Jet Propulsion Laboratory
California Institute of Technology

The Role of Regolith in the D/H Variation on Mars from the Poles to the Equator

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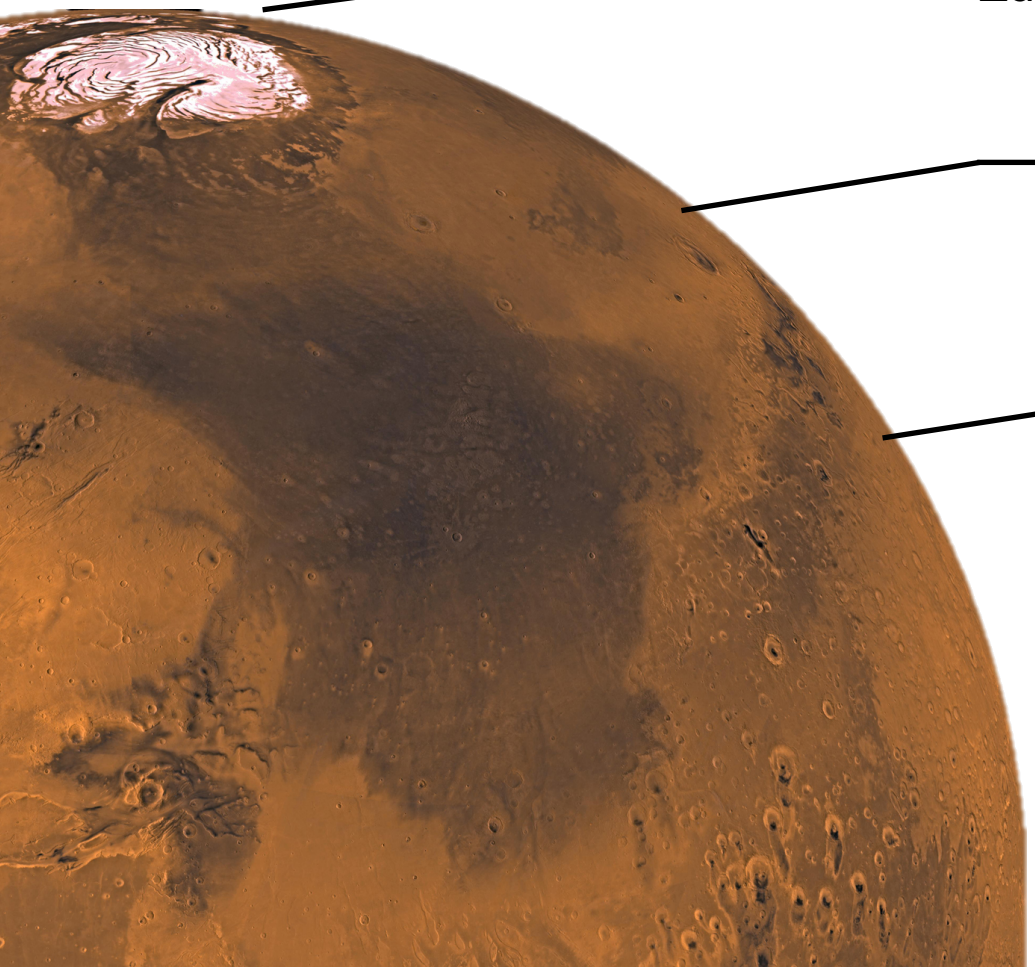
The 7th Mars Polar Science Conference

Surface Water Reservoirs on Mars



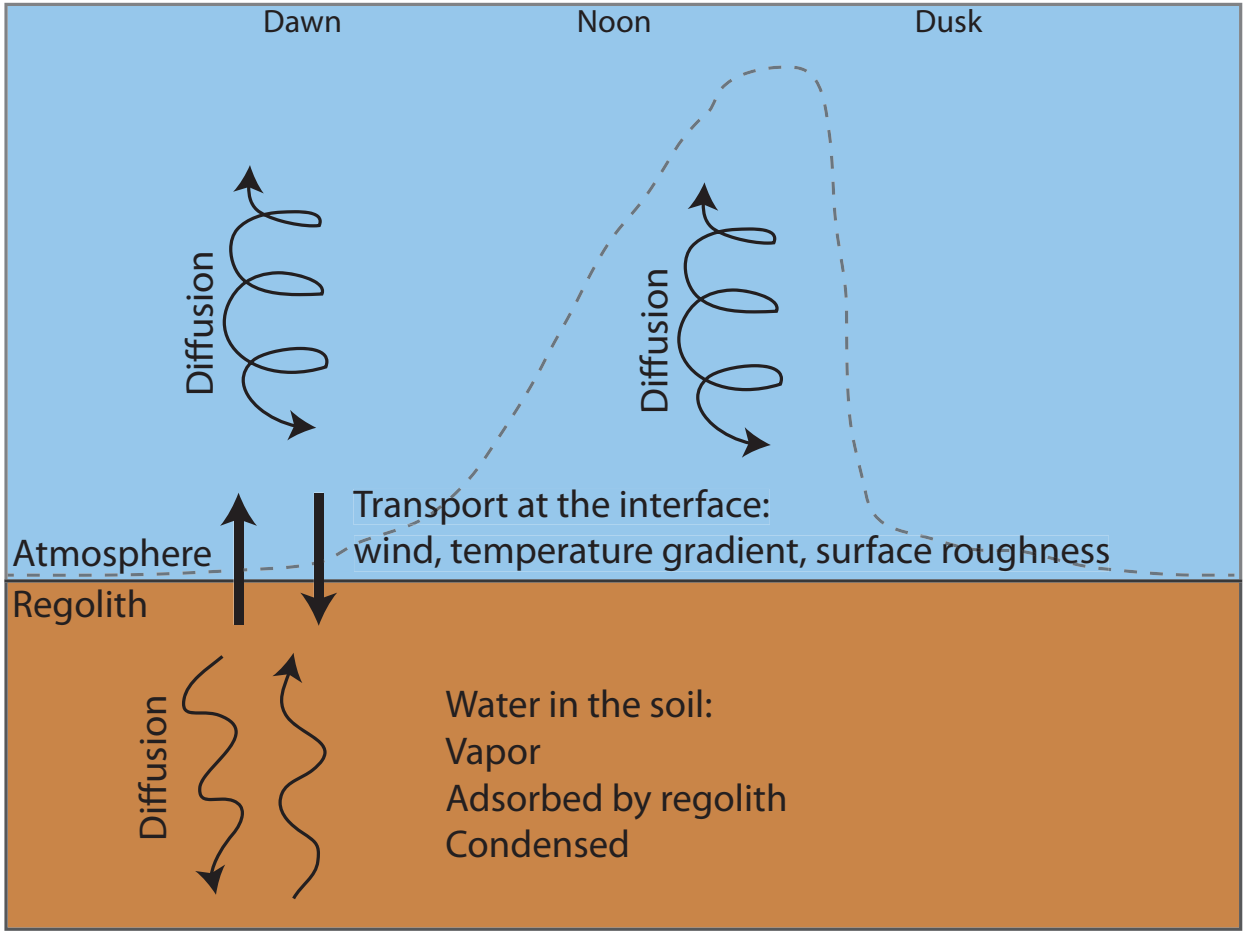
Polar layered deposits
21±3 m Global Equivalent Layer (GEL)
Zuber et al. 1998; Plaut et al. 2007

Ice-rich regolith (Lat>50°-60°)
7 m GEL
Mouginot et al. 2007

Localized shallow buried ice (Lat~30°-60°)
<5 m GEL
Carr & Head 2015

Atmosphere
~2×10^{-5} m GEL
Smith et al. 2009

Regolith-Atmosphere Exchange Model



Previous work shows regolith is a exchangeable reservoir for CO_2, H_2O, and N_2

Recent suggestion of a regolith reservoir of CH_4 (Hu et al. 2016)

The new model (Hu 2019) includes

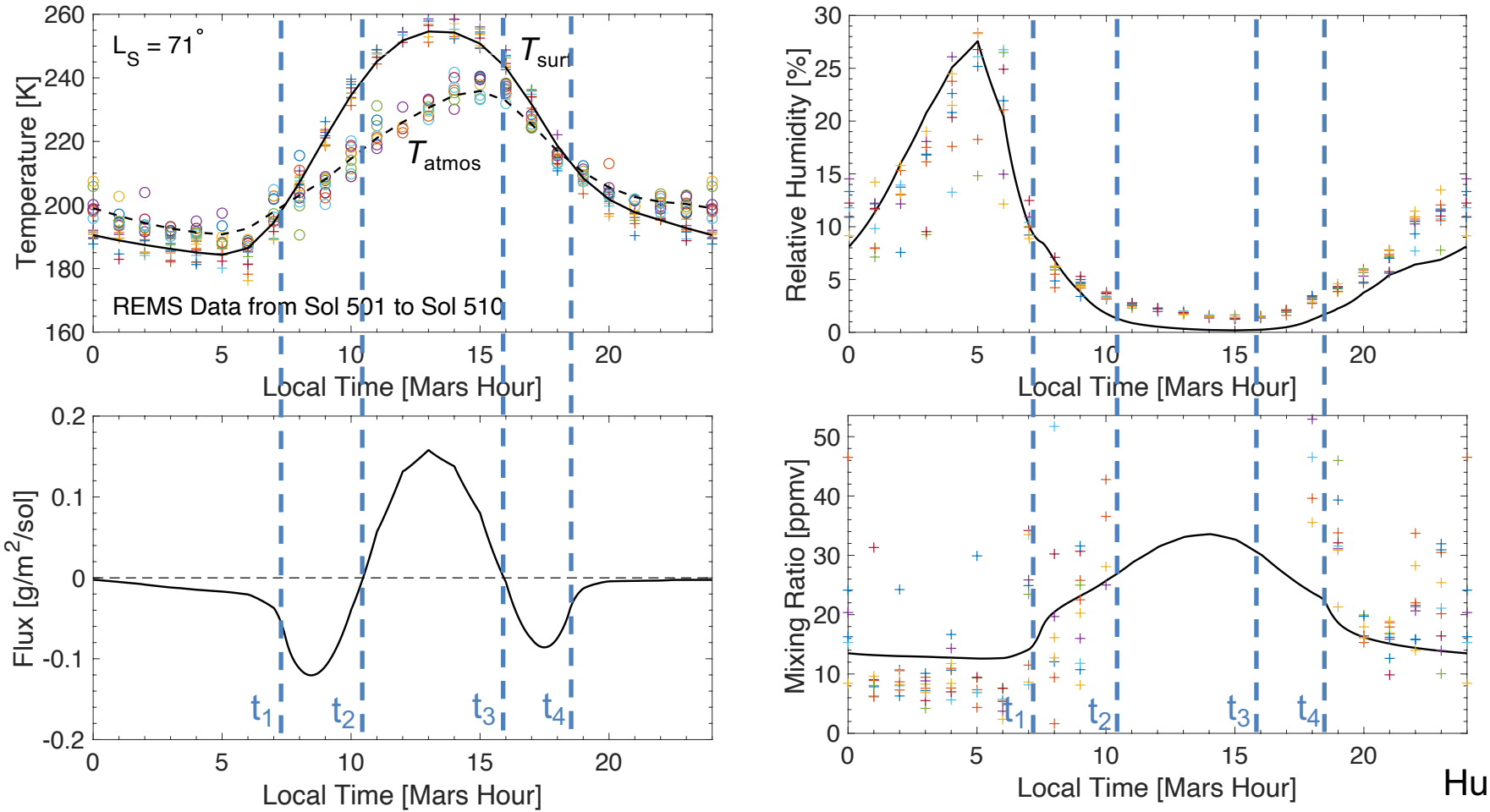
- isotope effects in adsorption (Moores et al. 2011) and condensation
- boundary layer with temperature and wind speed as parameters

Yung et al. 1988; Haberle et al. 1993; Zent et al. 1993; Savijärvi 1995; Hu et al. 2016; Hu 2019

Regolith-Atmosphere Exchange at Gale Crater

The regolith-atmosphere exchange model applied to Gale Crater

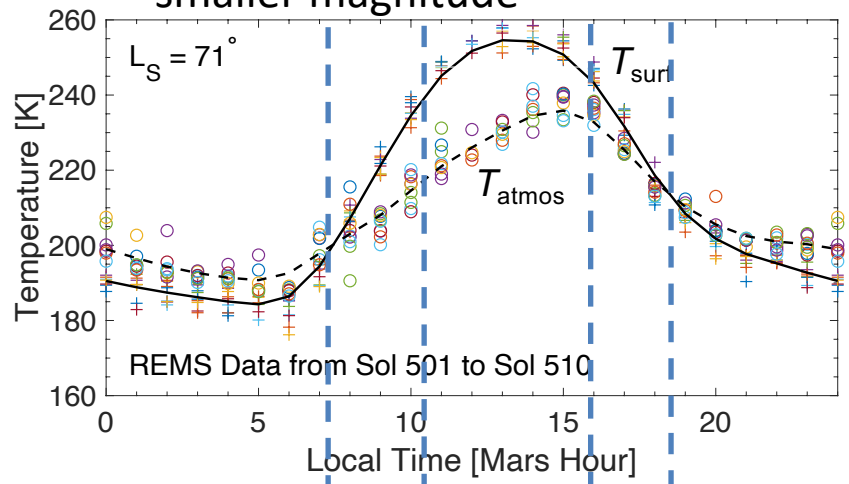
- surface temperature, atmospheric temperature, and wind speed from REMS
- water column abundance from ChemCam (McConnochie et al. 2018)

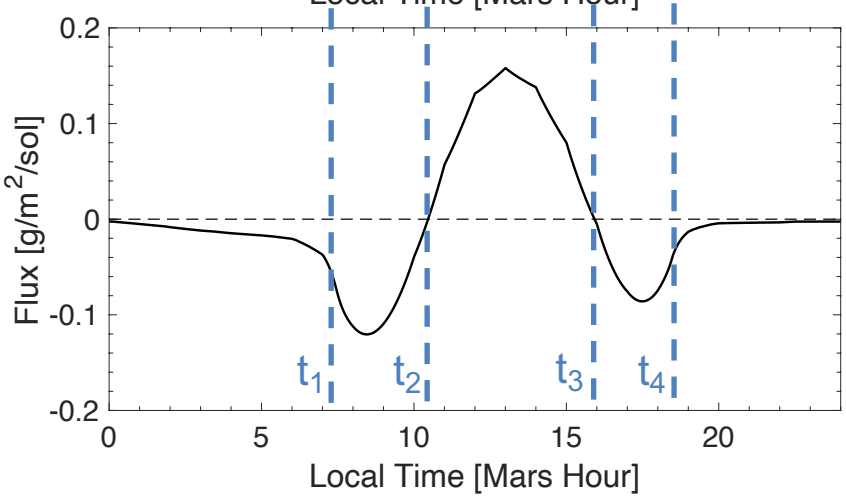


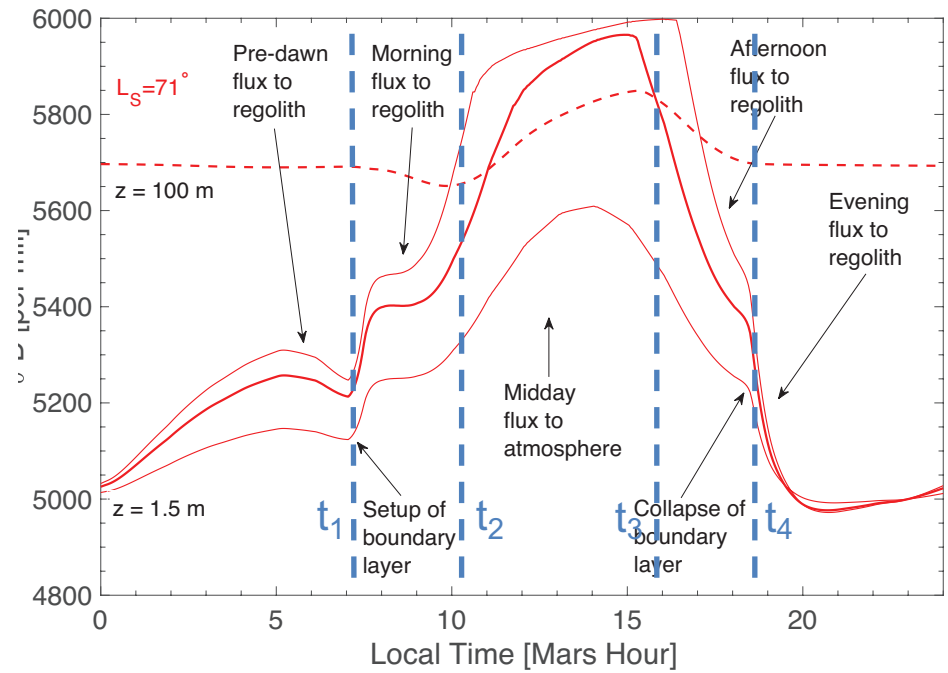
Hu 2019

Regolith-Atmosphere Exchange
Large diurnal variation in D/H

- The variation at the surface traces regolith adsorption/desorption cycle and boundary-layer mixing
- The variation at ~100 m has traces the regolith adsorption/desorption cycle with a smaller magnitude

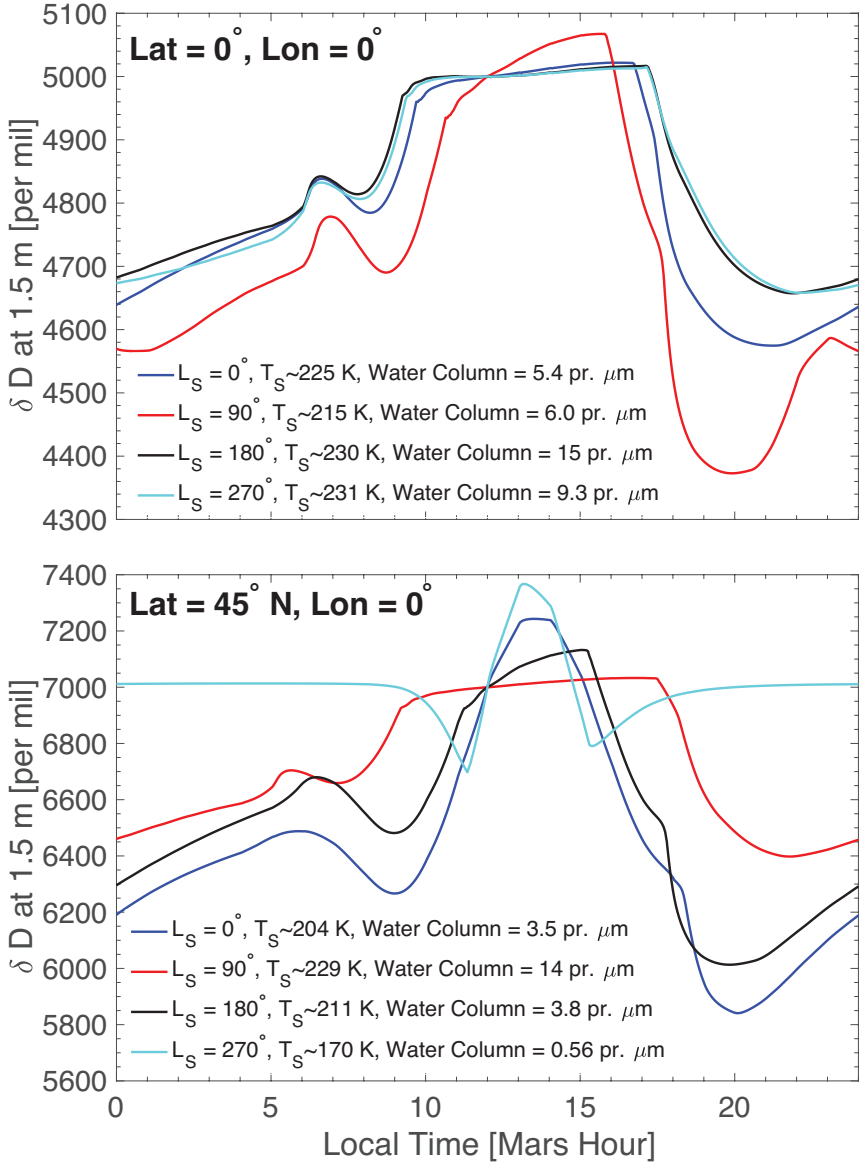






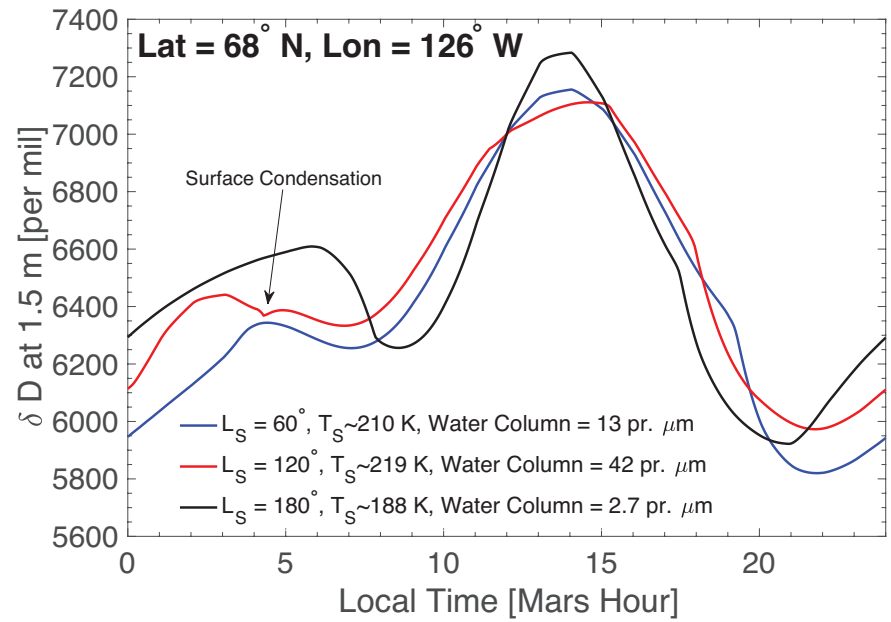
Hu 2019

Regolith-Atmosphere Exchange
Diurnal variation in D/H from equator to pole



δD can vary by 300 – 1400‰

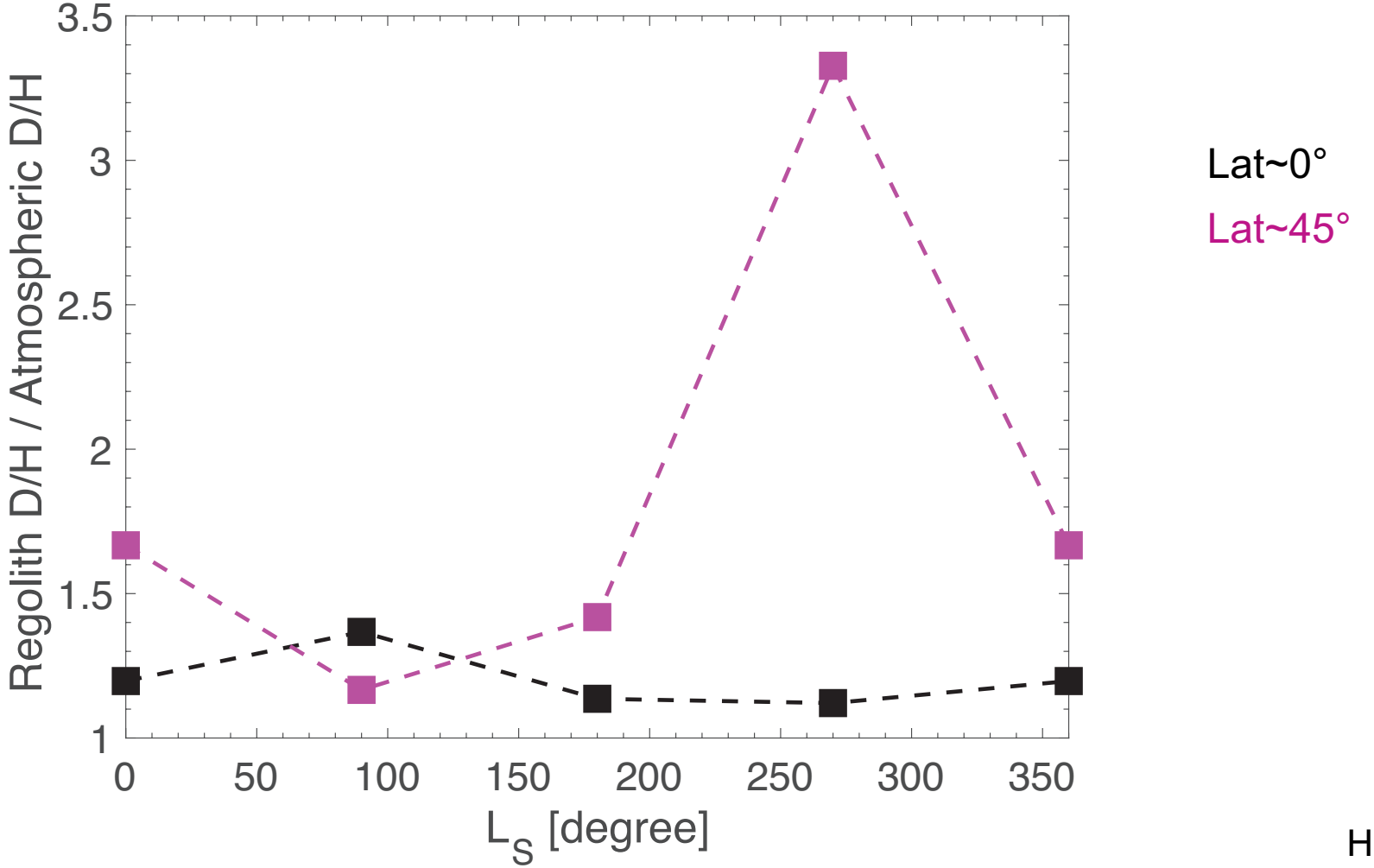
- shape of variation is general
- magnitude of variation is greater at a colder location or during a colder season
- surface condensation before dawn produces a unique feature



Hu 2019, with parameters from GCM (Forget et al. 1999)

Regolith-Atmosphere Exchange
Seasonal variation of D/H in the atmosphere

- Substantial seasonal variation driven by regolith in the mid latitudes
- Water in the regolith is more enriched than water in the atmosphere

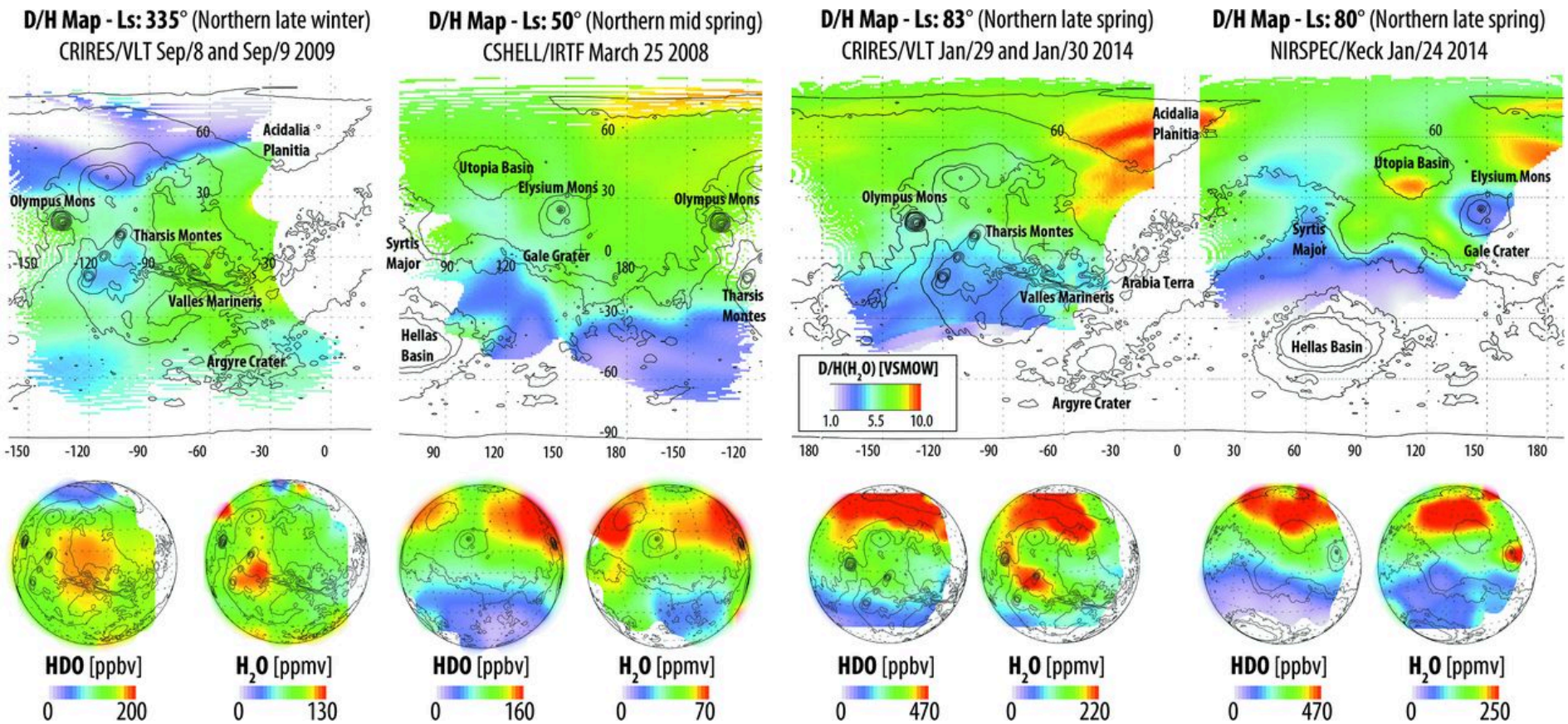


Hu 2019

Isotopes in the Annual Water Cycle

The observed D/H of atmospheric water drops faster than model predictions

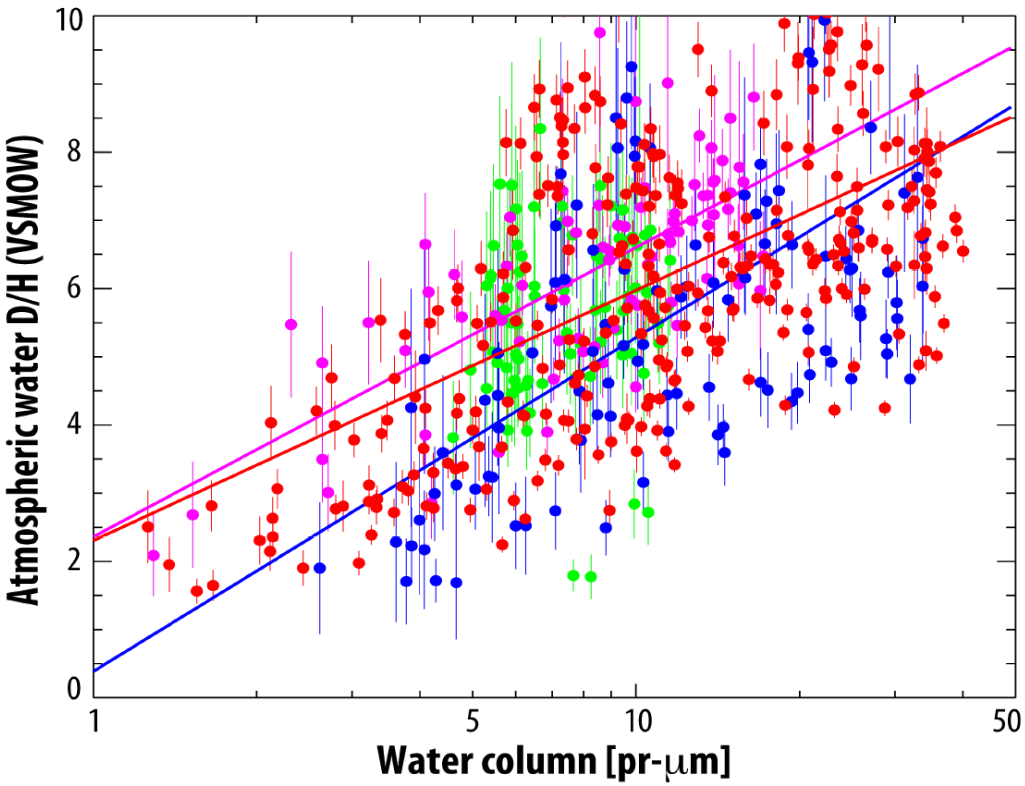
- Past model only includes atmospheric condensation



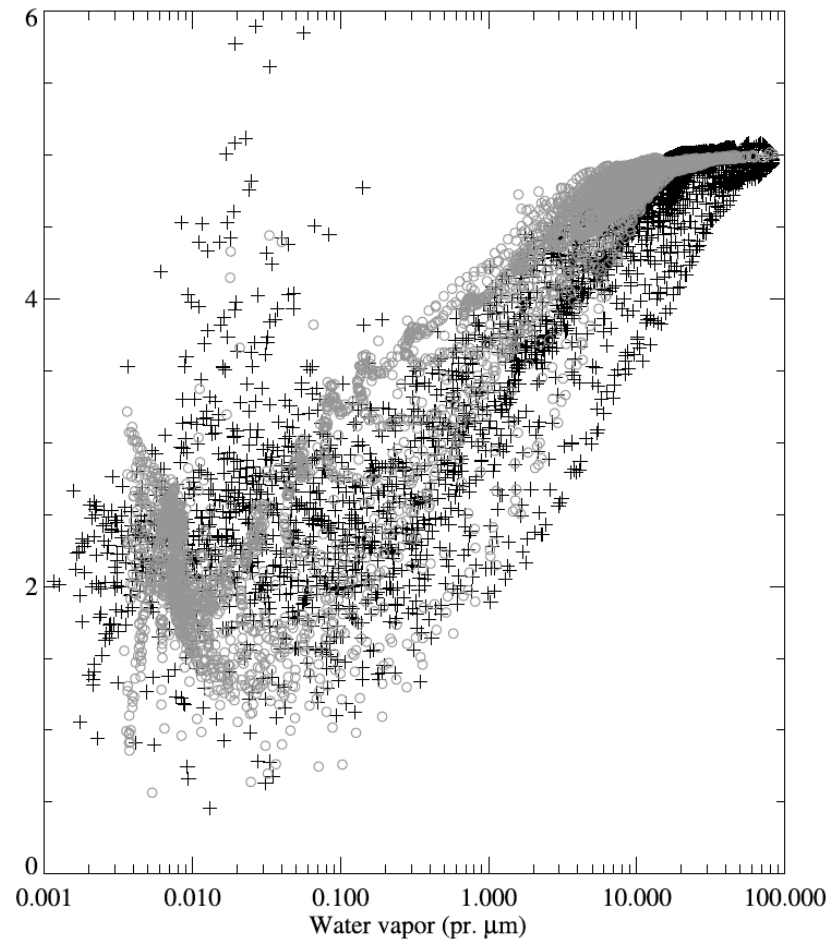
Villanueva et al. 2015

Fractionating Water Vapor

Observed:
D/H (VSMOW) ~ Column (pr. um) $^{0.8}$



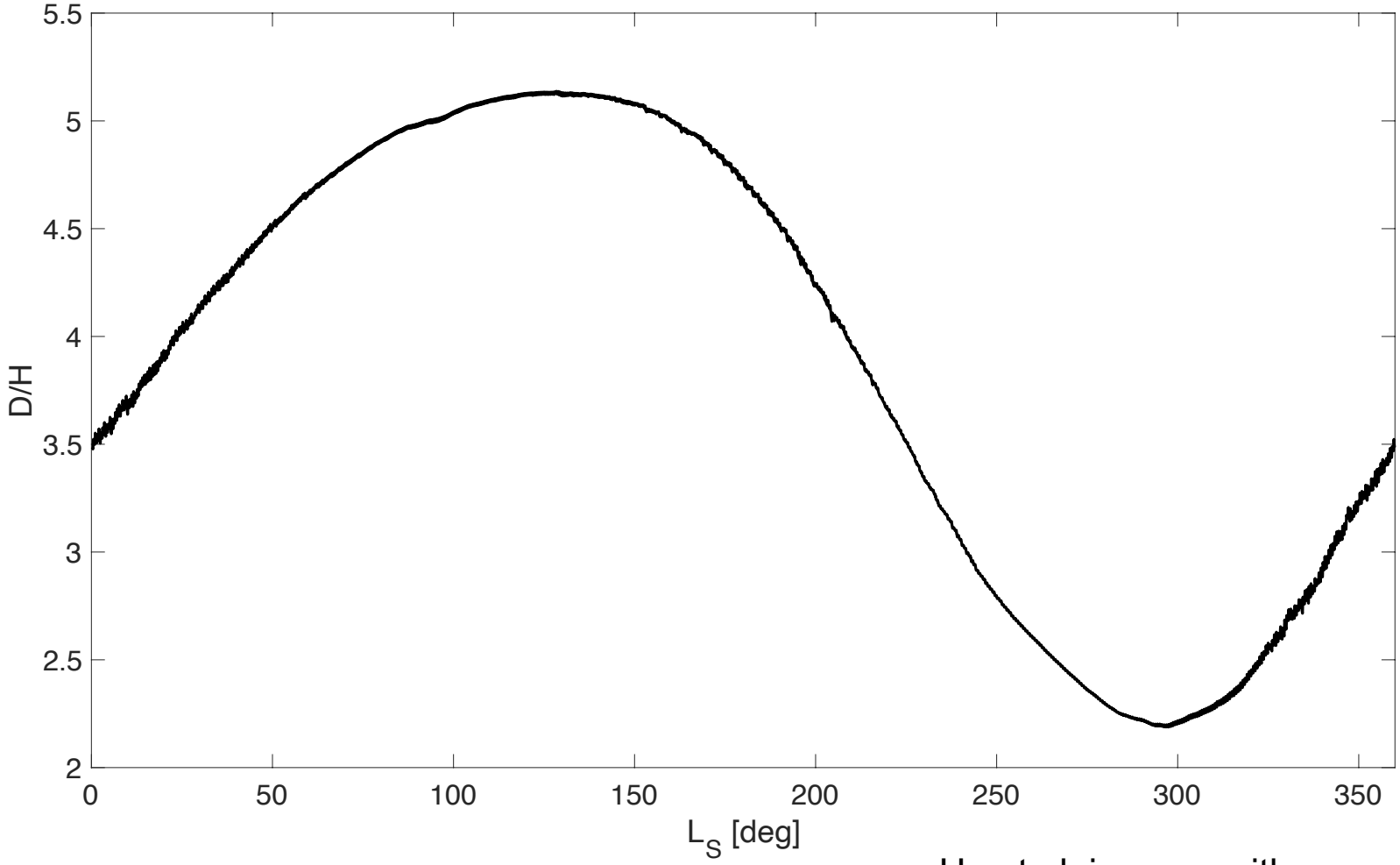
Modeled with atmos. condensation:
D/H (VSMOW) ~ 3 Column (pr. um) $^{0.2}$



Montmessin et al. 2005; Villanueva et al. 2015

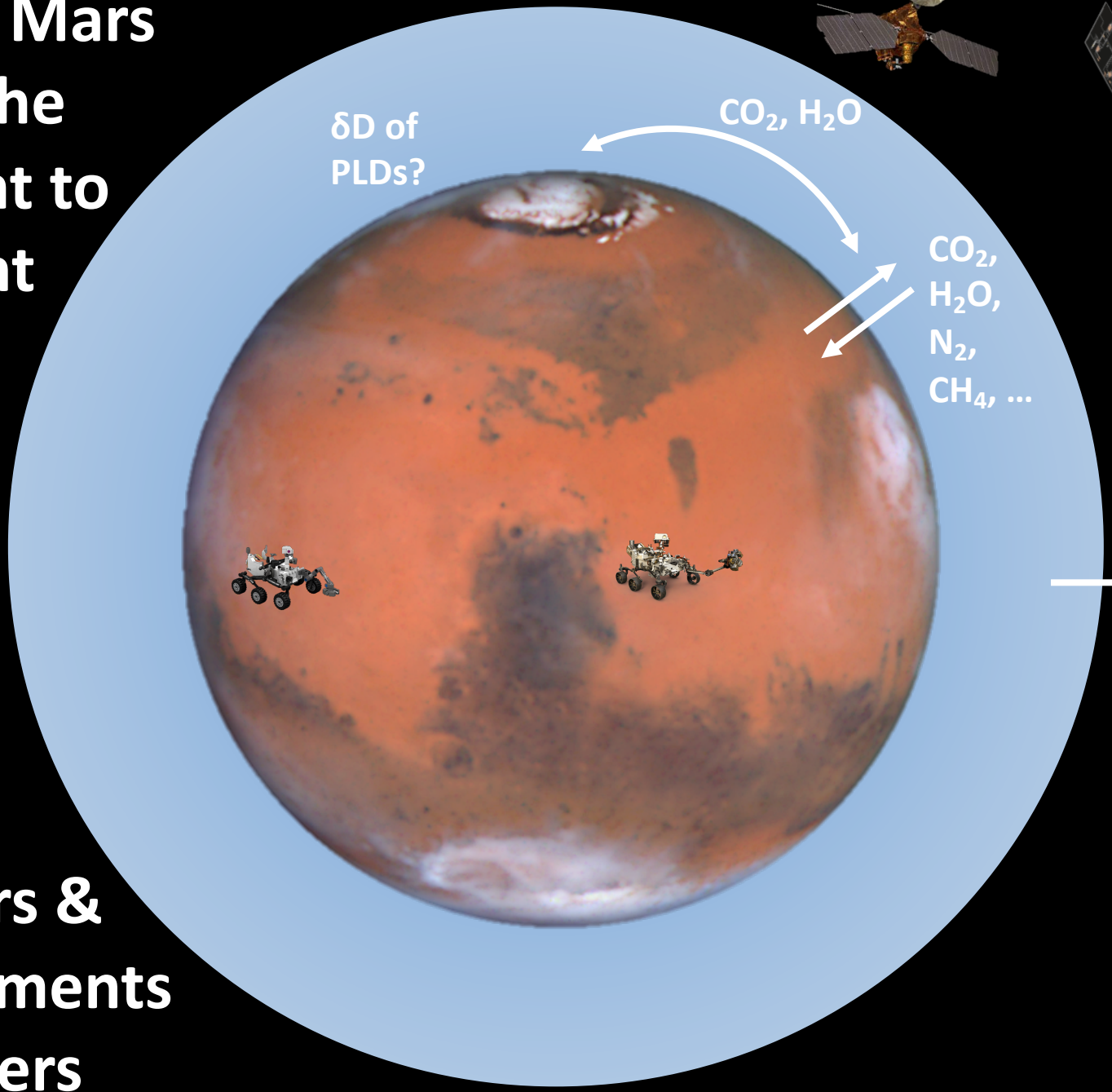
A Role of Regolith?

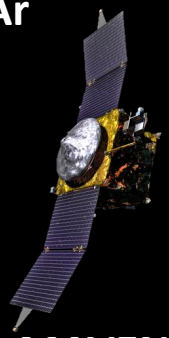
The seasonal regolith adsorption/desorption cycle alone can cause a large variation in the mean D/H of the water column



Hu et al. in prep. with parameters from GCM (Neary & Daerden 2018)

Active Mars from the Present to Ancient Times





Future orbiters & experiments on rovers

Conclusion

- We present a regolith-atmosphere transport model of water that includes the isotope effect in adsorption, condensation, and transport
- The model predicts a surprisingly large and potentially measurable diurnal variation of D/H at the surface
  - The variation probes the regolith-atmosphere exchange and the isotope composition of the subsurface reservoirs
- Preliminary results indicate that the regolith may play a significant role in the seasonal and latitudinal variation of the mean D/H of the atmospheric water column

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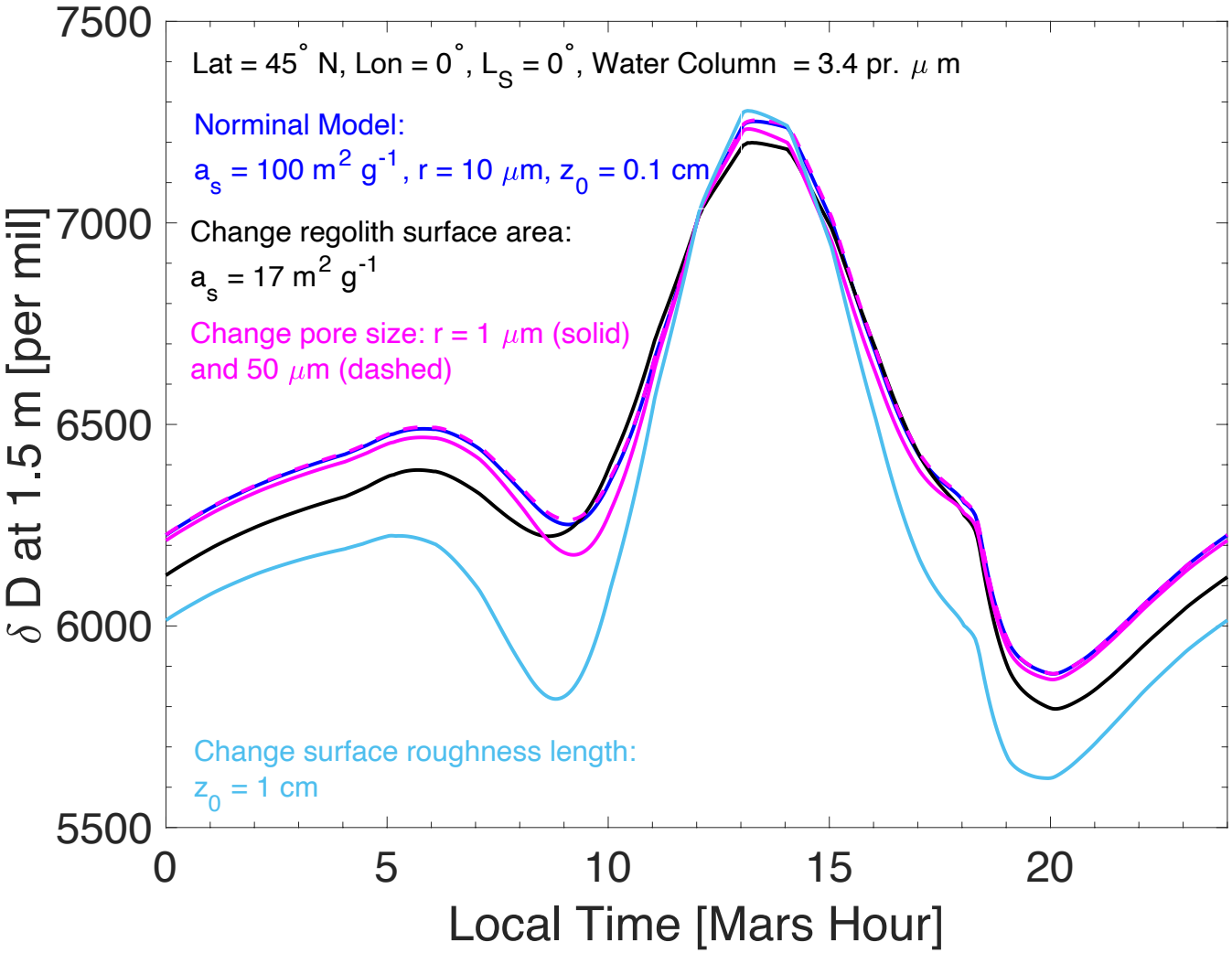
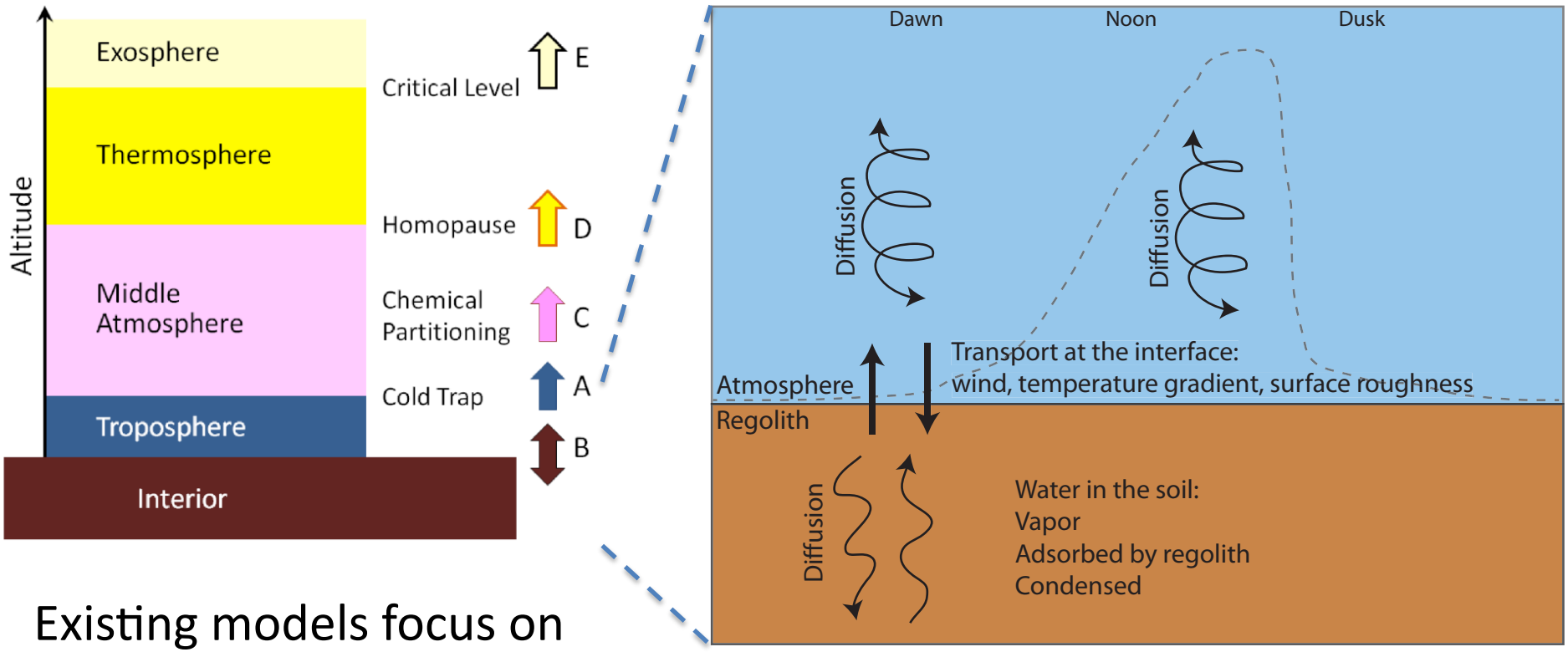
Regolith-Atmosphere Exchange
Sensitivity to soil properties



Hu 2019

Regolith-Atmosphere Exchange



Existing models focus on the abundance of H_2O and CO_2. Here we include isotopes.

Yung et al. 1988; Haberle et al. 1993; Zent et al. 1993; Savijärvi 1995; Hu 2019

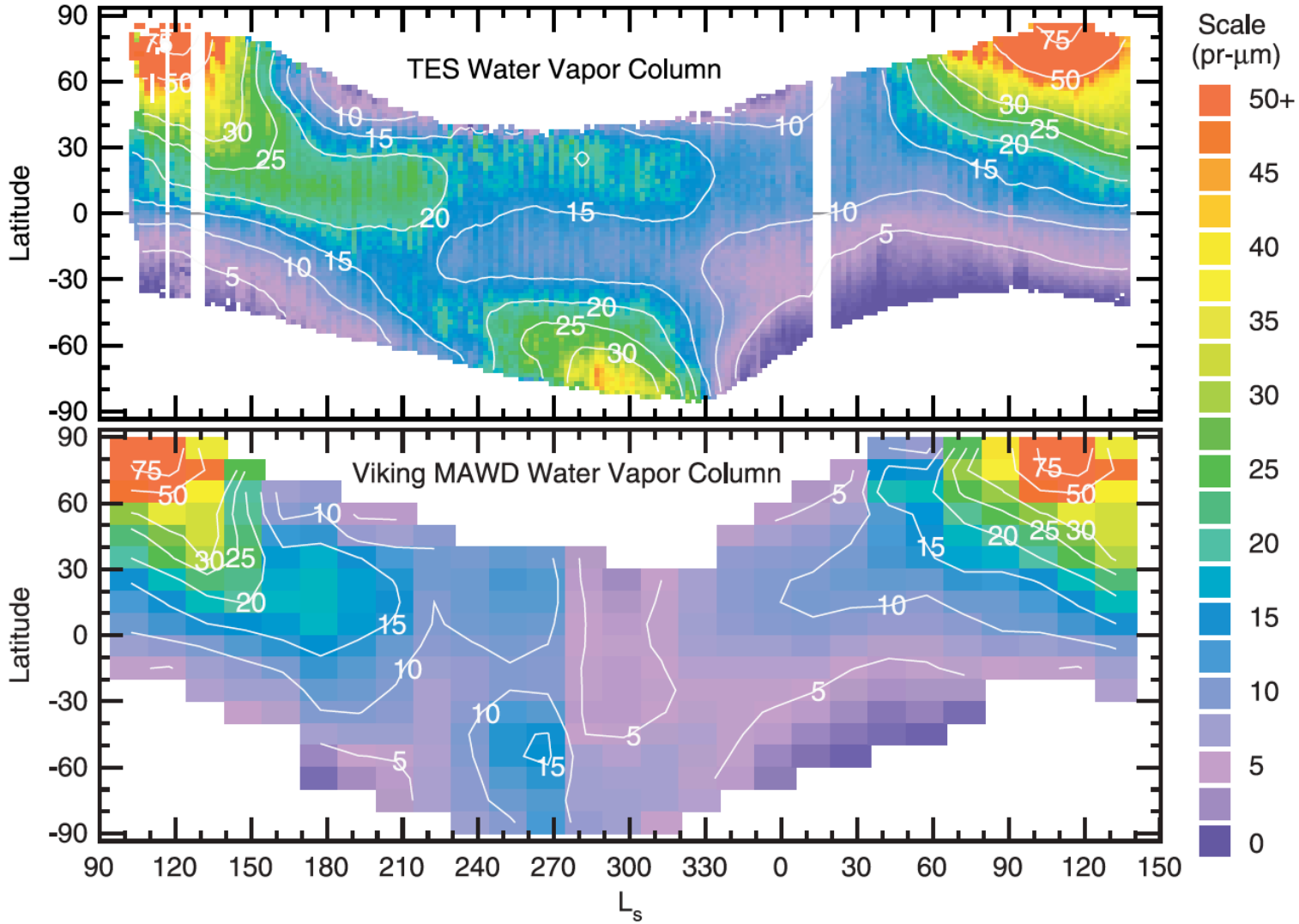
Model of Methane Transport

- Use the hourly averaged REMS data as the boundary condition of the subsurface temperature and humidity (Sol 70-89, Rocknest)
- Cap the daytime humidity at 20 pr. μm, based on TES measurements
- Include physical adsorption and desorption by regolith, condensation, and corrections due to soil porosity and tortuosity
- Allow deliquescence to occur using the measured DRH of calcium perchlorate
- Use Langmuir-Freundlich isotherm measured for palagonite, a terrestrial analogue of Martian basaltic soil
- Include co-adsorption of CO_2 in calculating methane adsorption

$$\theta_{CH_4} = \frac{K_{eq} n_{CH_4}}{1 + K_{eq} n_{CH_4} + K'_{eq} n_{CO_2}} \qquad K_{eq} = \frac{\nu h}{4\gamma_{CH_4} + k_b T} \exp(E_a / RT)$$

- Assume the active surface area of the dry regolith to be 17 – 100 $m^2\ g^{-1}$ based on Viking and lab measurements

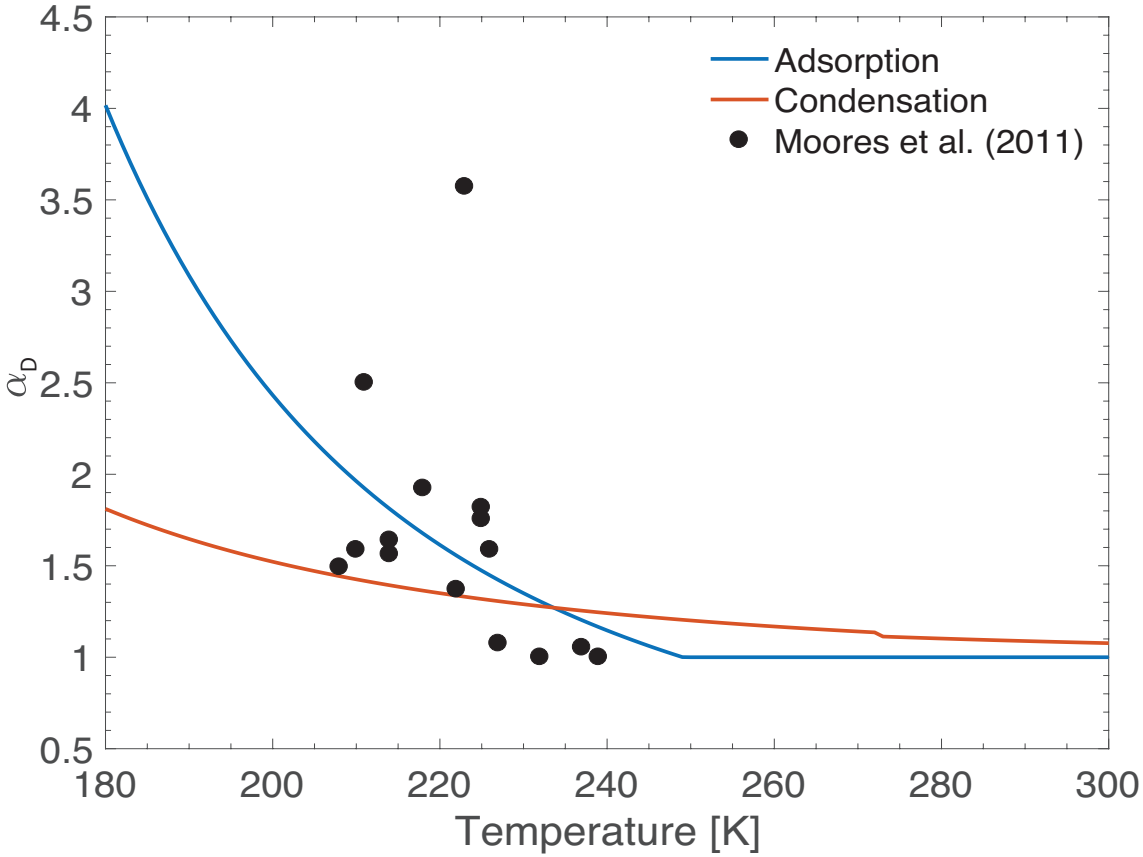
Annual Cycle of Water Vapor on Mars



Smith 2002

Regolith-Atmosphere Exchange
Isotope effect

Isotopic fractionation in adsorption and condensation



Hu 2019