Yale-NUIST Center on Atmospheric Environment

THE INTRINSIC BIOPHYSICAL THEORY OF LAND USE CHANGE:

CONCEPTUAL FRAMEWORK AND APPLICATIONS TO EDDY COVARIANCE AND CLIMATE MODELING

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Springer Atmospheric Sciences

Xuhui Lee

Fundamentals of Boundary-Layer Meteorology

This textbook introduces a set of fundamental equations that govern the conservation of mass (dry air, water vapor, trace gas), momentum and energy in the lower atmosphere. Simplifications of each of these equations are made in the context of boundary-layer processes. Extended from these equations the author then discusses a key set of issues, including (1) turbulence generation and destruction, (2) force balances in various portions of the lower atmosphere, (3) canopy flow, (4) tracer diffusion and footprint theory, (5) principles of flux measurement and interpretation, (6) models for land evaporation, (7) models for surface temperature response to land use change, and (8) boundary layer budget calculations for heat, water vapor and carbon dioxide. Problem sets are supplied at the end of each chapter to reinforce the concepts and theory presented in the main text. This volume offers the accumulation of insights gained by the author during his academic career as a researcher and teacher in the field of boundary-layer meteorology.

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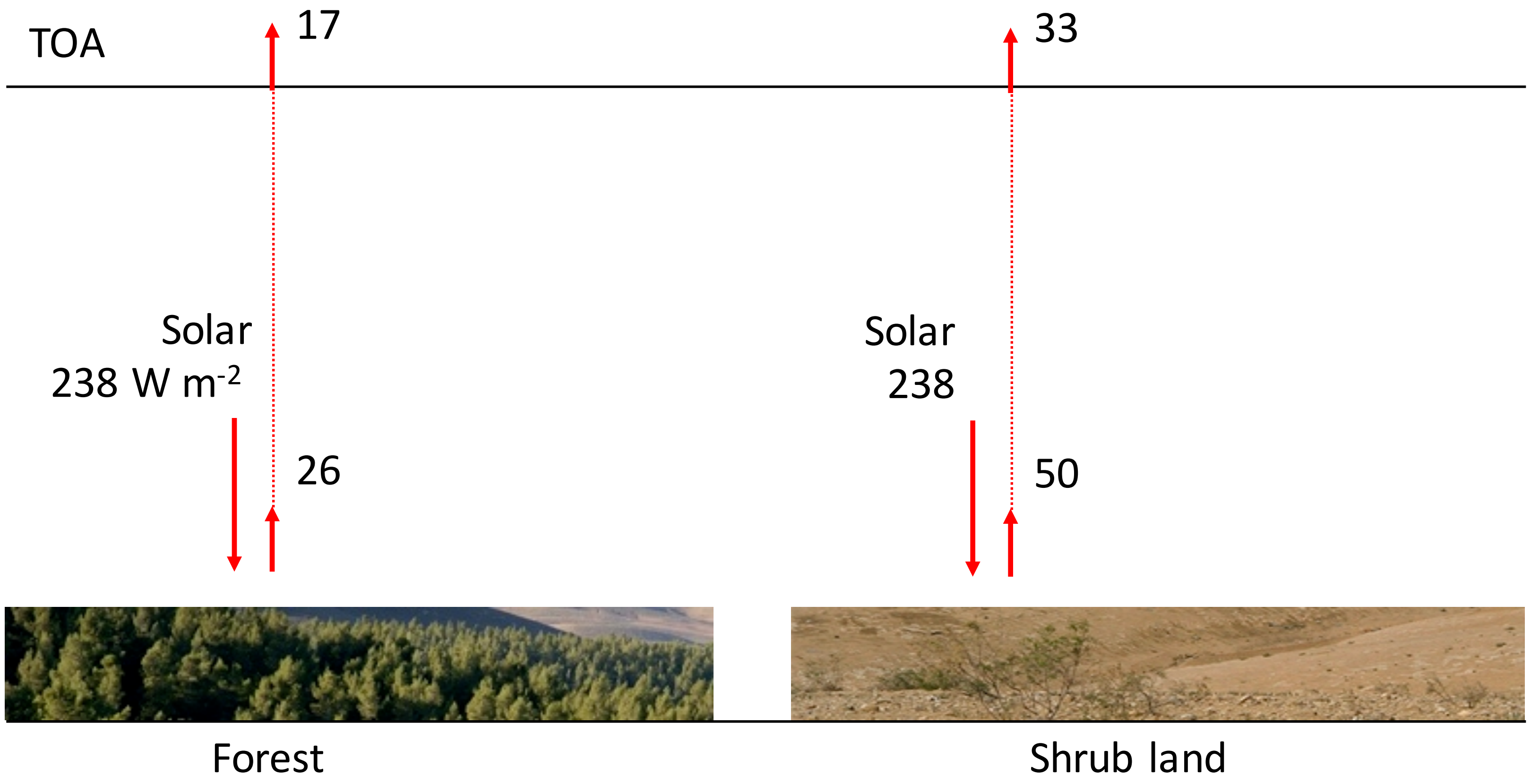
Effects of land use change on the climate system

- **Biogeochemical effect:** arising from changes in atmospheric CO_2 concentration
  - causing changes in radiative forcing of the atmosphere
  - consequences at global scale; no direct local impact
- **Biophysical effect:** associated with changes in albedo, surface roughness and evaporation
  - causing changes in energy balance and energy redistribution
  - impact at both global and local scale
  - effect on surface temperature depends on regional background climate

Longwave radiation feedback arising from land use change



Radiation-only solution:

$$\Delta T_s = \lambda_0 (\Delta S)$$

Local climate sensitivity:

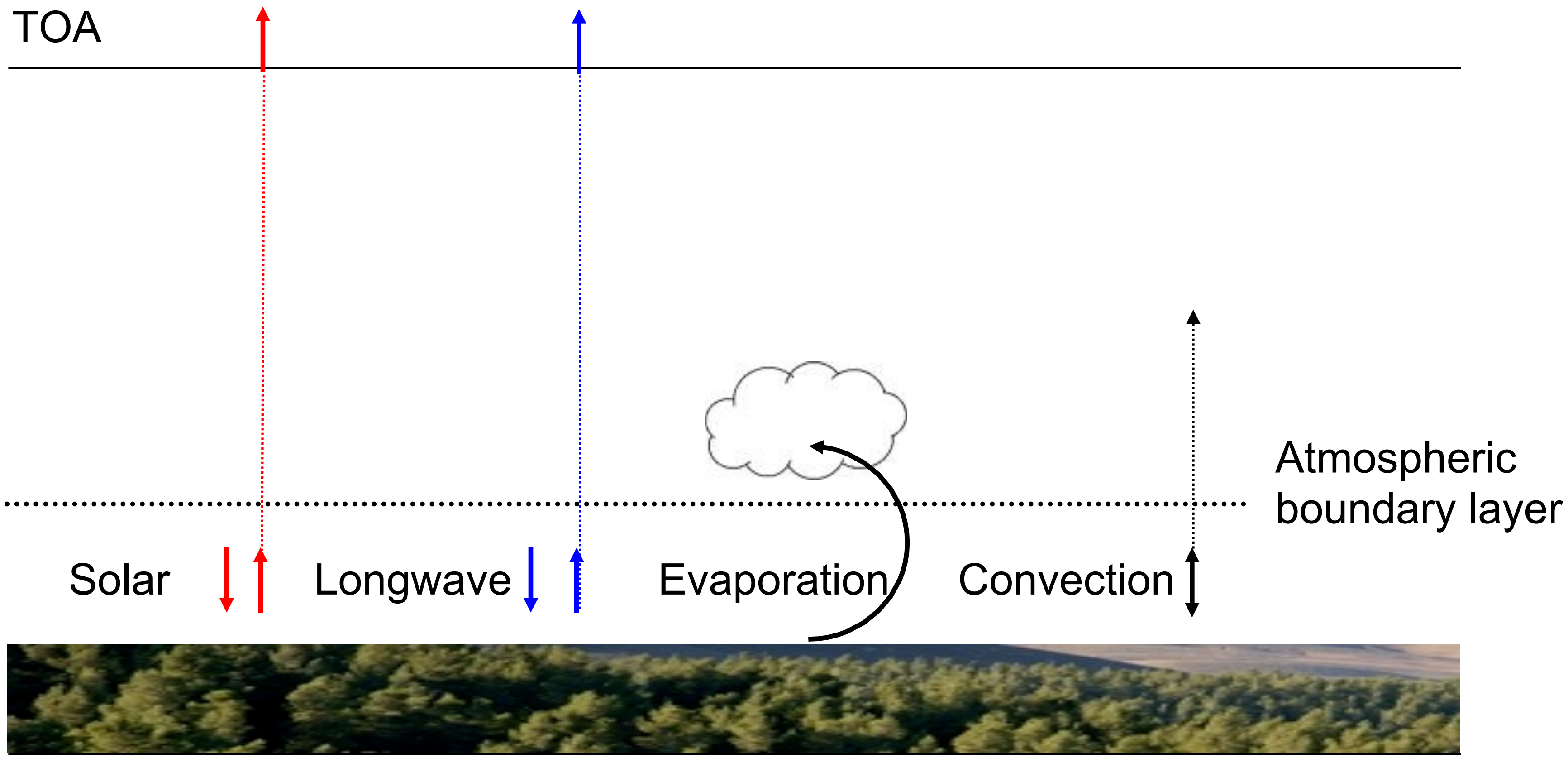
$$\lambda_0 \approx 0.2 \text{ W m}^{-2} \text{ K}^{-1}$$

Prediction:

$$\Delta T_s = -4.8 \text{ K}$$

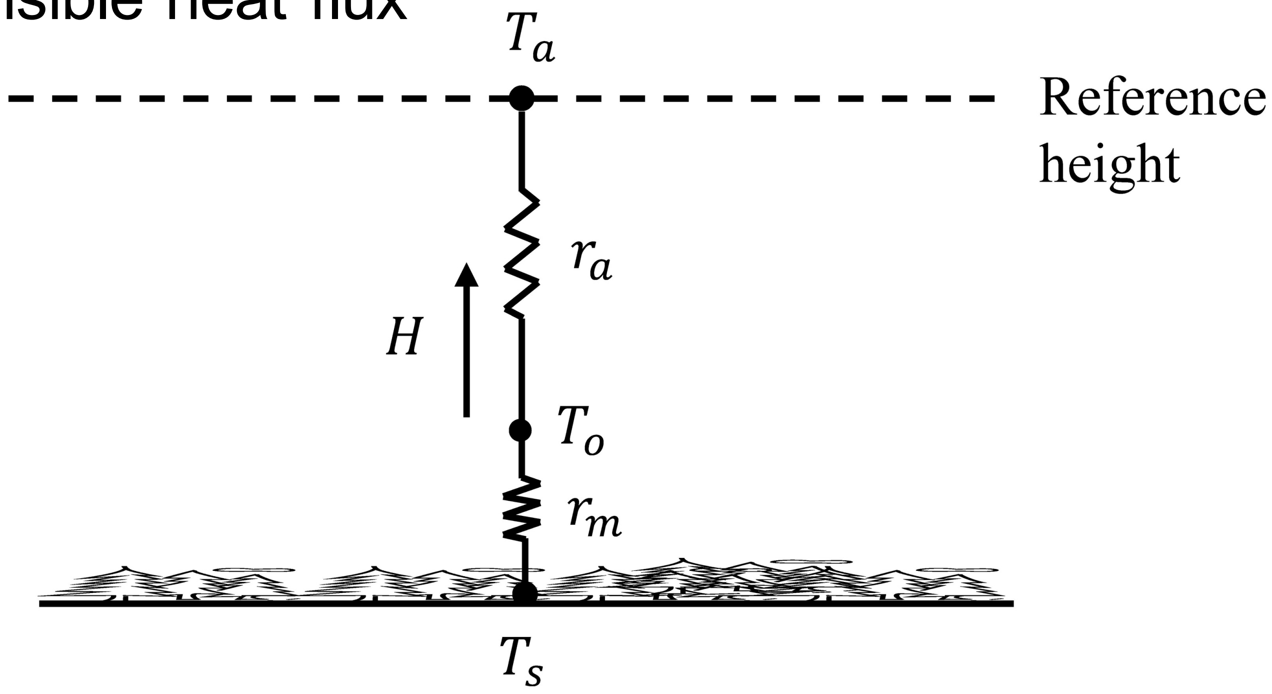
Data source: Rotenberg and Yakir (2010) *Science*, 327: 451-454

Radiative feedback versus energy redistributions



The intrinsic biophysical mechanism

One source model of sensible heat flux



Surface energy balance

$$(1-\alpha)K_{\downarrow} + L_{\downarrow} - \sigma T_s^4 = H + \lambda E + G$$

The intrinsic biophysical mechanism

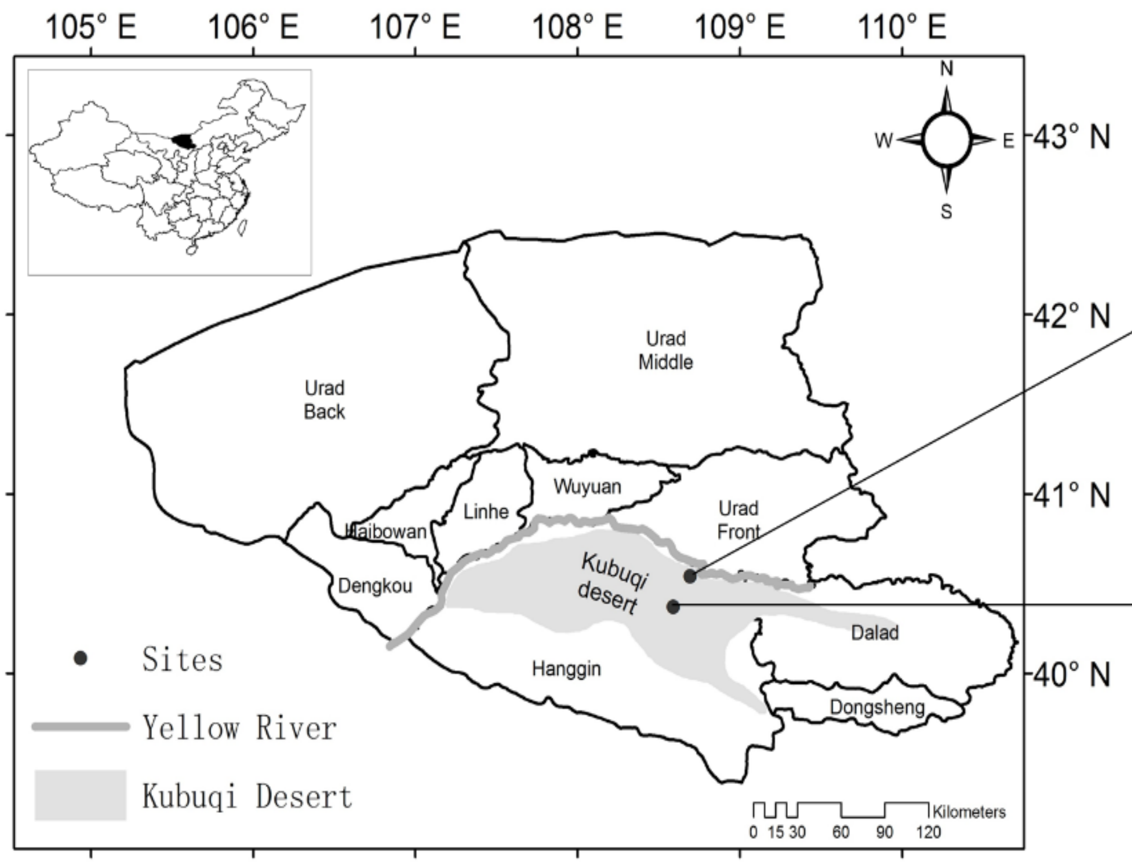
Surface temperature $$T_s = T_a + \frac{\lambda_0}{1+f}(R_n^* - G)$$

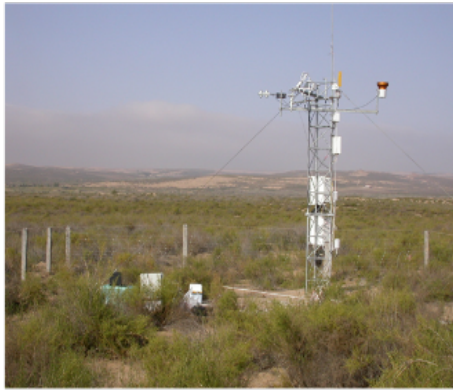
Surface temperature difference between two adjacent land types

$$\Delta T_s \simeq \underbrace{\frac{\lambda_0}{1+f}(\Delta S)}_{1} + \underbrace{\frac{\lambda_0}{(1+f)^2} R_n^* (\Delta f_1)}_{2} + \underbrace{\frac{\lambda_0}{(1+f)^2} R_n^* (\Delta f_2)}_{3}$$

1: local radiative forcing
2: energy redistribution due to roughness change
3: energy redistribution due to Bowen ratio change

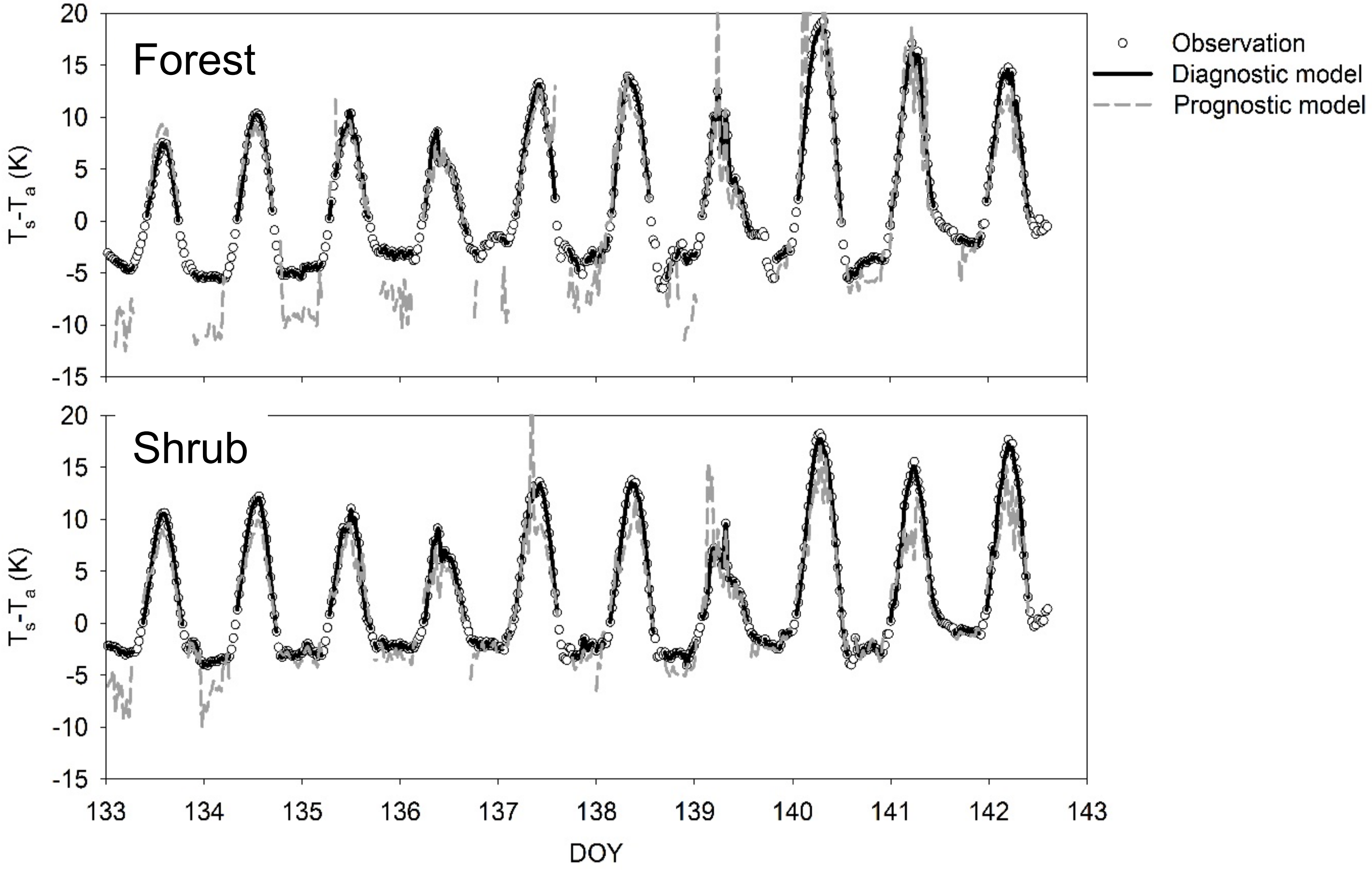
Forest versus shrub land, Kubuqi Desert, Inner Mongolia





Source: Wang, Lee, Lin et al. (2017), manuscript in review

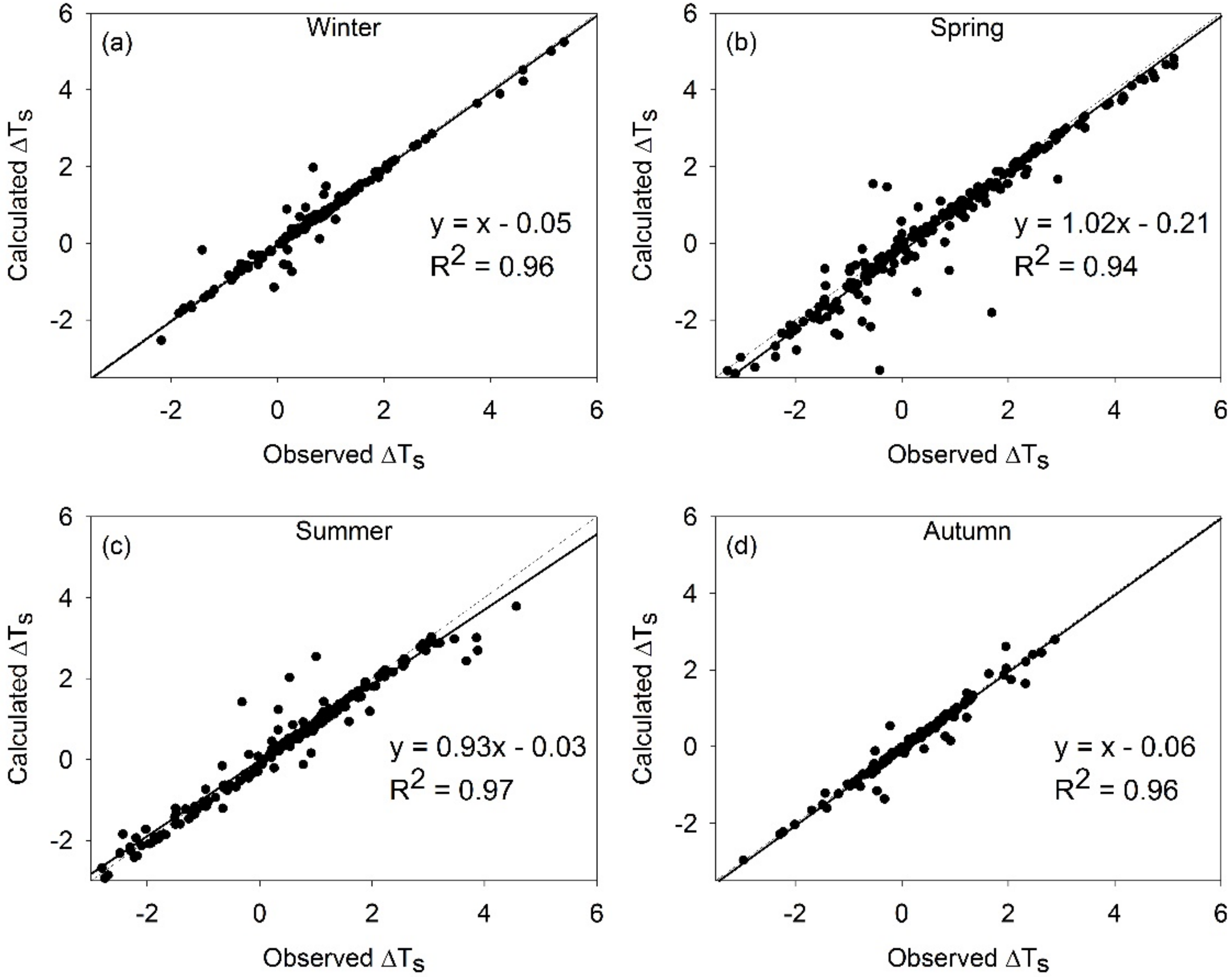
Comparison of modeled and observed surface temperature



Source: Wang, Lee, Lin et al. (2017), manuscript in review

Comparison of surface temperature difference between shrub land and forest, Inner Mongolia

Daytime



Source: Wang, Lee, Lin et al. (2017), manuscript in review

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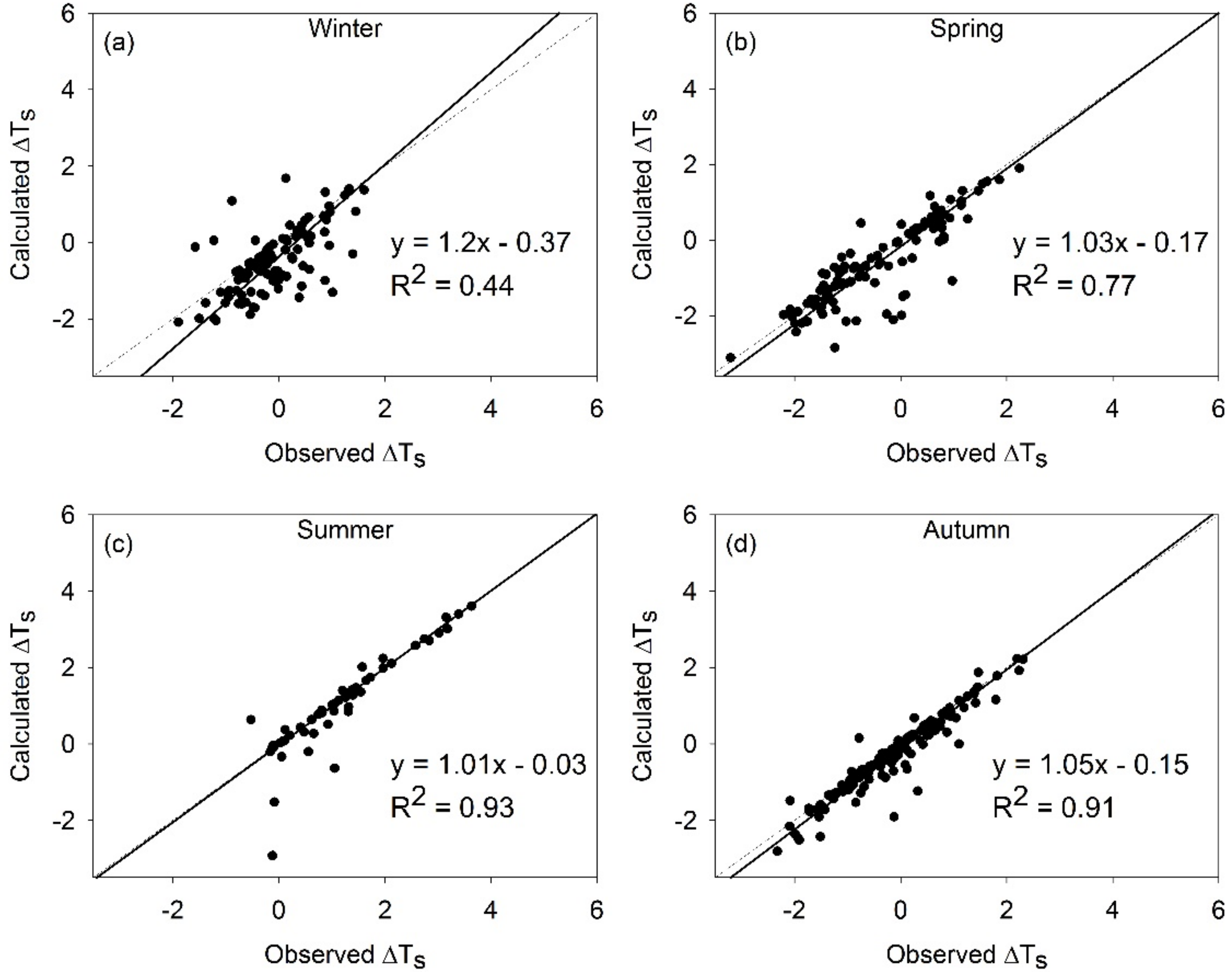
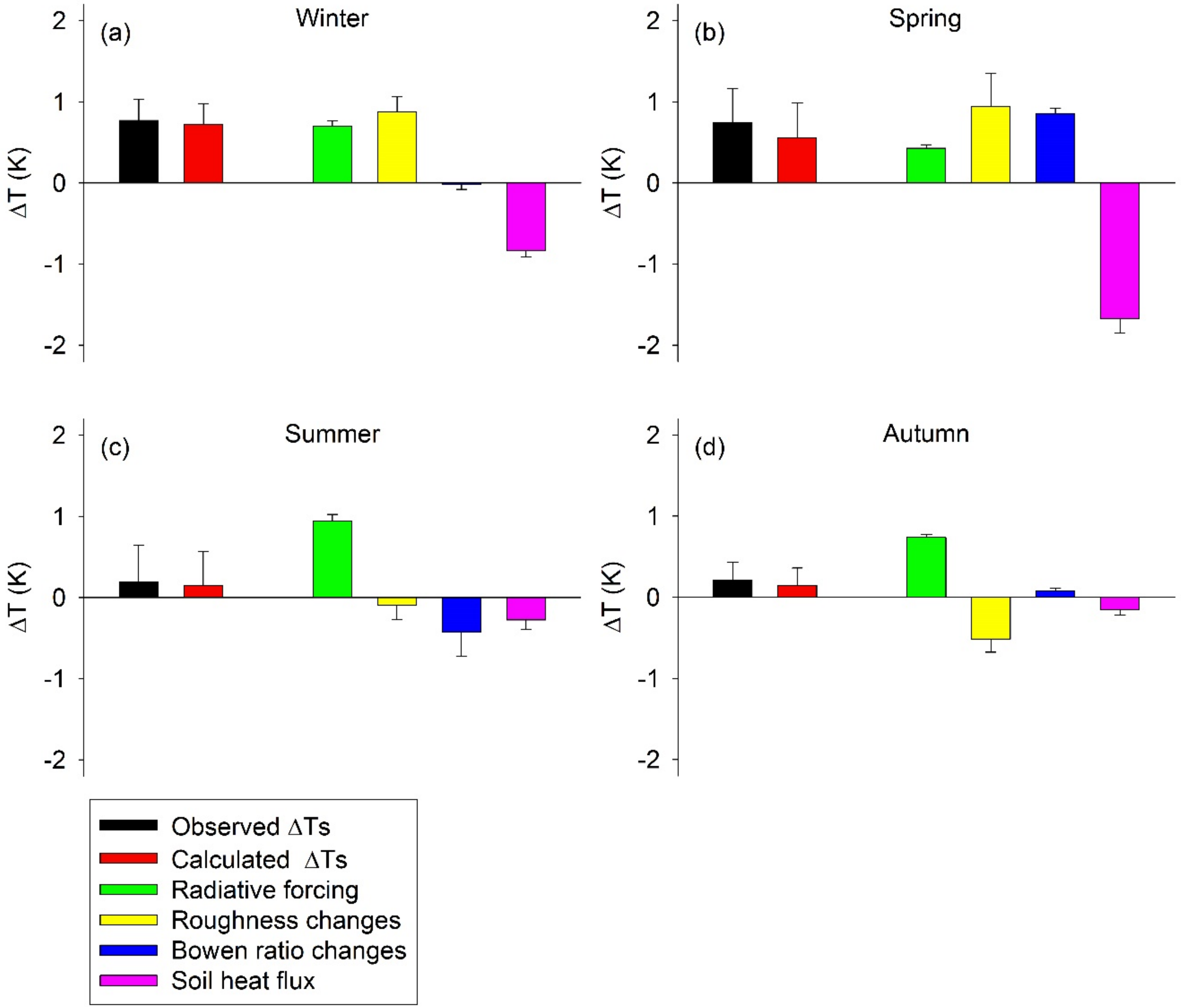


Source: Wang, Lee, Lin et al. (2017), manuscript in review

Attribution of land use effect (shrub versus forest)
Inner Mongolia

Daytime



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Attribution of land use effect (shrub versus forest)
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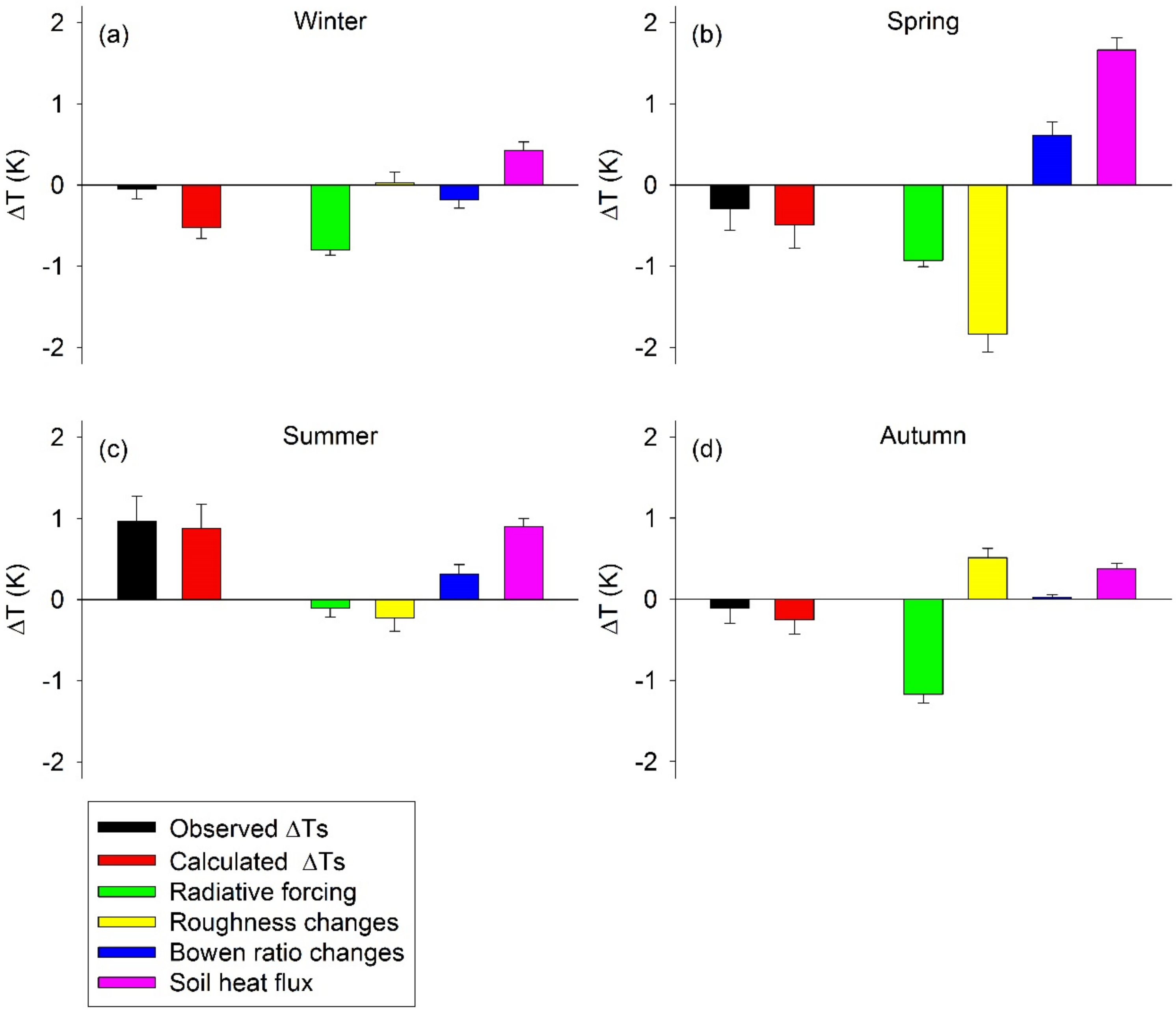
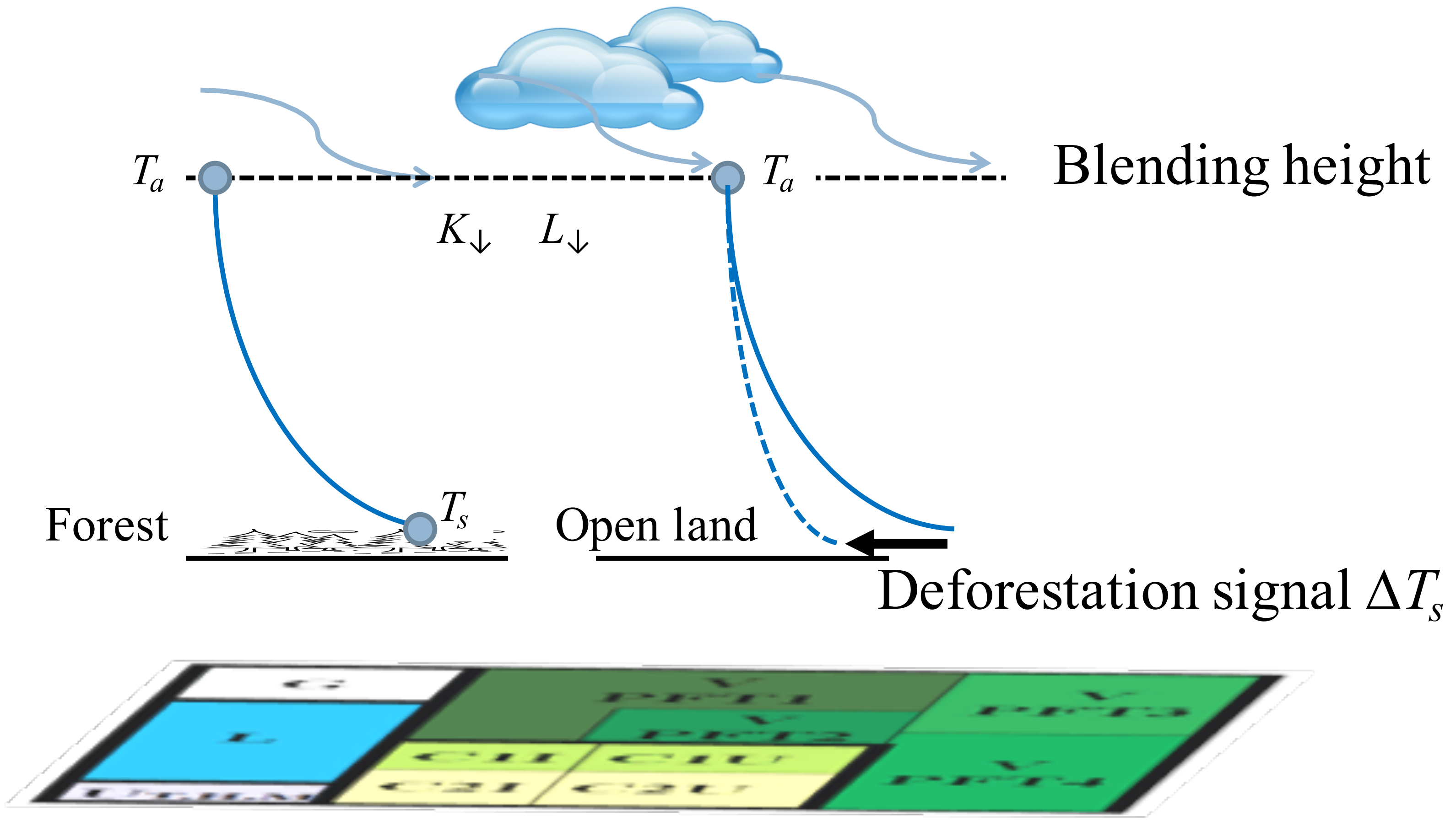


Source: Wang, Lee, Lin et al. (2017), manuscript in review

Blending height in a model grid



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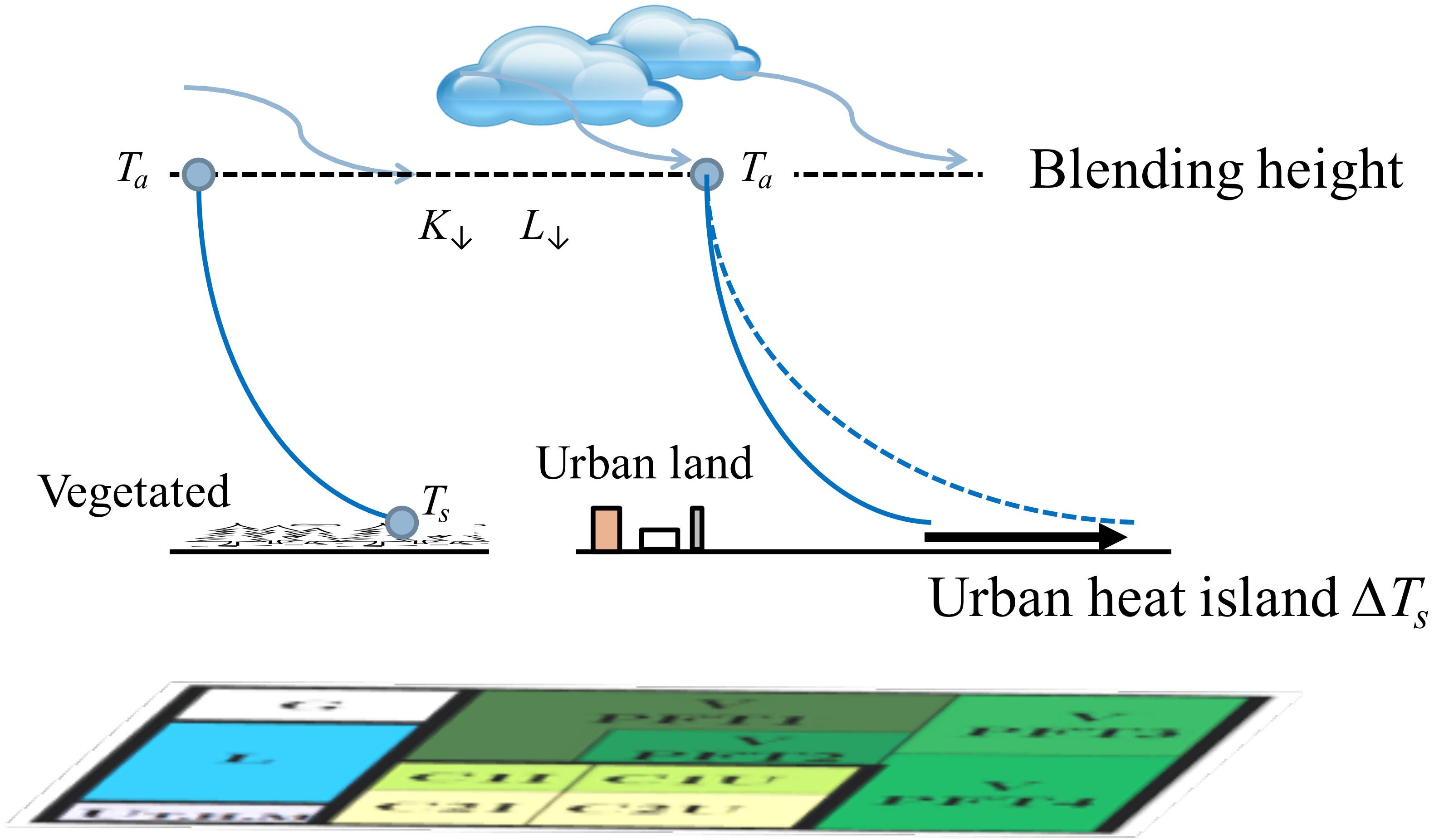
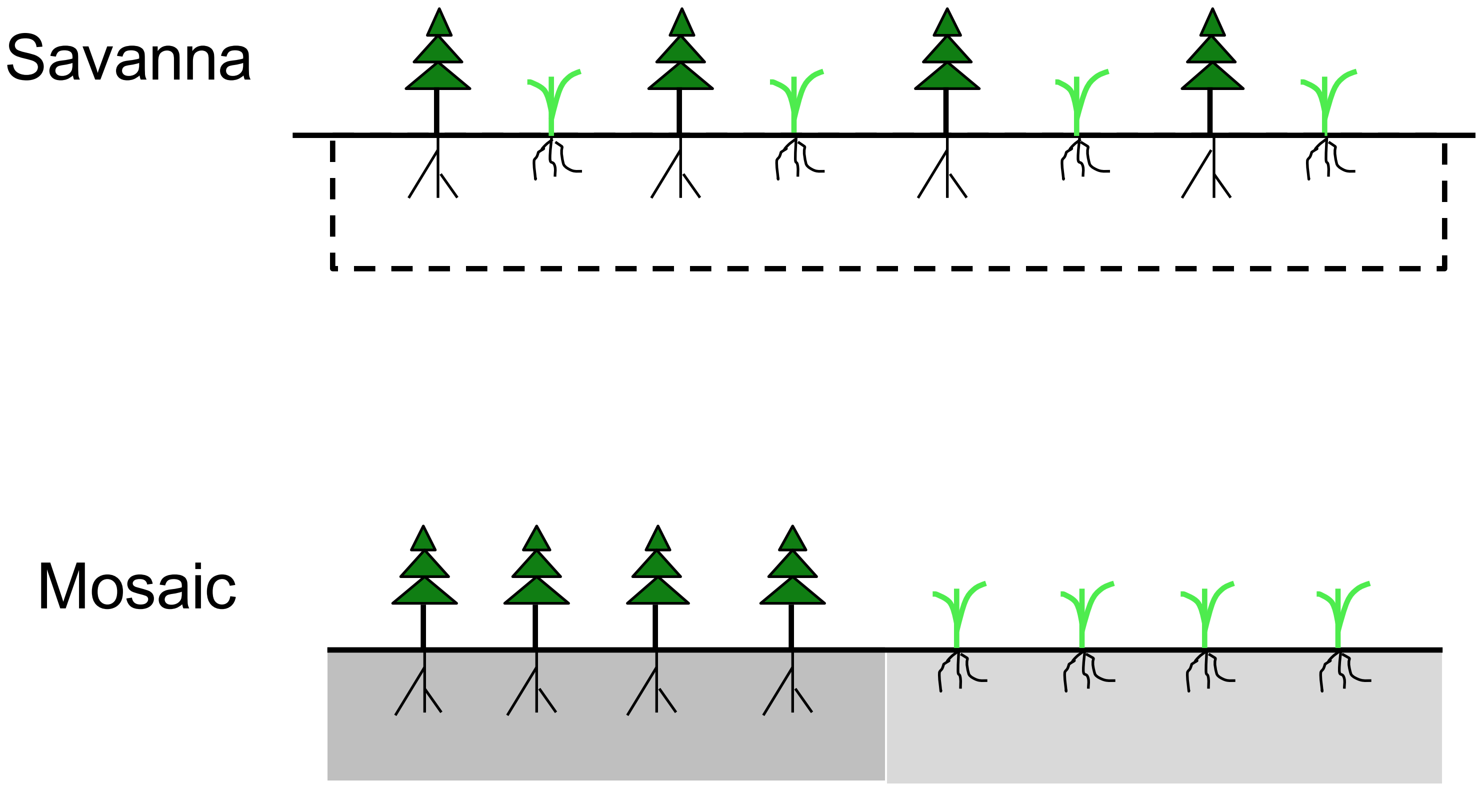
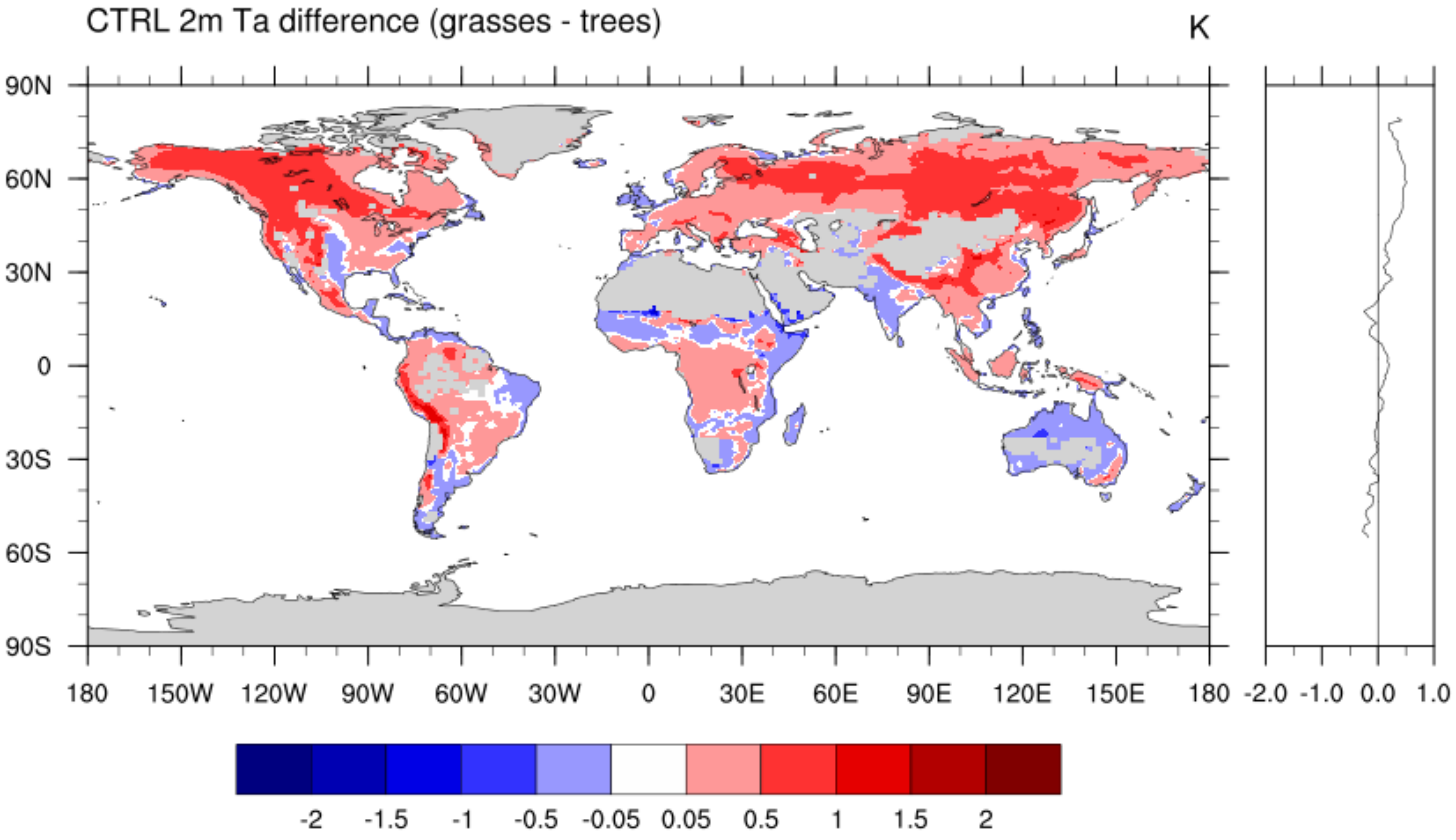


Vegetation pattern in a model grid

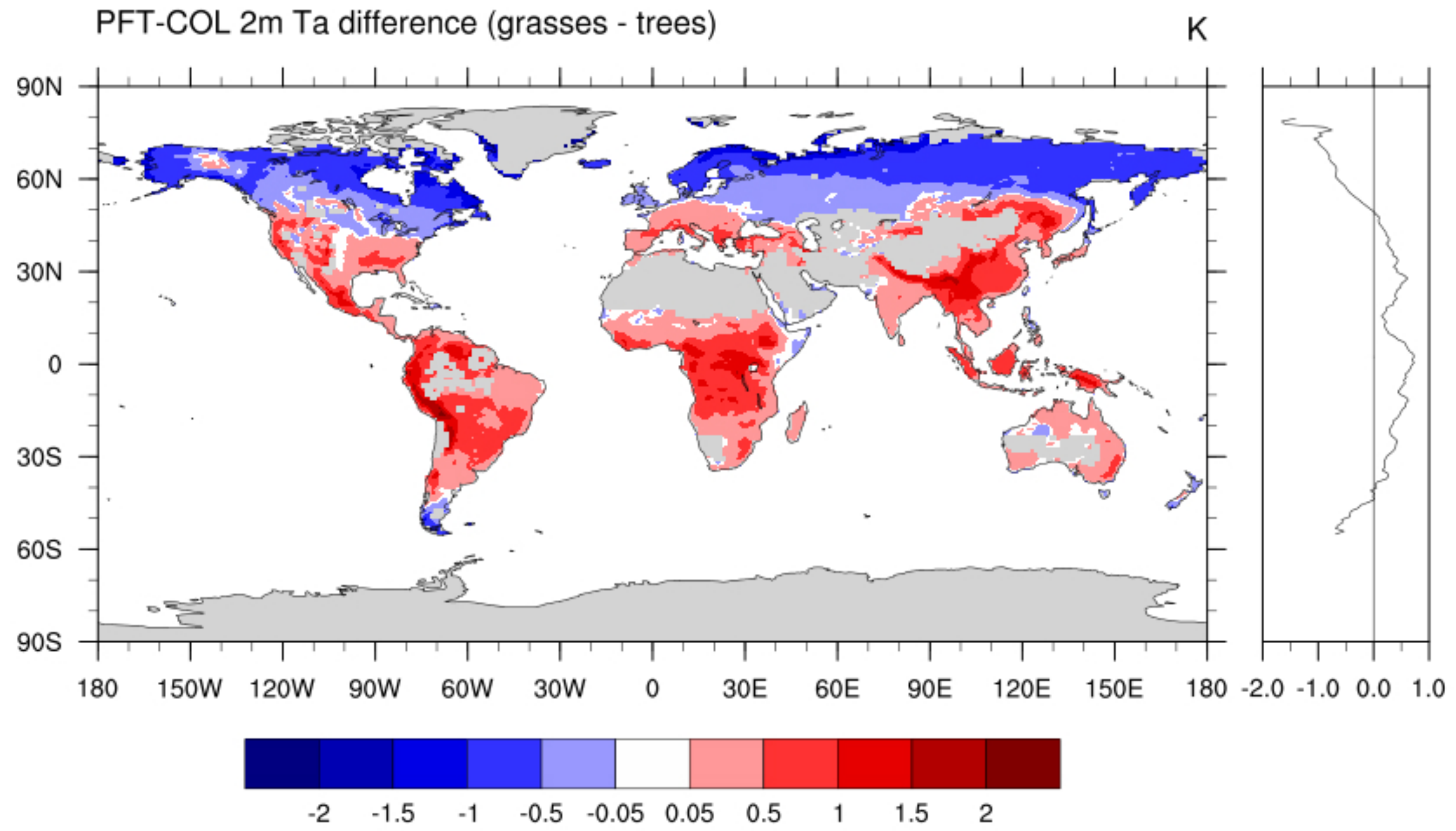


Deforestation effect using savanna-type land model



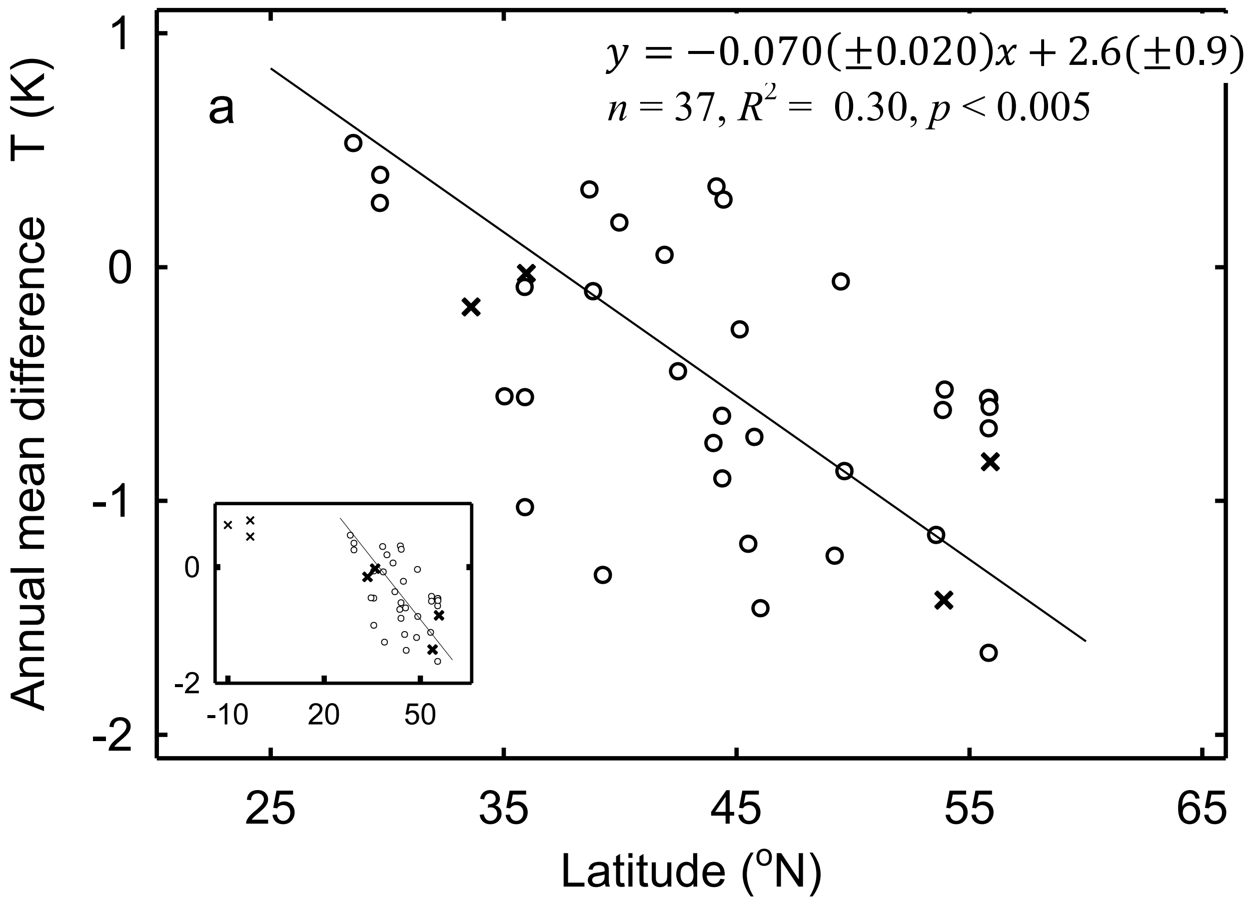
Source: Schultz, Lee, Lawrence et al. (2016) *J Geophysical Research – Atmospheres* 121: 6133-6147.

Deforestation effect using mosaic-type land model



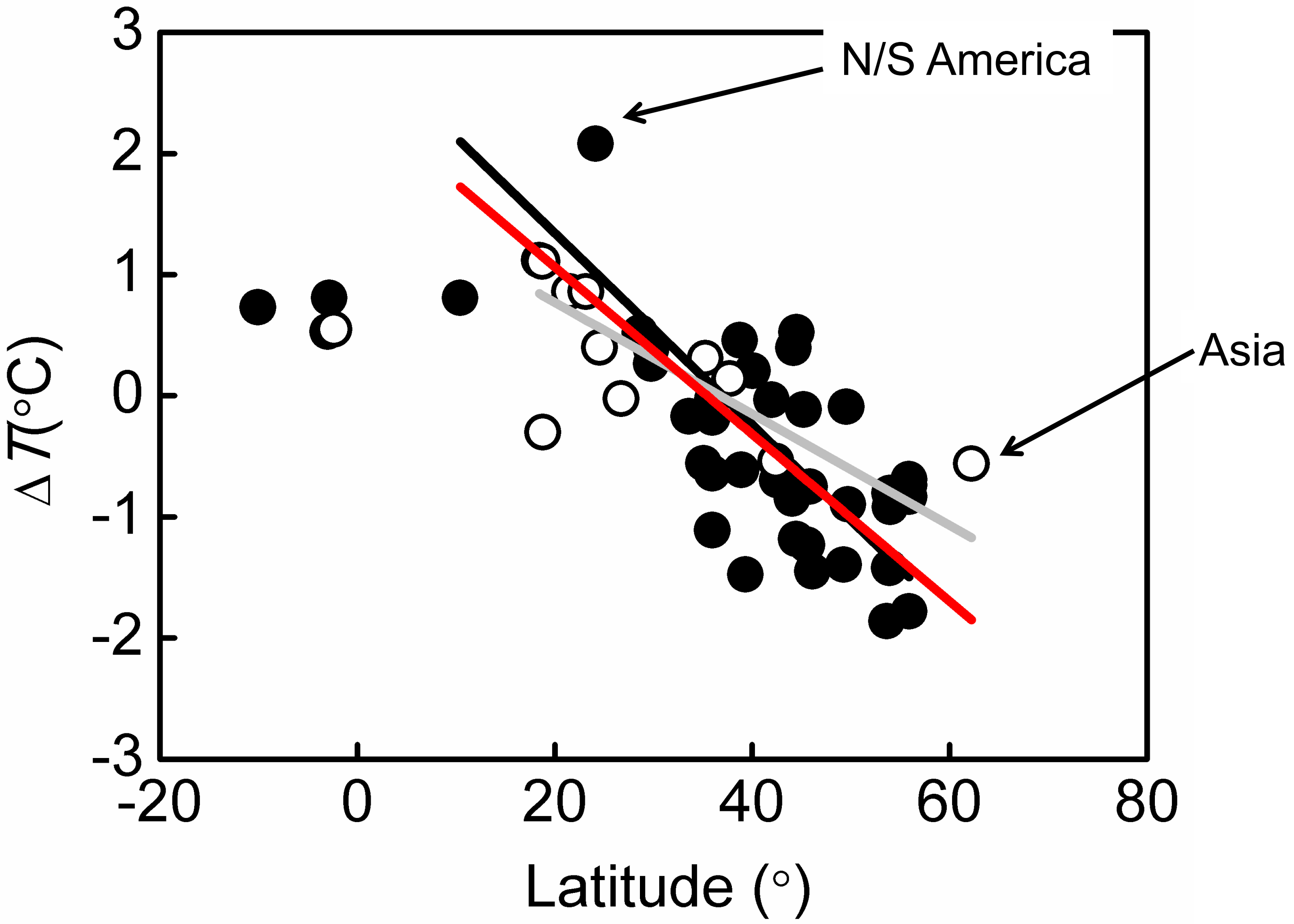
Source: Schultz, Lee, Lawrence et al. (2016) *J Geophysical Research – Atmospheres* 121: 6133-6147.

Deforestation effect on surface air temperature (open land minus forest land)



Source: Lee, Goulden, Hollinger et al. (2011) *Nature* 497: 384-387

Deforestation effect on surface air temperature (open land minus forest land)



Source: Zhang, Lee, Yu, et al. (2014) *Environ Res Letters* 9: 034002

White roof, green roof, solar roof, and street trees

White roof in California

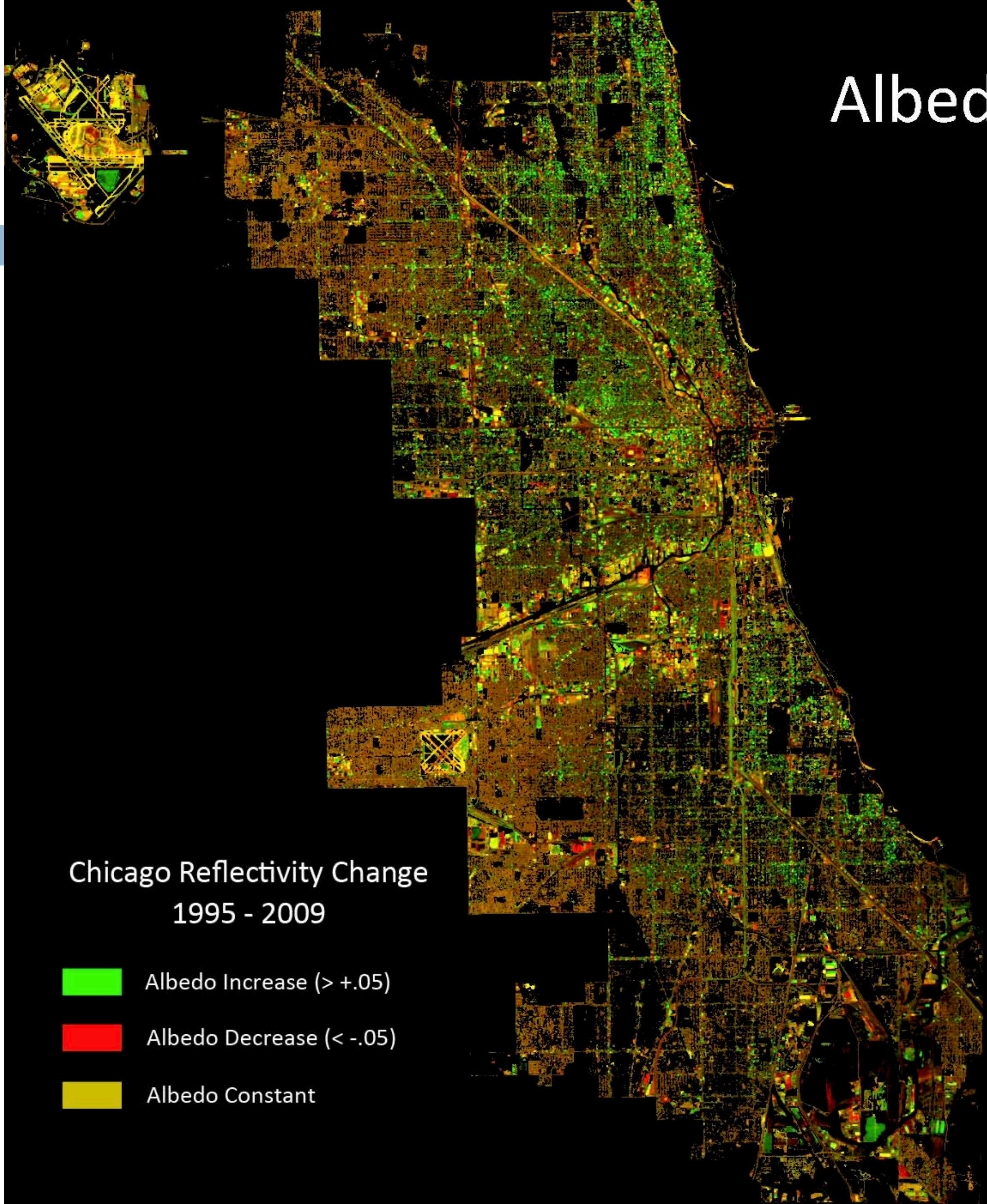
Green roof, Chicago City Hall

Solar roof, Yale University

Street trees, Nanjing

Sources: www.ens-newswire.com/ens/sep2008/2008-09-23-01.html; http://aasid.parsons.edu/

Albedo Change Detection
Chicago



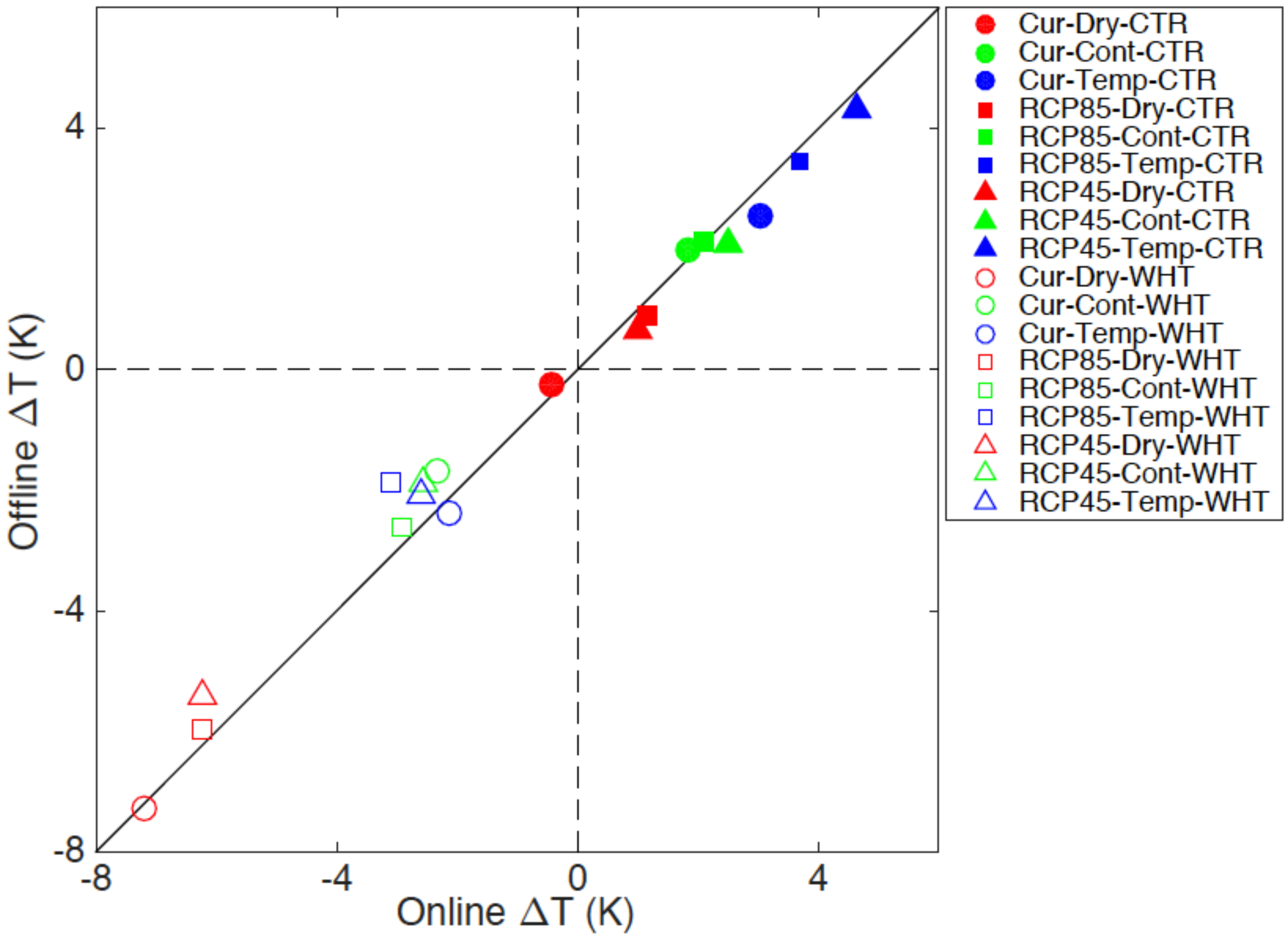
Source: Mackay, Lee and Smith (2012) *Building & Environ* 49: 348-358

Homework exercise

- According to this satellite study, use of reflective roofs increased the citywide albedo by about 0.02 from 1995 to 2010. Estimate the surface temperature reduction caused by the albedo change.

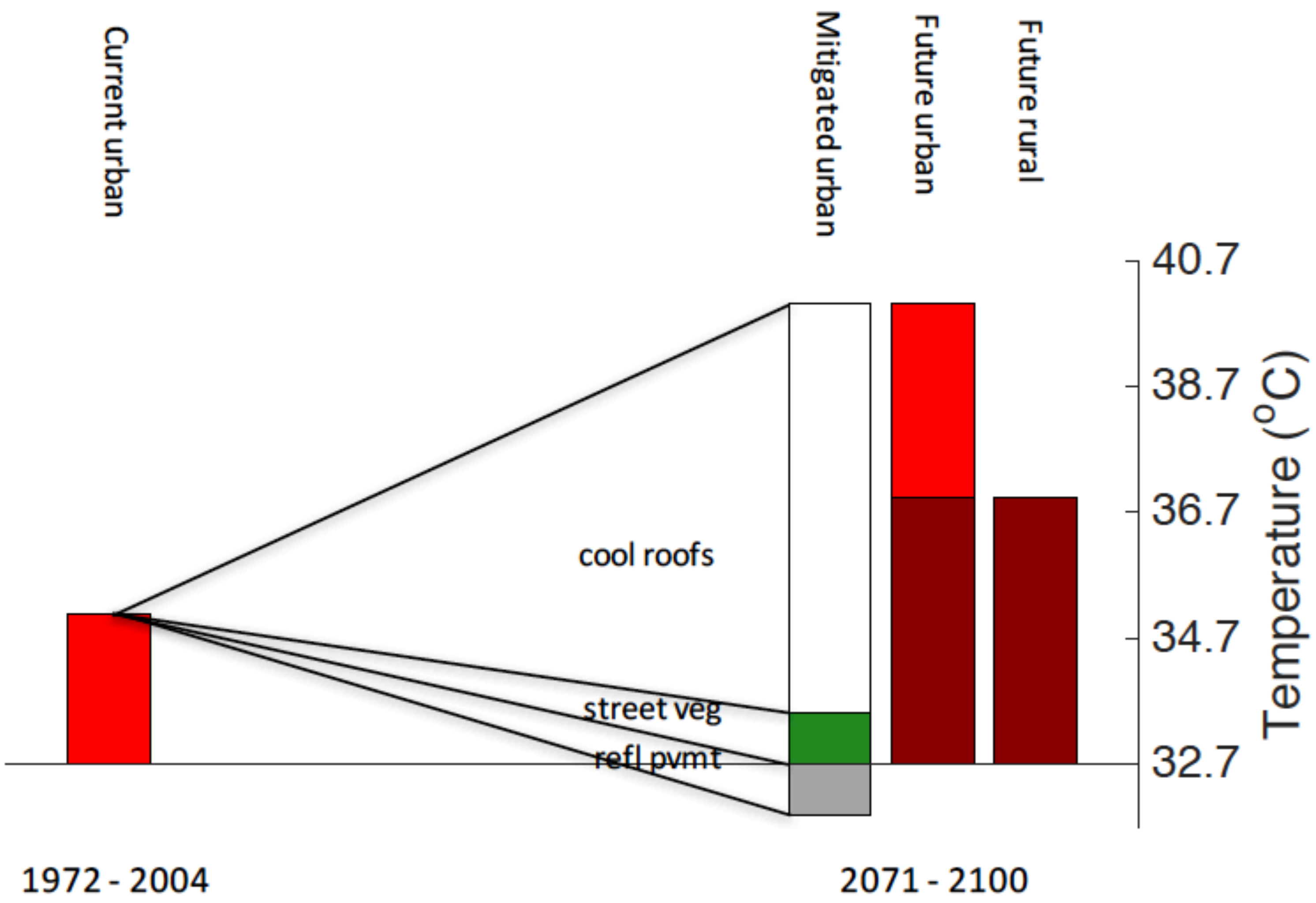
$$\Delta T_s \simeq \frac{\lambda_0}{1+f}(\Delta S)$$

Urban surface temperature change in response to use of reflective roofs



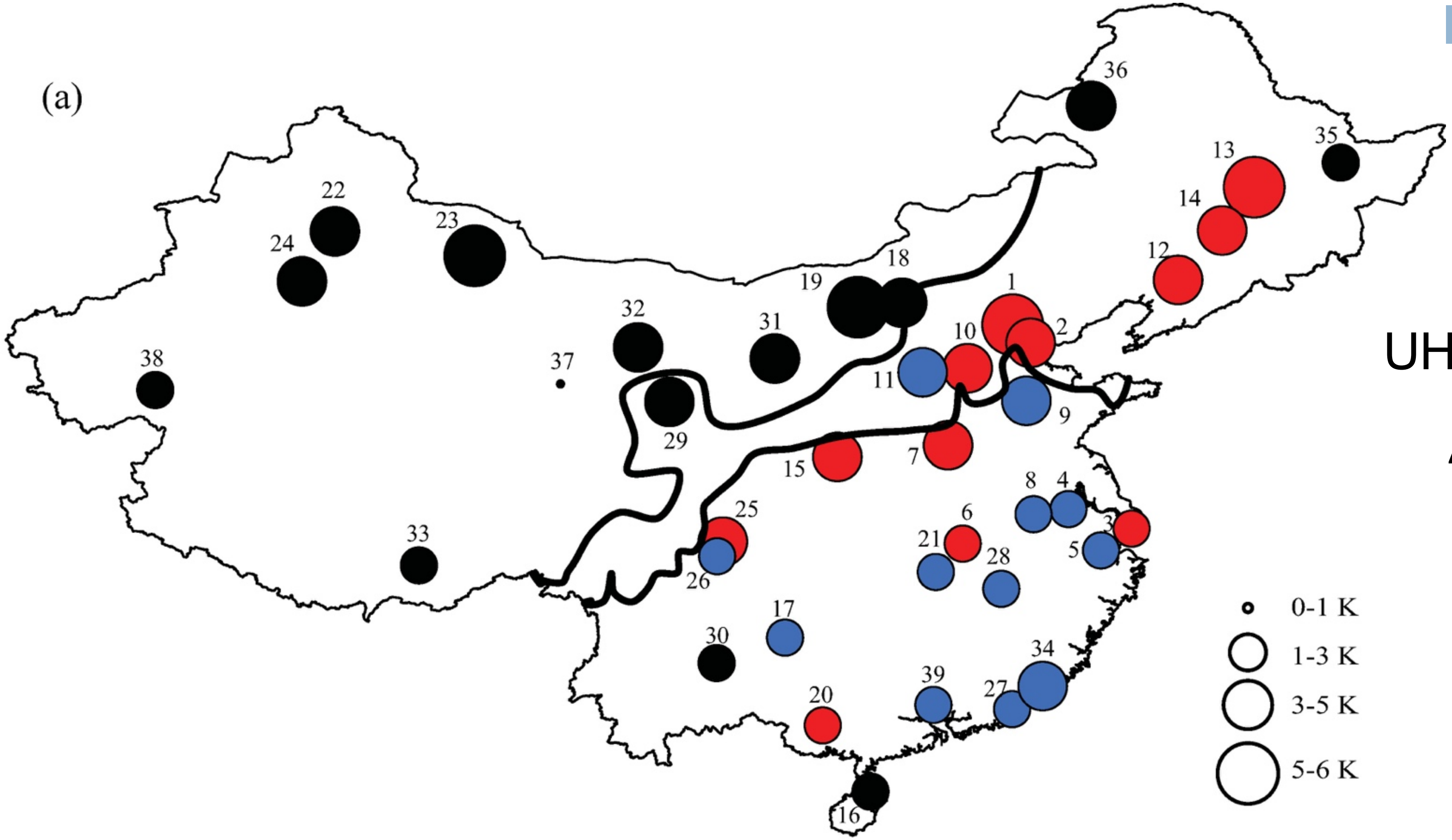
Source: Zhao, Lee, Schultz (2017) *Atmospheric Chemistry and Physics* 17: 9067–9080

UHI mitigation wedges for cities in United States (summer midday conditions)



Source: Zhao, Lee, Schultz (2017) *Atmospheric Chemistry and Physics* 17: 9067–9080

Nighttime urban heat island in Chinese cities

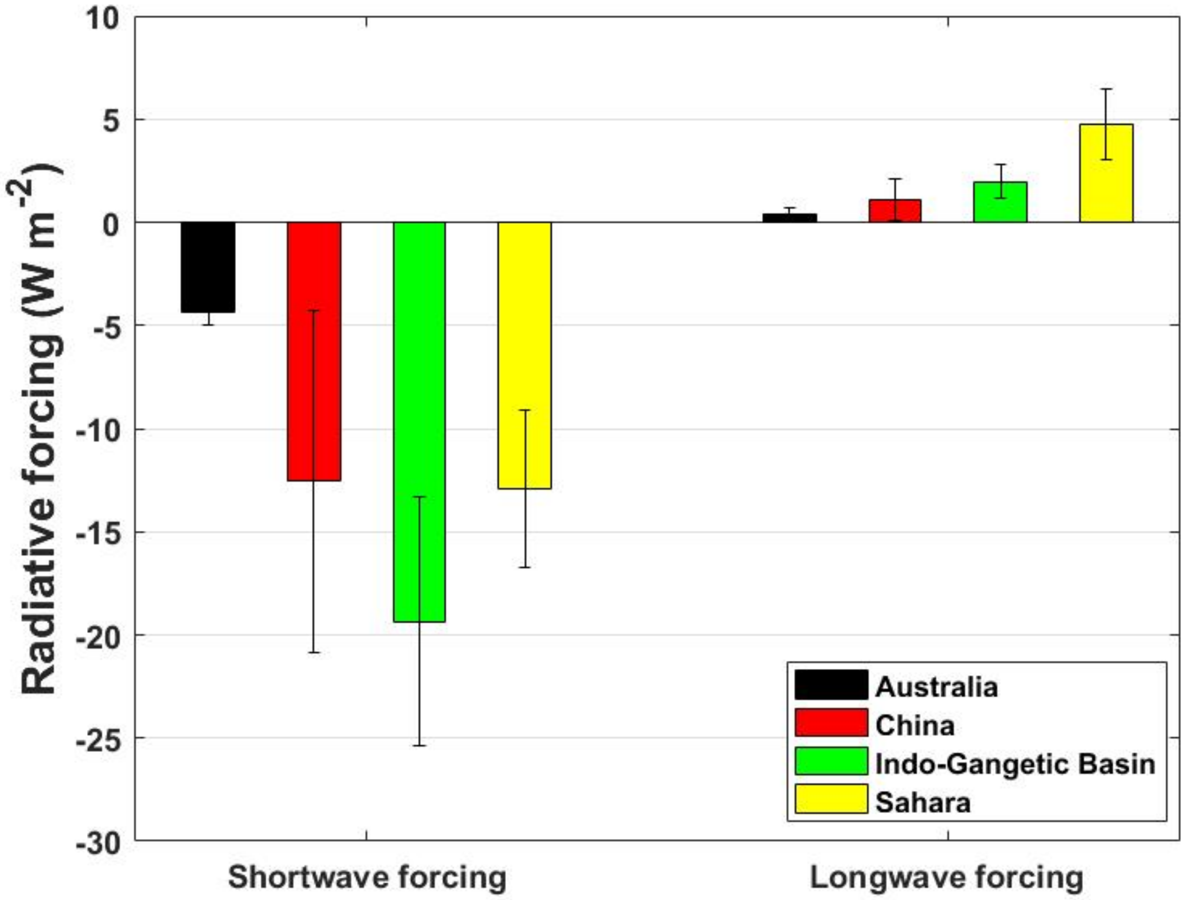


UHI enhanced by haze

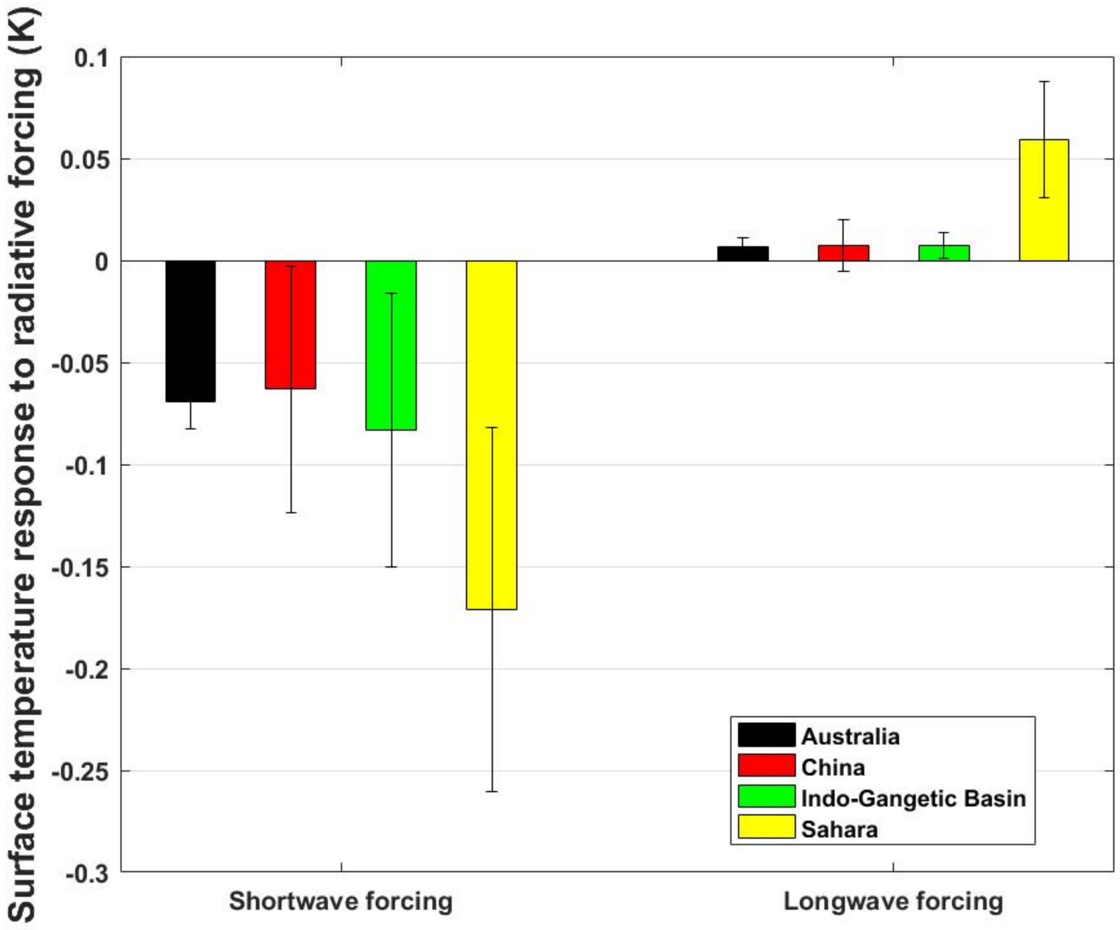
$$\Delta T_s = \frac{\lambda_0}{1+f}(\Delta L_{\downarrow})$$

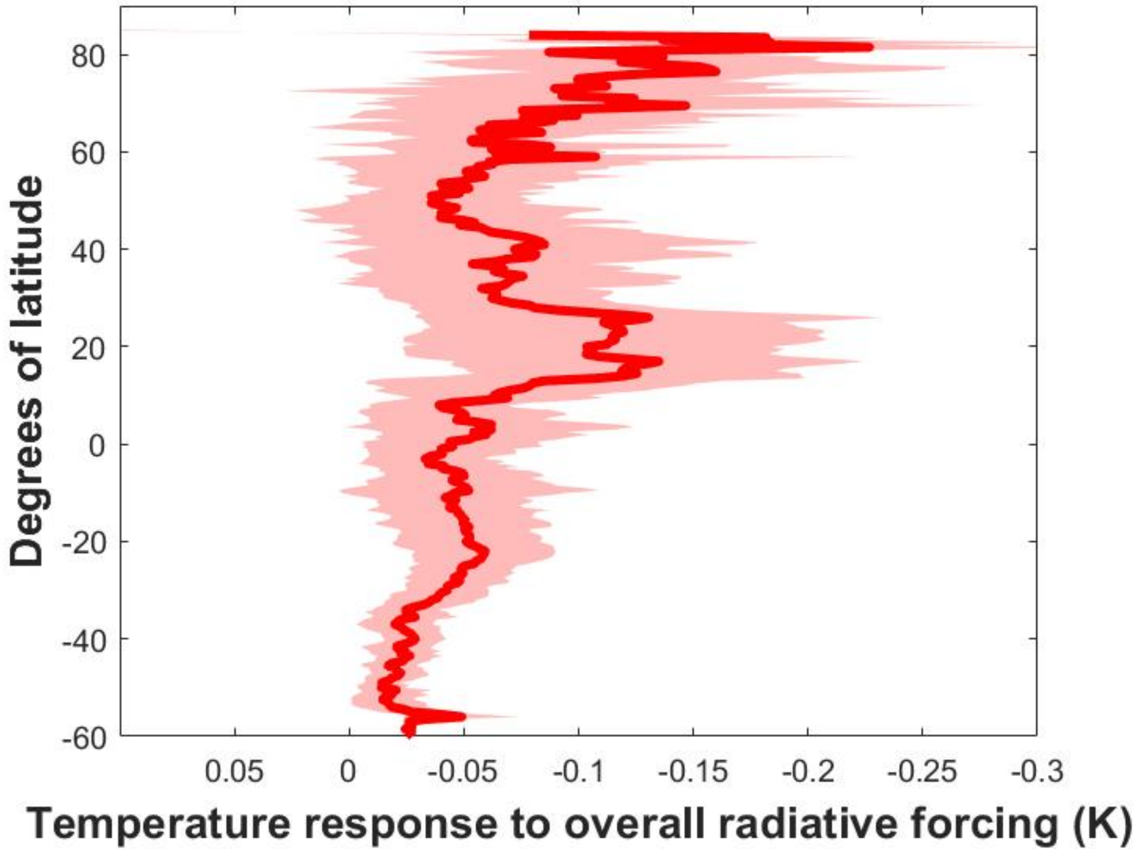
Source: Cao C, X Lee, S Liu, et al (2016) *Nature Communications* doi: 10.1038/ncomms12509

Changes in surface radiation due to atmospheric aerosols



Effect of aerosols on surface temperature





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