Climate-driven urban humid heat exposure and cooling challenges

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CESM Land Model Working Group

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

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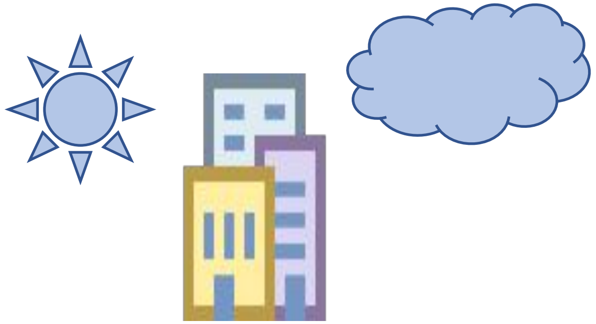

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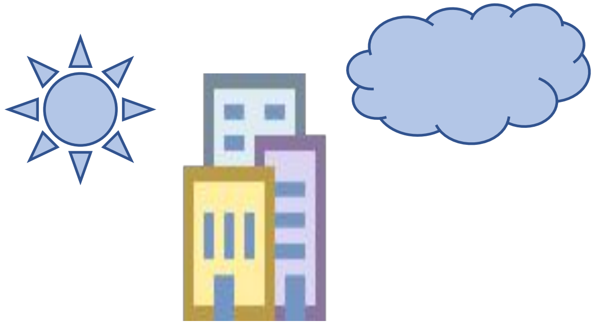
- Both climate change and urbanization tend to result in **higher temperatures and lower humidity** in urban areas.



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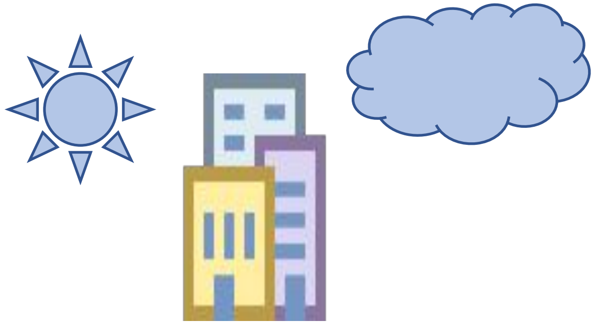

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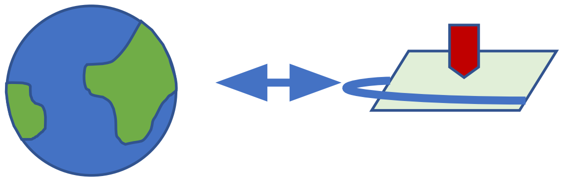
- CLMU enables the study of the interactions between large-scale climate change and local-scale urbanization.



Our goals were to assess future exposure to urban humid heat stress and potential challenges to cooling, using urban-specific climate outputs from CESM.

Future Exposure	1. Future changes in, 2. Exposure to, and 3. Drivers of urban humid heat stress
Future Cooling	1. Climate-driven cooling challenges and 2. Impact of climate change on cooling with urban greenery

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- Simulations:
  - Historical (1850-2014)
  - Future (2015-2100, SSP3-RCP7)
- Resolution:
  - Spatial: 0.9˚ x 1.25˚
  - Temporal: decadal JJA means for the first and last decades of the 21st century
- Variables:
  - Future Exposure
    - Urban wet-bulb temperature (Stull, 2011)
      - + Urban population projections (Jones and O’Neill, 2016)
      - Contributions from climate change and urbanization
  - Future Cooling
    - Precipitation (Long-term average) – proxy for irrigation needs
    - Urban Green Cooling Efficacy (UGC) – proxy for cooling efficacy
      - $UGC = T_A - T_W$

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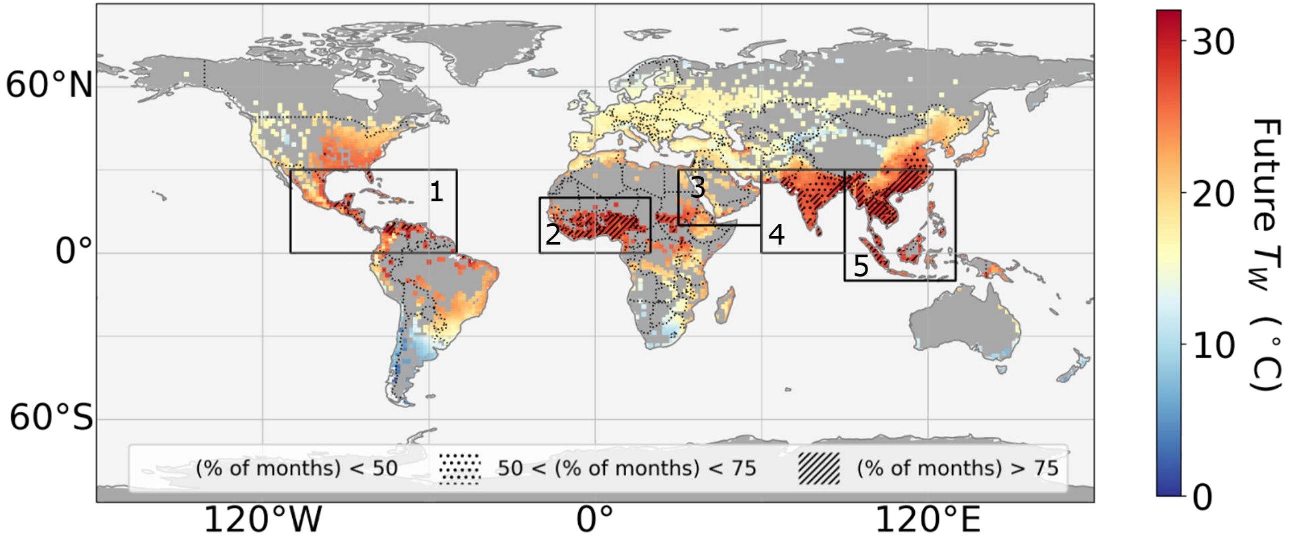

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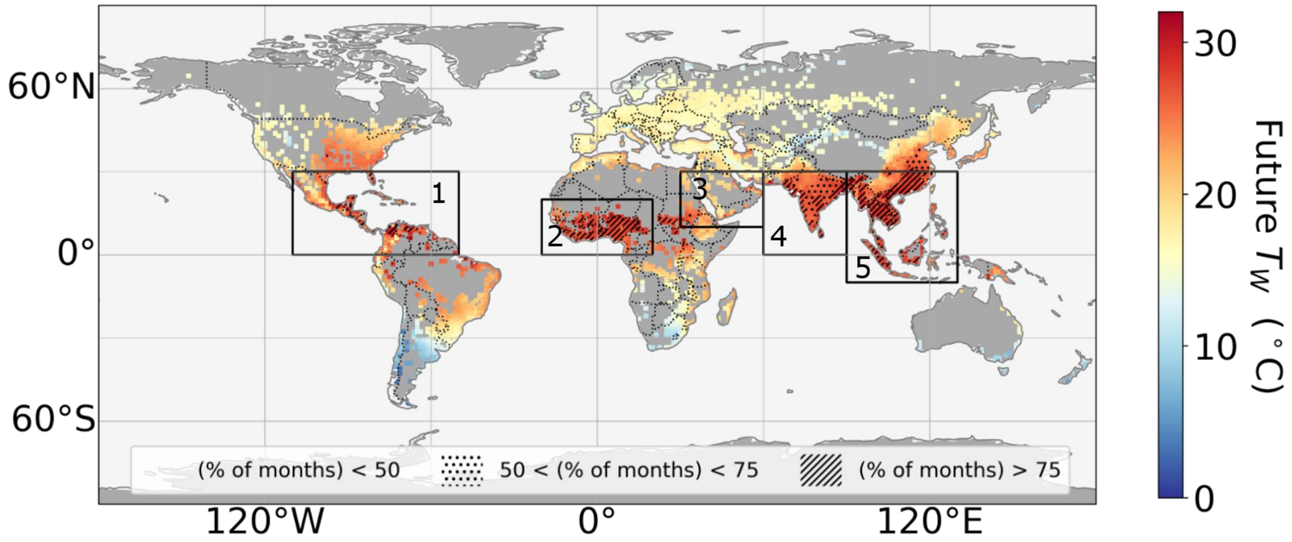

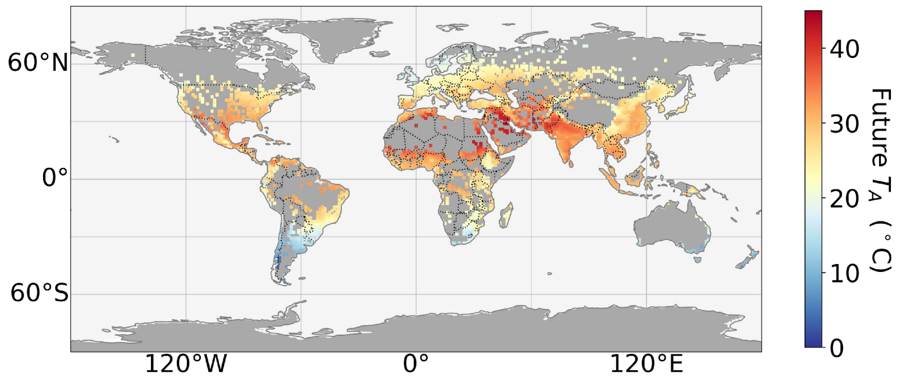

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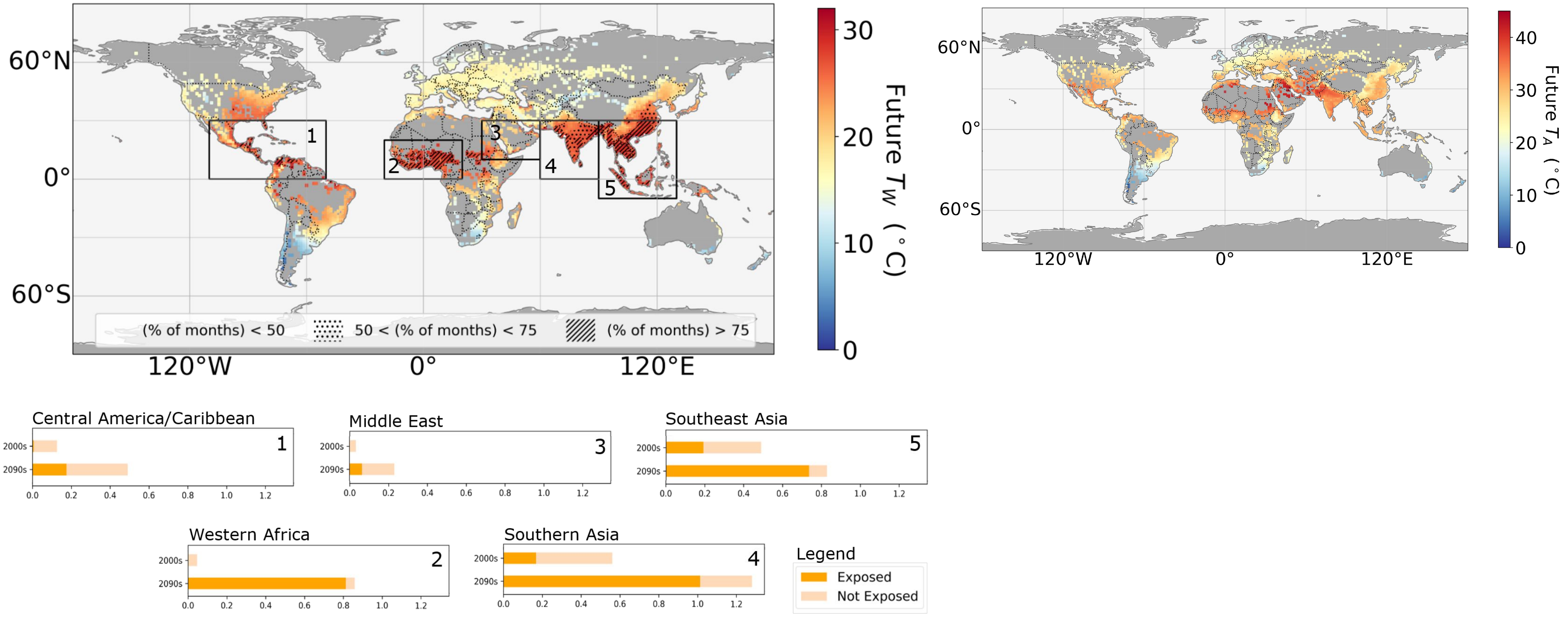

Figure 1: Urban humid heat stress and exposure under SSP3-RCP7

We decompose the changes in urban humid heat into the contributions of air temperature and specific humidity, and further into climate change and urbanization.

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$$dT_W = \left(\frac{\partial TW}{\partial TA} + \frac{\partial TW}{\partial RH} * \frac{\partial RH}{\partial TA}\right) dT_{A,ubz} + \left(\frac{\partial TW}{\partial TA} + \frac{\partial TW}{\partial RH} * \frac{\partial RH}{\partial TA}\right) dT_{A,cc} + \left(\frac{\partial TW}{\partial RH} * \frac{\partial RH}{\partial Q}\right) dQ_{ubz} + \left(\frac{\partial TW}{\partial RH} * \frac{\partial RH}{\partial Q}\right) dQ$$

CESM

$$urbanization\ (ubz) = urban\ (2090s) - rural\ (2090s)$$
$$climate\ change\ (cc) = rural\ (2090s) - rural\ (2000s)$$

The increase in global urban humid heat is largely driven by increases in specific humidity due to climate change, followed by air temperature.

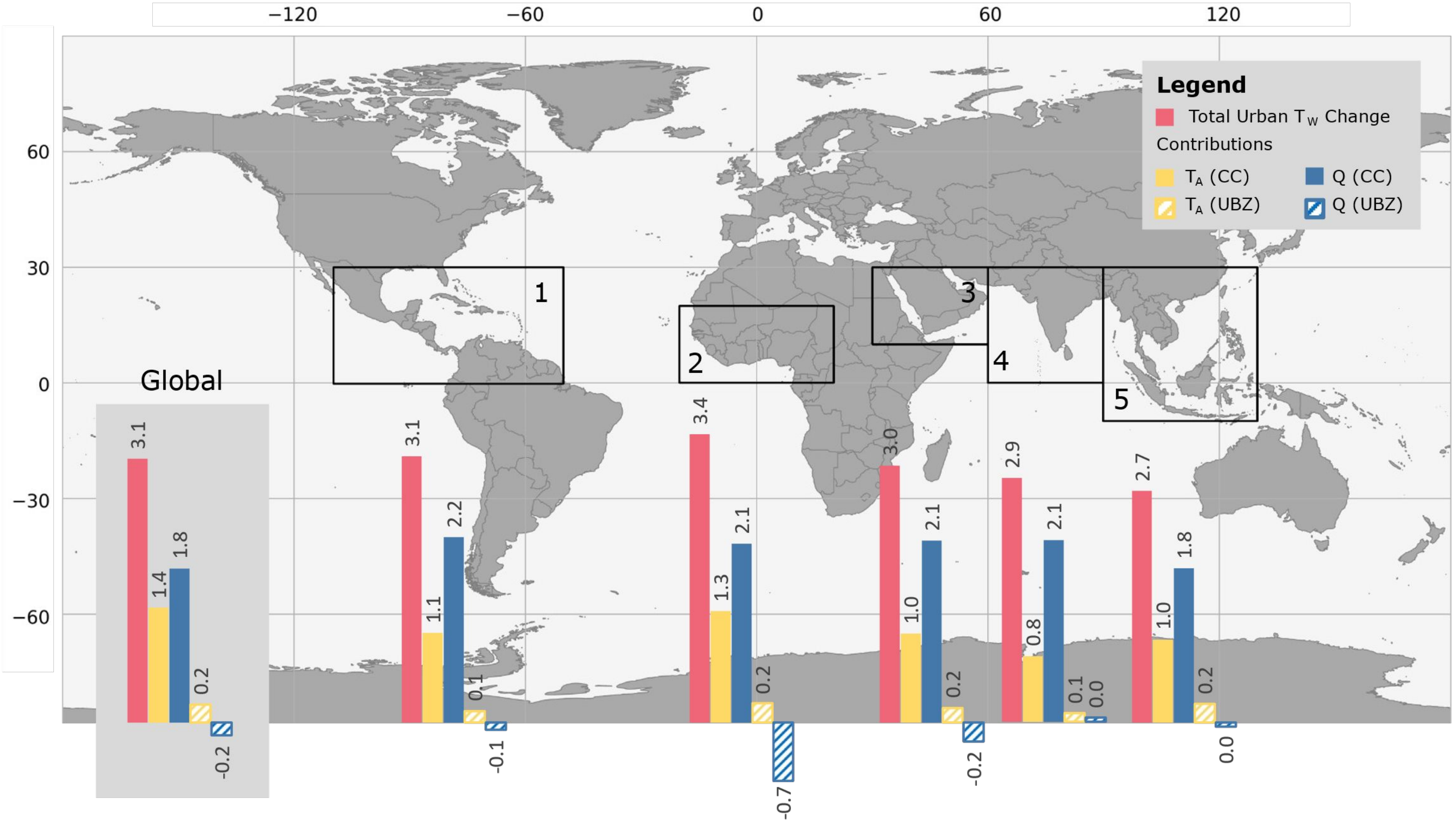


Figure 2: Total urban T_W change and decomposed contributions from changes in air temperature and specific humidity from both climate change and urbanization

We find a globally-consistent, potential climate-driven limitation to cooling through urban greenery – where cities with greater (lower) atmospheric water availability tend to have lower (greater) cooling efficacy.

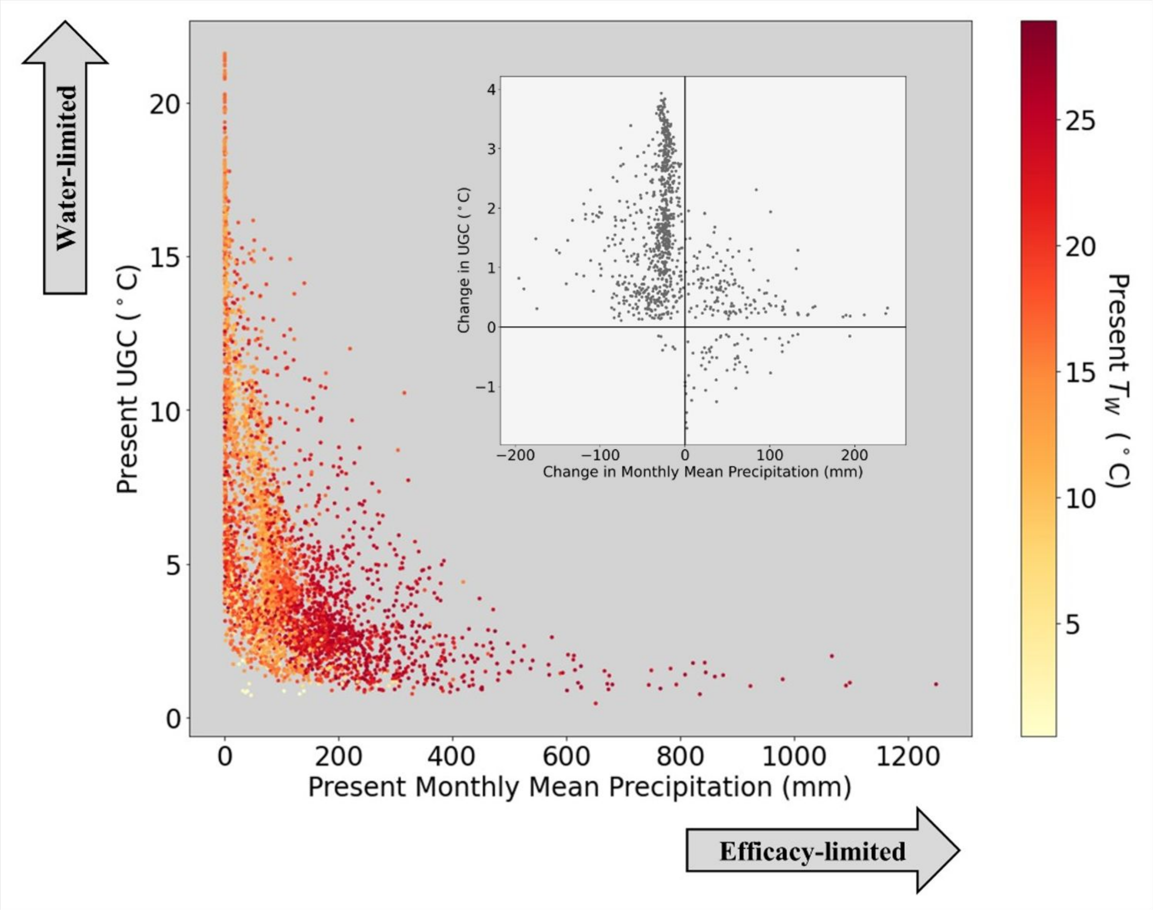


Figure 3: Long-term average precipitation and cooling efficacy of urban green infrastructure (present and future).

Urban-specific variables help highlight similarities and differences in key mechanisms affecting climate change adaptation, recognition of which can support knowledge sharing across cities.

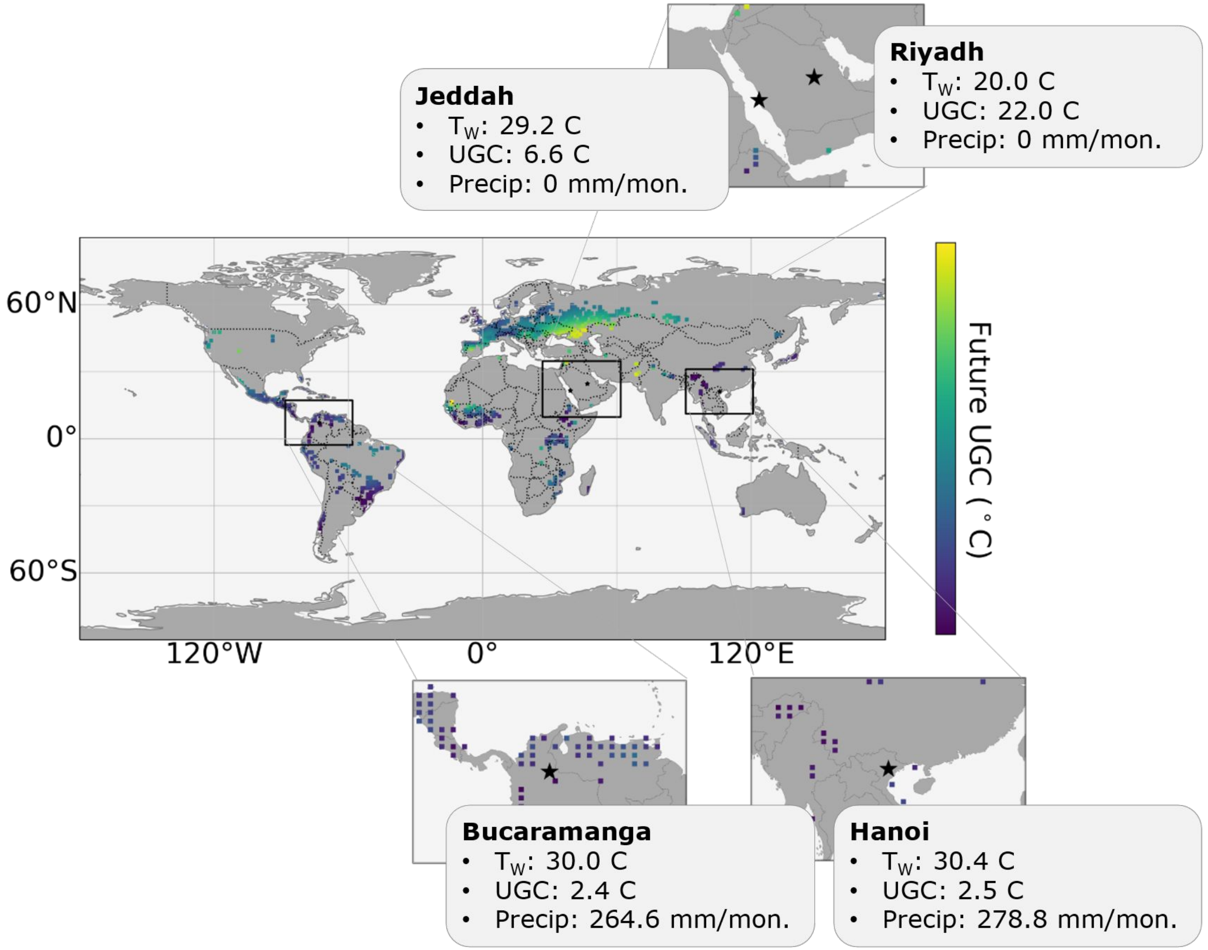
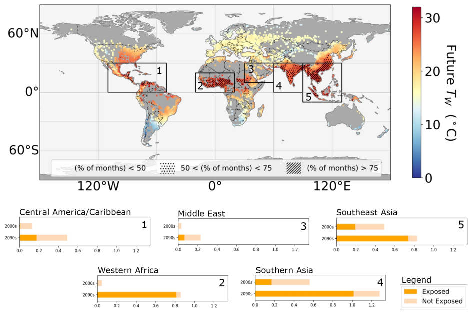


Figure 4: Future Urban Green Cooling Efficacy (UGC).

Conclusions

- Humid adaptation is urgently needed in **tropical, coastal urban areas**, which are also particularly vulnerable to other climate change risks.



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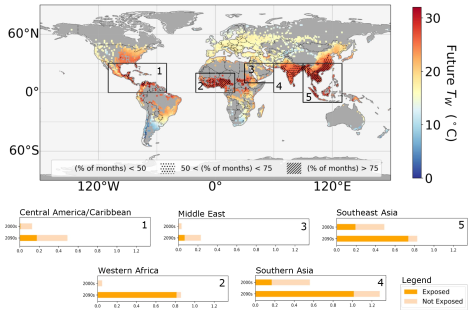
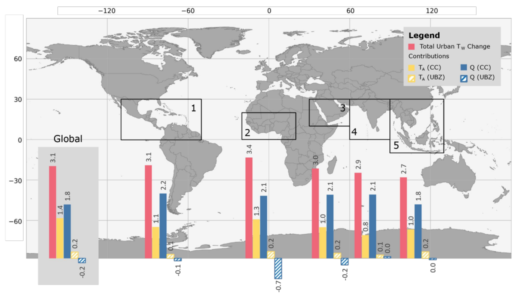
- Humidity is a major variable in human-perceived heat stress and **key driver of future increases** in urban humid heat.





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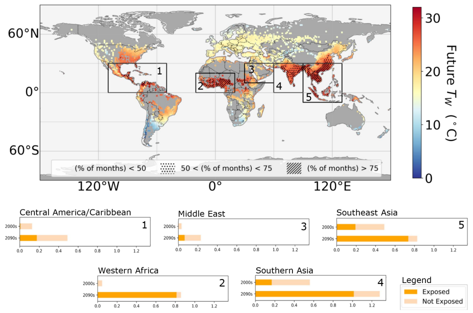
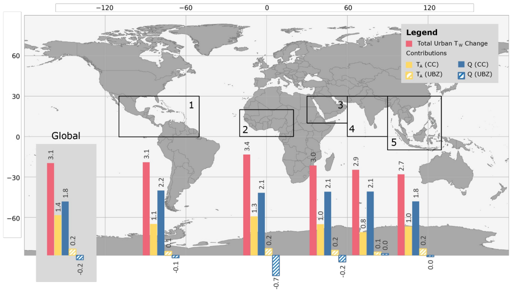
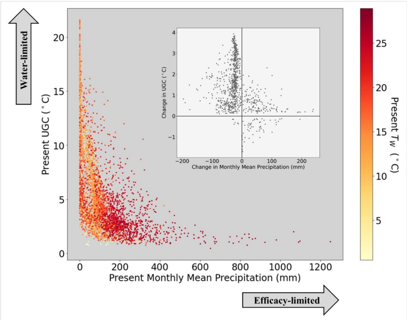
- Cooling solutions are **impacted by the same climatic change** driving the need for cooling.







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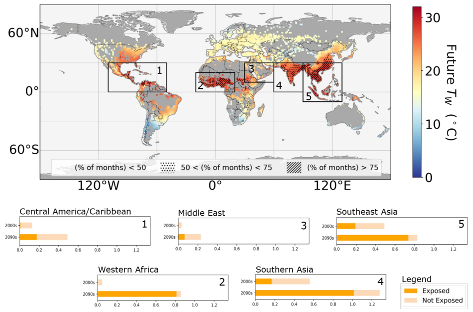
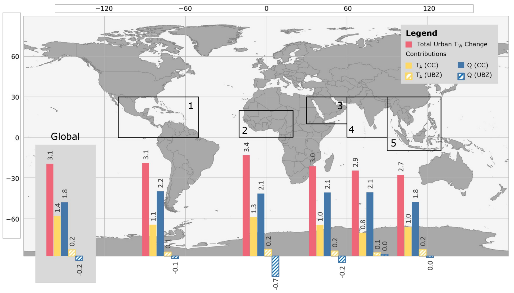
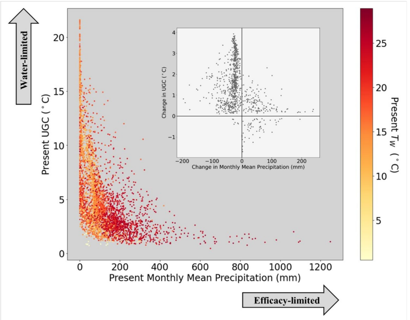
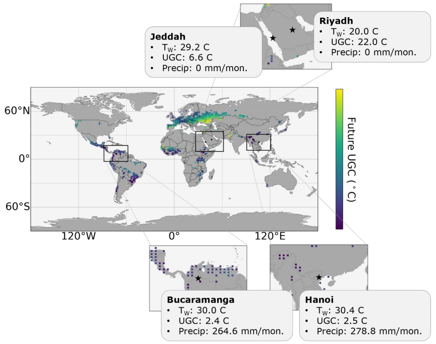
- Humidity is a major variable in human-perceived heat stress and **key driver of future increases** in urban humid heat.
- Cooling solutions are **impacted by the same climatic change** driving the need for cooling.
- **Urban-explicit projections** of future cooling contexts are crucial for improving the resiliency of urban cooling and the livability of cities in a changing climate.









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References

- Jones B and O'Neill B C 2016 Spatially explicit global population scenarios consistent with the Shared Socioeconomic Pathways Environ. Res. Lett. 11 084003
- Stull R 2011 Wet-Bulb Temperature from Relative Humidity and Air Temperature 3