Bridging the gap between leaf surface and canopy air space: Leaf size matters

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Picture by Jonathan D Muller

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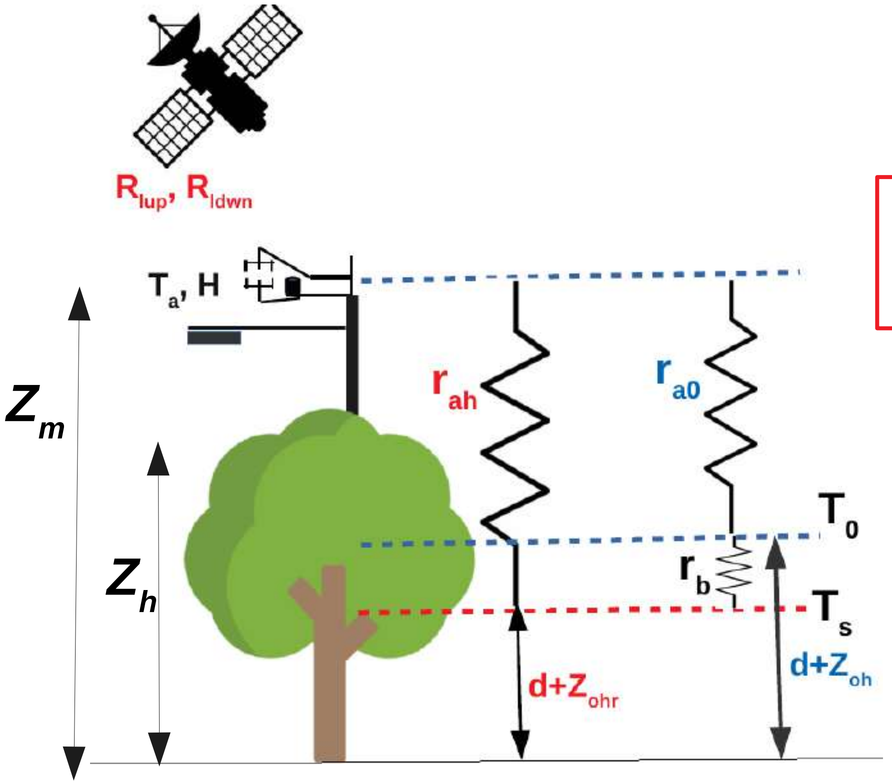
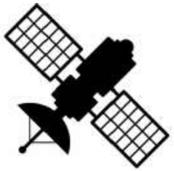
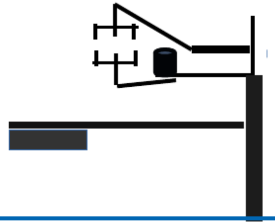
Motivation:







$$H = \frac{\rho C_p}{r_{ah}}(T_s - T_a)$$

$$H = \frac{\rho C_p}{r_{a0}}(T_0 - T_a)$$

Missing link between the leaf surface and the canopy-air space ?

ρ: air density (Kgm^{-3}), **C_p:** heat capacity (JKg^{-1} K^{-1}), **d:** displacement height (m), **H:** sensible heat flux (Wm^{-2}), **r_{ah}:** heat transfer resistance using T_s (ms^{-1}), **r_{a0}:** heat transfer resistance using T_0 (sm^{-1}), **r_b:** fitting parameter (sm^{-1}), **KB^{-1}** , **T_a:** observed air temperature (K), **T_0 :** aerodynamic temperature (K), **T_s:** remotely sensed surface temperature (K), **Z_h:** canopy height (m), **Z_m:** measurement height (m) **Z_{oh}:** aerodynamic roughness length (m), **Z_{ohr}:** radiometric roughness length (m)

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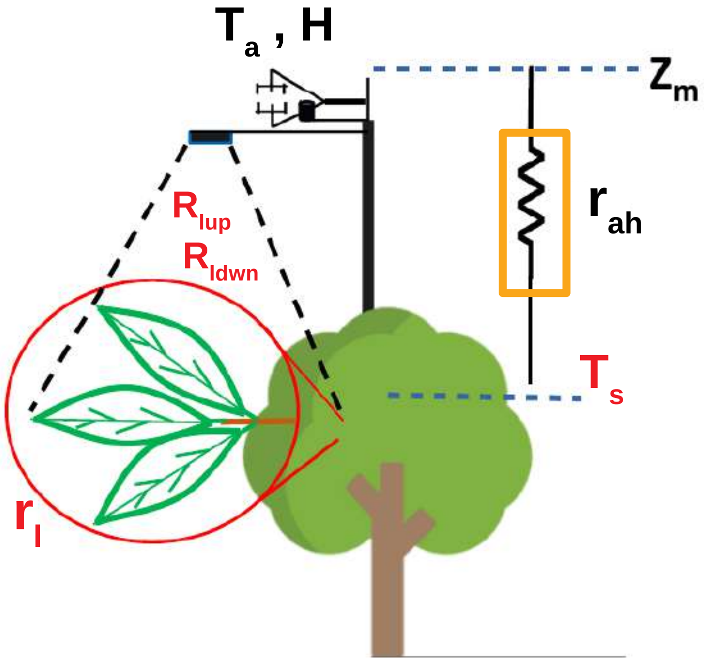
Objectives:

1. Estimate **total heat transfer resistance (r_{ah})**

- from the leaf surface to atmosphere
- using eddy covariance data.

2. Develop a consistent canopy-scale resistance formulation

- including **leaf boundary layer resistance (r_l)**
- canopy-air space resistance using **resistivity curve**



R_{lup}: upwelling longwave (Wm^{-2})
R_{ldwn}: downwelling longwave (Wm^{-2})
r_{ah}: total resistance to heat transfer (sm^{-1})
r_l: leaf boundary layer resistance (sm^{-1})
T_s: surface temperature (K)
T_a: observed air temperature (K)

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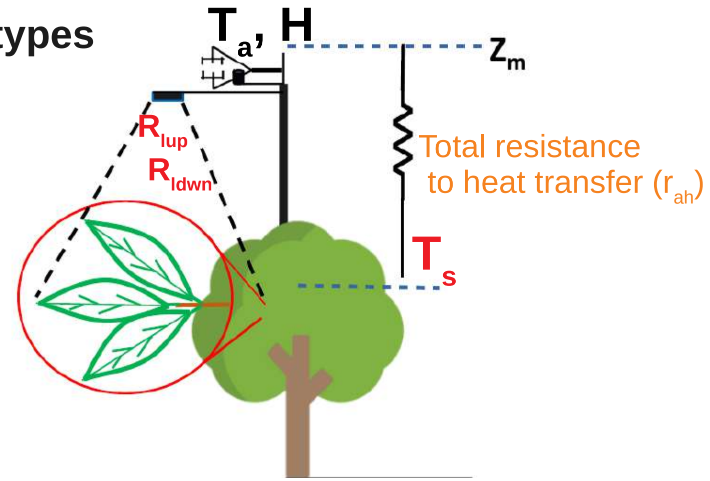
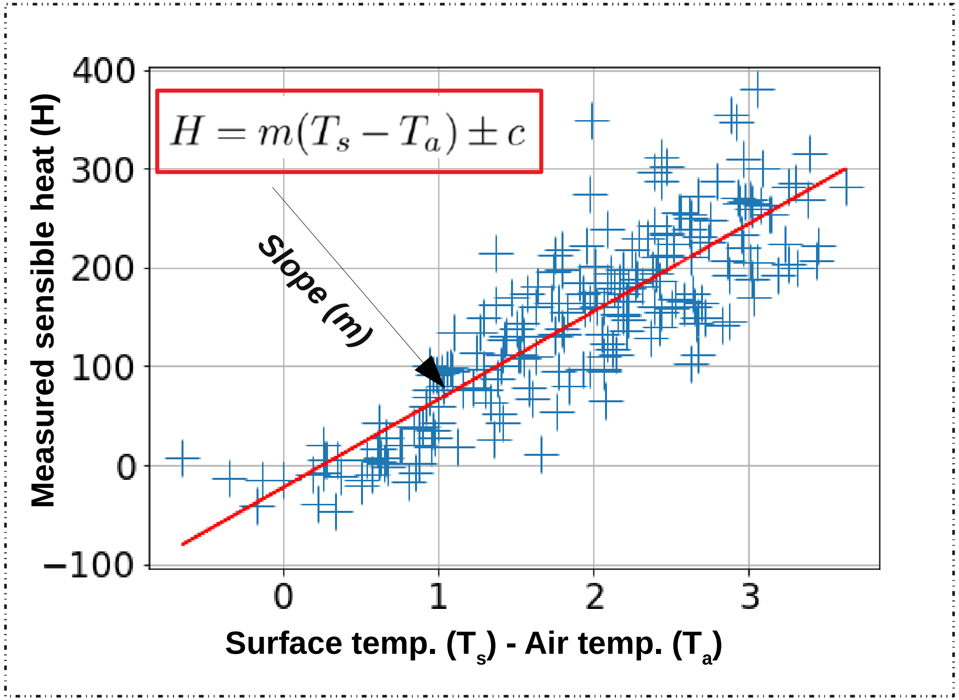
Methods: r_{ah} estimation using observations

- **Day-time flux data: 11 eddy covariance sites, different landcover types**



Objective 1: Estimate r_{ah} using eddy covariance measurements



$$T_s = \sqrt[4]{\frac{R_{ldwn}}{\sigma} - \frac{R_{ldwn}}{\epsilon\sigma} + \frac{R_{lup}}{\epsilon\sigma}}$$

$$r_{ah} = \frac{C_p \rho}{m}$$

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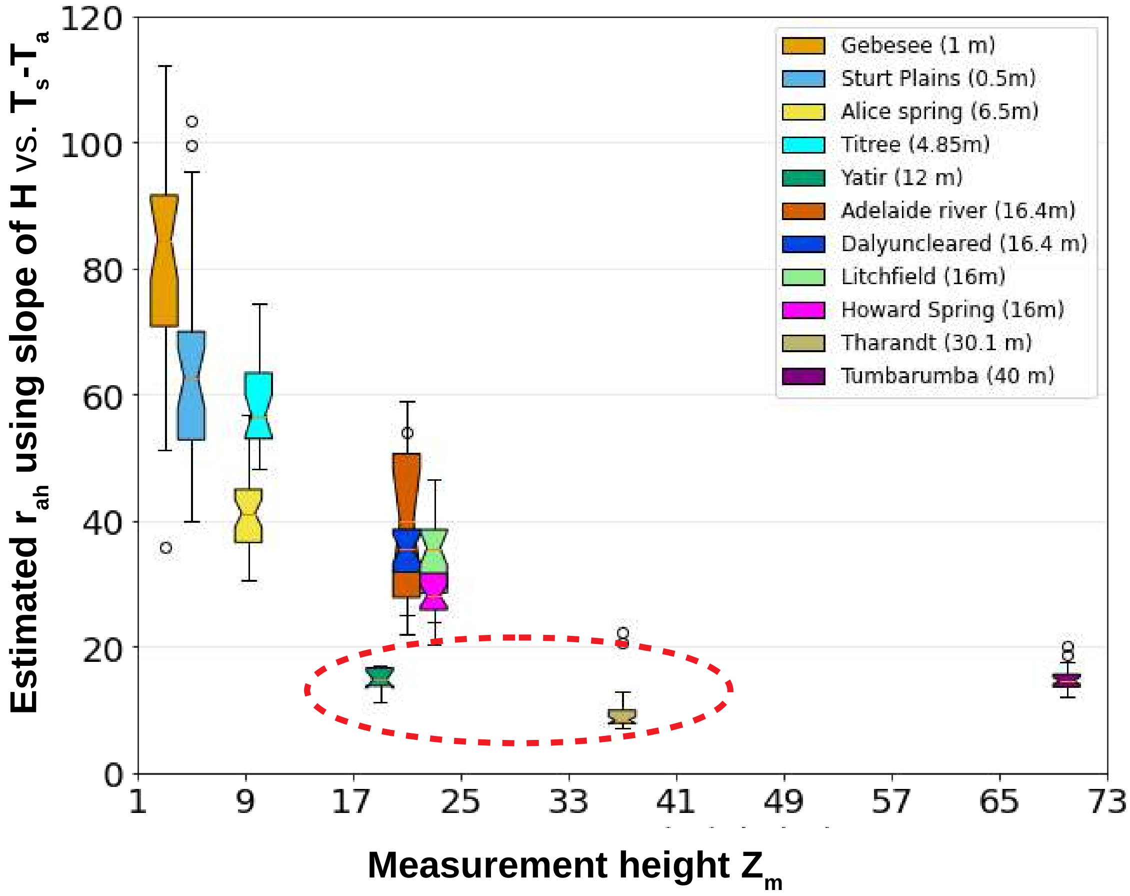
Results: Estimated total resistance (r_{ah})



- Estimated r_{ah} reduces exponentially with measurement height
- Pine forests have lower resistance than broad-leaf sites

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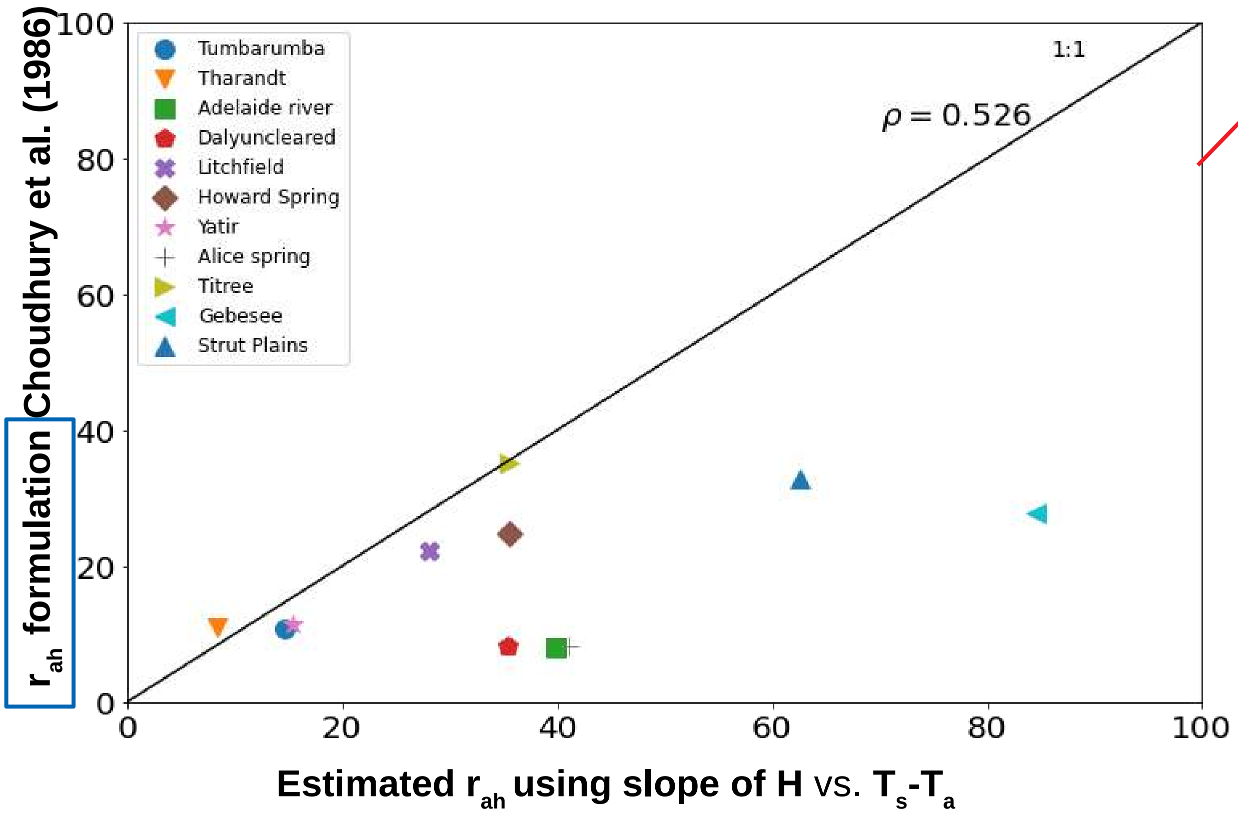
Existing formulations under-estimate r_{ah}:



All current formulations under-estimate r_{ah}

Inputs for r_{ah} by Choudhury

- Measurement height
- Displacement height
- Momentum roughness length
- Heat roughness length
- Air temperature
- Surface temperature
- **KB^{-1}**

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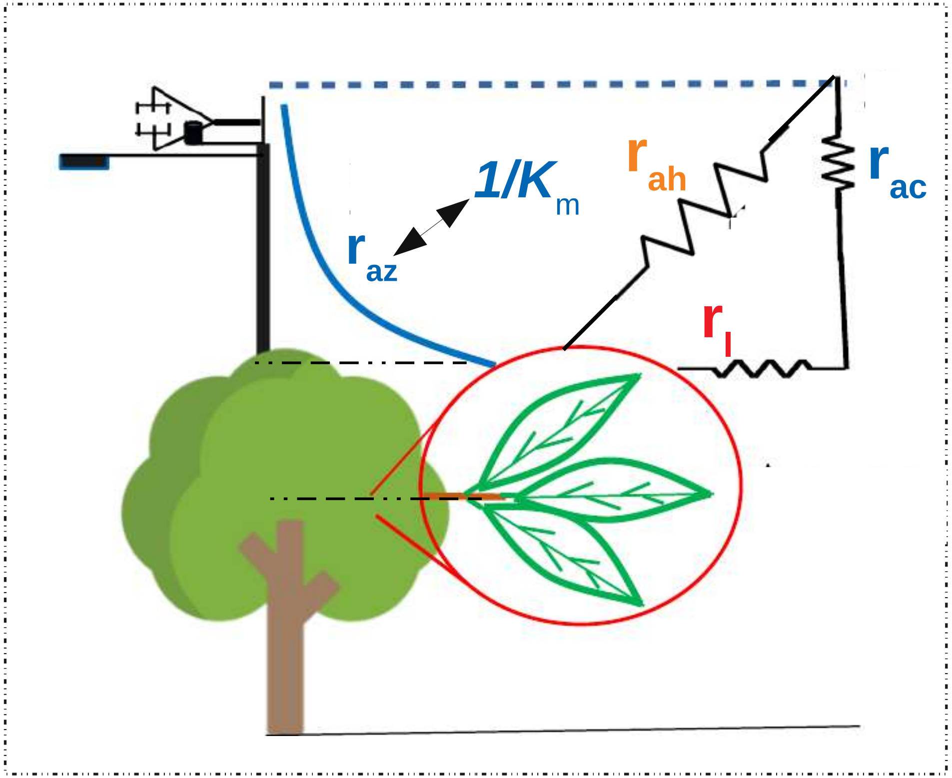
Methods: r_{ah} explained by leaves, resistivity profile

- **Day-time flux data: Eddy covariance sites having LAI >1**

Objective 2: Explaining r_{ah} using leaf resistance + resistivity curve



$$r_{ah} = \int_{Z_h}^{Z_m} r_{az}\, dz + r_l$$

$$r_{ac} = \int_{Z_h}^{Z_m} r_{az}\, dz$$

r_{az} : momentum resistivity (sm^{-2})
K_m: momentum eddy diffusivity (m^2s^{-1})
r_{ac} : canopy-air space resistance (sm^{-1})
r_l : leaf boundary layer resistance (sm^{-1})

Input for Leaf boundary resistance (r_l)

- Air temperature at canopy top
- Wind speed at canopy top
- Leaf width
- Leaf area index

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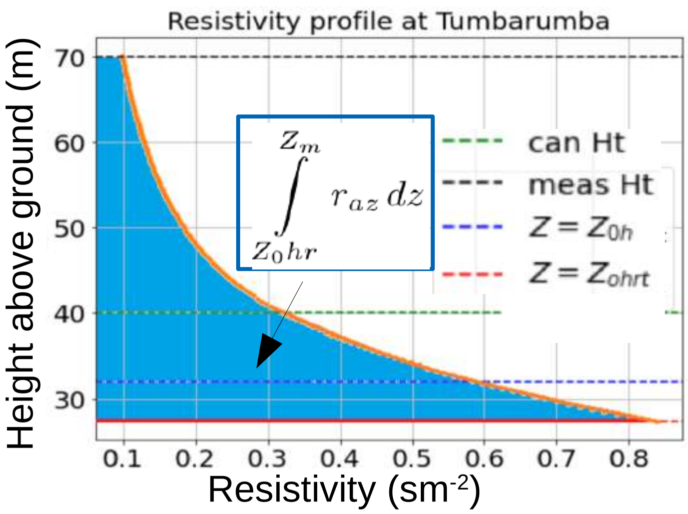
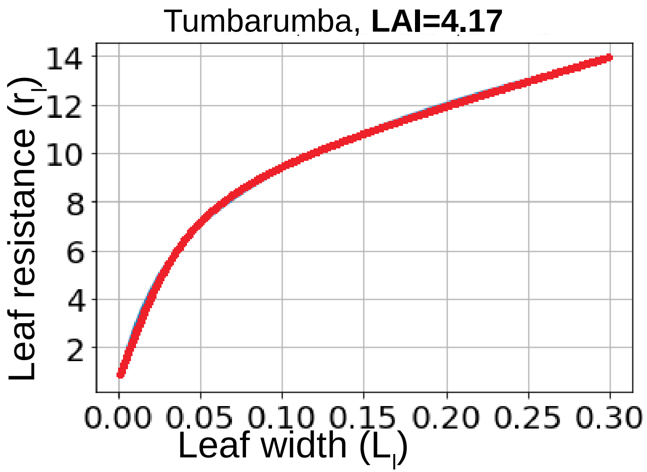
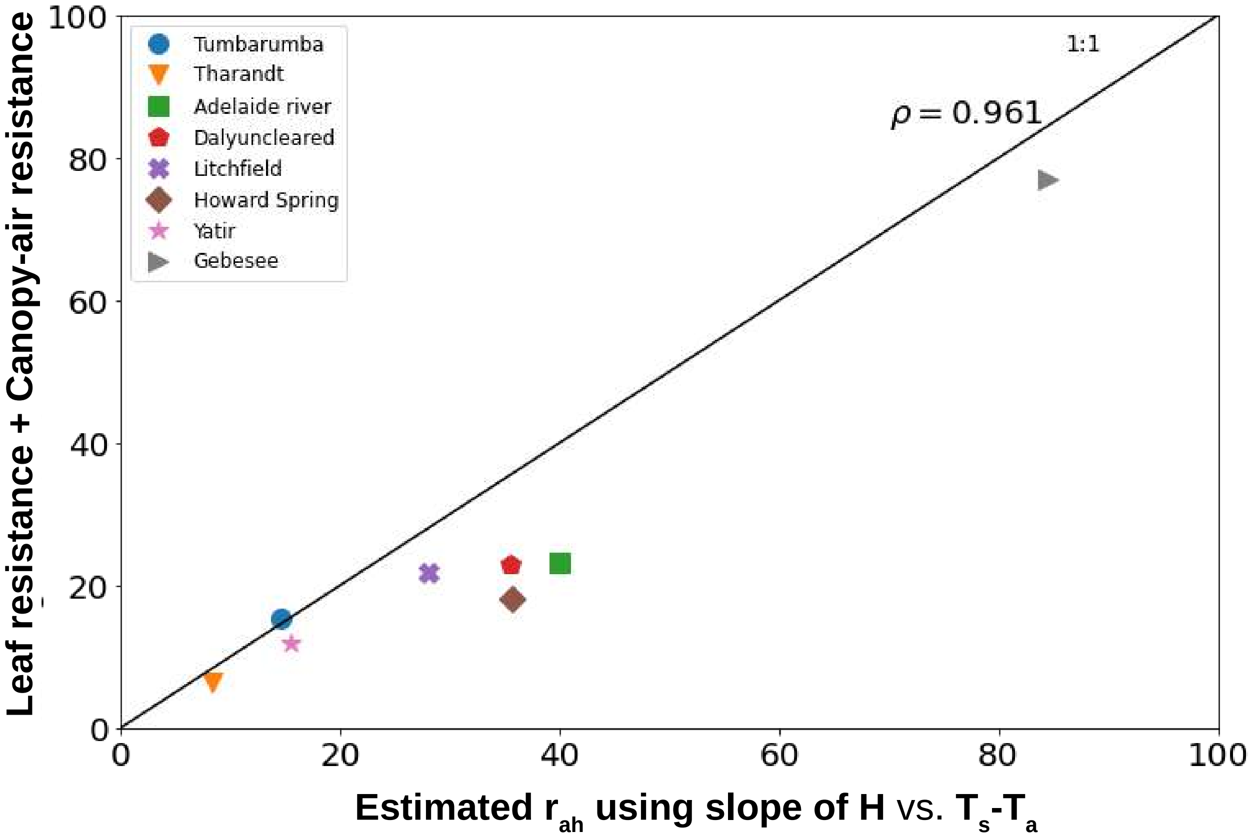
Our model: Canopy-air space + Leaf boundary layer







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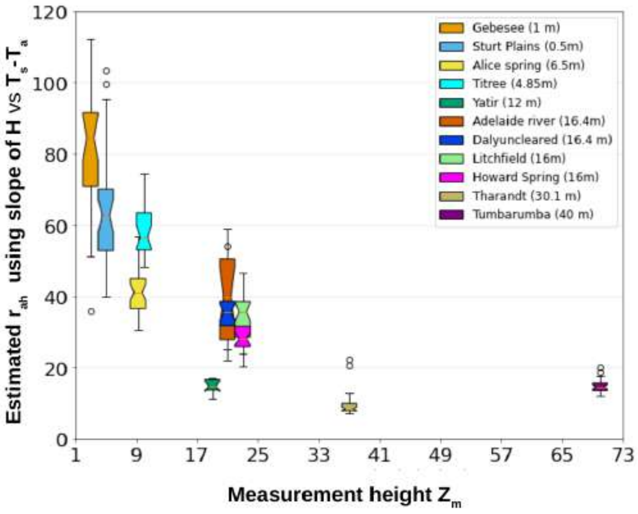
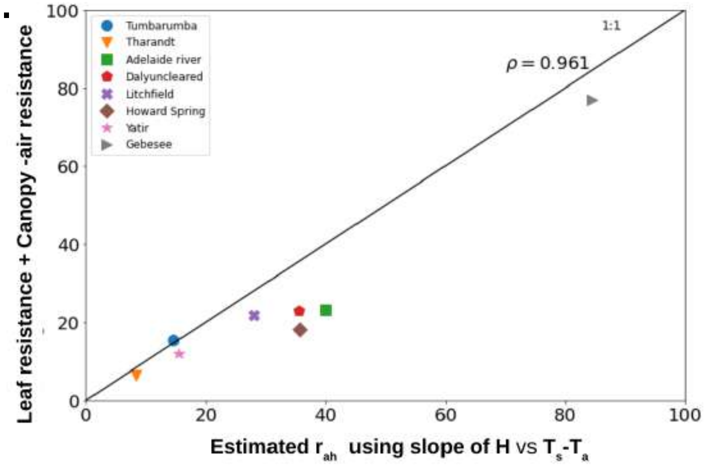
Conclusions:

1. Slope of sensible heat flux vs. Ts-Ta represents effective total resistance to heat transport.



2. Combination of leaf boundary layer resistance, leaf area and the vertical integral of resistivity captures site-to-site variation in total resistance to heat transfer.



Outlook: This enables a more explicit and self-consistent connection between leaf-scale processes and canopy fluxes

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