index HSI

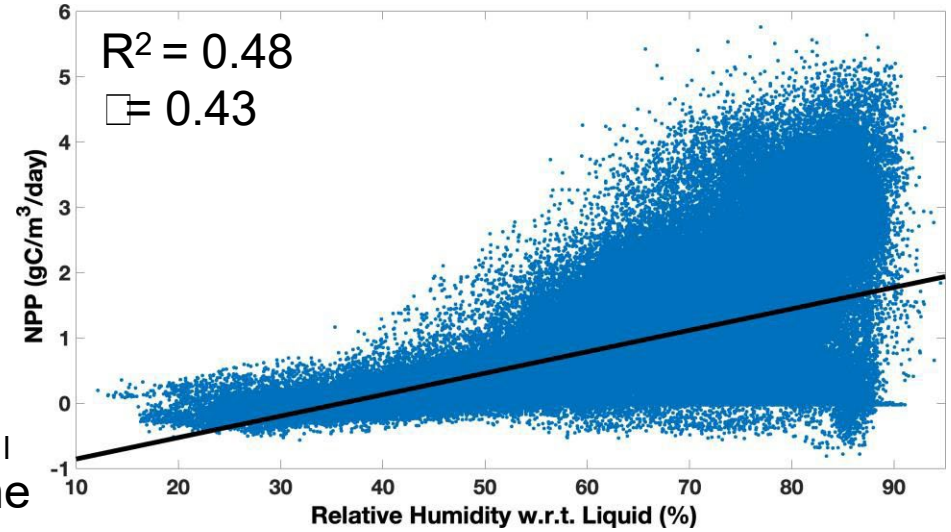
Rivera-Valentín et al., submitted to PSJ

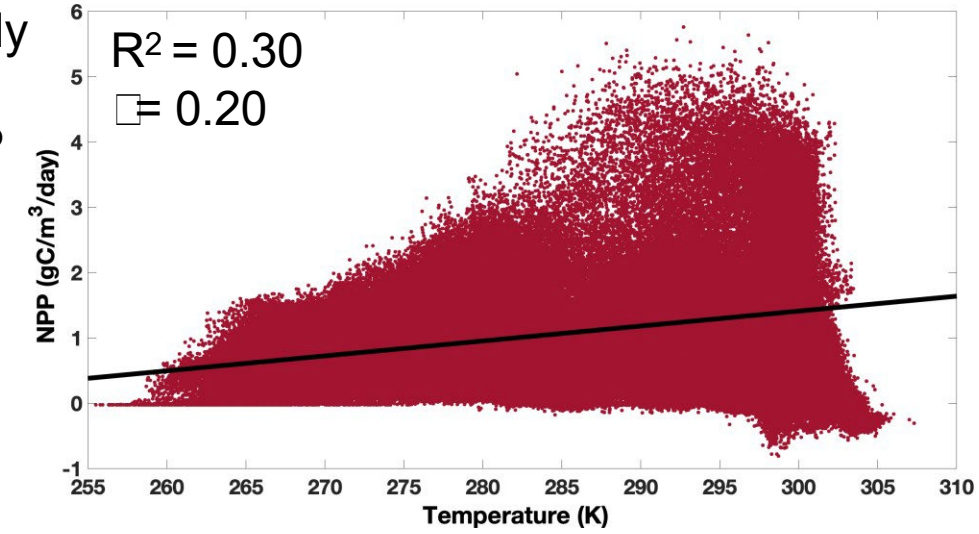
Validation Against Net Primary Productivity (NPP)





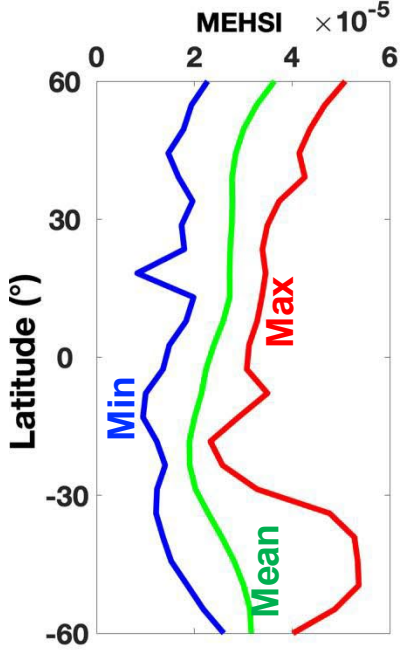
- There is evidence that MEHSI and MAHSI provide information for the prediction of NPP
- Although T and RH_l are important for the developed HSIs, they are individually not sufficient to predict global NPP values.

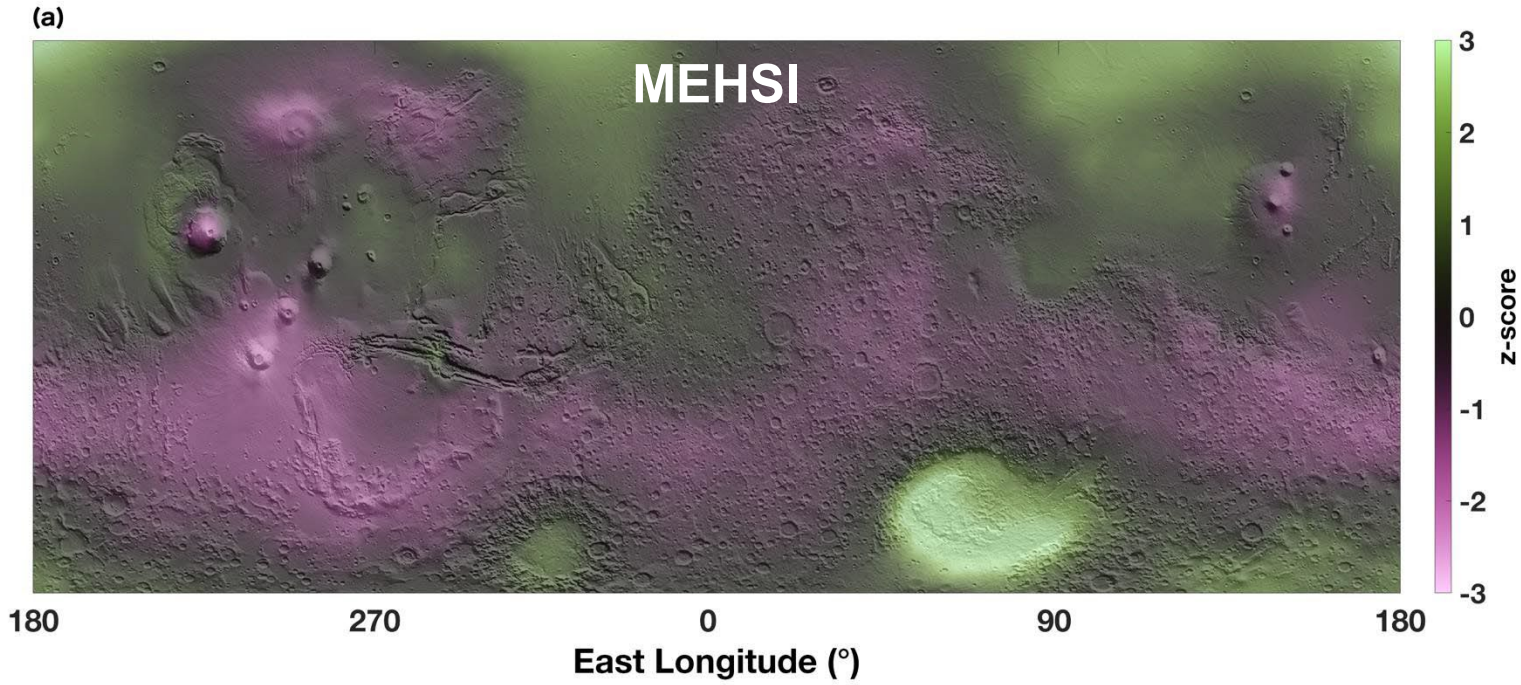


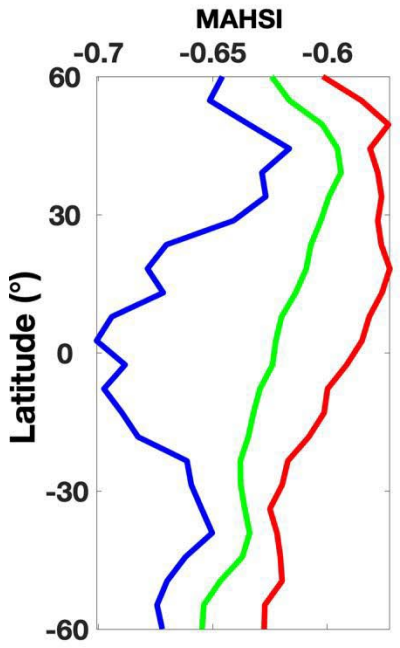


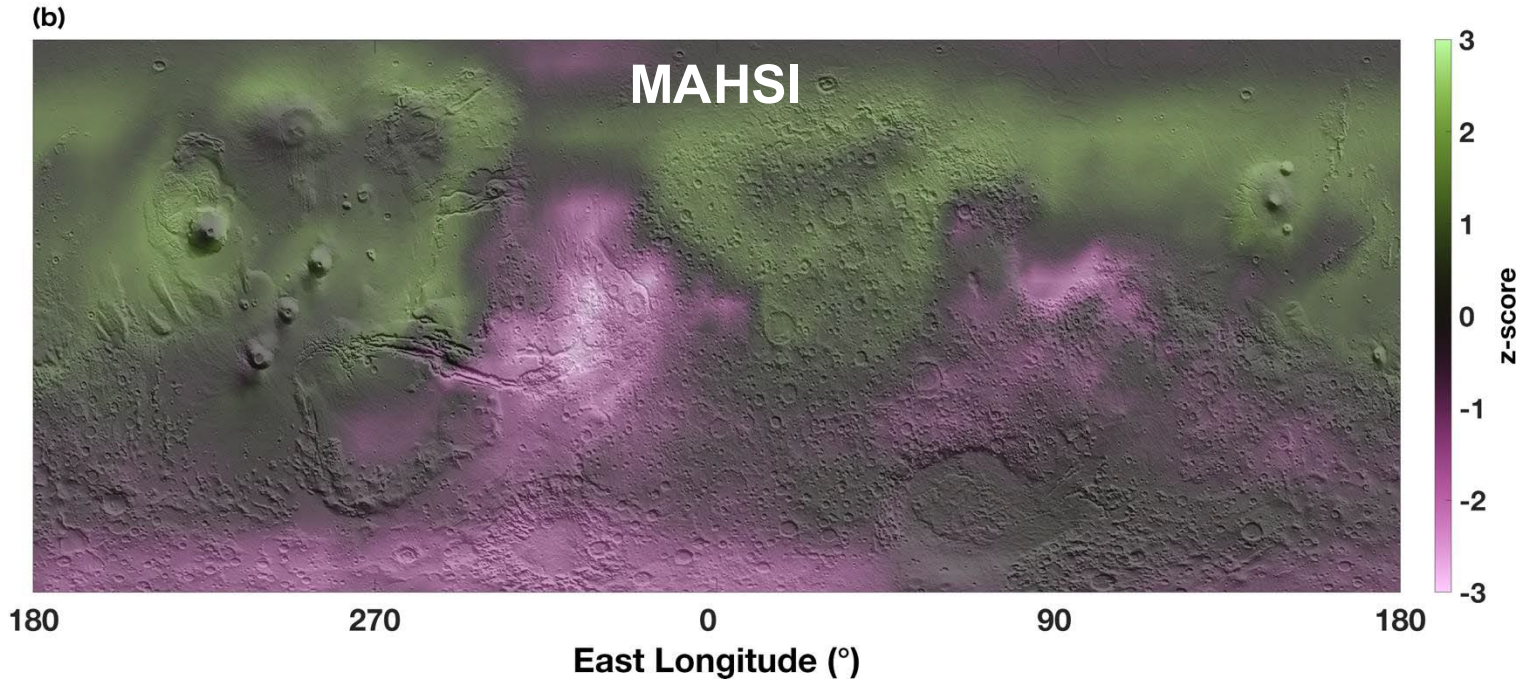
Results

- Results for annual average MEHSI and MAHSI between ±60°
- Both HSIs suggest the north has more suitable conditions
- For MAHSI, the best conditions occur for
  T = 215 K
  $a_w = 0.6$



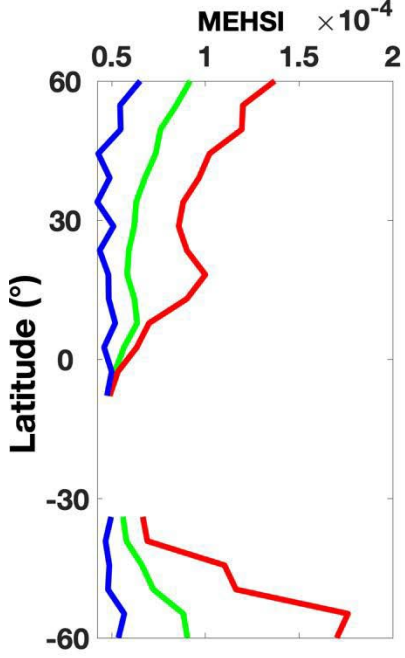


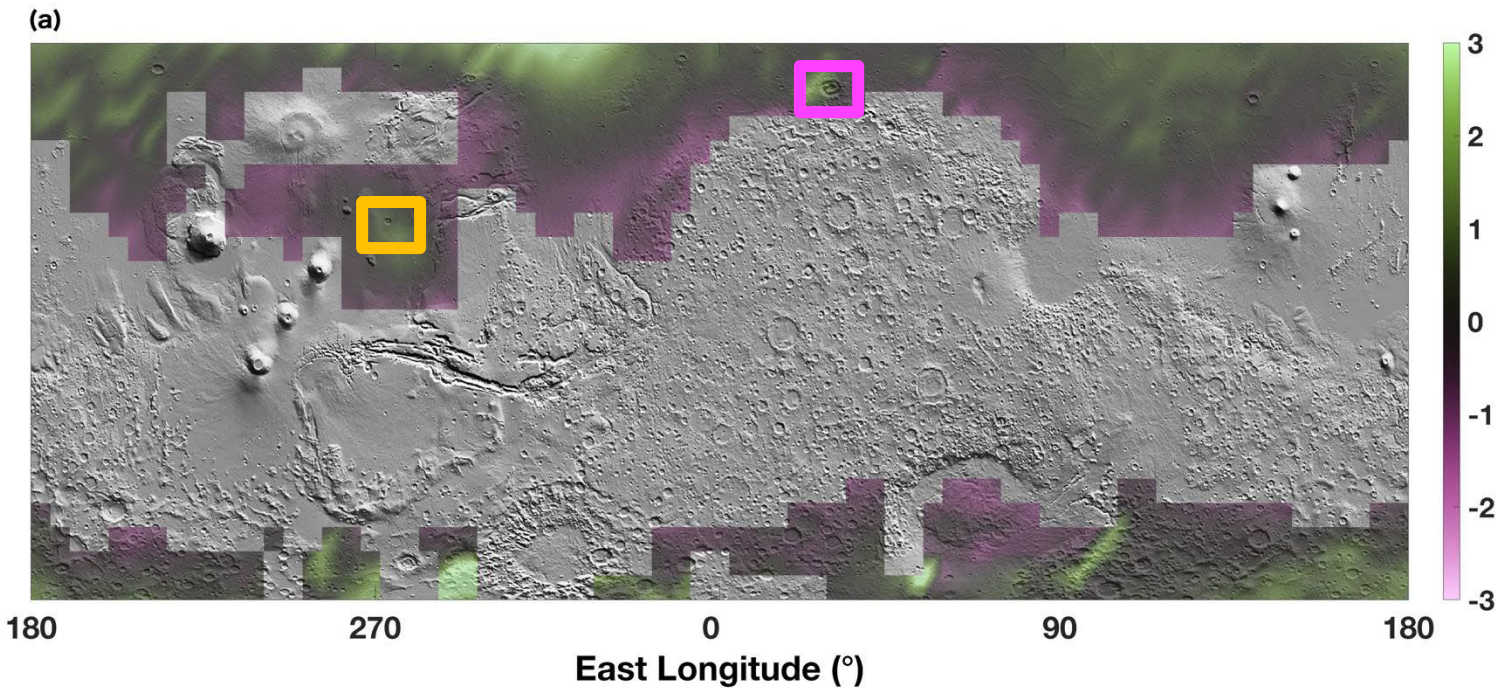


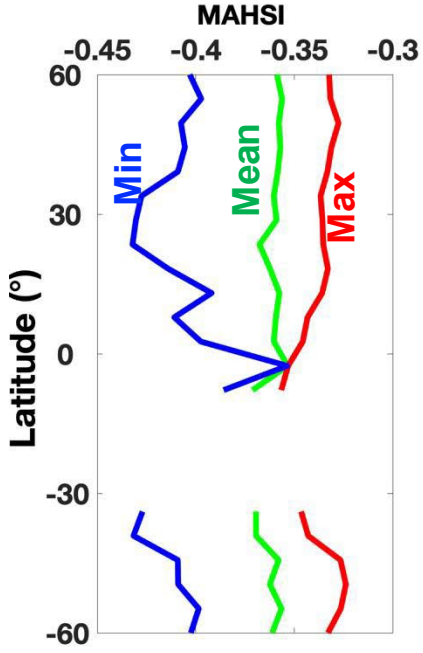


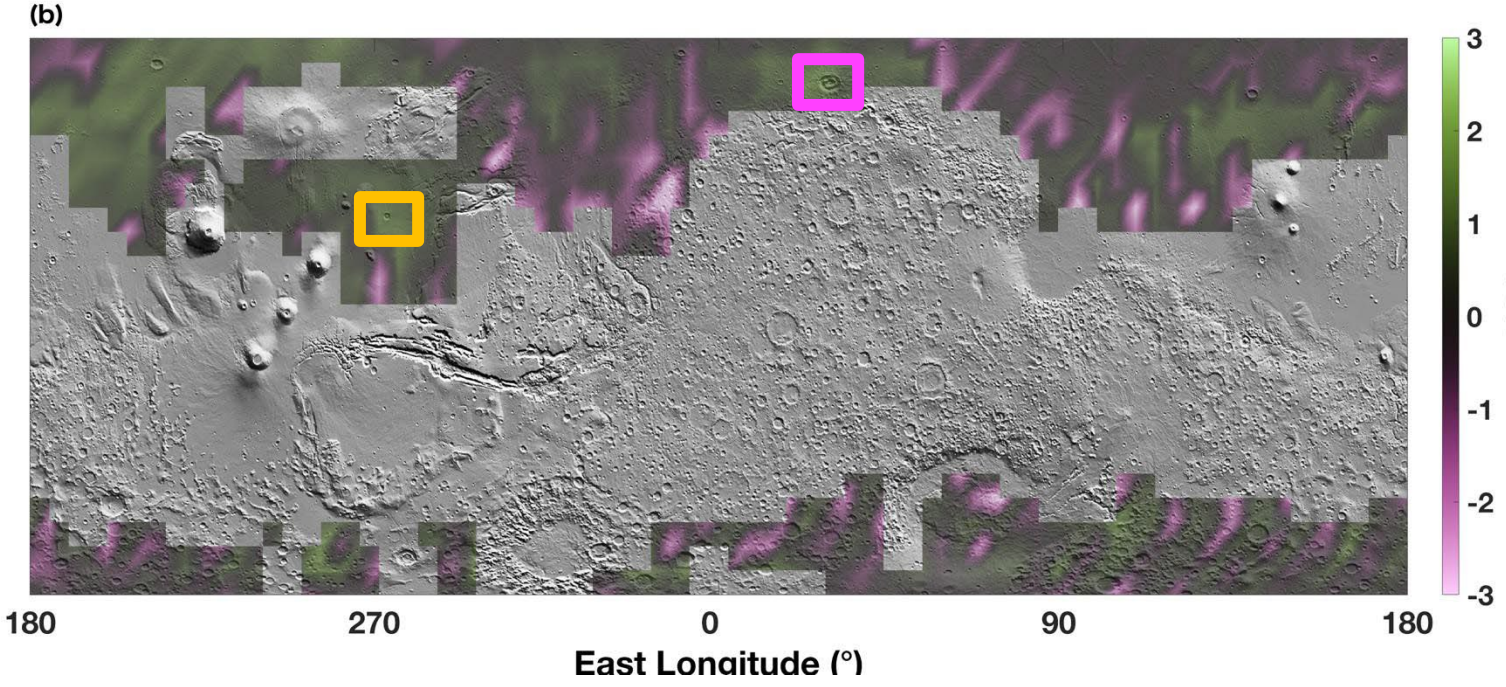
Results

- Conditions during brine formation are an order of magnitude better for MEHSI
- Lyot Crater
  - Brines possible for 0.02% of the year
  - MAHSI ~2□ higher
- Fesenkov Crater
  - Brines possible 0.2% of the year
  - MAHSI ~2□ higher

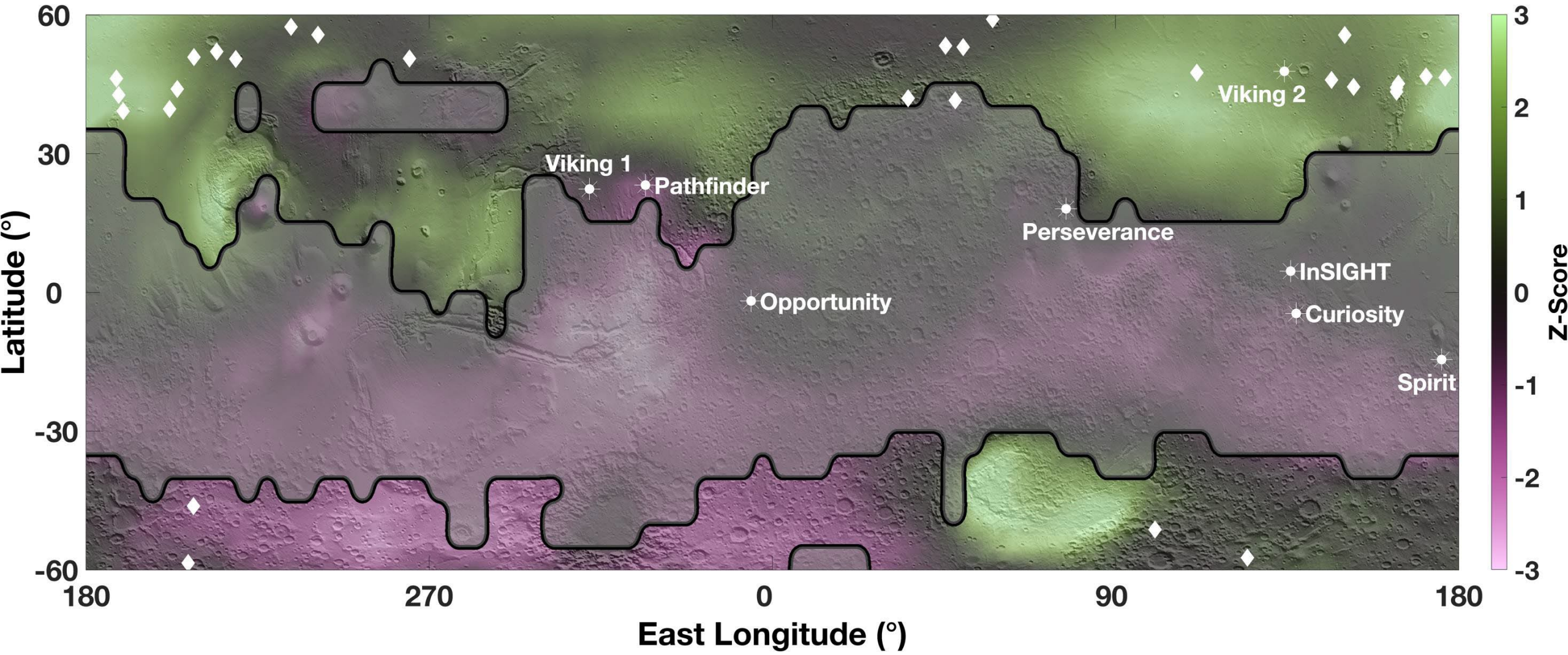








All Together Now



Summary

- **Habitat Suitability Index (HSI) models provide a framework to quantify planetary habitability in a continuous and consistent manner**
- **Developed MAHSI and MEHSI and applied to Mars and found that:**
  - Northern hemisphere is on average more suitable
  - Best conditions occur at T = 215 K, a_w = 0.6
  - Some locations identified as regions of interest:
    - Lyot Crater (50.8°N, 29.3°E), with brines possible 0.02% of the year
    - Fesenkov crater (18.3°N, 271.3°E), with brines possible 0.2% of the year
- **HSI models can inform landing site selection for life detection missions**
  - Can use GCMs to conduct a temporal analysis over a range of obliquities to investigate dynamic habitability
- **HSIs can help inform implementation of planetary protection protocols for missions to Mars**

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