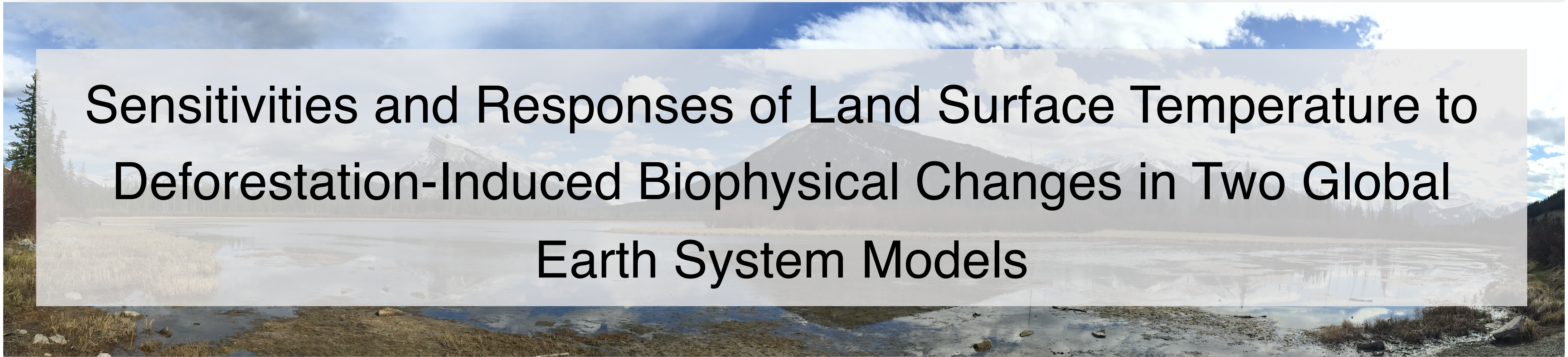
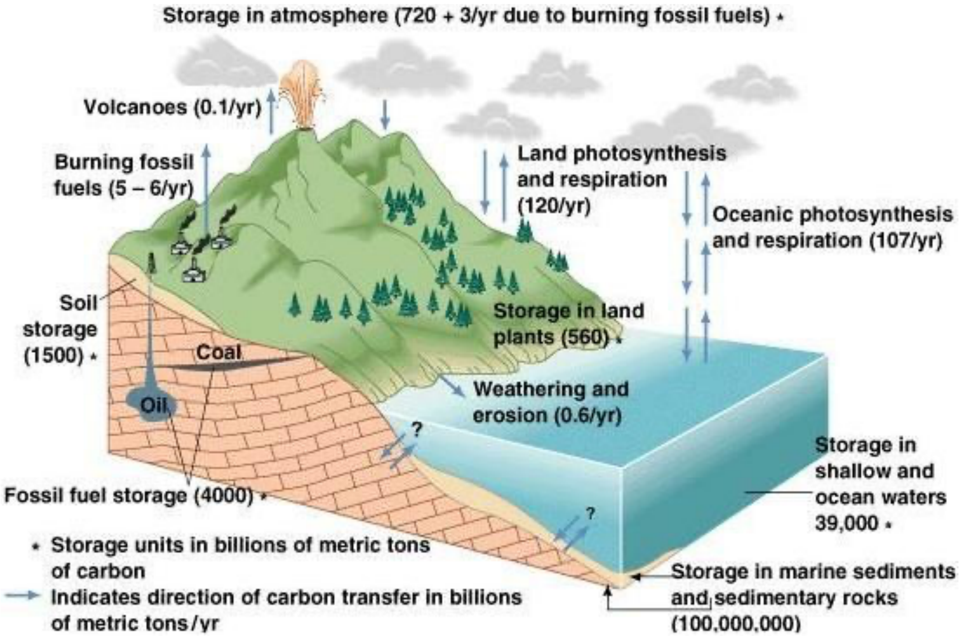


Sensitivities and Responses of Land Surface Temperature to Deforestation-Induced Biophysical Changes in Two Global Earth System Models

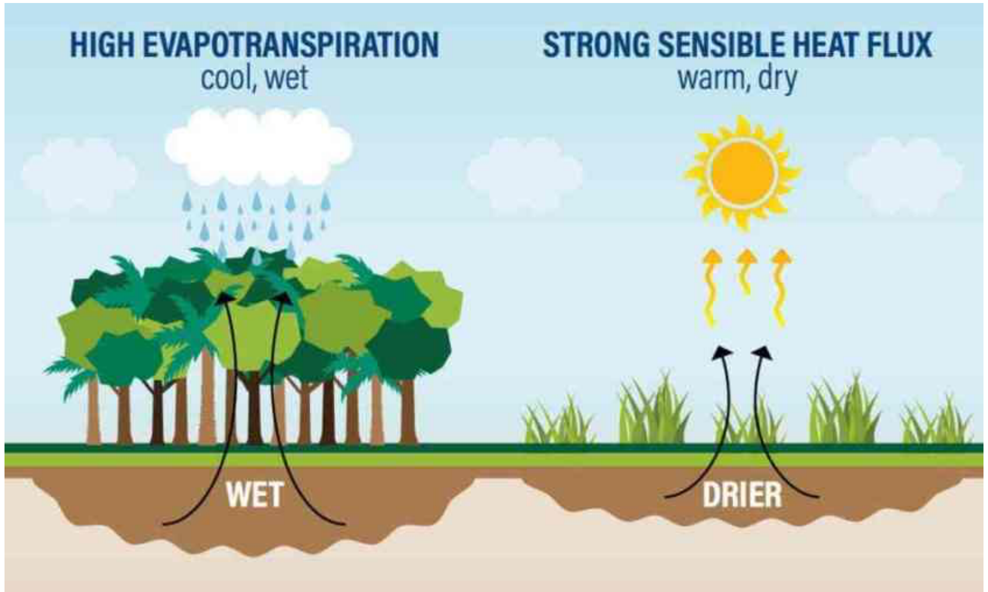
Weilin Liao, Xiaoping Liu, Elizabeth Burakowski, Dagang Wang, Linying Wang, and Dan Li

Weilin Liao, Xiaoping Liu*, Elizabeth Burakowski, Dagang Wang, Linying Wang, and Dan Li (2020). Sensitivities and Responses of Land Surface Temperature to Deforestation-Induced Biophysical Changes in Two Global Earth System Models. *Journal of Climate*. 33(19): 8381-8399.

The impacts of deforestation on land surface temperature



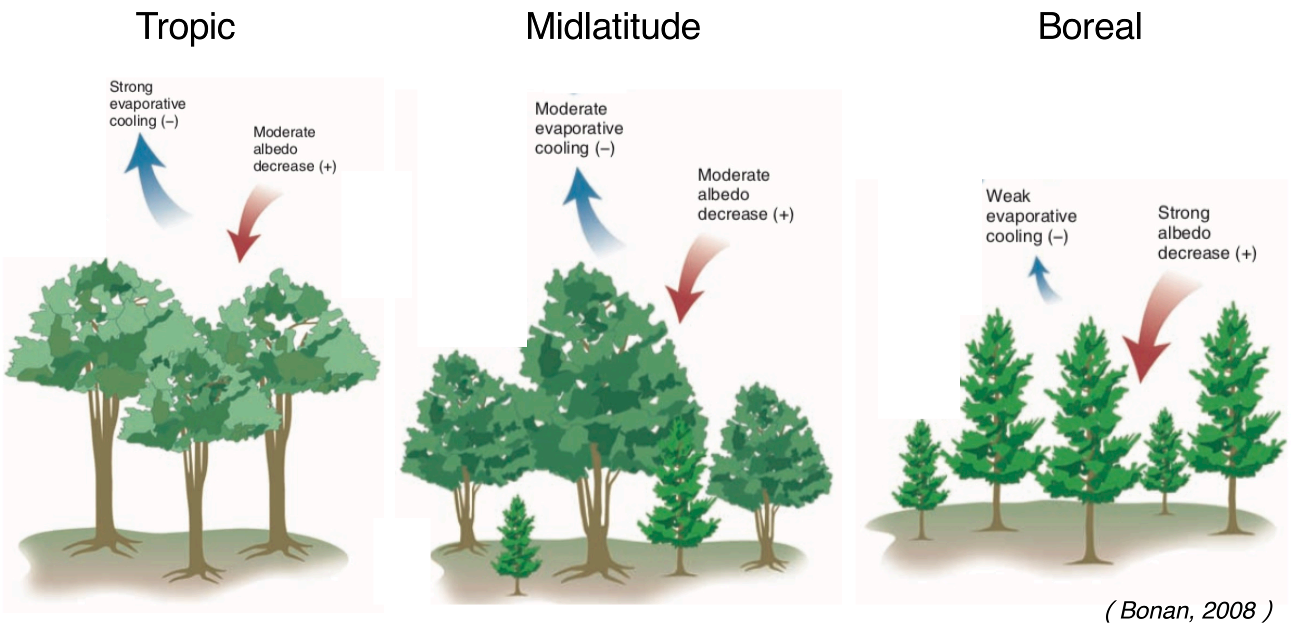
biogeochemical effect



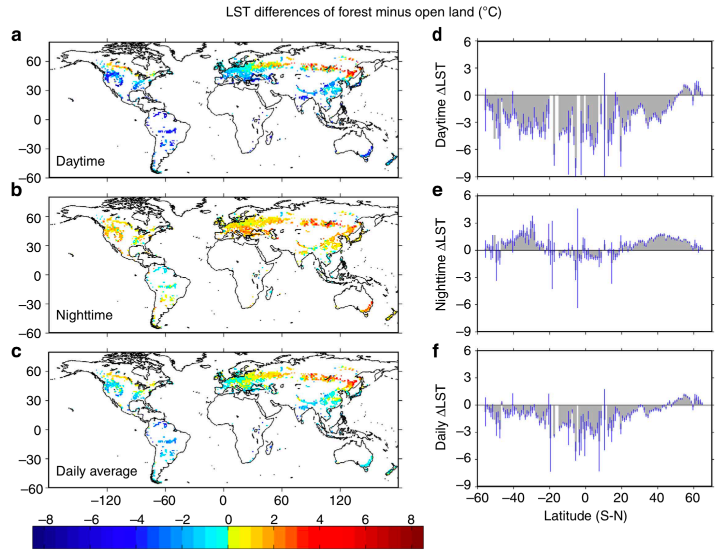
biophysical effect

The impacts of deforestation on land surface temperature

- Decrease in evapotranspiration dominating in the tropics (a warming effect)
- Increase in albedo dominating in the boreal regions (a cooling effect)
- Whether deforestation has a net cooling or warming effect remains elusive in the midlatitudes.



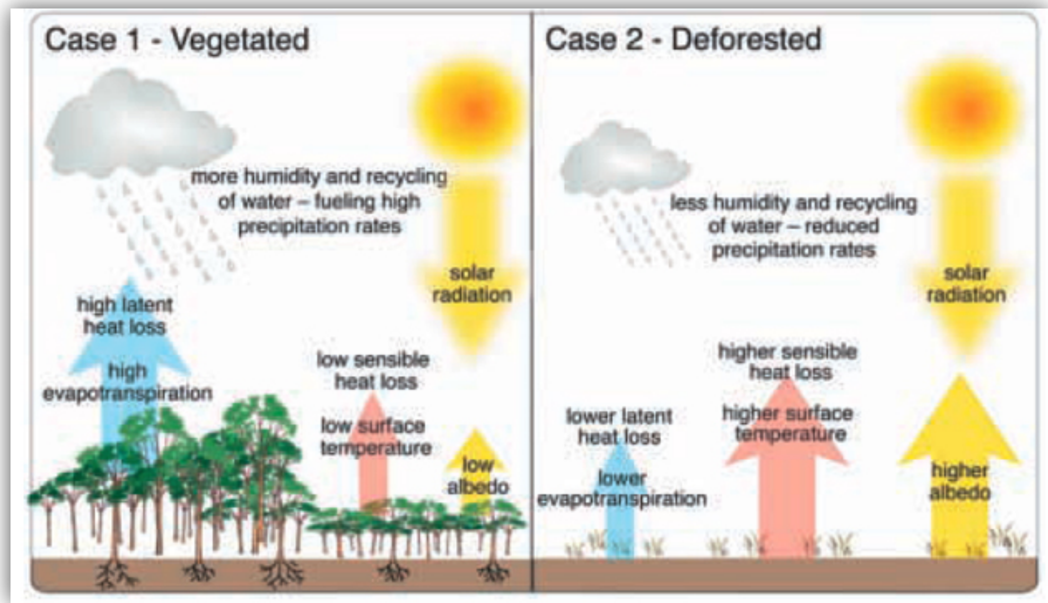
(Bonan, 2008)



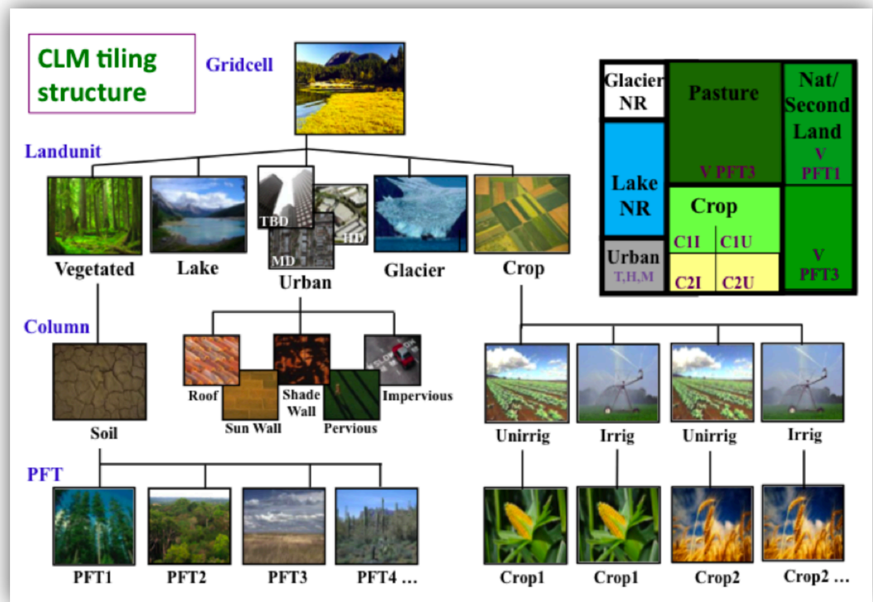
(Li et al., 2015)

The impacts of deforestation on land surface temperature

- Many previous studies used the difference between two experiments forced by different land-cover scenarios to represent the impact of deforestation.
- These differences can be affected by model internal variability.



(Marengo, 2006)



The impacts of deforestation on land surface temperature

LETTER
doi:10.1038/nature13462

Strong contributions of local background climate to urban heat islands

Lei Zhao[1,2], Xuhui Lee[1,2], Ronald B. Smith[3] & Keith Oleson[4]

The urban heat island (UHI), a common phenomenon in which surface temperatures are higher in urban areas than in surrounding rural areas, represents one of the most significant human-induced changes to Earth's surface climate[1,2]. Even though they are localized hotspots in the landscape, UHIs have a profound impact on the lives of urban residents, who comprise more than half of the world's population[3]. A barrier to UHI mitigation is the lack of quantitative attribution of the various contributions to UHI intensity[4] (expressed as the temperature difference between urban and rural areas, ΔT). A common perception is that reduction in evaporative cooling in urban land is the dominant driver of ΔT (ref. 5). Here we use a climate model to show that, for cities across North America, geographic variations in daytime ΔT are largely explained by variations in the efficiency with which urban and rural areas convect heat to the lower atmosphere. If urban areas are aerodynamically smoother than surrounding rural areas, urban heat dissipation is relatively less efficient and urban warming occurs (and vice versa). This convection effect depends on the local background climate, increasing daytime ΔT by 3.0 ± 0.3 kelvin (mean and standard error) in humid climates but decreasing ΔT by 1.5 ± 0.2 kelvin in dry climates. In the humid eastern United States, there is evidence of higher ΔT in drier years. These relationships imply that UHIs will exacerbate heatwave stress on human health in wet climates where high temperature effects are already compounded by high air humidity[6,7] and in drier years when positive temperature anomalies may be reinforced by a precipitation–temperature feedback[8]. Our results support albedo management as a viable means of reducing ΔT on large scales[9,10].

The conversion of natural land to urban land causes several notable perturbations to the Earth's surface energy balance. Reduction of evaporative cooling is generally thought to be the dominant factor contributing to UHI. Anthropogenic heat release is an added energy input to the energy balance and should increase the surface temperature. Energy input by solar radiation will also increase if albedo is reduced in the process of land conversion. Buildings and other artificial materials can store more radiation energy in the daytime than can natural vegetation and soil; release of the stored energy at night contributes to night-time

(*Zhao et al., 2014*)

nature COMMUNICATIONS

ARTICLE

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OPEN

Urban heat islands in China enhanced by haze pollution

Chang Cao[1,2], Xuhui Lee[1,2], Shoudong Liu[1], Natalie Schultz[2], Wei Xiao[1,2], Mi Zhang[1] & Lei Zhao[1,2,3]

The urban heat island (UHI), the phenomenon of higher temperatures in urban land than the surrounding rural land, is commonly attributed to changes in biophysical properties of the land surface associated with urbanization. Here we provide evidence for a long-held hypothesis that the biogeochemical effect of urban aerosol or haze pollution is also a contributor to the UHI. Our results are based on satellite observations and urban climate model calculations. We find that a significant factor controlling the nighttime surface UHI across China is the urban–rural difference in the haze pollution level. The average haze contribution to the nighttime surface UHI is 0.7 ± 0.3 K (mean ± 1 s.e.) for semi-arid cities, which is stronger than that in the humid climate due to a stronger longwave radiative forcing of coarser aerosols. Mitigation of haze pollution therefore provides a co-benefit of reducing heat stress on urban residents.

(*Cao et al., 2016*)

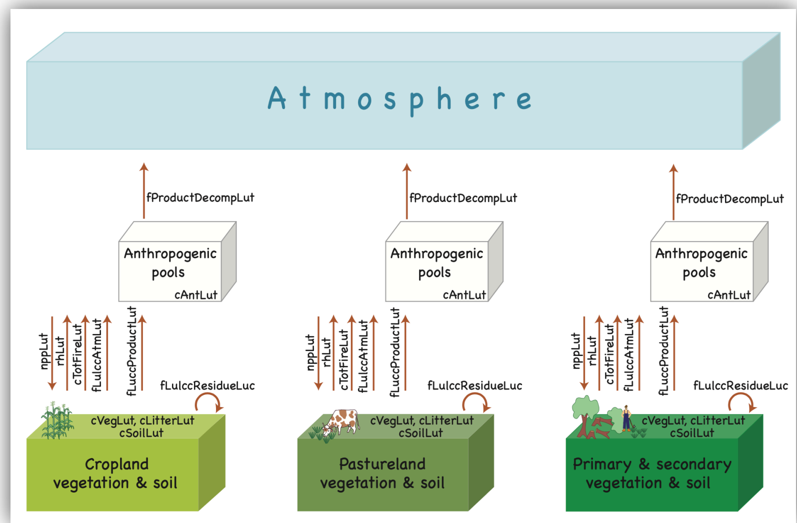
Question

How the local land surface temperature response to deforestation simulated by different ESMs can be compared?

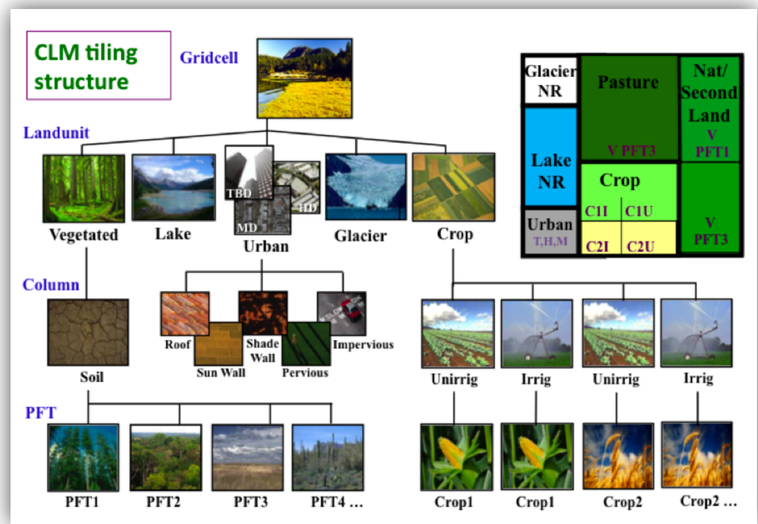
Goal

Compare the sensitivities and responses of LST to deforestation based on the subgrid-scale outputs from global ESMs using an improved attribution framework.

GFDL



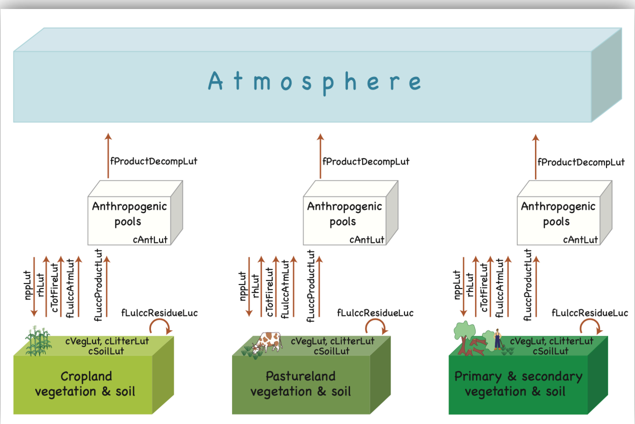
CESM



Method

Model simulations

GFDL ESM2Mb



- Subgrid-level outputs
- The period of 1980-2005
- Temporal resolution: monthly
- Spatial resolution: 2° latitude by 2.5° longitude

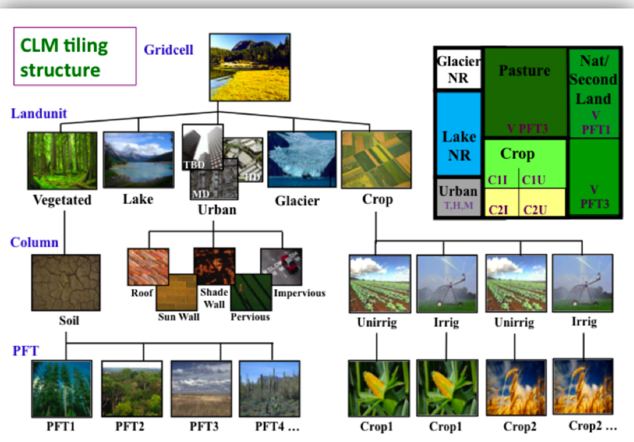
2° latitude by 2.5° longitude

cropland tile natural vegetation tile

$$\Delta T_s = T_{cropland} - T_{forest}$$

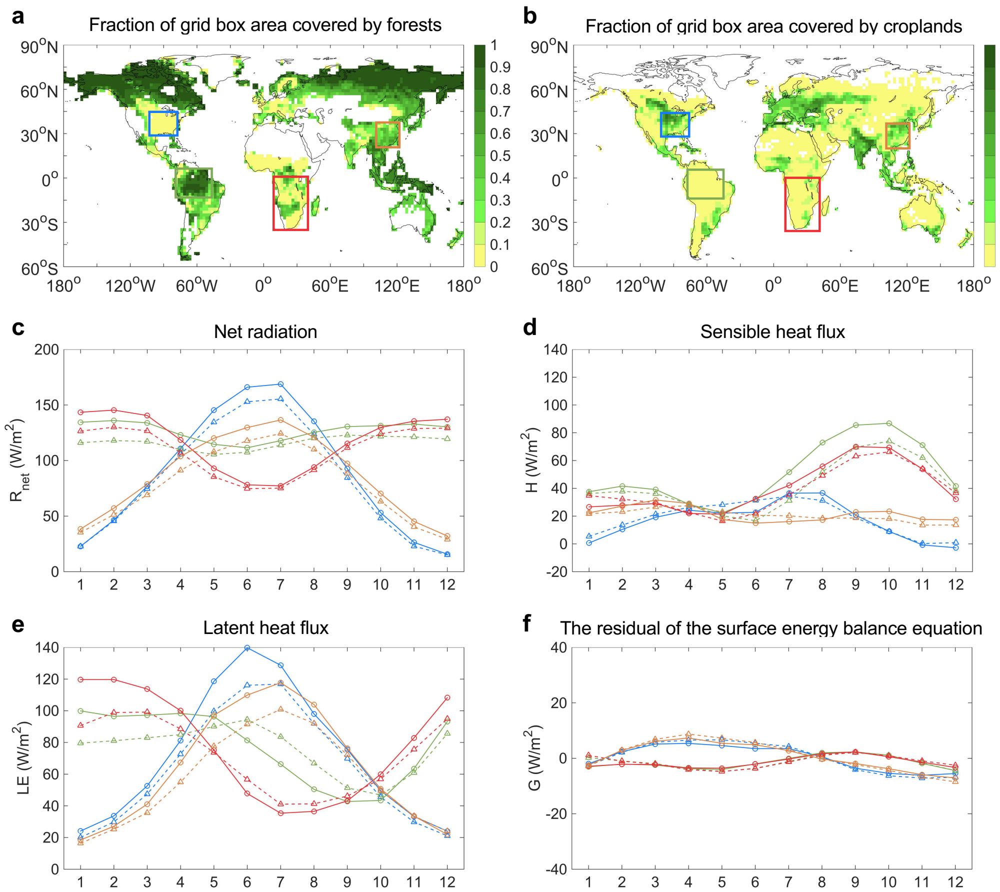
unmanaged rainfed crops all types of trees

CESM

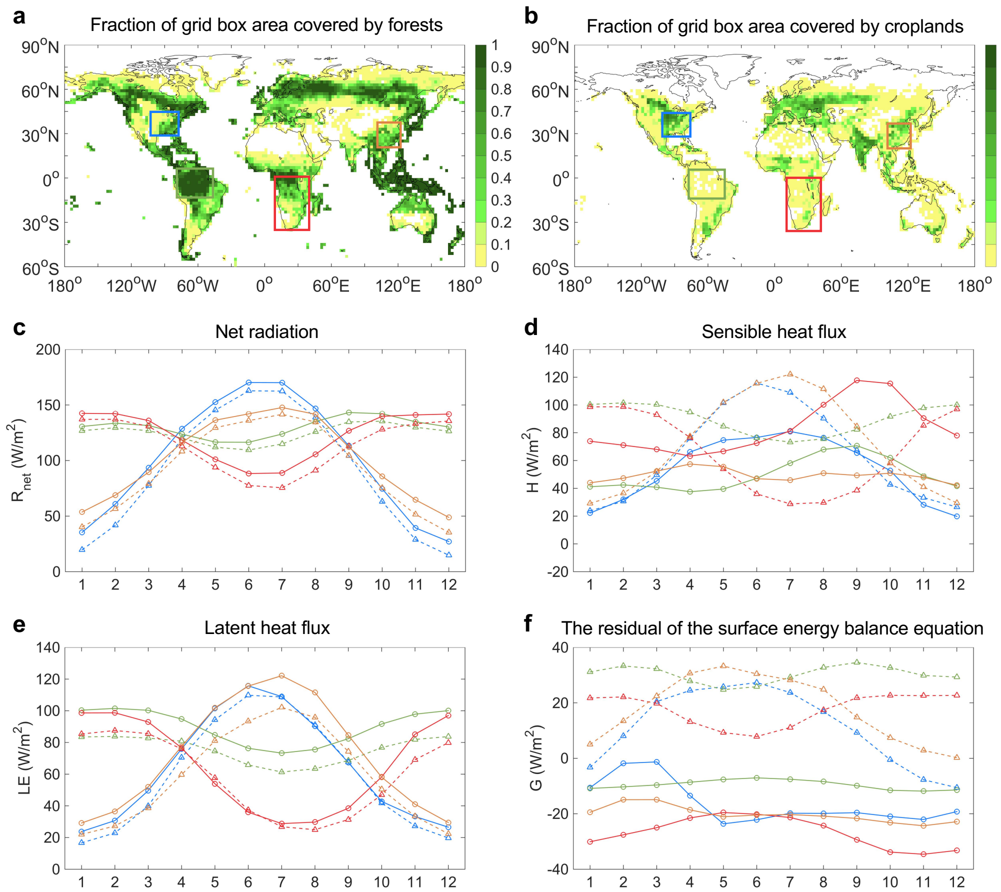


- Subgrid PFT-level outputs
- The period of 1980-2005
- Temporal resolution: monthly
- Spatial resolution: 1° latitude by 1° longitude

The impacts of deforestation on surface fluxes in the two models



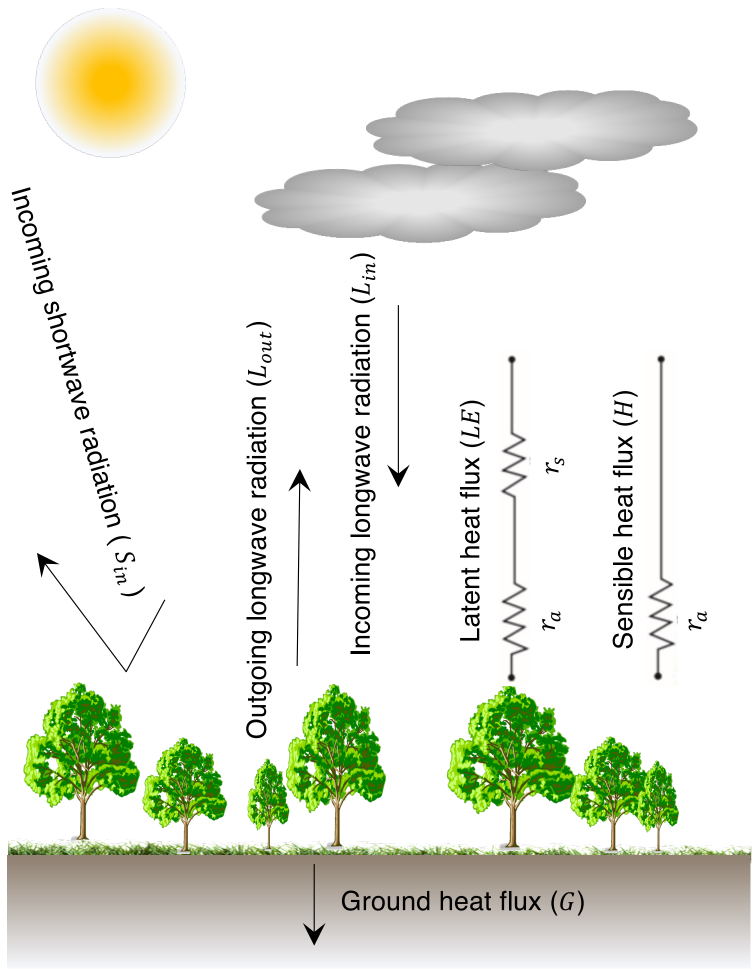
GFDL ESM2Mb



CESM

Forests and croplands have large differences in terms of radiative and turbulent fluxes, which are caused by their contrasting surface biophysical properties.

The attribution framework



$$L_{out} = \varepsilon\sigma T_s^4$$

$$LE = \frac{\rho L_v}{(r_a + r_s)}\left(q_s^*(T_s) - q_a\right)$$

$$S_{in} - S_{out} + L_{in} - L_{out} = H + LE + G$$

$$S_{out} = \alpha S_{in}$$

$$H = \frac{\rho c_p}{r_a}(T_s - T_a)$$

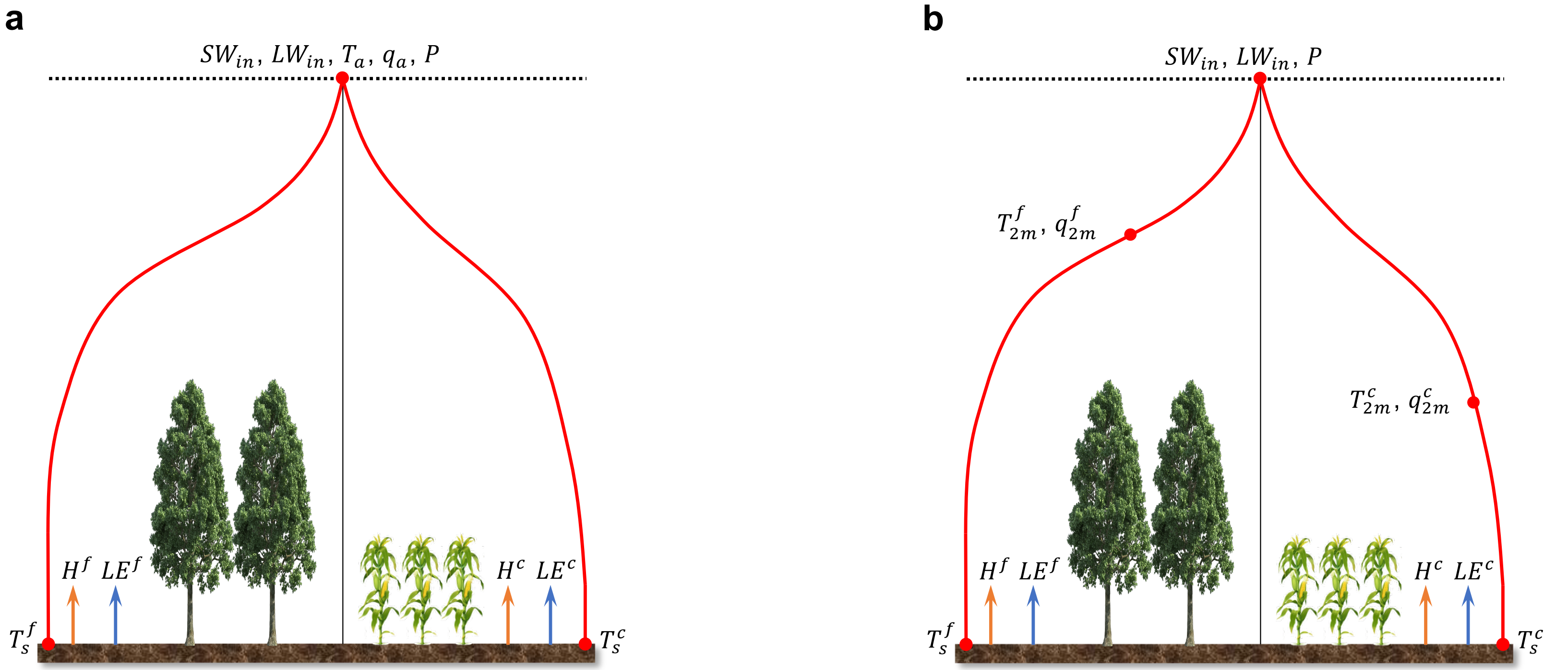
$$S_{in}(1-\alpha) + L_{in} - \varepsilon\sigma T_s^4 = \frac{\rho c_p}{r_a}(T_s - T_a) + \frac{\rho L_v}{(r_a + r_s)}\left(q_s^*(T_s) - q_a\right) + G$$

$$T_s = \frac{\lambda_o\left[R_n^* - G - \frac{\rho L_v}{(r_a + r_s)}\left(q_a^*(T_a) - q_a\right)\right]}{1 + f_{TRM}} + T_a \quad \text{where ,} \quad \begin{cases} R_n^* = S_{in}(1-\alpha) + \varepsilon L_{in} - \varepsilon\sigma T_a^4 \\ \lambda_o = 1/(4\varepsilon\sigma T_a^3), \quad r_o = \rho c_p \lambda_o \\ f_{TRM} = \frac{r_o}{r_a}\left[1 + \frac{\delta}{\gamma}\left(\frac{r_a}{r_a + r_s}\right)\right] \\ \delta = \left.\frac{\partial e^*}{\partial T}\right|_{T_a}, \quad \gamma = \frac{c_p P}{0.622 L_v} \end{cases}$$

(Rigden and Li, 2017)

The attribution framework

$$\Delta T_s = \overbrace{\frac{\partial T_s}{\partial \alpha}\Delta\alpha + \frac{\partial T_s}{\partial \varepsilon}\Delta\varepsilon + \frac{\partial T_s}{\partial r_a}\Delta r_a + \frac{\partial T_s}{\partial r_s}\Delta r_s + \frac{\partial T_s}{\partial G}\Delta G}^{\text{land}} + \overbrace{\frac{\partial T_s}{\partial q_a}\Delta q_a + \frac{\partial T_s}{\partial T_a}\Delta T_a + \frac{\partial T_s}{\partial S_{in}}\Delta S_{in} + \frac{\partial T_s}{\partial L_{in}}\Delta L_{in}}^{\text{atmosphere}}$$



$$\Delta T_s = \frac{\partial T_s}{\partial \alpha}\Delta\alpha + \frac{\partial T_s}{\partial r_a}\Delta r_a + \frac{\partial T_s}{\partial r_s}\Delta r_s + \frac{\partial T_s}{\partial G}\Delta G$$

$$\Delta T_s = \frac{\partial T_s}{\partial \alpha}\Delta\alpha + \frac{\partial T_s}{\partial r_a}\Delta r_a + \frac{\partial T_s}{\partial r_s}\Delta r_s + \frac{\partial T_s}{\partial G}\Delta G + \frac{\partial T_s}{\partial q_a}\Delta q_a + \frac{\partial T_s}{\partial T_a}\Delta T_a$$

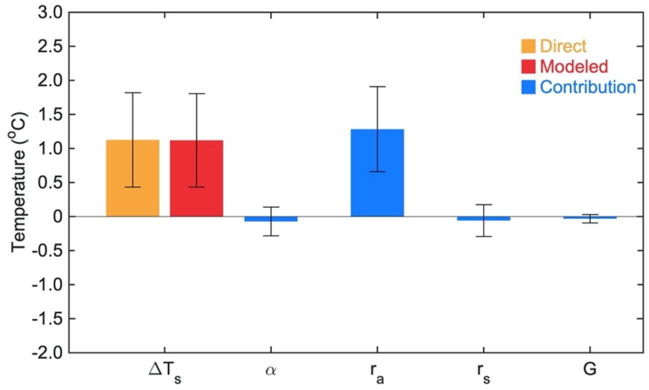
Results

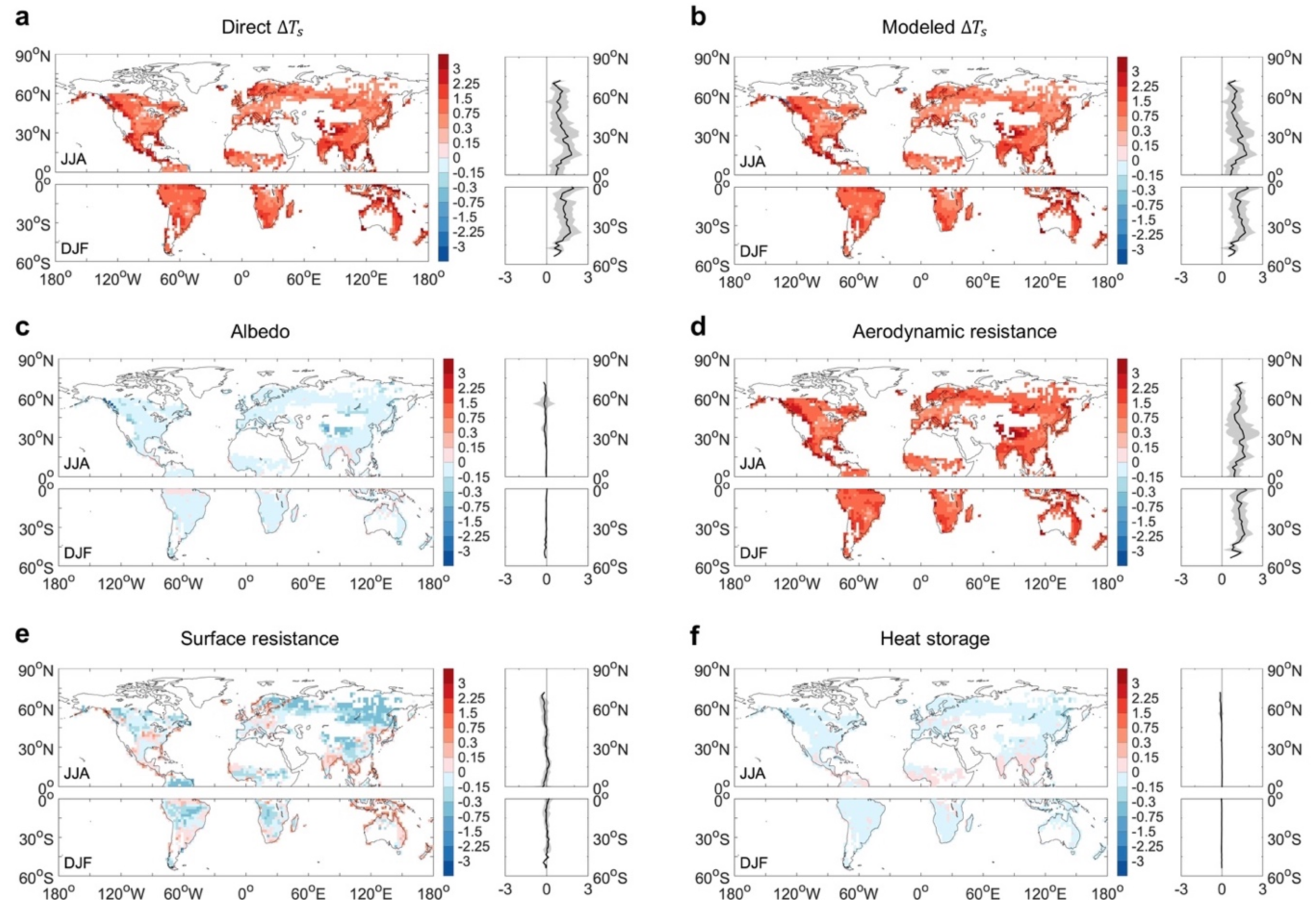
Attribution of the LST response to deforestation in the GFDL-ESM2Mb model (summer)

- Converting forests to croplands results in warming during summer.

(Note: $\Delta T_s = T_{cropland} - T_{forest}$)

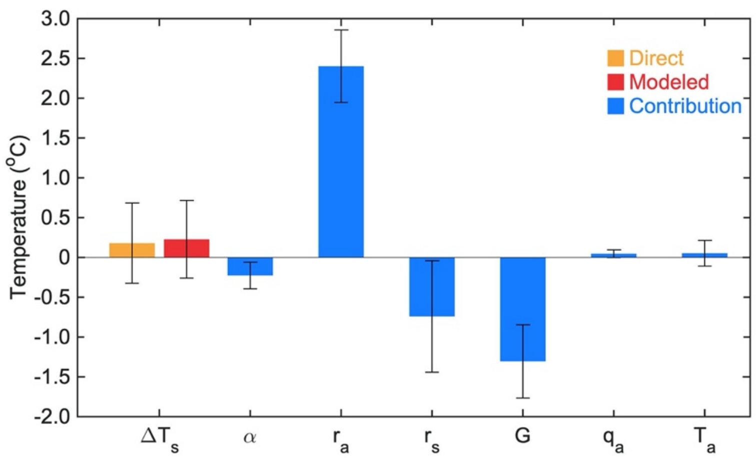
- Modeled ΔT_s agrees well with that calculated directly by taking their temperature difference.
- ΔT_s is larger in the midlatitudes and relatively smaller in the high latitudes and the tropics.
- Largely explained by changes in aerodynamic resistance.

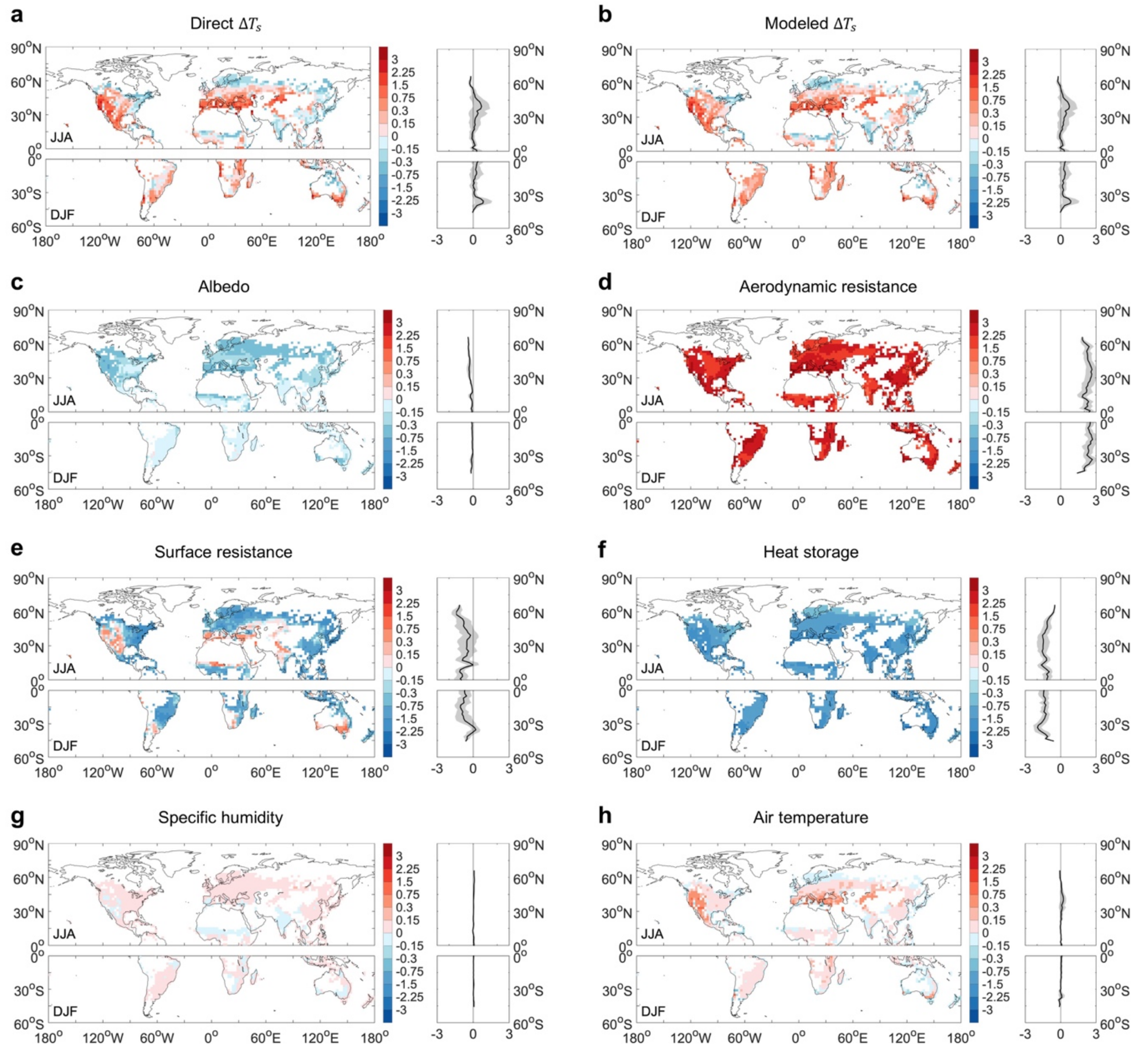




Attribution of the LST response to deforestation in the CESM model (summer)

- The attribution method captures ΔT_s reasonably well.
- A cooling effect near the northern high latitudes and over eastern America, India, and China, but a warming effect over other regions.
- Largely explained by changes in aerodynamic resistance.





Comparison between results from the GFDL-ESM2Mb and CESM models (summer)

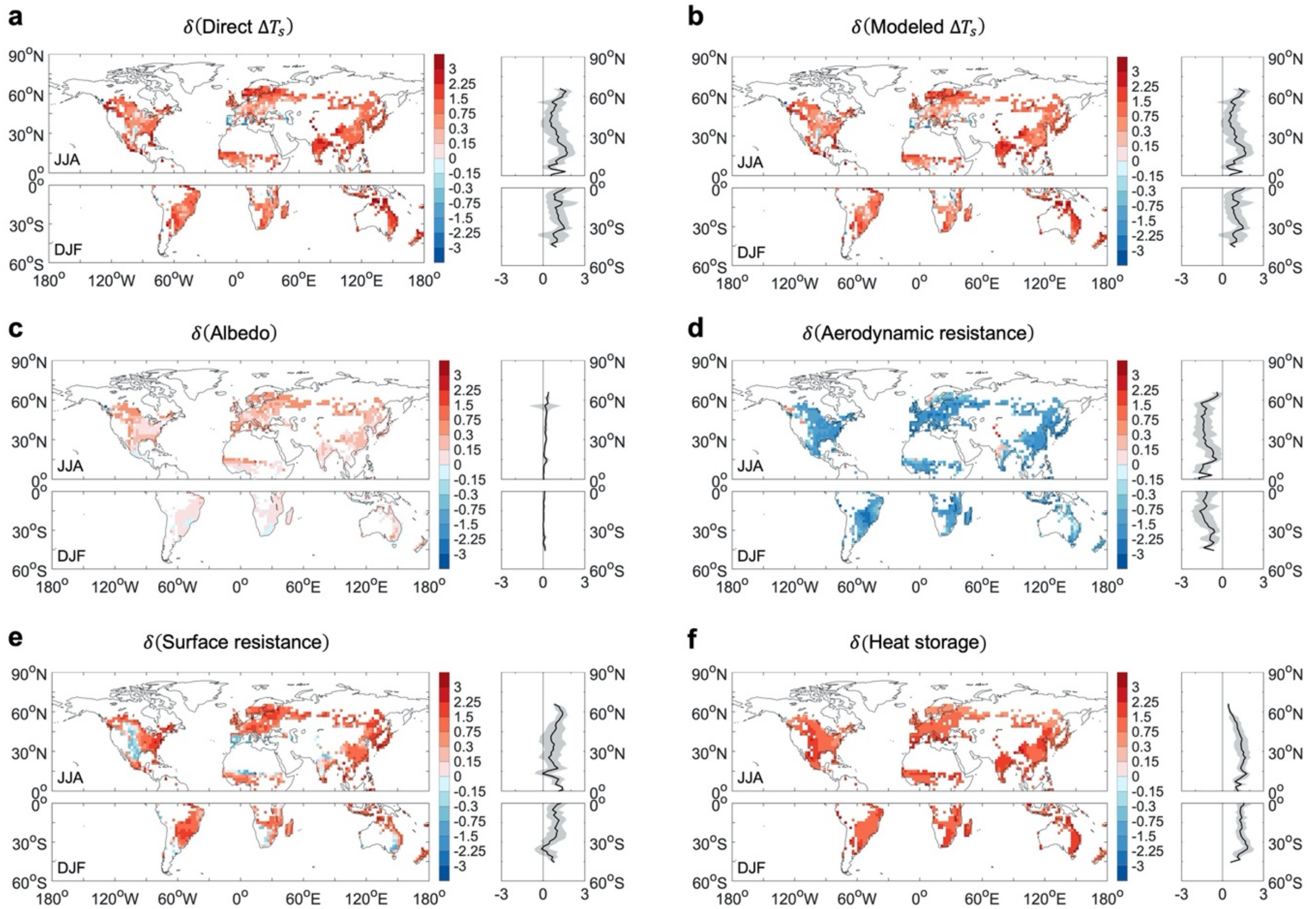
$$\delta = V_{GFDL} - V_{CESM}$$

- δ is positive for the albedo, surface resistance, and heat storage, and negative for the aerodynamic resistance.

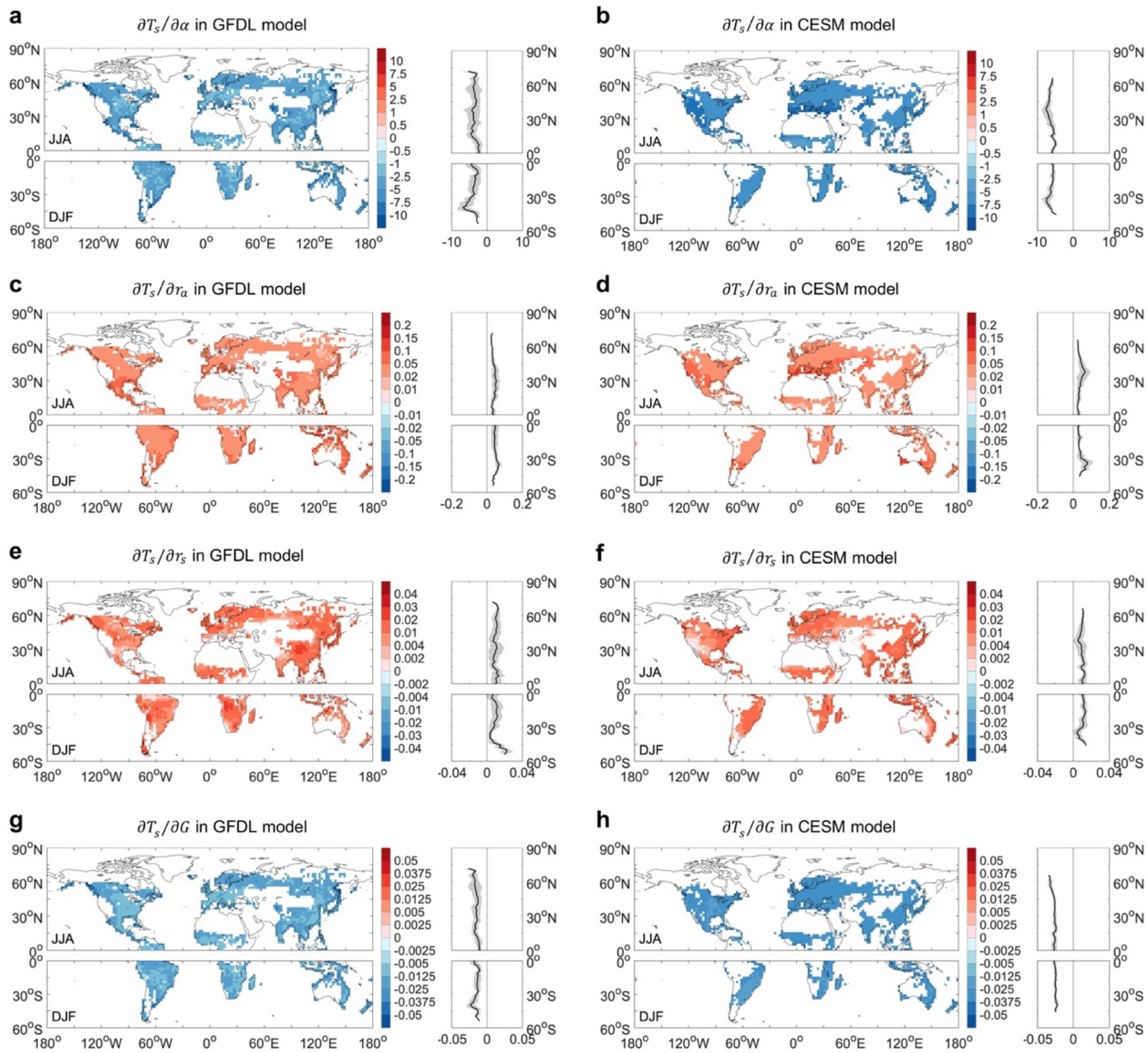
- Decompose:

$$\frac{\partial T_s}{\partial \alpha}\Delta\alpha \qquad \frac{\partial T_s}{\partial r_a}\Delta r_a$$

$$\frac{\partial T_s}{\partial r_s}\Delta r_s \qquad \frac{\partial T_s}{\partial G}\Delta G$$

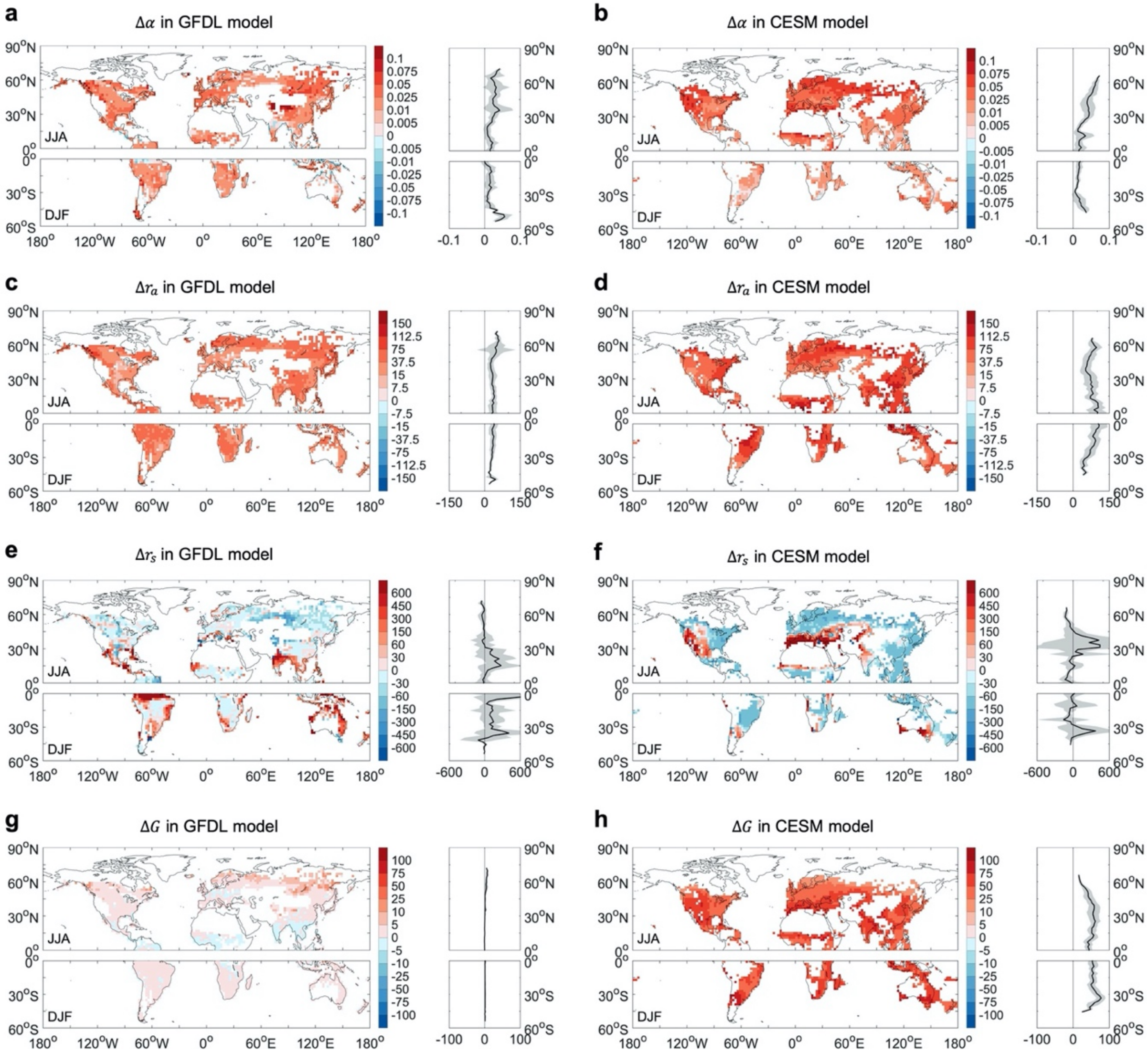


Comparison between results from the GFDL-ESM2Mb and CESM models (summer)



- The spatial pattern is overall similar in the two models.
- $\frac{\partial T_s}{\partial \alpha}$ is negative over the whole globe.
- $\frac{\partial T_s}{\partial r_a}$ is positive over the whole globe, indicating that the LST increases as the land surface becomes smoother.
- $\frac{\partial T_s}{\partial r_s}$ is positive over the whole globe, indicating that the surface becomes hotter when it becomes drier (less soil moisture or less vegetation).
- $\frac{\partial T_s}{\partial G}$ is negative over the whole globe, indicating that the surface becomes cooler when it diverts more energy into the subsurface.

Comparison between results from the GFDL-ESM2Mb and CESM models (summer)

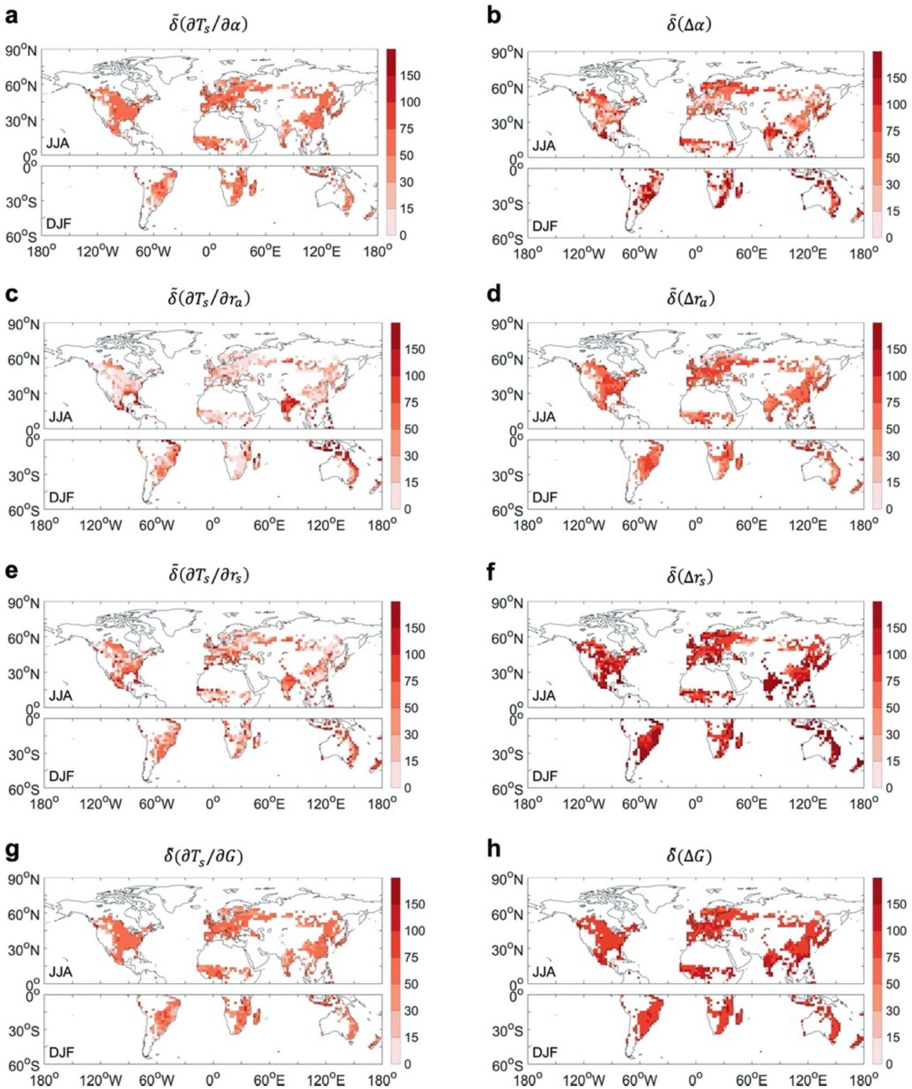


- Both models agree that croplands have higher albedo and aerodynamic resistance values than forests, implying that deforestation causes the land to be brighter and smoother.

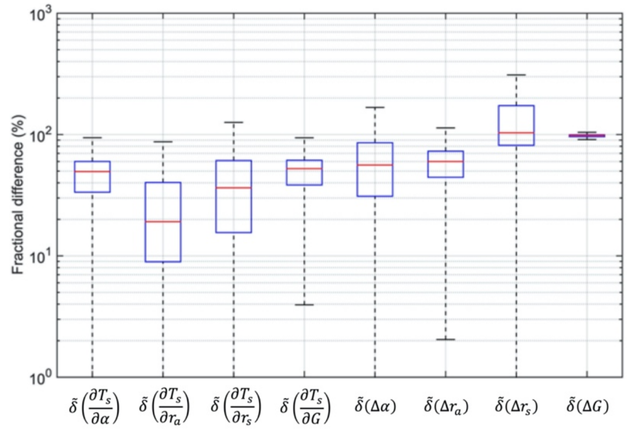
- For Δr_s, the differences between the two models are possibly due to the substantial difference in the physical parameterizations of evapotranspiration used in the two models.

- For ΔG, the CESM model shows much larger values than the GFDL model, which is due to the differences in the model structures.

Comparison between results from the GFDL-ESM2Mb and CESM models (summer)



$$\tilde{\delta} = \left|\frac{V_{GFDL} - V_{CESM}}{V_{CESM}}\right| \times 100\%$$



median value: 20% ~ 50% 55% ~ 100%

- The fractional differences in terms of the sensitivities are smaller than those of the corresponding changes.
- The biophysical changes are directly related to the model structure and parameterization differences.
- The sensitivities are constrained by the surface energy balance equation.

Conclusions

- Subgrid-scale information from land surface models is a powerful tool for investigating the impacts of LULCC on the local surface climate.
- Aerodynamic resistance is the key controlling factor for the LST changes induced by deforestation.
- The dissimilarity between the two models in terms of LST responses to deforestation is more related to the magnitude of biophysical changes.
- Related works:

Water Resources Research

RESEARCH ARTICLE
10.1029/2019WR024771

Key Points:
- Observations indicate that responses of evaporative fraction to heatwaves vary across land cover types
- An analytical attribution method is employed to quantify the relative roles of surface and atmospheric factors
- Heatwave-induced changes in evaporative fraction are mainly caused by changes in vapor pressure deficit and surface resistance

Supporting Information:
- Supporting Information S1

Correspondence to:
D. Li,
lidan@bu.edu

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Contrasting Evaporative Responses of Ecosystems to Heatwaves Traced to the Opposing Roles of Vapor Pressure Deficit and Surface Resistance

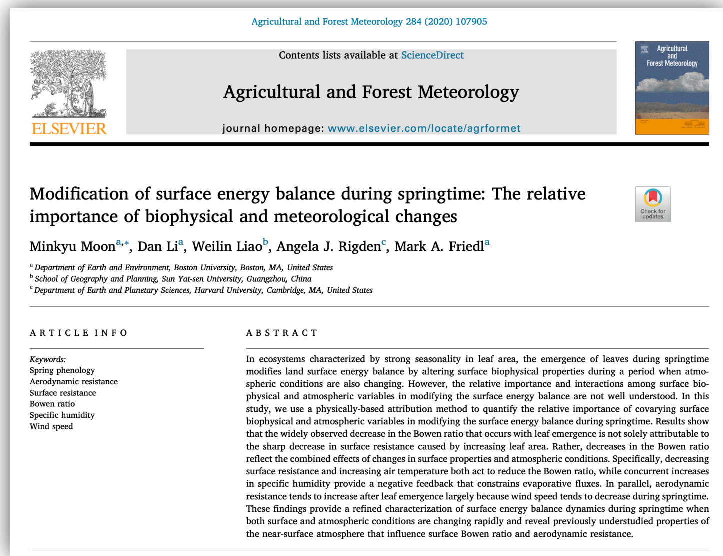
Peng Wang[1,2], Dan Li[2], Weilin Liao[3], Angela Rigden[4], and Wen Wang[1]

[1]State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing, China, [2]Department of Earth and Environment, Boston University, Boston, MA, USA, [3]School of Geography and Planning, Sun Yat-sen University, Guangzhou, China, [4]Department of Earth and Planetary Sciences, Harvard University, Boston, MA, USA

Abstract Understanding the evaporative response of ecosystems to heatwaves is critical for managing ecosystem services and water resources, especially under a changing climate. In this study, we examine the land-atmosphere exchange of water and heat fluxes under heatwave and nonheatwave conditions across five different land cover types, including grasslands, shrublands, croplands, deciduous broadleaf forests, and evergreen needleleaf forests, using data from eddy covariance towers. Results show that net radiation and sensible heat flux increase from nonheatwave to heatwave conditions across all five land cover types but latent heat flux shows contrasting responses to heatwaves. An attribution analysis further demonstrates that heatwave-induced changes in evaporative fraction are mainly caused by changes in vapor pressure deficit (positive contribution) and changes in surface resistance (negative contribution). The imbalance between the positive and negative contributions varies across the five land cover types and is responsible for their contrasting evaporative responses to heatwaves.

Plain Language Summary A heatwave is a period of extremely hot weather. Under a warming climate, heatwaves are expected to become more frequent, stronger, and longer lasting. Heatwaves are amongst the deadliest natural disasters. Within such contexts, key questions that need to be addressed include how different ecosystems respond to heatwaves differently and, more importantly, what factors control such contrasting responses. In this study, we employ an analytical attribution framework and combine it with observational data to explore the responses of evaporative fraction, a key indicator of the partition between sensible and latent heat fluxes, to heatwaves over five major land cover types. We quantify the contributions of various land surface and atmospheric factors in controlling changes in the evaporative

(Wang et al., 2019)



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ELSEVIER

Modification of surface energy balance during springtime: The relative importance of biophysical and meteorological changes

Minkyu Moon[a,*], Dan Li[a], Weilin Liao[b], Angela J. Rigden[c], Mark A. Friedl[a]

[a] Department of Earth and Environment, Boston University, Boston, MA, United States
[b] School of Geography and Planning, Sun Yat-sen University, Guangzhou, China
[c] Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA, United States

ARTICLE INFO

Keywords:
Spring phenology
Aerodynamic resistance
Surface resistance
Bowen ratio
Specific humidity
Wind speed

ABSTRACT

In ecosystems characterized by strong seasonality in leaf area, the emergence of leaves during springtime modifies land surface energy balance by altering surface biophysical properties during a period when atmospheric conditions are also changing. However, the relative importance and interactions among surface biophysical and atmospheric variables in modifying the surface energy balance are not well understood. In this study, we use a physically-based attribution method to quantify the relative importance of covarying surface biophysical and atmospheric variables in modifying the surface energy balance during springtime. Results show that the widely observed decrease in the Bowen ratio that occurs with leaf emergence is not solely attributable to the sharp decrease in surface resistance caused by increasing leaf area. Rather, decreases in the Bowen ratio reflect the combined effects of changes in surface properties and atmospheric conditions. Specifically, decreasing surface resistance and increasing air temperature both act to reduce the Bowen ratio, while concurrent increases in specific humidity provide a negative feedback that constrains evaporative fluxes. In parallel, aerodynamic resistance tends to increase after leaf emergence largely because wind speed tends to decrease during springtime. These findings provide a refined characterization of surface energy balance dynamics during springtime when both surface and atmospheric conditions are changing rapidly and reveal previously understudied properties of the near-surface atmosphere that influence surface Bowen ratio and aerodynamic resistance.

(Moon et al., 2020)

Thank you for your attention！

Email: liaoweilin@mail.sysu.edn.cn