



MAX PLANCK INSTITUTE
FOR BIOGEOCHEMISTRY

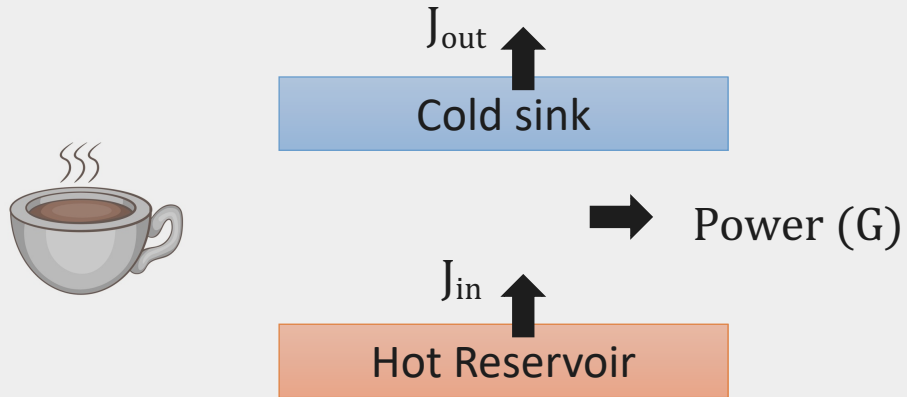


How much of the surface energy partitioning
can be explained by controls imposed by
thermodynamics?

Sarosh Alam Ghausi and Axel Kleidon

Overview

Laws of thermodynamics



First Law: Energy remains conserved

$$J_{in} = J_{out} + G$$

Second Law: Entropy of system can only increase

$$\frac{J_{in}}{T_{in}} \geq \frac{J_{out}}{T_{out}}$$

Maximum work that can be performed (Carnot limit)

$$G = J_{in} \left(\frac{T_{in} - T_{out}}{T_{in}} \right)$$

Land – atmosphere system

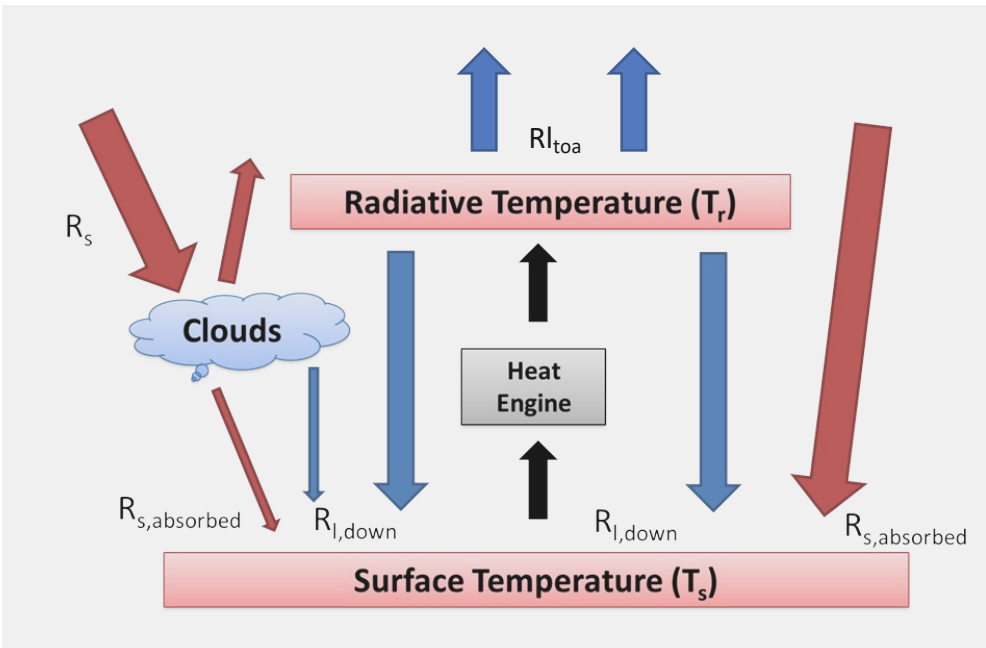
First Law: surface energy balance

$$R_s + R_{l,down} = R_{l,up} + J + G$$

Turbulent fluxes (H + LE)

Can we use second law of thermodynamics to constrain the amount of turbulent flux exchange?

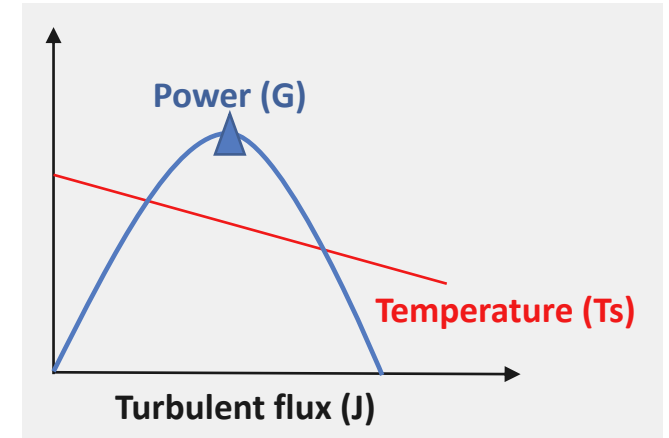
Thermodynamic limits on Earth system



Modified carnot limit

$$G = \left(J - \frac{dU}{dt} \right) \left(\frac{T_s}{T_r} - 1 \right)$$

Max power tradeoff



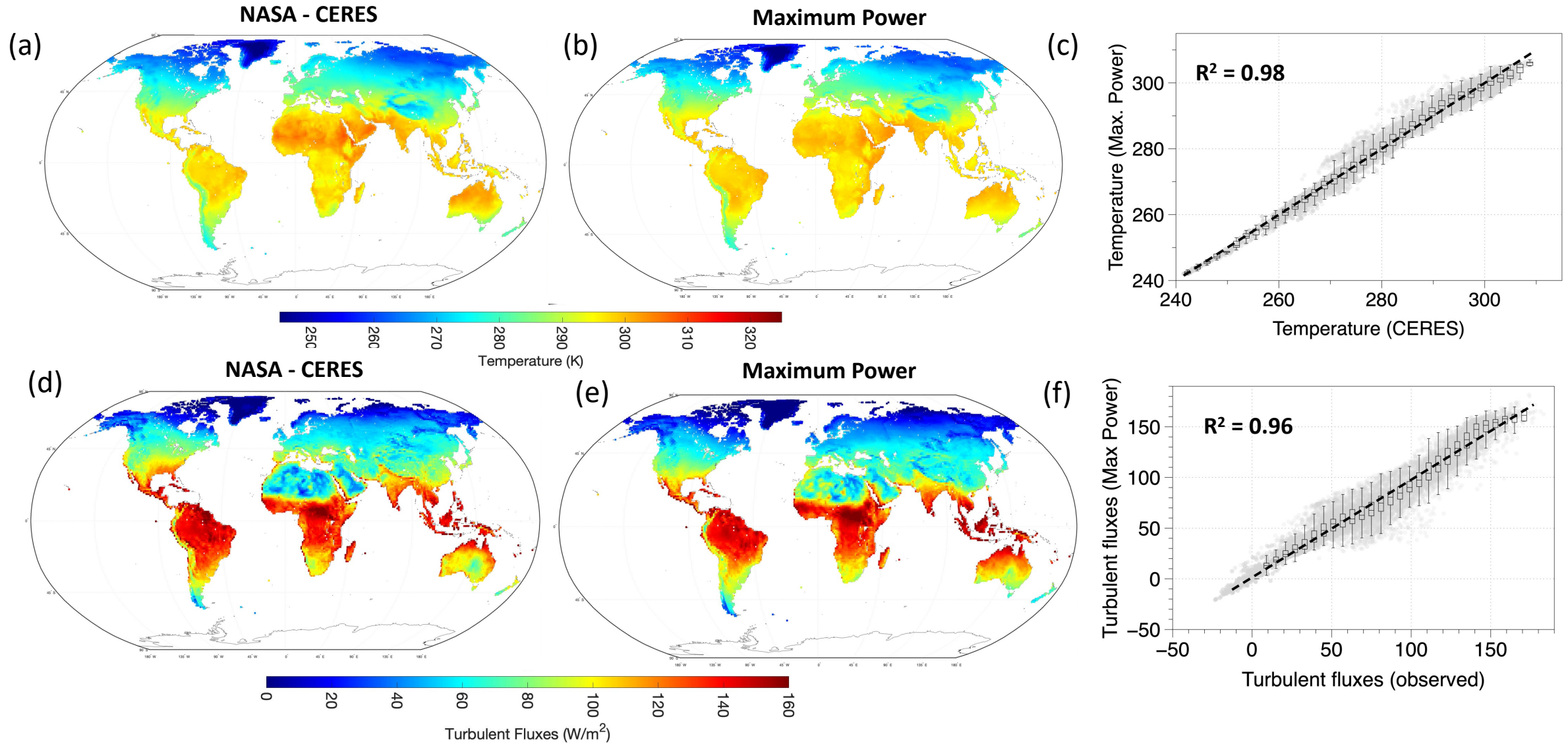
Surface energy balance

$$R_s + R_{ld} = R_{l,up} + \underbrace{H + LE}_{\text{Turbulent fluxes } (J)}$$

Maximising convective power G for optimum turbulent flux J

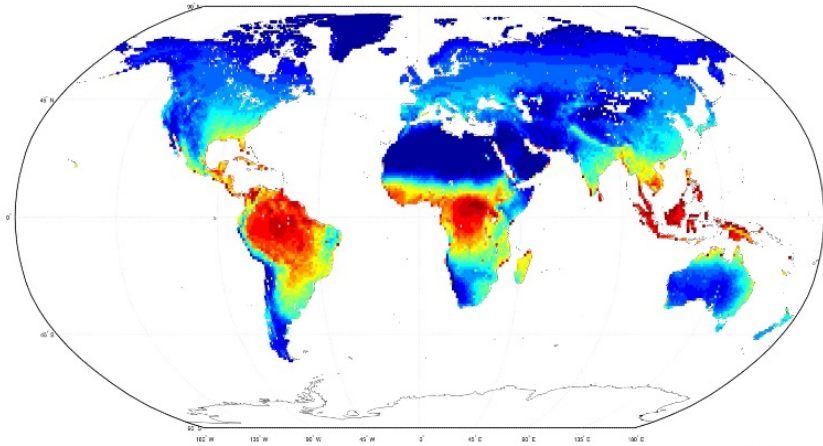
$$G(J) = \left(J - \frac{dU}{dt} \right) \left(\frac{\left(\frac{R_{in} - J}{\sigma} \right)^{0.25}}{T_r} - 1 \right)$$

Evaluating the maximum power limit at a global scale

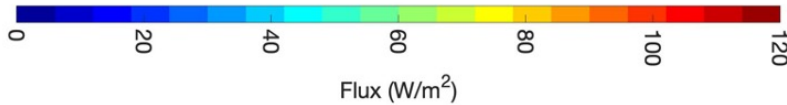
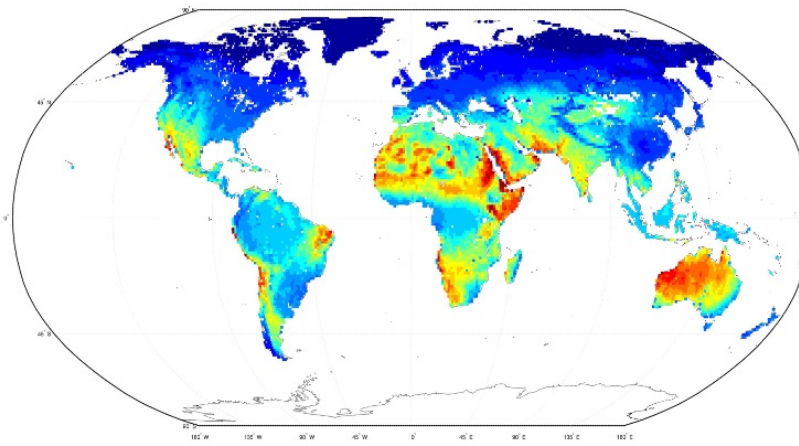


Surface energy partitioning for optimised turbulent fluxes

Latent Heat



Sensible Heat

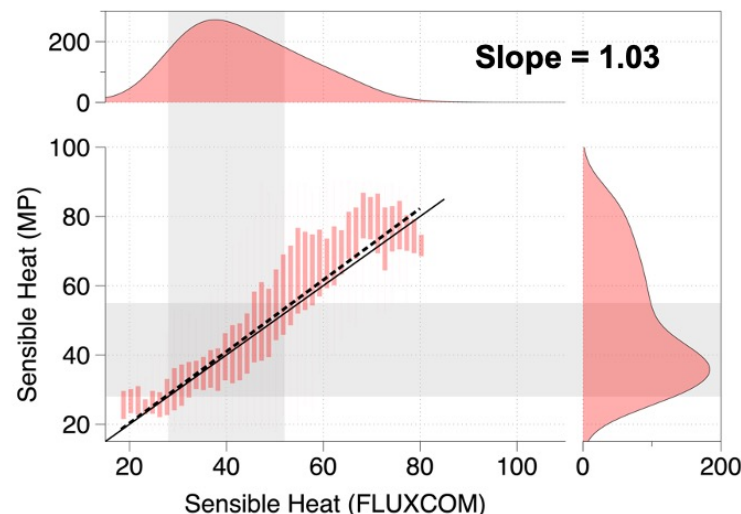
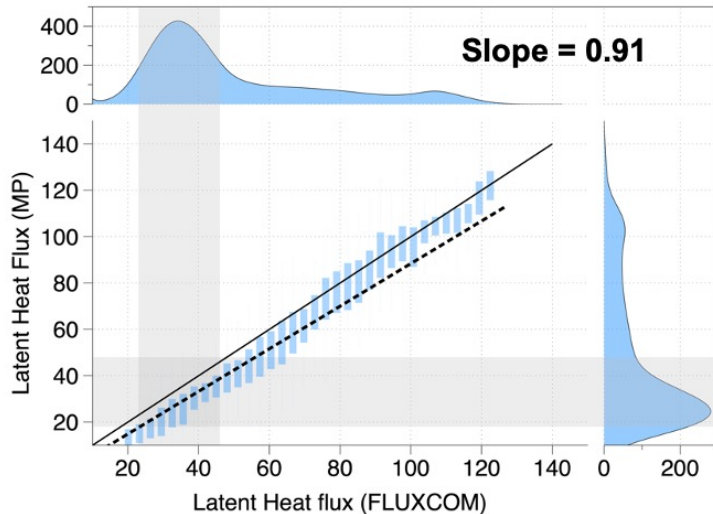


Equilibrium energy partitioning derived from thermodynamics (Kleidon et al., 2013)

$$LE_{opt} = f_w * \frac{s}{s+\gamma} J_{opt}$$

$$H_{opt} = J_{opt} \left(1 - f_w \frac{s}{s+\gamma} \right)$$

$$f_w = \frac{LE_{actual}}{LE_{potential}}$$

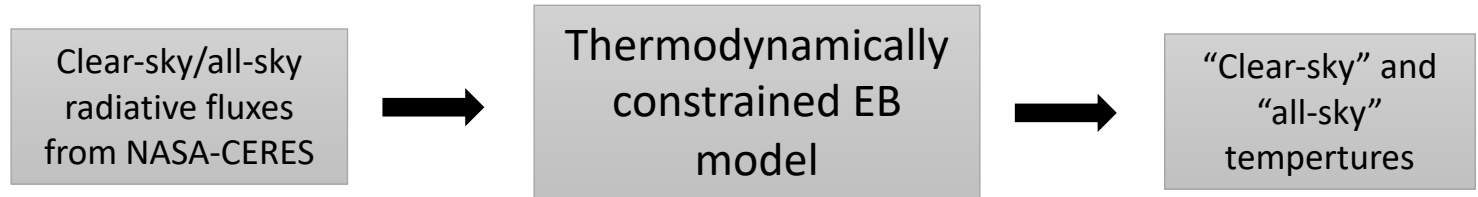
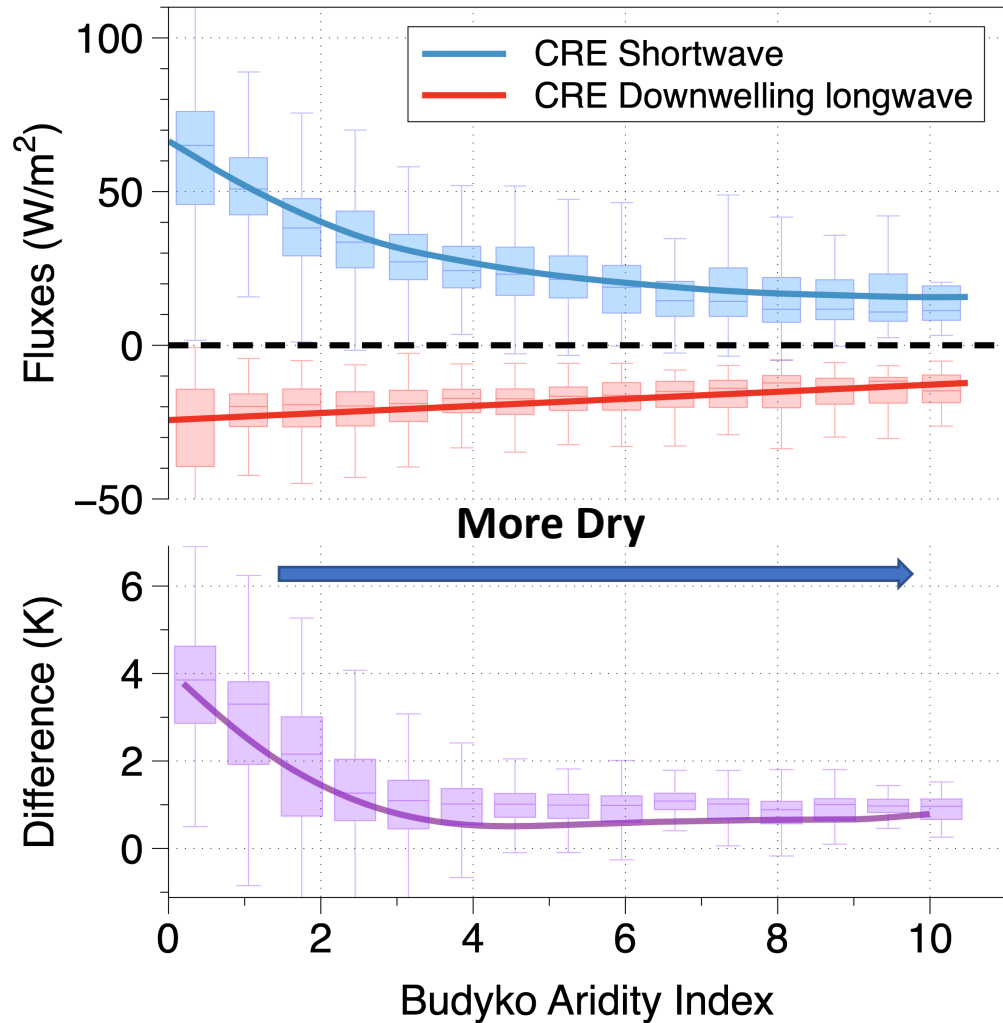


Where

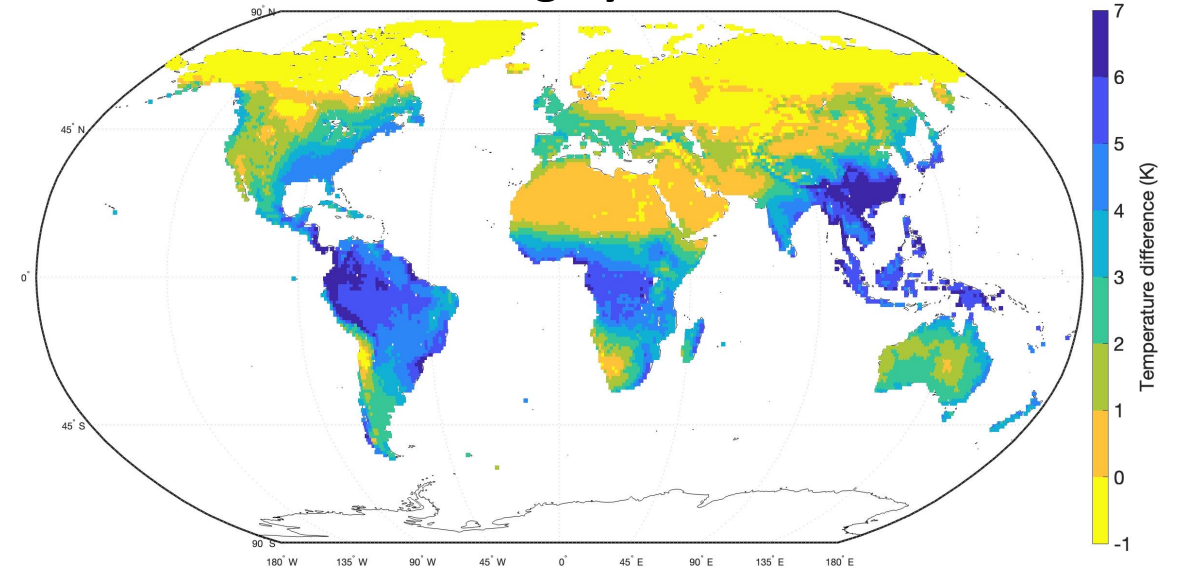
- “ f_w ” is the water limitation factor
- “ s ” is the slope of saturation vapor pressure curve
- “ γ ” is the psychrometric constant

Using the additional constraint to quantify the cloud radiative effects

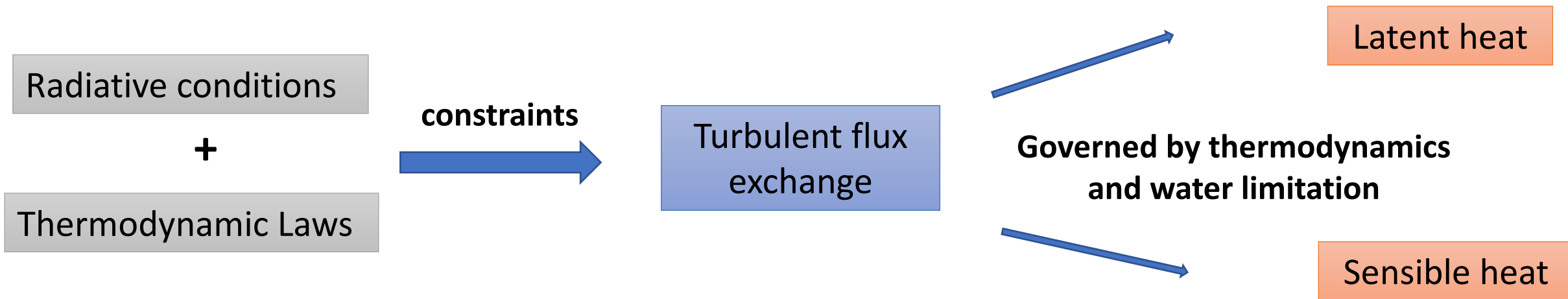
Differences (Clear sky – all sky)



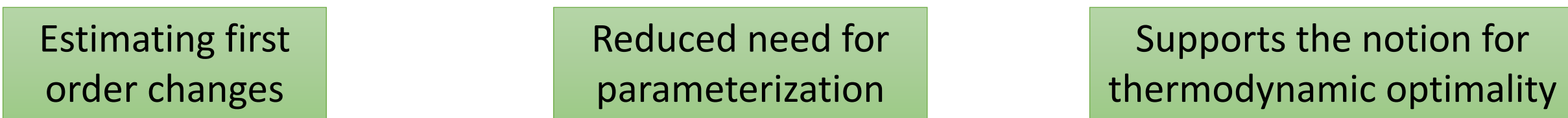
Cooling by clouds



Conclusions



Implications



Meet me during EGU for further discussion
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