Scale issue in quantifying the sensitivity of surface temperature to land use and land cover change-induced biophysical changes

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Overarching question

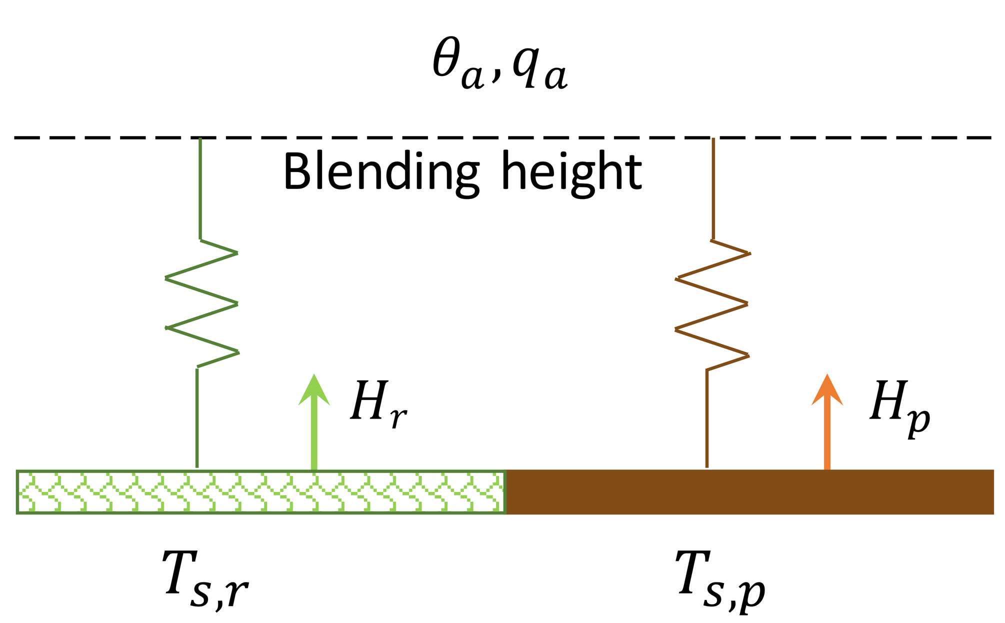
- How much does the surface temperature change when land surface biophysical factors, including surface albedo (α), aerodynamic features, as well as conditions that regulate water exchanges between the land and the atmosphere such as moisture availability (β), are perturbed by a finite amount (Δ)?

- Assumptions:

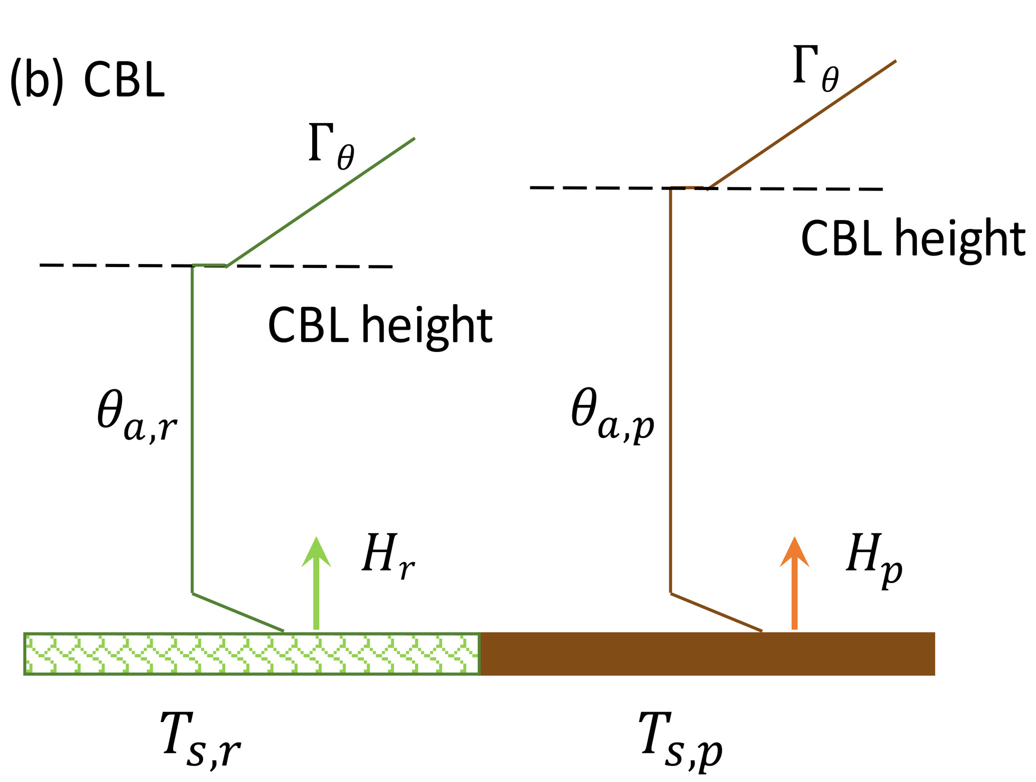
1. Part of an infinitely large and uniform reference patch is perturbed by altering certain biophysical factors, thereby creating a perturbed patch of a limited size (x_o) surrounded by the reference patch.
2. The perturbations are assumed to be uniform.
3. We treat this problem as either one-dimensional or two-dimensional.
4. We treat biophysical properties as external parameters to our coupled land-atmosphere system and thus ignore any feedbacks on biophysical properties. However, we do consider atmospheric feedbacks on the surface energy budget.

One-dimensional (z) conceptualization

(a) TRM

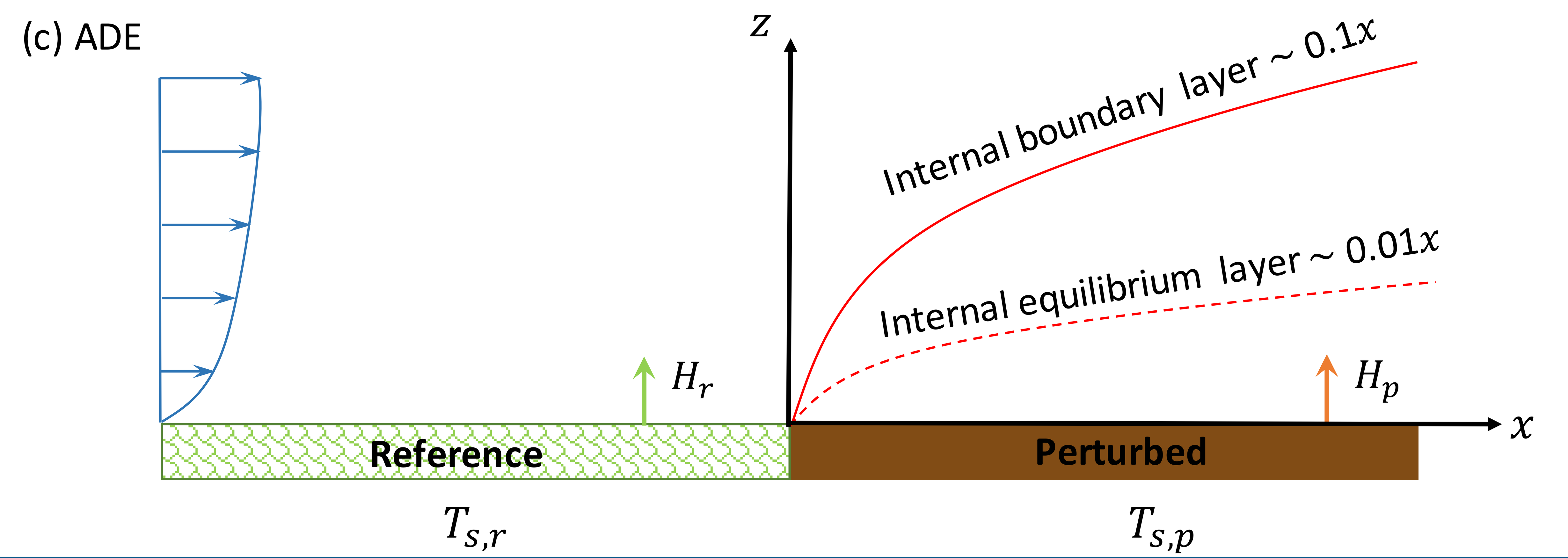


(b) CBL



Two-dimensional (x-z) conceptualization

(c) ADE



Three different models and their scales

(a) Two-Resistance Mechanism (TRM) model (Rigden and Li 2017; Liao et al. 2018)

1. Changes in biophysical properties only affect surface temperature, but not atmospheric properties.
2. Patch size x_o needs to be smaller than 10 z, where z is the height at which the atmospheric conditions are imposed. Given z ~ 10 m, x_o < 100 m.

(b) Convective Boundary Layer (CBL) model (Tennekes 1973)

1. Changes in biophysical properties affect surface temperature, and also atmospheric properties within the whole atmospheric boundary layer column.
2. Patch size x_o needs to be larger than $U(h/w_*)$, where h is the convective boundary layer height and w_* is the convective velocity scale. Given h ~ 1-2 km, U ~ 10 m/s and w_* ~ 1 m/s, x_o > 10 -20 km.

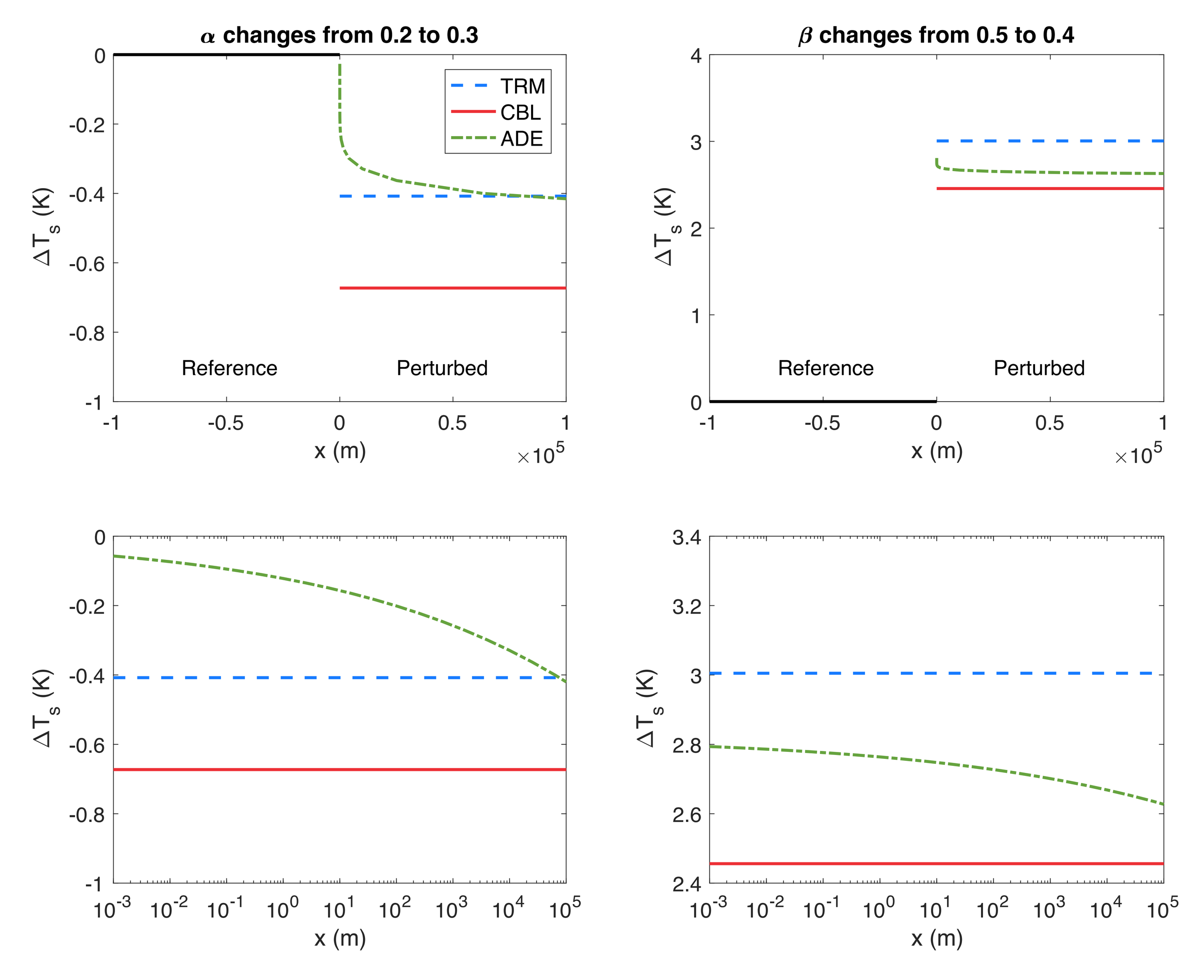
(c) Advection-Diffusion Equation (ADE) model (Philip 1959; Yeh and Brutsaert 1971; Li and Bou-Zeid 2013)

1. Changes in biophysical properties affect surface temperature, and also atmospheric properties in the near-surface region constrained by the advection-diffusion equation.
2. The advective effects need to be considered when 100 m < x_o < 10-20 km.

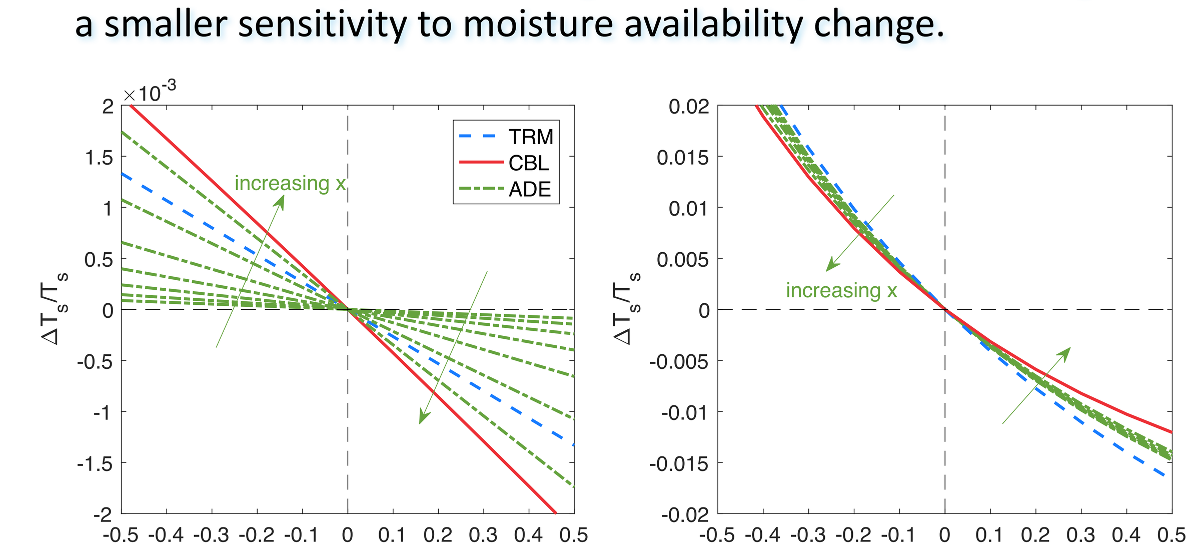
(d) Asymptotic behaviors

1. The differences between the ADE model at large and small x should resemble 'qualitatively' the differences between the CBL and TRM models.

Model Results



1. The TRM and CBL models produce scale-independent changes in surface temperature, while the ADE model produces scale-dependent changes in surface temperature, as expected.
2. The CBL model produces a larger sensitivity to albedo change, but a smaller sensitivity to moisture availability change.

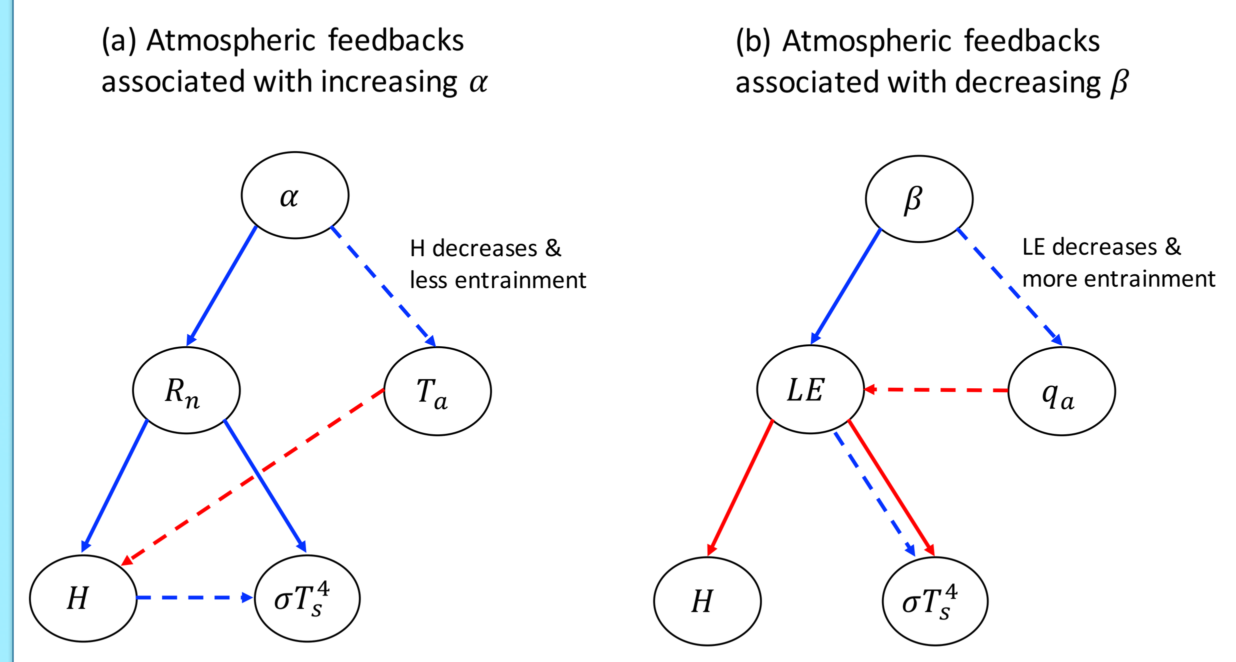


1. The sensitivity to albedo change (considering the magnitude) increases with increasing x, but the sensitivity to moisture availability change decreases with increasing x.
2. All models suggest that the sensitivity to moisture availability change is an order of magnitude larger than the sensitivity to albedo change.

Why?

Q: Why does the surface temperature sensitivity to albedo increase with x but its sensitivity to moisture availability decrease with x?

A: Atmospheric feedbacks.



Q: Why does the ADE model produces a discontinuity at x = 0 when the moisture availability changes?

A: $\Delta T_s = (1 - f_{ADE})(-\Delta\beta)T_1^* + f_{ADE}(-\Delta\alpha)T_2^*$

where $f_{ADE} \sim 0.01\, x^{1/9}$ and T_1^* and T_2^* are two scaling factors. Hence, $\Delta\beta$ creates discontinuity at x = 0 (i.e., at $f_{ADE} = 0$).

Conclusions

- Even when the perturbed patch has uniform biophysical parameters, its surface temperature is not uniform due to advective effects.
- Results indicate that the sensitivities of surface temperature to changes in surface albedo and surface moisture availability are scale-dependent but in an opposite way.
- Such scale-dependence can be understood from the perspective of atmospheric feedbacks, which tend to enhance the direct effect of changing surface albedo but hinder the direct effect of changing surface water availability.

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