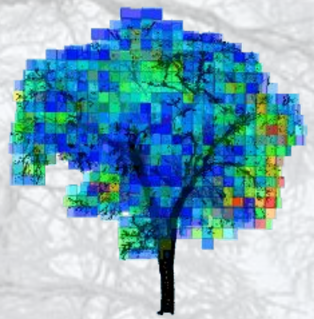
Stem heat storage in broad-leaved forests: modeling using ground lidar, and its role in the energy balance closure

Martin Beland (Digital Forest Lab, Laval University, Canada)
Gordon Bonan (NCAR)
Hideki Kobayashi (JAMSTEC, Japan)
Dennis Baldocchi (UC Berkeley)



CESM Land Model Working Group Meeting 2025

Context

- Stem heat storage affects forest **microclimates**, absorbing radiation during the day and releasing heat at night
- Studies of biomass heat storage have used simplified modeling approaches based on few experimental observations
- **Ground lidar** provides enhanced canopy structure information

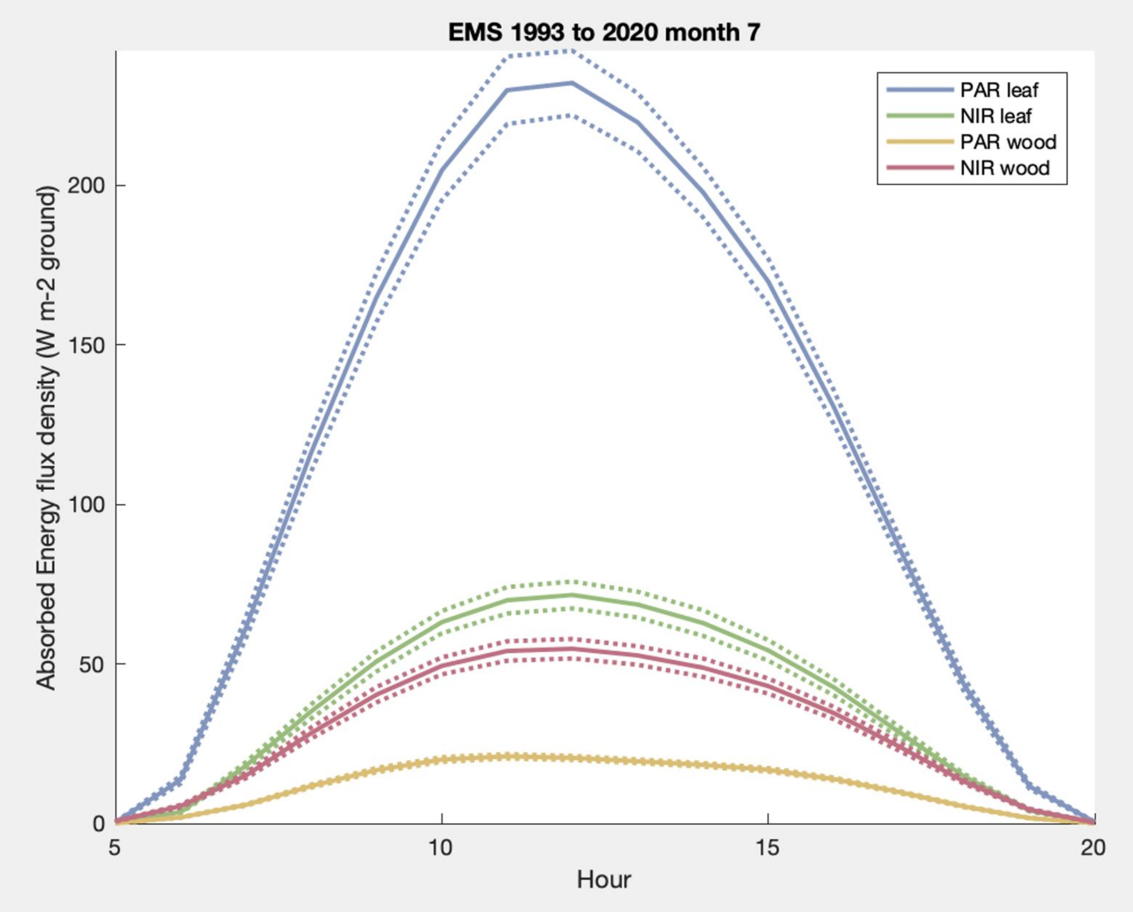
Questions asked

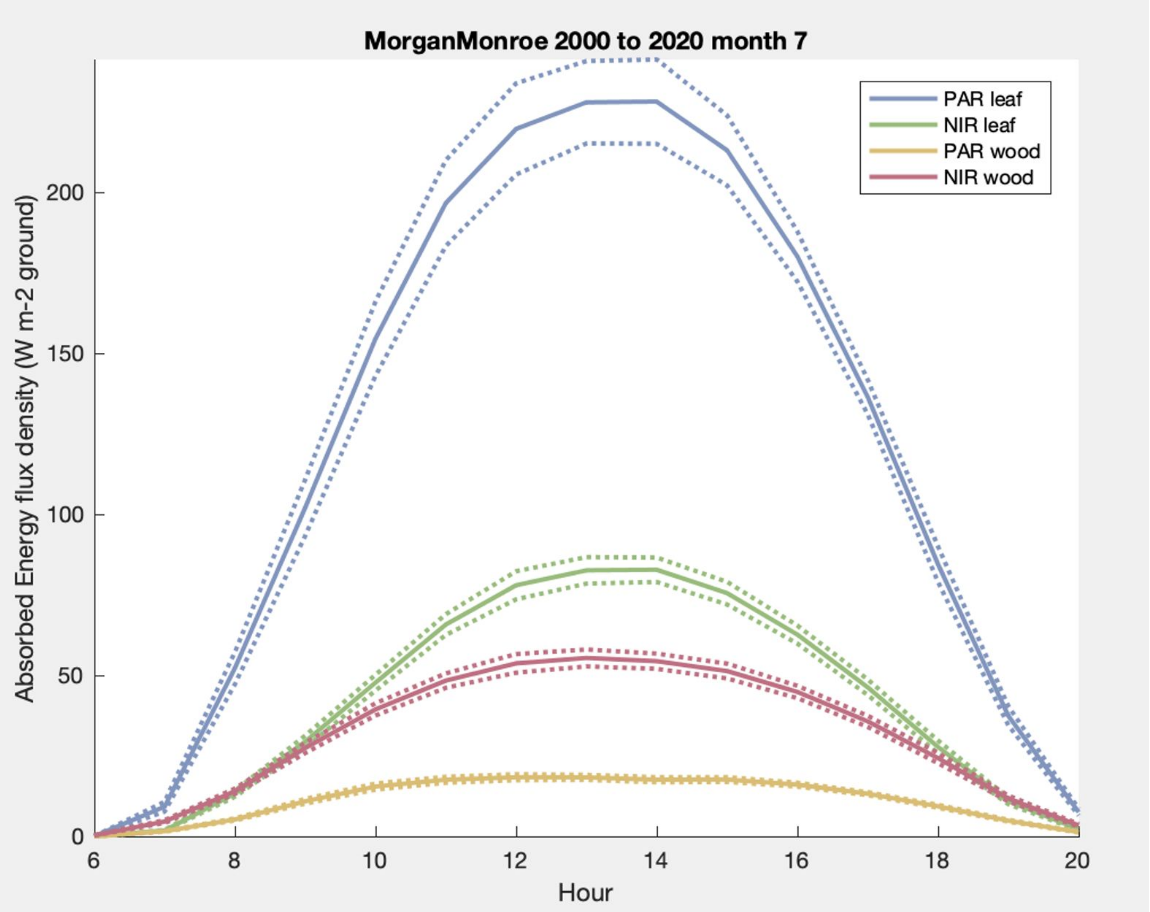
- How much radiation is absorbed by wood compared to leaves in broad-leaf forests?
- What is the role of stem heat storage in the energy balance closure at eddy covariance sites?
- Using a 1D radiative transfer models modified to consider radiation absorption wood and the effects of clumping, how close to 3D ray tracing estimates can we get?

PAR absorbed

NIR absorbed

Light absorption by leaves and wood





- In NIR, around 43% of energy absorption within the canopy was from wood
- In PAR, only about 10%

M. Beland, Agricultural and Forest Meteorology, in review

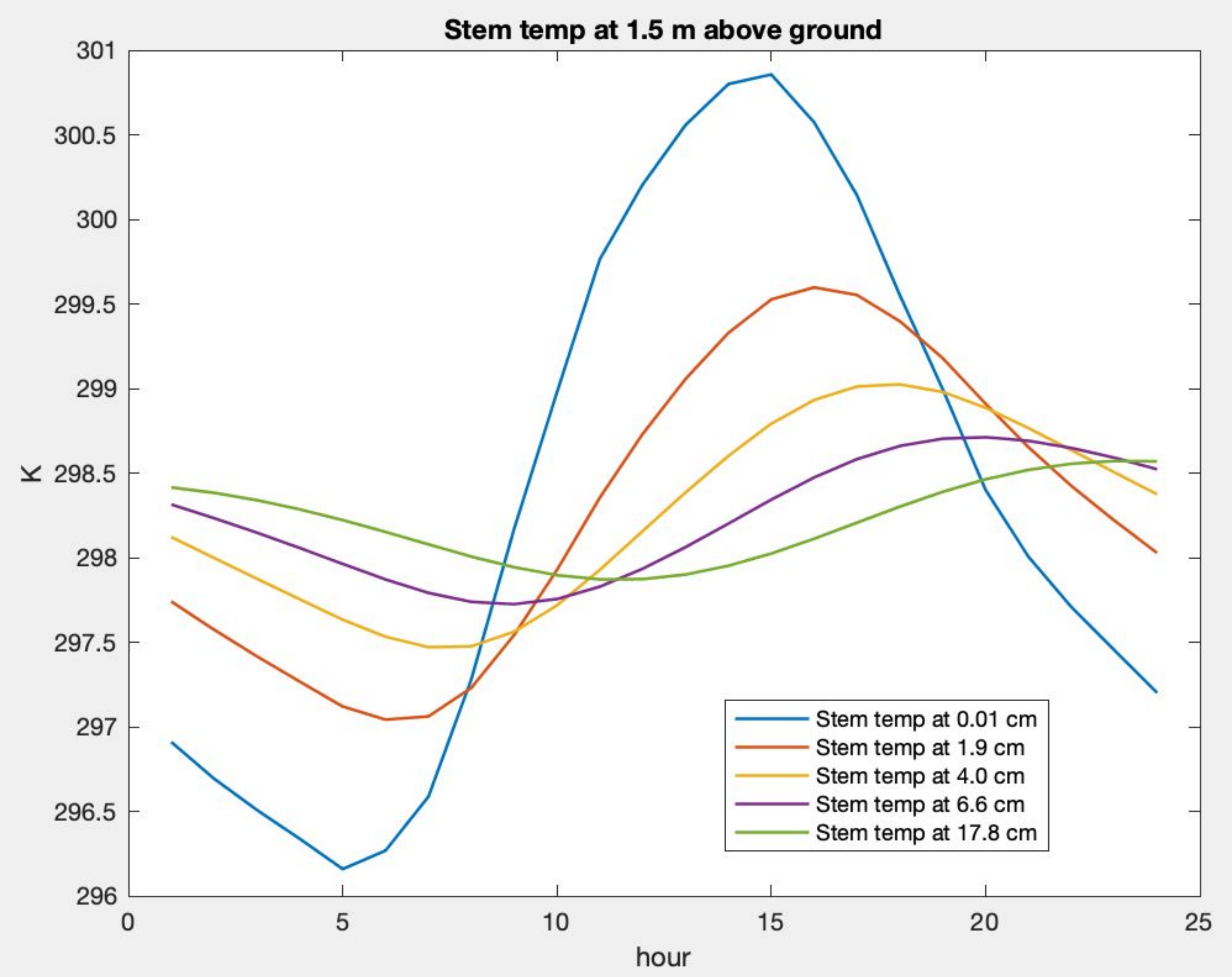
To model stem heat storage, we need :

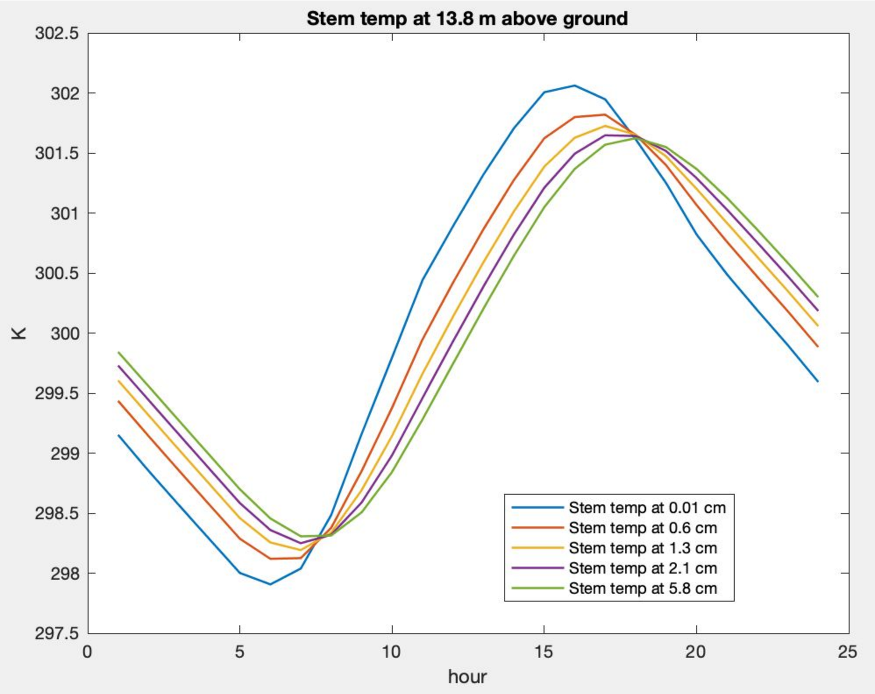
1. Amount of radiation absorbed by stems
2. Diameters of stems at different heights (a small branch has less volume to store heat than a large trunk)
3. Heat capacity and thermal conductance of stems
4. Theoretical approach and numerical methods to calculate stem surface temperature and heat conduction within stems

Stem heat storage - Methods

- **We used 3 sites along a canopy structure gradient:**
  - Harvard Forest
  - Morgan Monroe
  - Pasoh Forest (Malaysia)
- **Ground lidar provides:**
  - 3D mapping of wood structures and leaves
  - Vertical profiles of stem and branches diameters
- **3D ray tracing radiative transfer model:**
  - Mapping of absorbed solar radiation by leaves and wood
  - Output converted to 1-D for use in Canveg
- **Multilayer canopy model (Canveg)**
  - Scaling of CO_2, water vapor and heat transfer from leaf to canopy
  - Inputs environmental data (incoming radiation, air temp, CO_2, humidity,…)
  - Outputs turbulent fluxes, GPP, heat storage

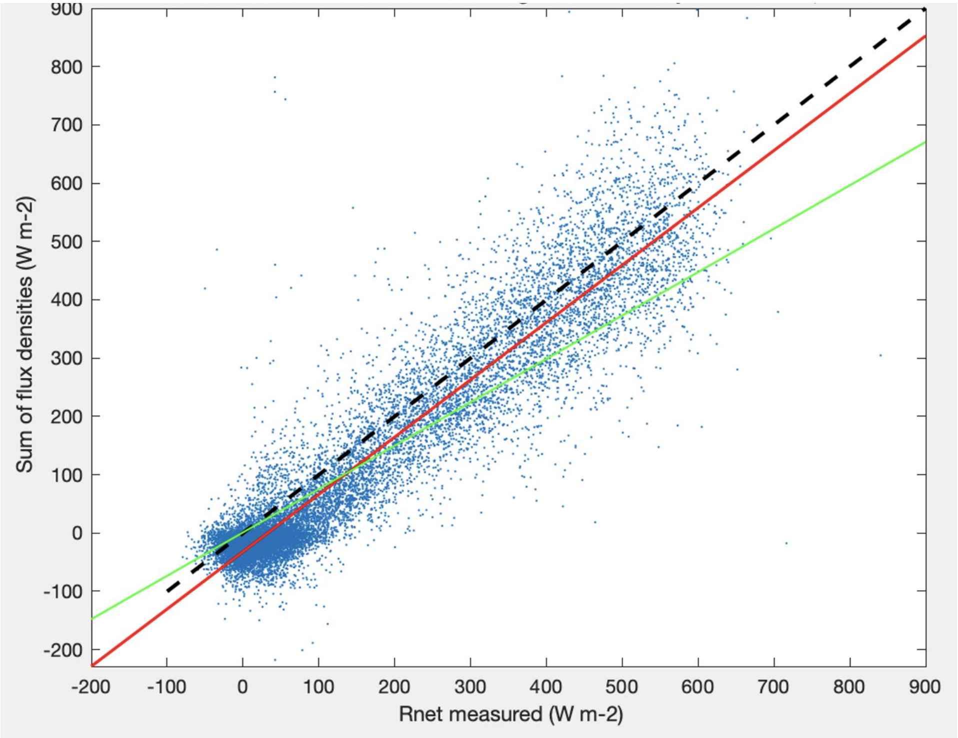
Heat conduction in stems



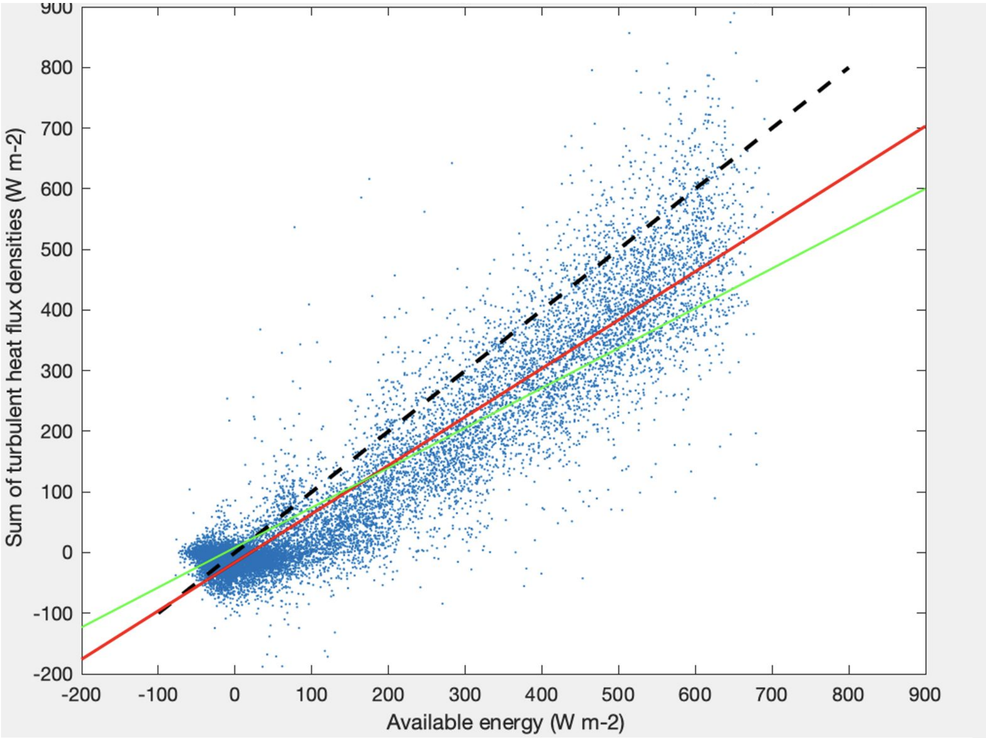


Contribution of stem heat storage to energy balance closure

Harvard Forest



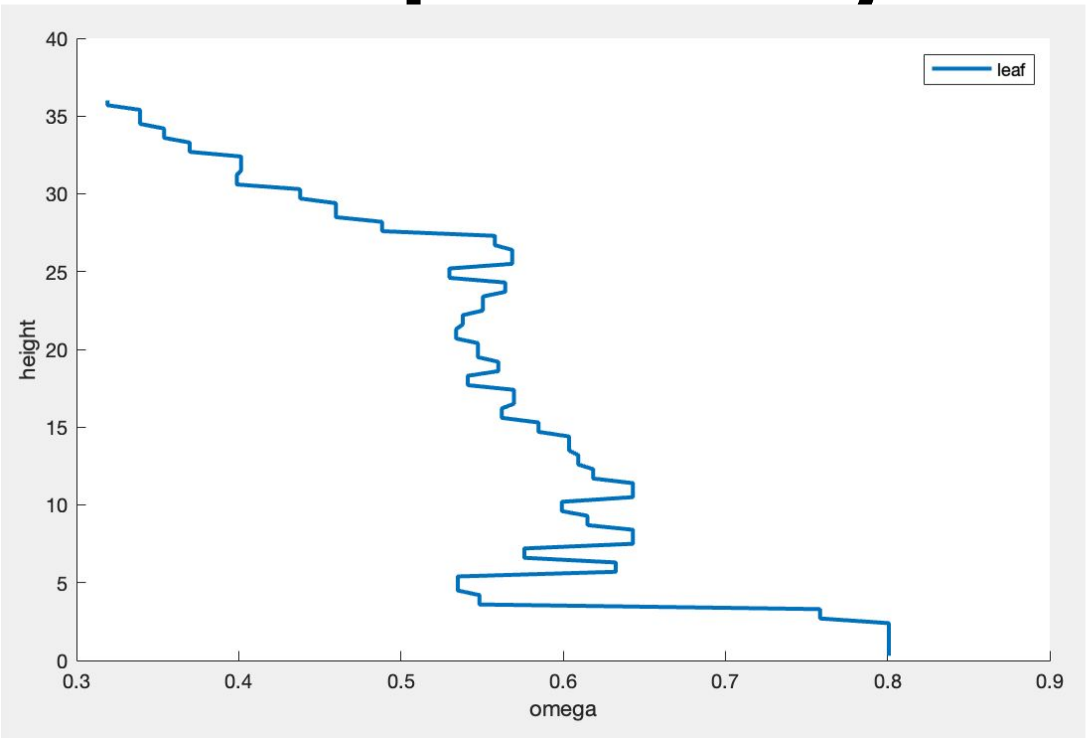
Morgan Monroe



Site	Slope of linear regression between available energy and turbulent heat	
	No stem heat storage	**With stem** heat storage
Harvard Forest	0.74 (0.8 with modeled G_{soil})	0.98 (23% ↑)
Morgan Monroe	0.66	0.81 (23% ↑)

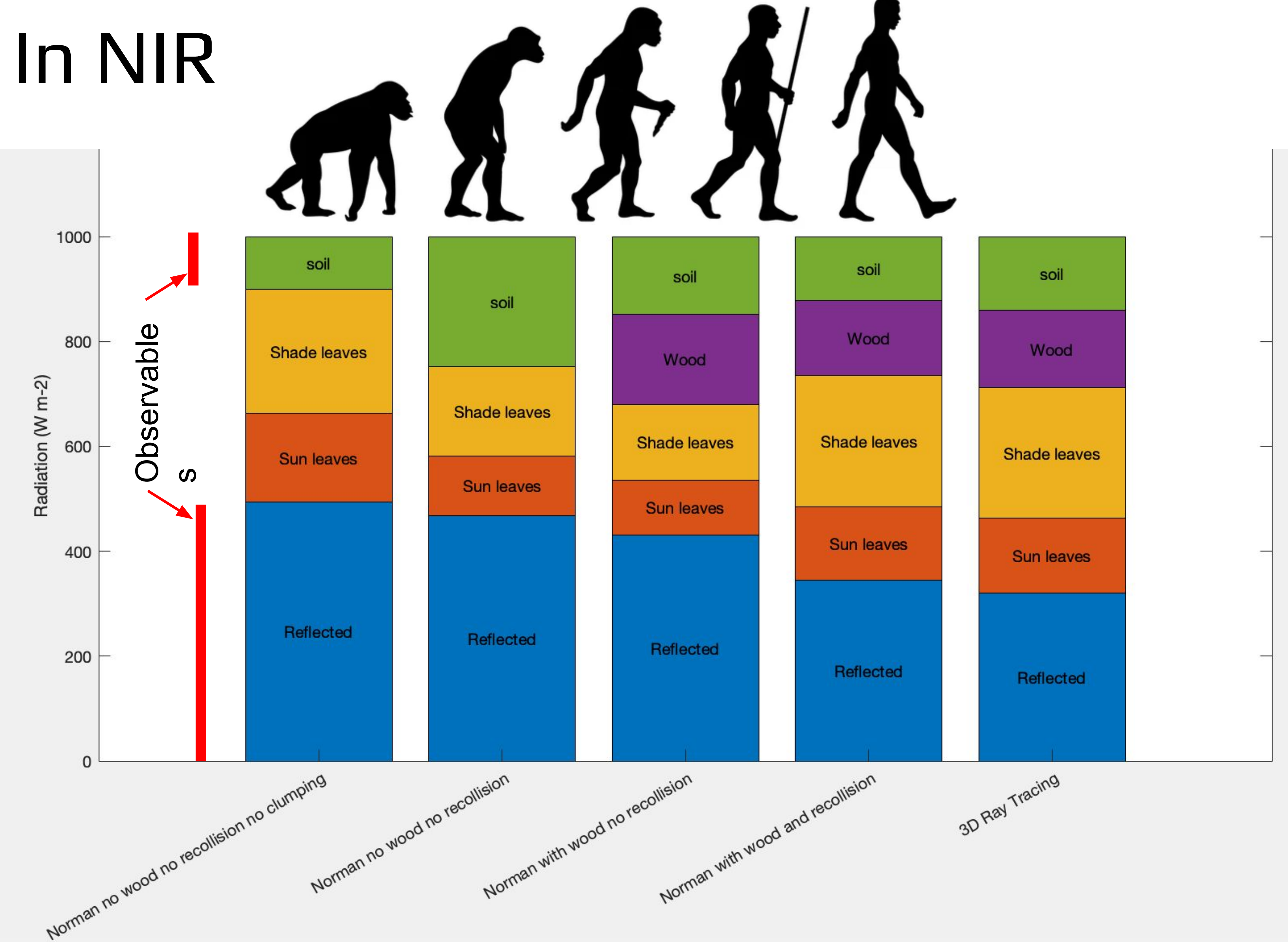
Beland et al. Agricultural and Forest Meteorology, in

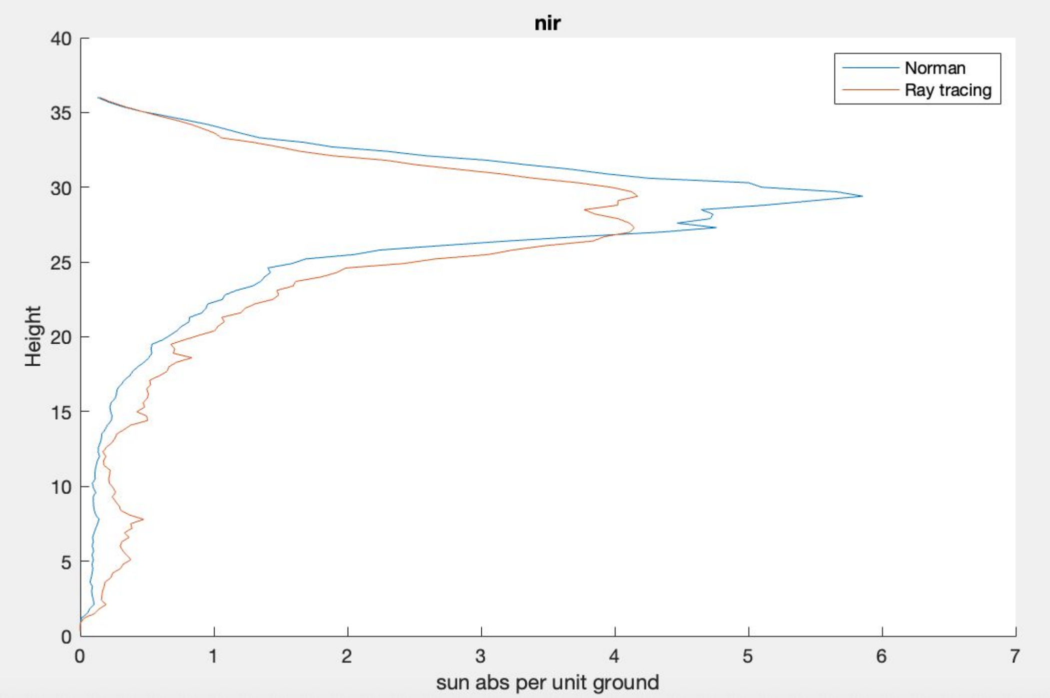
Previous results used 3D ray tracing, now to modify simple 1D Radiative transfer schemes to account for **clumping profiles**, **wood absorption** and **Recollision probability**



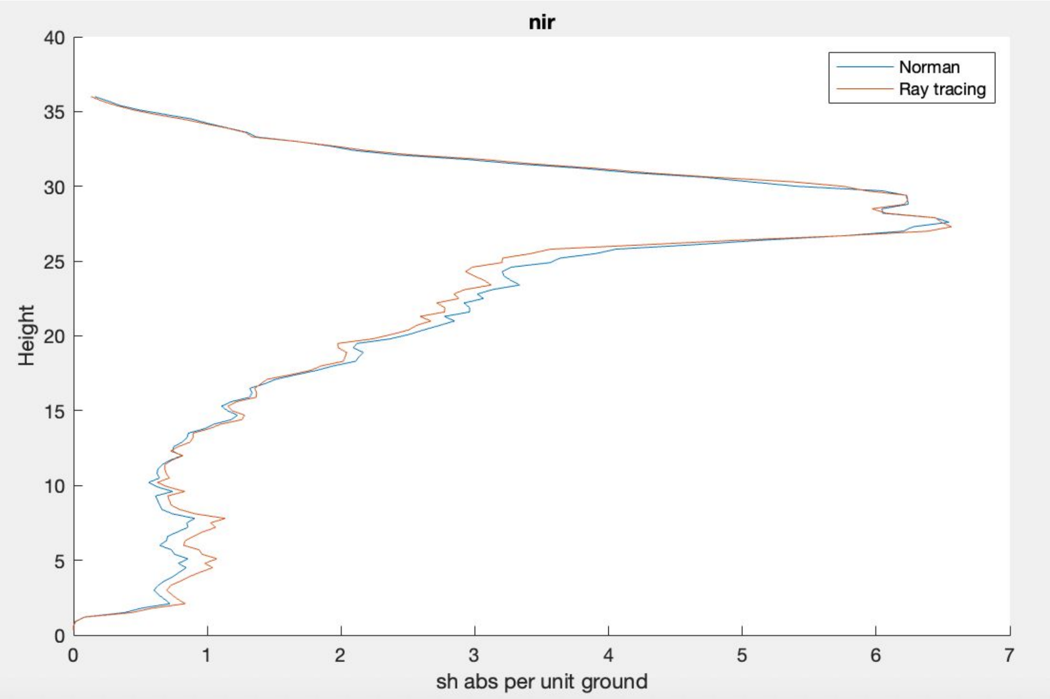
The evolution of radiative transfer modeling in forests

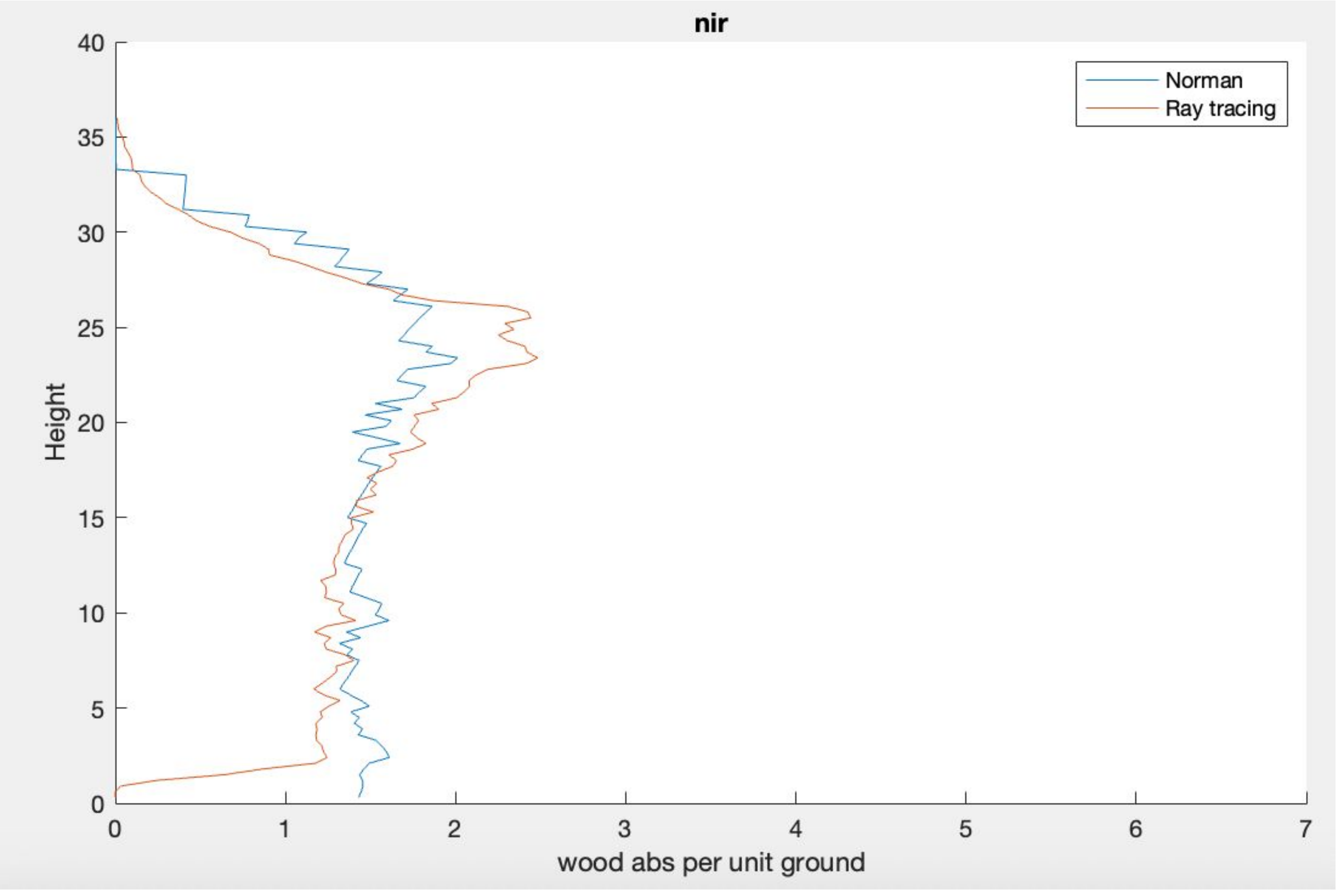
In NIR





3D vs 1D modeling of absorbed radiation vertical profiles





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Conclusion

- Ground lidar contributes to better observations of canopy structure and has a role in guiding improvements to simpler models
- Correctness of 1D model estimates are sensitive to clumping profiles (including wood clumping!) which are difficult to observe, and such observations remain rare
- This work aims at **improving overall agreement between observations and model parameters & outputs,** to reduce model adjustments which may result in intractable effects