# Contrasting urban and rural heat stress responses to climate change

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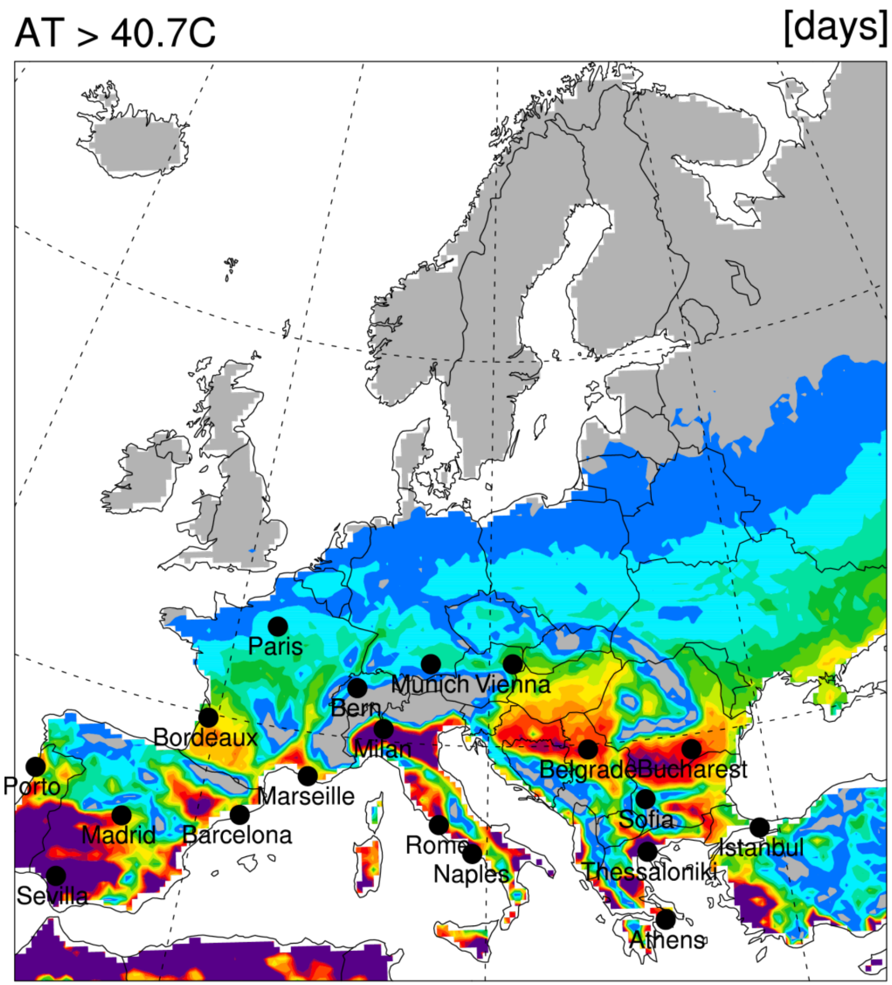
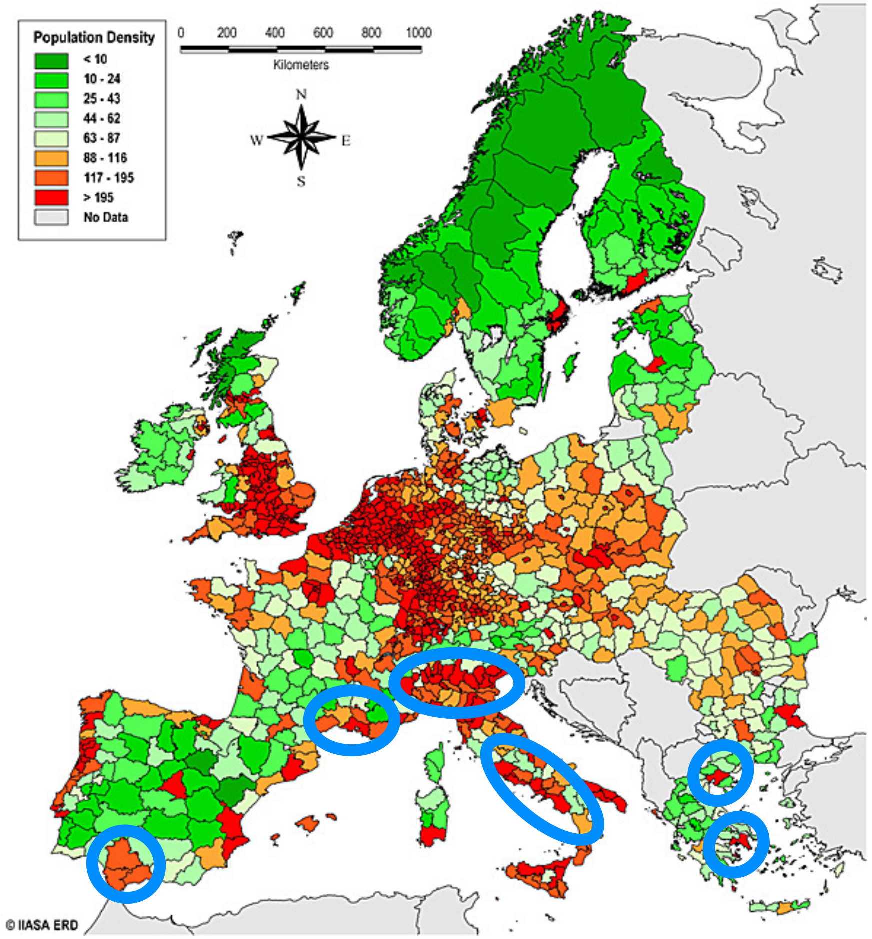
# Motivation




Fischer and Schär, *Nature Geoscience* (2010)




Source IIASA

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# Research questions

- Urban areas are warmer and drier: What is the net effect on heat stress in a GCM framework?

- Which areas of the globe experience the largest change in heat stress in response to $2xCO_2$ ?

**Notice: This is a model experiment lacking extensive validation and not suited for local impact and adaptation studies!**

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# Heat stress definition

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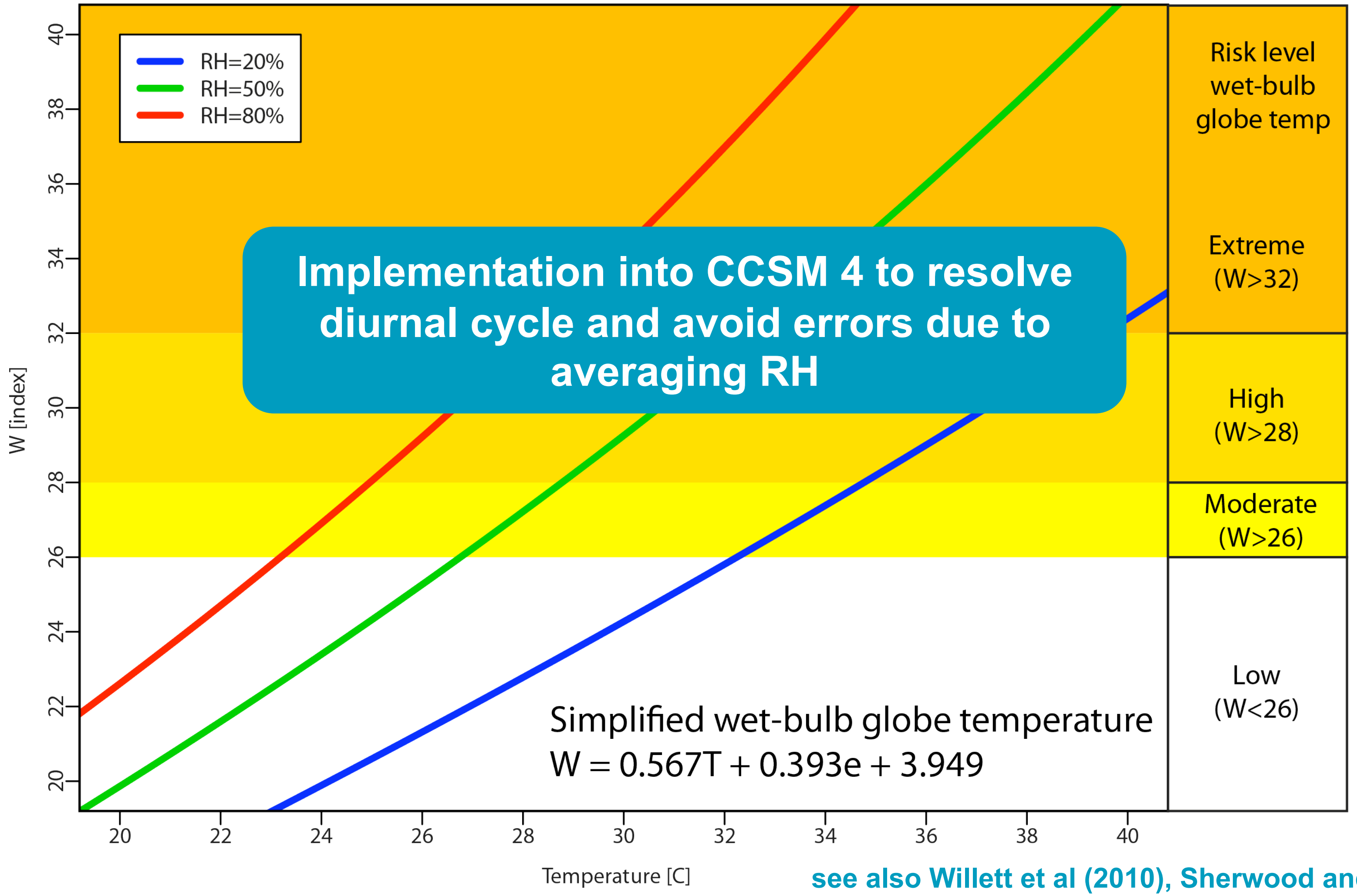
# Simplified wet-bulb globe temperature (W)




**Implementation into CCSM 4 to resolve diurnal cycle and avoid errors due to averaging RH**

see also Willett et al (2010), Sherwood and Huber (2010)

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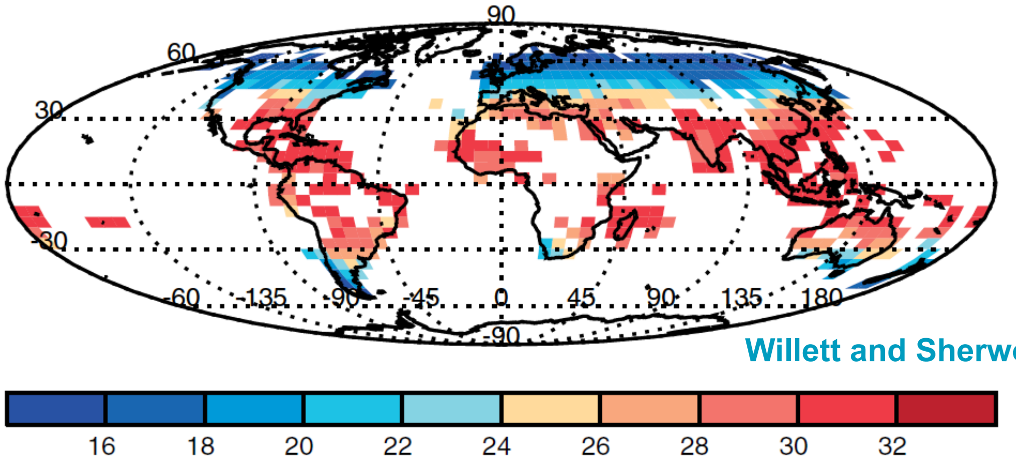
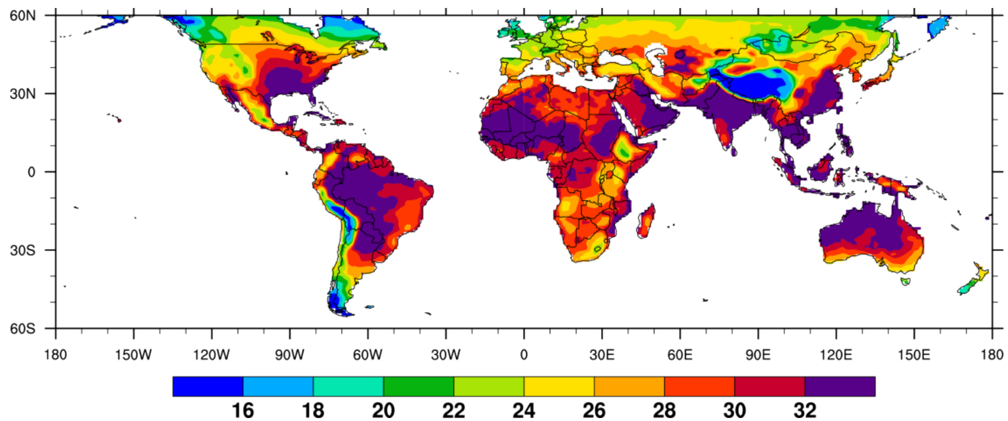
# Qualitative validation of WBGT

## Observations JJA WBGT




Willett and Sherwood (2010)

## CCSM 1xCO2 JJA WBGT




**Good qualitative agreement on global pattern between CCSM4 and Willett and Sherwood (2010)**

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# Urban-rural contrast

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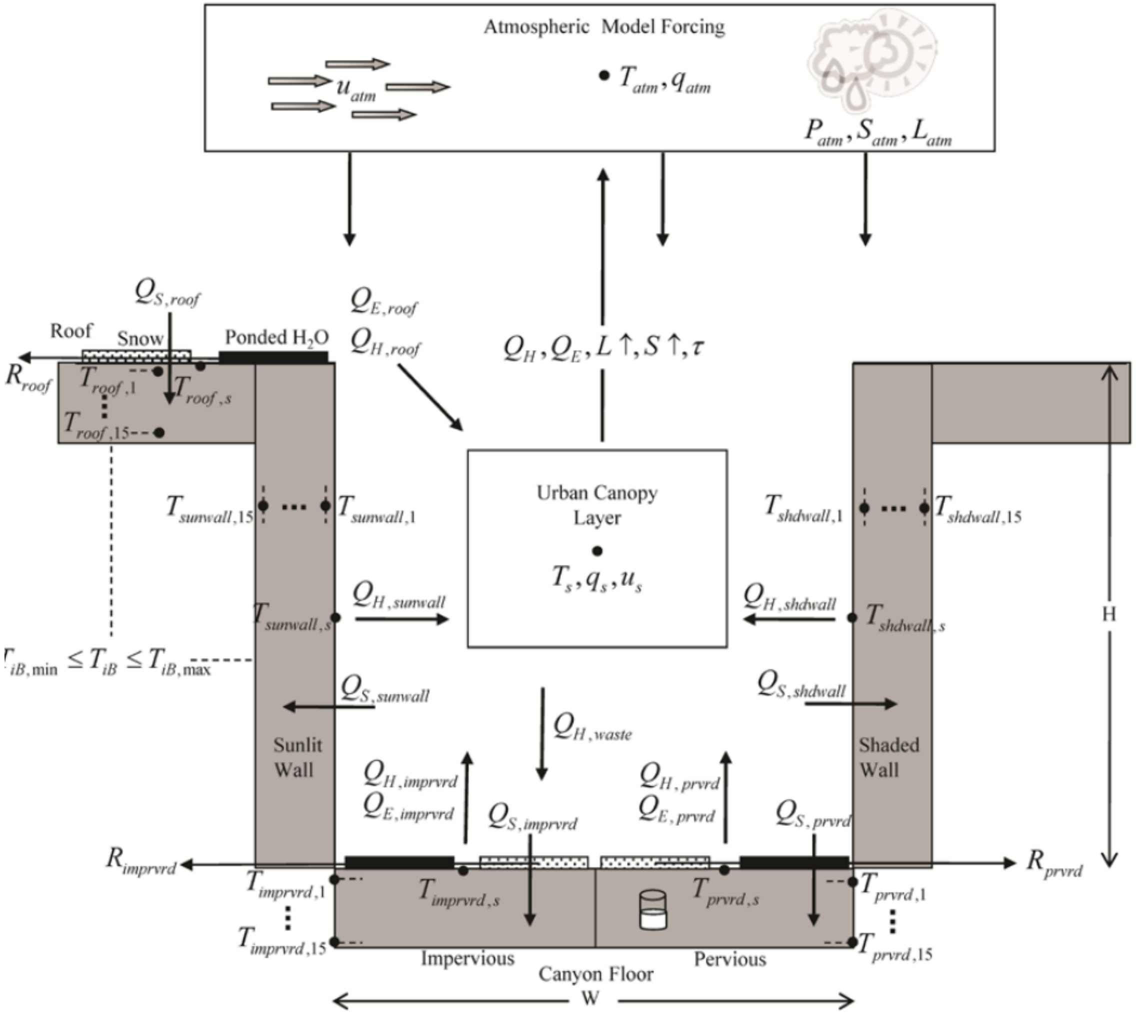
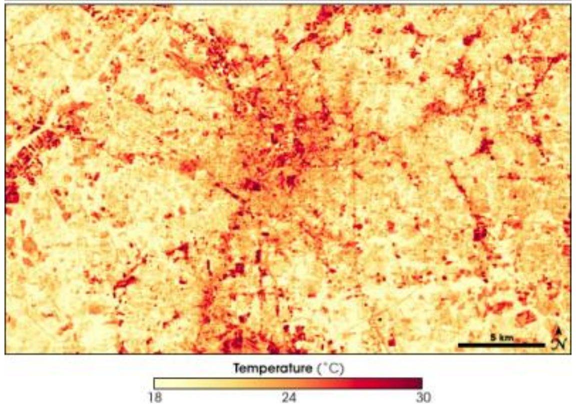
# Urban model in CESM1/CCSM4




NASA 2010

**CCSM urban model was extensively validated by Oleson et al. (2008)**

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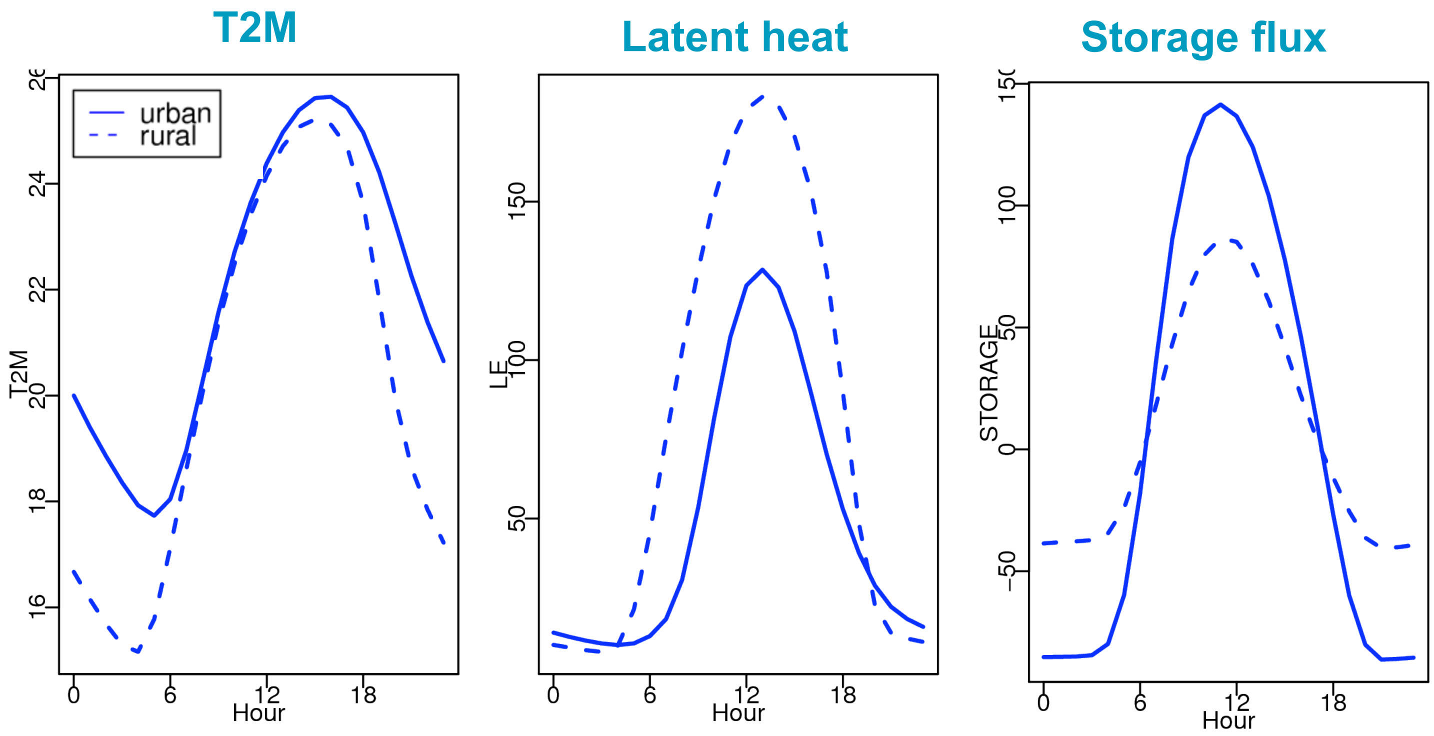
# Urban heat island over N Europe (JJA mean)




see Oleson et al. (2010a) for details

- Higher thermal admittance
- Longwave trapping
- Albedo contrast
- More impervious surface -> reduced latent heat flux
- Anthropogenic heat, HAC

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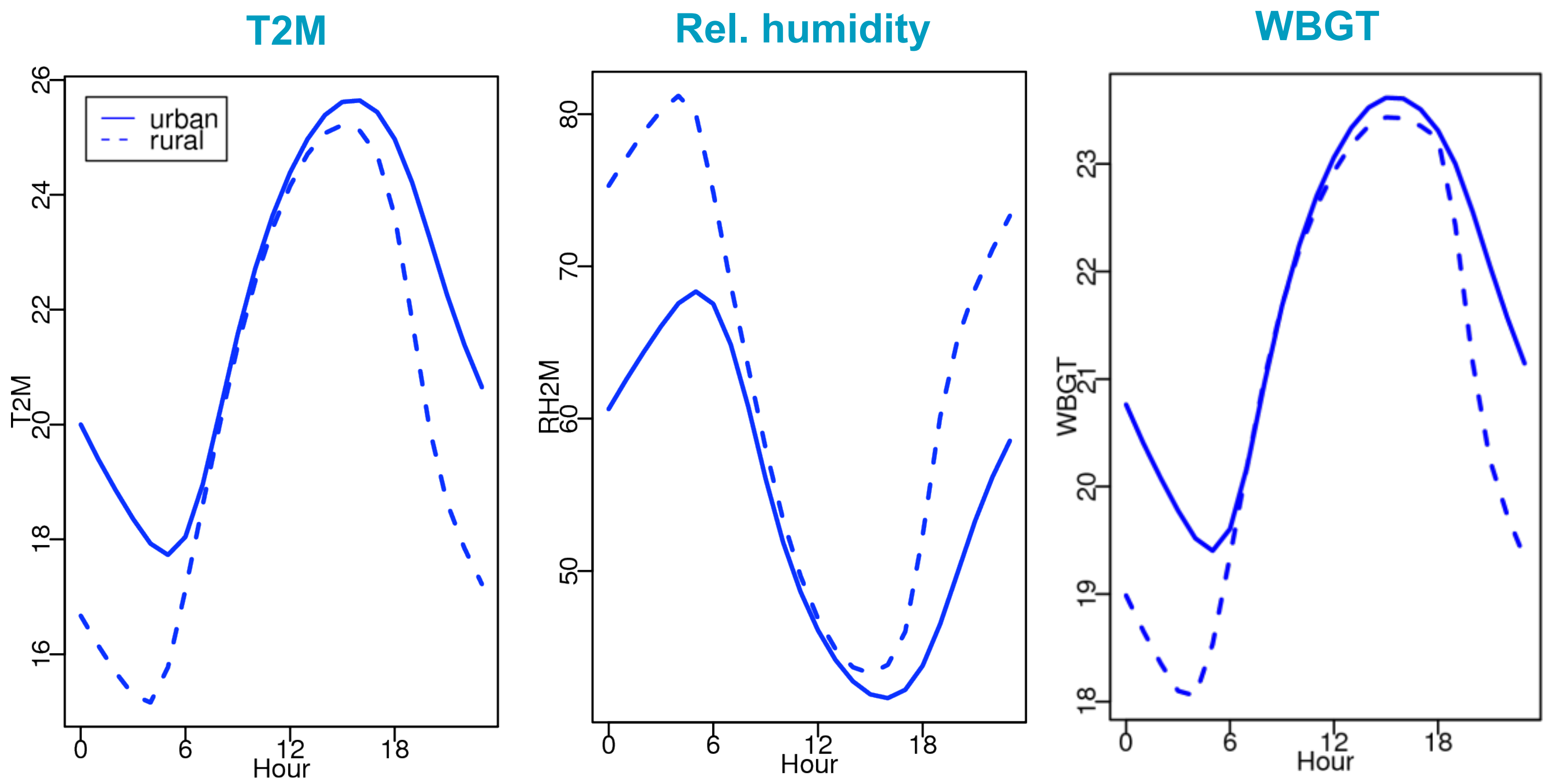
# Urban amplification or reduction of heat stress




**Temperature contrast dominates but is somewhat offset by humidity deficit**

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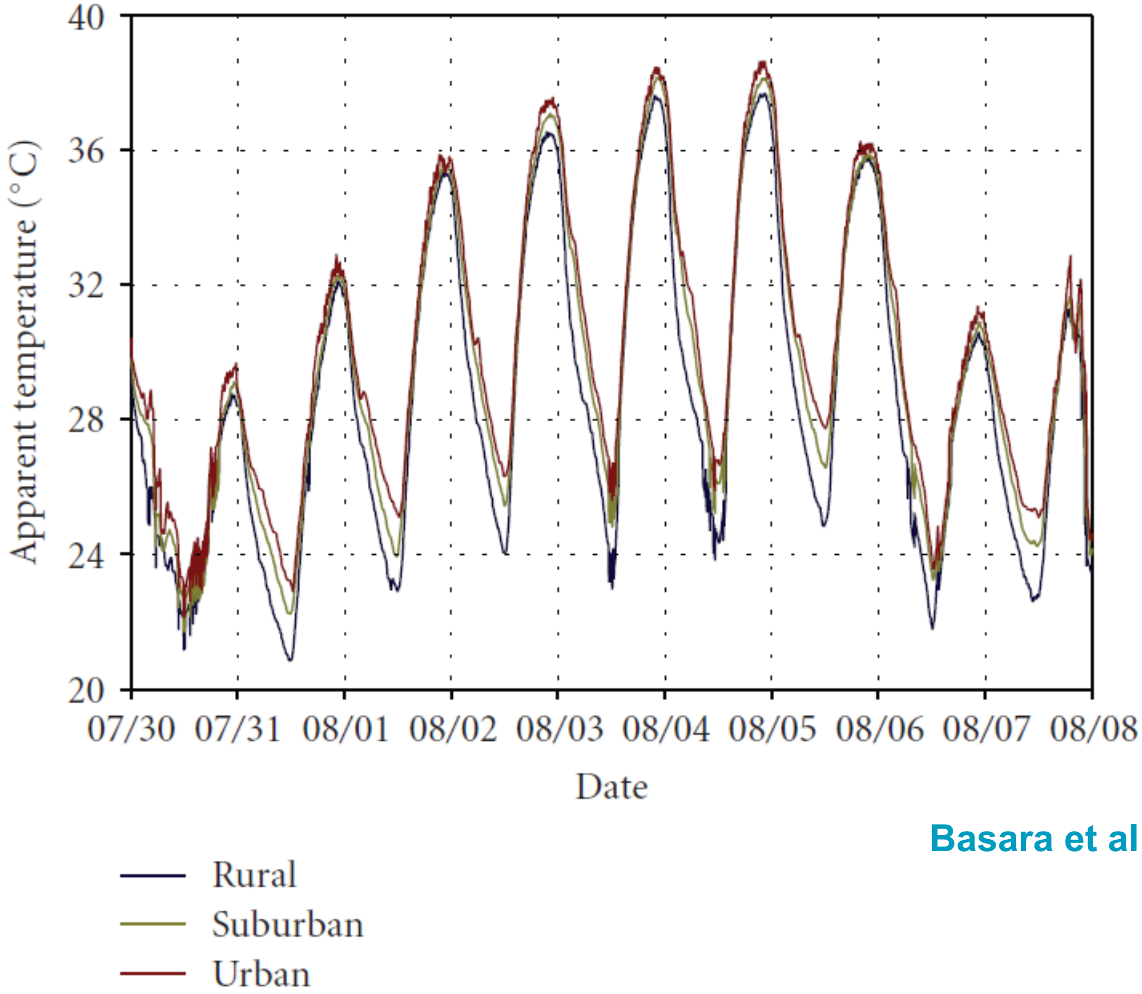
# Consistent with observation (Oklahoma City)




Basara et al (2010)

Temperature dominates RH deficit in observations

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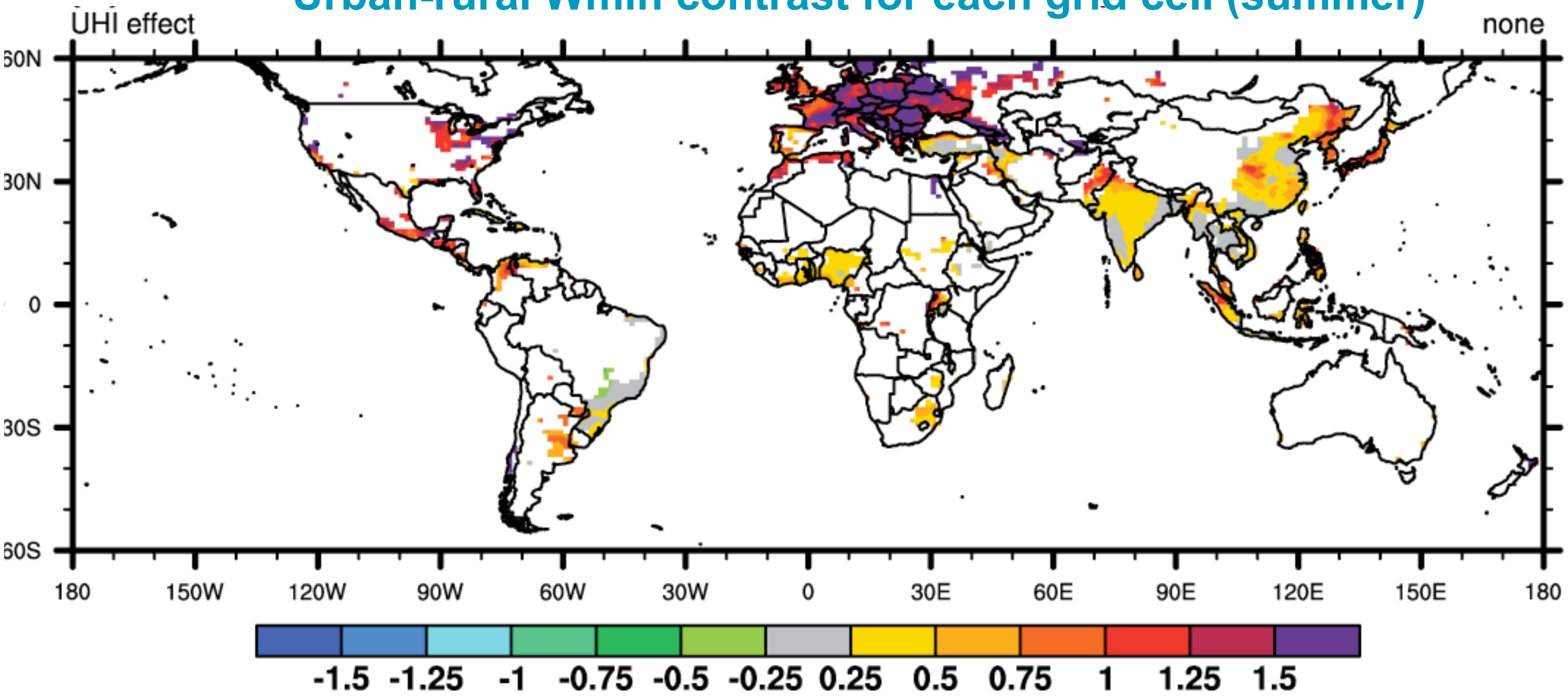
# Urban-rural nighttime heat stress contrast

## Urban-rural Wmin contrast for each grid cell (summer)




**Consistent with observations urban-rural contrast is large over mid-latitudes and subtropics and small over tropics**

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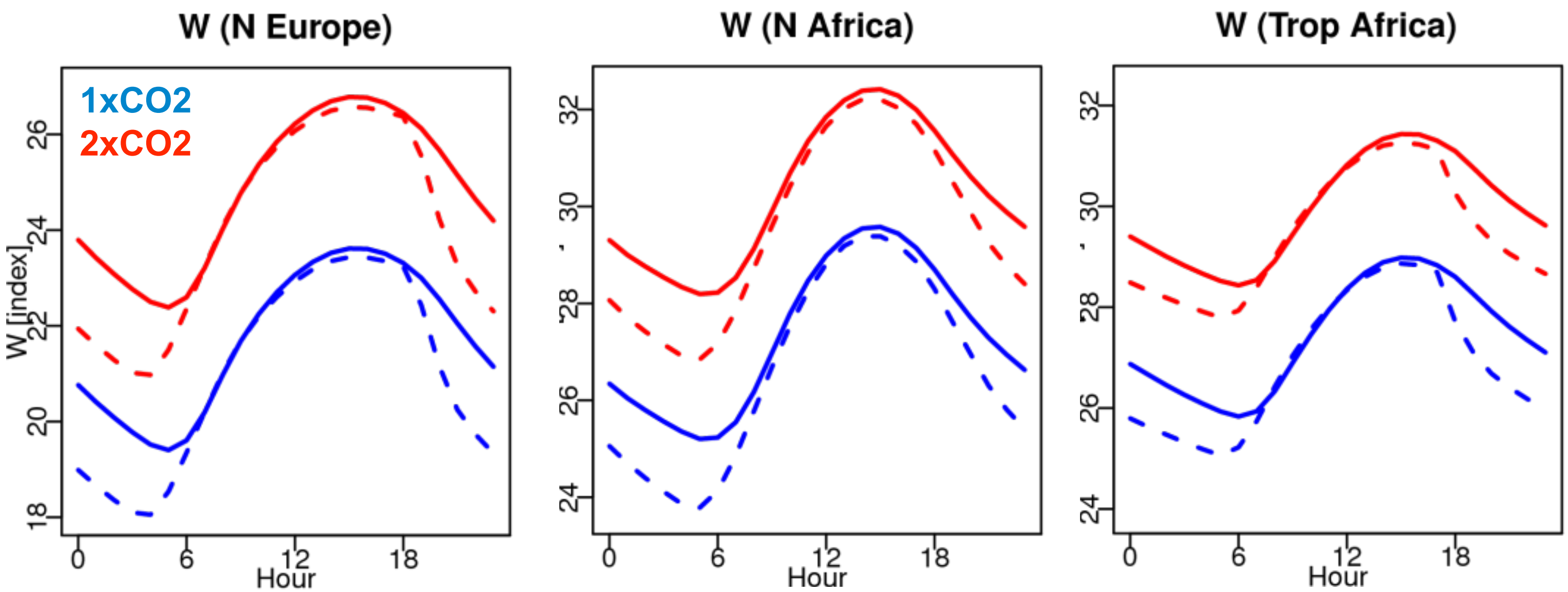
# Heat stress response to 2xCO2




Roughly same heat stress response over urban and rural

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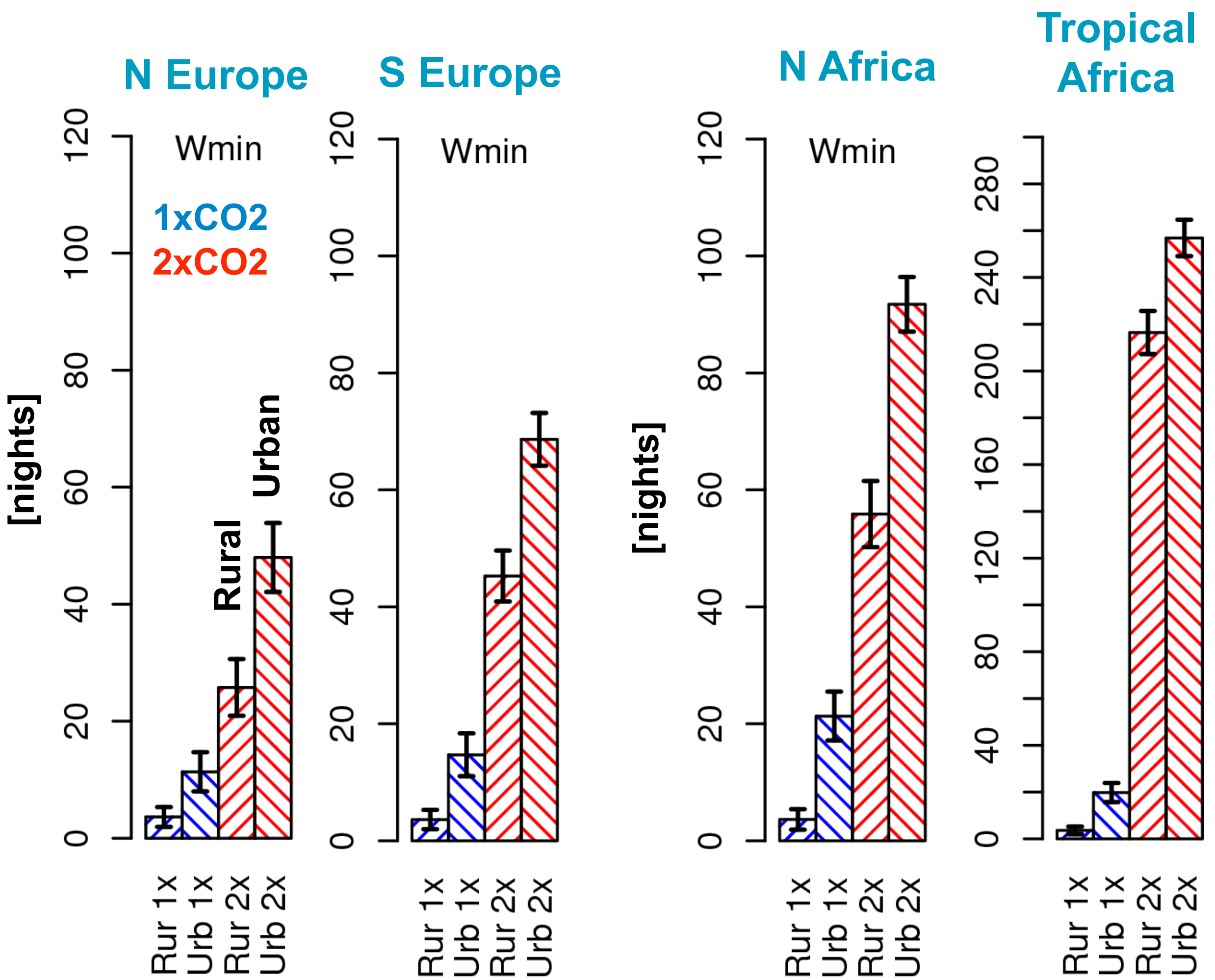
# Number of "high-heat-stress nights"




**Higher change in urban threshold exceedance**

for temperature only see McCarthy et al (2010) and Oleson (2011, in press)

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# Weak warming, large change. A reversed global pattern?

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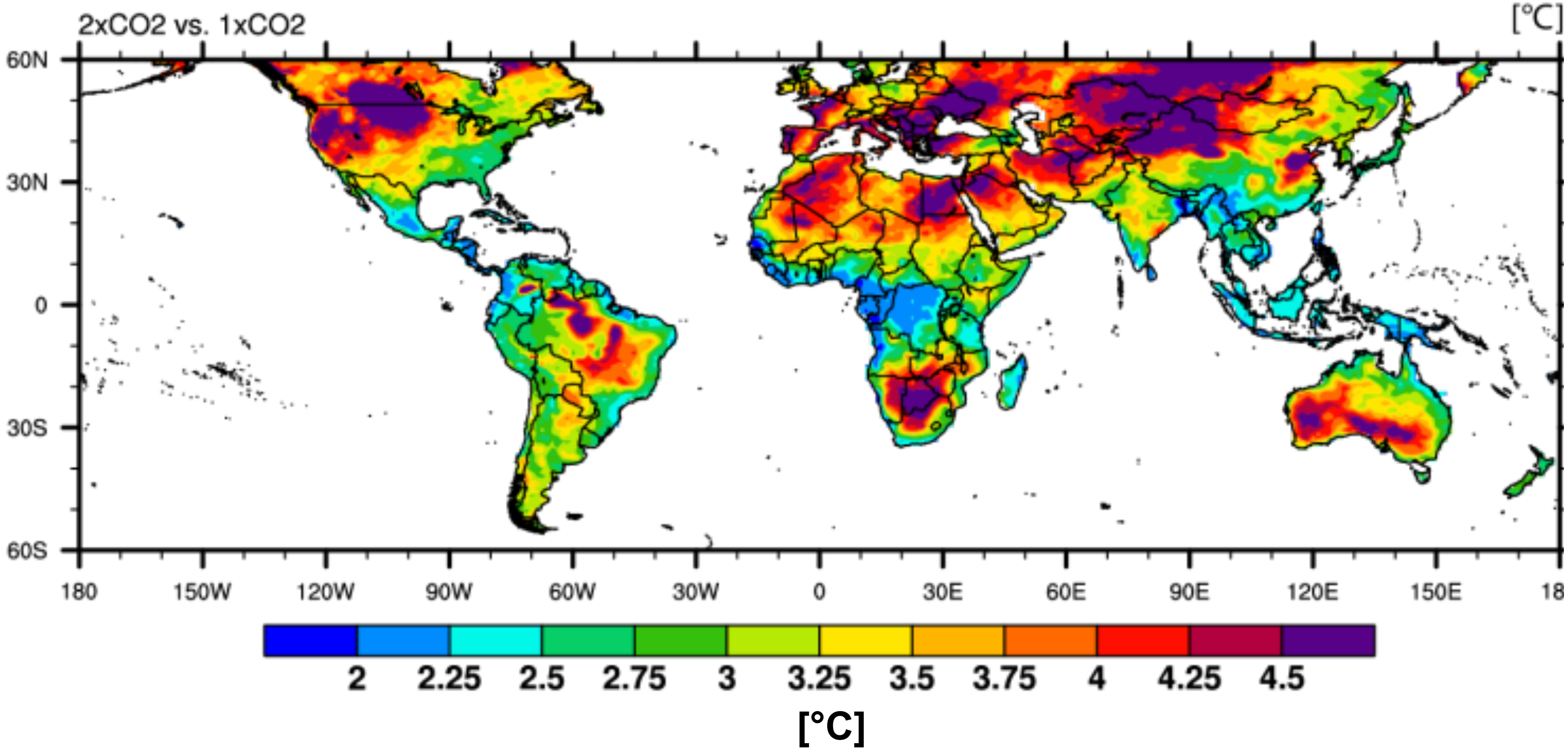
# Temperature response of warmest nights

ΔTmin99 ($2xCO_2$ vs. $1xCO_2$)




**Strongest warming over midlatitudes**

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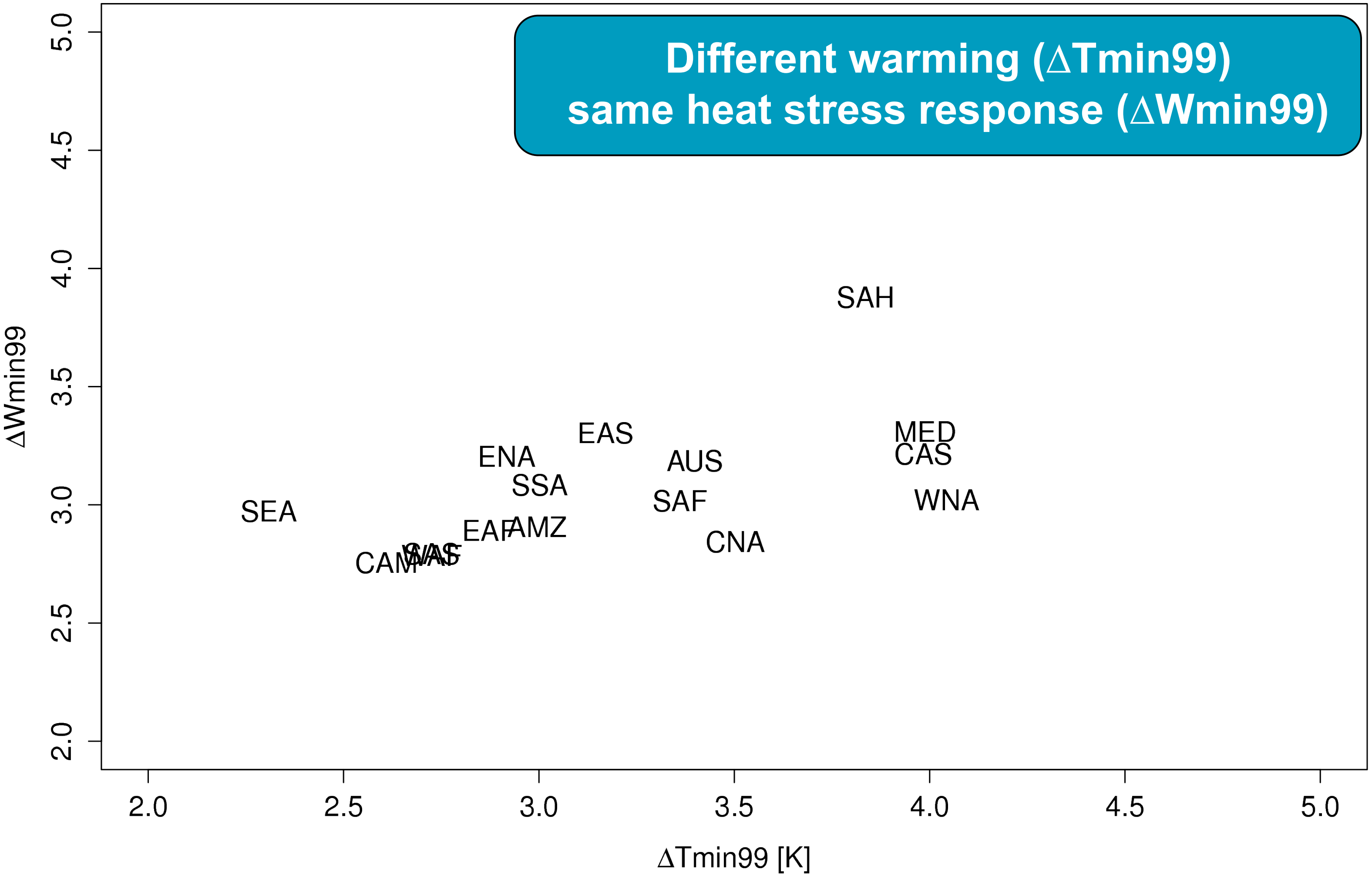
# Different warming – same heat stress response



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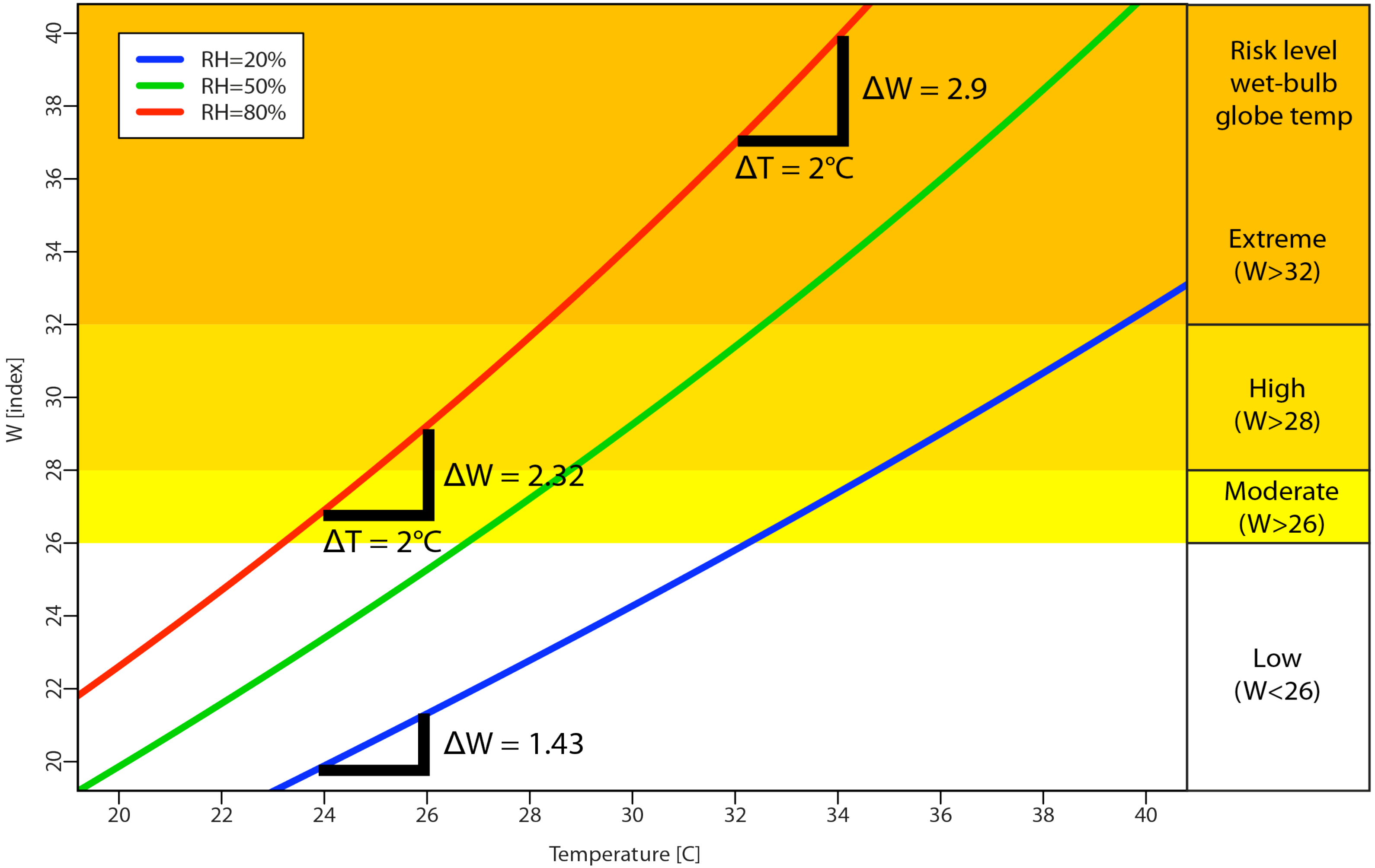
# Same warming different response



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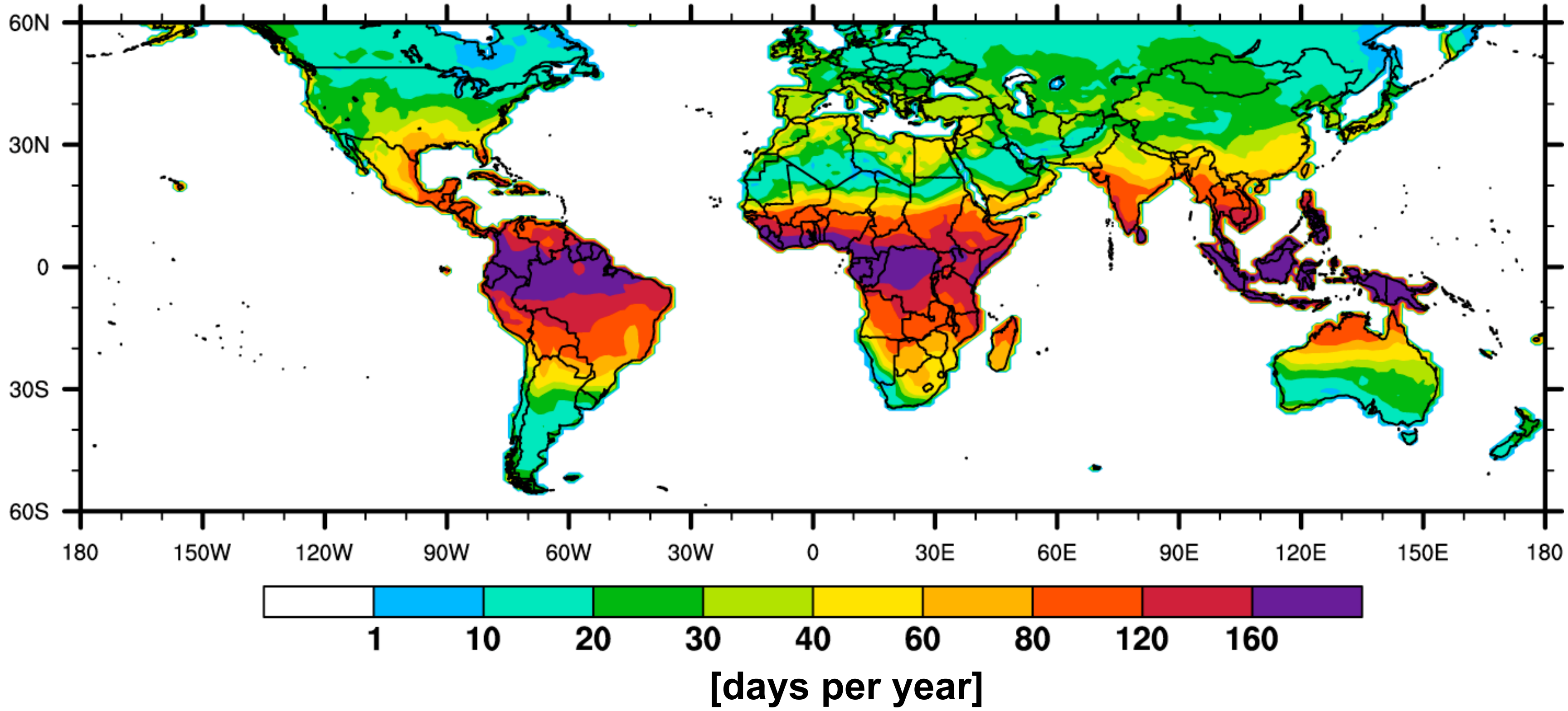
# Tropics hit hardest?

## Exceedance frequency of present-day Wmin99 in 2xCO2




**Half of nights per year exceed today's heat stress maximum**

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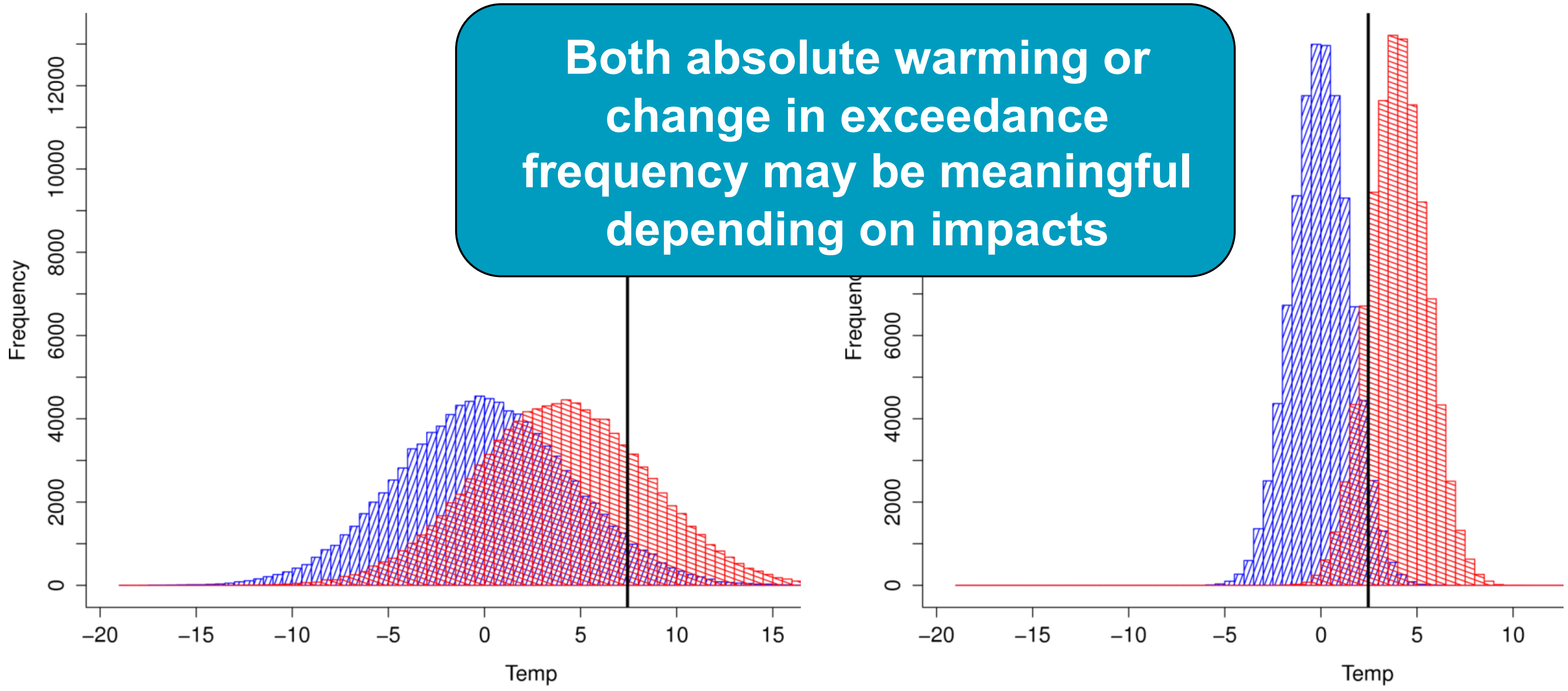
# Same shift – different climatology

**Weak warming but higher occurrence of unprecedented conditions**




**Both absolute warming or change in exceedance frequency may be meaningful depending on impacts**

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# Conclusions

- GCM captures main characteristics in global pattern of heat stress and urban-rural contrast
- Urban heat stress is larger than rural (present-day) but response to 2x$CO_2$ is similar
- Stronger increase in urban than rural “high-heat-stress nights” due to 2x$CO_2$
- Response pattern maybe different than for temperature with tropics potentially most affected

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# Limitations

- Lack of validation: Urban model needs more validation particularly in terms of RH
- Urban growth not accounted for
- Humidity from combustion not accounted for
- Wind and radiation effects on human health not accounted for
- Vulnerability within a local population varies strongly (age, medical pre-conditions, income)

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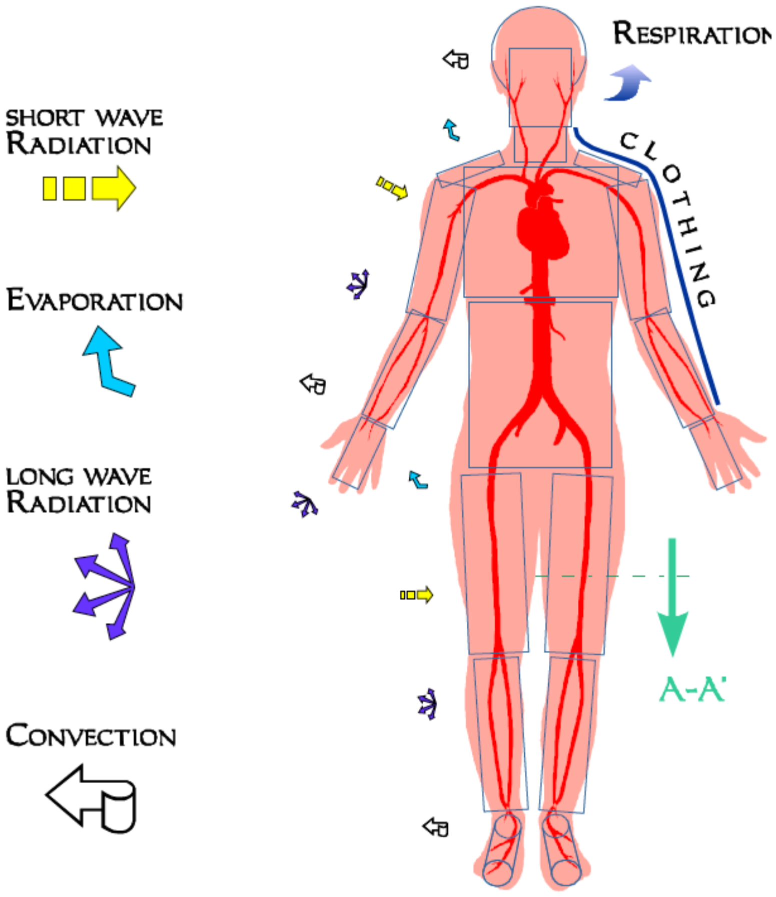
# Human thermoregulation




Fiala et al. (1999)

- Heat stress changes relevant not only for mortality but **human discomfort** and **work inefficiency**
- ~100W of metabolic heat transported away through **heat conduction**, **evaporative cooling**, and net infrared **radiative cooling** (Sherwood and Huber 2010)
- High ambient **temperature** and **humidity** reduces heat loss

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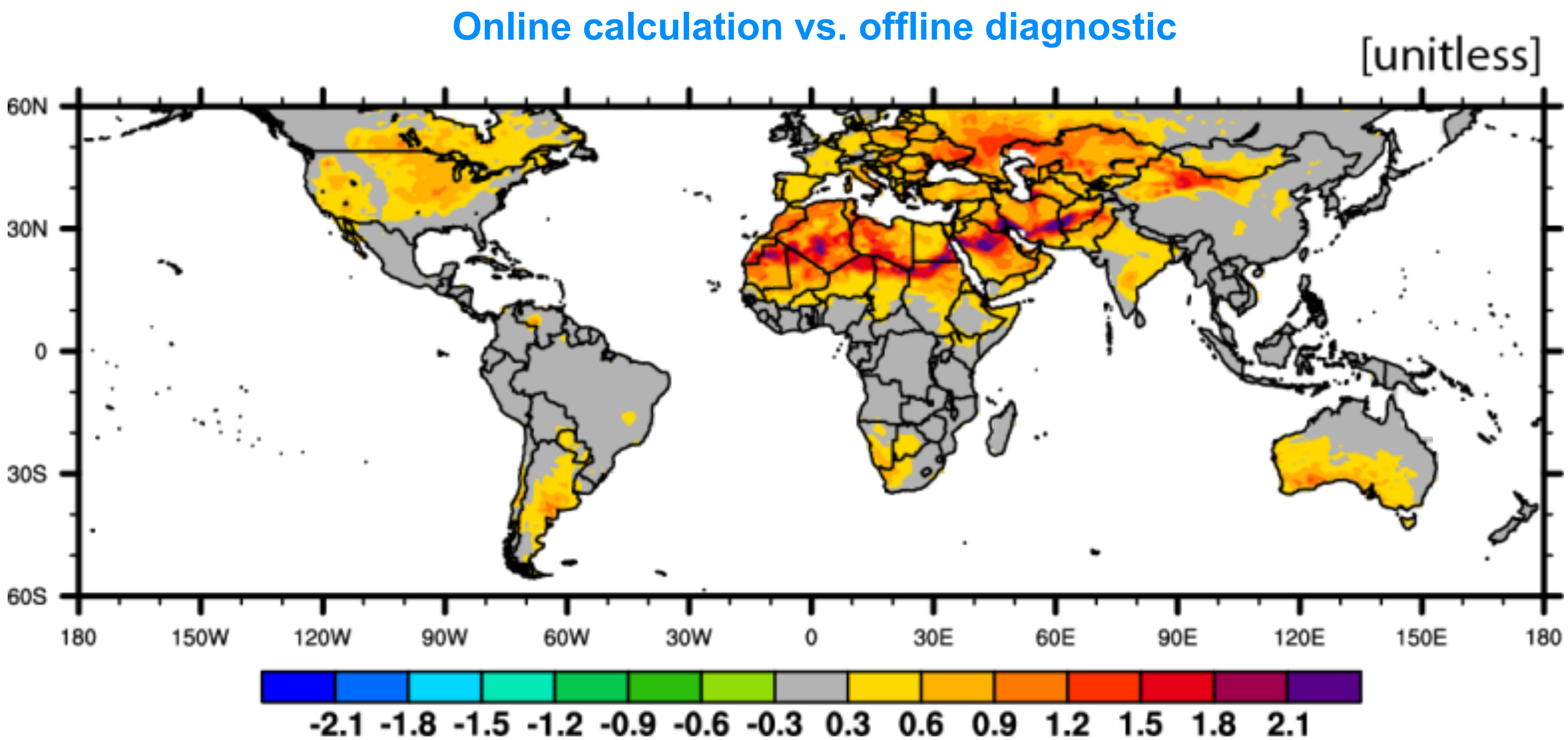
# Benefit of online calculation



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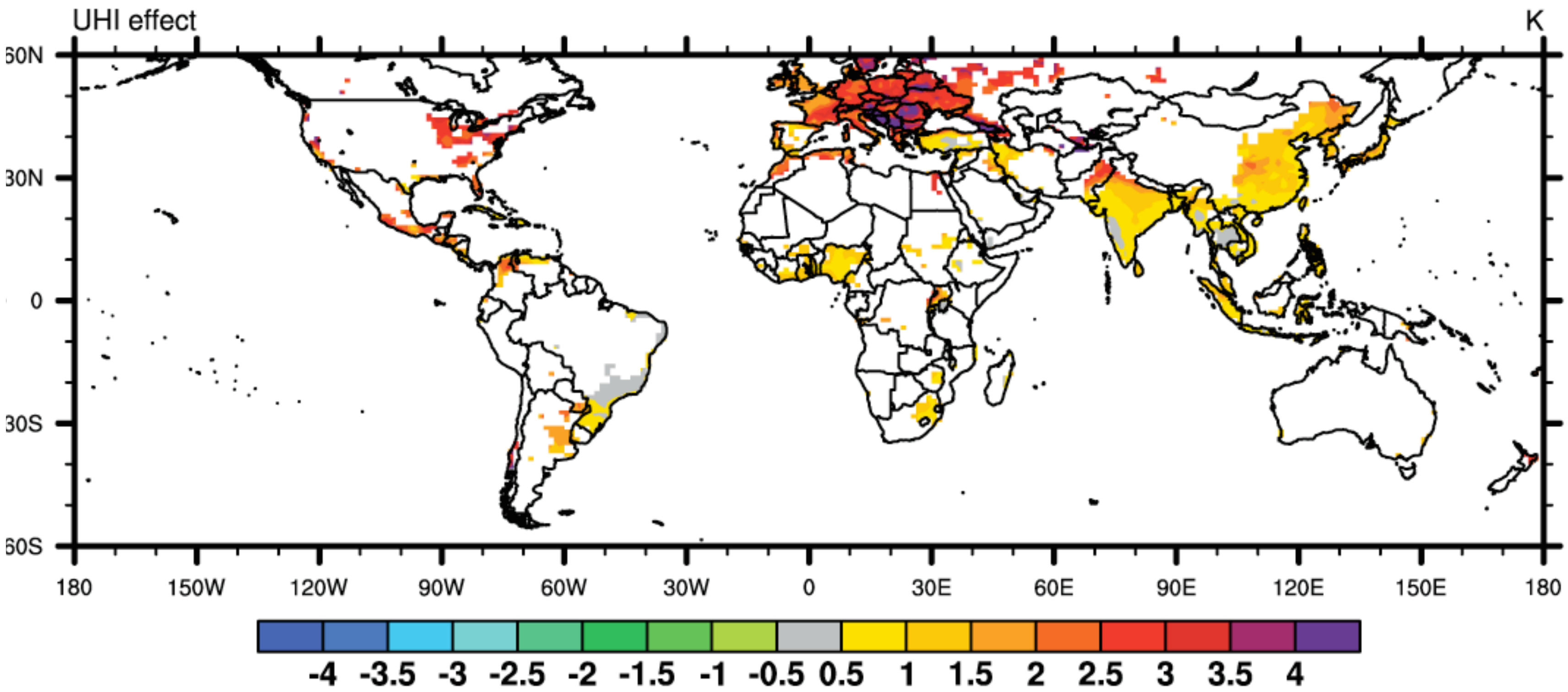
# Urban-rural TMIN contrast (summer)



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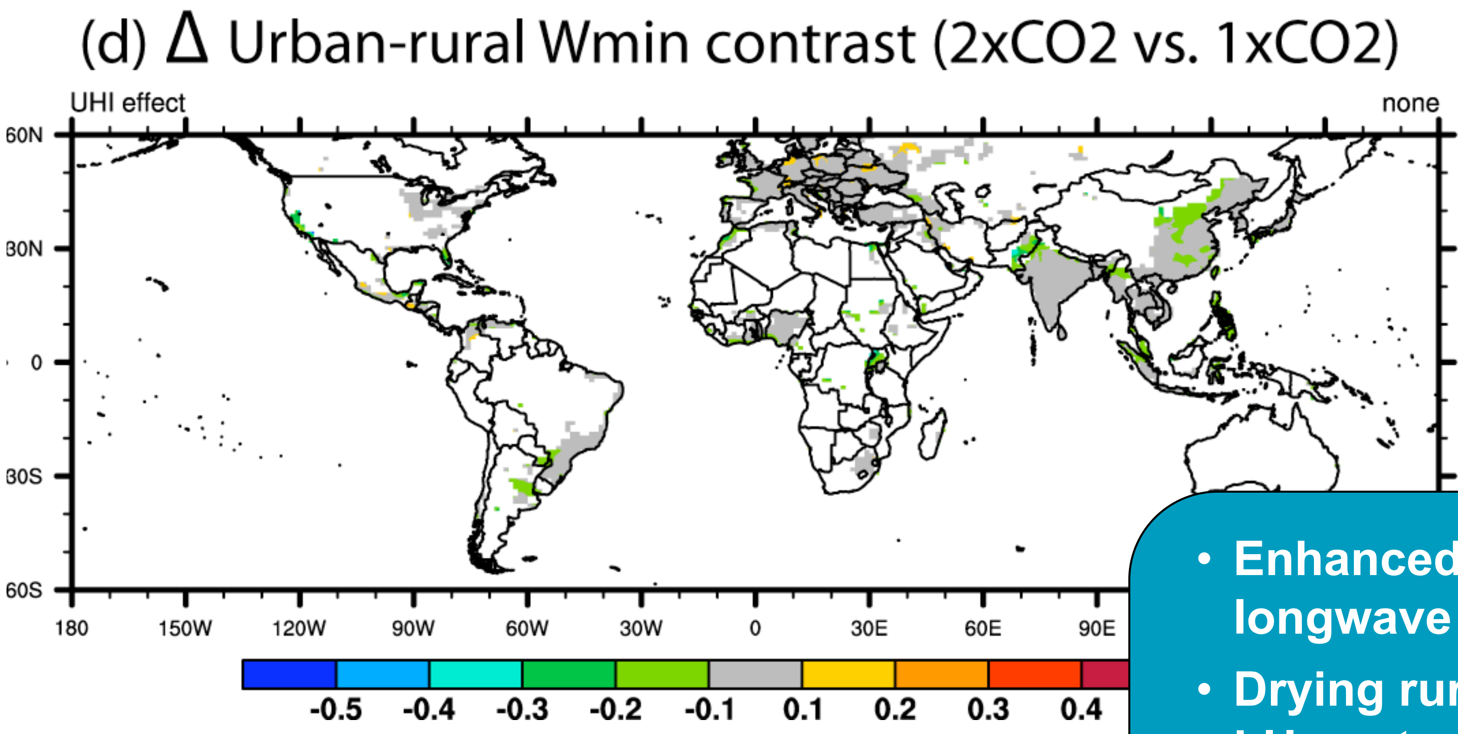
# Response to 2xCO2




- Enhanced downward longwave
- Drying rural -> reduced LH contrast
- Drying rural -> Higher admittance contrast
- Less clouds

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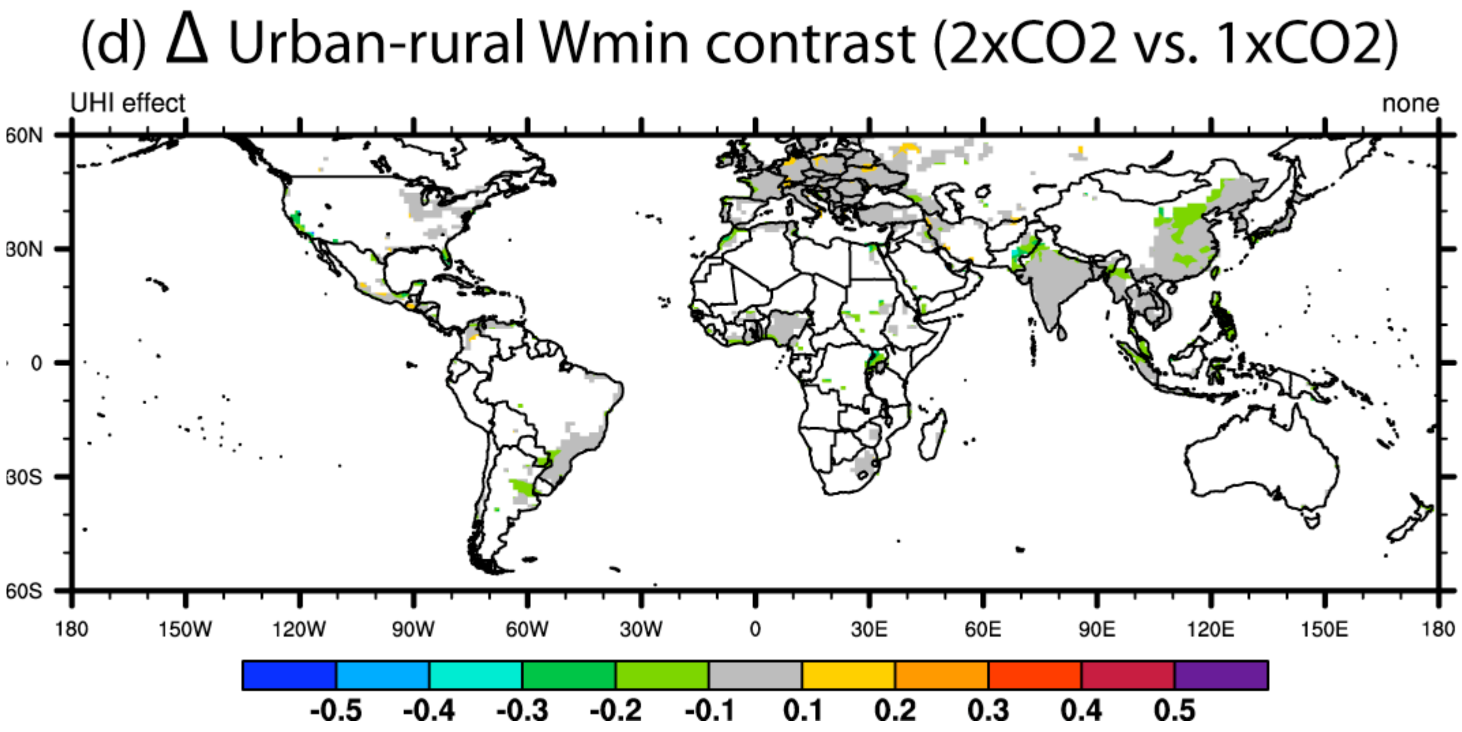
# Response to 2xCO2




**Fluxes are changing considerably but tend to compensate (e.g. enhanced downward longwave or drying rural surface)**

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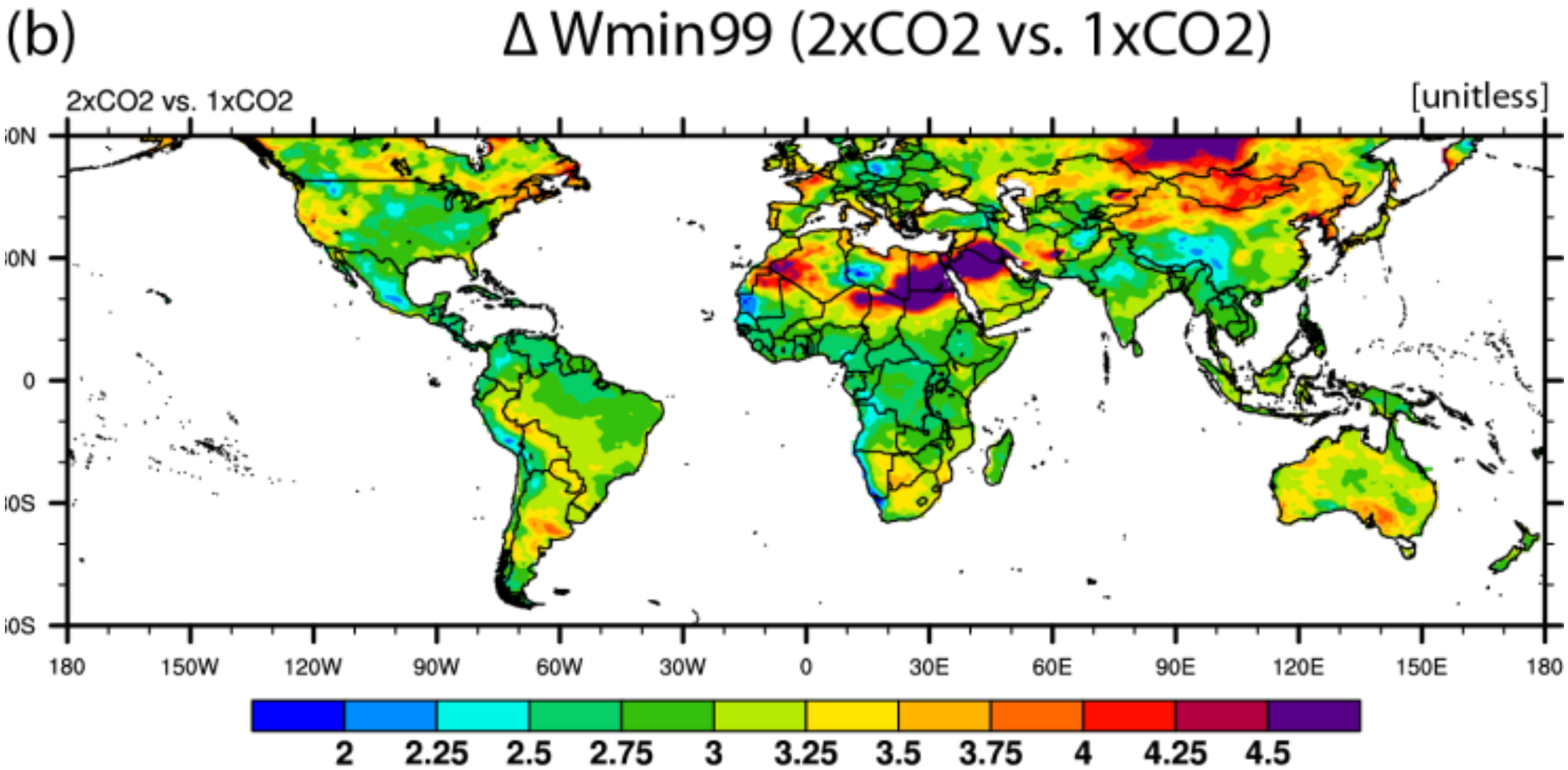
# Change in nights of highest heat-stress




**Different warming – similar change in W**

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# CMIP3

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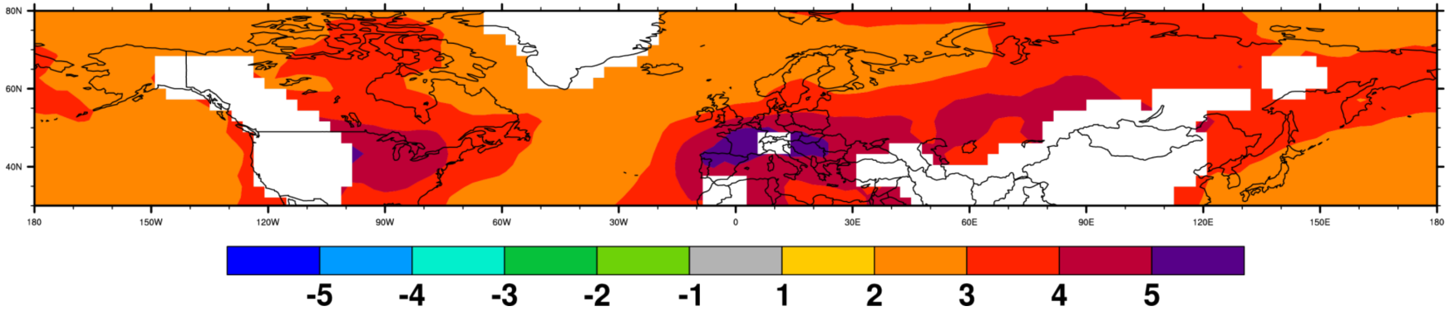
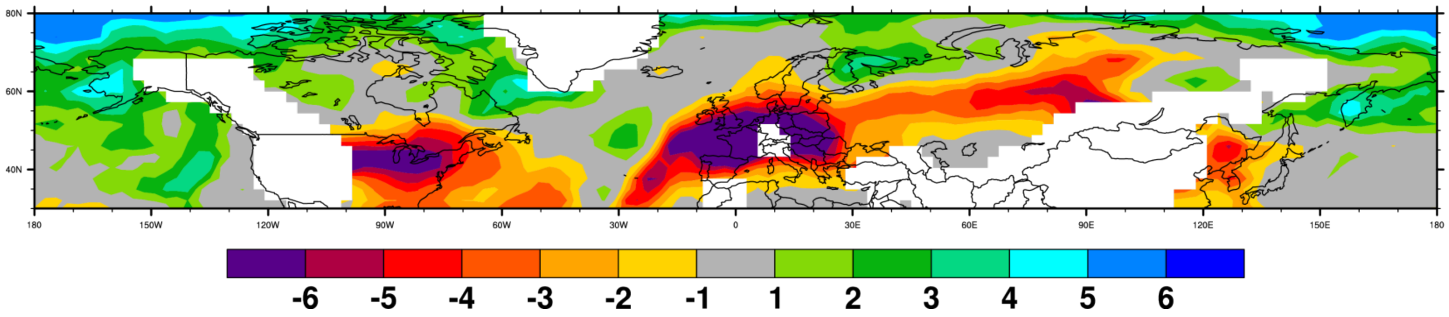
# Temperature goes up, RH down

**99th percentile of temperature (2081-2100 vs. 1981-2000)**




**Simultaneous change in RH (2081-2100 vs. 1981-2000)**



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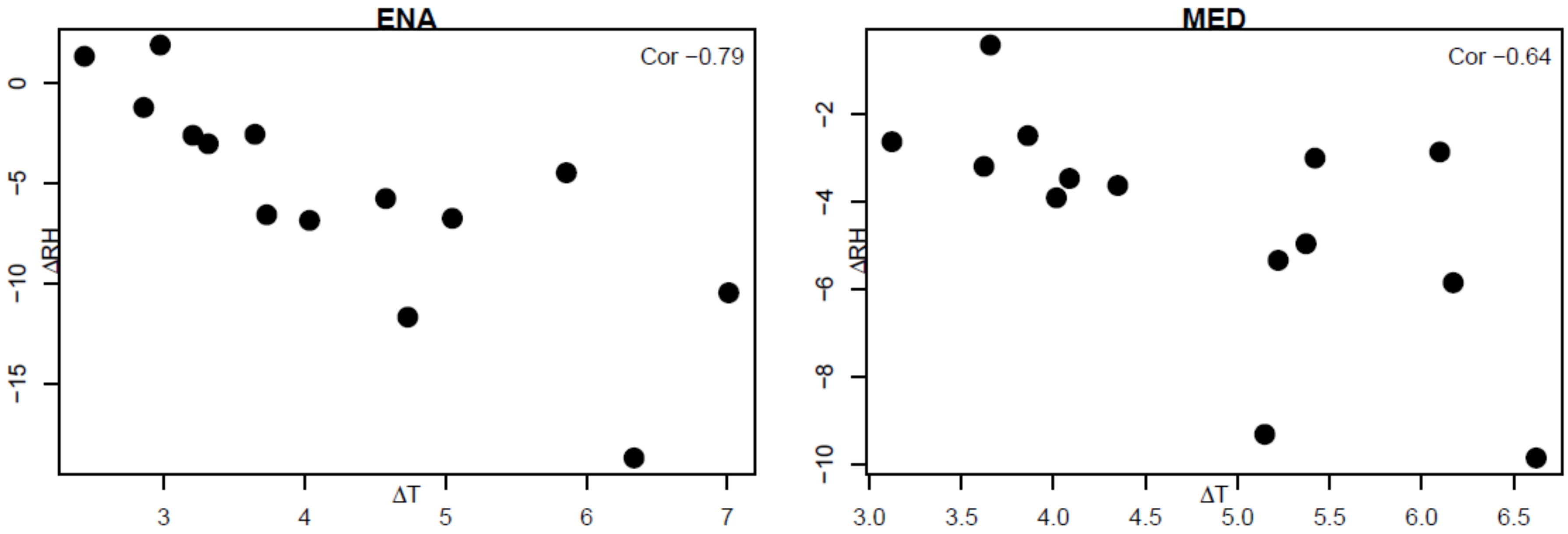
# The more warming – the drier the air



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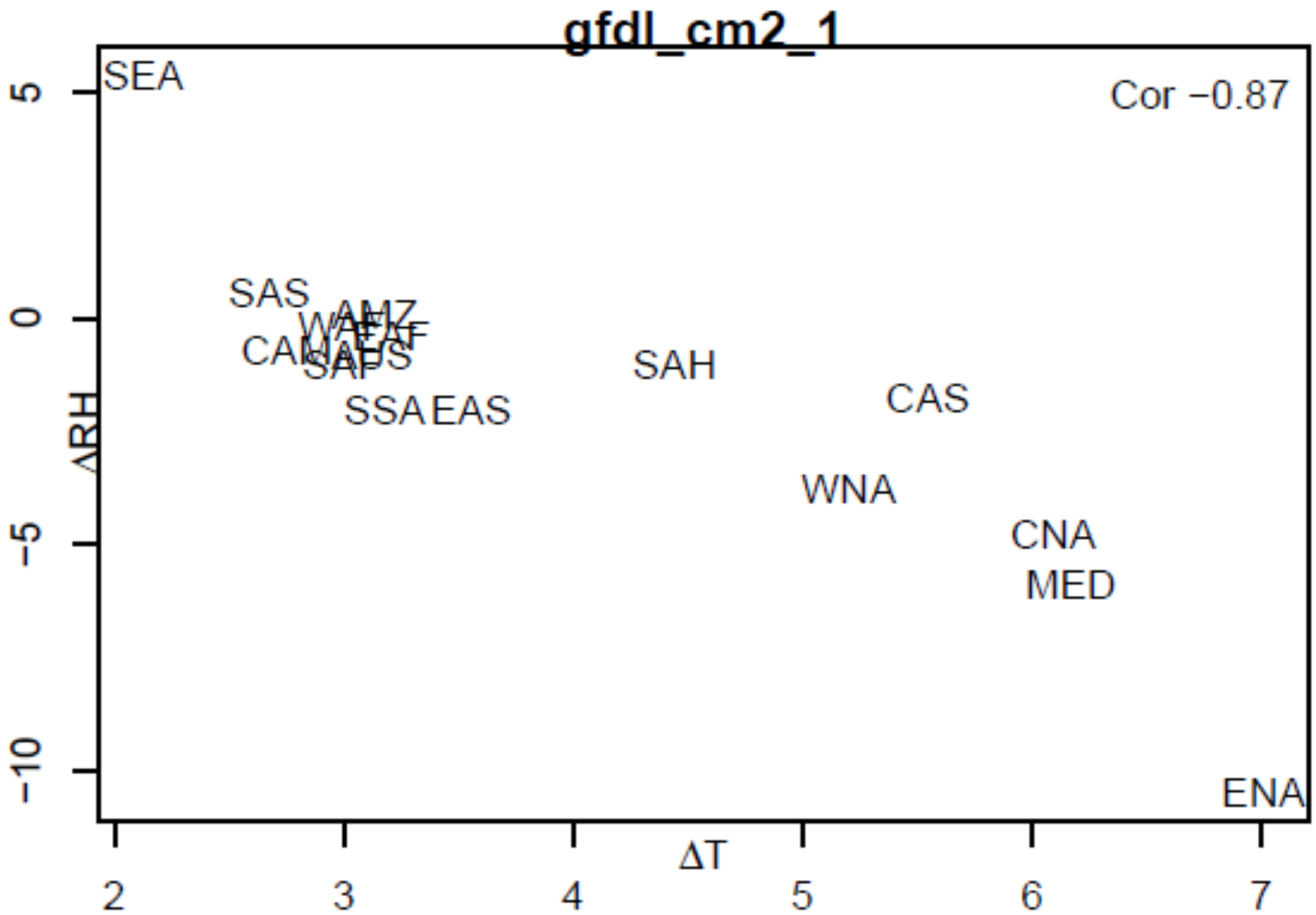
# Regions: more warming – the drier the air



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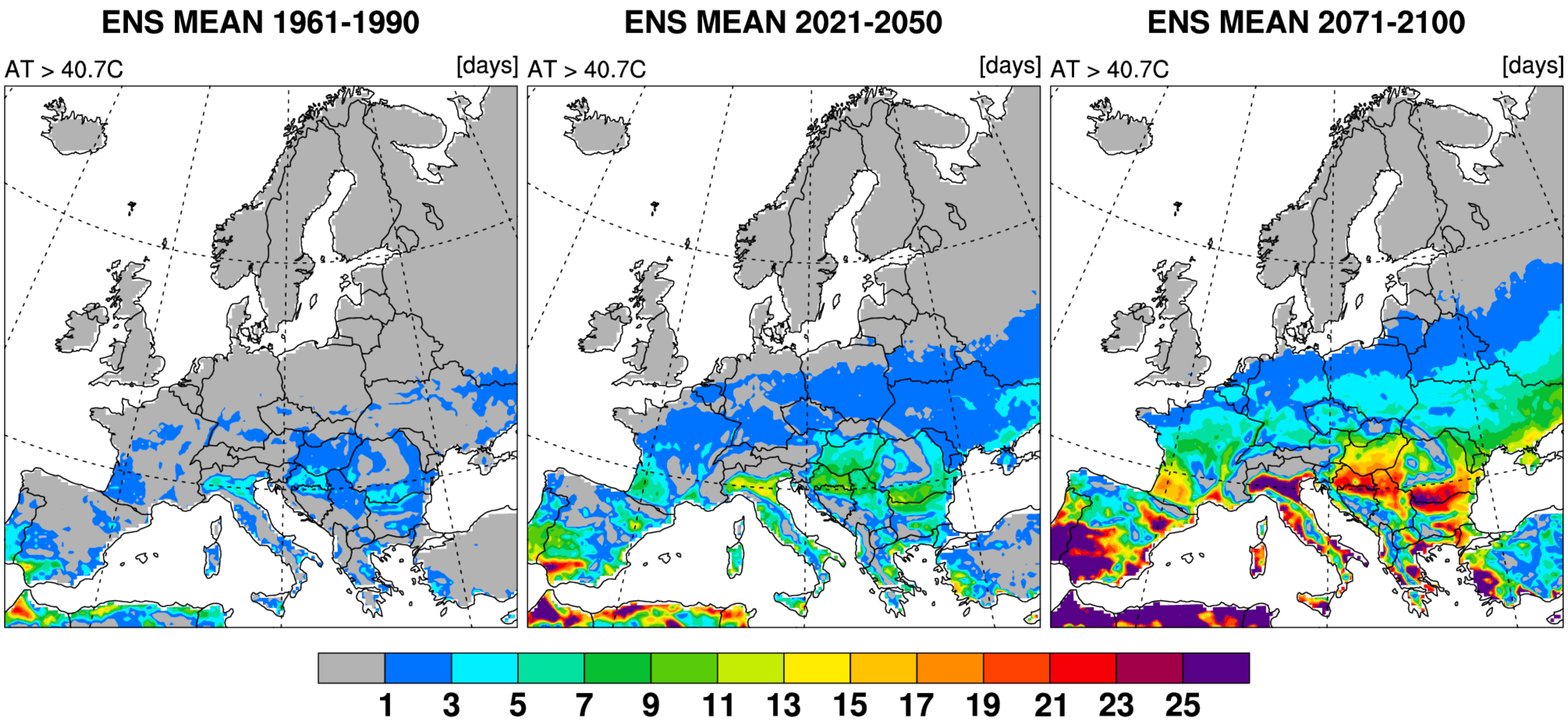
# Apparent temperature > 105°F/40.6°C




***Changes are strongest over humid and warm regions (coasts and river basins)***

Fischer and Schär, *Nature Geoscience* (2010)

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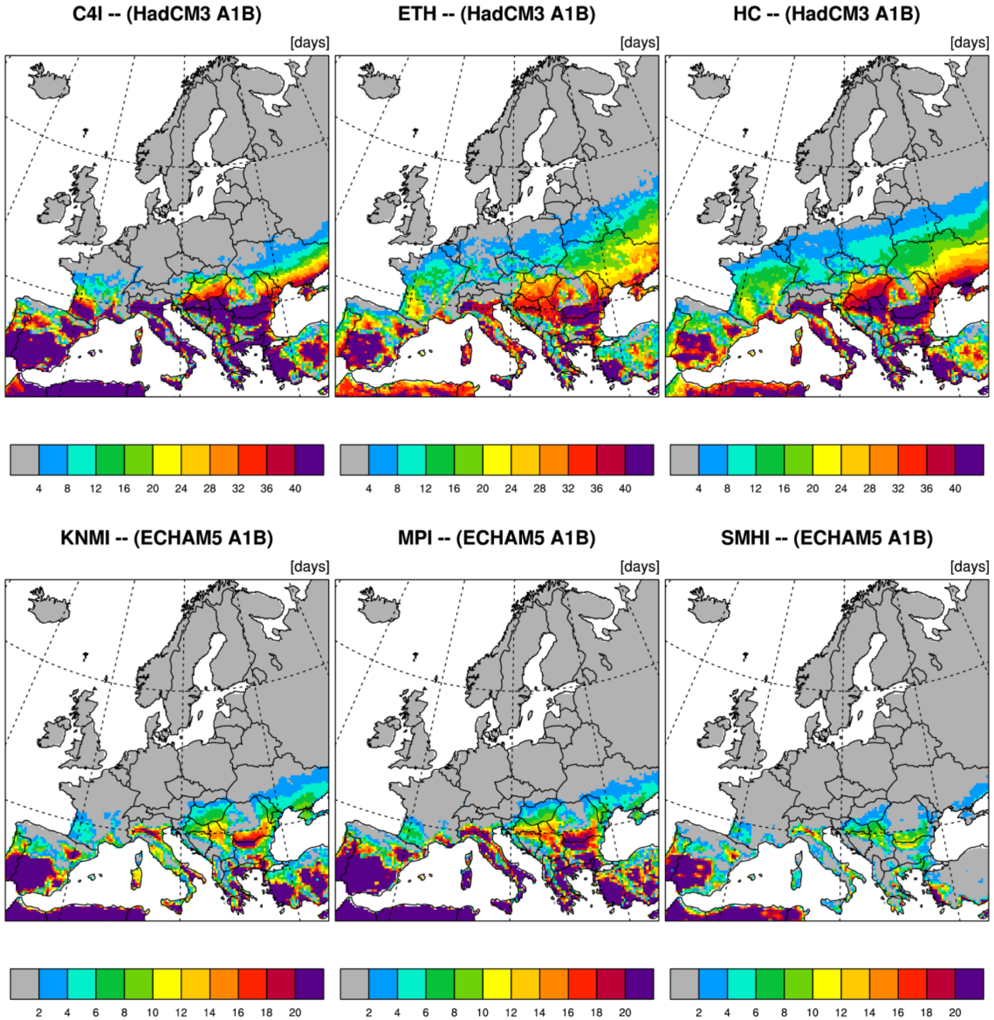
# Individual ensemble members




***Spatial patterns consistent despite major differences in magnitude***