LPICEA | Lab of Plant Interactions: Climate, Ecosystem & Atmosphere

Department of Earth System Science | Tsinghua University

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# The coordination between hydraulic and photosynthetic traits

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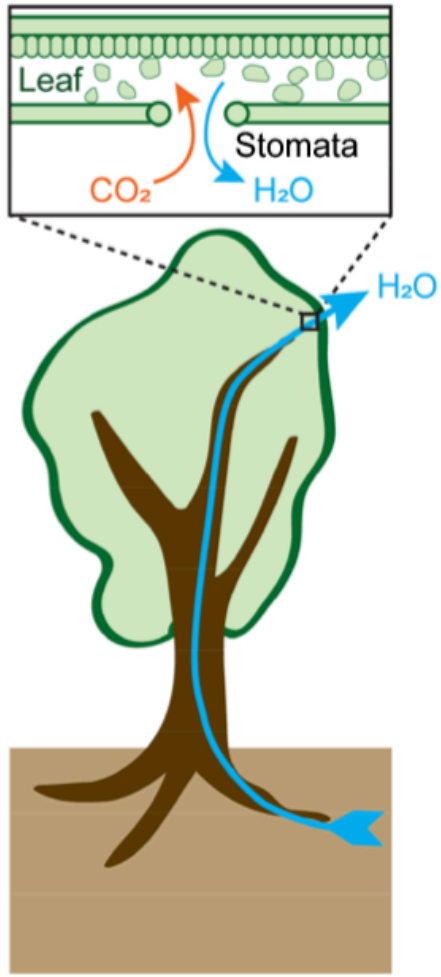
# Plant hydraulics tightly coordinated with photosynthesis

- Photosynthesis is constrained by hydraulics because water transported through the xylem must replenish water lost through stomata during $CO_2$ uptake
- A tight coordination between hydraulic and photosynthetic traits observed in the field (Scoffoni et al. 2016; Zhu et al. 2018)
- However, this coordination is not fully understood

*How do hydraulic and photosynthetic traits coordinate **quantitively***

- Quantitive understanding could remove a large source of uncertainty in models especially under drought




(Anderegg and Venturas 2020)

# Theory to connect hydraulic and photosynthetic traits

Under optimal condition

When transpiration (E, mol $m^{-2}$ $s^{-1}$) reaches maximum, water loss through stomata should equal water transport through xylem to balance water demand and supply

## Water supply (Darcy's law)

$$E = K_S \, \Delta\Psi_{max} \, SA \, \rho_w / (LA \, h) = \boldsymbol{v_H \, K_S \, \Delta\Psi_{max} \, \rho_w / h}$$

- $K_S$ (kg $s^{-1}$ $m^{-1}$ $MPa^{-1}$): sapwood conductivity
- $\Delta\Psi_{max}$ (MPa): the maximum difference between leaf and soil water potential
- $h$ (m): path length, approximately equal to plant height
- LA ($m^2$): leaf area
- SA ($m^2$): sapwood area
- $\rho_w$ (kg $m^{-3}$): water density
- $v_H$ (Huber Value): sapwood to leaf area ratio

## Water demand

$$E = 1.6 \, g_s \, D \,, \; g_s = A / [c_a(1 - \chi)]$$ (Fick's law)

$$A = m_C \, V_{cmax} \,, \; m_C = (c_i - \Gamma^*)/(c_i + K)$$ (Farquhar et al. 1980)

- $g_s$ is stomatal conductance (to $CO_2$)
- $D$ is leaf-to-air vapour pressure deficit (vpd)
- A is the assimilation (photosynthesis) rate
- $c_a$ is the ambient partial pressure of $CO_2$
- $\chi = c_i/c_a$
- $c_i$ is the leaf-internal partial pressure of $CO_2$.
- $\Gamma^*$ is the photorespiratory compensation point
- K is the effective Michaelis-Menten coefficient of Rubisco
- $V_{cmax}$ is the maximum carboxylation capacity

$$\ln v_H = \underbrace{\ln D - \ln c_a}_{\text{environment}} + \underbrace{\ln m_C + \ln V_{cmax} - \ln (1 - \chi)}_{\text{photosynthesis}} - \underbrace{\ln K_S - \ln \Delta\Psi_{max}}_{\text{hydraulics}} + \ln h$$

# Traits collection in Gongga Mountain, China

11 sites, 176 samples, 107 species
3000-m elevational transect

**Hydraulic traits:**

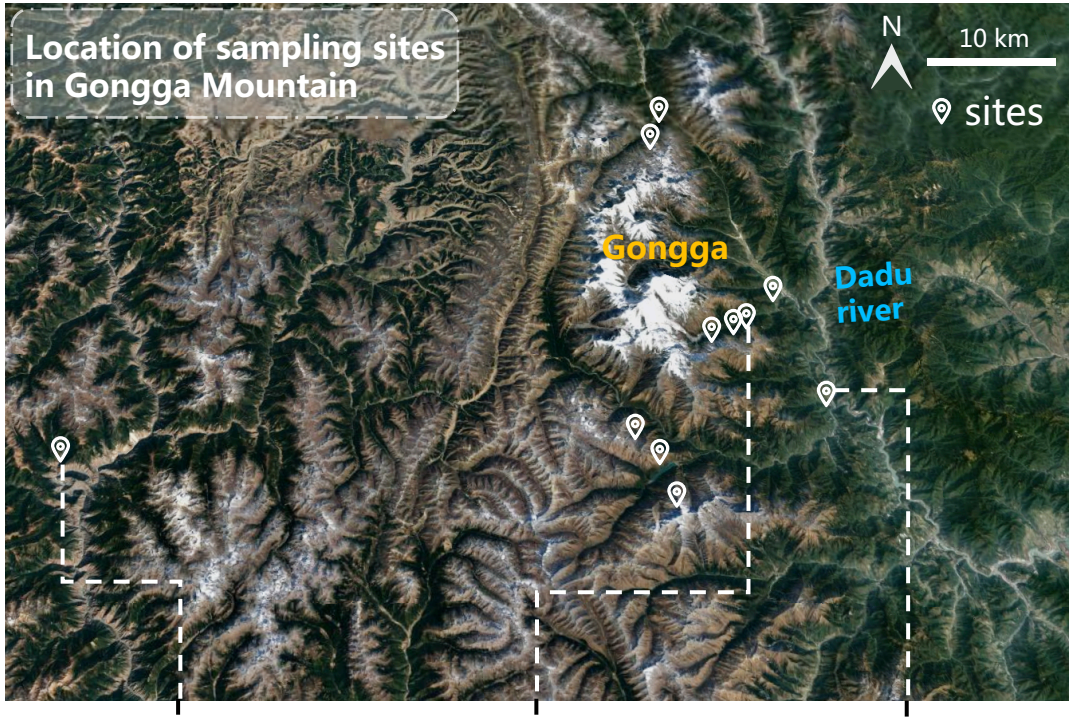
- $K_S$: sapwood conductivity
- $\Psi_{tlp}$: turgor loss point
- WD: wood density
- $v_H$: sapwood to leaf area ratio

**Photosynthetic trait:**

- $V_{cmax}$: photosynthetic capacity
- $\chi$: $c_i/c_a$

**Leaf economics spectrum trait:**

- LMA: leaf mass per area
- $N_{area}$: leaf nitrogen content



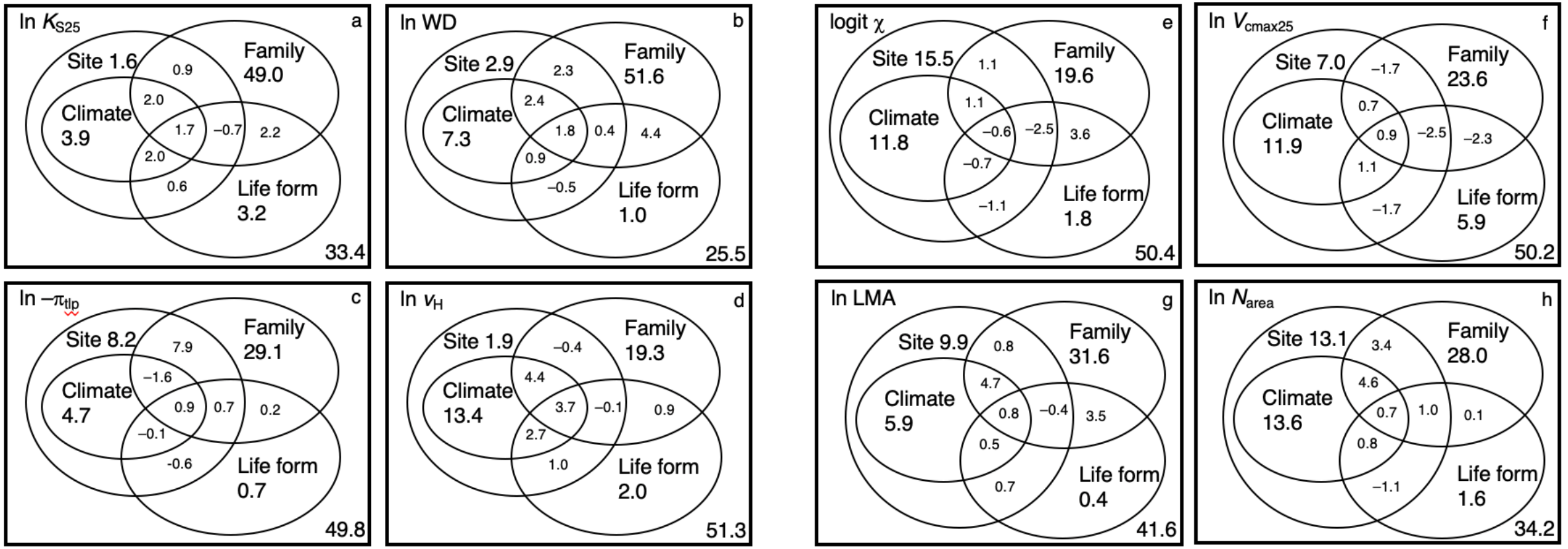

2019.08
**4361** m
Deciduous shrubland

2018.07
2782 m
Deciduous broadleaf forest

2019.08
**1143** m
Deciduous broadleaf forest

# Results: variance partitioning of traits

- Hydraulic and leaf-economic traits were less plastic, and more closely associated with phylogeny, than photosynthetic traits
- $v_H$ were least influenced by phylogeny, LMA is more controlled by family

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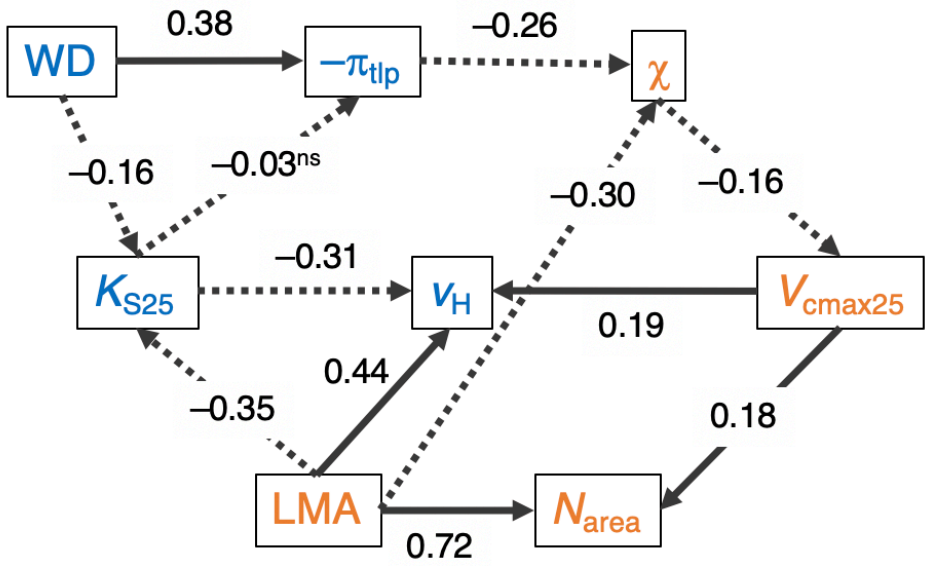
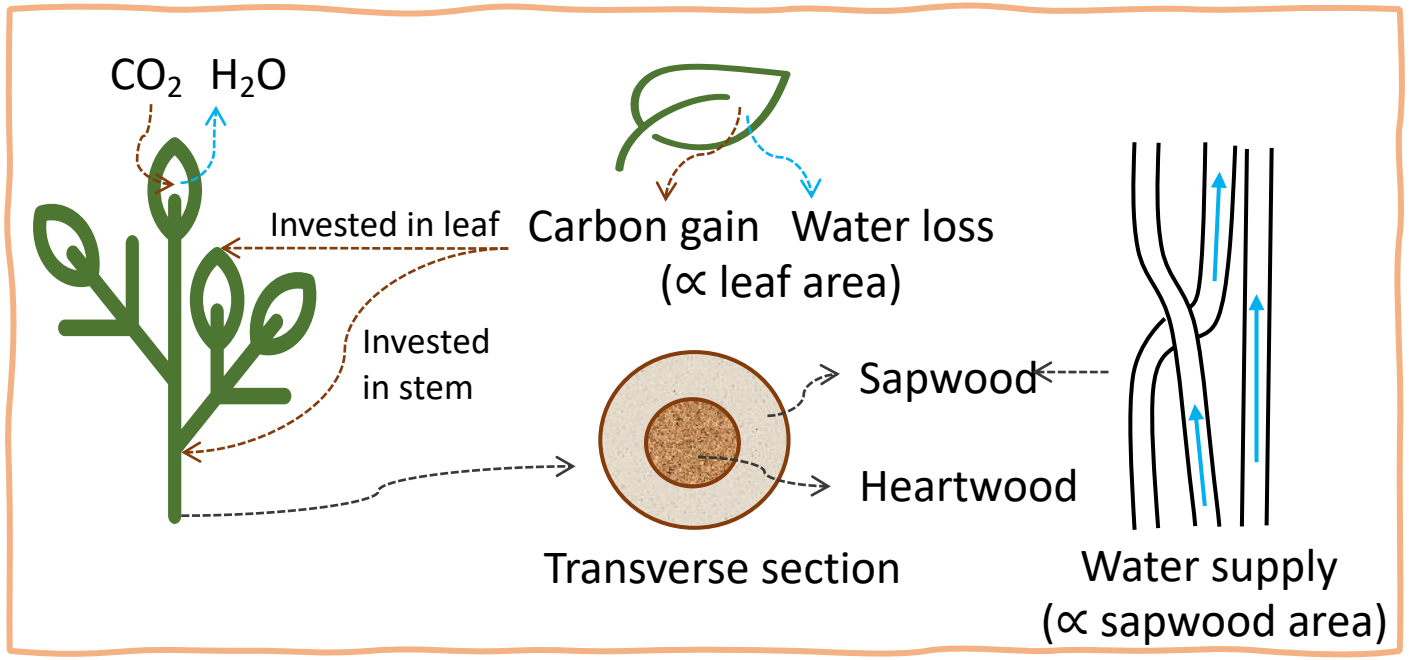
# Results: path analysis of traits coordination

- $v_H$ as the key trait linking the two sets of traits
- $v_H$ decreased with $K_{S25}$, but increased with $V_{cmax25}$
- WD was negatively related to $K_{S25}$, and positively related to $-\Psi_{tlp}$
- LMA and $-\Psi_{tlp}$ both negatively influenced χ

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# Results: prediction of Huber Value

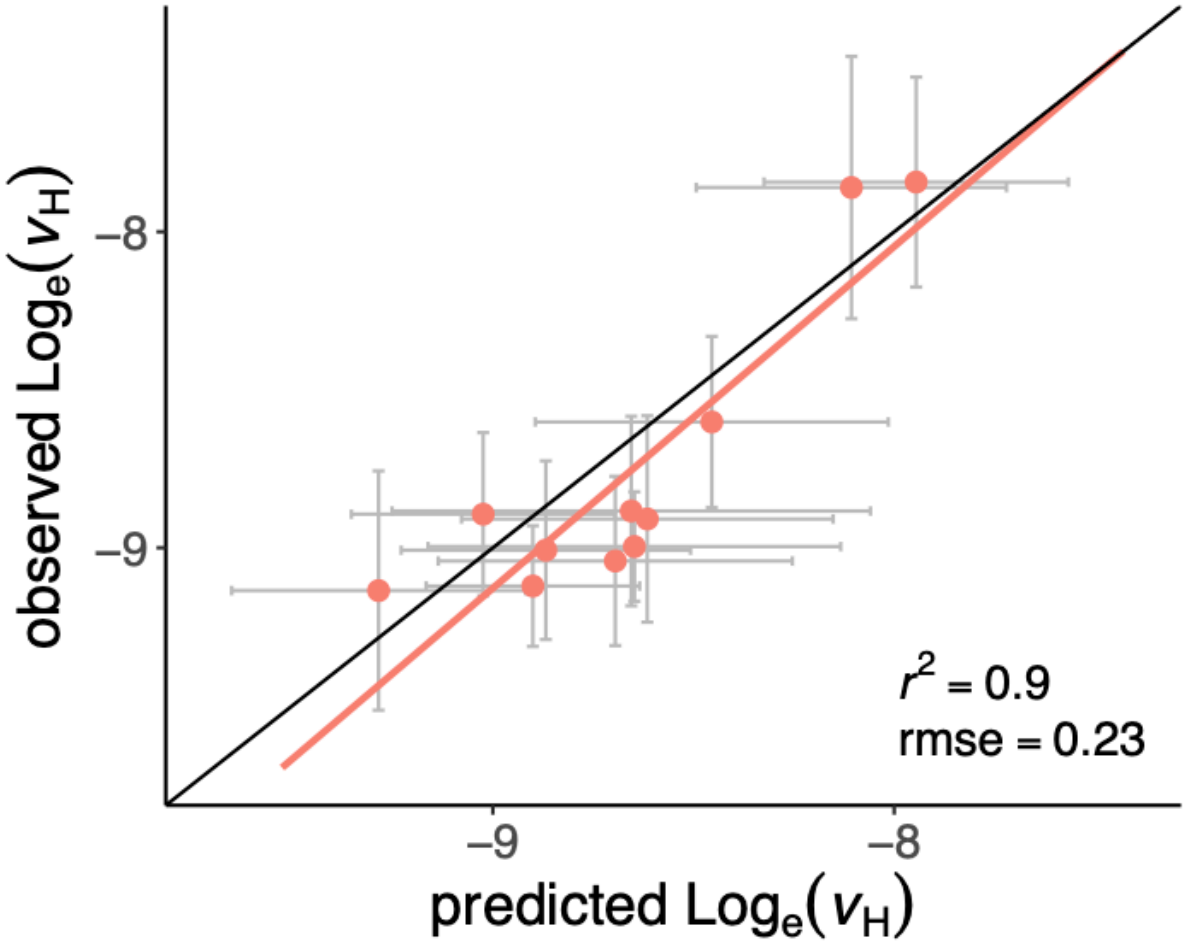
**The predictability of $v_H$ using this theory**

$$\ln v_H = \ln D - \ln c_a + \ln m_C + \ln V_{cmax} - \ln (1 - \chi) - \ln K_S - \ln (-\Psi_{tlp}) + C$$

$$m_C = (c_i - \Gamma^*)/(c_i + K)$$

C: fitted intercept, including tree height information

- $V_{cmax}$, $\chi$, $m_C$ : predicted using temperature, D, radiation and elevation (Wang et al. 2017; Smith et al. 2019)
- $K_S$, $\Psi_{tlp}$ : observed data

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# Results: contribution of different predictors

(a)

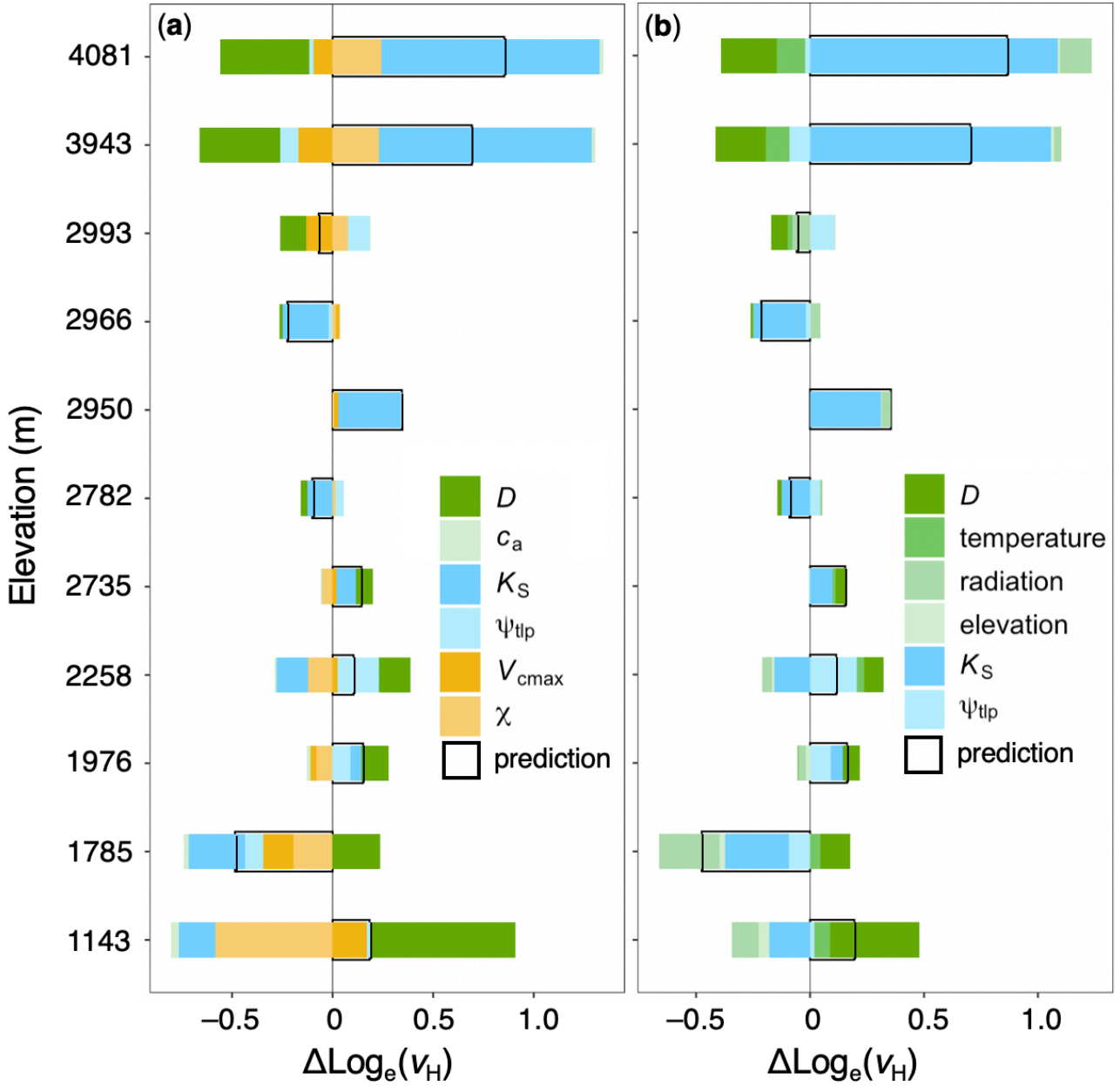
$\ln v_H = \ln D - \ln c_a + \ln m_C + \ln V_{cmax} - \ln (1 - \chi$

$- \ln K_S - \ln (-\Psi_{tlp})$

(b)

$\ln v_H = \ln D + f$(temperature, radiation, D, elevation) $- \ln K_S - \ln (-\Psi_{tlp})$

- $K_S$ and $D$ are the most important predictor of the variation in site-mean $v_H$
- $\Psi_{tlp}$ contributes little to $v_H$ variation

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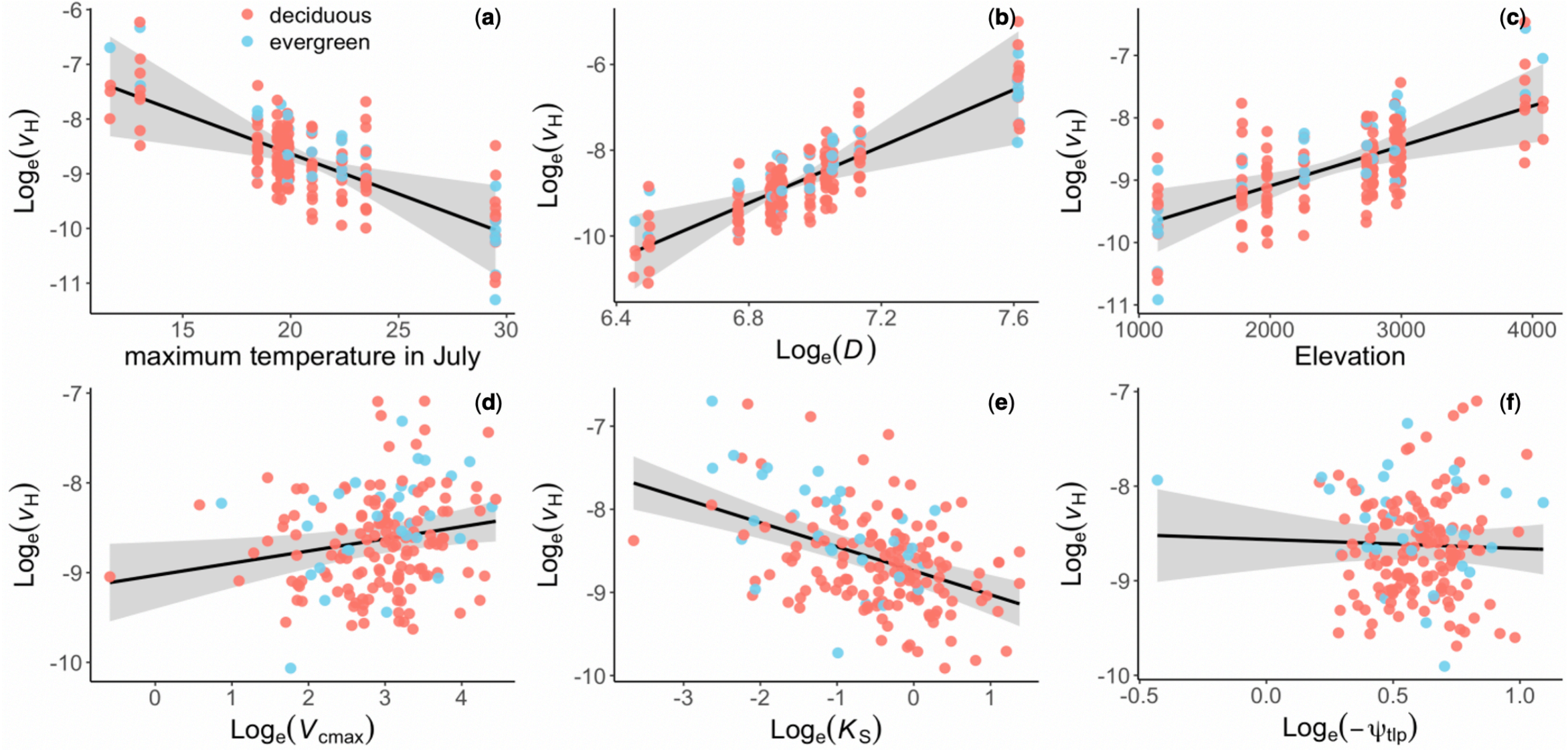
# Results: Huber value response to different predictors

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# Take-home messages

- **Hydraulic and leaf-economic traits are less plastic**, and more closely associated with phylogeny, than photosynthetic traits
- Plant hydraulics and photosynthesis coordinate to **balance water supply and demand**
- **Huber value is the link** between hydraulics and photosynthesis
- Vapour pressure deficit has a **positive** effect on Huber value variation

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# Thank you!

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