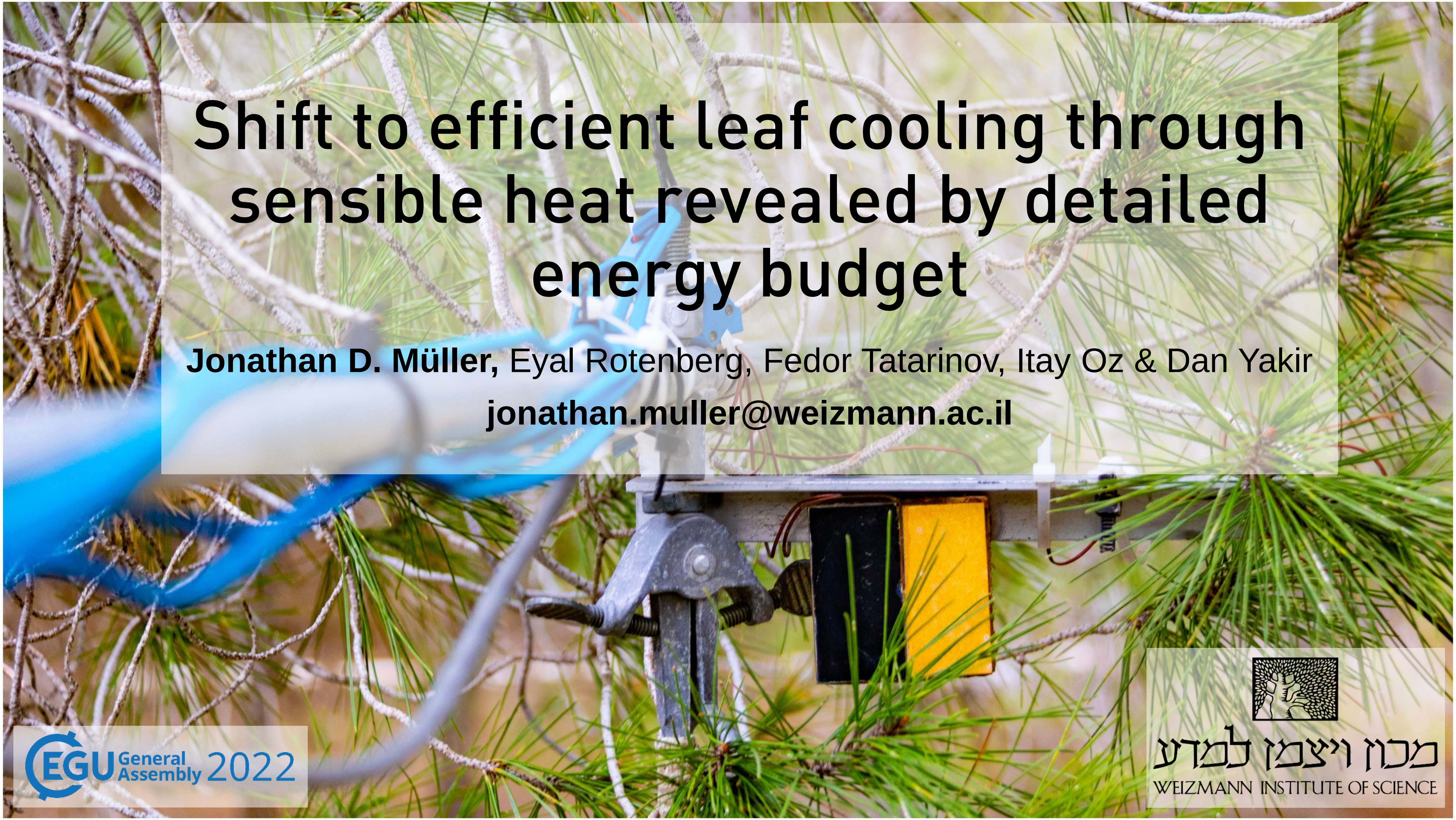

Shift to efficient leaf cooling through sensible heat revealed by detailed energy budget

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מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

The convector effect ‘paradox’

- Dryland ecosystems:
  - Forests absorb more radiation than surrounding deserts
  - No evaporative cooling
  - But: canopy temperature close to air and lower than desert ground
  - Reason: Turbulent air flow & low resistance in forests
  - Has implications for local environment and climate

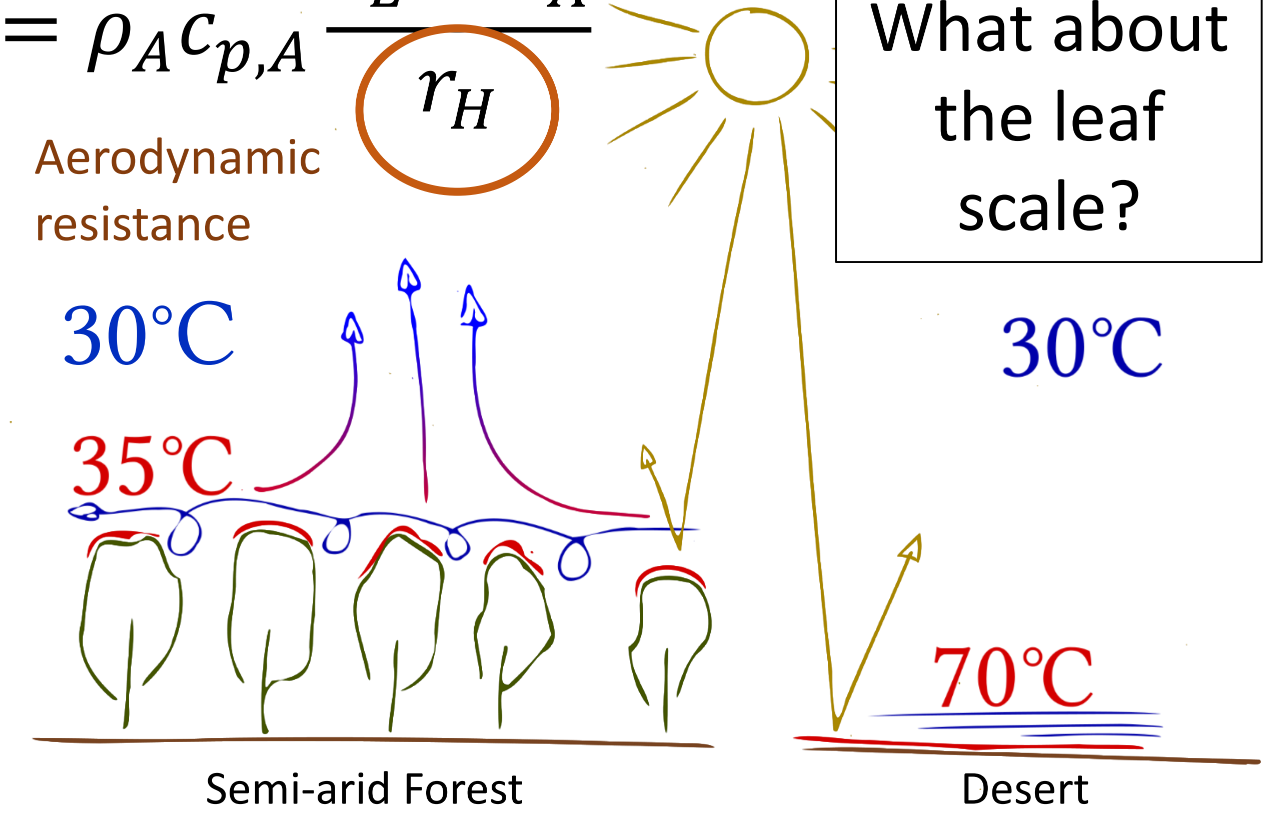
Sensible heat

$$S_{abs} + L_n = H + \cancel{LE} + \text{minor contributions}$$

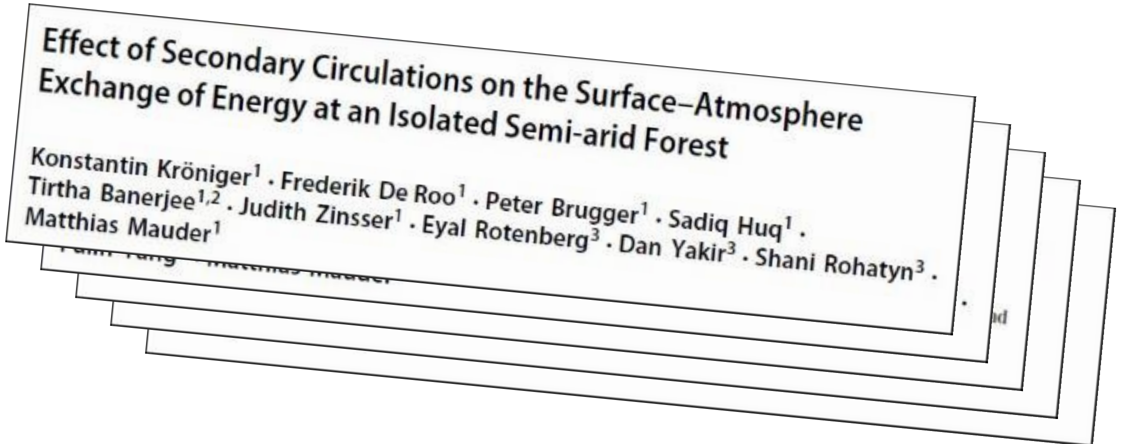
$$H = \rho_A c_{p,A} \frac{T_L - T_A}{r_H}$$

Aerodynamic resistance

What about the leaf scale?

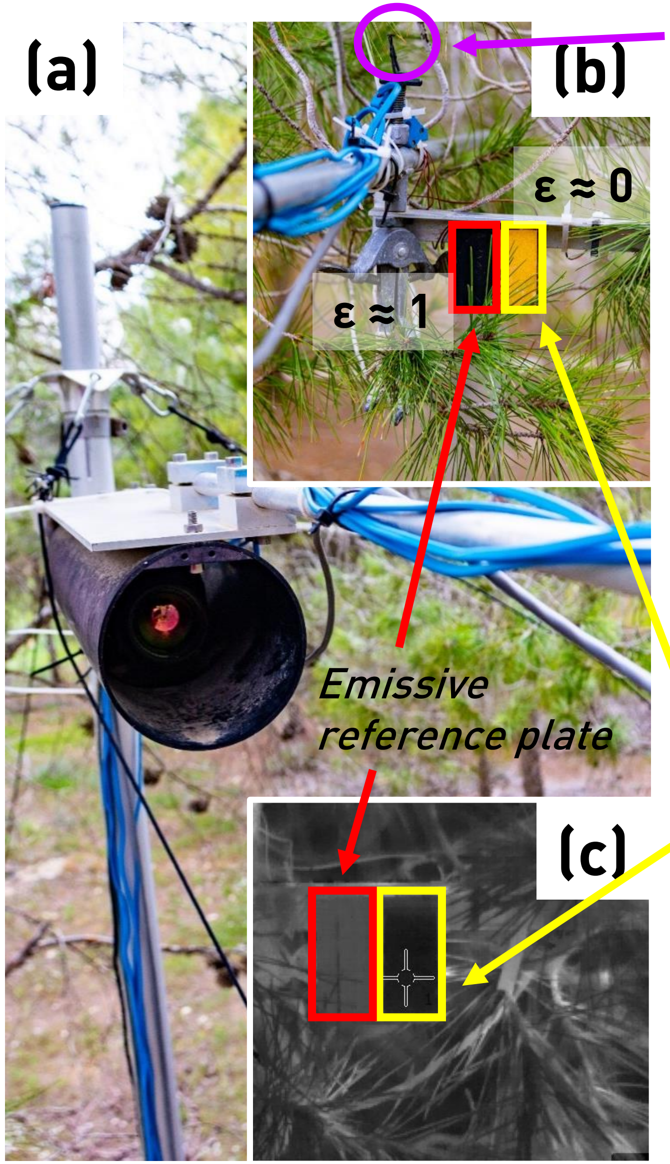


Albedo (Reflectance): forest 0.11 vs. desert 0.21


Effect of Secondary Circulations on the Surface–Atmosphere Exchange of Energy at an Isolated Semi-arid Forest

Konstantin Kröniger[1] · Frederik De Roo[1] · Peter Brugger[1] · Sadiq Huq[1] · Tirtha Banerjee[1,2] · Judith Zinsser[1] · Eyal Rotenberg[3] · Dan Yakir[3] · Shani Rohatyn[3] · Matthias Mauder[1]

Methods: Combining leaf- and twig-scale systems



Reflective reference plate

Accurate leaf system:

(a) Shortwave radiation
(b) Leaf-air temperature difference (accuracy: ±0.25°C)
(c) Longwave radiation, in & out (accuracy: ±3.45 W m^{-2} & ±1.32 W m^{-2})

Corrections for:

(a) Systematic camera offset
(b) Background radiation

(a) Thermal infrared camera,
(b) Picture frame of the camera, with the needles being measured, reference plates, and PAR sensor
(c) Infrared image of the setup

Publication: Muller et al. 2021; 'Dual-reference' method for high-precision infrared measurement of leaf surface temperature under field conditions https://doi.org/10.1111/nph.17720

$$\boxed{S_{abs} + L_n} = H + \boxed{LE + B + G}$$

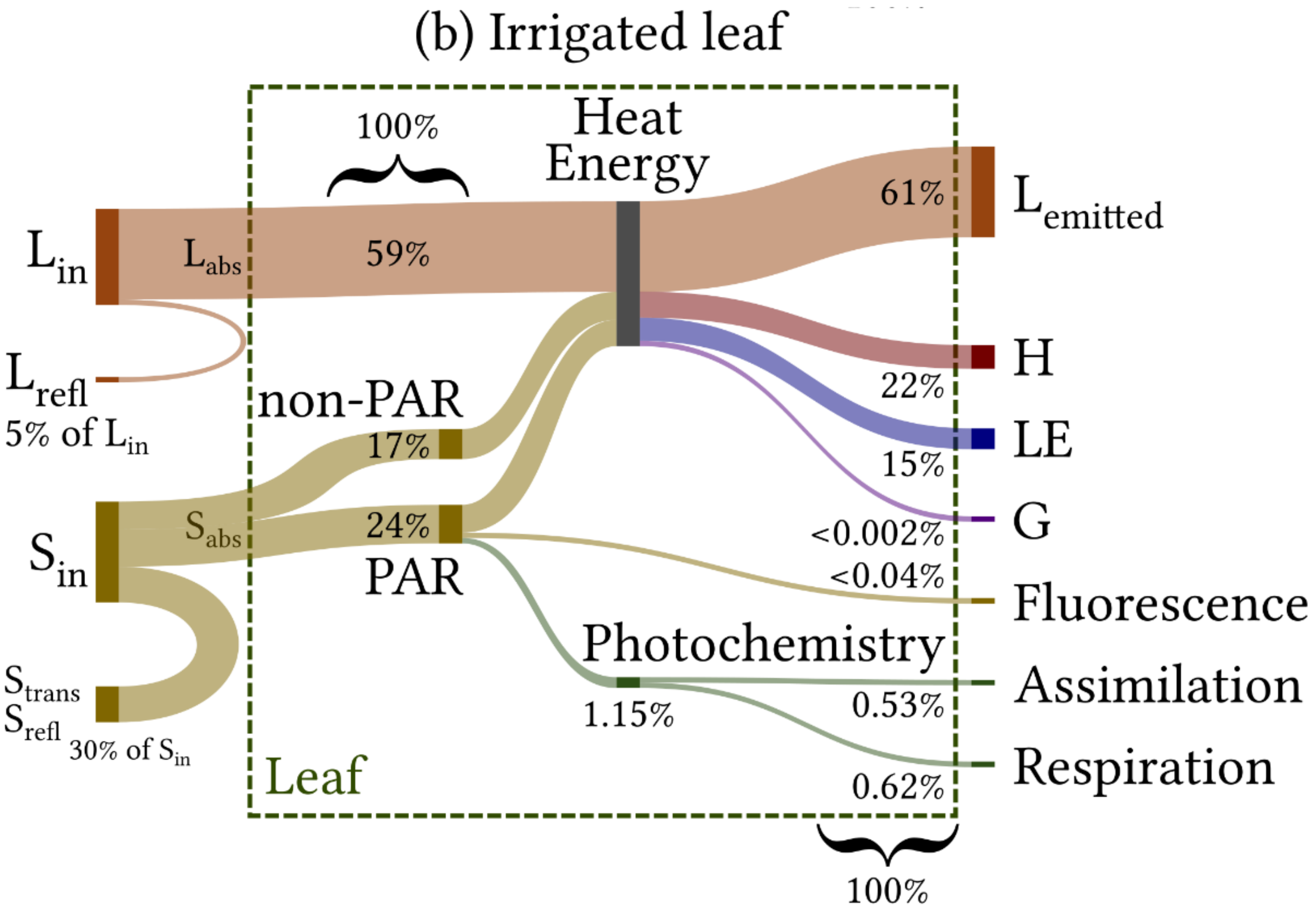
Twig-scale flux system with 16 chambers:

(a) H_2O & CO_2 flux using multiple IRGAs
(b) Combined with leaf measurements, provides: LE , B, G

Gas exchange chambers

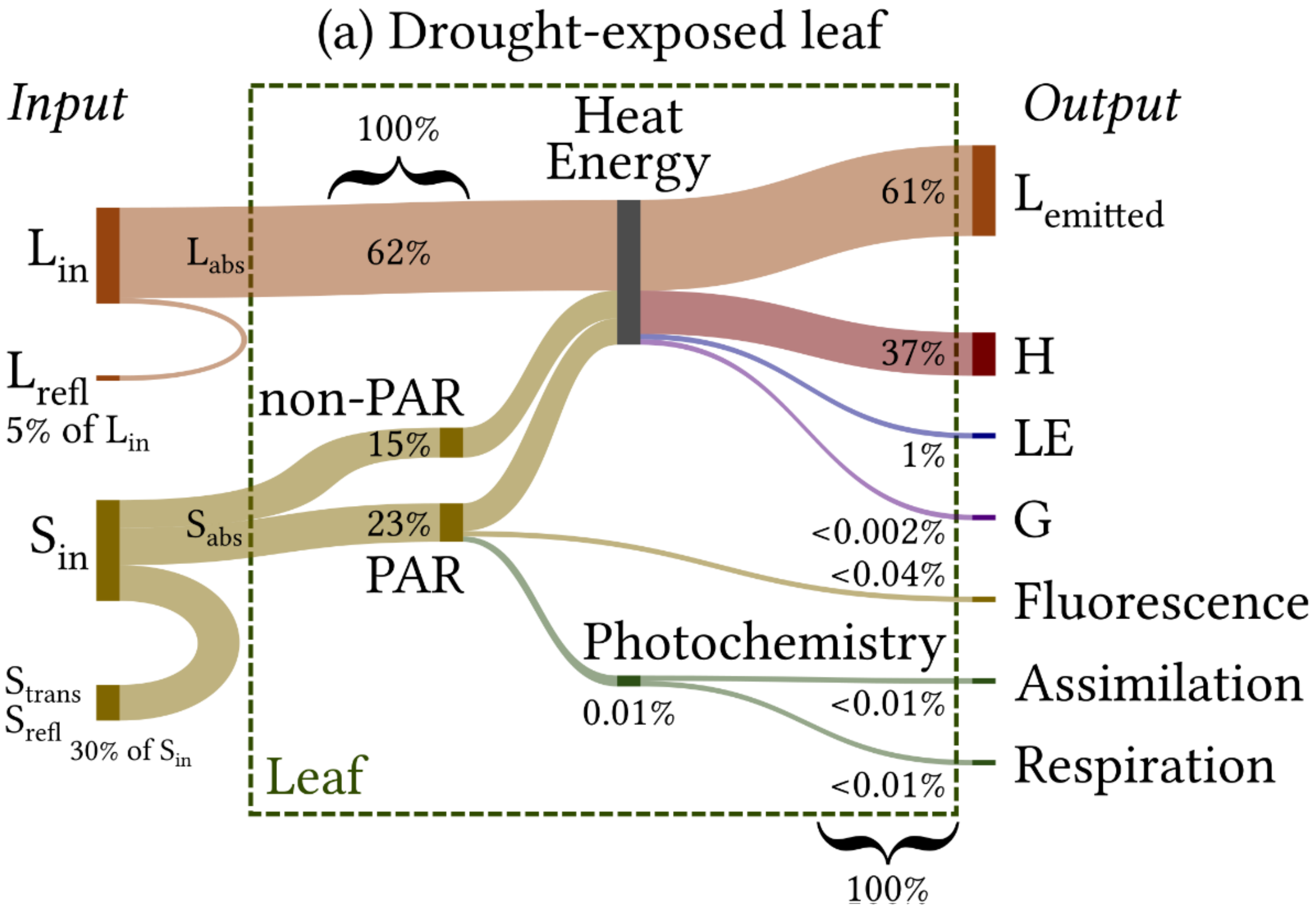
Leaf energy budgets: Irrigated, evaporating

- Ca. 60% incoming radiation longwave, 40% shortwave
- Ca. 24% PAR
- Ca. 98% to heat
- Out:
  - Ca. 60% longwave
  - Bowen ratio ca. 1.5



Leaf energy budgets: Droughted

- Ca. 60% incoming radiation longwave, 40% shortwave
- Ca. 24% PAR
- Ca. 98% to heat
- Out:
  - Ca. 60% longwave
  - Bowen ratio ca. 37 (!)
- All the heat dissipated through H

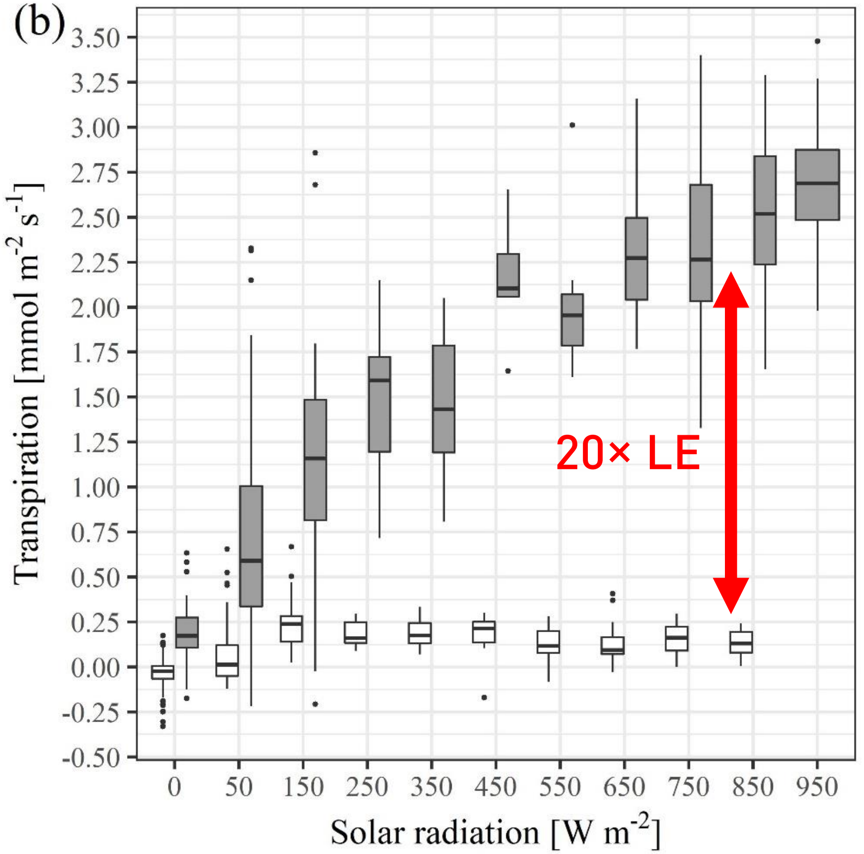


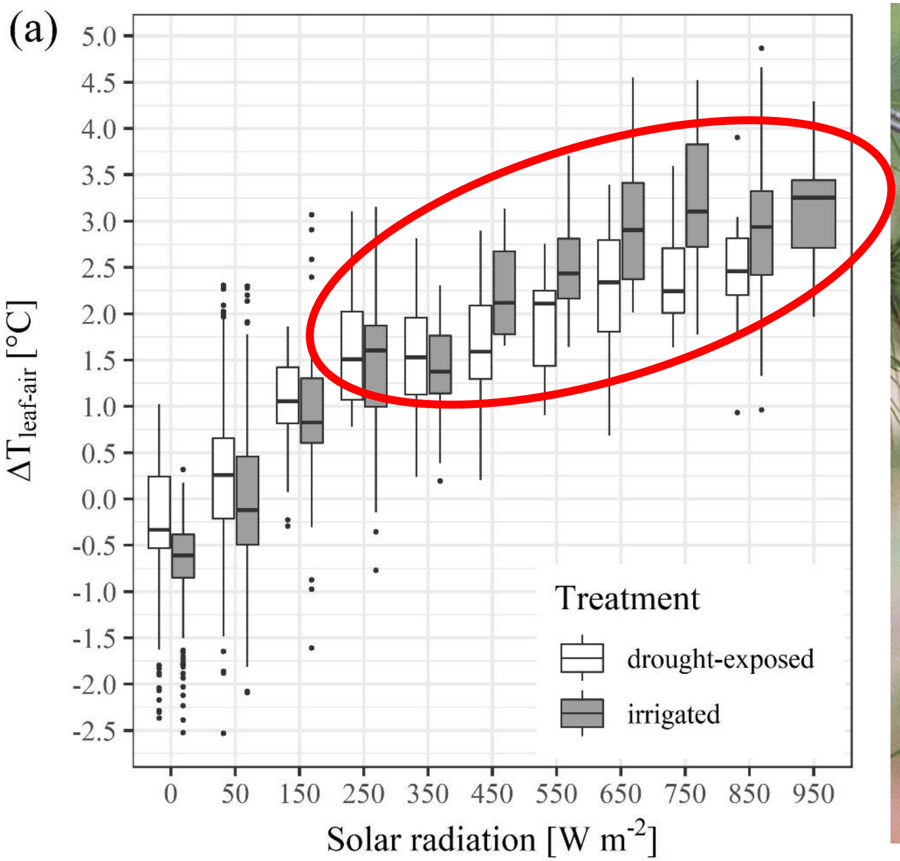
$\Delta T_{leaf\text{-}air}$ & Transpiration vs. Solar radiation

- Different transpiration throughout the day
- 20× LE in irrigation (W m^{-2})
  - Irrigation: 103 W m^{-2}
  - Drought-exposed: 5 W m^{-2}

- But: Leaf-to-air temperature difference ($\Delta T_{leaf\text{-}air}$) not significantly lower
- Leaves max. ~3.5°C above air

Publication: Muller et al. 2021; Evidence for efficient nonevaporative leaf-to-air heat dissipation in a pine forest under drought conditions https://doi.org/10.1111/nph.17742





What 'air cooling' mechanism?

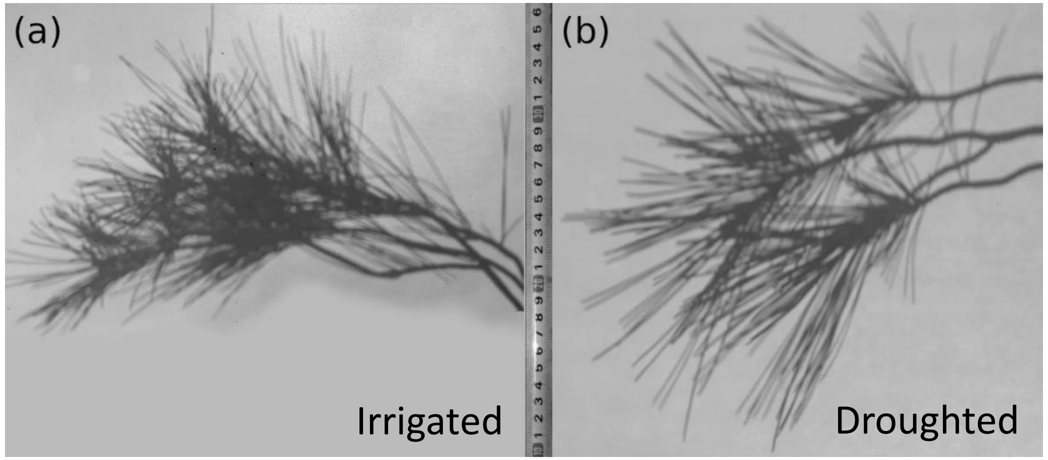
- What could explain the lack in $\Delta T_{leaf\text{-}air}$ difference?
  - Same radiation load
  - Drought: ~20× less LE
  - Similar $\Delta T_{leaf\text{-}air}$
  - Explanation: 2× lower r_H in leaves of droughted trees

Radiation load, Sensible heat, Latent heat

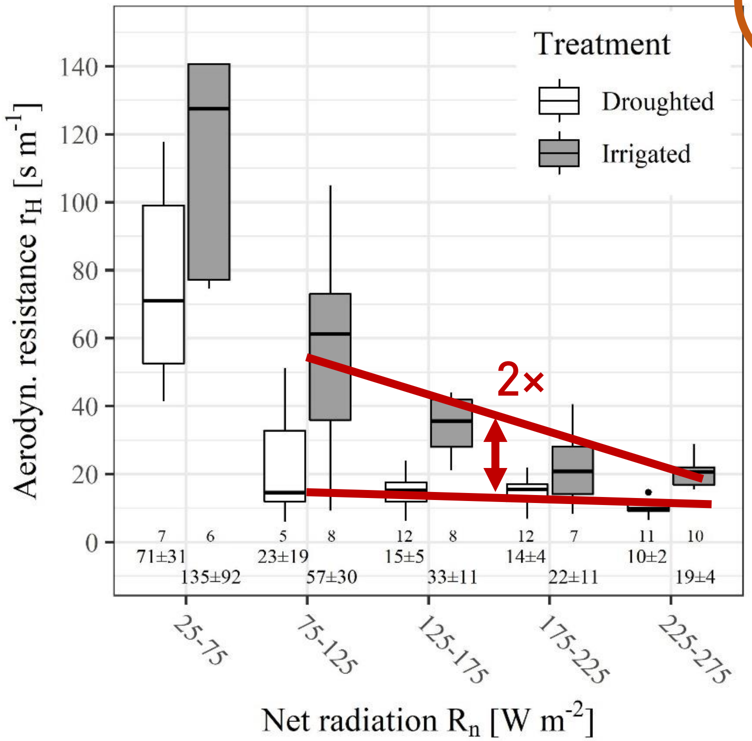
$$S_{abs} + L_n = H + LE + \text{minor contributions}$$

$$H = \rho_A c_{p,A} \frac{\Delta T_{leaf-air}}{r_H}$$

Aerodynamic resistance



Leaf distribution



Thank you

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Conclusions

- Plants optimise the energy budget to adjust to drought
  - Adjust aerodynamic resistance for cooling
  - r_H is an important parameter in Penman-Monteith and Priestly-Taylor equations
- Implications for:
  - Modelling approaches
  - Understanding how plants can adjust to climate change

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