ISOLATING AND COMPARING THE COOLING EFFICIENCY OF TREES AND SHORT VEGETATION IN LARGE CITIES ACROSS THE GLOBE

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1 Why? We are living in warming cities!

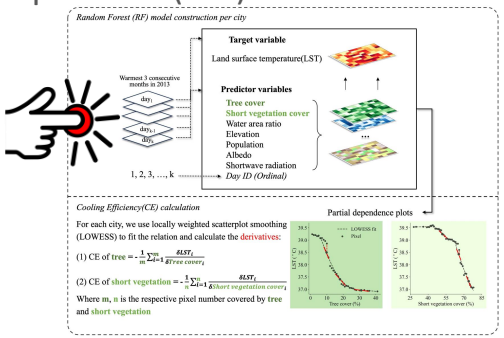
Vegetations are helpful in cooling the cities, but…

- How **efficiently** vegetations can help to cool the warming cities?
- Will **short vegetation** also be helpful?

Image source: https://www.coolandcovered.com.au/projects/effective-tree-shade/
Icon source: https://www.downloadclipart.net/browse/19591/press-button-clipart

2 How? Random forest (RF) can help!

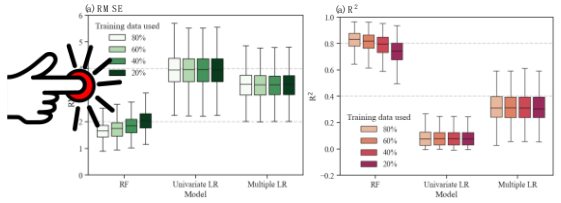
RF models help to **isolate** trees' and short vegetation's influences on land surface temperature (LST).



Framework of this study

3 Does it work? RF outperforms traditional ways!

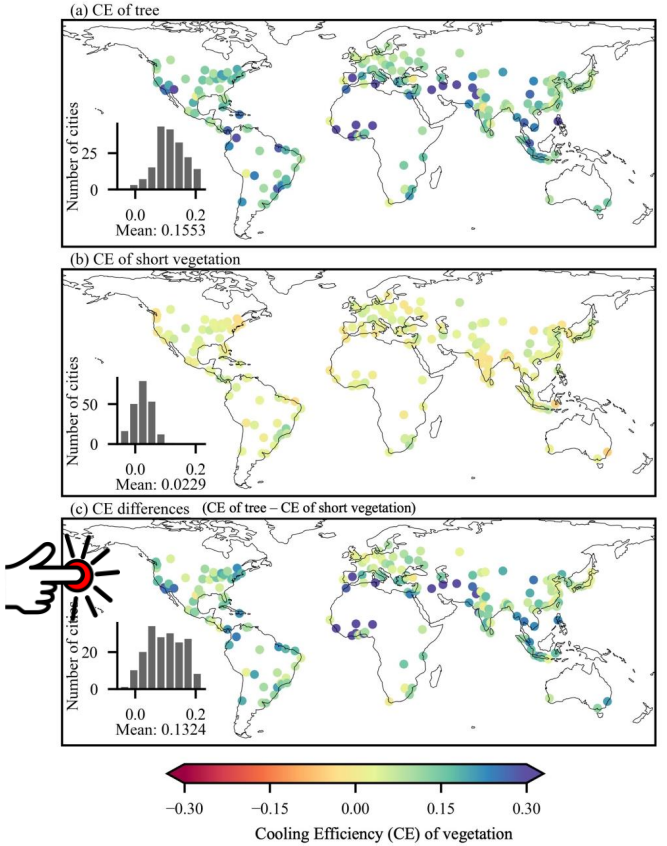
RF has smaller RMSE and larger R^2 compared with linear regression models no matter the training data size.



(a)RMSE and (2)R^2 comparisons among different models for reproducing LST

4 Tree CEs are larger, but they are comparable with short vegetation in some cities!

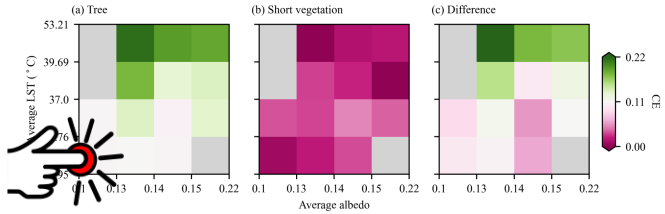
- Trees' CE is about 5.6 times of that for short vegetation on average, but in some cities they are comparable.
- In the 20% hottest days, CE of tree increases but CE of short vegetation decreases.



Map of LST change associated with 1% (a)tree, (b)short vegetation cover increase in cities globally and the (c) CE differences between two vegetation types

5 And then? Implications on urban planning.

Cities with **lower average tree cover** and **lower albedo** enjoy higher cooling efficiency (CE) of trees.



Cooling efficiency of (a)tree, (b)short vegetation and (c)differences across different regimes

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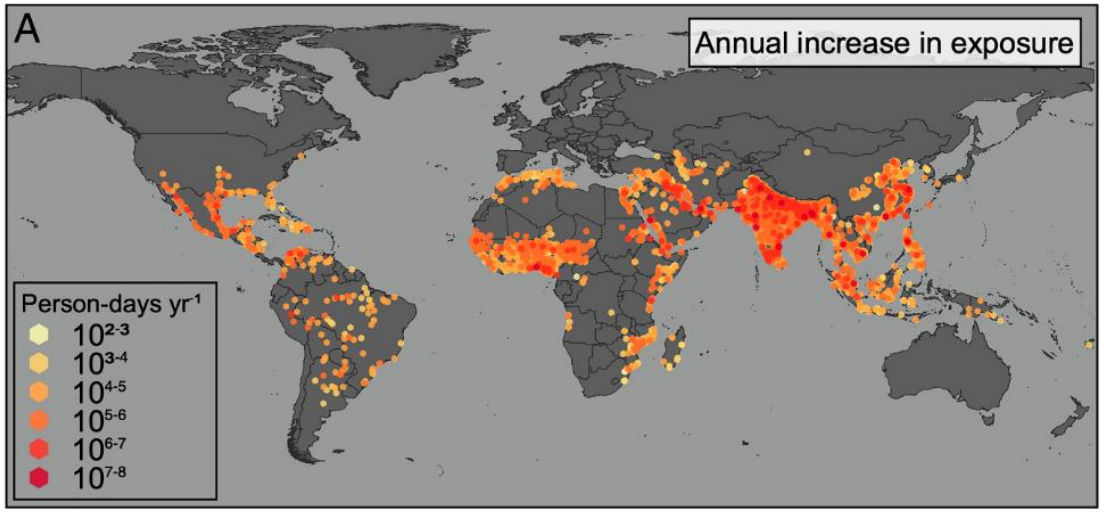
Abstract

1 Why we care about urban vegetation cooling?

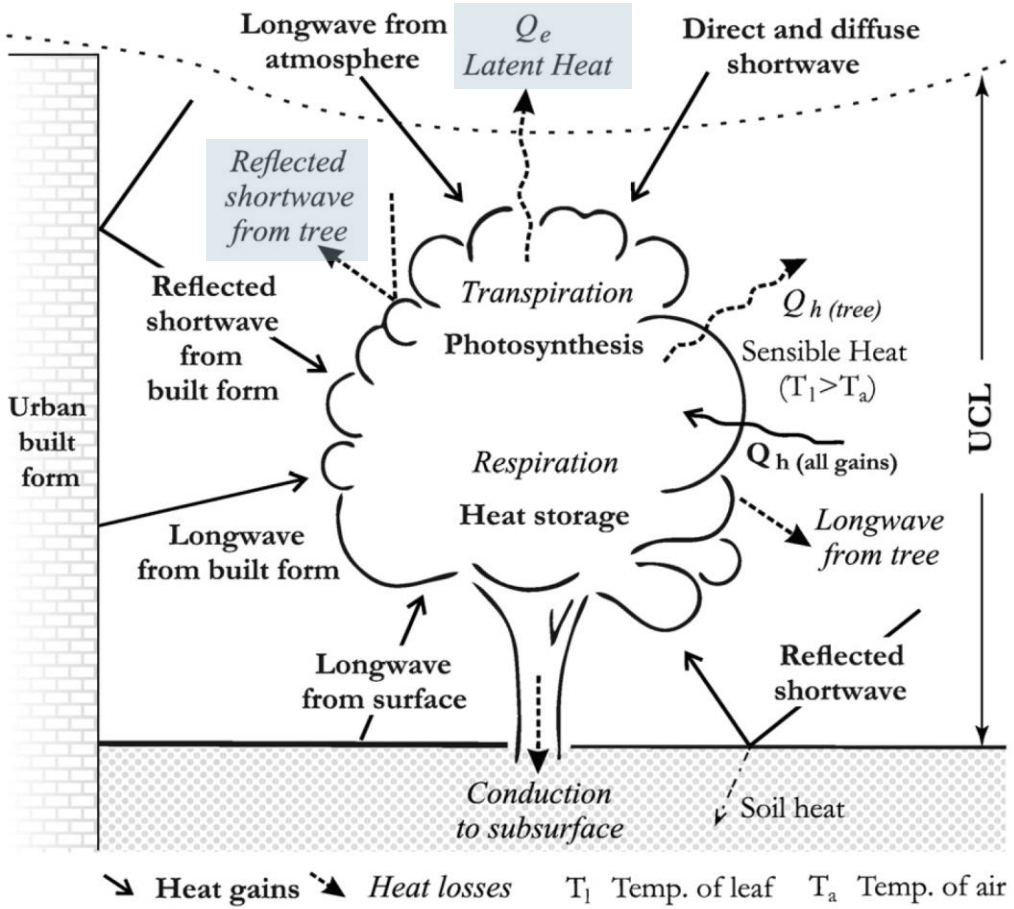
❑ Urban residents heat exposure increases



Municipality-level increase in the rate of urban population exposure to extreme heat from 1983 to 2016
(Tuholske et al., 2020, Proceedings of the National Academy of Sciences)

But we have limited spaces and can't increase vegetation cover infinitely. So we need to think about 'efficiency'.

❑ Vegetation can cool cities by **transpiration and shades**



Daytime energy exchanges between a tree and urban built form
(Gunawardena et al., 2017, Science of the Total Environment)

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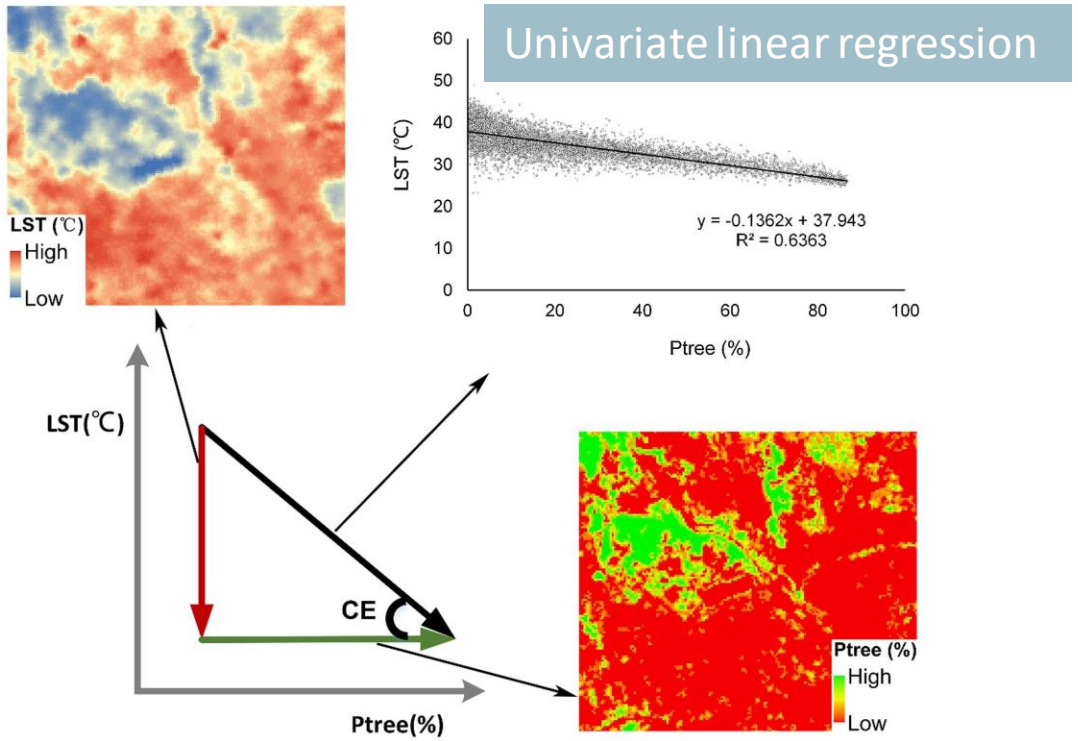
1 What is cooling efficiency (CE) of vegetation?

❑ CE quantifies the LST effect of 1% increase of vegetation cover



Quantification for cooling efficiency based on the linear regression between Ptree and LST
(Wang et al., 2020, ISPRS Journal of Photogrammetry and Remote Sensing)

Drawbacks

- Overlook other influential factors on LST
- Can't deal with collinearity among predictor factors
- Simplify the relationship between LST and vegetation cover to be linear

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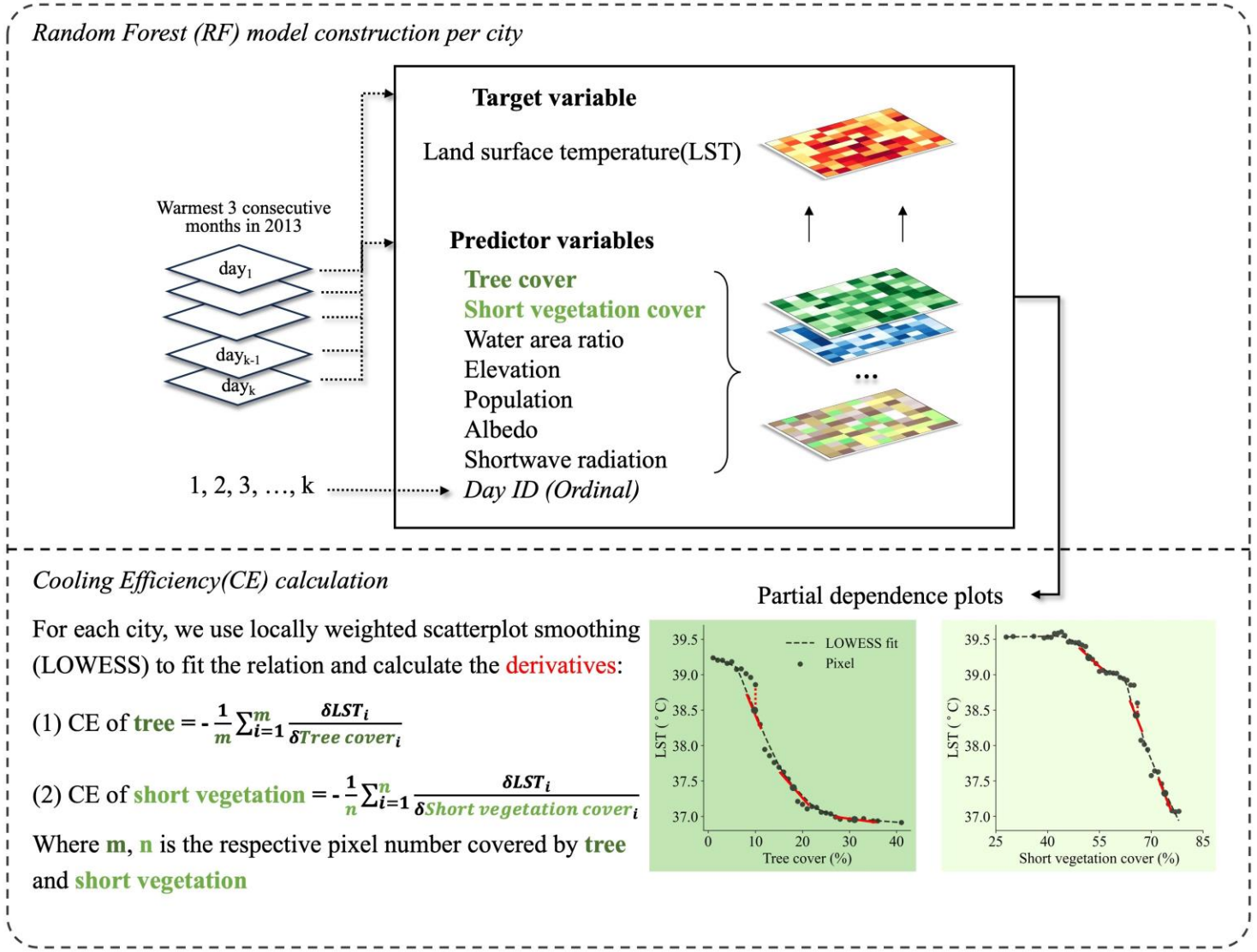
2 CE calculation: random forest and partial dependence fitting.

❑ Framework of CE calculation



Meaning of CE:

The average LST effect caused by 1% vegetation cover increase across the city.

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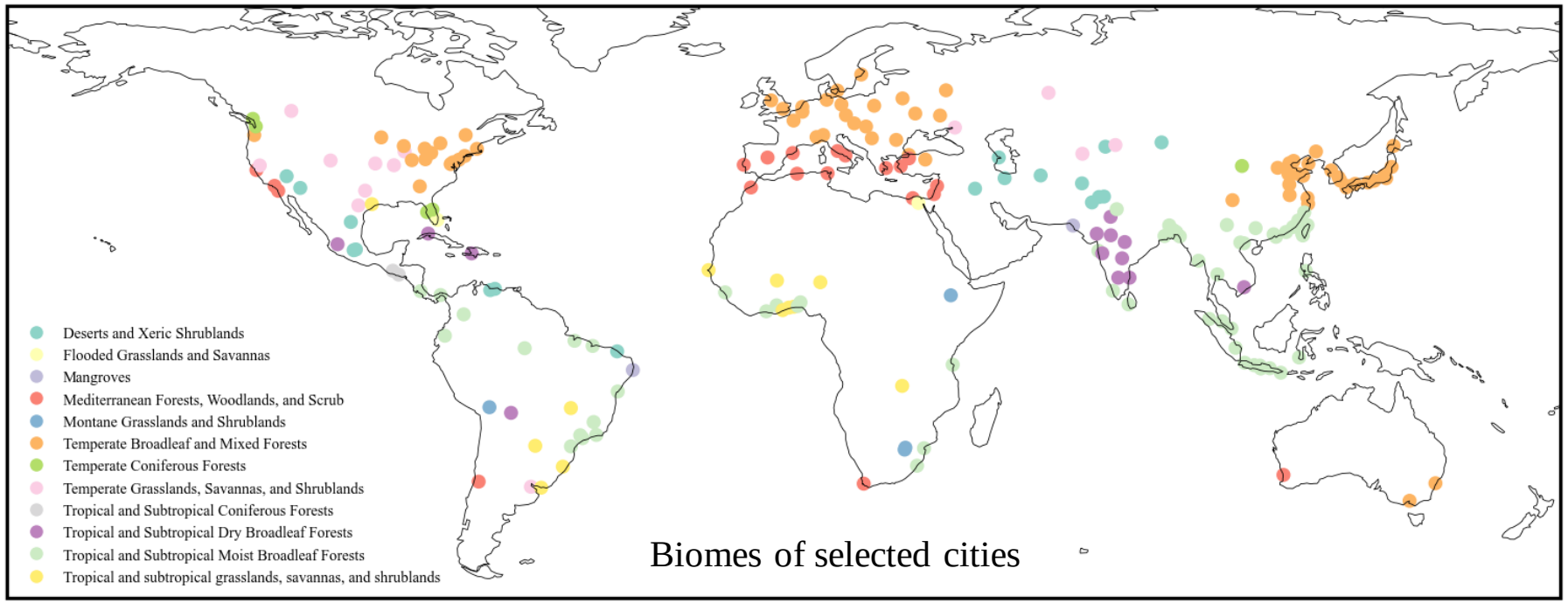
2 Cities selection criteria and study period.

❑ 216 cities are selected globally



Biomes of selected cities

- Urban center areas larger than **100 km²**
- Populations exceeding **1 million**
- At least one meteorological station within built-up area
- **216** cities were selected

❑ Study period

- The **warmest three consecutive months** for each city. For most cities, it is the year **2013/2014.**

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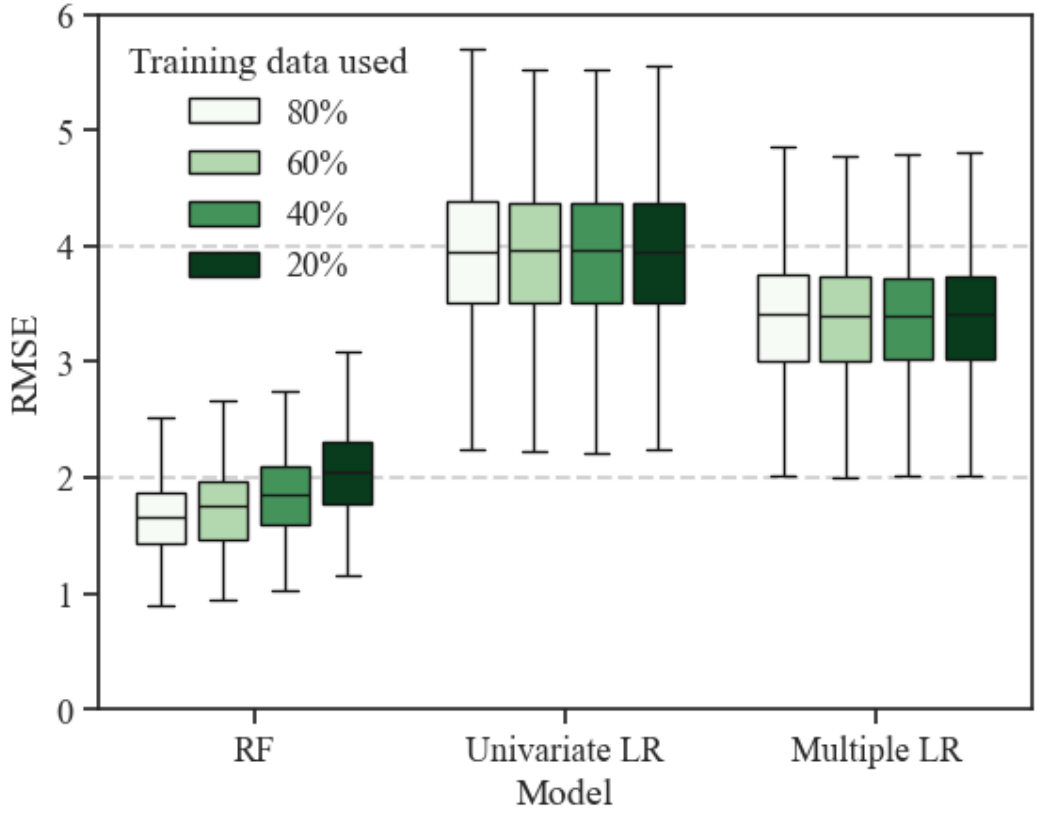
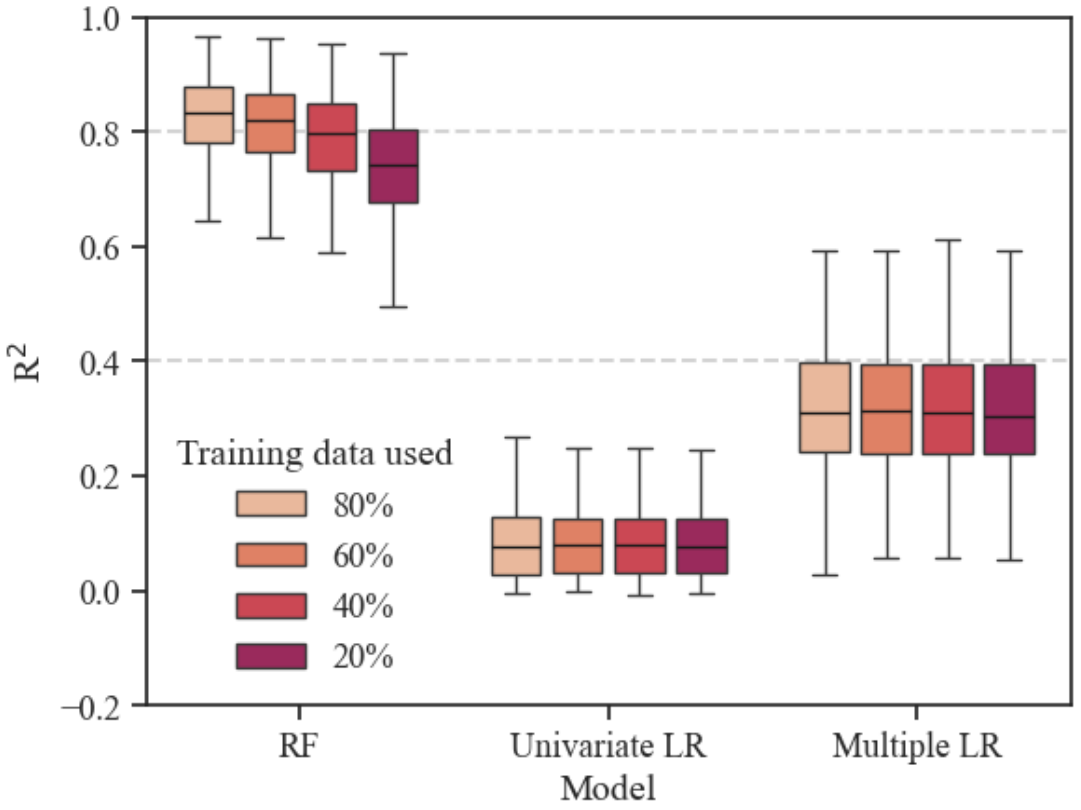
3 Random forest models outperform linear regression models.

❑ Comparisons of model performances





- RF model always performs the best no matter the training data size.
- RF models improve significantly when the training data increases.

For all RF models,
OOB score: mean=0.833 (0.487-0.970)
R^2: mean=0.977 (0.931-0.0.995)

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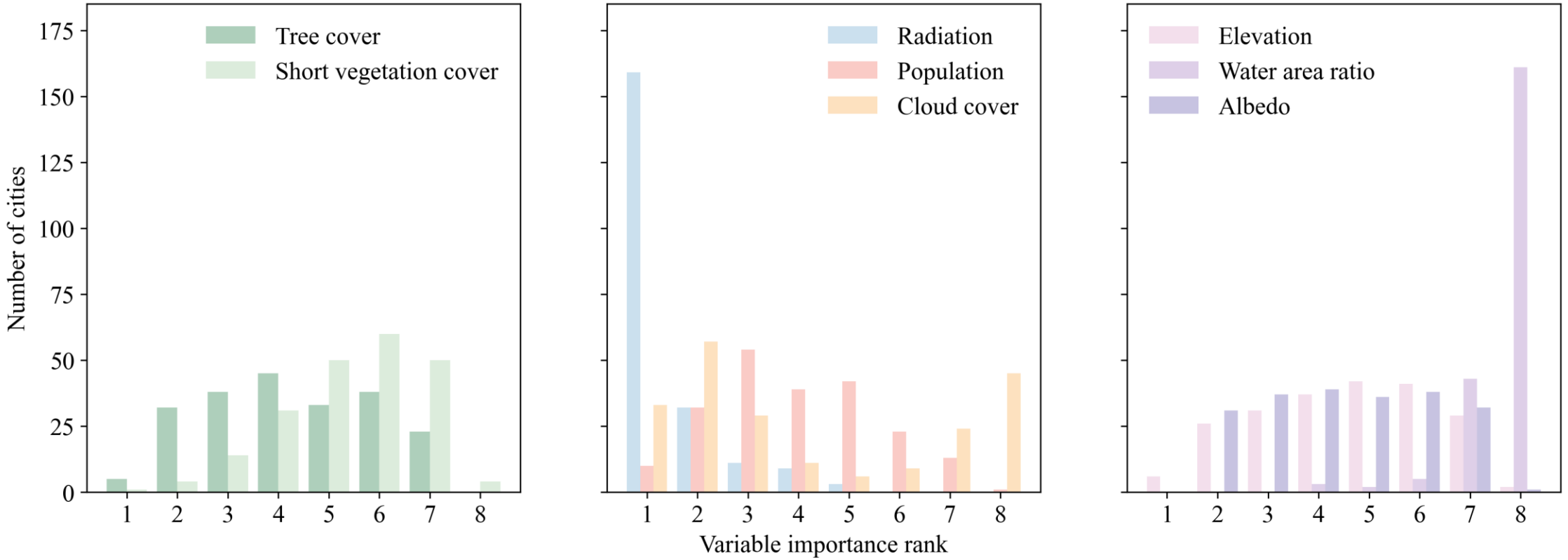
3 It’s important to consider other variables.

❑ Permutation importance of predictor variables



- Tree cover has higher importance rank than short vegetation cover in most cities.
- The high importance of shortwave radiation, cloud cover and population showed the potential flaw of CE calculation without considering these variables.

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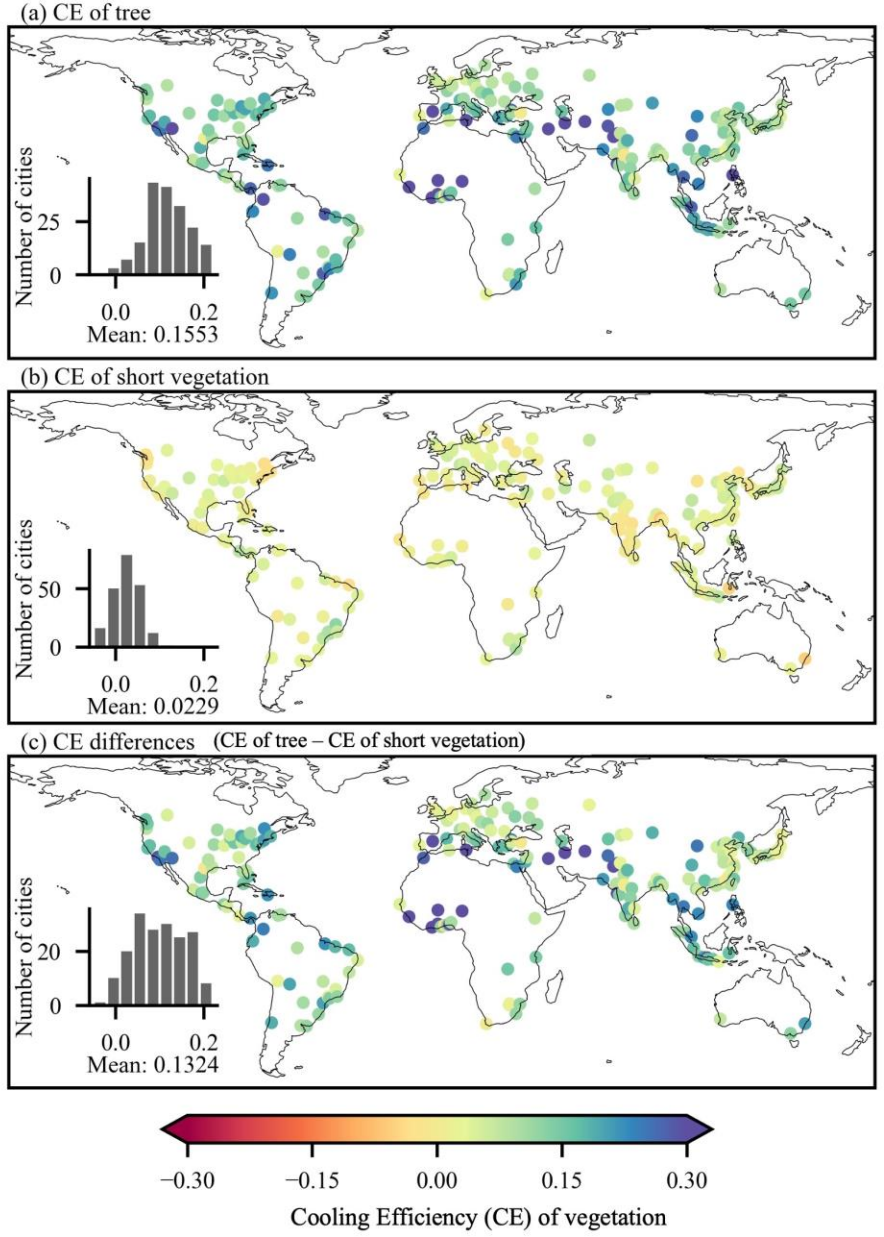
4 CE of trees is about 5.6 times of short vegetation.

❑ LST effect of increasing 1% vegetation cover in cities

- Increasing 1% tree cover, LST will decrease **-0.05-0.78°C**, and the counterpart for short vegetation is **-0.07 to 0.12°C** in different cities.
- **Arid** areas such as Western coast of the US, Middle East, northwest of Indian peninsula have larger CE of tree. Most of these cities are located around 30°N and the equator.
- In some cities, the CEs of tree and short vegetation are comparable.



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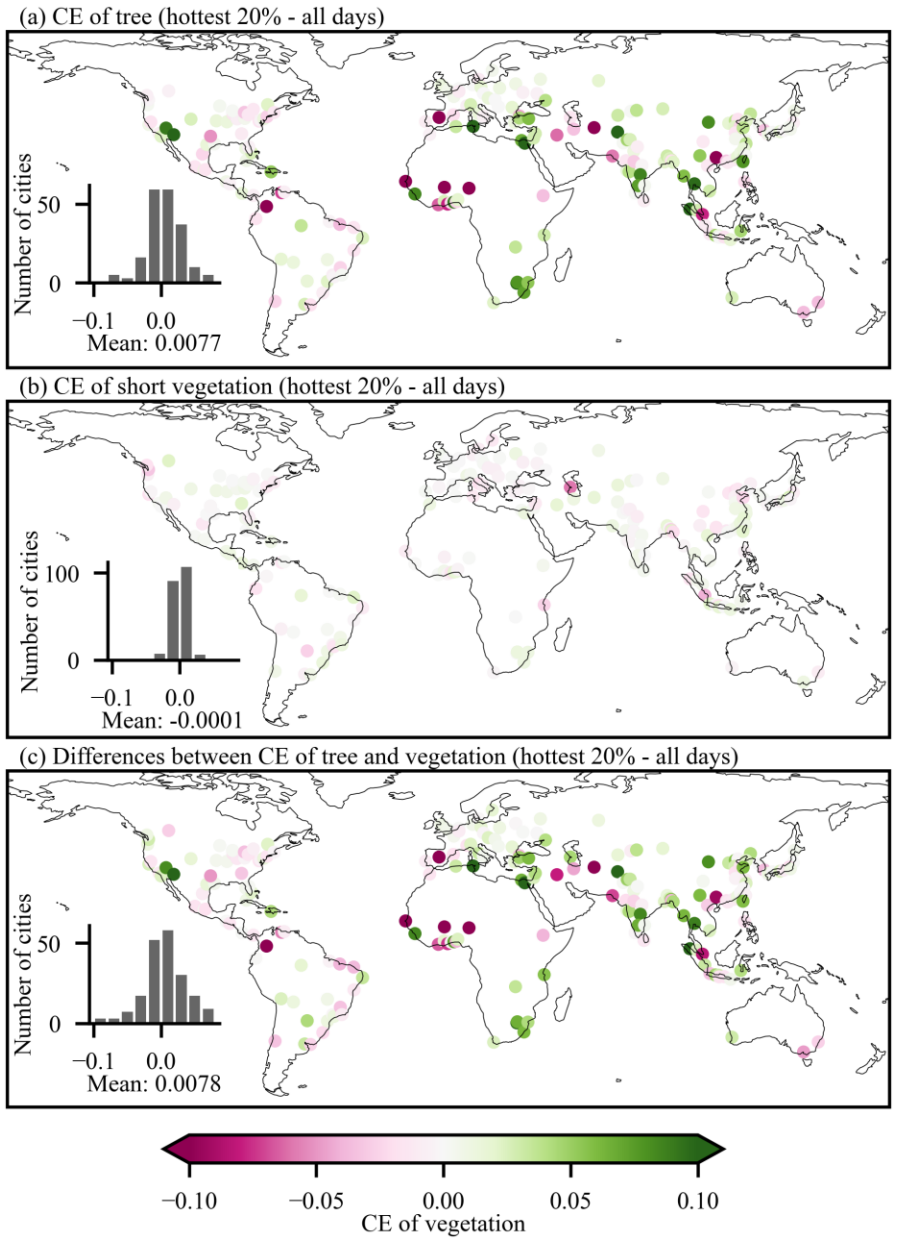
4 CE of trees is larger during the hottest days in more cities.

❑ Differences of CE between all days and hottest days

- The average **CE of trees increases** a little, from 0.1553 to 0.1629, but in some regions where CE is already large, it decreases.
- But **CE of short vegetation decreases** a little, from 0.0229 to 0.0226.
- It may due to trees have deeper roots and stronger ability to transpire and thus can tolerate more in hotter days.



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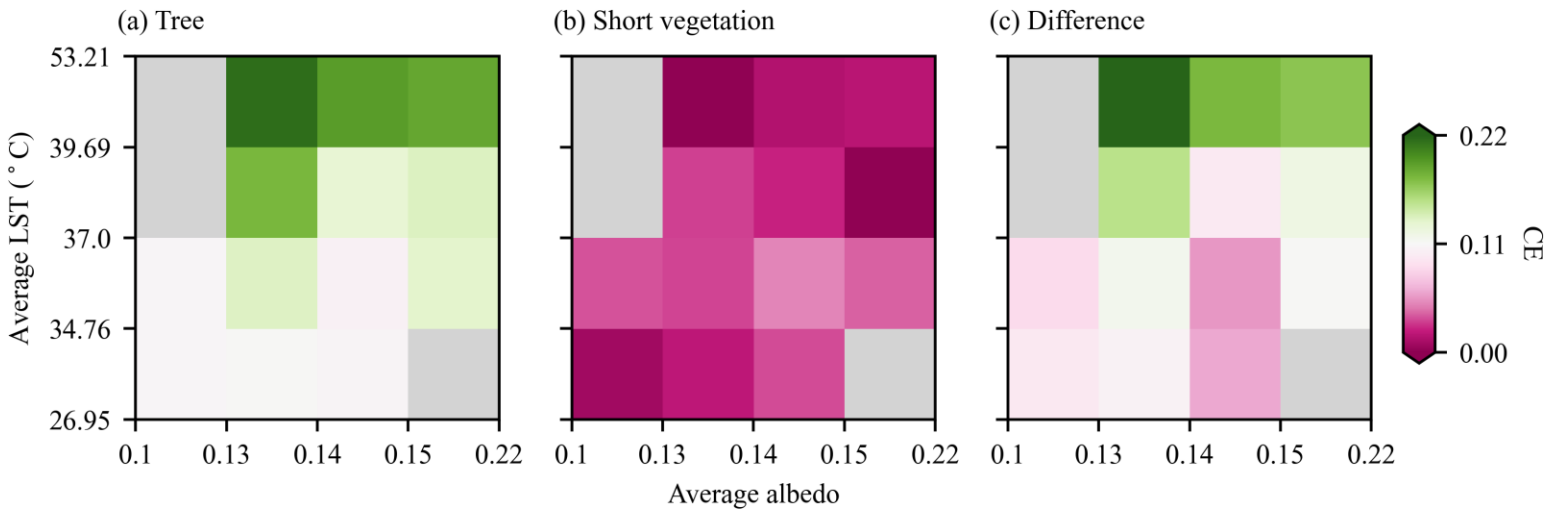
5 CE of trees tends to be larger when albedo is lower and LST is higher.

❑ Energy-related variables' influences on CE



Median CE of vegetation and CE differences in different groups of land surface temperature (LST) and albedo

- Cities with higher average LST tend to be along with larger CE of tree, but not CE of short vegetation.
- CE of tree also tends to be larger when the average albedo is lower.

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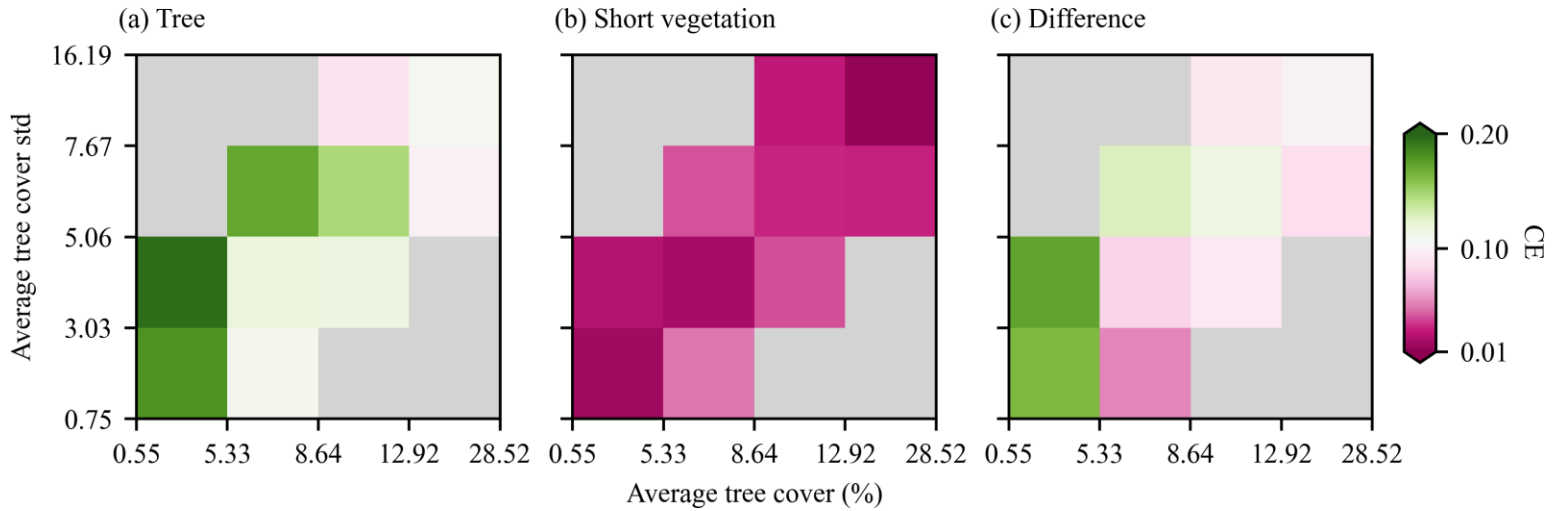
5 CE of trees has a marginal diminishing effect, not for short vegetation.

❑ Tree cover background's influences on CE



Median CE of vegetation and CE differences in different groups of tree cover and tree cover standard deviation

- The standard deviation of trees serves as the proxy for the spatial pattern of trees.
- When the tree cover is lower, CE of tree tends to be larger. It has a diminishing marginal utility in cooling.

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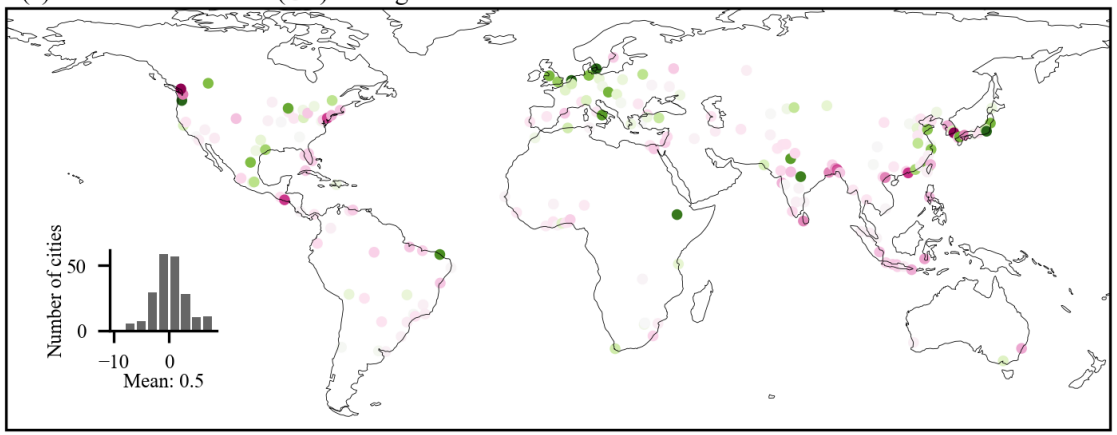
5 CE of trees has a marginal diminishing effect, not for short vegetation.

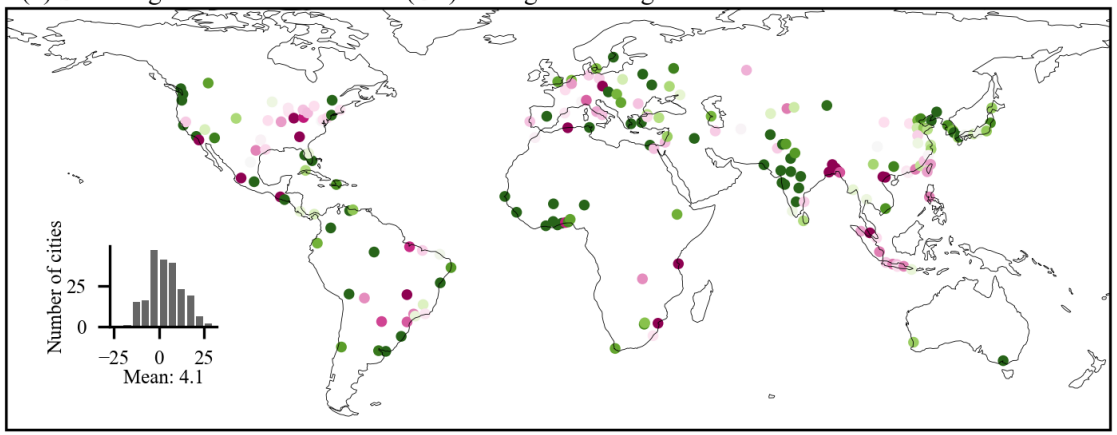
❑ Differences between vegetation cover the largest CE and average vegetation cover

- More negative values for the differences for trees, which may indicate more cities have larger CE of trees when tree cover is lower.
- But more positive values for short vegetation, which indicates more cities have larger CE of short vegetation when vegetation cover is higher.

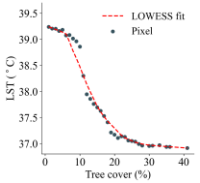
(a) Tree cover with max(CE)-average tree cover

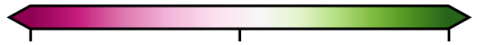


(b) Short vegetation cover with max(CE)-average short vegetation cover

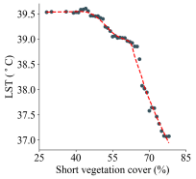


Decreasing derevitives





Increasing derevitives



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