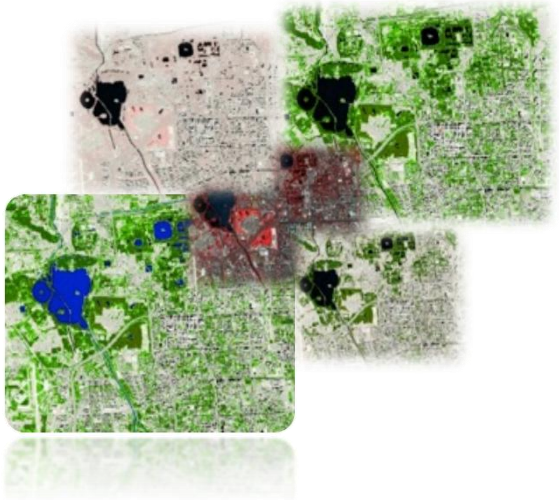


国家自然科学基金委员会
National Natural Science Foundation of China

FAPESP
SCIENCE, CULTURE AND DEVELOPMENT

Sustainable Development International Cooperation Program (2022)

Resilience and adaptability of cities to climate change based on nature-based solutions

Weiqi Zhou

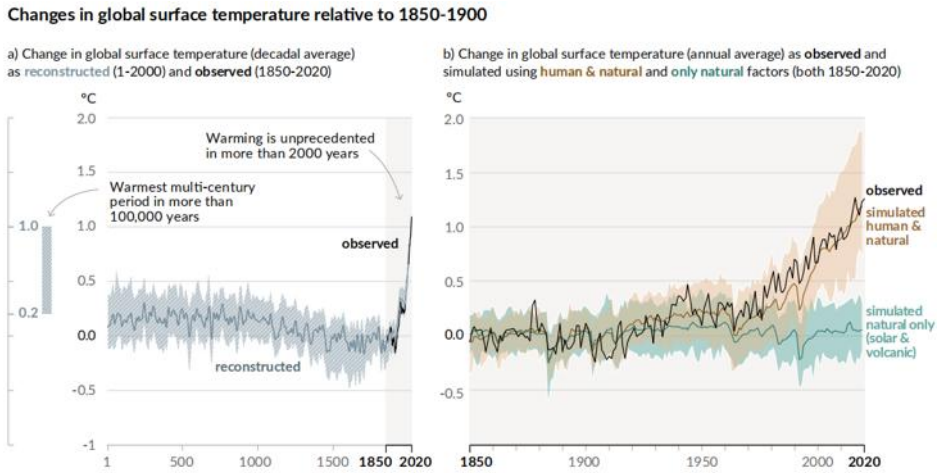
State Key Laboratory of Urban and Regional Ecology

Research Center for Eco-Environmental Sciences

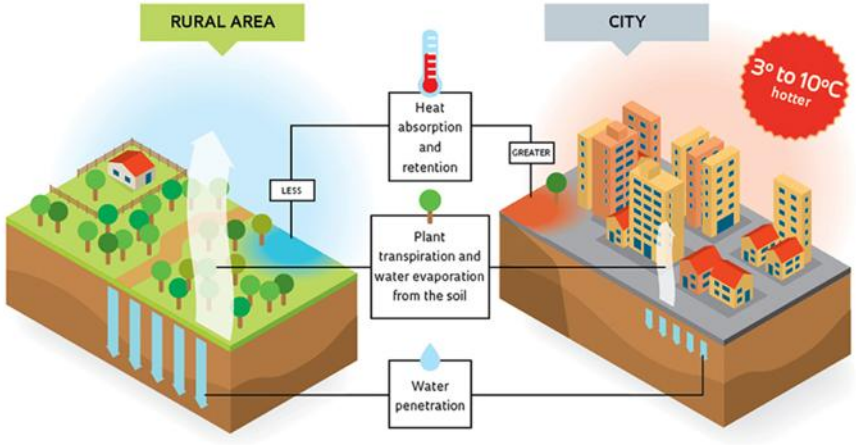
Chinese Academy of Sciences

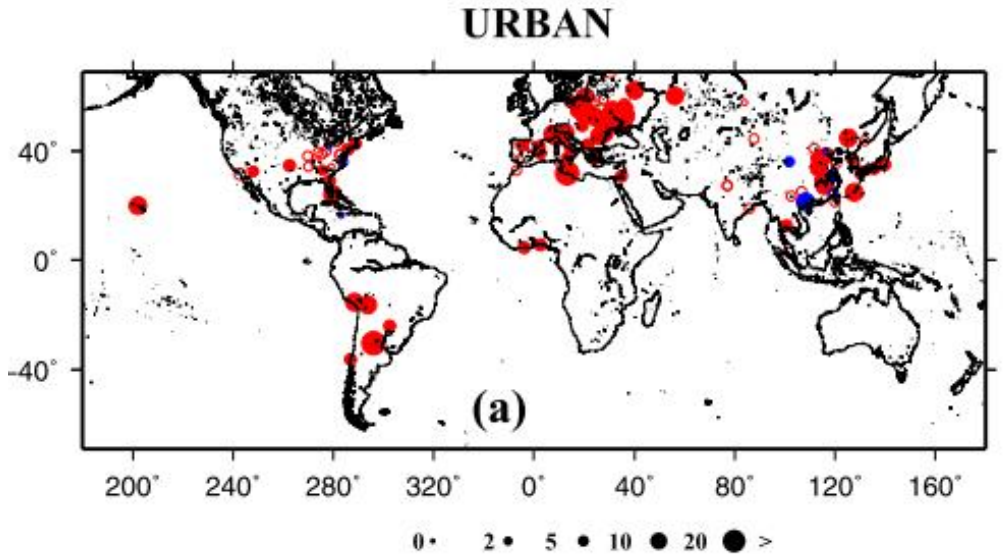
Climate change: Cities face intensified warming

More frequent and intense hot extremes in cities: Synergistic interactions between climate change and urban heat island effects

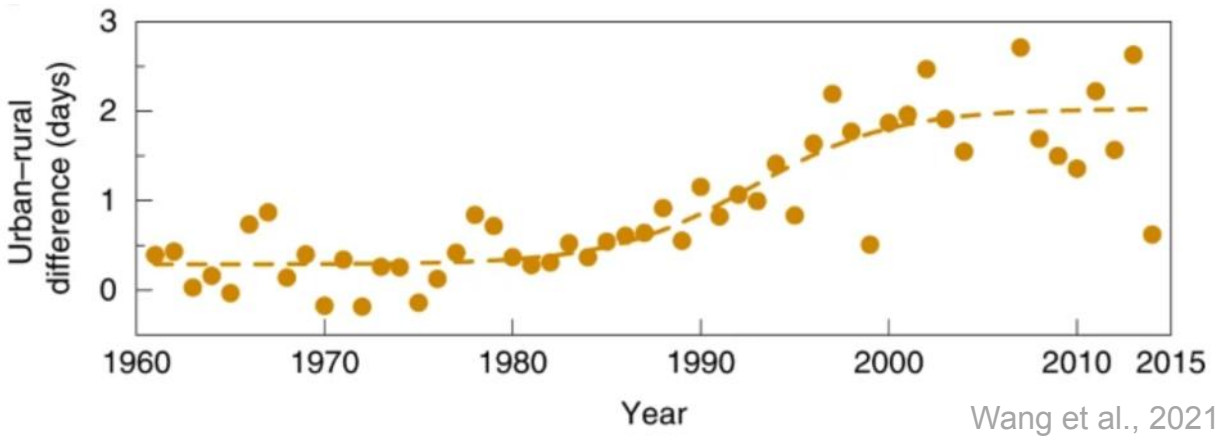


（IPCC, 2021）





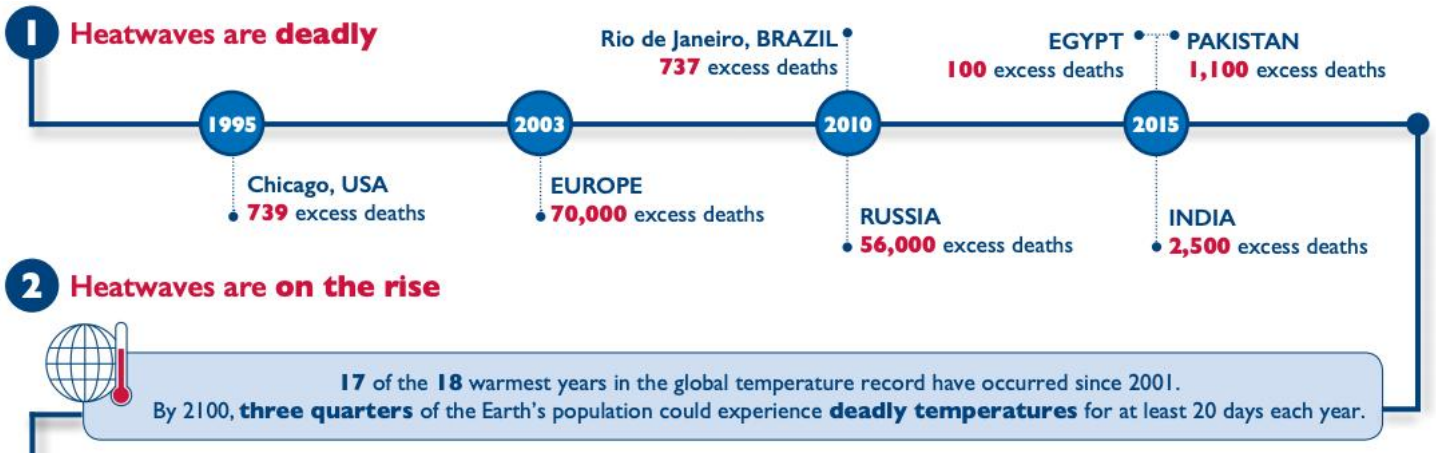
More extreme events in urban areas



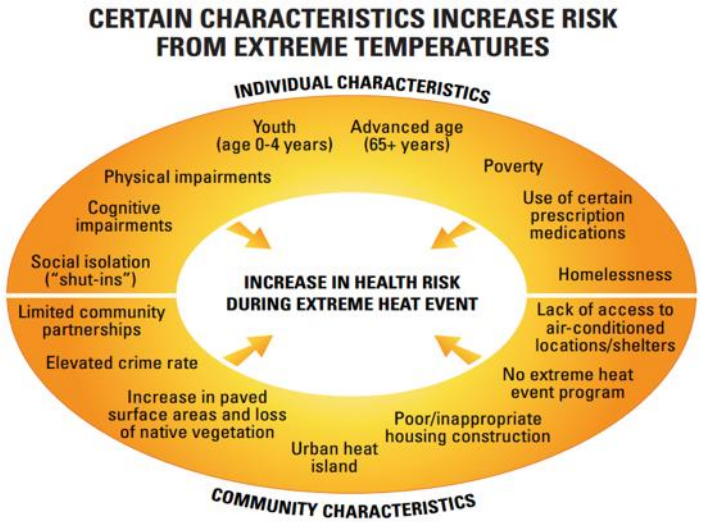
Wang et al., 2021

Climate change: Cities are vulnerable and at risks

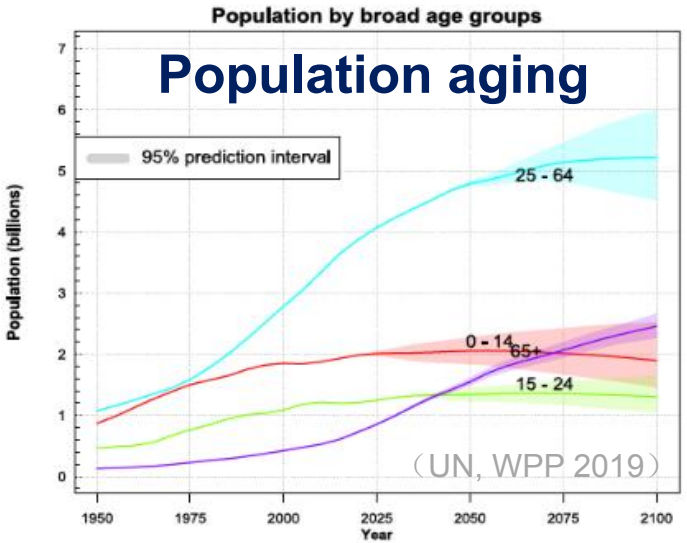
Climate change is an urgent threat to the quality of life in urban areas



（ATLAS project, 2020）



Certain personal and community characteristics increase the risk of experiencing health problems during an extreme heat event.[4,9,10,11]



（UN, WPP 2019）

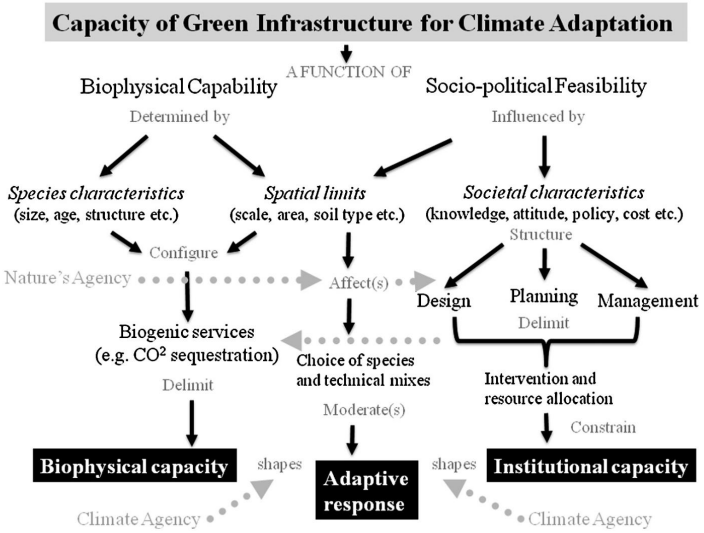
Cities are leading the fight against climate change

"…a solution to societal challenges that is inspired or supported by nature, which is cost-effective, simultaneously provides environmental, social and economic benefits and helps build resilience. These solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions."

From: Department of Research and Innovation of the European Commission

Nature-based Solutions

Rosenzweig et al. 2010; Matthews et al. 2015; UNEP 2021



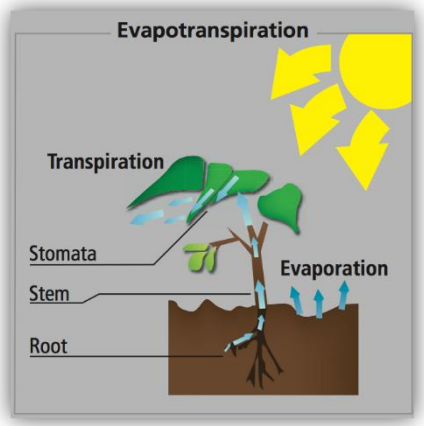
Hongkong: energy-efficient skyscrapers

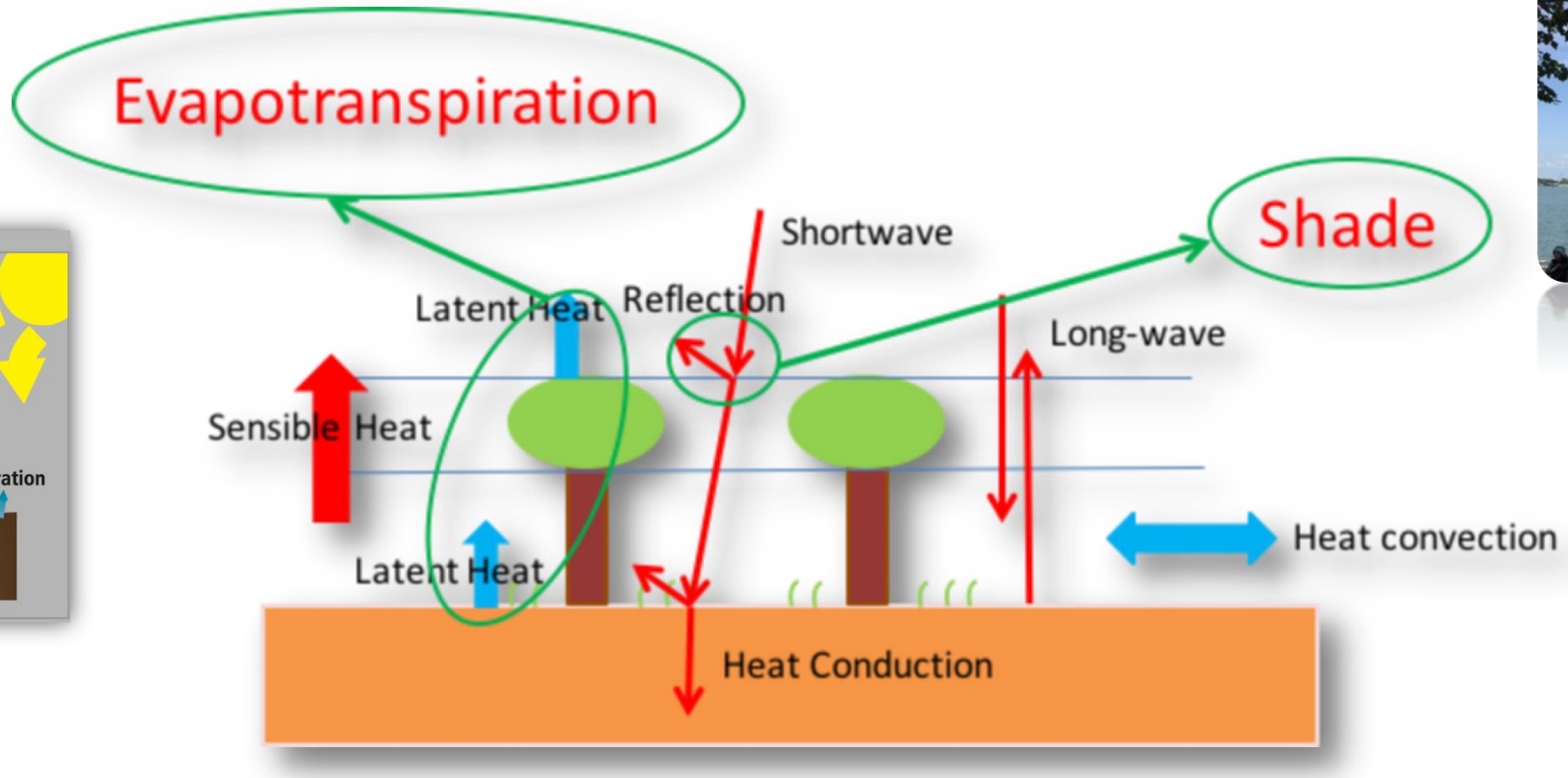
Paris: car-free (in the center, at least)

Urban green infrastructure

Cities use trees to adapt to climate change

Urban trees: constitute one of the most proposed nature-based mitigation tools in cities around the world, regardless of the climate context.





Cities use trees to adapt to climate change

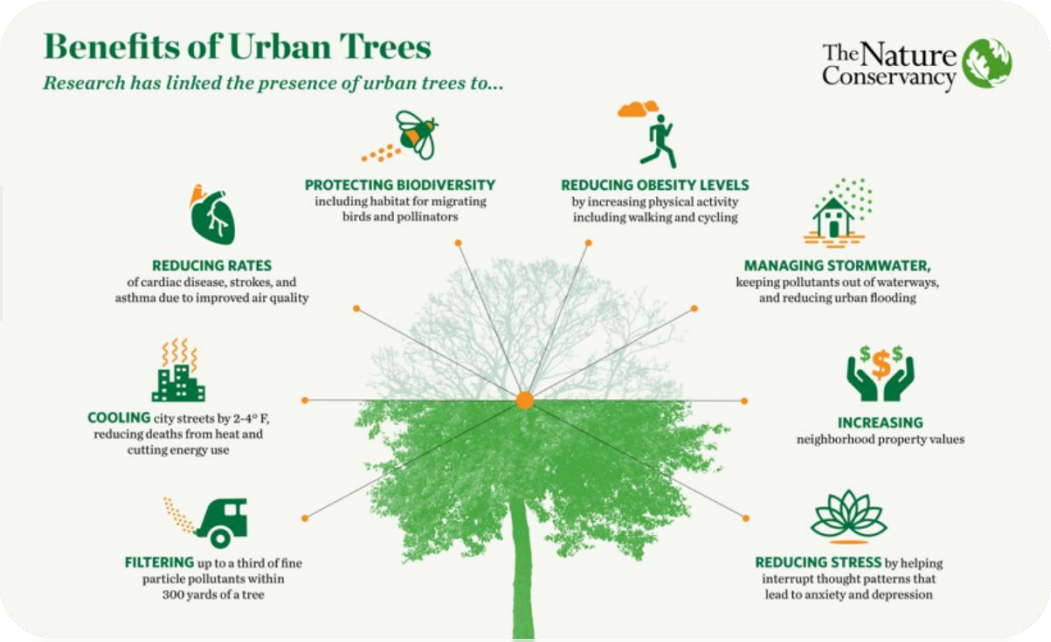
Urban trees: constitute one of the most proposed nature-based mitigation tools in cities around the world, regardless of the climate context.

Replanting Brazil's Fruit Trees

by Fruit Tree Planting Foundation

TreeBaltimore

More than cooling: trees bring many benefits



Beijing: Million Mu Trees

5 Million Tree Campaign

millionTreesNYC

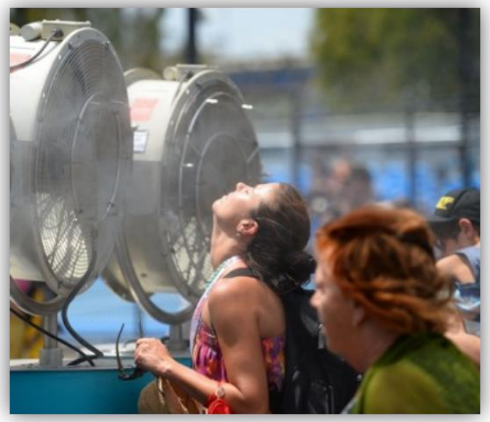
A PLANYC INITIATIVE WITH NYC PARKS AND NEW YORK RESTORATION PROJECT

Cities use trees to adapt to climate change

Where to Plant?

Grand challenges

- Cities have limited space and resources for greening.
- Heat disproportionally affects different urban populations, with the urban poor and people of color being more exposed and having limited capacity to mitigate heat or adapt to extreme heat events.



Affects people differently

Pictures from the internet

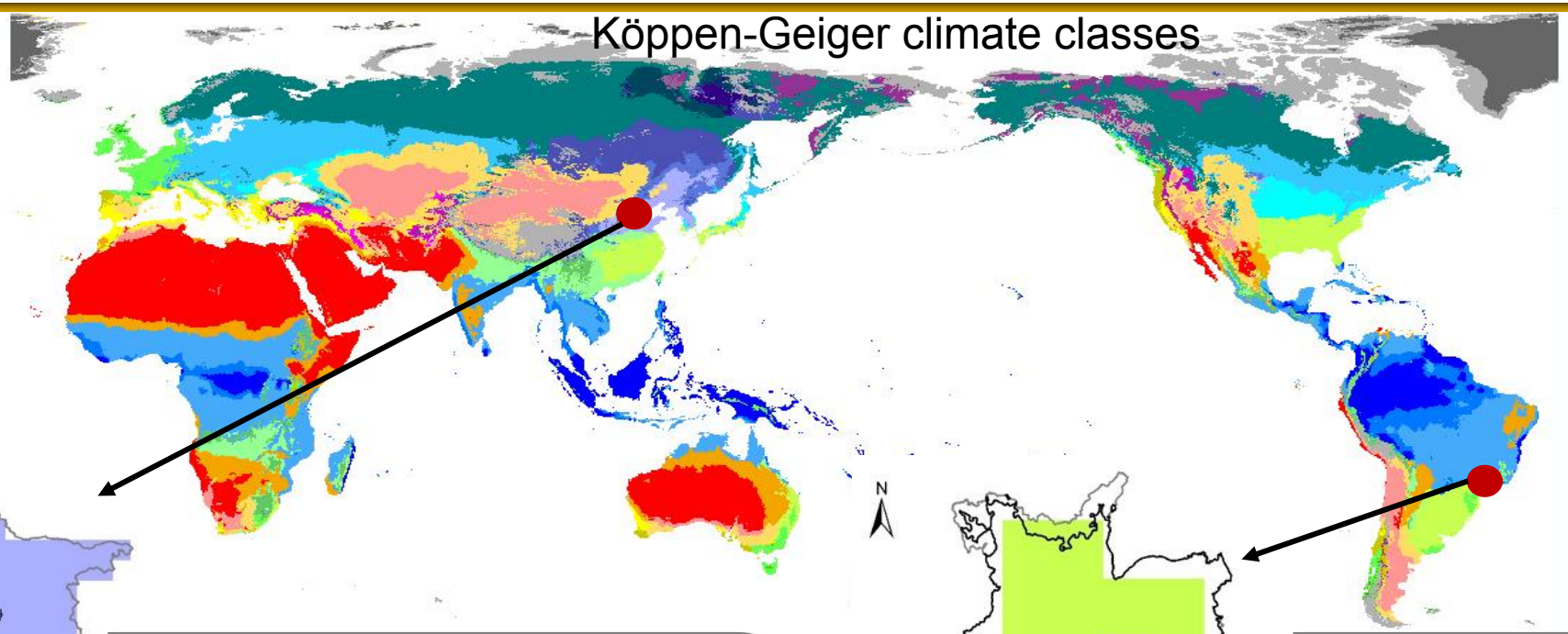
Understanding who is most vulnerable, where they live, and whether they have equal access to benefits of trees for cooling is a critical starting point for prioritizing urban heat interventions in planning and policy at several levels of governance.

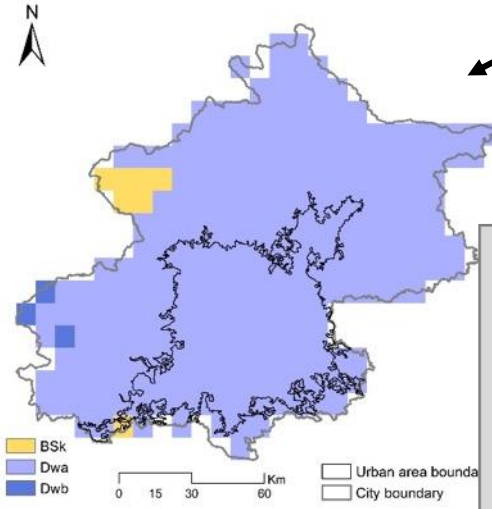
Research Questions

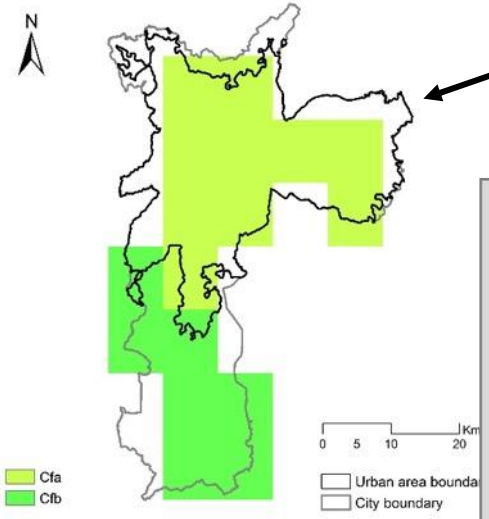
The overarching goal of this project is to enhance our understanding on how nature-based solutions such as tree planting can help build more resilient and adaptive cities for climate change. Specifically, we aim to address these following three questions:

- What are the synergistic effects of climate change and urbanization on extreme heat events in cities?
- How do urban extreme heat events disproportionately affect urban residents?
- In what physical and social conditions does the cooling capacity of trees have the greatest environmental and social impact? /How to maximize the cooling effects of urban trees for more resilient and adaptive cities?

Study area







Beijing

- The Capital of China
- Climate: Cold, dry winter, hot summer
- Area: 16,410.5 Km^2
- Pop: 21.89 million
- GDP: 591,374 million US$

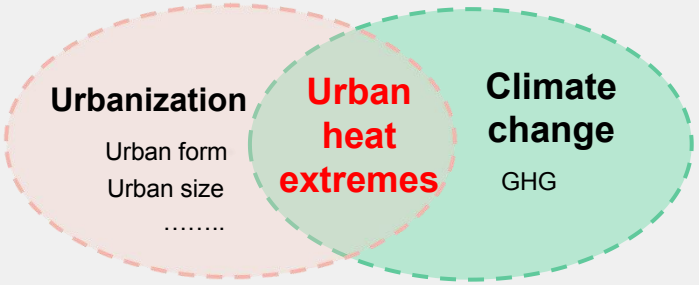
São Paulo

- The most populous city in Brazil
- Climate: Temperate, no dry season, hot summer
- Area: 1,521.11 Km^2
- Pop: 12.40 million
- GDP: 261,642 million US$

Research framework

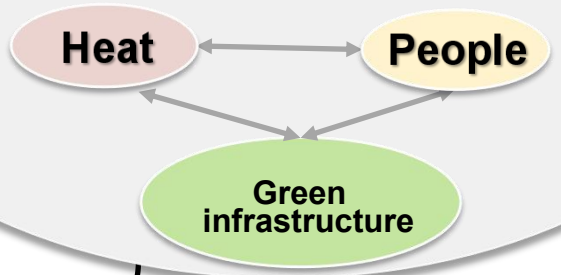
Urban heat extremes

1. Spatiotemporal patterns of urban heat extremes
2. The synergistic effects of urbanization and climate change to urban heat extremes



Heat risk assessment

1. Where and who are the most at risk to urban heat hazards?
2. How it change with the change of heat and socio-ecological patterns?



NBS for heat mitigation and adaptation

1. Does the cooling efficiency of urban trees/vegetation tend to be higher in the places with higher heat risks
2. How to optimize the spatial pattern of urban trees/vegetation to cope with extreme heat events under future climate change?

Heat
- High temperature
- Vulnerable people

Vegetation
- Amount
- Spatial configuration

→ Resilience and adaptability of cities

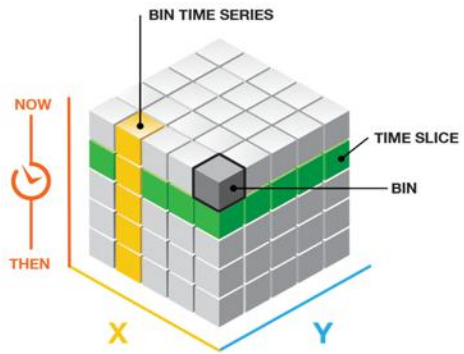
1. The spatiotemporal patterns of extreme heat events and the attribution to climate change and urbanization

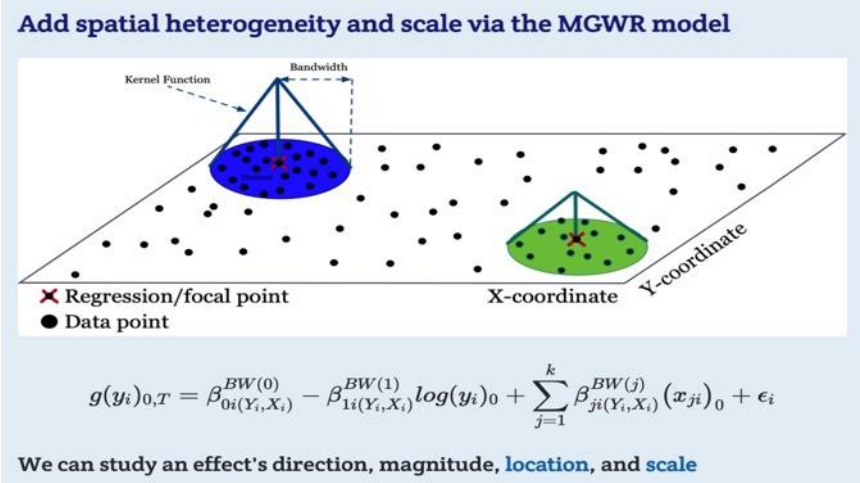
- Quantify the temporal characteristics of the frequency, intensity, duration and spatial extent of extreme heat events in Beijing and Sao Paulo;
- Investigate the within-city spatial heterogeneity of extreme heat events and to identify the hotspots;
- Quantify the contribution of climate change and urbanization on urban extreme heat, and their interaction over time.

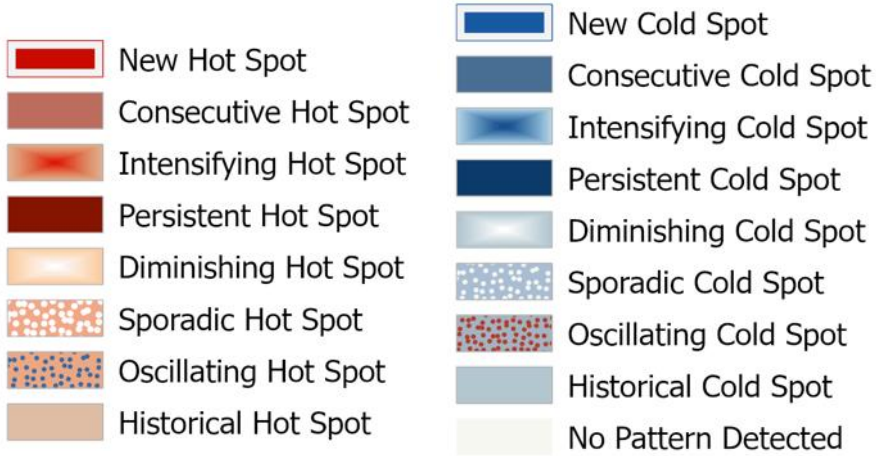
1. The spatiotemporal patterns of extreme heat events and the attribution to climate change and urbanization

Key methods

- **Emerging Hot Spot Analysis**, integrating:
  - Time-series analysis -- Mann-Kendall trend test
  - Spatial pattern analysis -- Getis-Ord Gi* statistic
  - 2D and 3D visualization techniques







- **Multi-scale Geographically Weighted Regression (MGWR)**
  - Climate change: Greenhouse Gas...
  - Urbanization: Urban expansion (i.e., size, population)...

2. Urban heat risk assessment using an integrative social-ecological approach

- Quantify the spatiotemporal patterns of urban heat risk applying an integrative social-ecological framework to understand where and who are the most vulnerable to urban extreme heat, and thereby to address the environmental justice issue;
- Investigate the spatial relationships between urban heat exposure and extreme heat, socioeconomic vulnerability, and urban green infrastructure (e.g., urban trees) to understand the contribution of these factors to the increase in exposure.

2. Urban heat risk assessment using an integrative social-ecological approach

Key methods

- **Heat risk assessment used the framework in AR5 of IPCC**, including :
  - Heat Hazards:

$$H = 0.5 \times [(3.96T + 49.8) + (RH \times 0.094)]$$

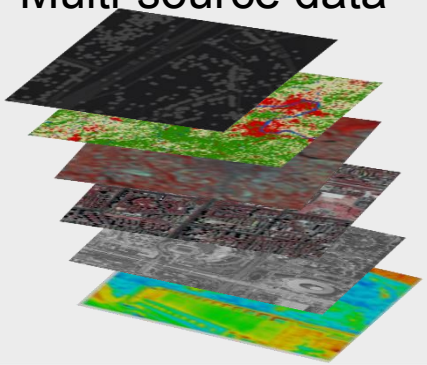
  - Heat Exposure:

$$E = \sum_{j=1}^{n} w_j \, x_{ij}$$

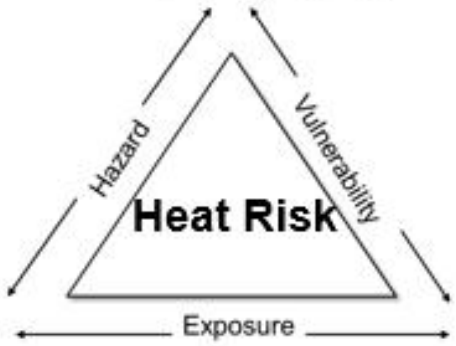
  - Heat Vulnerability：

$$HV = \sum_{j=1}^{n} a_j \, y_{ij}(\boldsymbol{S}) - \sum_{j=1}^{n} k_j \, z_{ij}(\boldsymbol{A})$$

Multi-source data



$$R = f(H, E, V)$$



Extreme heat：**Where?**
Vulnerability： **Who?**
Greenery allocated: **How?**

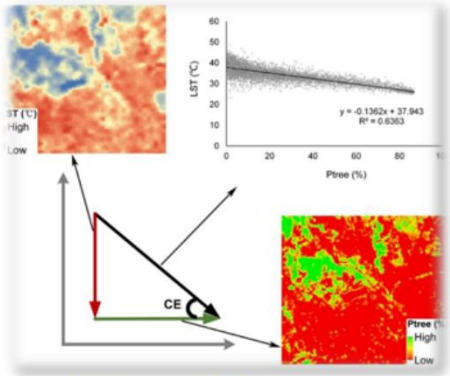
3. Urban tree planting as a nature-based solution to enhance the resilience and adaptability of cities to climate change

- Examine the within-city spatial heterogeneity of urban trees' cooling efficiency, and quantify how urban trees' cooling efficiency change under extreme heat;
- Develop tools to facilitate spatial prioritizing neighborhoods in need of heat interventions, and to identify potential locations for tree planting;
- Propose spatial plans for tree planting under different scenarios based on future climate change and urbanization.

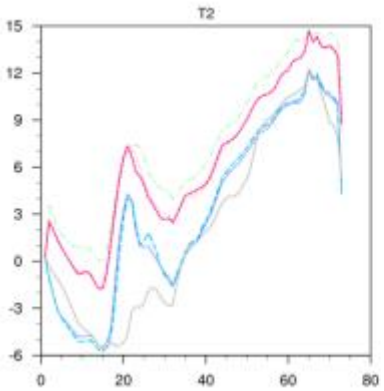
3. Urban tree planting as a nature-based solution to enhance the resilience and adaptability of cities to climate change

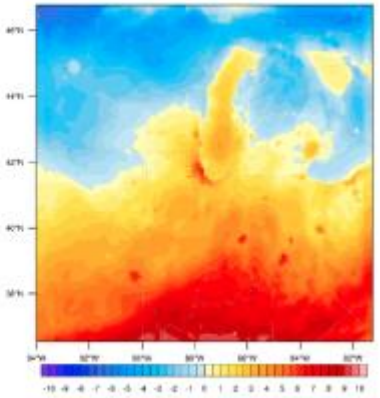
Key methods

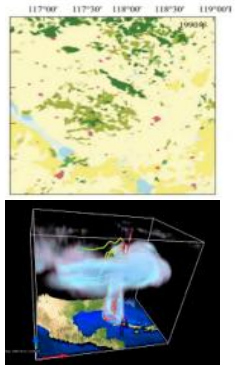
- **Cooling efficiency (CE)** measured:
  - Ordinary Least Squares (OLS) Regression
- **Within-city spatial variation** of CE analysis:
  - Geographically Weighted Regression (GWR)
- **Scenarios simulations:**
  - The Weather Research and Forecasting Model (WRF)

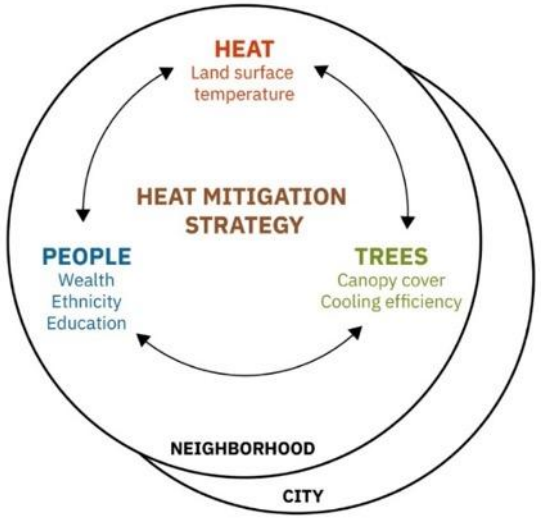


Cooling efficiency (CE): magnitude of temperature reduction associated with one percent (1%) increase of UTC cover









Social-ecological win-wins needs comprehensive understanding that relates excessive **urban heat, people, and urban trees**

Collected data in Beijing

Socioeconomic data

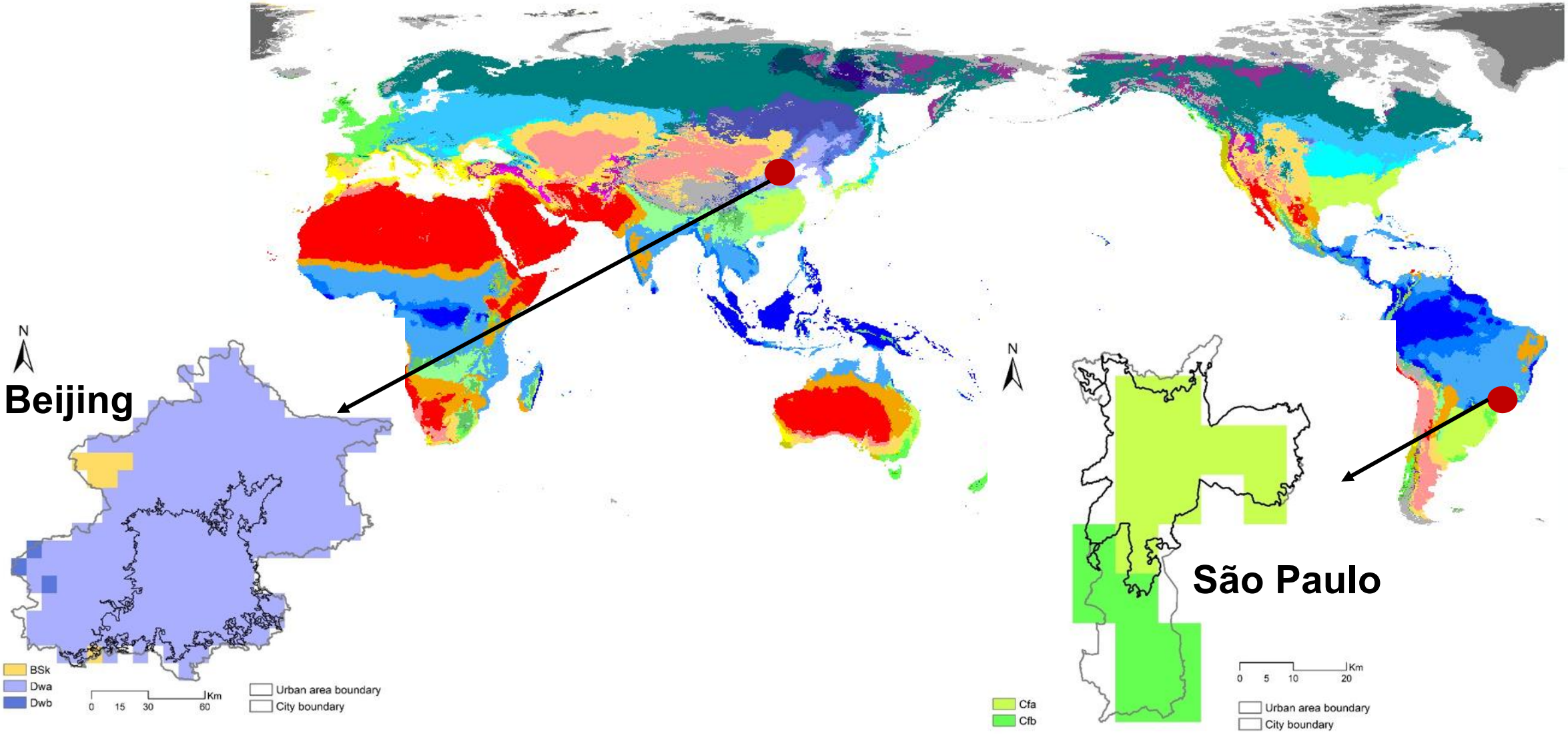
- Socioeconomic survey data from Beijing Statistical Yearbook, including Population, GDP, education……
- Point of Interest Data (POI) from big data (i.e., cellular signaling data, Sina Weibo)

Meteorological monitoring data

- The hourly air temperature, daily average temperature, daily minimum temperature and daily maximum temperature from 2000 to 2020
- The hourly relative humidity from 2000 to 2020
- Wind speed, daily precipitation and atmospheric pressure from 2000 to 2020

Multi-source remote sensing products and land cover data

- Landsat ：MSS/TM/ETM/OLI (1980-2020)
- Meteorological interpolation products：ERA5-Land (0.1°) , CHIRTS-daily (0.05°)
- Land cover data：spatial resolution：0.5m (2020) 1.5m (2015, 2020),2.5m (2005,2010), 30m (1985 , 1990 , 2020 , 2010 , 2020)
- Population data：Landscan with 1km spatial resolution
- DEM data：90m



Thank you & Questions

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