

---

# Evolution of the Indian monsoon since the last glacial maximum: forcing vs feedbacks

---

Chetankumar Jalihal

**Guided by:** Prof. J. Srinivasan &  
Prof. Arindam Chakraborty



# OBJECTIVE

---

**Identify** the feedbacks. (TraCE-21k)

---

**Quantify** the role of forcings and feedbacks.



# ENERGETICS FRAMEWORK

(Neelin & Held 1987; Raymond 2009)

$$P - E = \frac{Q_{div}}{GMS}$$

Net energy flux into atmosphere

Gross Moist Stability

$$GMS = - \frac{\int_{P_B}^{P_T} \vec{U} \cdot \nabla m + \omega \frac{\partial m}{\partial p} dp}{L_v \int_{P_B}^{P_T} \vec{U} \cdot \nabla q + \omega \frac{\partial q}{\partial p} dp}$$



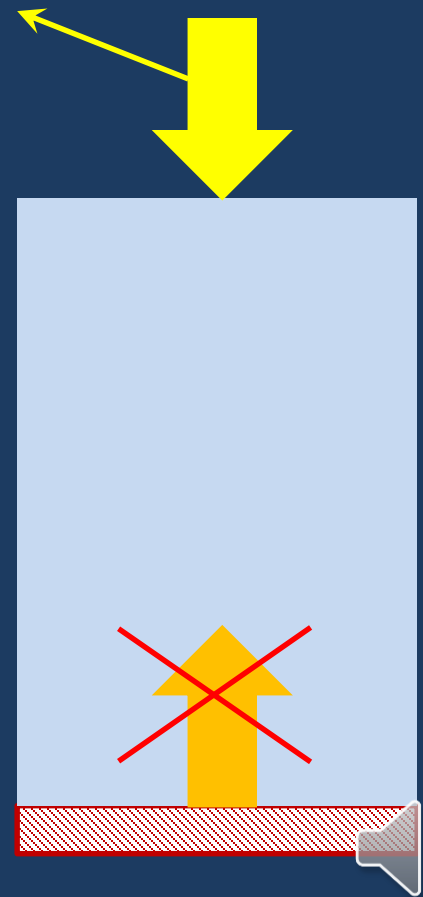
# ENERGETICS FRAMEWORK

(Neelin & Held 1987; Raymond 2009)

$$P - E = \frac{Q_{div}}{GMS}$$

Includes effect of insolation & cloud radiative feedbacks

Over land



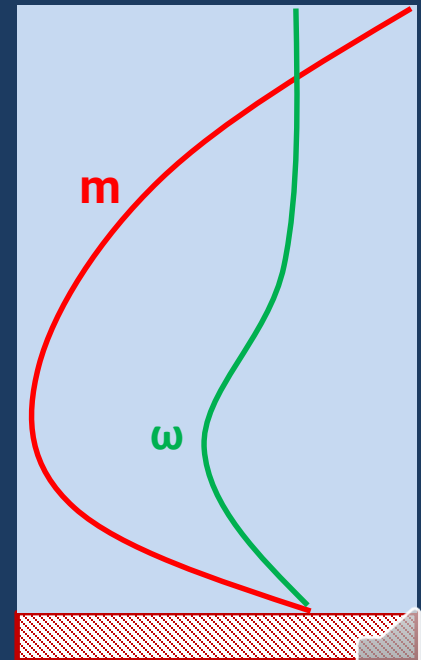
$$GMS = - \frac{\int_{P_B}^{P_T} \vec{U} \cdot \nabla m + \omega \frac{\partial m}{\partial p} dp}{L_v \int_{P_B}^{P_T} \vec{U} \cdot \nabla q + \omega \frac{\partial q}{\partial p} dp}$$

# ENERGETICS FRAMEWORK

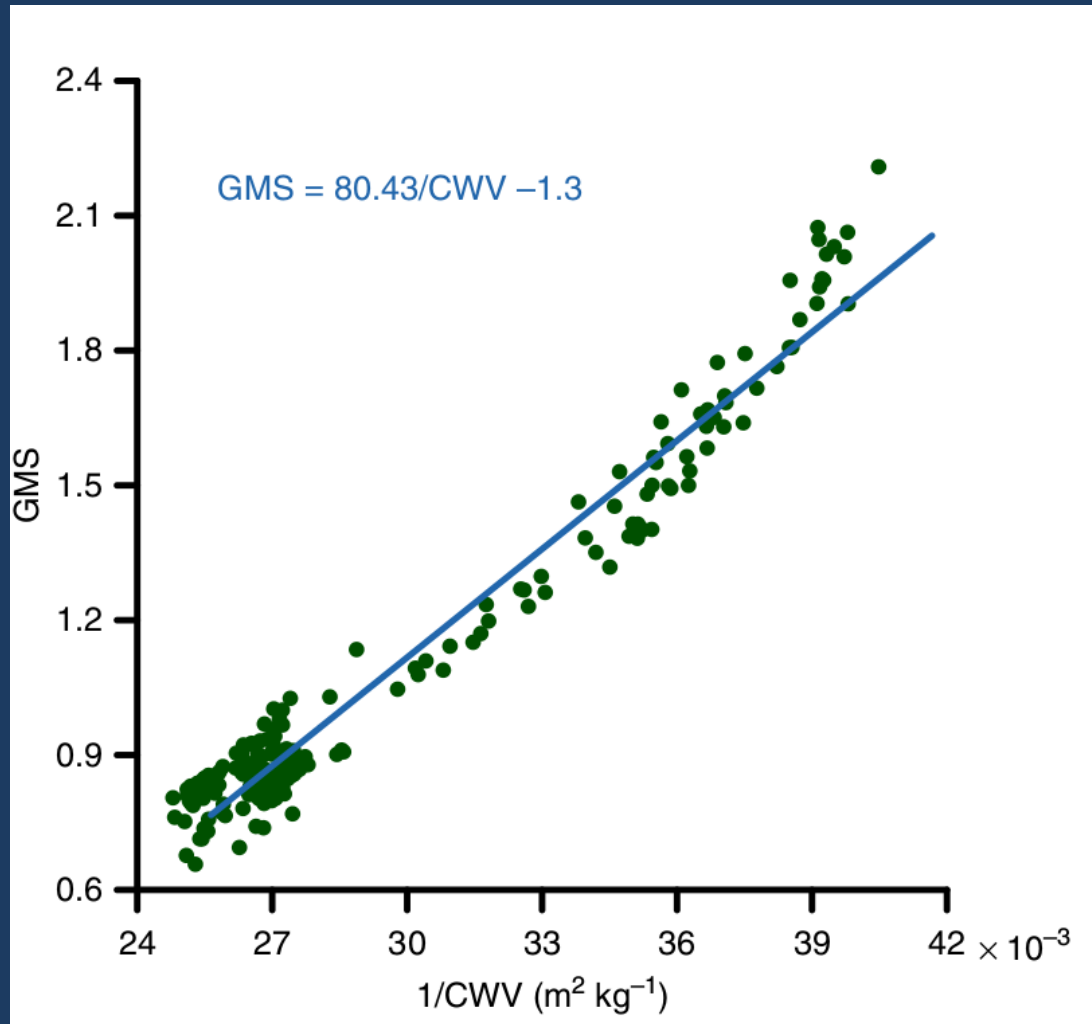
(Neelin & Held 1987; Raymond 2009)

$$P - E = \frac{Q_{div}}{GMS}$$

$$GMS = - \frac{\int_{P_B}^{P_T} \vec{U} \cdot \nabla m + \omega \frac{\partial m}{\partial p} dp}{L_v \int_{P_B}^{P_T} \vec{U} \cdot \nabla q + \omega \frac{\partial q}{\partial p} dp}$$



# GMS IS A UNIQUE FUNCTION OF WATER VAPOR



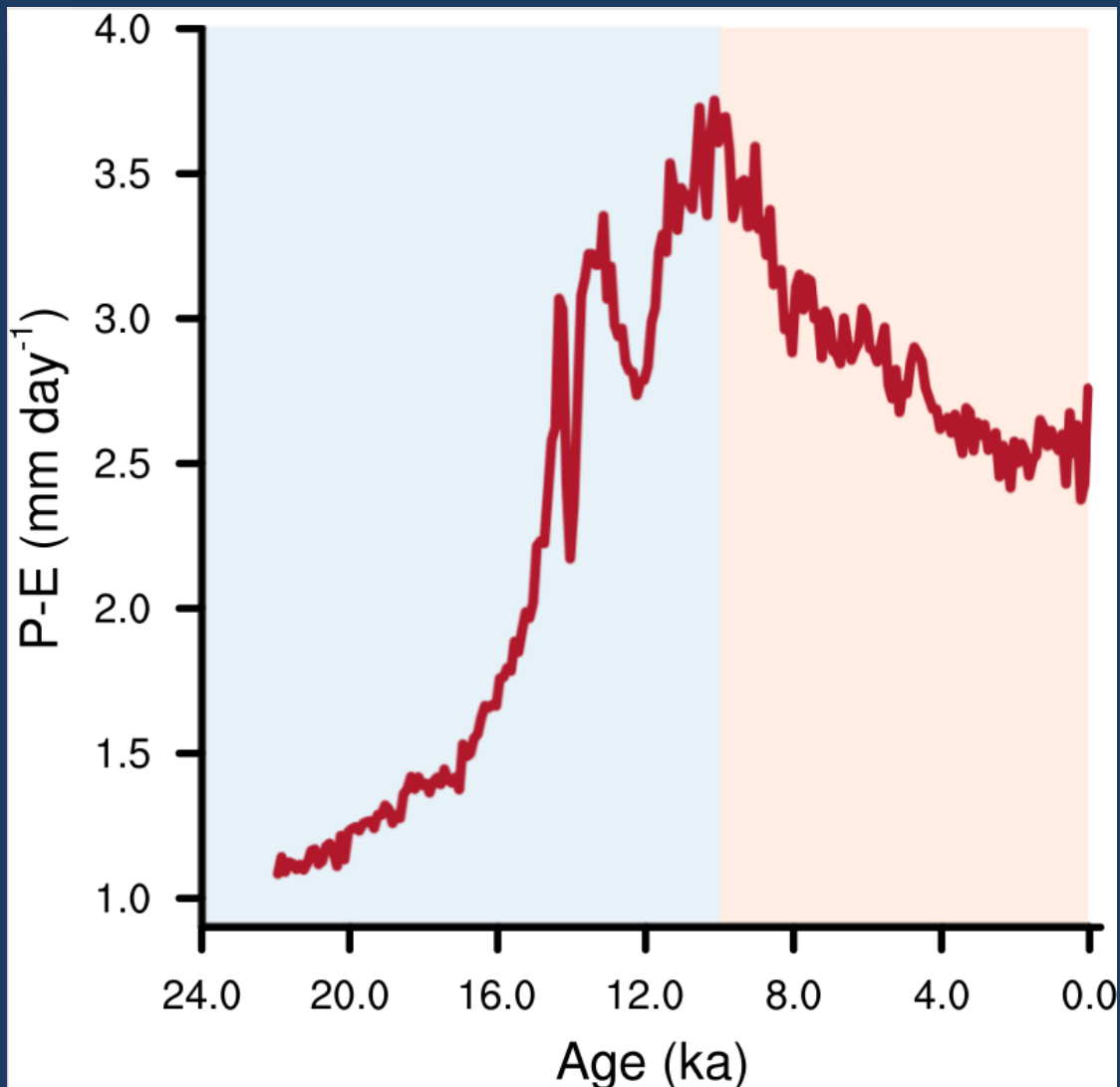
Jalihal et al. (2019) Nat. Comm.

$$P - E = \frac{Q_{div}}{GMS}$$

$$P - E = \frac{Q_{div}}{80.4/CWV - 1.3}$$



# (P-E) OVER THE LAST 22,000 YRS

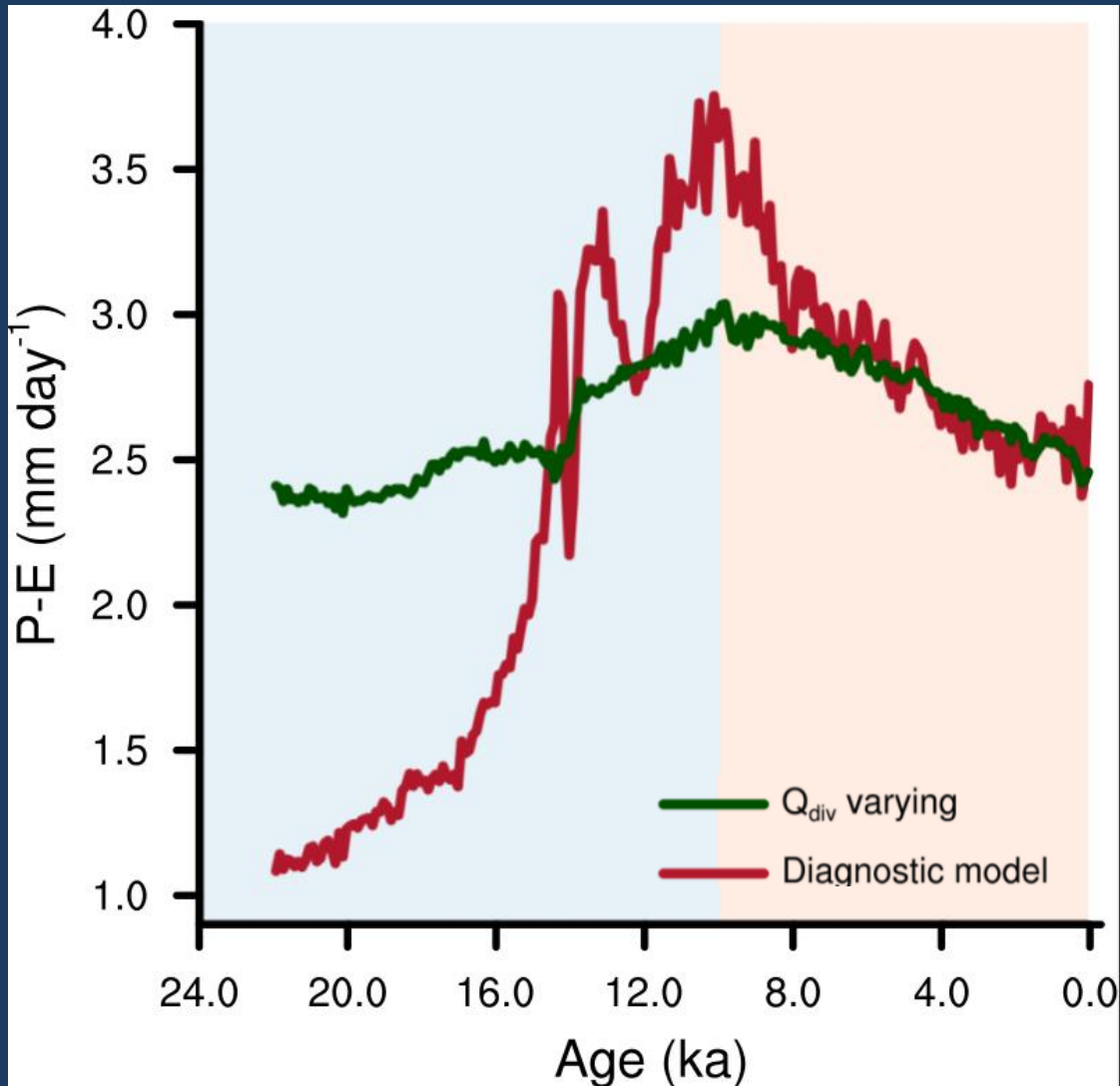


$$P - E = \frac{Q_{div}}{80.4 / CWV - 1.3}$$

*Jalihal et al. (2019) Nat. Comm.*



# $Q_{DIV}$ DRIVES (P-E) DURING HOLOCENE



$$P - E = \frac{Q_{div}}{80.4 / CWV - 1.3}$$

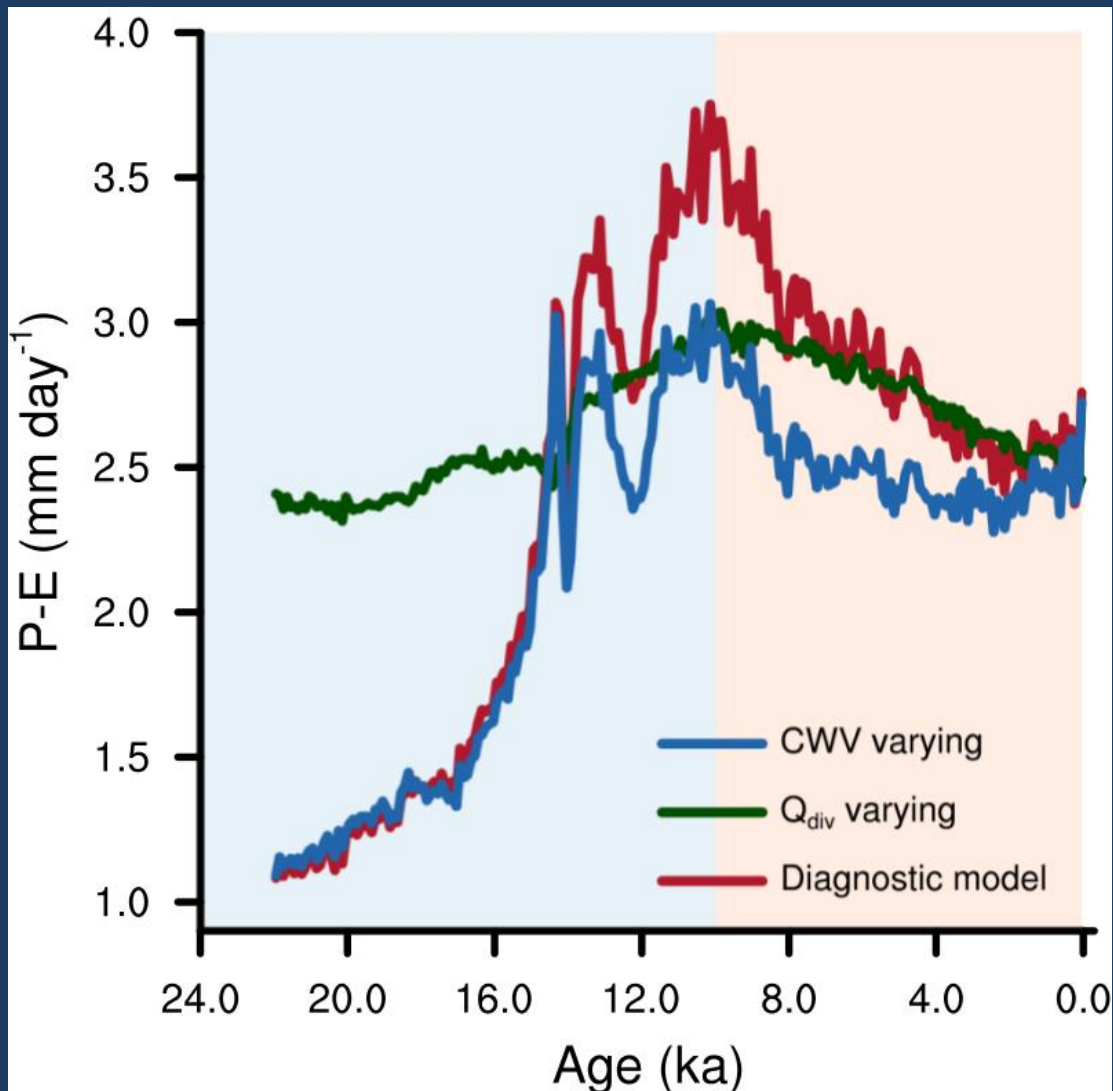
CWV fixed at pre-industrial values.

Jalihal et al. (2019) Nat. Comm.





# WATER VAPOR PLAYS CRUCIAL ROLE DURING DEGLACIAL

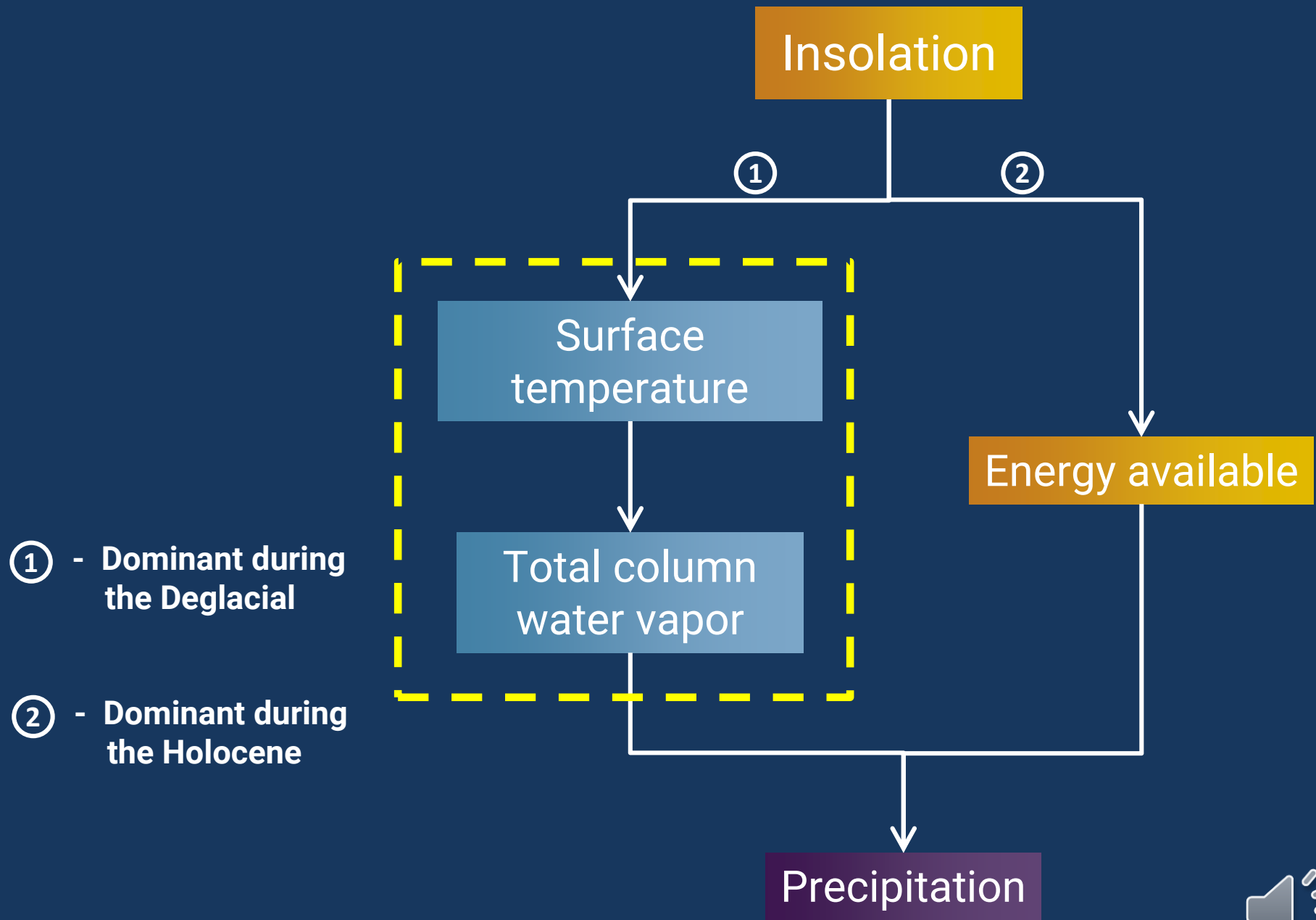


$$P - E = \frac{Q_{div}}{80.4 / CWV - 1.3}$$

**Q<sub>div</sub> fixed at pre-industrial values.**

Jalihal et al. (2019) Nat. Comm.





GHG & Ice sheets

Insolation

①

②

Surface temperature

Total column water vapor

Energy available

Precipitation

① - Dominant during the Deglacial

② - Dominant during the Holocene

GHG & Ice sheets

Insolation

①

②

Surface temperature

Energy available

Total column water vapor

Precipitation

① - Dominant during the Deglacial

② - Dominant during the Holocene



---

Thank you

---

