The Role of Diurnal Hysteresis between Near-surface Temperature and Relative Humidity on Mitigating Near-surface Atmospheric Dryness

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HydroClimatology Group

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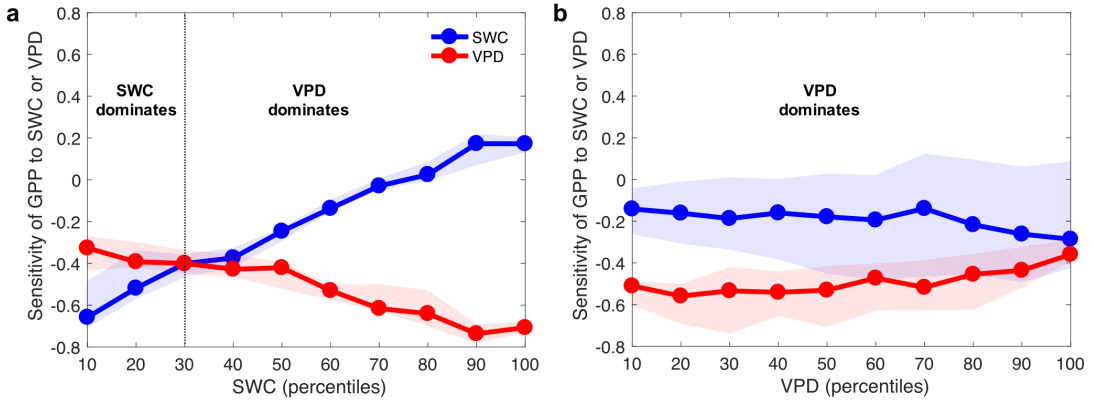
Introduction

Atmospheric Dryness

$$VPD = e_s - e_a$$

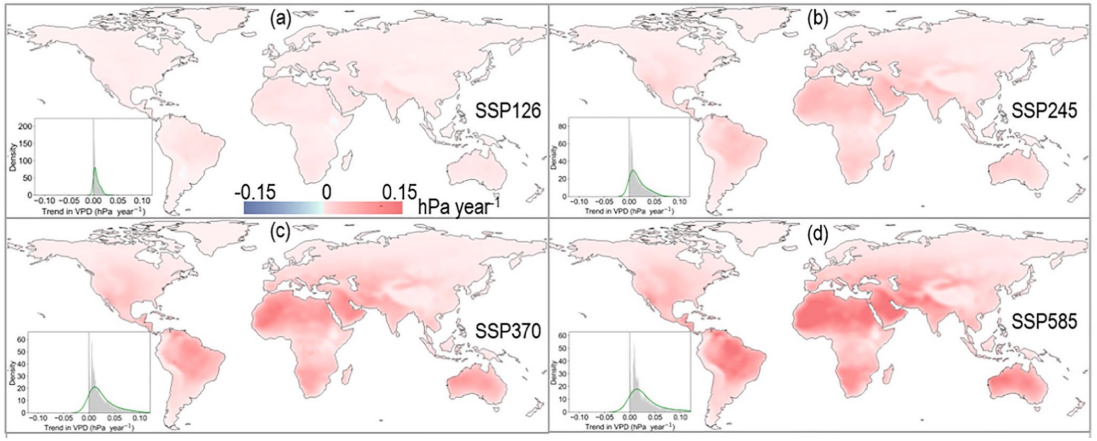
- Atmosphere dryness may exhibit a larger influence on ET and ecosystem production efficiency than soil dryness

  (Fu et al., 2022; Green et al., 2020)



Fu et al., 2022

- VPD has been observed to increase across all climatic zones in the 21st century, potentially exacerbating risks to terrestrial ecosystems (Fang et al., 2022; Ficklin & Novick, 2017)



Fang et al., 2022

$$VPD = e_s - e_a = e_s(T)\left[1 - \frac{RH}{100}\right]$$

Introduction

Diurnal Cycle of T and RH

$$VPD = e_s - e_a$$

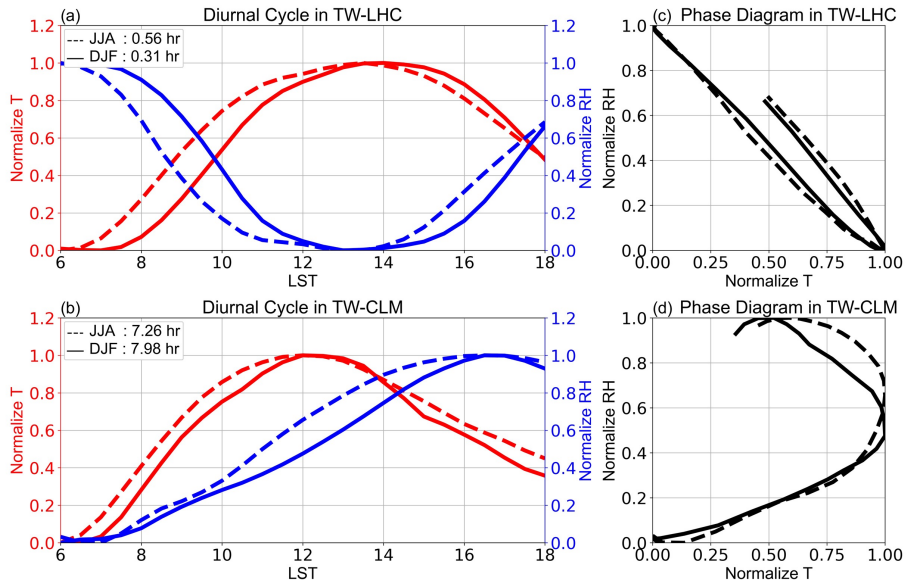
- It is widely accepted that diurnal surface temperature and relative humidity variations are inversely locked in phase

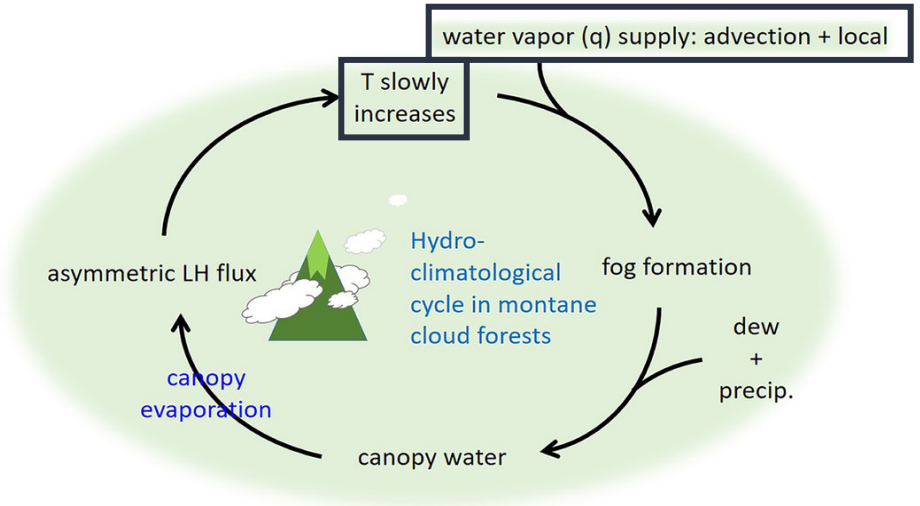
  (Dai et al., 2023)

- The out-of-phase diurnal characteristic between temperature and relative humidity can be found in some regional studies

  (Gu et al., 2021)

- Daily VPD is often underestimated due to the non-linear relationship between saturated vapor pressure and temperature



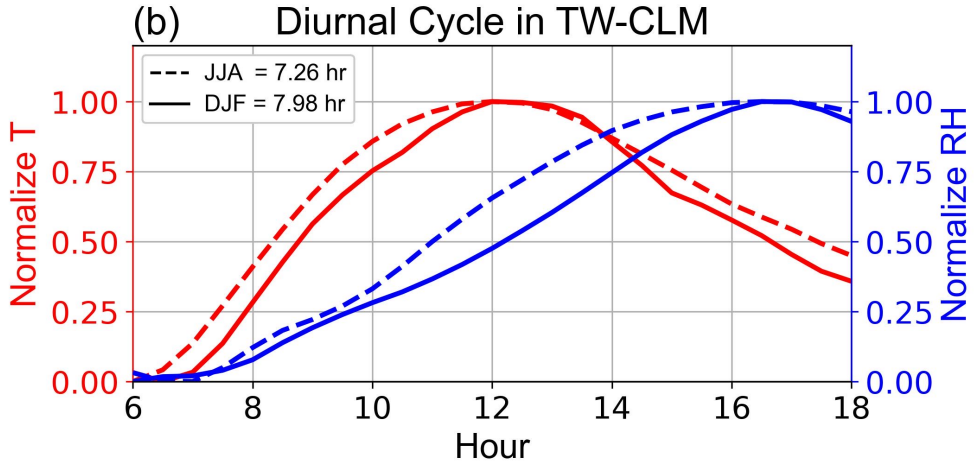


Gu et al., 2021

Introduction

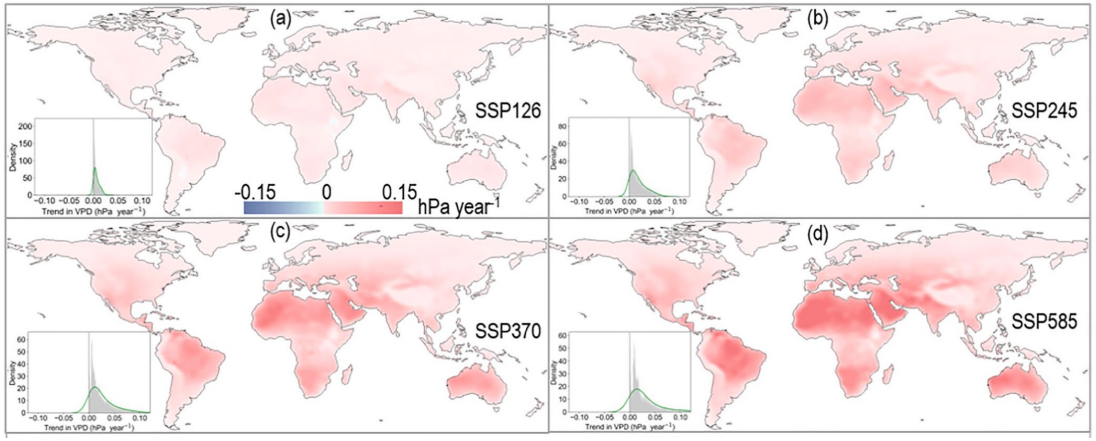
Knowledge Gap

- The diurnal hysteresis between T and RH have not been examined at a global scale



Objective

- Systematically investigate the regions exhibiting diurnal hysteresis between T and RH worldwide
  - The presence at a global scale
  - The impact of diurnal hysteresis on local microclimate
  - The potential change of diurnal hysteresis under global warming

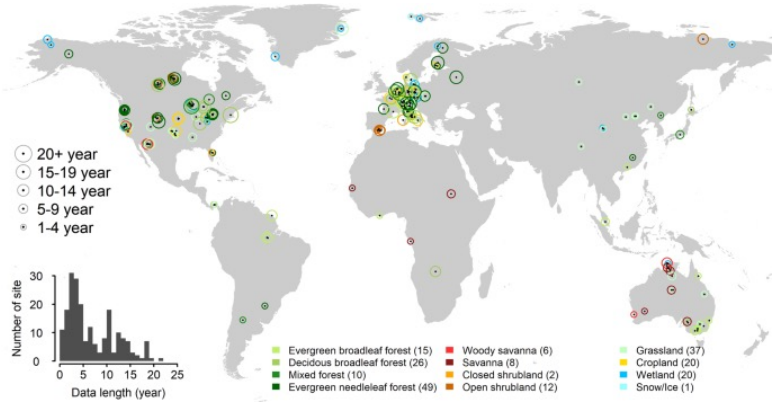


Fang et al., 2022

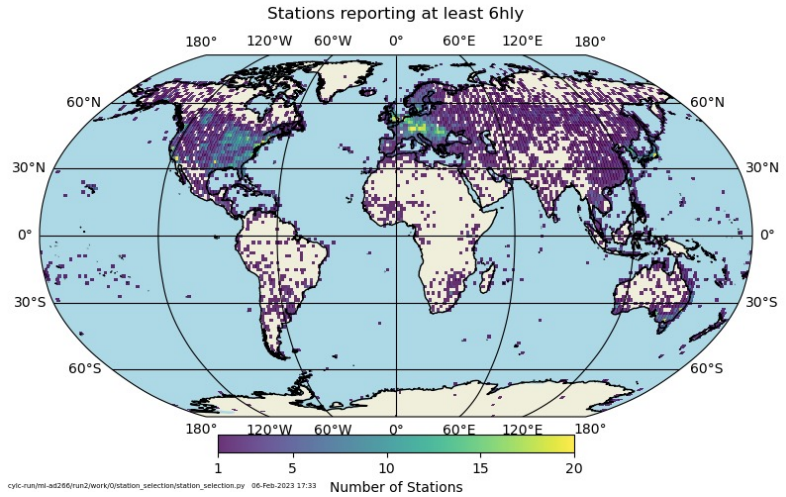
Methodology – Data

Observations

- Flux towers
  - Taiwan Flux tower (Gu et al., 2021): 2 sites
  - FLUXNET2015 (Pastorello et al., 2020): 194 sites
- Surface weather stations
  - HadISD (Pastorello et al., 2020): 4244 sites



Pastorello et al., 2020

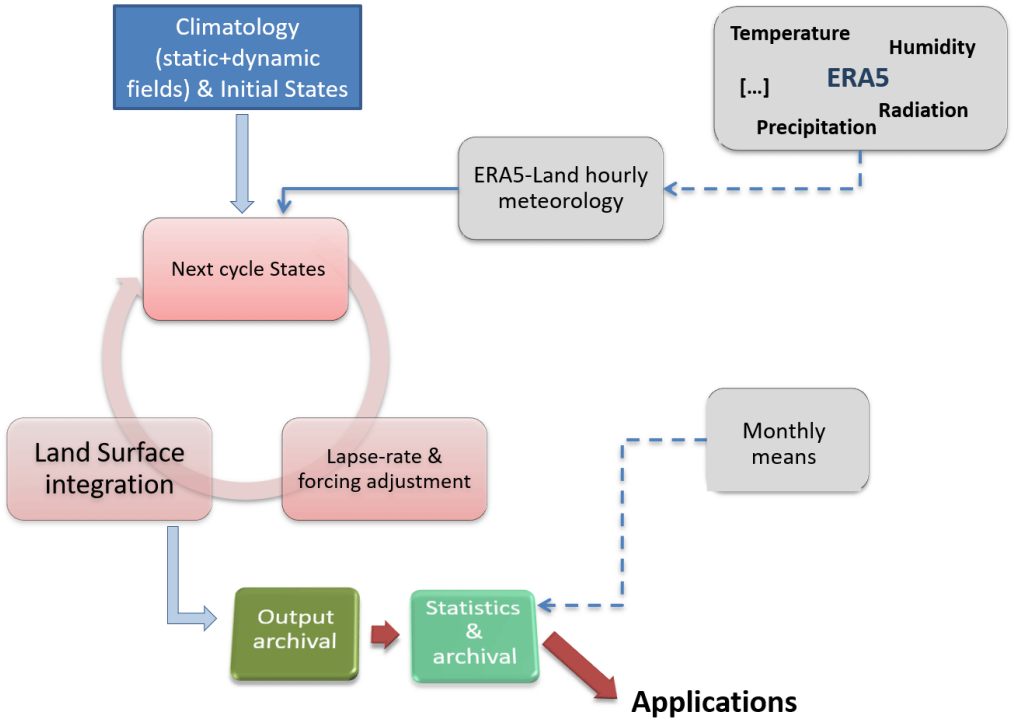


Dunn et al., 2019

Methodology – Data

ERA5-Land

- Temporal resolution: hourly
- Spatial resolution: 0.1º (9 km)
- Seasonal-averaged diurnal cycle in boreal summer (JJA) and winter (DJF) from 1951 to 2020



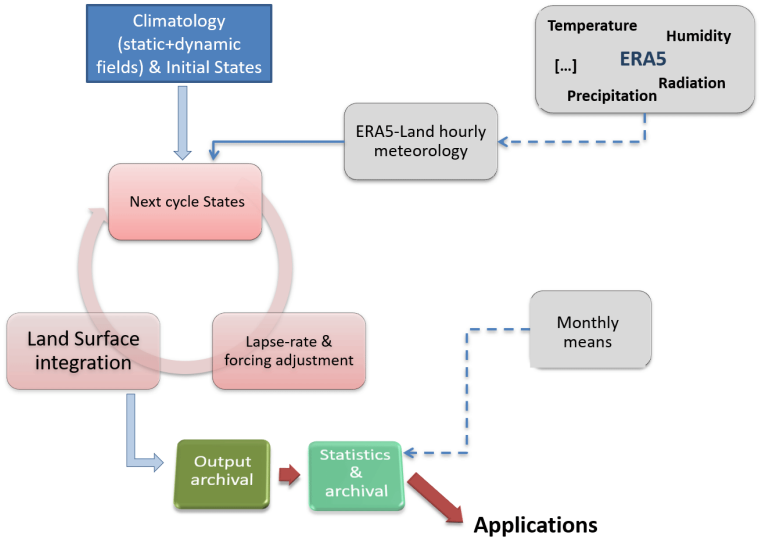
Muñoz-Sabater et al., 2021

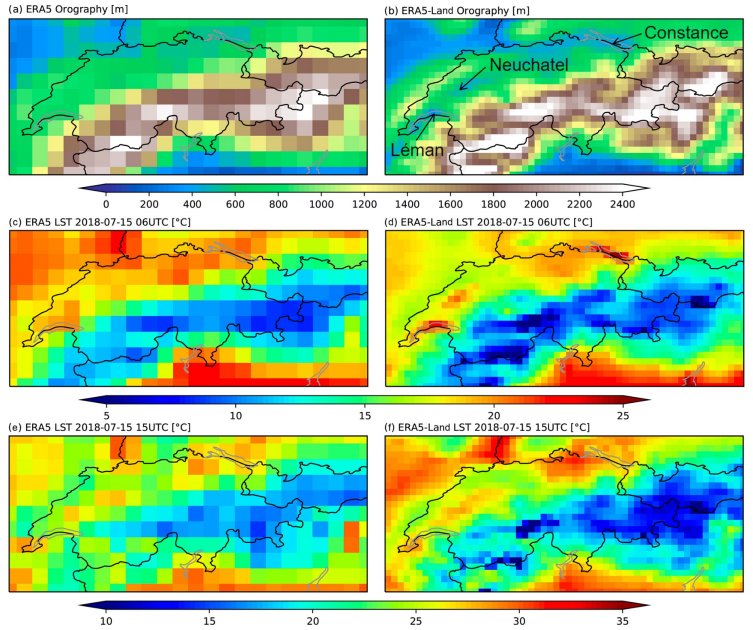
Methodology – Data

ERA5-Land

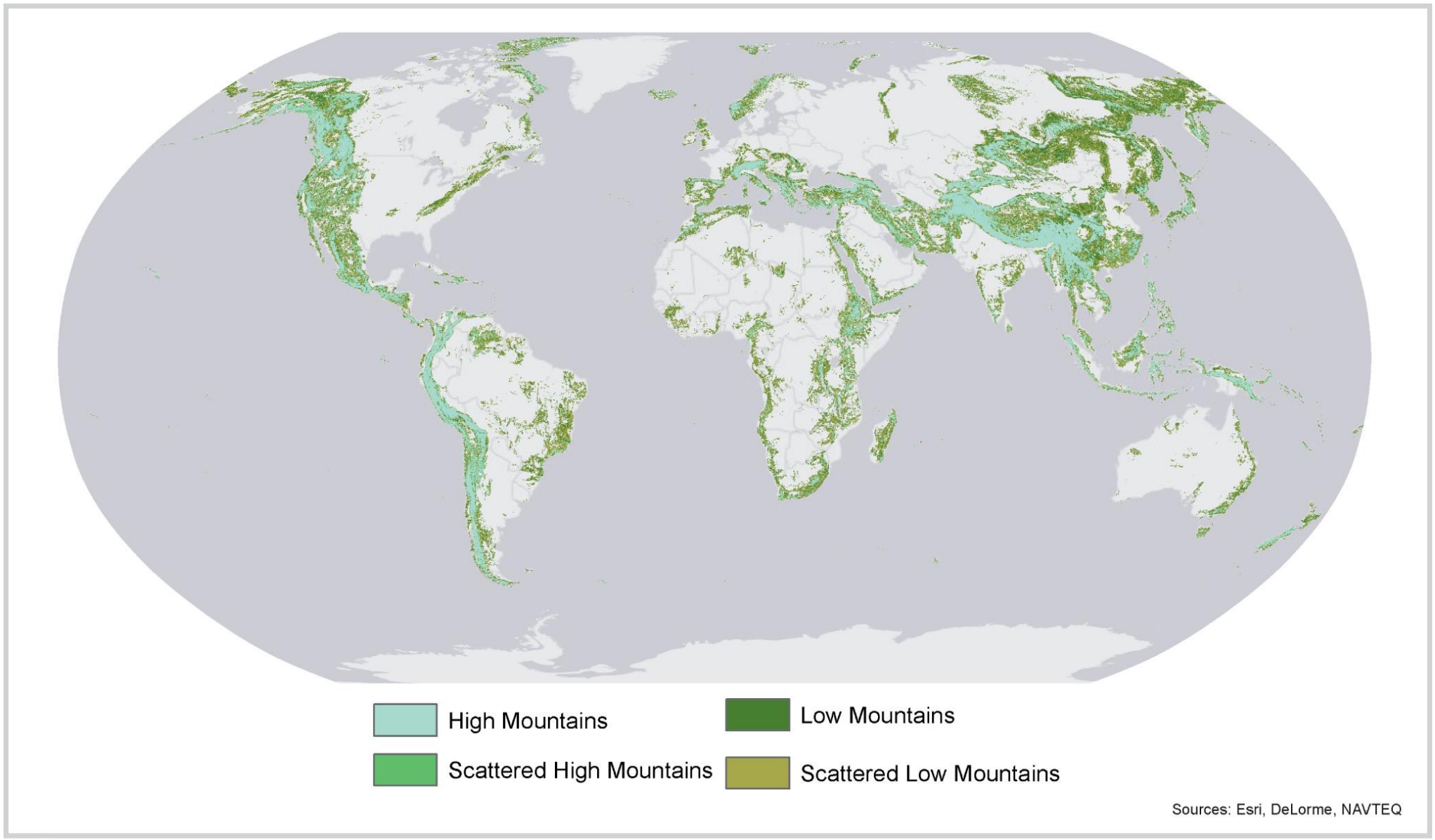
- CHTESSEL(ECMWF land surface model) is driven by
  - Meteorology state: T, Q, WS, P in ERA5 model level 137
  - Flux fields: downward SW and LW, rainfall

- Meteorology state is processed by:
  - T, Q, WS, P is linearly interpolated to 9 km
  - T is adjusted for altitude differences by ELR (Dutra et al., 2020)
  - P is corrected by altitude difference and corrected T
  - Q is corrected by corrected T and P





Mountain Distribution (Sayre et al., 2023)



Methodology – Metrics

Phase Shift Analysis

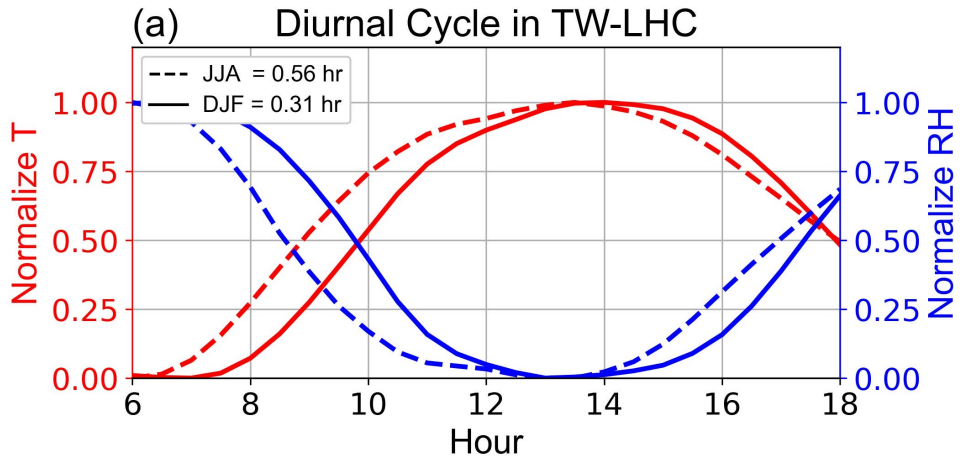
- Use multi-linear regression with the Camuffo-Bernardi equation to obtain a quantitative measure of the hysteretic pattern between diurnal cycles in daytime (6 a.m.-6 p.m.)

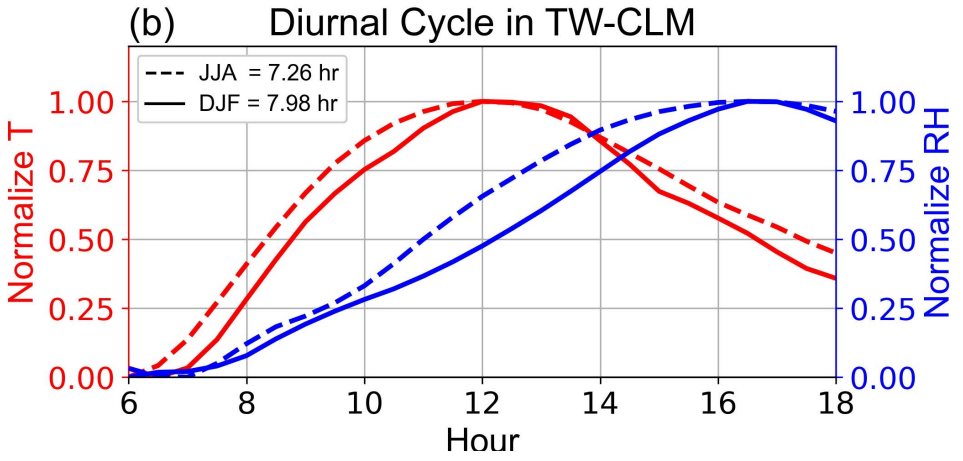
$$RH(t) = \beta_0 + \beta_1 T(t) + \beta_2 \frac{dT(t)}{dt} + \epsilon(t)$$

- The phase lag between T and RH can be estimated by:

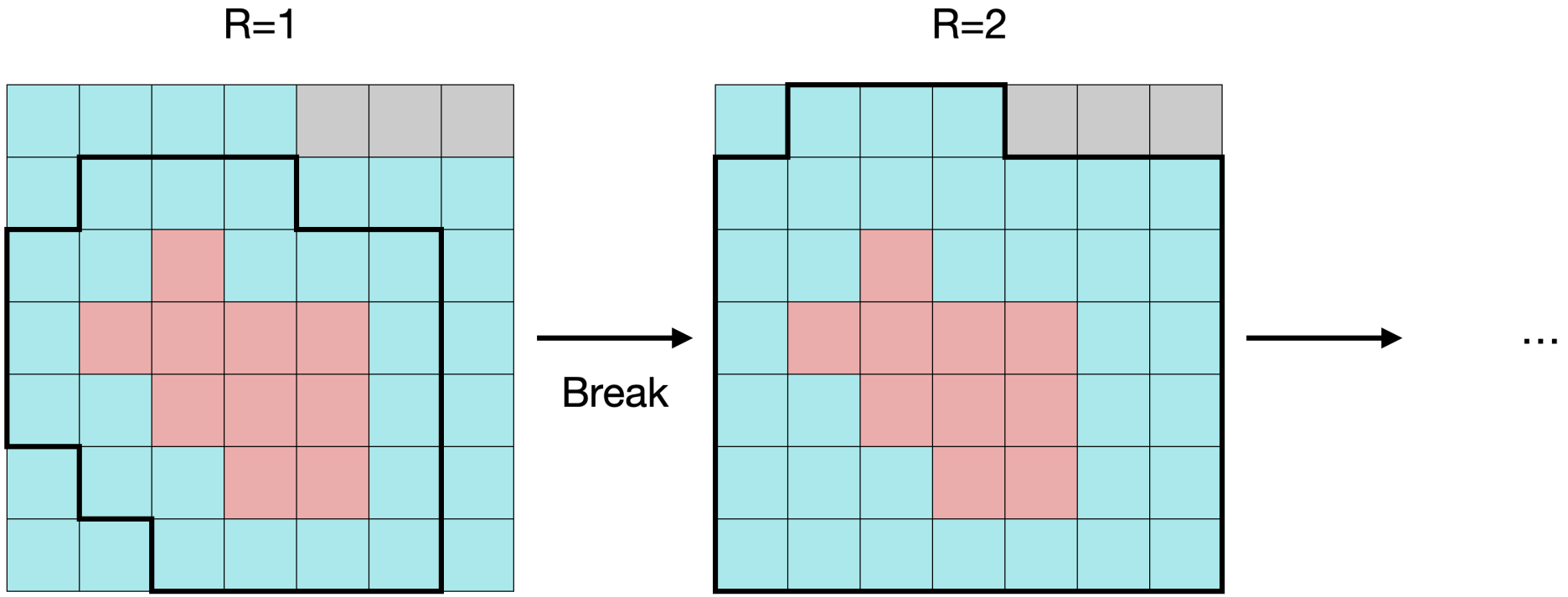
$$t_{lag} = \tan^{-1}\left(\frac{2\pi}{n_d}\frac{\beta_2}{\beta_1}\right)\frac{24}{2\pi}$$

- Diurnal hysteresis is defined as $t_{lag} \geq 1\ hr$, where RH(t) is lead to T(t) more than one hour





Methodology – Ways to find adjacent area

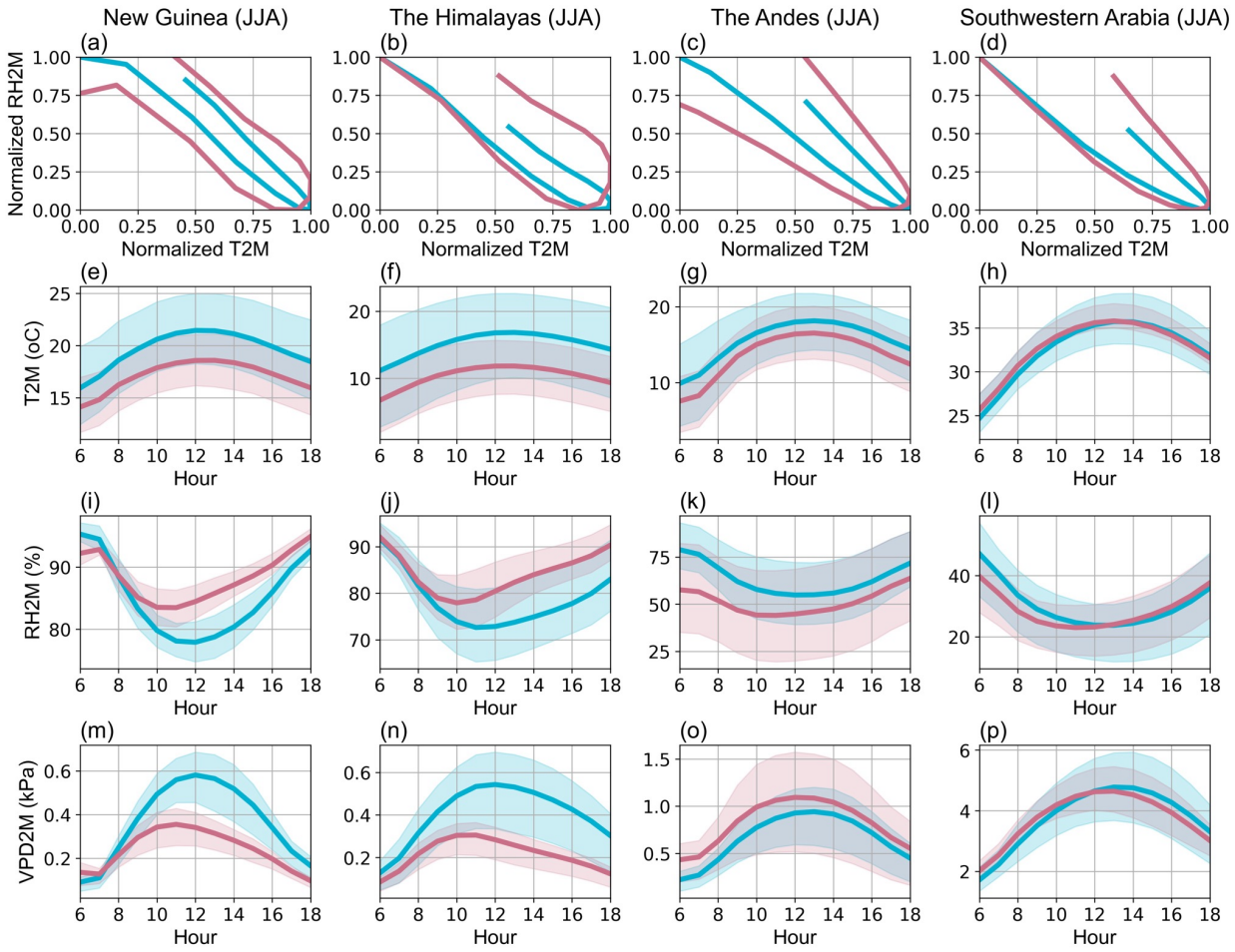


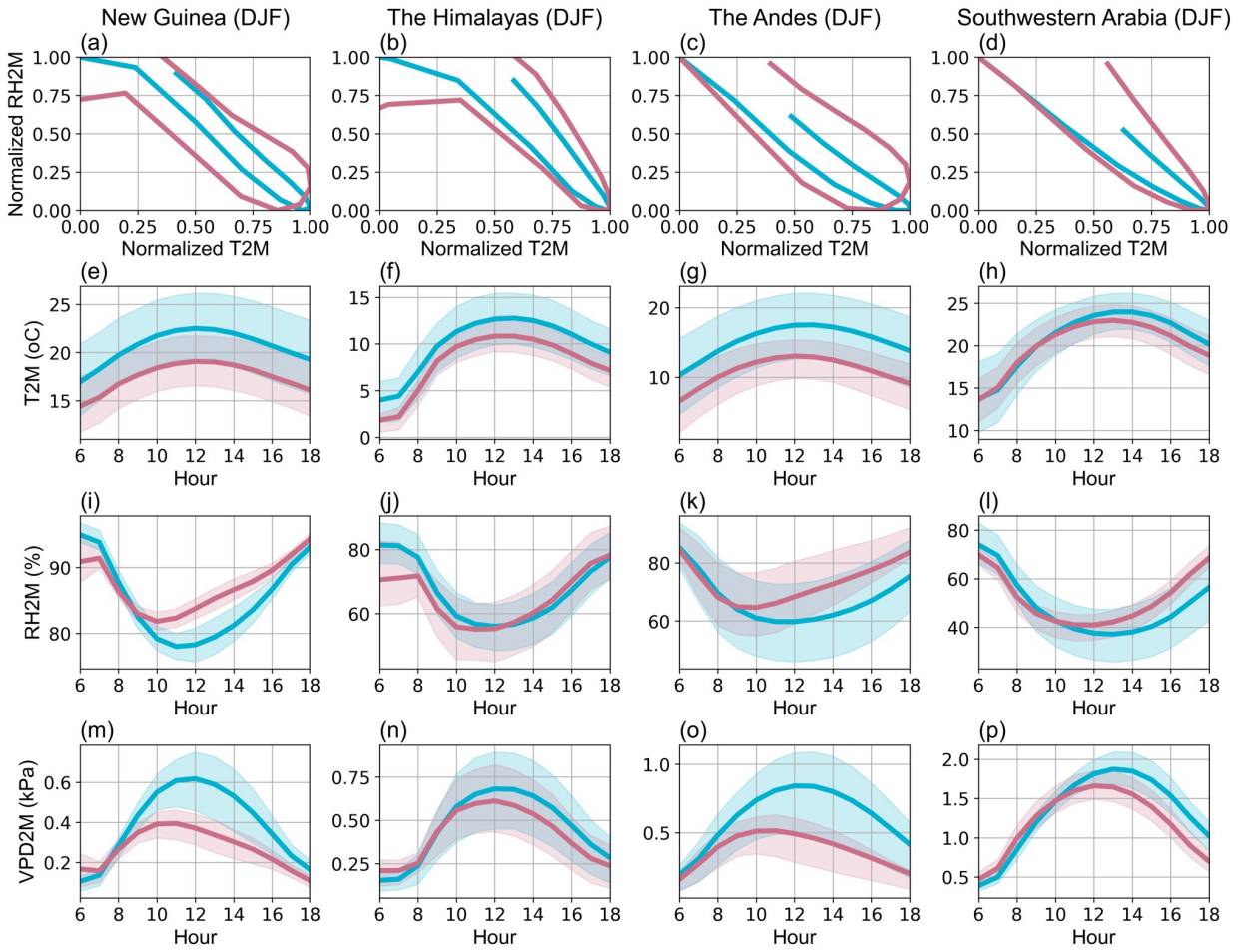
	R=1	R=2	R=...
Lag>1hr	10	10	...
Lag<1hr	20	35	...

Result 2: Microclimate

Diurnal Cycle

- Diurnal hysteresis between T and RH leads to a unified effect in mitigating vapor pressure deficit (VPD)

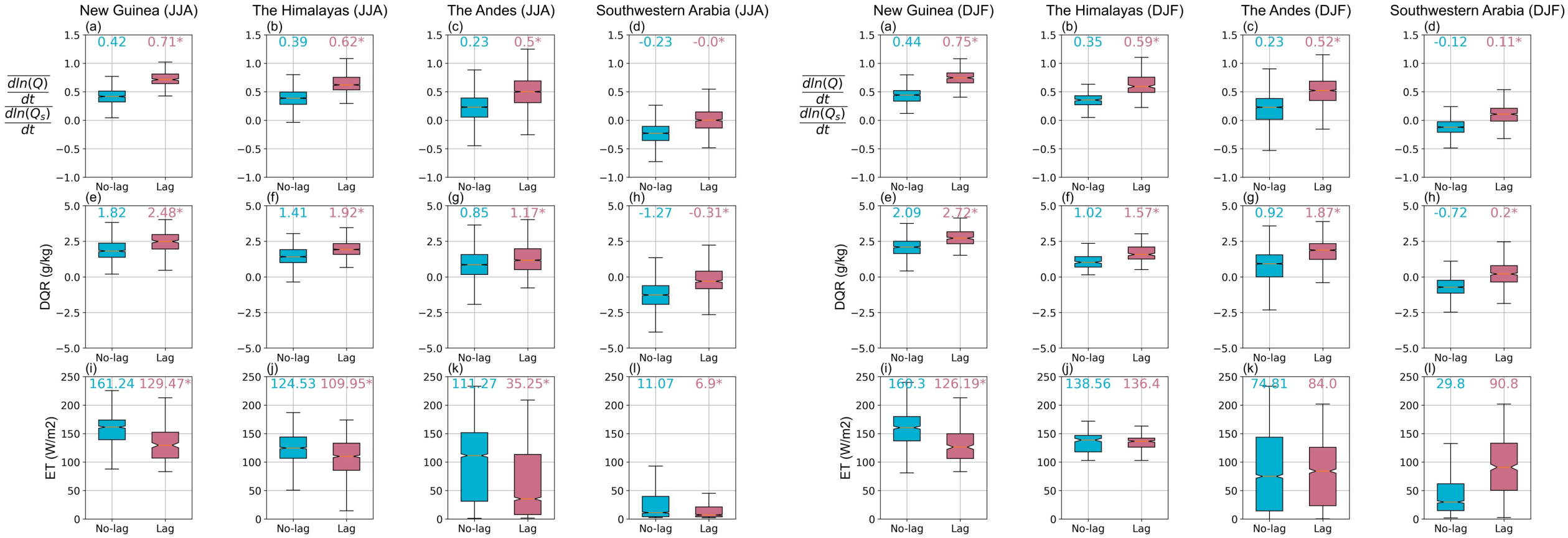




Result 2: Microclimate

Budget Analysis

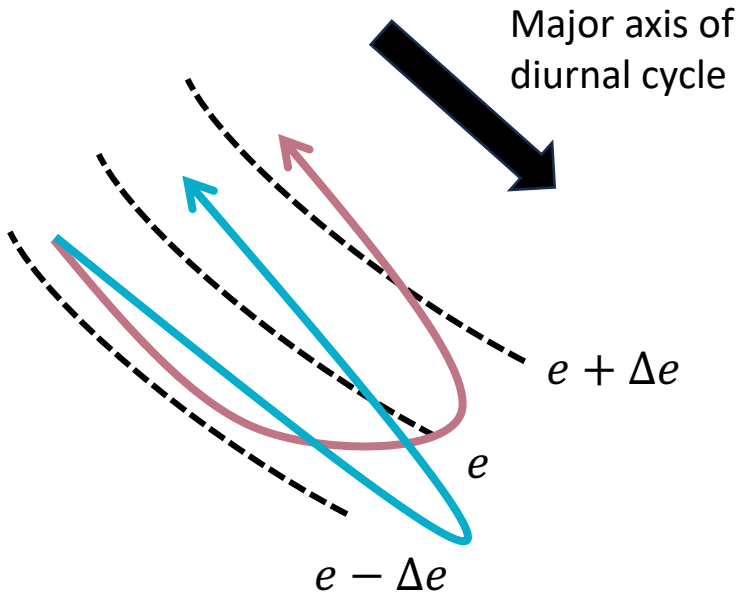
- Non-local water vapor plays an important role on formulating diurnal hysteresis

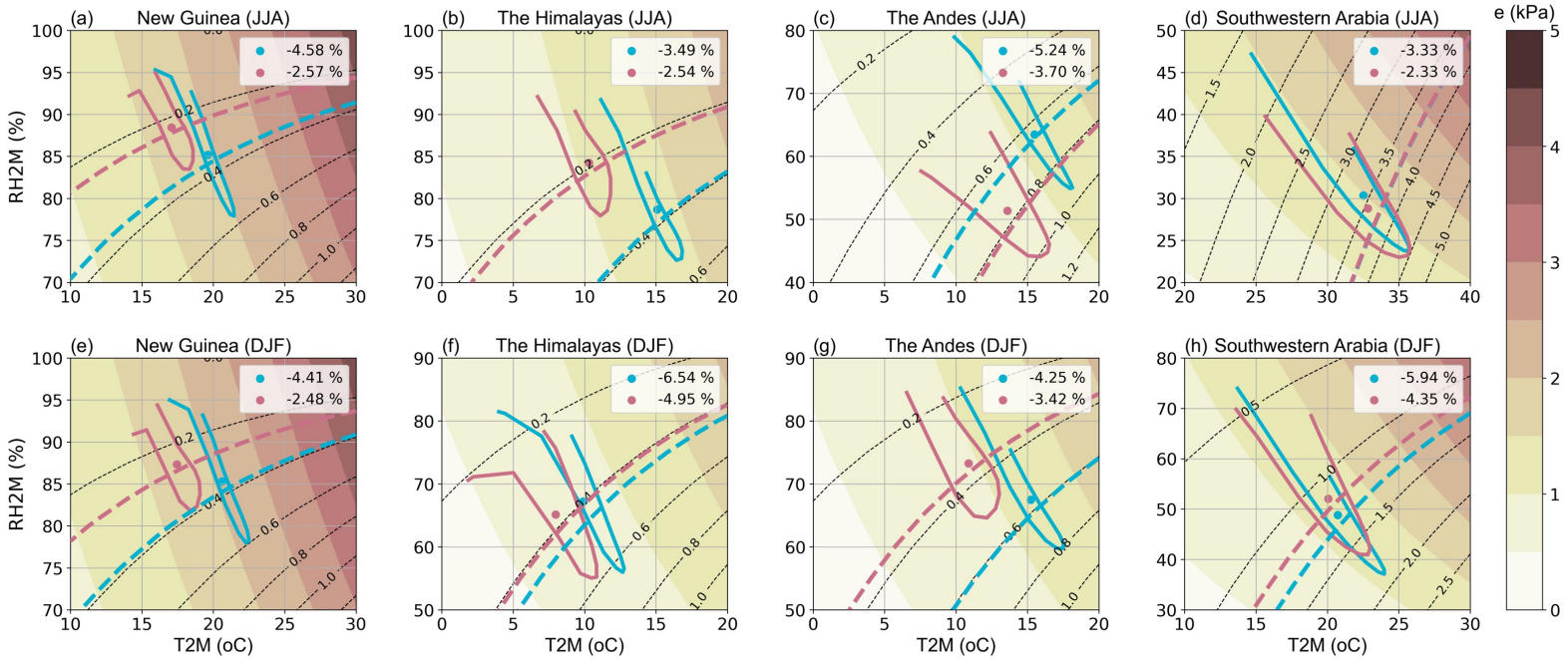


Result 2: Microclimate

Diurnal Phase Diagram

- For regions exhibiting diurnal hysteresis
  - Larger width of hysteretic loop
  - Higher vapor pressure range
  - Less underestimation of daily VPD due to mitigation effect





Result 2: Microclimate

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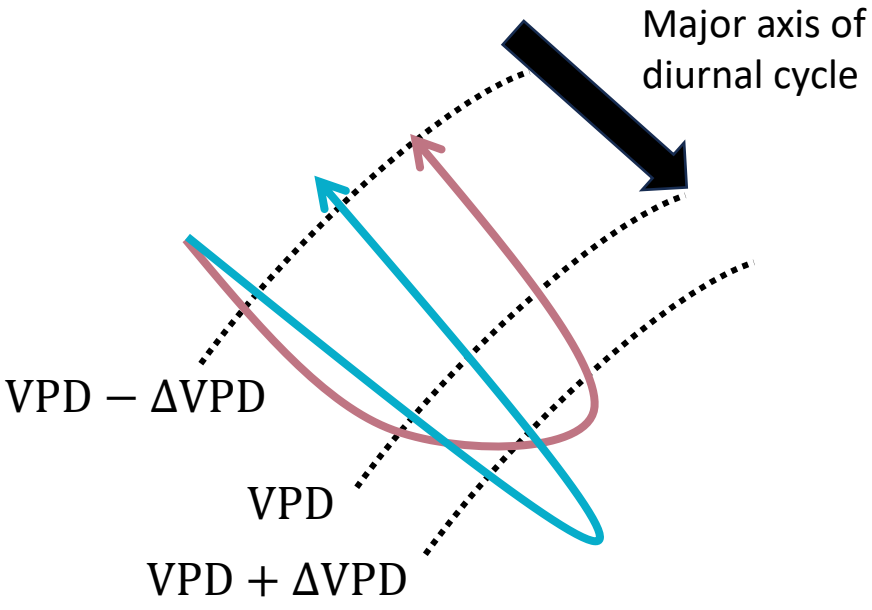
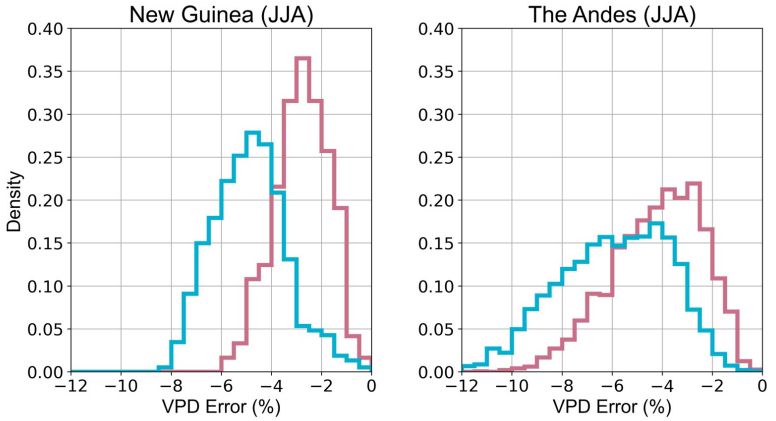
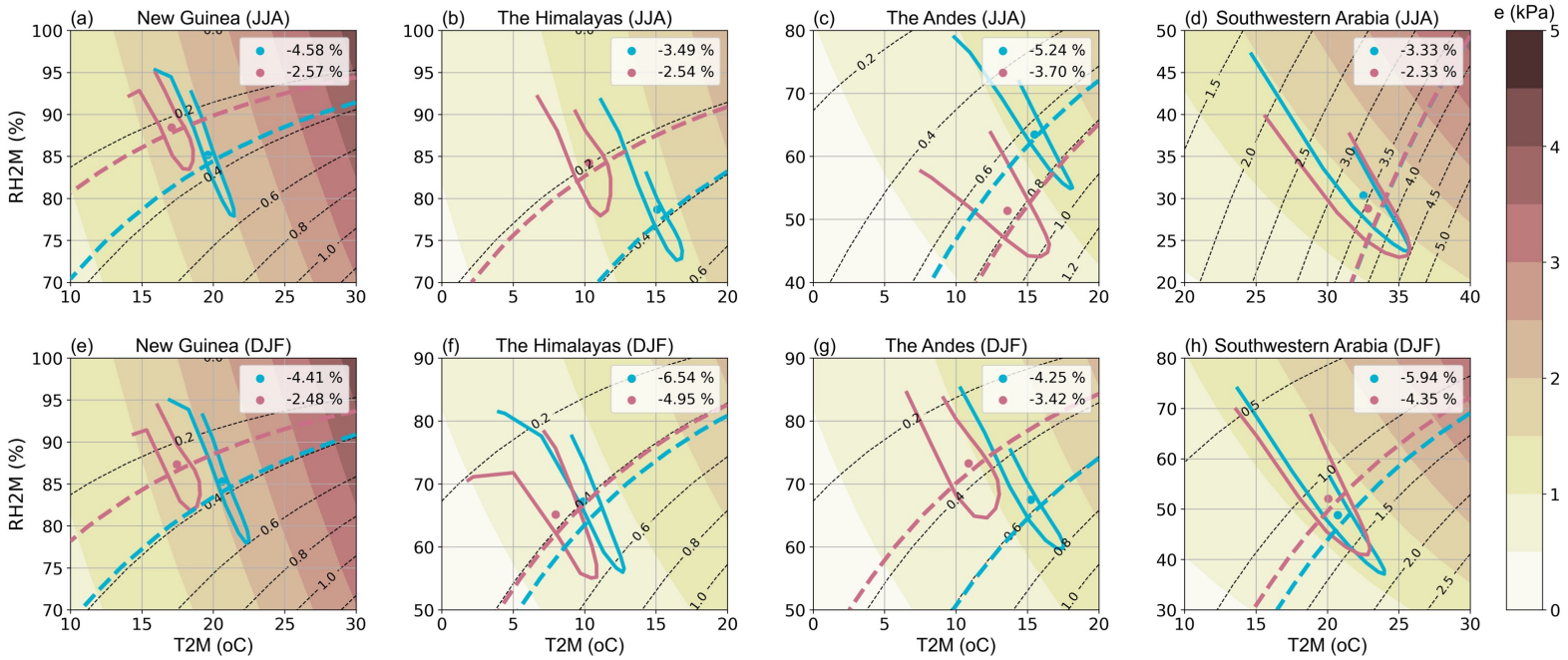






Result 3: Global Warming

ERA5-Land 70 years trend

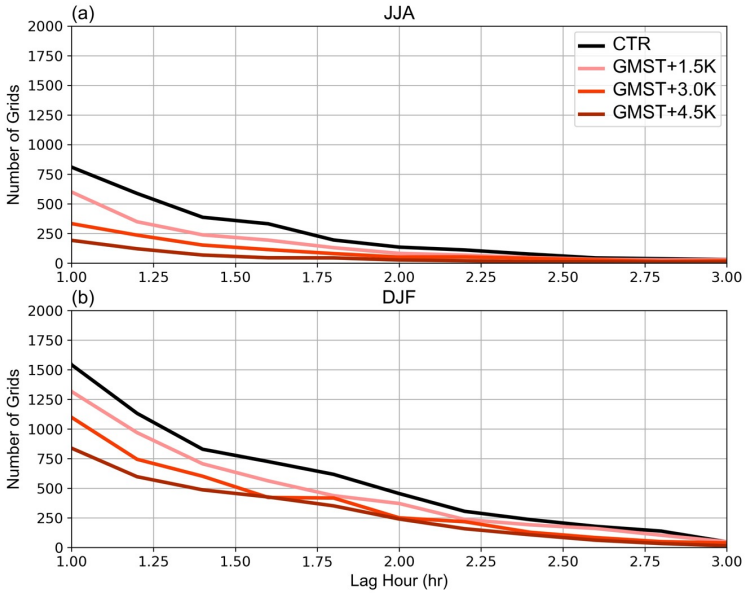
- More than 100 m/70yr increased trend in the elevation was found in the Andes (JJA/DJF), the Himalayas (JJA) and New Guinea (DJF)
- The hysteretic relationship has a significantly decreased trend in the Andes and southwestern Arabia

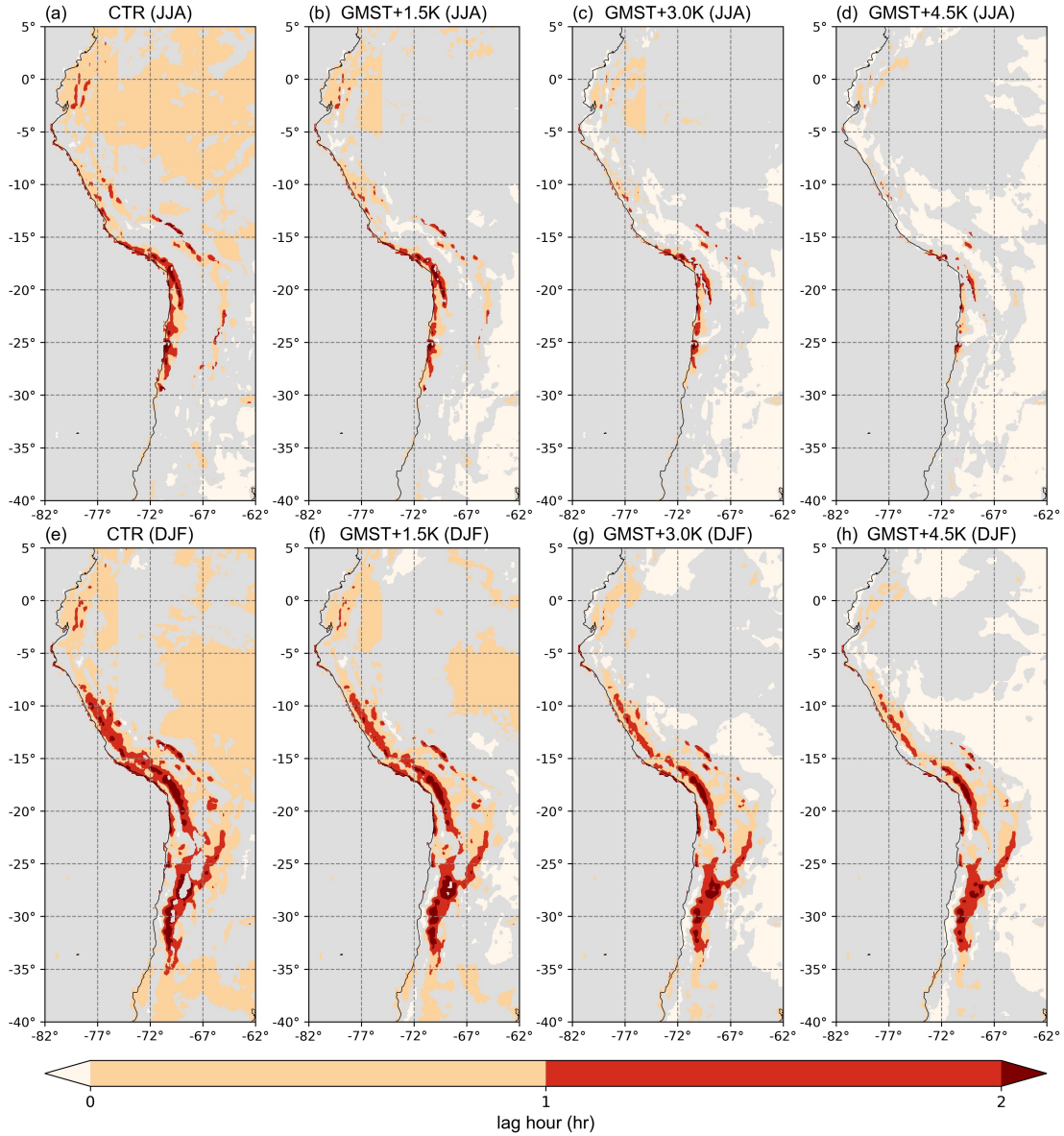
→ Apply pseudo global warming (PGW) approach on the Andes was utilized for the analysis under global warming

Result 3: Global Warming

Under Global Warming

- The number of grids exhibiting diurnal hysteresis decreases as warming intensifies





Future Work and Take Home Message

Future Work

- Quantify the role of diurnal VPD variations due to mitigation effect in affecting evapotranspiration and L-A interactions in different regions
- Investigate the response of the diurnal hysteresis of temperature and relative humidity due to natural variability and anthropogenic forcings

Take Home Message

- Diurnal hysteretic relationship is expected to diminish under global warming, which potentially exacerbate risks to terrestrial ecosystems

Thank You!