

Non-radiative heat dissipation across scales in a water stressed pine forest: From the leaf to the planetary boundary layer

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Boundary layer scale: The 'convector effect'

With suppressed latent heat flux (LE) because of lack of water, the forest is transformed into an effective “convector” that exploits the low tree density and open canopy and, consequently, high canopy-atmosphere aerodynamic coupling.

Contribution of Semi-Arid Forests to the Climate System

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Water-cooled canopy...



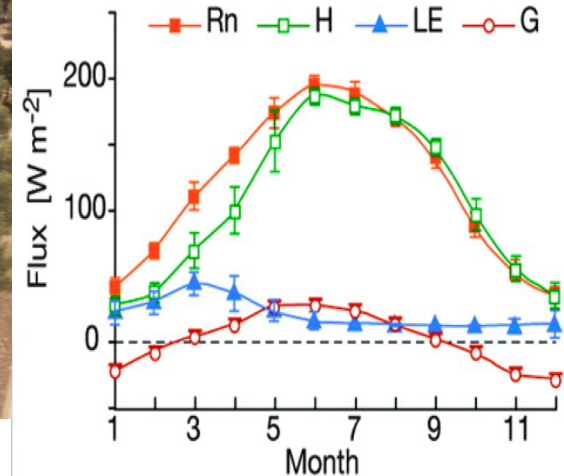
Air-cooled canopy...



Forest cooling -5C annual mean

High roughness->low r_h

$$H = \rho_a C_a \frac{(T - T_a)}{r_h}$$

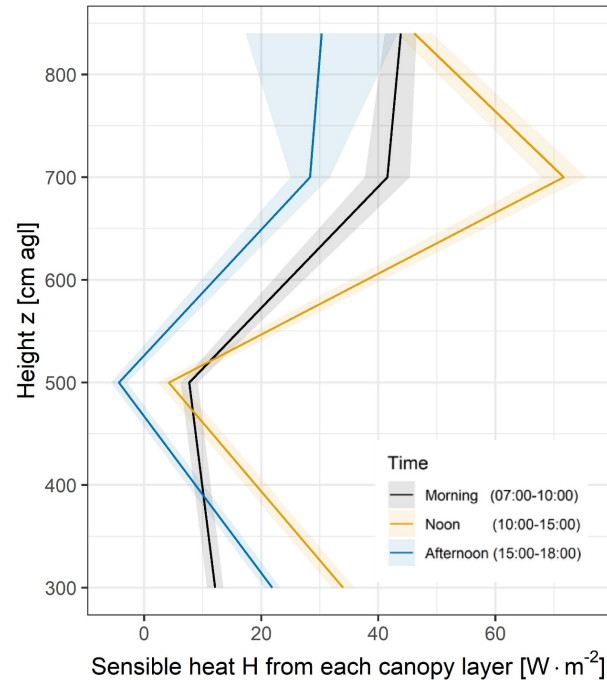


- Latent heat flux (LE) is minor
- Sensible heat (H) balance net radiation R_n

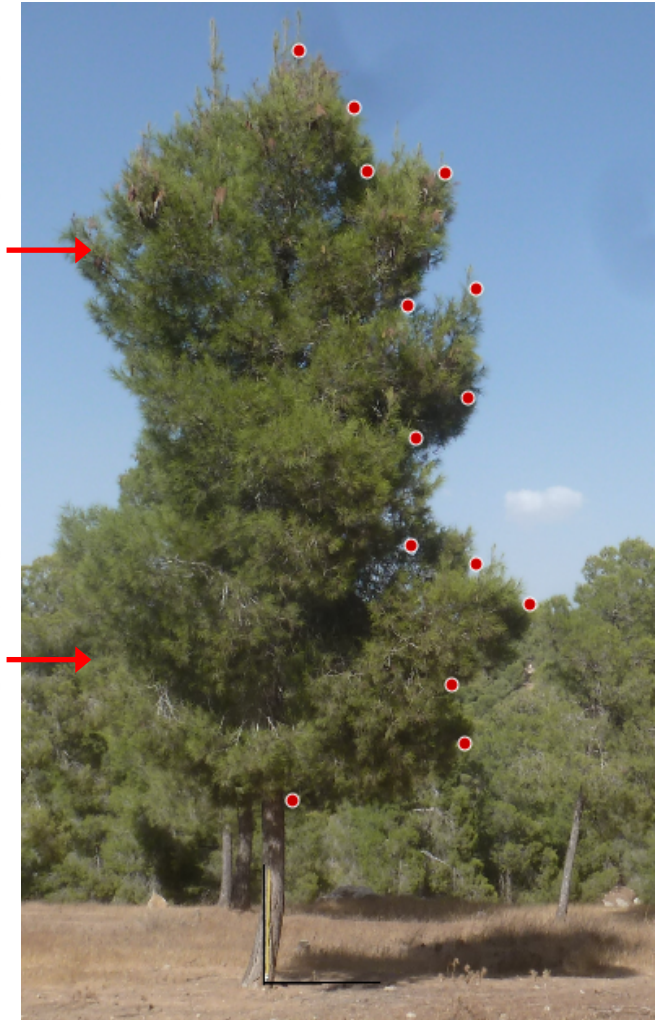


Jonathan Muller

Tree scale 1: Sensible heat from the hottest part of the canopy

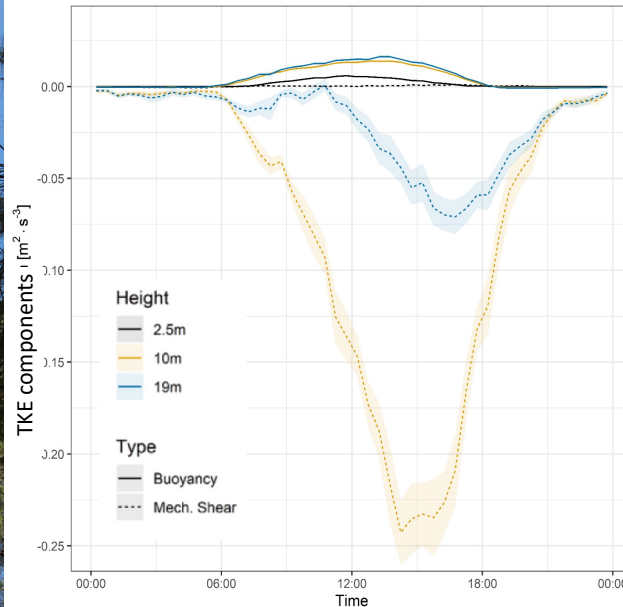


Sensible heat (H) production peak where leaf to air temperature difference is maximal

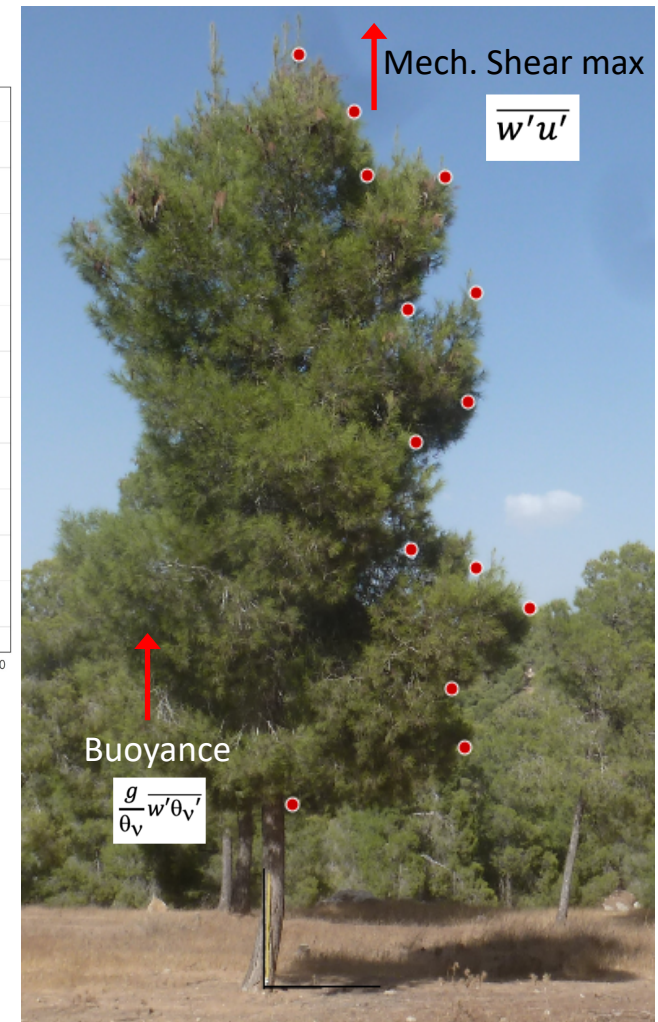


Tree scale 2: Buoyancy below canopy, mech. shear at the top

Measuring flux profiles



The main components of TKE: Mech. shear is dominant at the top of canopy (yellow); decreasing up (blue), and down (black) where Buoyancy becomes relatively more significant



Leaf scale 1: High precision leaf temperature measurements



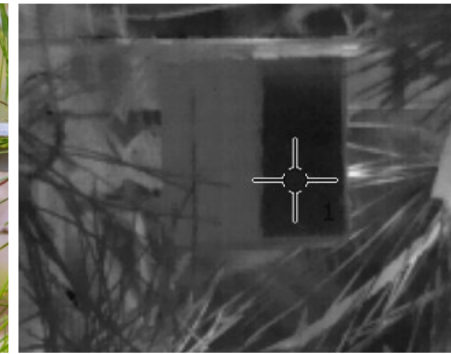
IR camera



IR camera



Low Refl. T calibration

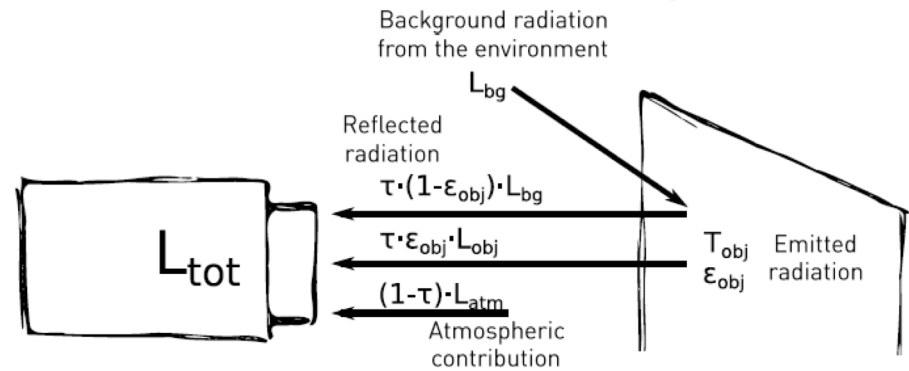


High Refl. Background correction

IR image



Measurement methods for leaf temperature



$$L_{tot} = \tau \cdot \epsilon_{obj} \cdot L_{obj} + \tau \cdot (1 - \epsilon_{obj}) \cdot L_{bg} + (1 - \tau) \cdot L_{atm}$$

Quantity of interest

Reference plate with high reflectivity

Ignored due to small distance



- Leaf temperature similar with x10 rate of evaporation
- Efficient sensible heat production at the leaf scale
- Needle leaf: low heat capacity, large surface area, low density

Figure 1 is a scatter plot showing the relationship between Photosynthetically active radiation (PAR) and the temperature difference (ΔT) between the needle and the air. The x-axis represents PAR in $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, ranging from 0 to 700. The y-axis represents ΔT in $^{\circ}\text{C}$, ranging from 0.0 to 2.5. Data points are labeled with numbers (e.g., 1515, 845, 1215, 1015, 1045, 1315, 1115, 1245, 745, 1615, 1785, 1315, 1415, 1515, 1815, 1915, 2015, 2115, 2215, 2315, 2415, 2515, 2615, 2715, 2815, 2915, 3015, 3115, 3215, 3315, 3415, 3515, 3615, 3715, 3815, 3915, 4015, 4115, 4215, 4315, 4415, 4515, 4615, 4715, 4815, 4915, 5015, 5115, 5215, 5315, 5415, 5515, 5615, 5715, 5815, 5915, 6015, 6115, 6215, 6315, 6415, 6515, 6615, 6715, 6815, 6915, 7015, 7115, 7215, 7315, 7415, 7515, 7615, 7715, 7815, 7915, 8015, 8115, 8215, 8315, 8415, 8515, 8615, 8715, 8815, 8915, 9015, 9115, 9215, 9315, 9415, 9515, 9615, 9715, 9815, 9915, 10015, 10115, 10215, 10315, 10415, 10515, 10615, 10715, 10815, 10915, 11015, 11115, 11215, 11315, 11415, 11515, 11615, 11715, 11815, 11915, 12015, 12115, 12215, 12315, 12415, 12515, 12615, 12715, 12815, 12915, 13015, 13115, 13215, 13315, 13415, 13515, 13615, 13715, 13815, 13915, 14015, 14115, 14215, 14315, 14415, 14515, 14615, 14715, 14815, 14915, 15015, 15115, 15215, 15315, 15415, 15515, 15615, 15715, 15815, 15915, 16015, 16115, 16215, 16315, 16415, 16515, 16615, 16715, 16815, 16915, 17015, 17115, 17215, 17315, 17415, 17515, 17615, 17715, 17815, 17915, 18015, 18115, 18215, 18315, 18415, 18515, 18615, 18715, 18815, 18915, 19015, 19115, 19215, 19315, 19415, 19515, 19615, 19715, 19815, 19915, 20015, 20115, 20215, 20315, 20415, 20515, 20615, 20715, 20815, 20915, 21015, 21115, 21215, 21315, 21415, 21515, 21615, 21715, 21815, 21915, 22015, 22115, 22215, 22315, 22415, 22515, 22615, 22715, 22815, 22915, 23015, 23115, 23215, 23315, 23415, 23515, 23615, 23715, 23815, 23915, 24015, 24115, 24215, 24315, 24415, 24515, 24615, 24715, 24815, 24915, 25015, 25115, 25215, 25315, 25415, 25515, 25615, 25715, 25815, 25915, 26015, 26115, 26215, 26315, 26415, 26515, 26615, 26715, 26815, 26915, 27015, 27115, 27215, 27315, 27415, 27515, 27615, 27715, 27815, 27915, 28015, 28115, 28215, 28315, 28415, 28515, 28615, 28715, 28815, 28915, 29015, 29115, 29215, 29315, 29415, 29515, 29615, 29715, 29815, 29915, 30015, 30115, 30215, 30315, 30415, 30515, 30615, 30715, 30815, 30915, 31015, 31115, 31215, 31315, 31415, 31515, 31615, 31715, 31815, 31915, 32015, 32115, 32215, 32315, 32415, 32515, 32615, 32715, 32815, 32915, 33015, 33115, 33215, 33315, 33415, 33515, 33615, 33715, 33815, 33915, 34015, 34115, 34215, 34315, 34415, 34515, 34615, 34715, 34815, 34915, 35015, 35115, 35215, 35315, 35415, 35515, 35615, 35715, 35815, 35915, 36015, 36115, 36215, 36315, 36415, 36515, 36615, 36715, 36815, 36915, 37015, 37115, 37215, 37315, 37415, 37515, 37615, 37715, 37815, 37915, 38015, 38115, 38215, 38315, 38415, 38515, 38615, 38715, 38815, 38915, 39015, 39115, 39215, 39315, 39415, 39515, 39615, 39715, 39815, 39915, 40015, 40115, 40215, 40315, 40415, 40515, 40615, 40715, 40815, 40915, 41015, 41115, 41215, 41315, 41415, 41515, 41615, 41715, 41815, 41915, 42015, 42115, 42215, 42315, 42415, 42515, 42615, 42715, 42815, 42915, 43015, 43115, 43215, 43315, 43415, 43515, 43615, 43715, 43815, 43915, 44015, 44115, 44215, 44315, 44415, 44515, 44615, 44715, 44815, 44915, 45015, 45115, 45215, 45315, 45415, 45515, 45615, 45715, 45815, 45915, 46015, 46115, 46215, 46315, 46415, 46515, 46615, 46715, 46815, 46915, 47015, 47115, 47215, 47315, 47415, 47515, 47615, 47715, 47815, 47915, 48015, 48115, 48215, 48315, 48415, 48515, 48615, 48715, 48815, 48915, 49015, 49115, 49215, 49315, 49415, 49515, 49615, 49715, 49815, 49915, 50015, 50115, 50215, 50315, 50415, 50515, 50615, 50715, 50815, 50915, 51015, 51115, 51215, 51315, 51415, 51515, 51615, 51715, 51815, 51915, 52015, 52115, 52215, 52315, 52415, 52515, 52615, 52715, 52815, 52915, 53015, 53115, 53215, 53315, 53415, 53515, 53615, 53715, 53815, 53915, 54015, 54115, 54215, 54315, 54415, 54515, 54615, 54715, 54815, 54915, 55015, 55115, 55215, 55315, 55415, 55515, 55615, 55715, 55815, 55915, 56015, 56115, 56215, 56315

Figure 1 is a scatter plot showing the relationship between Transpiration (mmol m⁻² s⁻¹) on the y-axis and VPD (kPa) on the x-axis. The y-axis ranges from 0 to 5, and the x-axis ranges from 0 to 6. Two data series are plotted: irrigated trees (blue circles) and drought trees (red triangles). Both series include error bars. The irrigated trees show a positive correlation, with a regression line and R²=0.97. The drought trees show a negative correlation, with a regression line and R²=0.63. The plot is labeled 'Irrigated trees' and 'drought trees' on the right side.

VPD (kPa)	Irrigated trees Transpiration (mmol m ⁻² s ⁻¹)	Drought trees Transpiration (mmol m ⁻² s ⁻¹)
0.2	0.5	0.4
0.8	0.9	0.5
1.2	1.3	0.5
1.6	1.6	0.4
2.2	2.1	0.3
2.6	2.4	0.3
3.2	2.7	0.3
3.6	3.0	0.3
4.2	3.2	0.3
4.6	3.1	0.4
5.2	4.2	0.4

Conclusions

- The "convective effect" evolves from the leaf, through tree, to the canopy scale
- Main source of sensible heat below top of canopy, with Buoyancy (B) production of turbulence below and Mech. Shear (MS) production above
- Leaf temperature can be controlled independently of evaporation rate
- At all scales, heat is dissipated via non evaporative and non-radiative processes
- Such processes infer resilience to forests under dry conditions
- Indicating potential adjustments in forest in regions undergoing drying and warming climatic trends

