Understanding variations in precipitation isotope ratios using process-oriented water tracers

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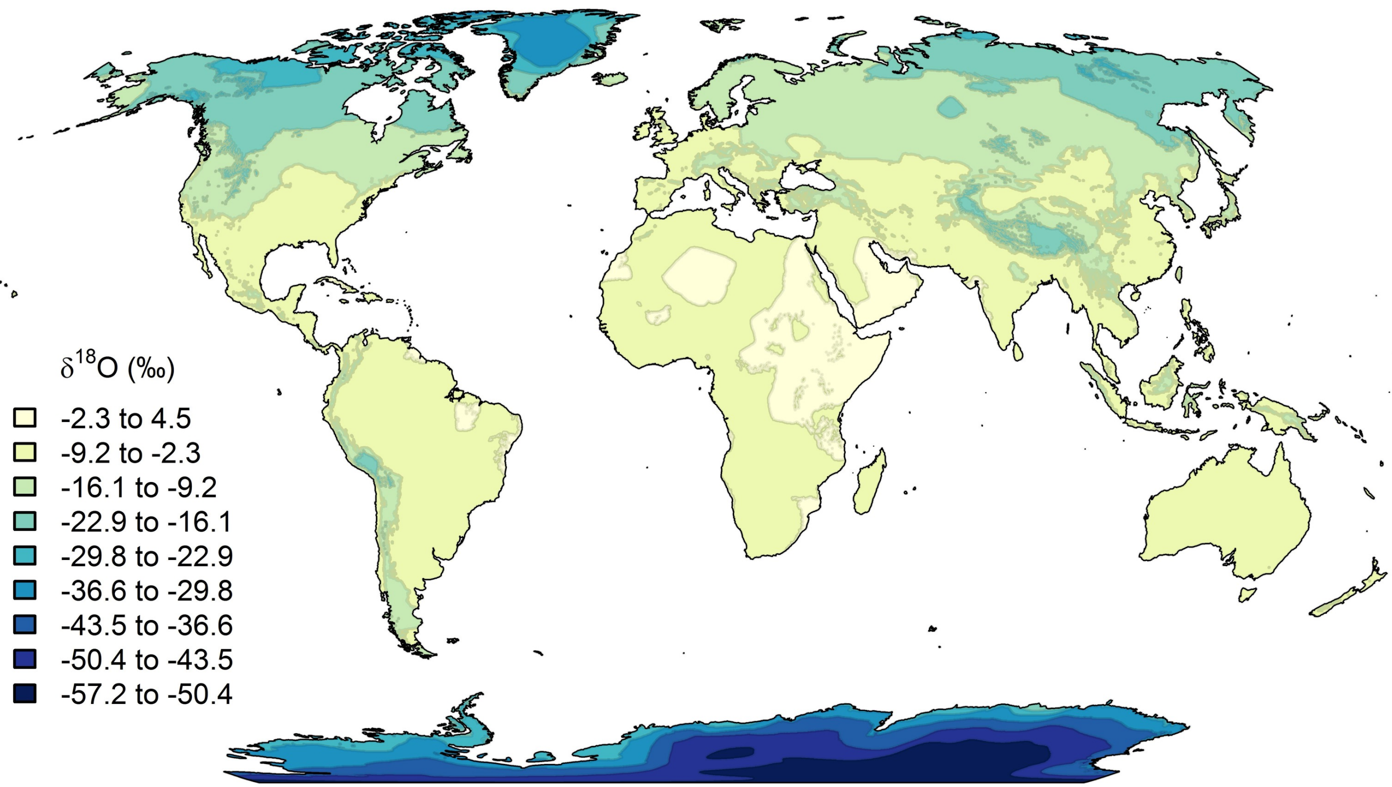
Dependence of isotope ratios on climate

Isotope ratios show strong spatial pattern, low at:

- High latitude
- High altitude
- Continental interiors

– preserved in a lot of materials!



http://waterisotopes.org

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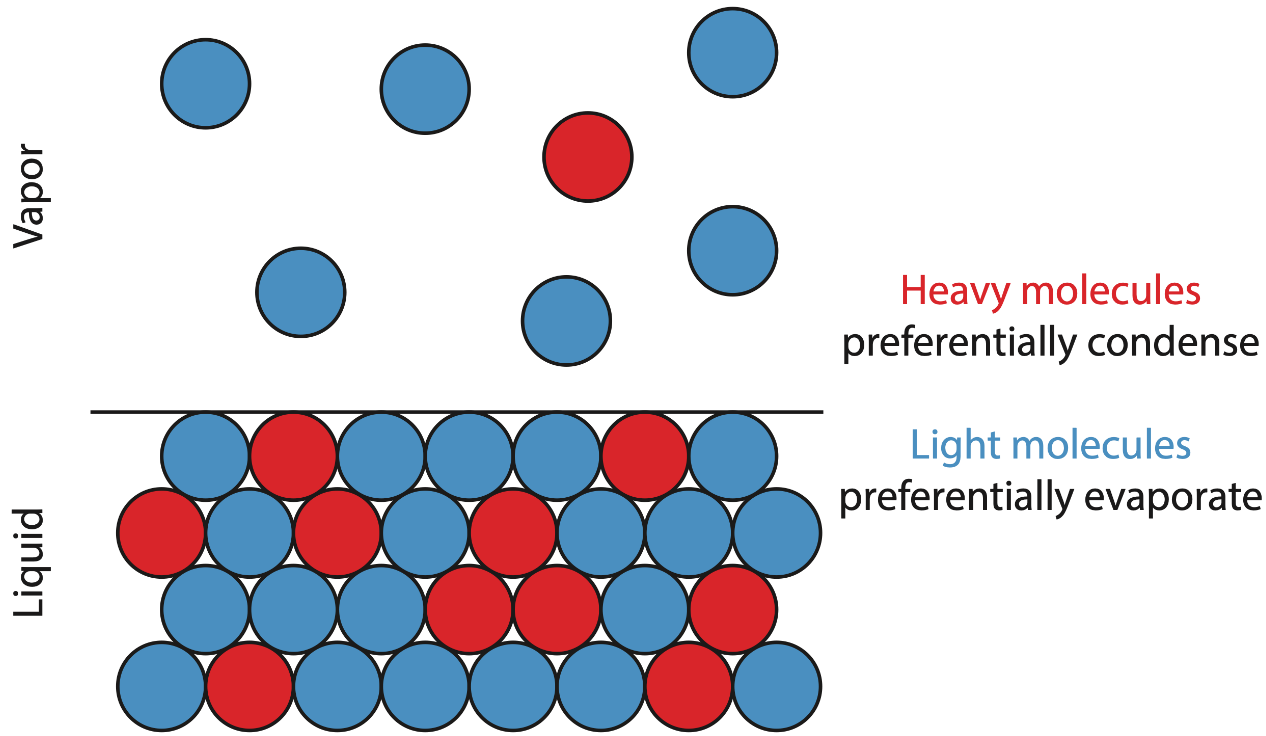
Isotope Fractionation

Oxygen: 99.76% ^{16}O, 0.2% ^{18}O

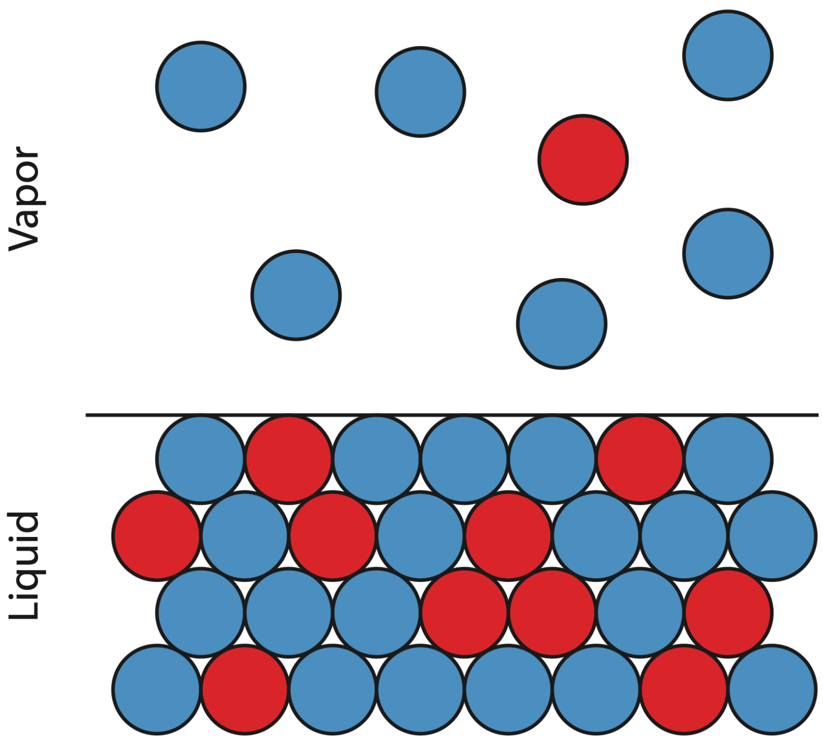
Hydrogen: 99.99% ^{1}H, 0.01% ^{2}H

Water isotopologues:

- $^{1}H_2{}^{16}O$ - 99.74%
- $^{1}H_2{}^{18}O$ - 0.20%
- $^{1}H^{2}H^{16}O$ - 0.01%
- Others - 0.05%



Isotopic Fractionation



Heavy molecules
preferentially condense

Light molecules
preferentially evaporate

$$R = \frac{heavy}{light}$$

$$\alpha = \frac{R_{liquid}}{R_{vapor}}$$

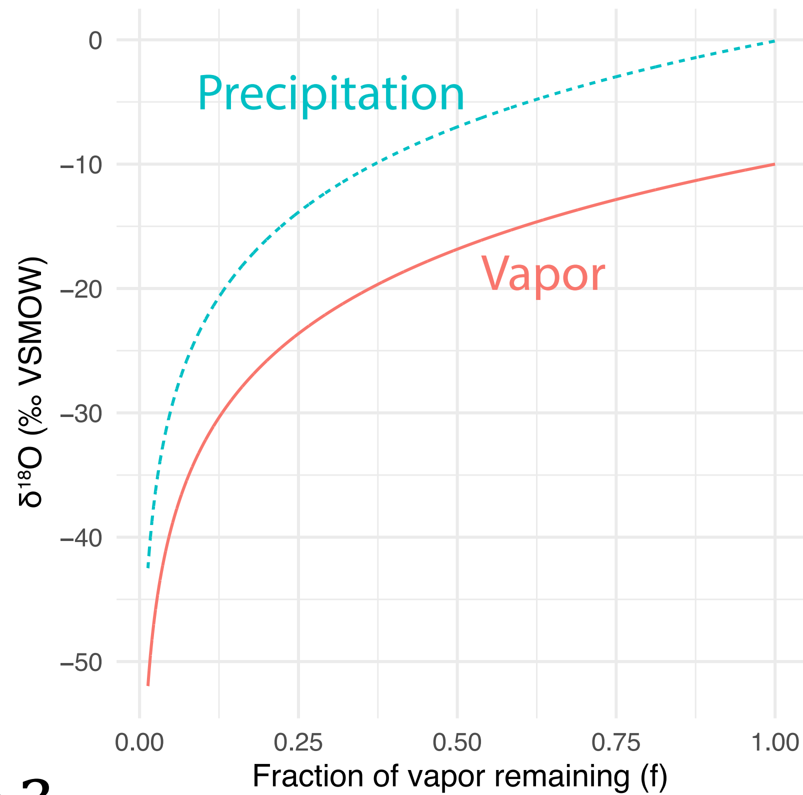
$$\delta = 10^3 \left(\frac{R}{R_{std}} - 1 \right)$$

Rayleigh distillation

Dominant model to explain isotope ratio variability in precipitation, based on idealized open-system condensation

$$R = R_0\left(\frac{q}{q_0}\right)^{\alpha-1}$$

$$\delta = (\delta_0 + 10^3)\left(\frac{q}{q_0}\right)^{\alpha-1} - 10^3$$



How well does Rayleigh distillation explain precipitation isotope ratios?

1950s - ~1990s: “simple” applications of the rainout effect: local temperature (ground or cloud), local precipitation amount (“amount effect”), “continentality” (distance from coast). More data has resulted in more mechanisms:

Lessons learned from oxygen isotopes in modern precipitation applied to interpretation of speleothem records of paleoclimate from eastern Asia

Katherine E. Dayem [a,*], Peter Molnar [a], David S. Battisti [b], Gerard H. Roe [c]

Annual variation in event-scale precipitation δ^2H at Barrow, AK, reflects vapor source region

Annie L. Putman[1,2], Xiahong Feng[1], Leslie J. Sonder[1], and Eric S. Posmentier[1]

Stable isotopes in global precipitation: A unified interpretation based on atmospheric moisture residence time

Pradeep K. Aggarwal,[1] Oleg A. Alduchov,[2] Klaus O. Froehlich,[1] Luis J. Araguas-Araguas,[1] Neil C. Sturchio,[3] and Naoyuki Kurita[1,4]

Patterns of Evaporation and Precipitation Drive Global Isotopic Changes in Atmospheric Moisture

Adriana Bailey[1,2], Eric Posmentier[1], and Xiahong Feng[1]

Spatiotemporal variability of modern precipitation δ^{18}O in the central Andes and implications for paleoclimate and paleoaltimetry estimates

Richard P. Fiorella[1], Christopher J. Poulsen[1], Ramiro S. Pillco Zolá[2], Jason B. Barnes[1,3], Clay R. Tabor[1], and Todd A. Ehlers[4]

Proportions of convective and stratiform precipitation revealed in water isotope ratios

Pradeep K. Aggarwal[1*], Ulrike Romatschke[1], Luis Araguas-Araguas[1], Dagnachew Belachew[1], Frederick J. Longstaffe[2], Peter Berg[3], Courtney Schumacher[4] and Aaron Funk[4]

A moisture budget perspective of the amount effect

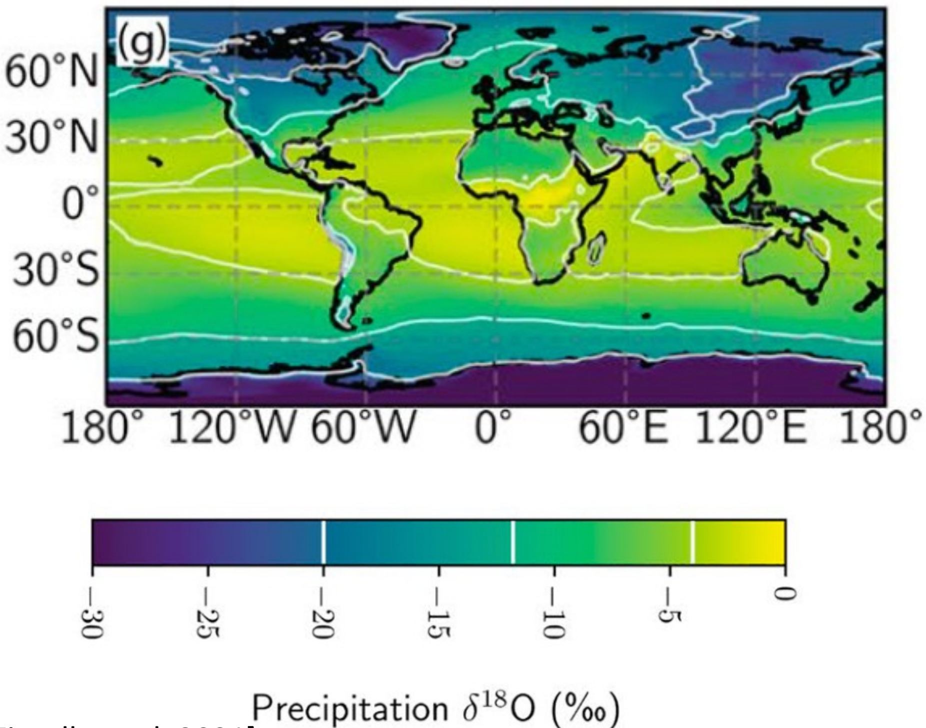
M. Moore[1], Z. Kuang[1,2], and P. N. Blossey[3]

The Influence of Competing Hydroclimate Processes on Stable Isotope Ratios in Tropical Rainfall

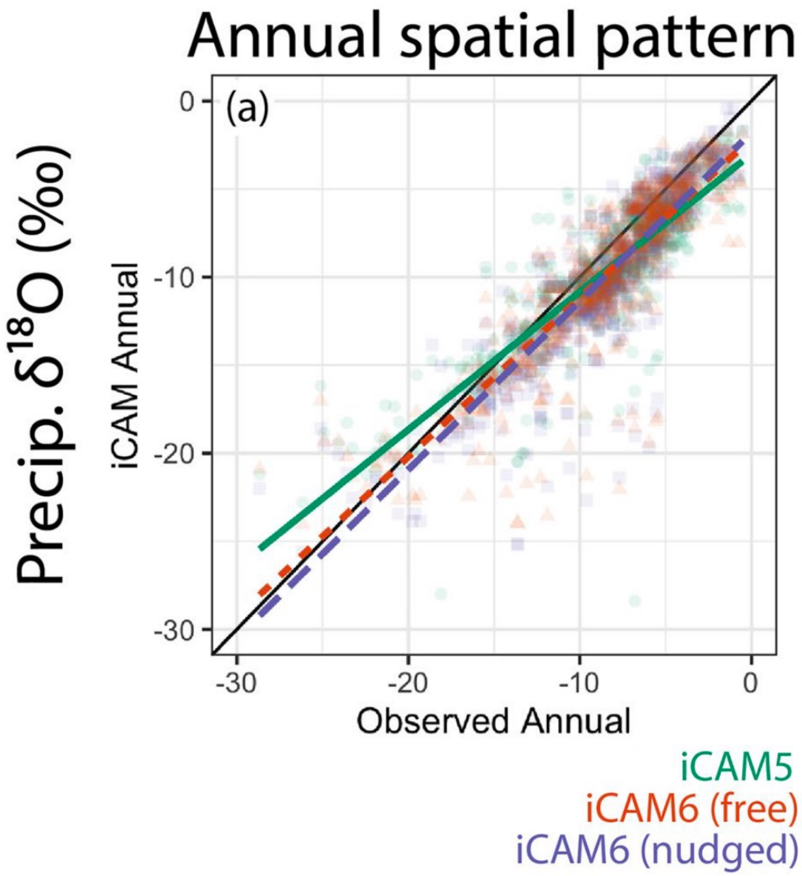
B. L. Konecky[1,2], D. C. Noone[3], and K. M. Cobb[4]

Isotope tracers in Earth system models

CAM6, F compset (atm+lnd), 0.9x1.25°FV,
nudged to ERA5, 1980-2004 mean
[since been extended through 2022]

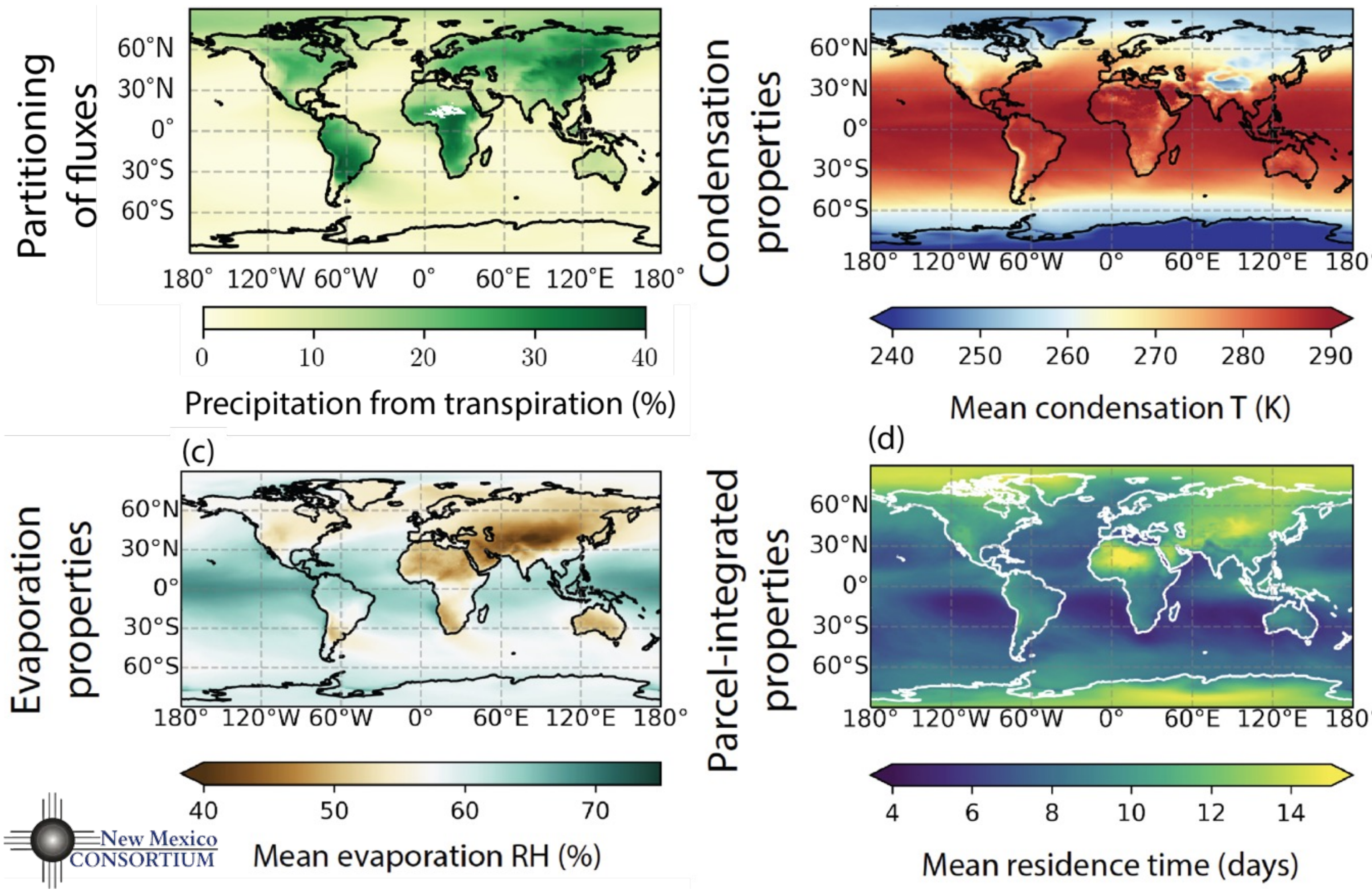


[Fiorella et al. 2021]



Enhanced hypothesis testing and model metrics

Extracting more information on hydrological processes using "process" tracers



What do isotope ratios in precipitation actually tell us?

I won't touch on actual paleoclimate much today, but instead will discuss how these process-tracers could have a lot of power to help with analysis of paleoclimate data and model simulations. Some motivating questions I'll cover today:

1. Lots of recent discussion in literature of "non-Rayleigh" behavior – how well does Rayleigh distillation describe precipitation isotope ratios?
2. Deuterium excess (d-excess, $\delta^2H - 8\delta^{18}O$) is often thought to preserve information (e.g., T or RH) about the evaporative source – what information is actually recorded in d-excess?

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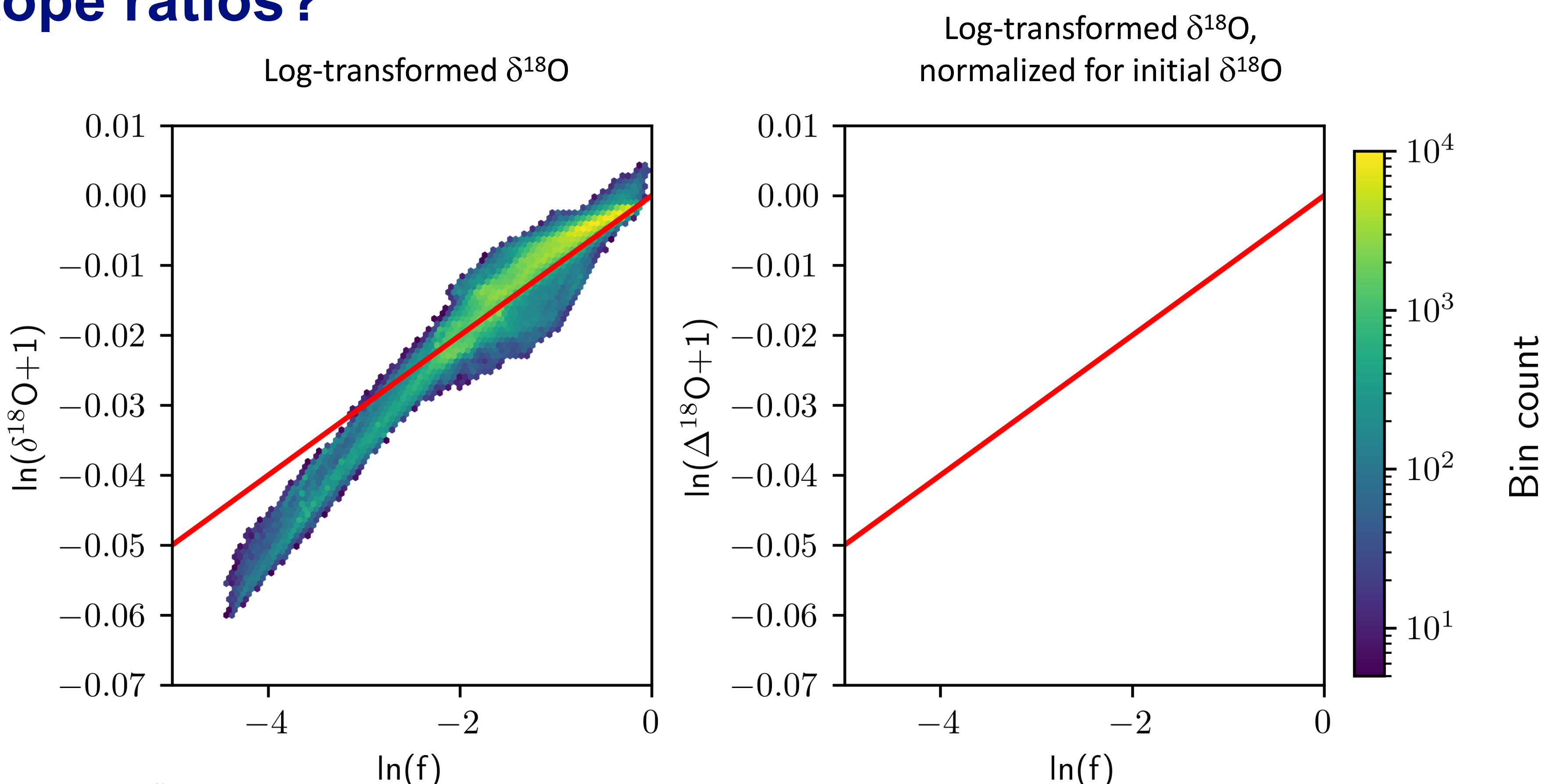
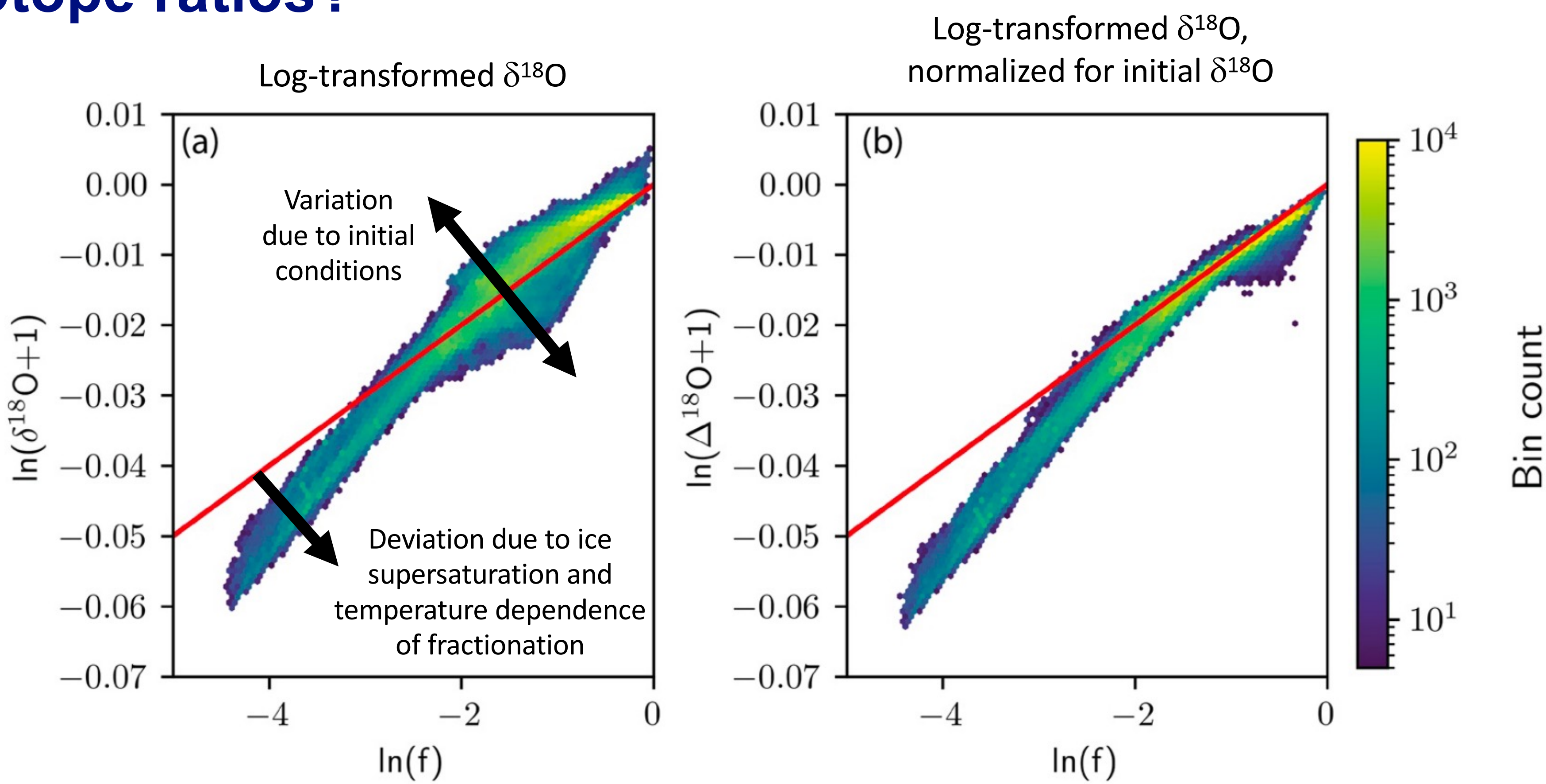
How well does Rayleigh distillation explain precipitation isotope ratios?



$$\ln(\delta + 1) = \ln(\delta_0) + (\alpha - 1)\ln(f)$$

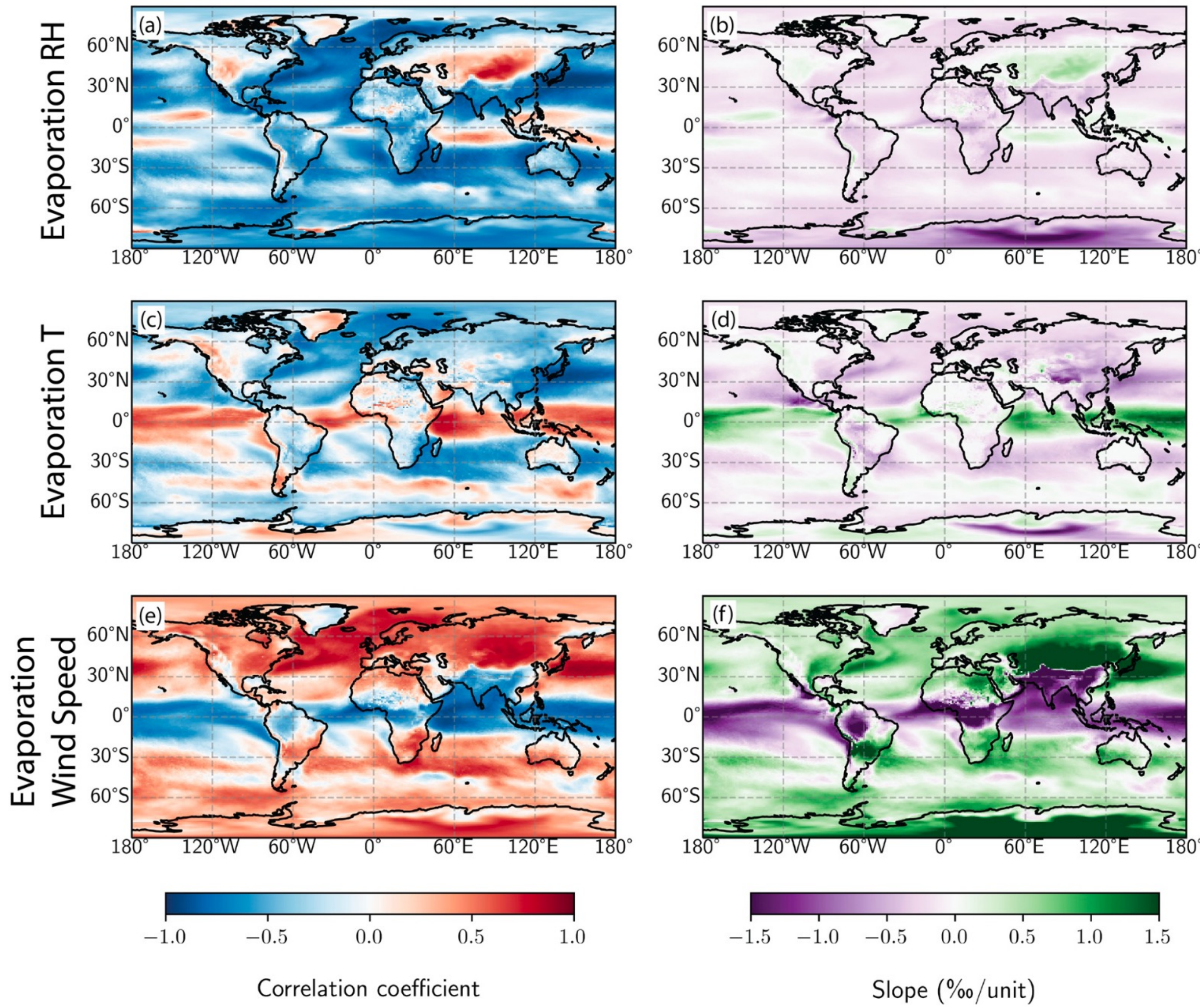
[Fiorella et al. 2021]

How well does Rayleigh distillation explain precipitation isotope ratios?



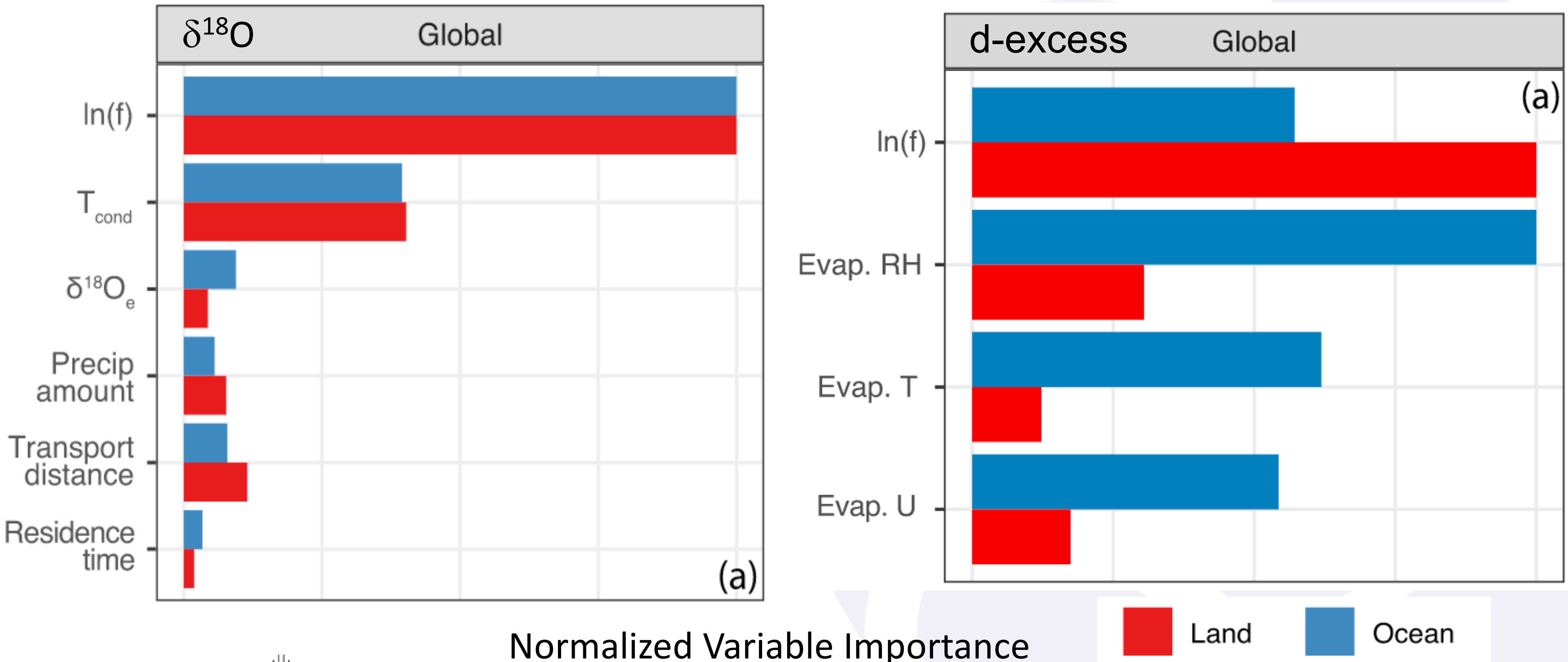
[Fiorella et al. 2021] $\ln(\delta + 1) = \ln(\delta_0) + (\alpha - 1)\ln(f)$

What information does d-excess retain about evaporative conditions?



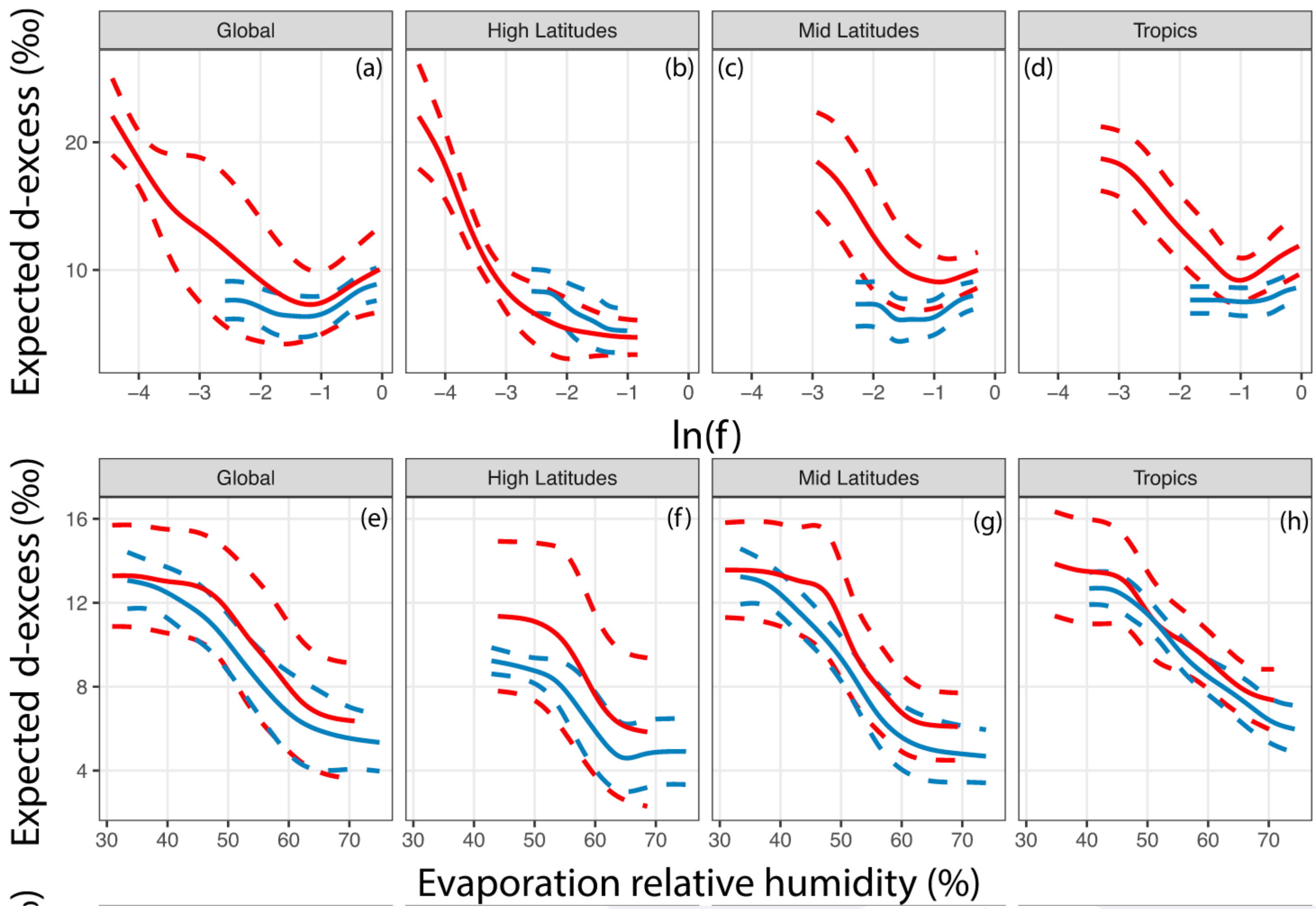
[Fiorella et al. 2021]

New variables for regression/machine learning: how important are different drivers of precipitation $\delta^{18}O$ and d-excess?



[Fiorella et al. 2021]

Partial dependences from ML models



[Fiorella et al. 2021]

A fully-coupled water tracer infrastructure in E3SM (stay tuned)

MATT SIMON SCIENCE OCT 17, 2022 7:00 AM

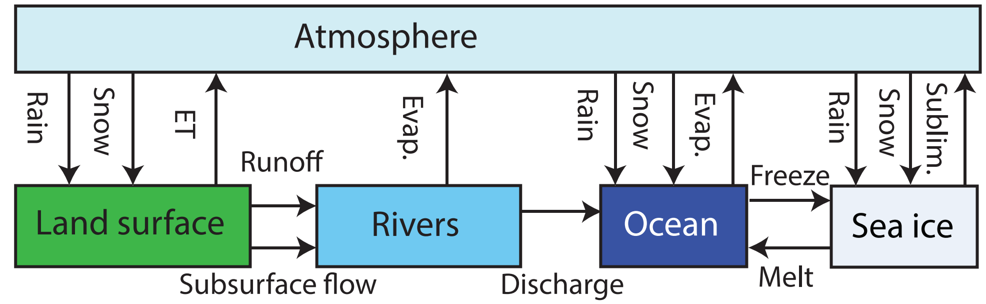
If You Don't Already Live in a Sponge City, You Will Soon

Less pavement and more green spaces help absorb water instead of funneling it all away—a win-win for people and urban ecosystems.

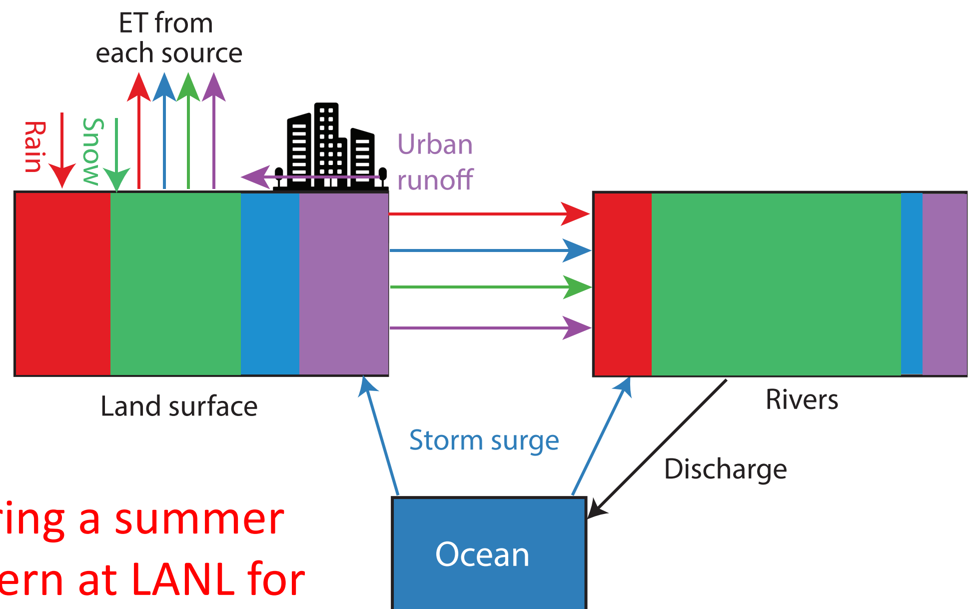
Los Angeles' Tujunga Spreading Grounds collect stormwater and let it percolate into the earth. Such "sponge city" projects are changing urbanites' relationship with water. COURTESY OF LOS ANGELES DEPARTMENT OF WATER AND POWER

[WIRED Magazine]

Current ESMs



Water tracers and isotope ratios for process tracking (example using only land surface, rivers, and ocean for clarity)



Will be hiring a summer student intern at LANL for this project!

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Acknowledgments

Collaborators: David Noone (U. Auckland), Nick Siler (OSU), Jesse Nusbaumer (NCAR); summer students: Dianne Deauna and Christopher Grover

(Stay tuned for some new work led by Nick Siler, Sophia Macarewich, and Tyler Kukla)

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