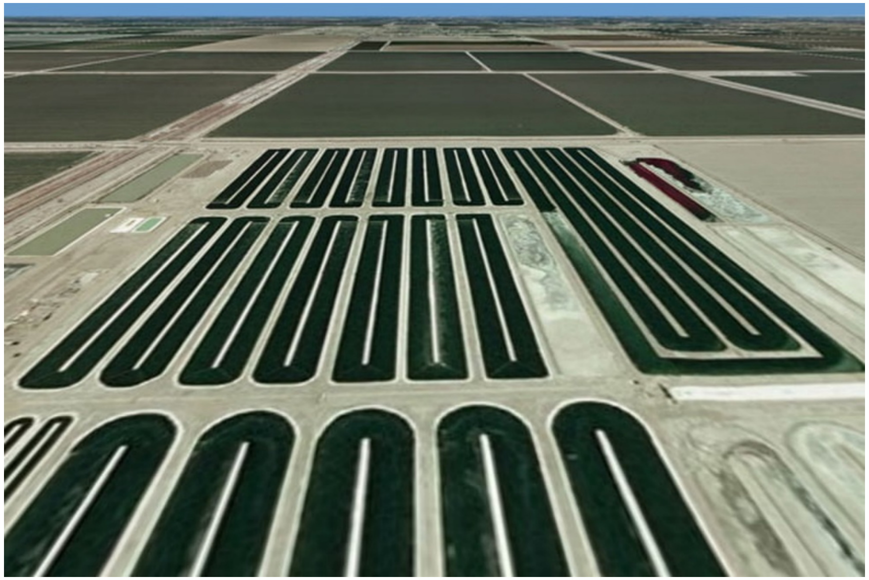
Which scenario do we pick?

Business as usual

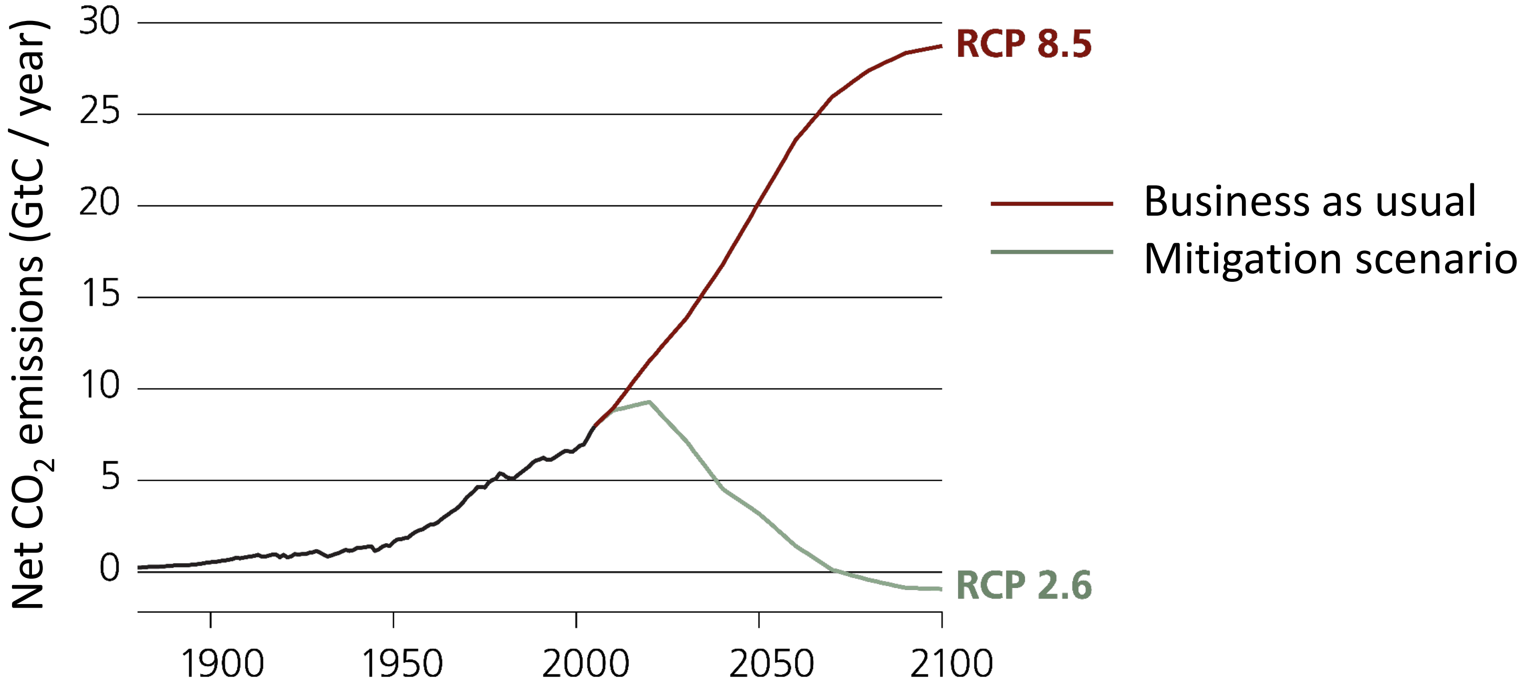
Strong mitigation



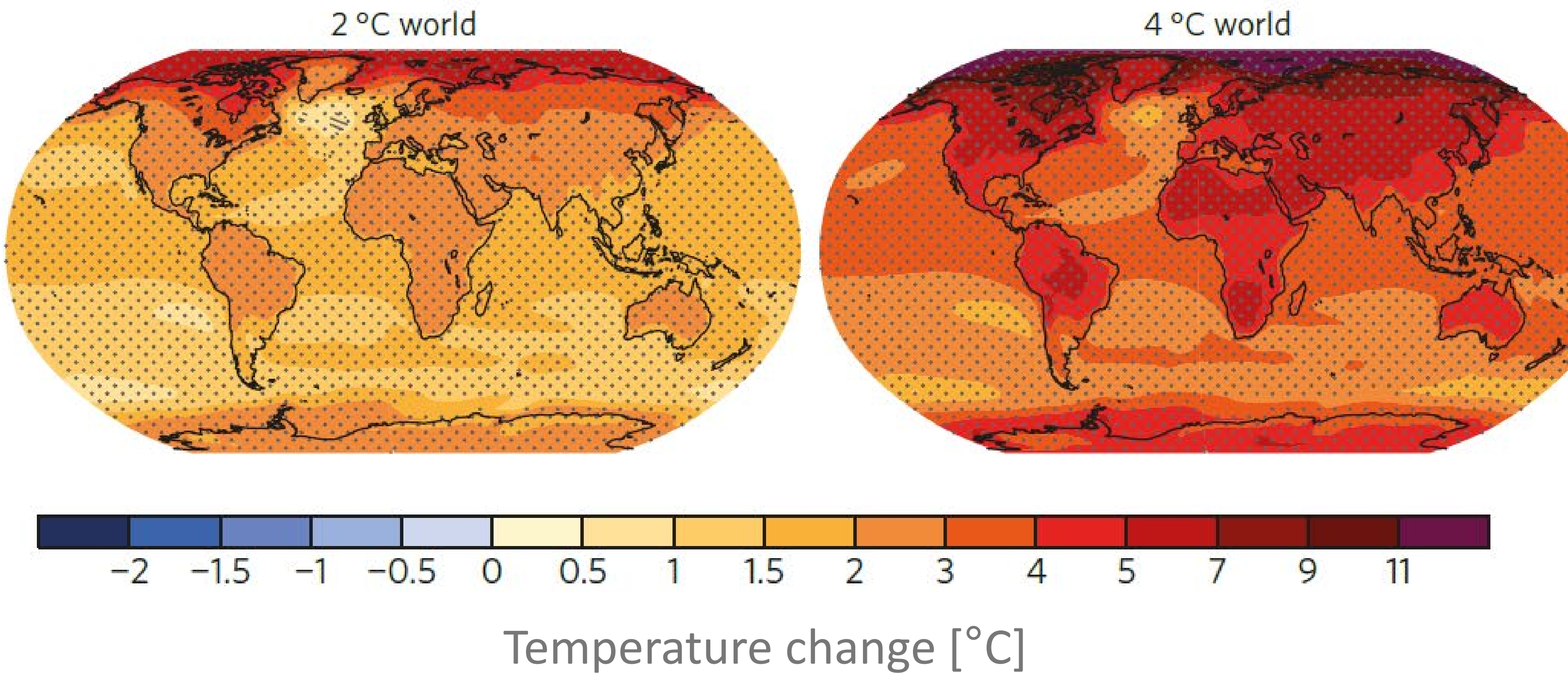
Which scenario do we pick?

Emission scenarios

Global net CO_2 emisson from fossil fuel and industrial emissions

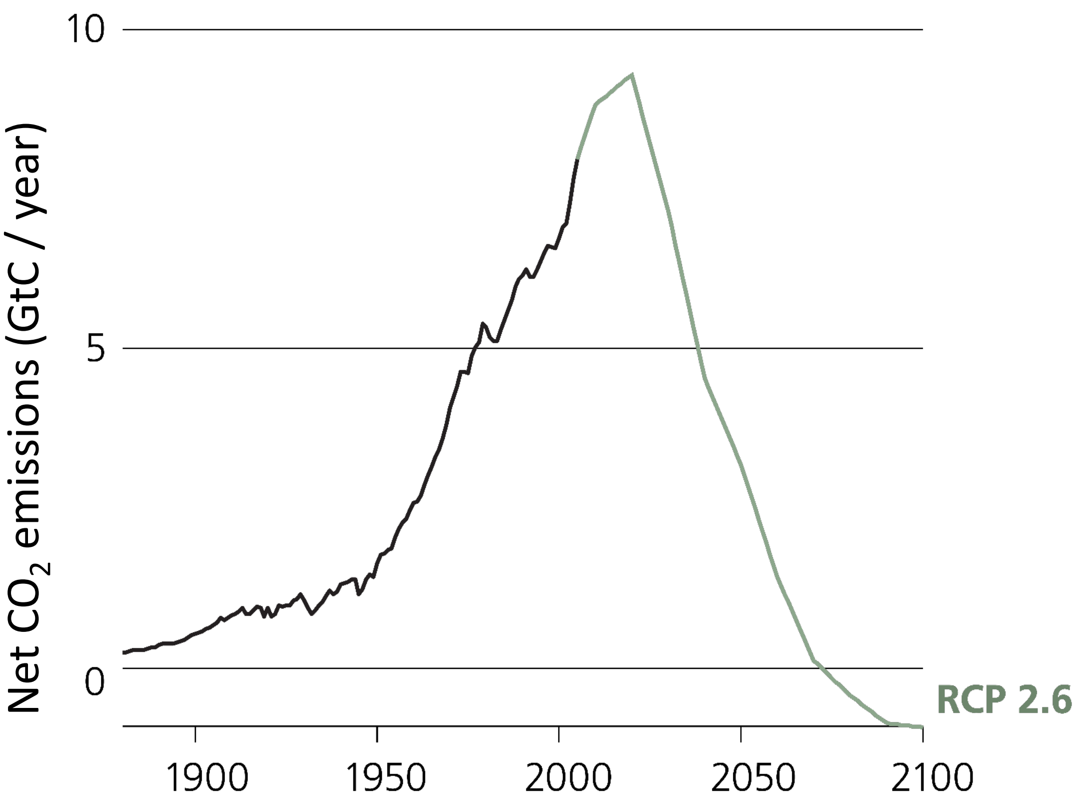


Projections: what if…

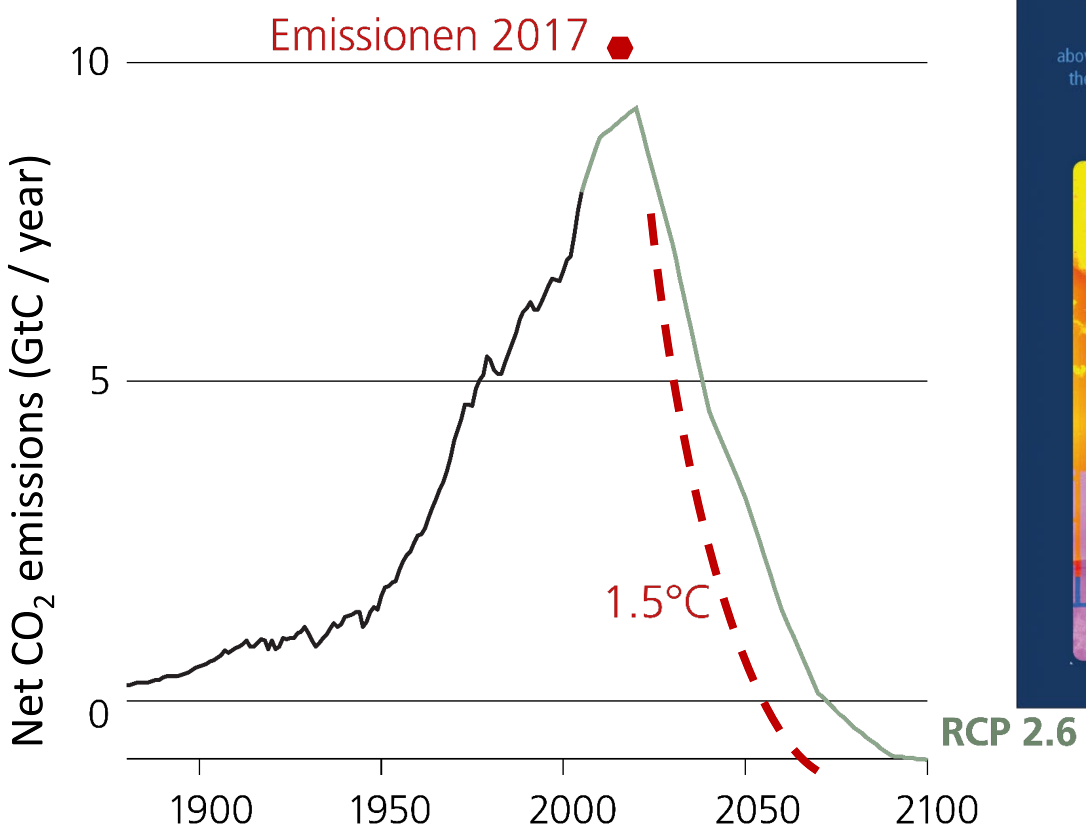


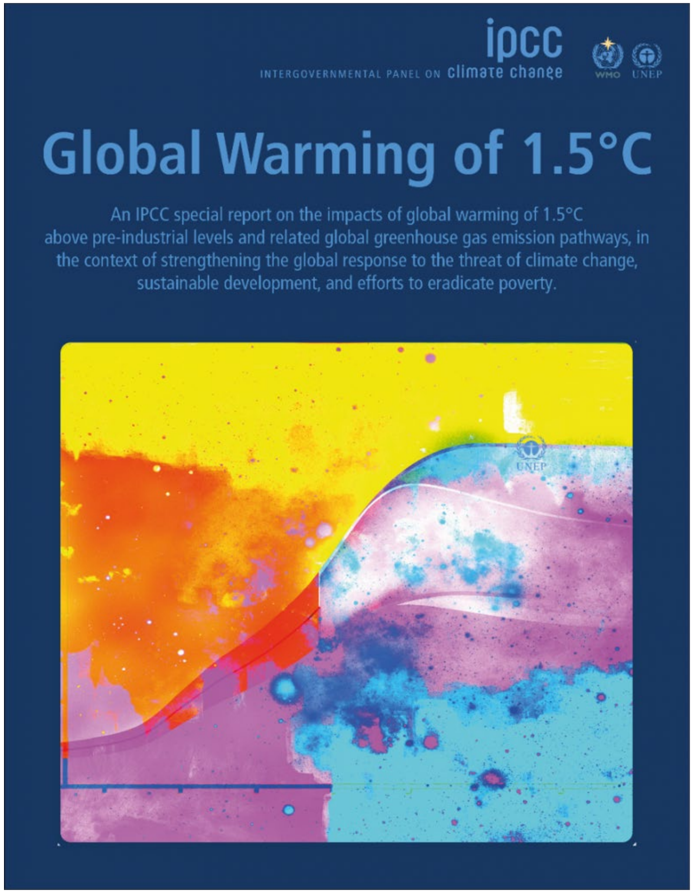
Knutti et al. (2016)

Mitigation scenario is very ambitious



…1.5°C target is extremely ambitious

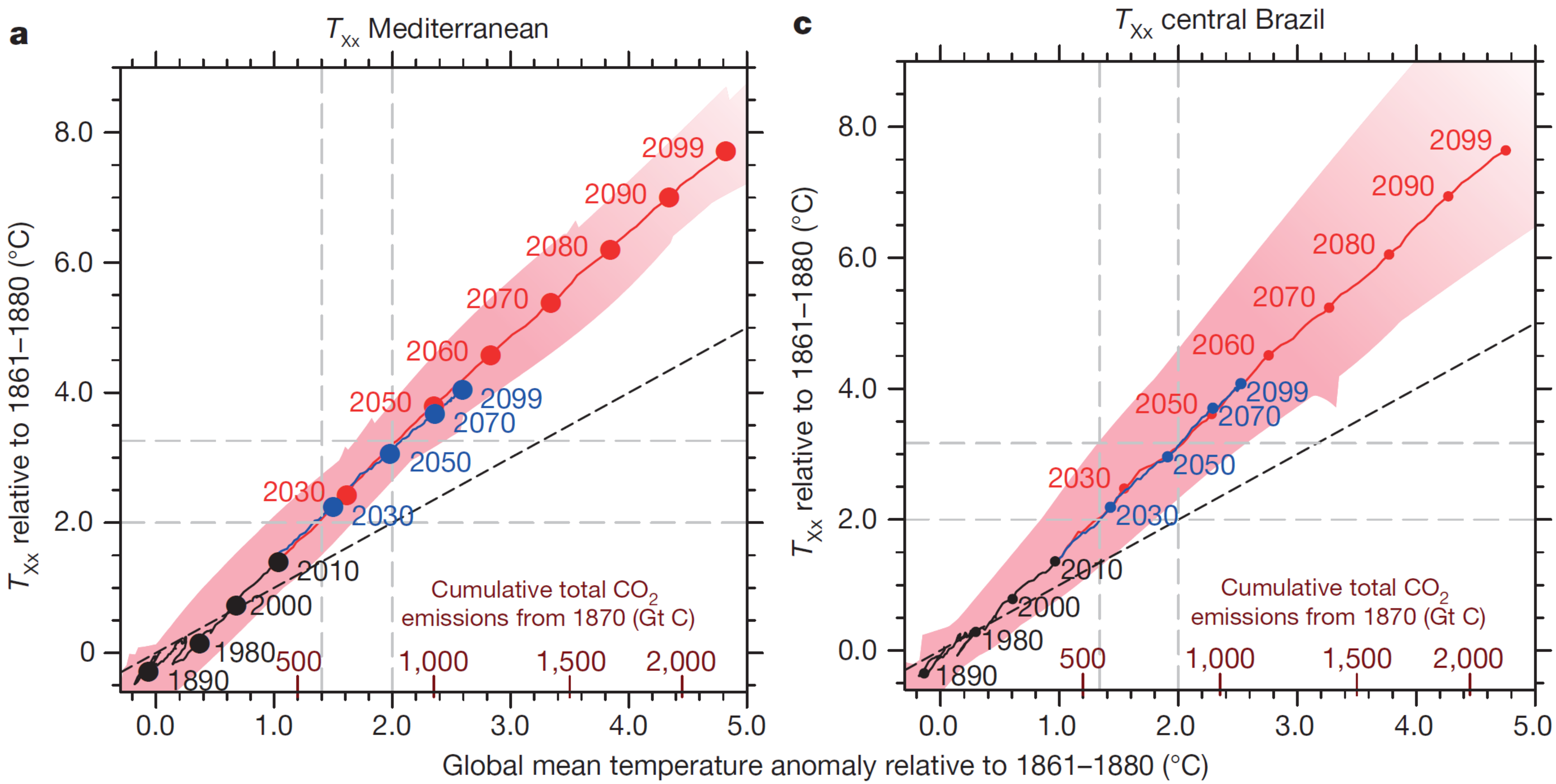




Scaling is mostly quite linear

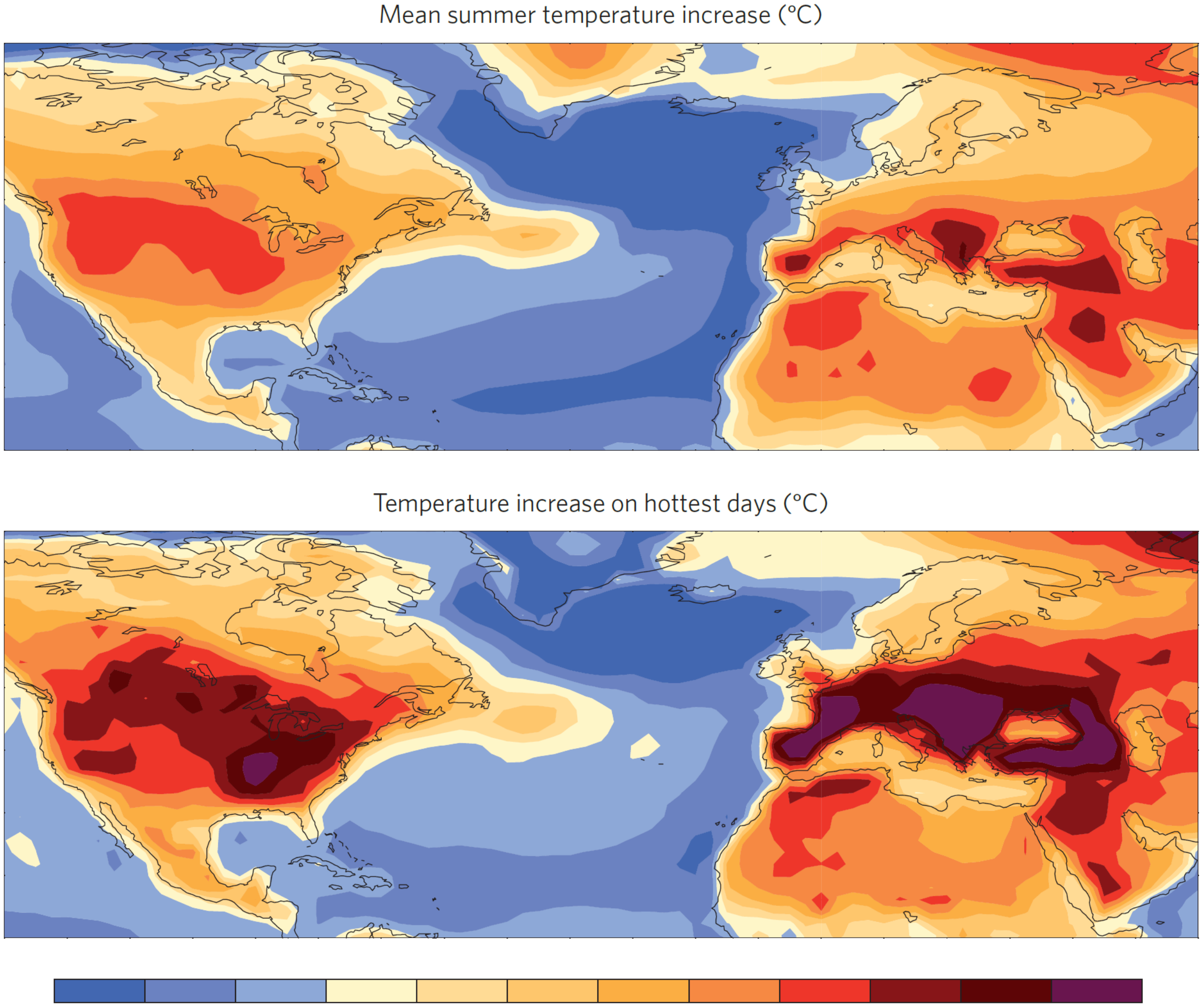
Annual maximum temperature (TXx)

Annual maximum temperature (TXx)



Seneviratne et al., 2016, *Nature*

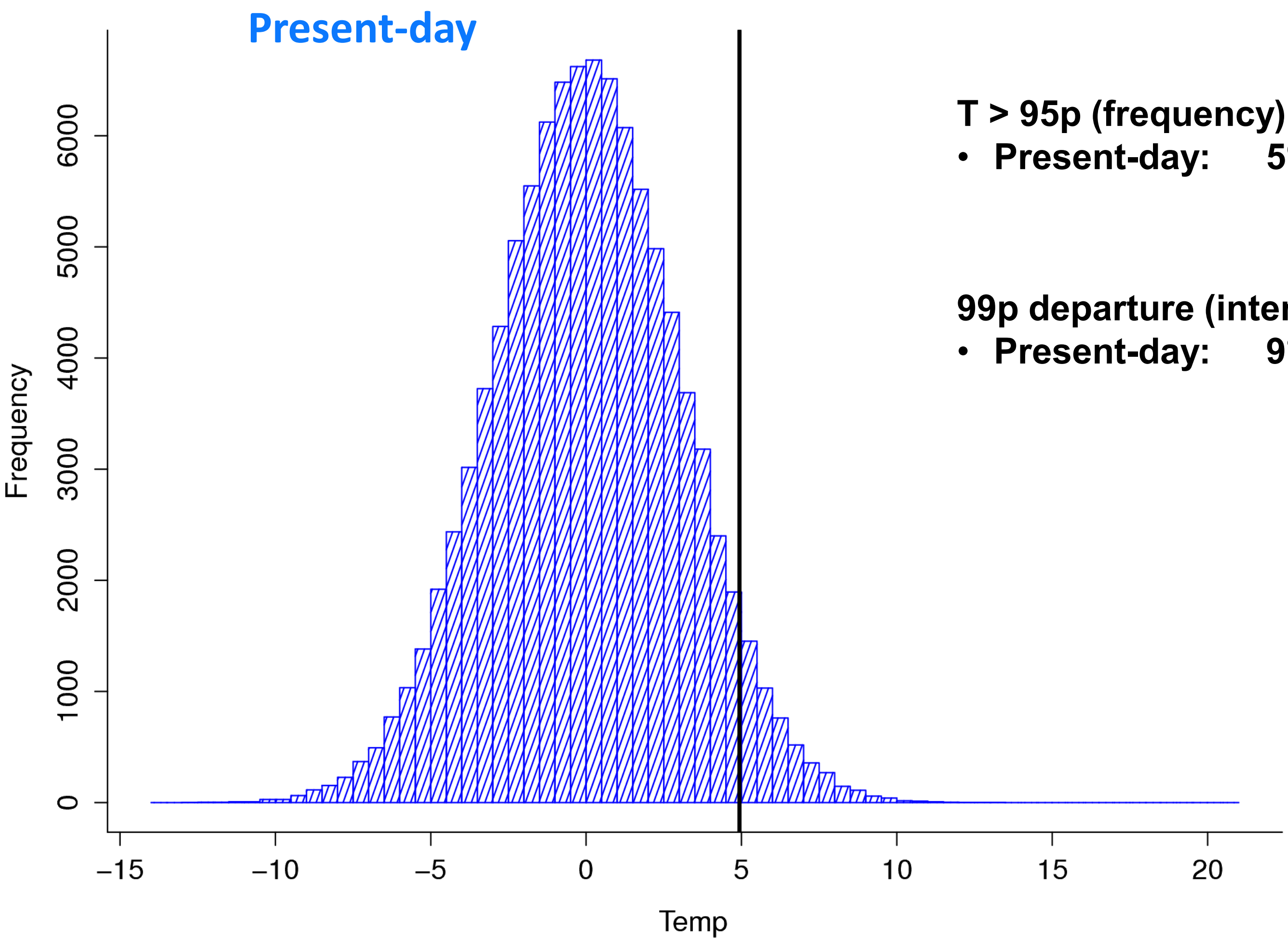
Intensity hotspot in mid-latitudes



Fischer 2014, *Nature Geoscience*

see also Fischer and Schär (2010) *Nature Geoscience*

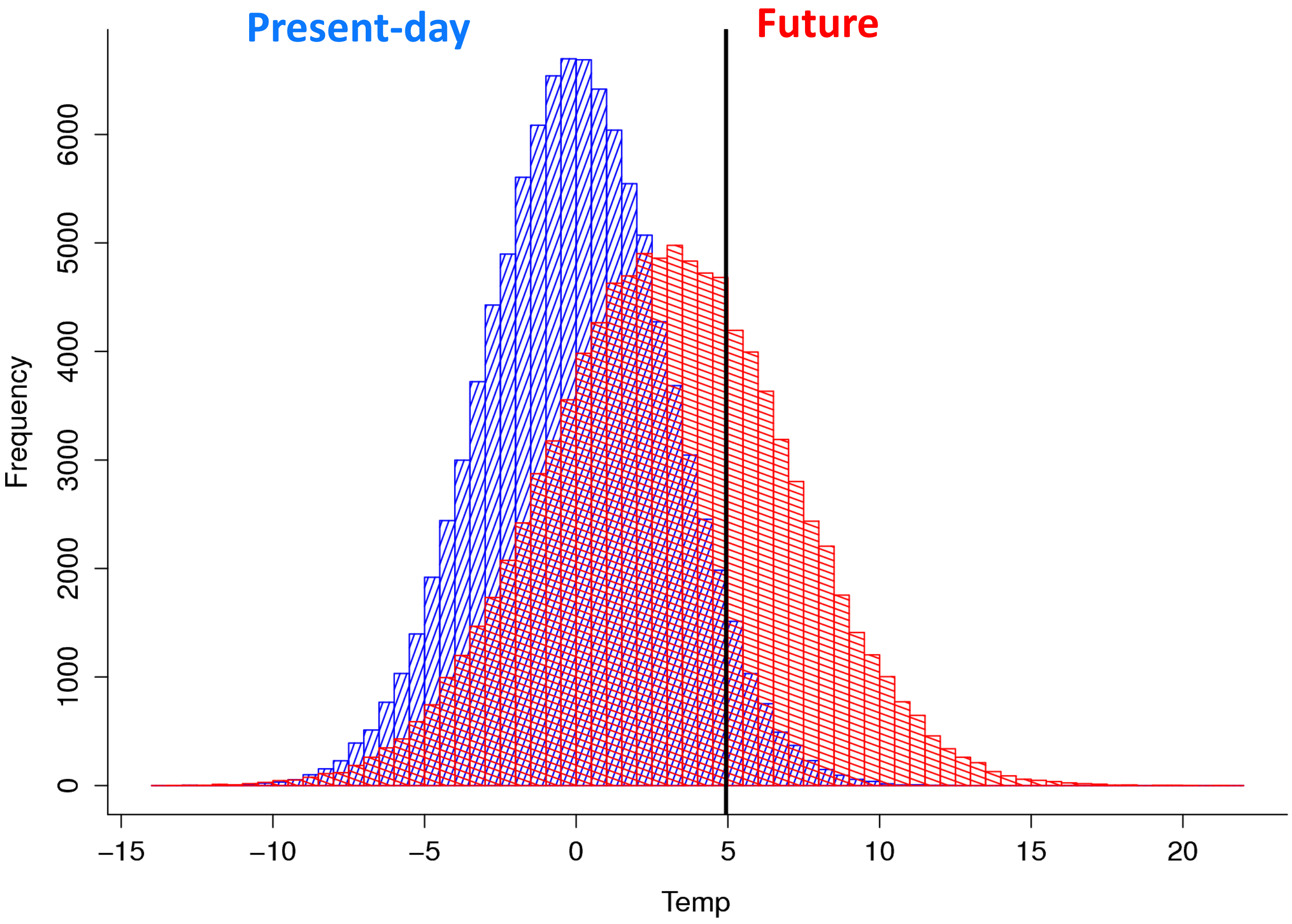
Mean and variability change?

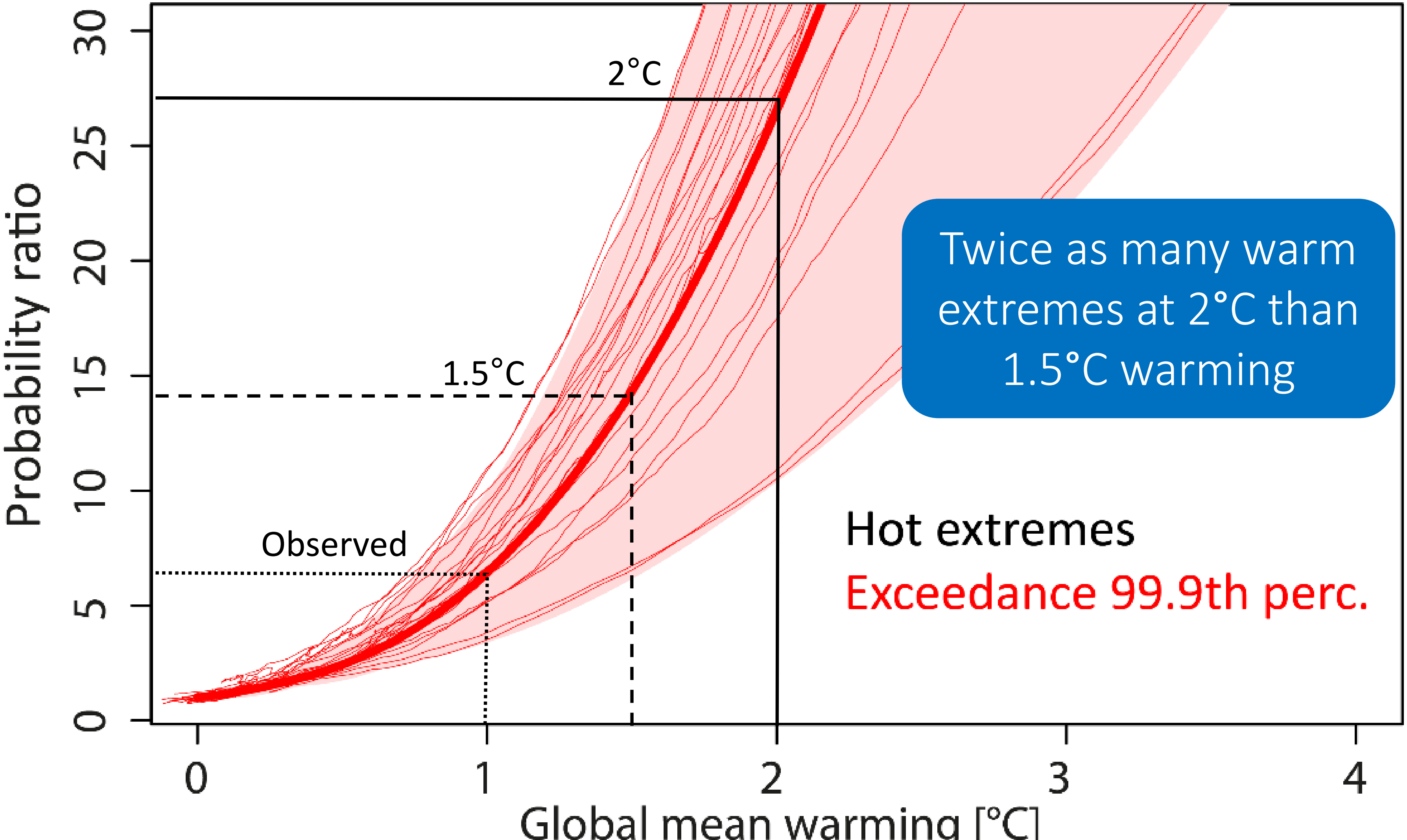


T > 95p (frequency)
- **Present-day: 5%**

99p departure (intensity/amplitude)
- **Present-day: 9°C**

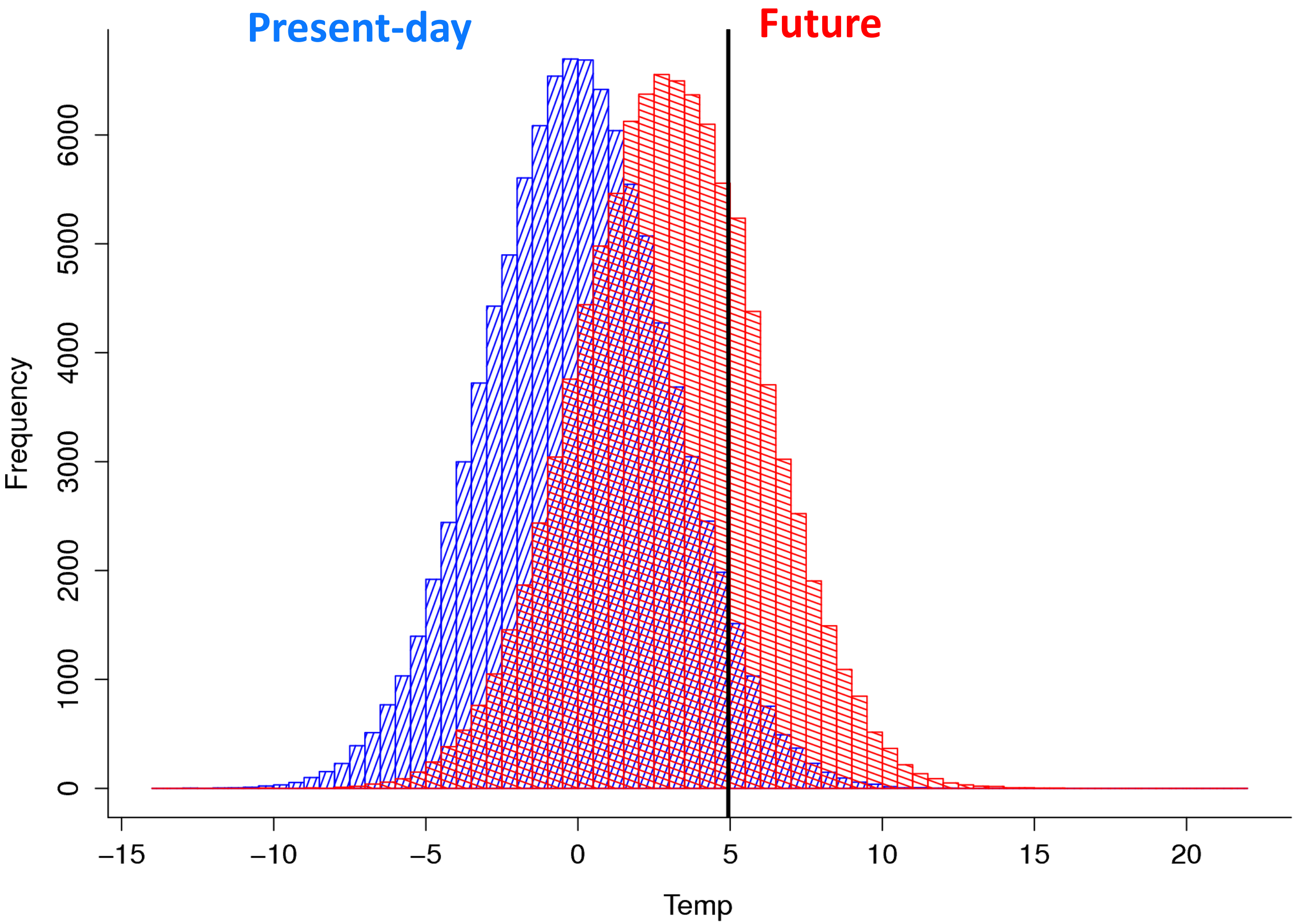
Role of variability changes





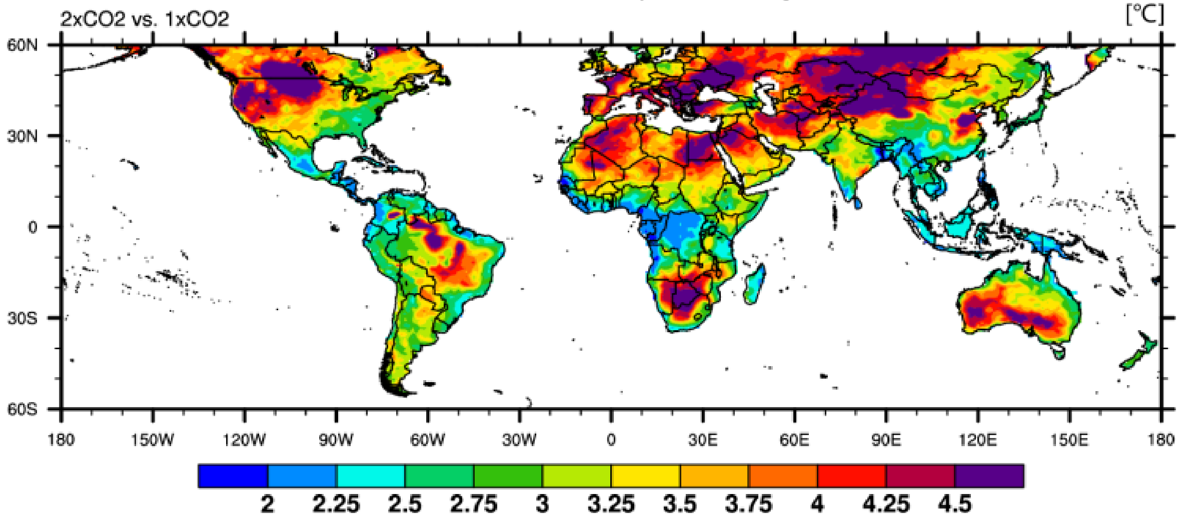
Fischer and Knutti 2015, *Nature CC*

Role of variability changes

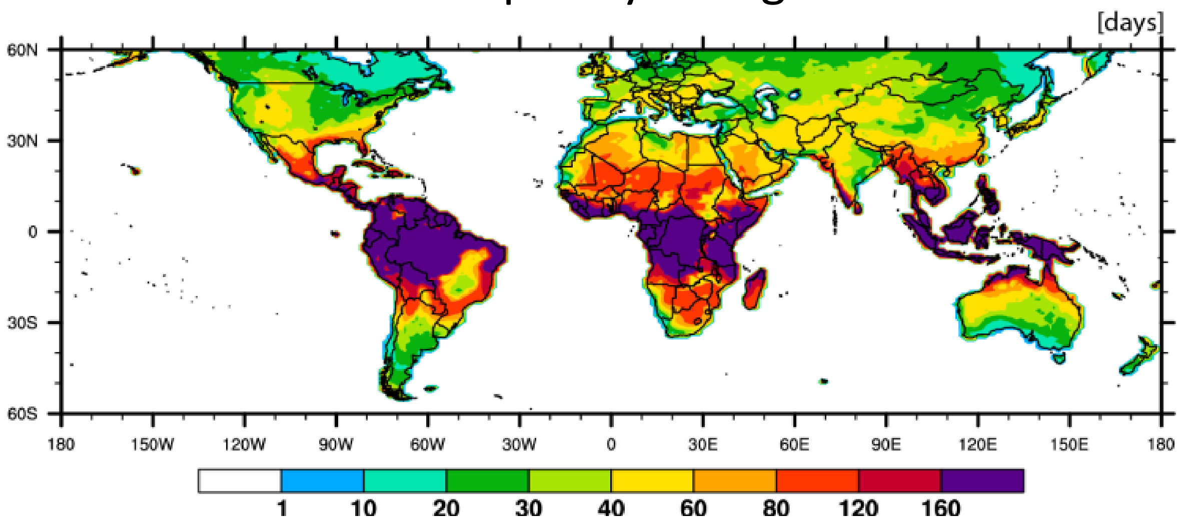


Frequency vs. intensity

(a) Intensity change



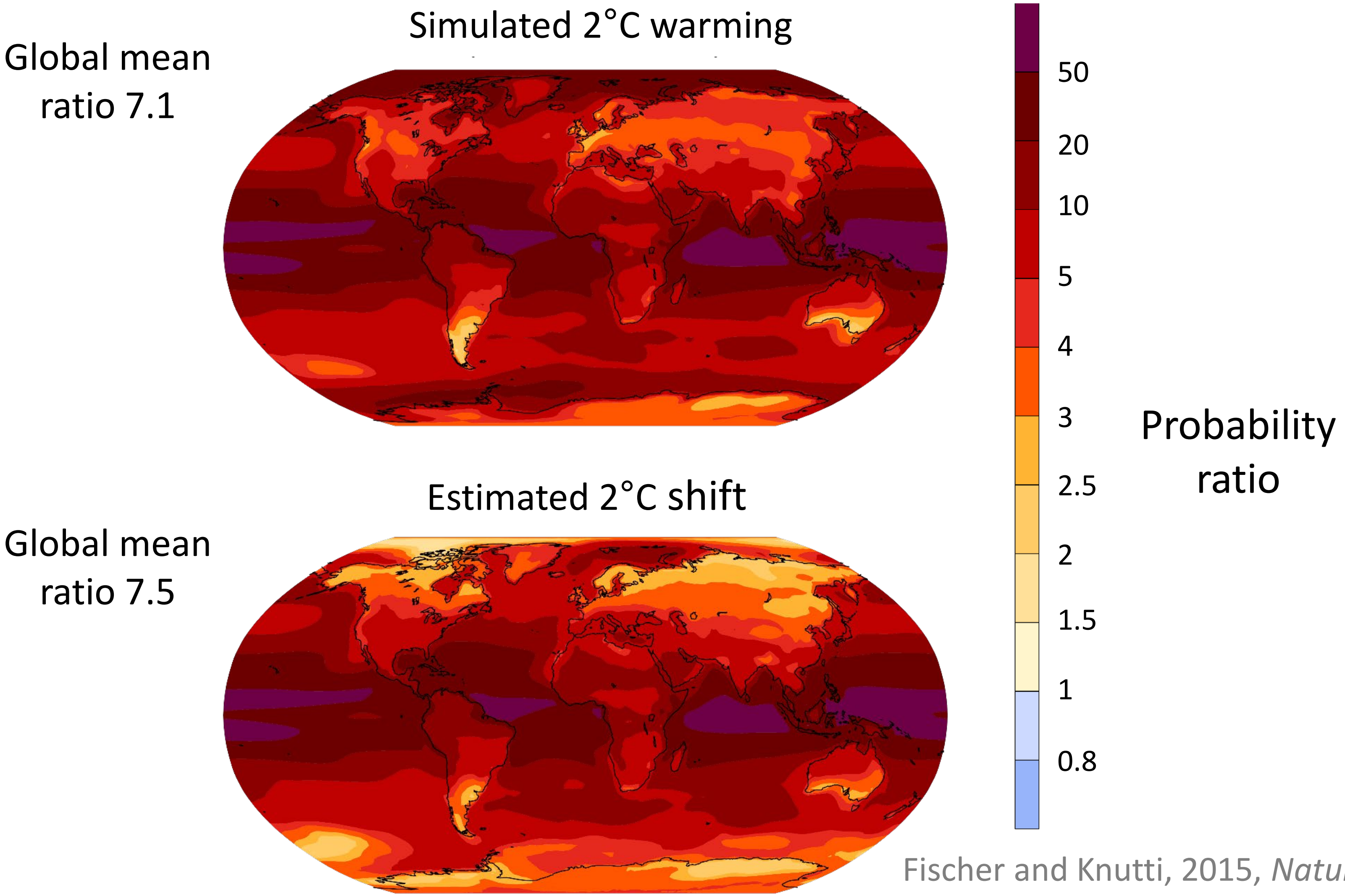
(c) Frequency change



Changes in drivers?

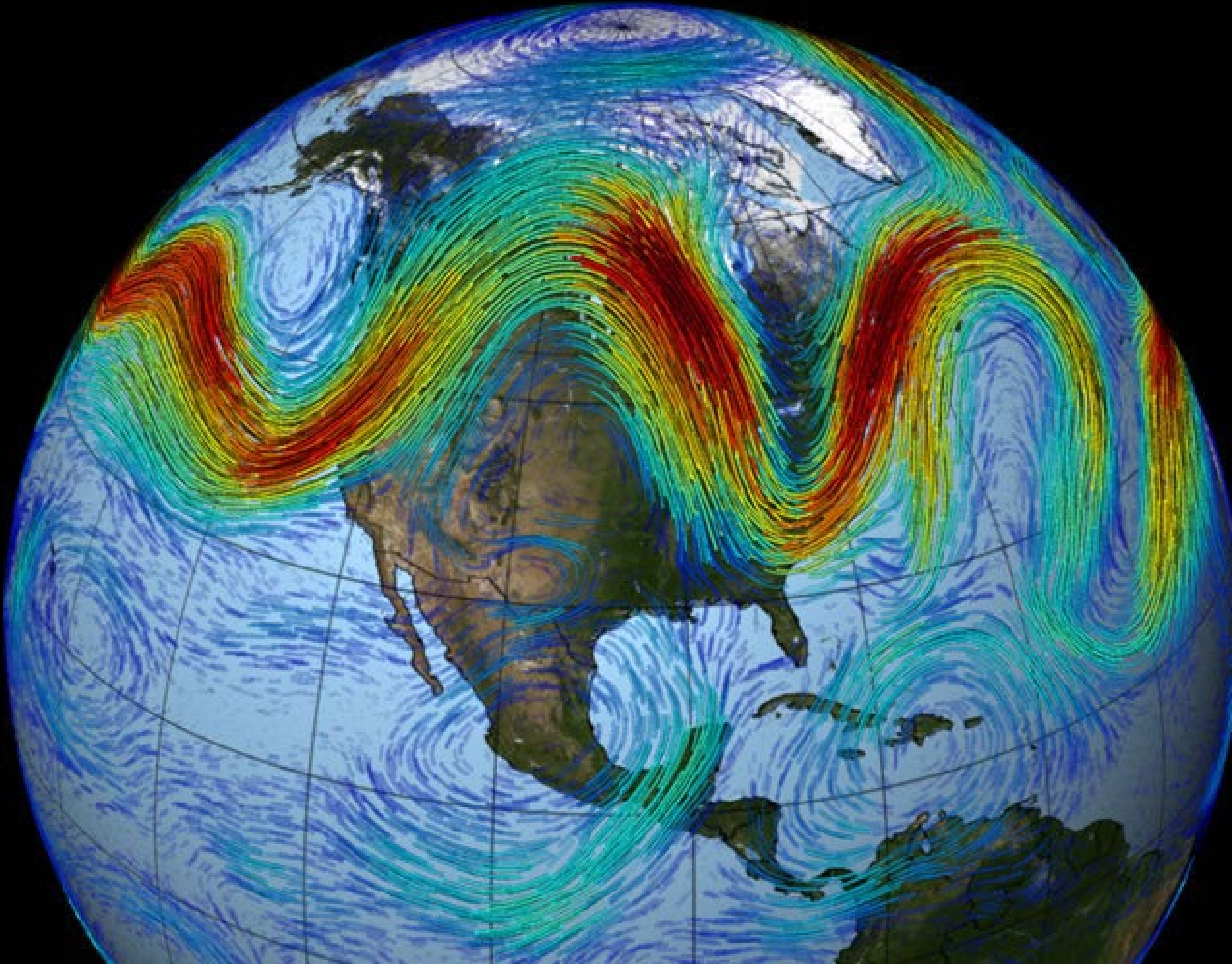
Warming explains most changes in hot days

Change in number of hot days at 2°C global warming



Fischer and Knutti, 2015, *Nature CC*

Consistent with Cattiaux et al. (2016), Fischer and Schär (2010), Schaller et al. (2018)



GEOPHYSICAL RESEARCH LETTERS, VOL. 39, L06801, doi:10.1029/2012GL051000, 2012

Evidence linking Arctic amplification to extreme weather in mid-latitudes

Jennifer A. Francis[1] and Stephen J. Vavrus[2]

Received 17 January 2012; revised 20 February 2012; accepted 21 February 2012; published 17 March 2012.

[1] Arctic amplification (AA) – the observed enhanced warming in high northern latitudes relative to the northern hemisphere – is evident in lower-tropospheric temperatures and in 1000-to-500 hPa thicknesses. Daily fields of 500 hPa heights from the National Centers for Environmental Prediction Reanalysis are analyzed over N. America and the N. Atlantic to assess changes in north-south (Rossby) wave characteristics associated with AA and the relaxation of poleward thickness gradients. Two effects are identified that

[3] Exploration of the atmospheric response to Arctic change has been an active area of research during the past decade. Both observational and modeling studies have identified a variety of large-scale changes in the atmospheric circulation associated with sea-ice loss and earlier snow melt, which in turn affect precipitation, seasonal temperatures, storm tracks, and surface winds in mid-latitudes [e.g., *Budikova*, 2009; *Honda et al.*, 2009; *Francis et al.*, 2009; *Overland and Wang*, 2010; *Petoukhov and Semenov*, 2010;

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 4734–4739, doi:10.1002/grl.50880, 2013

Revisiting the evidence linking Arctic amplification to extreme weather in midlatitudes

Elizabeth A. Barnes[1]

Received 17 July 2013; revised 8 August 2013; accepted 14 August 2013; published 4 September 2013.

[1] Previous studies have suggested that Arctic amplification has caused planetary-scale waves to elongate meridionally and slow down, resulting in more frequent blocking patterns and extreme weather. Here trends in the meridional extent of atmospheric waves over North America and the North Atlantic are investigated in three reanalyses, and it is demonstrated that previously reported posi- hereafter) suggest that atmospheric Rossby waves have elongated meridionally in recent decades due to Arctic amplification. They hypothesize that these elongated waves propagate more slowly and favor more extreme weather conditions. They speculate that as the earth continues to warm, Arctic amplification will increasingly influence the North Atlantic atmospheric circulation, potentially causing more extreme

PNAS

Quasiresonant amplification of planetary w and recent Northern Hemisphere weather

Vladimir Petoukhov[a,1], Stefan Rahmstorf[a], Stefan Petri[a], and Hans Joachim Schellnhuber[a,b,1]

[a]Potsdam Institute for Climate Impact Research, D-14412 Potsdam, Germany; and [b]Santa Fe Institute, Santa Fe, NM 87501

Contributed by Hans Joachim Schellnhuber, January 16, 2013 (sent for review June 15, 2012)

In recent years, the Northern Hemisphere has suffered several devastating regional summer weather extremes, such as the European heat wav in Pakista Here, we sistent lo atmosphe Those pat

I. Quasiresonance Hypothesis

Generally the large-scale midlatitude atmospheric circulation is

LETT

edite nifer Sills

Global Wa g and Winter Weather

IN MID-JANUAR BE OF THE POLAR VORTEX SAGGED SOUTHWARD OVER THE CENTRAL and eastern Un ates. All-time low temperature records for the calendar date were set at O'Hare Airport in Chicago [–16°F (–27°C), 6 January], at Central Park in New York [4°F (–15.6°C), 7 Ja and at many other stations (*1*). Since that event, several substantial snow storms have bla the East Coast. Some have been touting such stretches of extreme cold as evidence tha warming is a hoax, while others have been citing them as evidence that global warming is causing a "global weirding" of the weather. In our view, it is neither.

temperate latitudes. It's an interesting idea, but alternative observational analyses and simulations with climate models have not confirmed the hypothesis, and we do not view the theoretical arguments underlying it as compelling [see (*3*–*6*)].

Other studies have suggested that the loss of Arctic sea ice may influence the atmospheric circulation in mid-latitudes during summer [e.g., (*7*)]. Sea-ice losses dur-

news & views

IMPACTS

Heated debate on cold weather

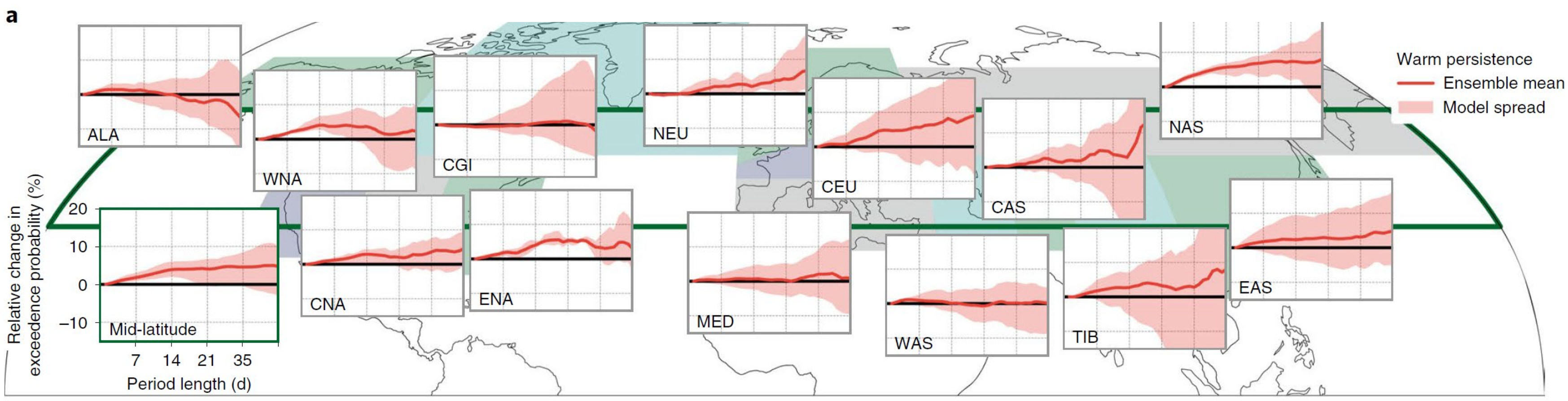
Erich M. Fischer and Reto Knutti

Arctic warming has reduced cold-season temperature variability in the northern mid- to high-latitudes. Thus, the coldest autumn and winter days have warmed more than the warmest days, contrary to recent speculations.

LETTERS
https://doi.org/10.1038/s41558-019-0555-0
nature climate change

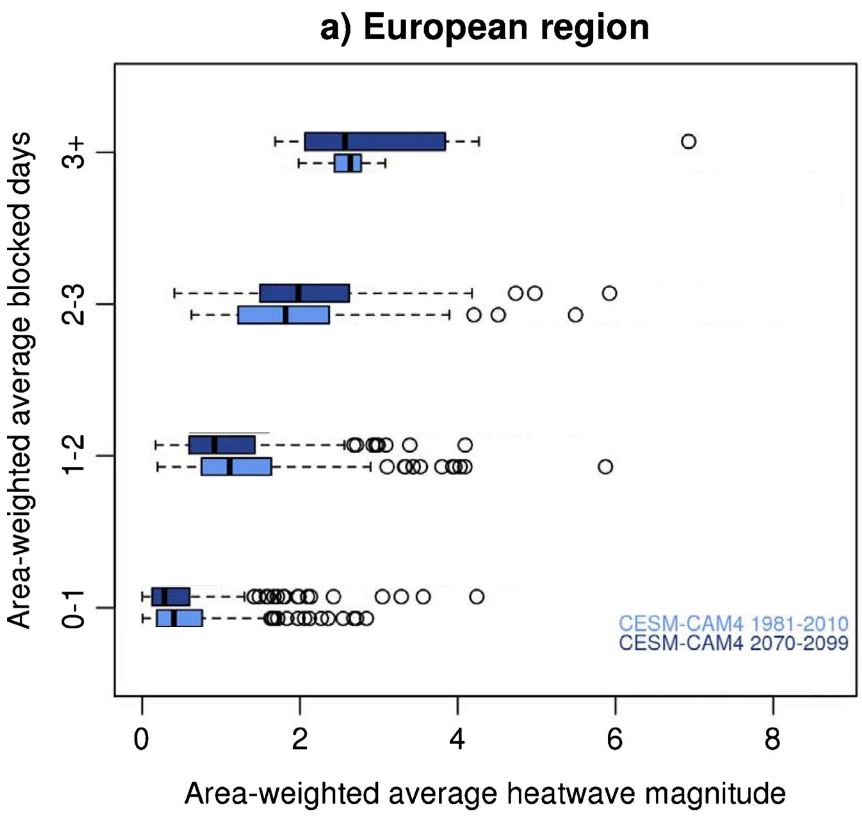
Summer weather becomes more persistent in a 2 °C world

Peter Pfleiderer[1,2,3*], Carl-Friedrich Schleussner[1,2,3], Kai Kornhuber[4,5,6] and Dim Coumou[2,7]



Pfleiderer et al. (2019), *Nature CC*

Same blocking – same relative HW

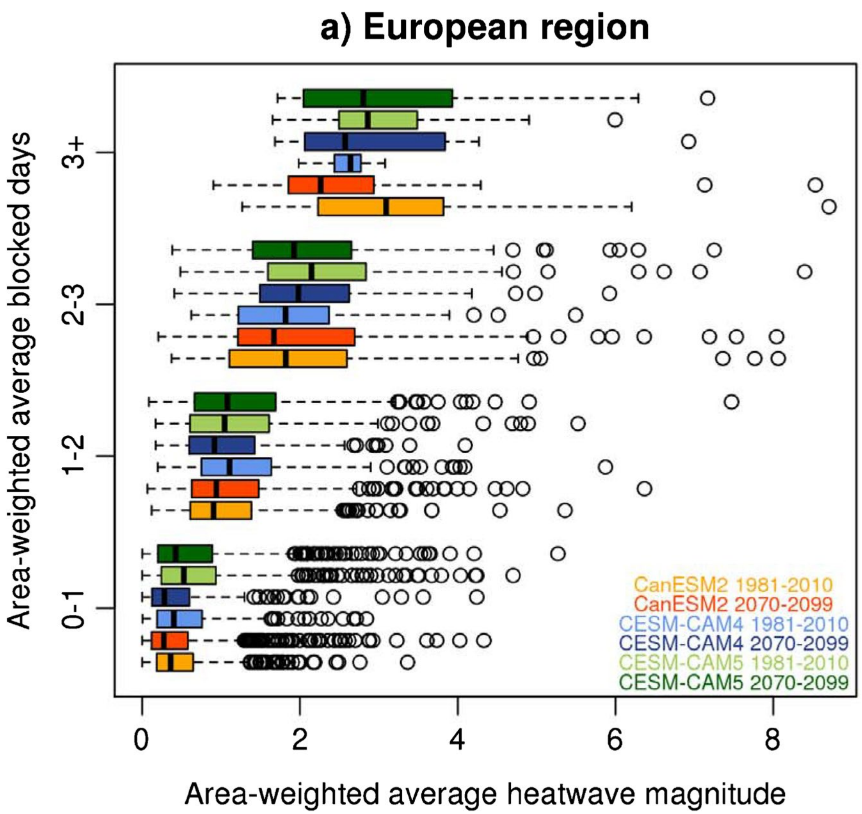


Future HWs are defined wrt future climatology.

Absolute HW magnitude increases strongly

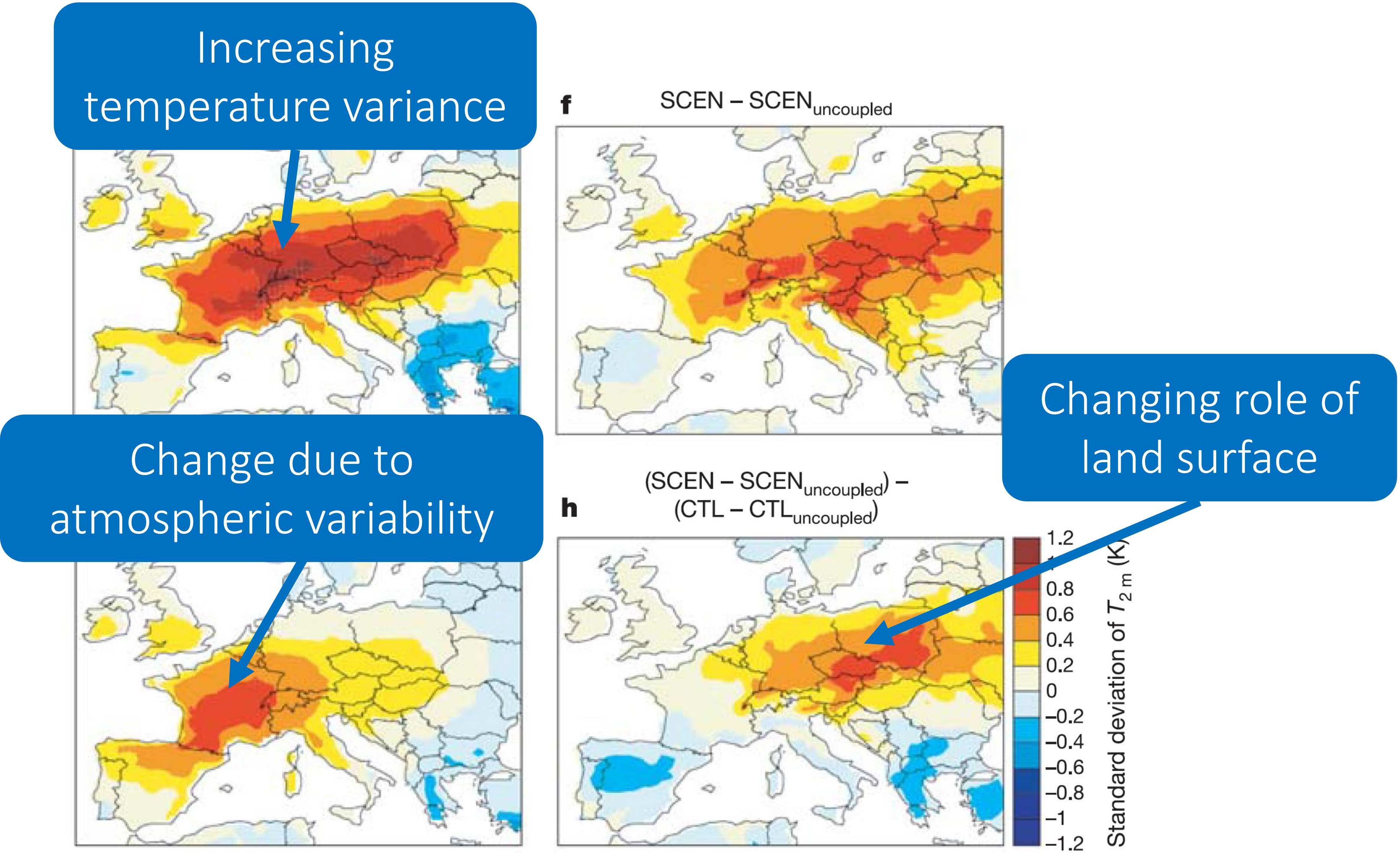
Schaller et al. (2018), *ERL*

No robust change in dynamical drivers



Schaller et al. (2018), *ERL*

Changing role of land-atmosphere interactions



Seneviratne et al. (2006), *Nature*

Conclusions

- Thermodynamic changes in temperature dominate projected temperature changes
- Changes in atmospheric dynamics remain a major uncertainty
- Changing land-atmosphere interactions may act as an amplification factor

Heat stress, urban heat island, marine heatwaves

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Institute for Atmospheric and Climate Science
ETH Zurich
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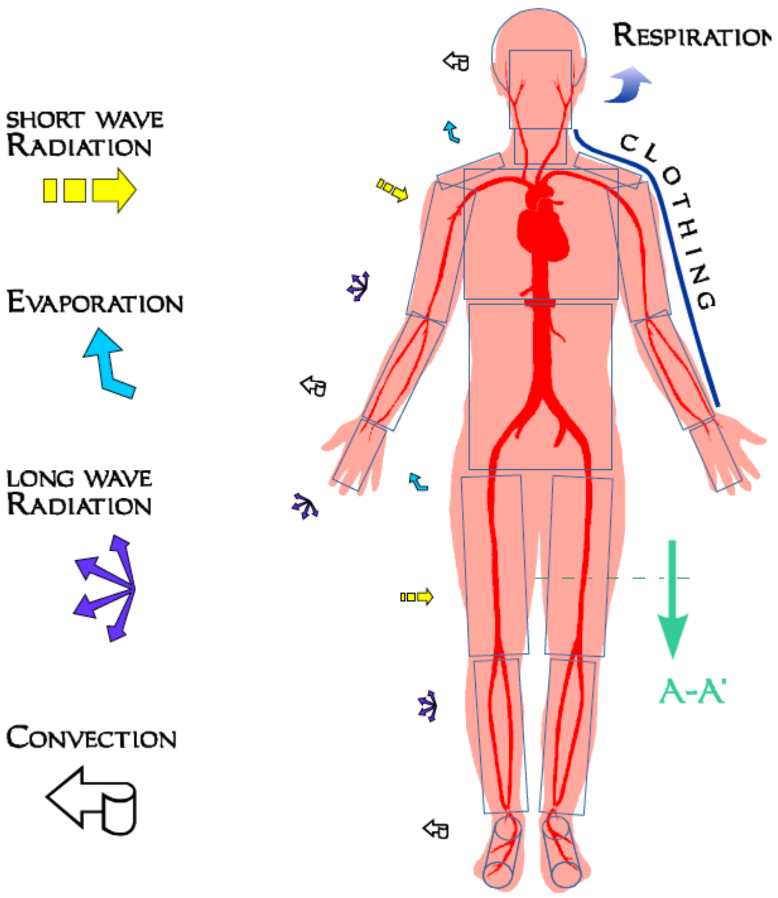
ETH zürich

Heat stress

Human thermal regulation



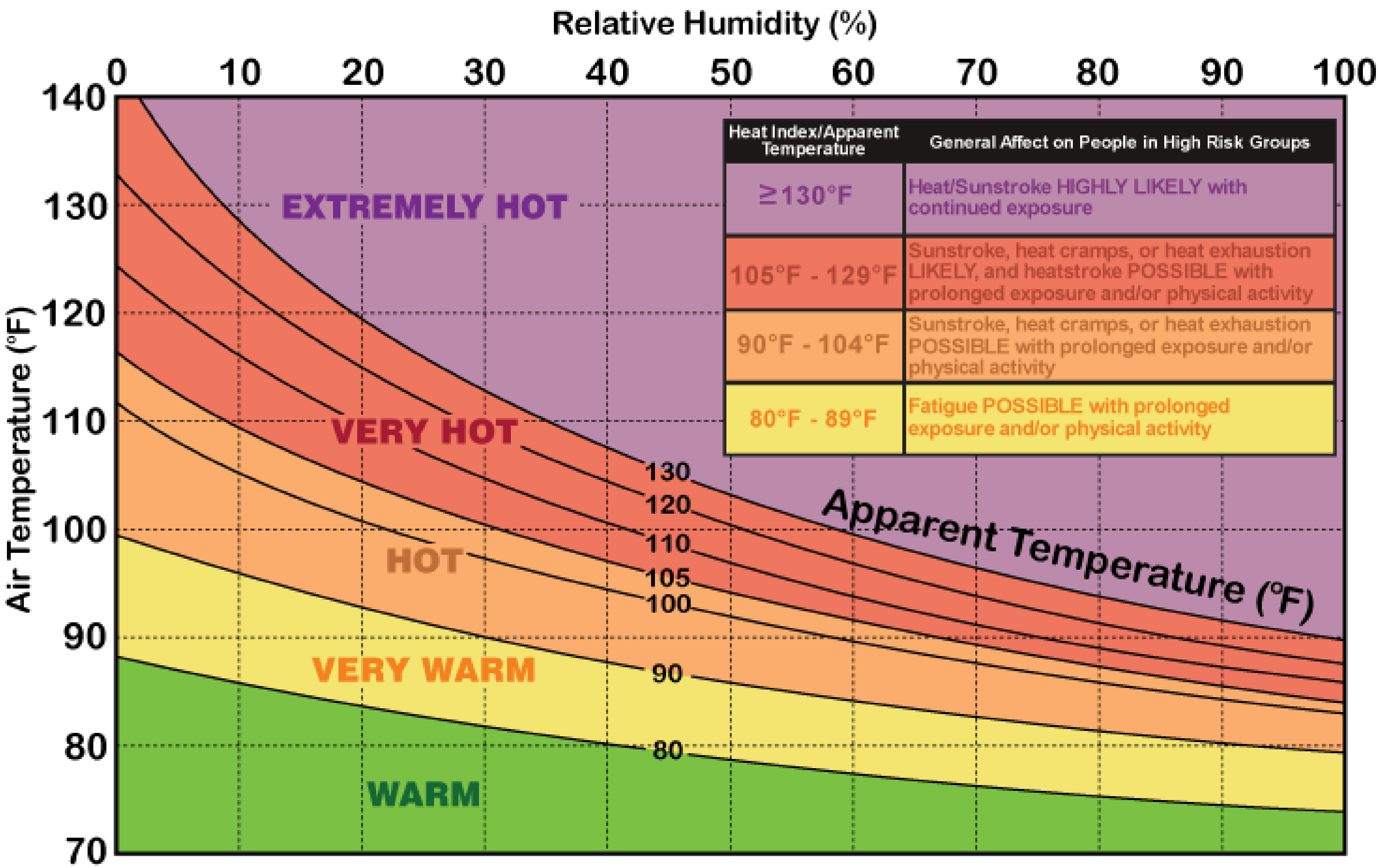
Fiala et al. (1999)

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)

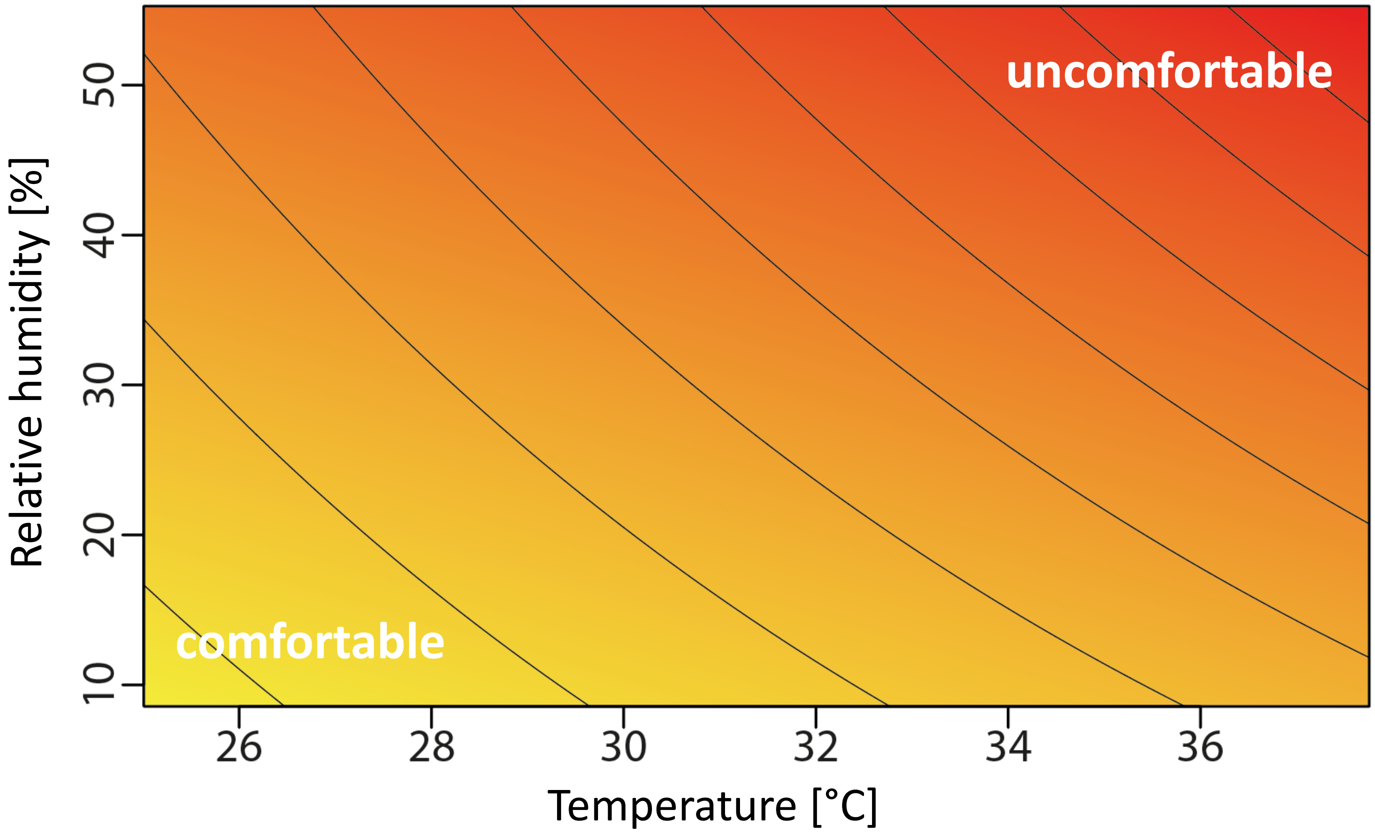
High ambient temperature and humidity reduces heat loss

US Heat index: Temperature and humidity



Simplified Wet Bulb Globe Temperature

Heat stress: function of temperature and humidity

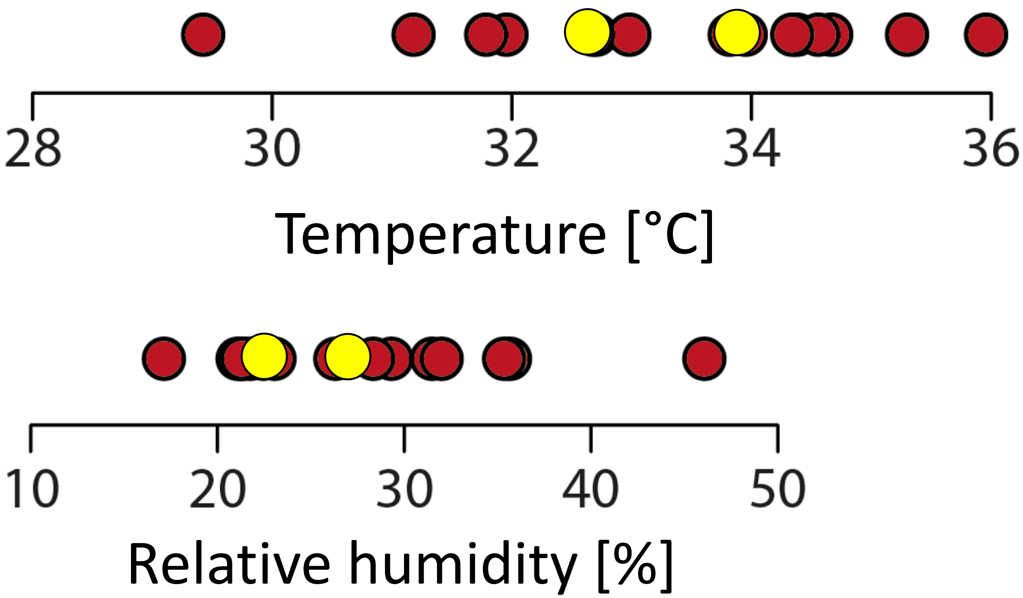


$$W = 0.567T + 0.393e + 3.94$$

Fischer and Knutti, 2013, *Nature CC*

Heat stress in Southern Australia

CMIP5 models (1% hottest days 1986-2005)

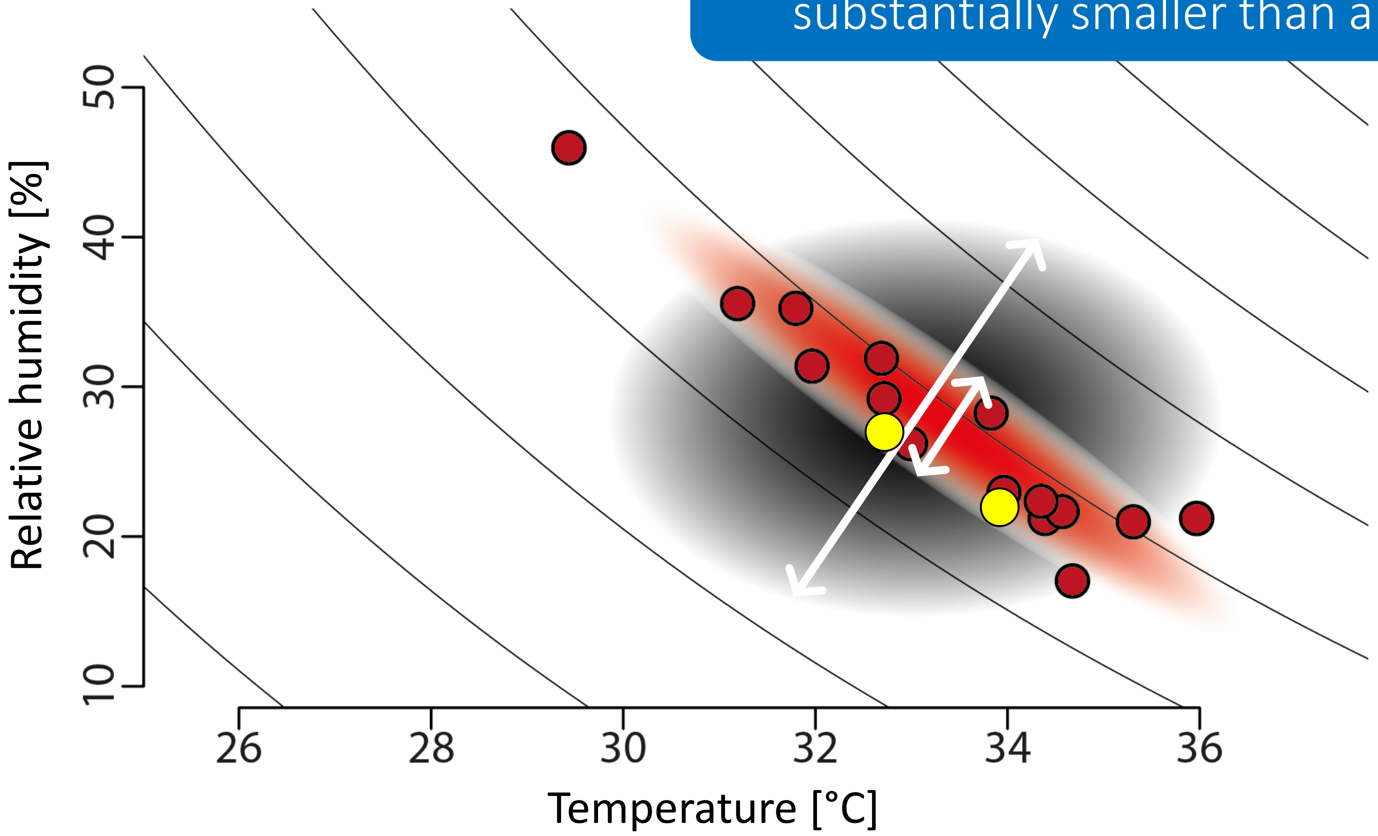


Major model spread and biases in T and RH

Fischer and Knutti, 2013, *Nature CC*

Heat stress in Southern Australia

Model biases in combined indicator are substantially smaller than anticipated

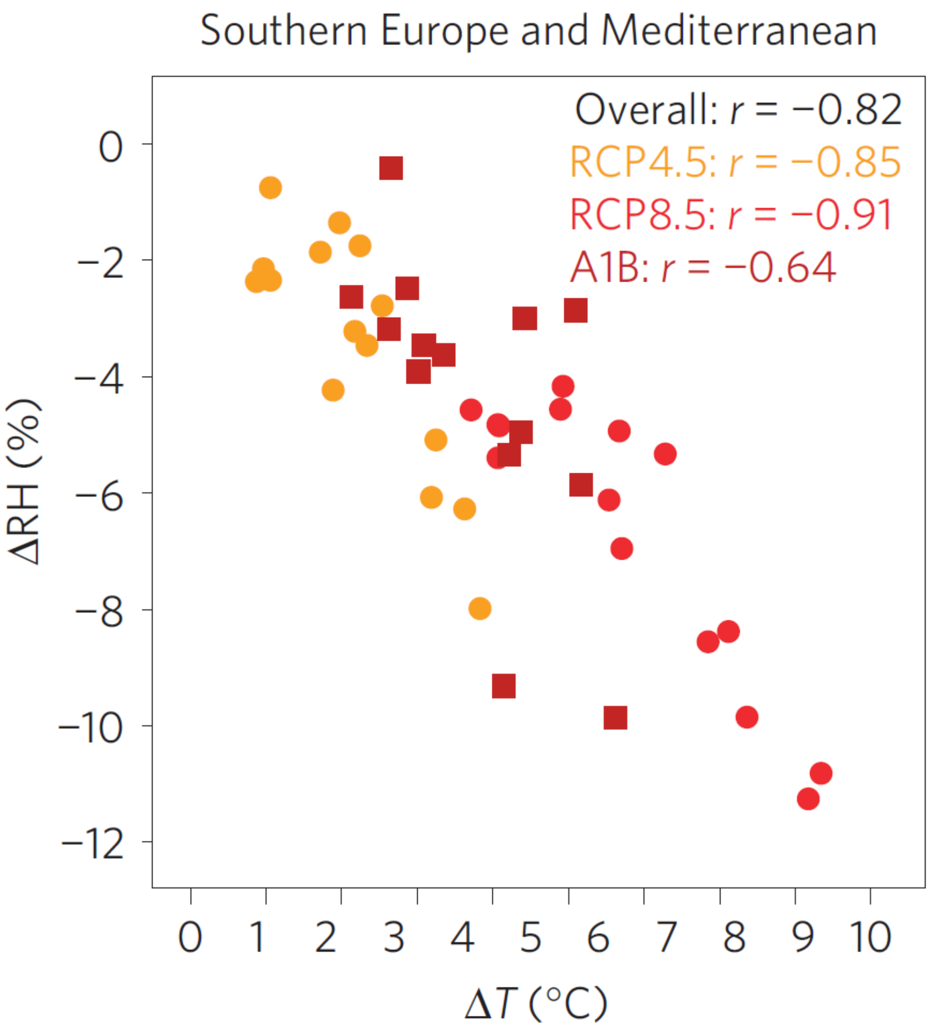


Fischer and Knutti, 2013, *Nature CC*

The hotter, the drier the air

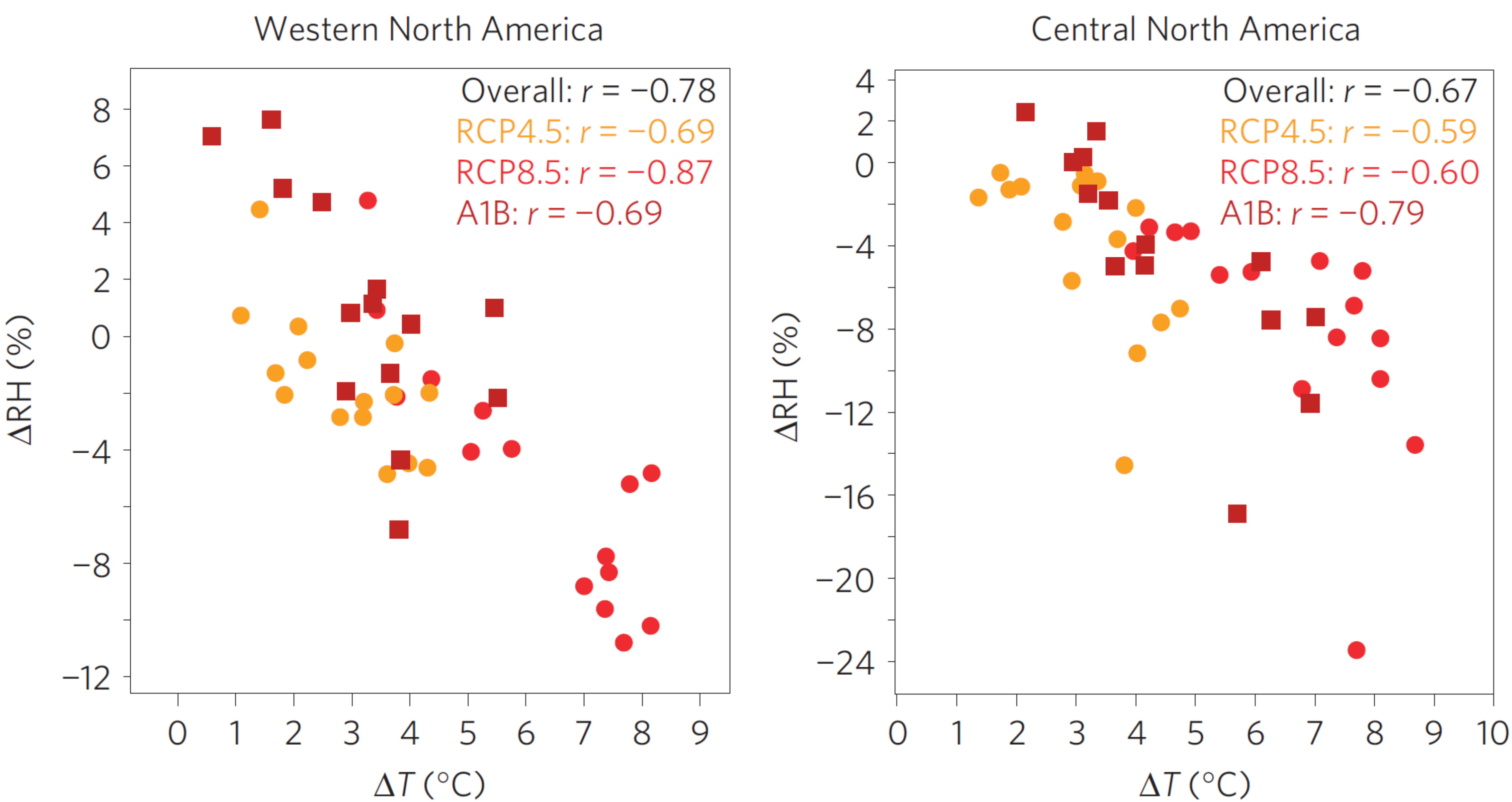
ΔT vs. ΔRH (1% hottest days)

2081-2100 wrt 1986-2005



Fischer and Knutti, 2013, *Nature CC*

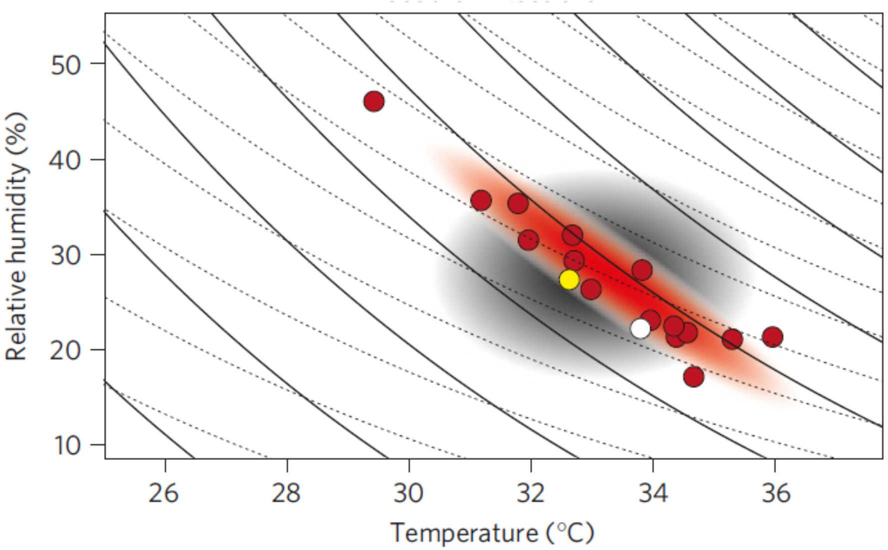
The hotter, the drier the air



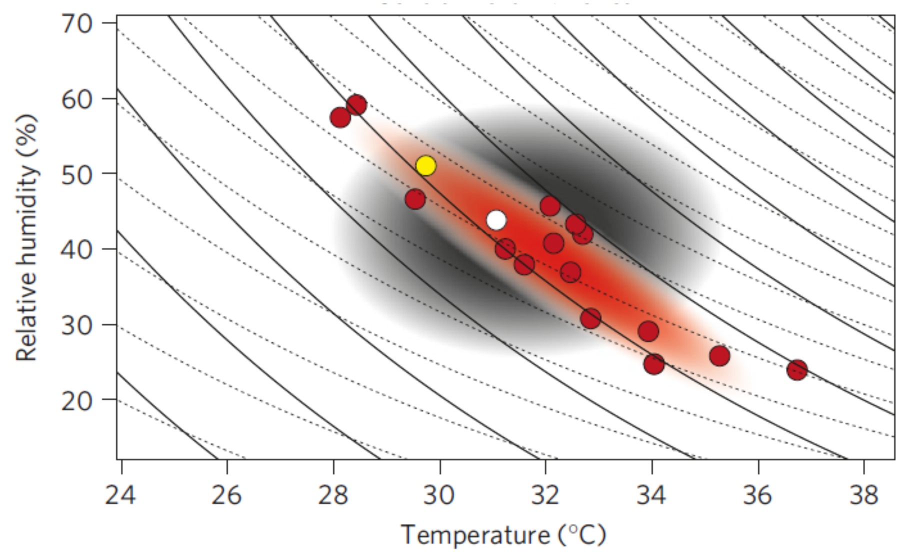
Fischer and Knutti, 2013, *Nature CC*

Consistent with first principles

Southern Australia



Central North America



— T_{eq} isolines

--- W isolines

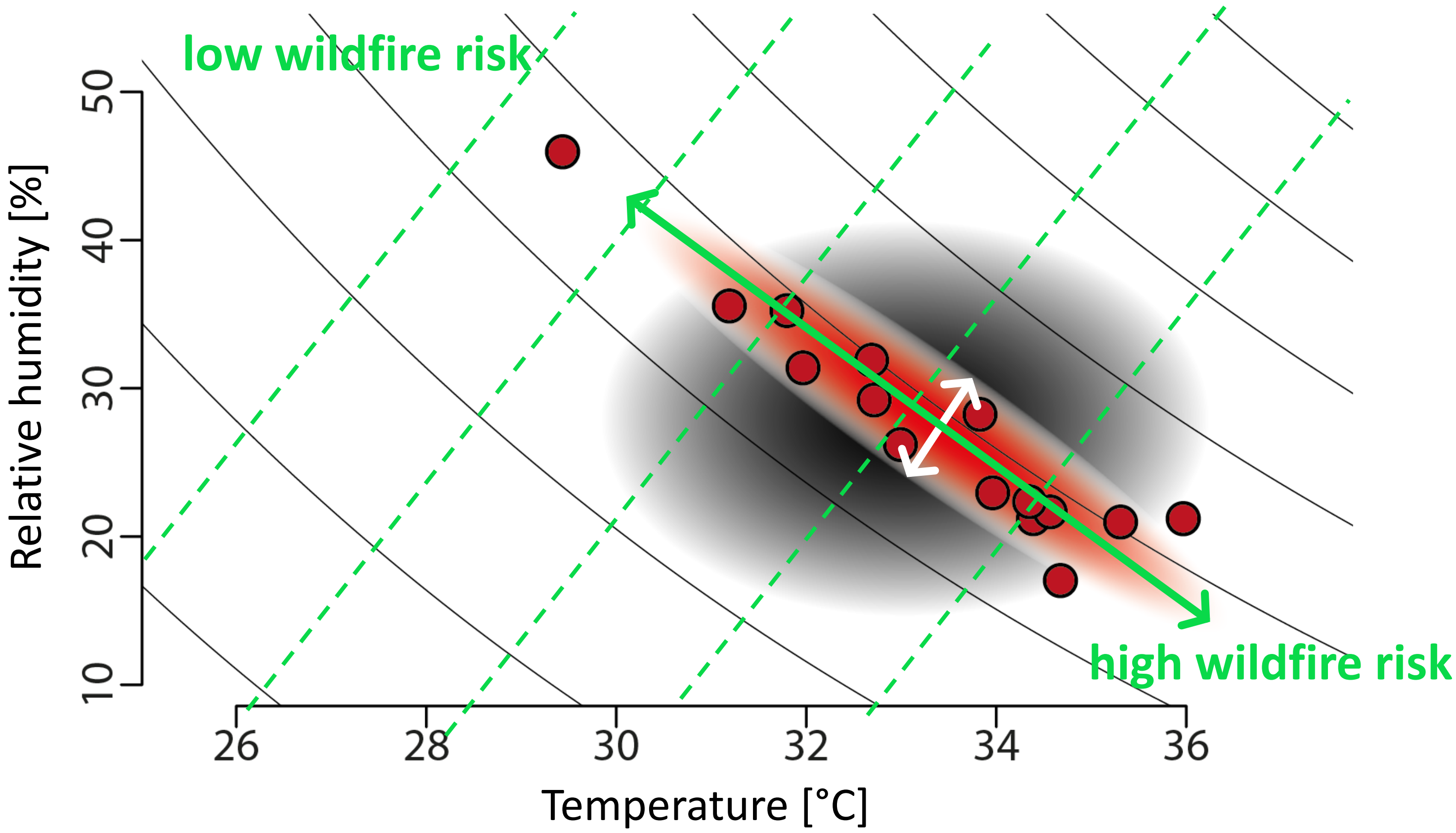
$$T_{\mathrm{eq}} = H/C_{\mathrm{p}} = T + (L_{\mathrm{v}}q)/C_{\mathrm{p}}$$

T_{eq}	equivalent temperature	L_v	latent heat of vaporization
T	2m air temperature	q	specific humidity

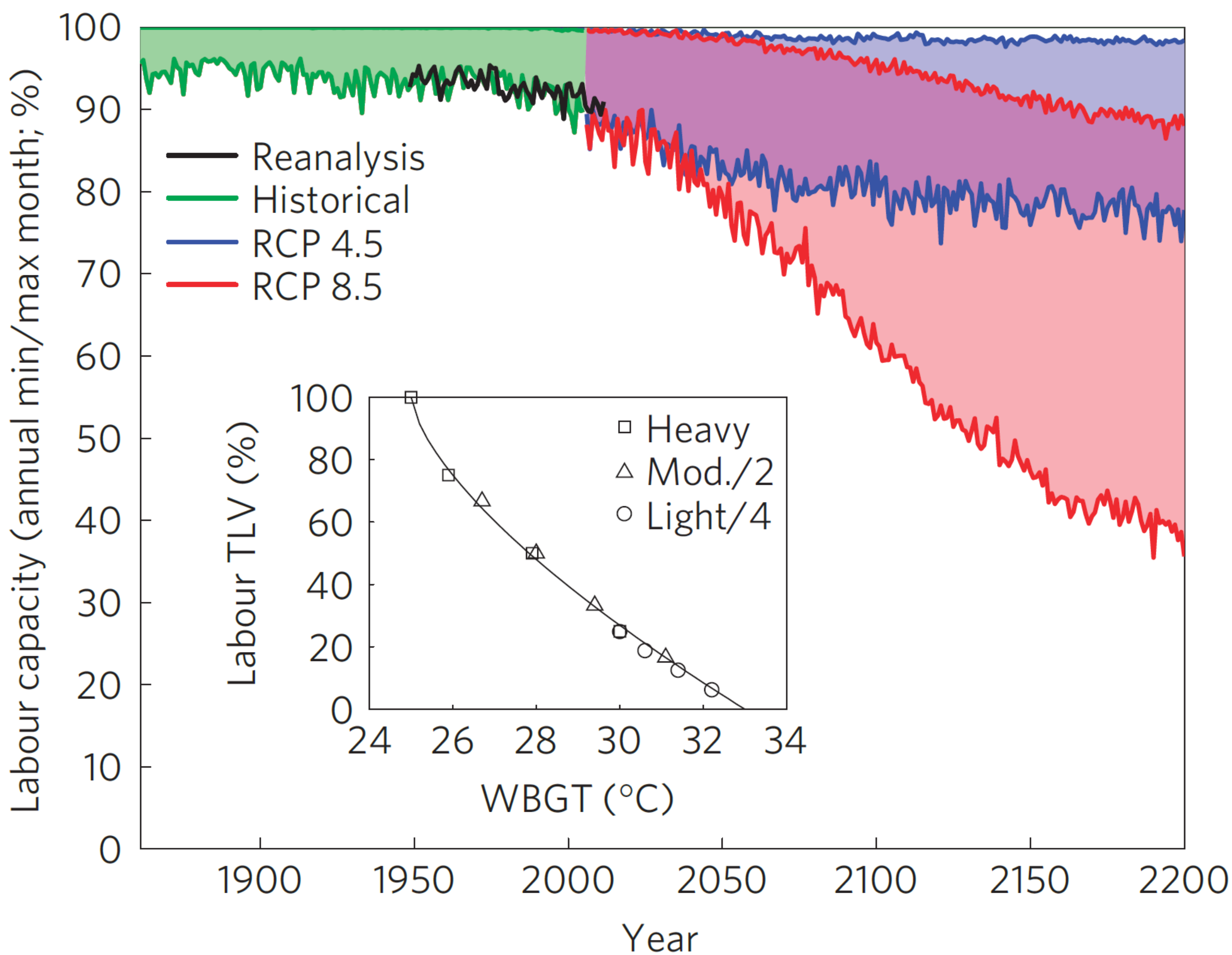
Fischer and Knutti, 2013, *Nature CC*

Projections of heat stress may be **more robust** than for temperature

Wildfire probability



Outdoor labor productive seriously declines

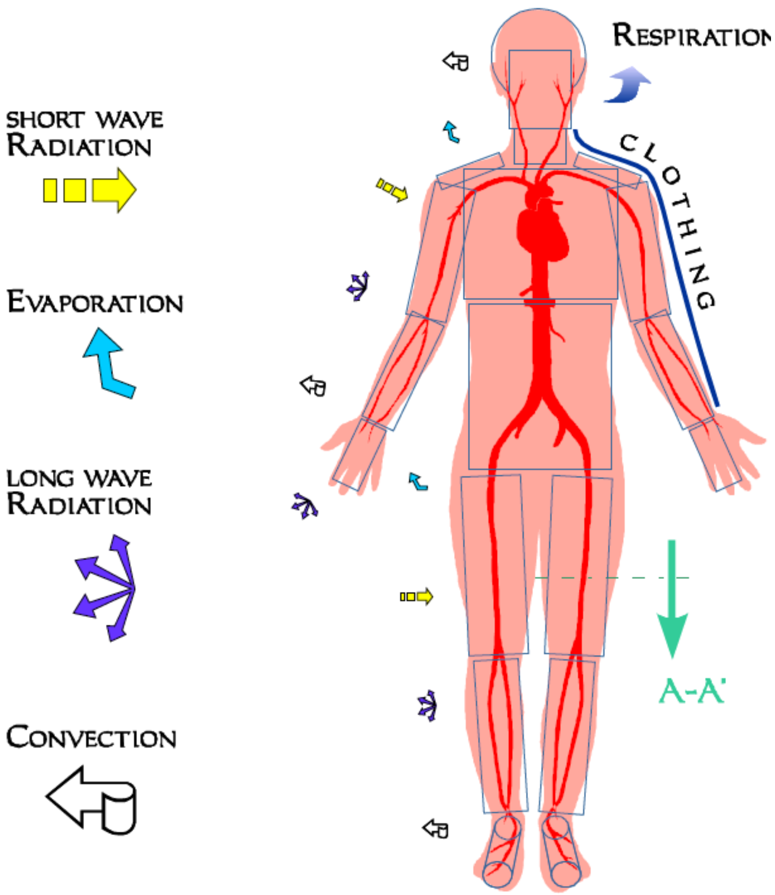


Dunne et al., 2013, *Nature CC*

An adaptability limit to climate change due to heat stress

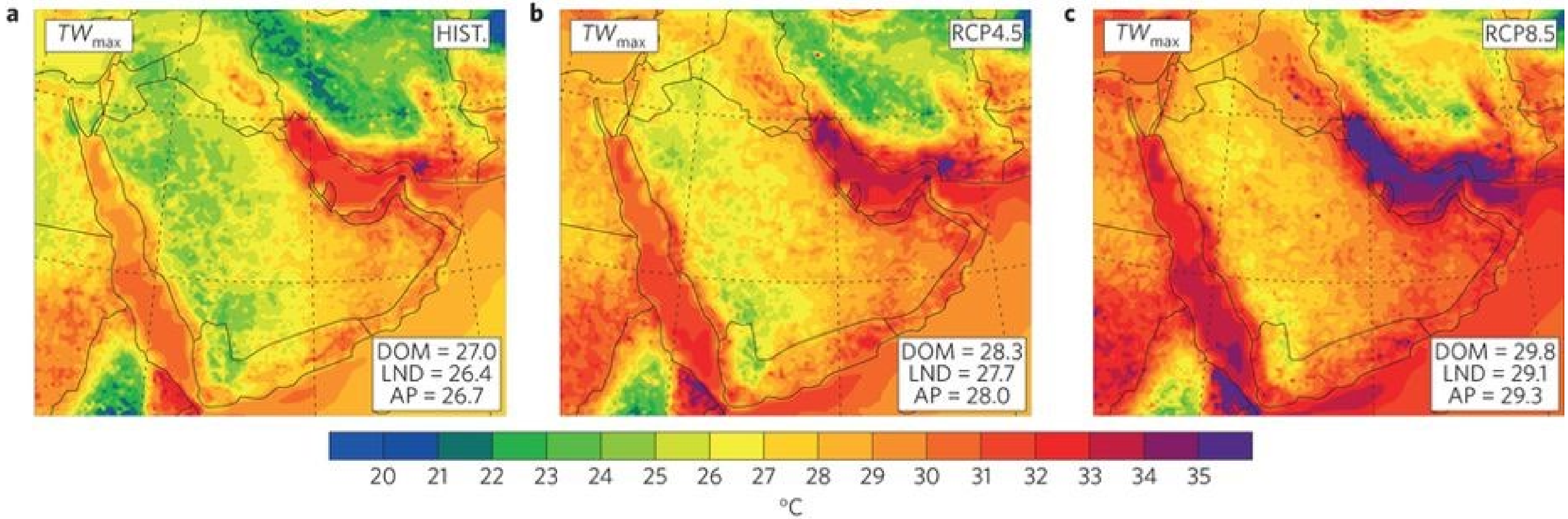
Steven C. Sherwood[a,1] and Matthew Huber[b]

[a]Climate Change Research Centre, University of New South Wales, Sydney, New South Wales 2052, Australia; and [b]Purdue Climate Change Research Center, Purdue University, West Lafayette, IN 47907



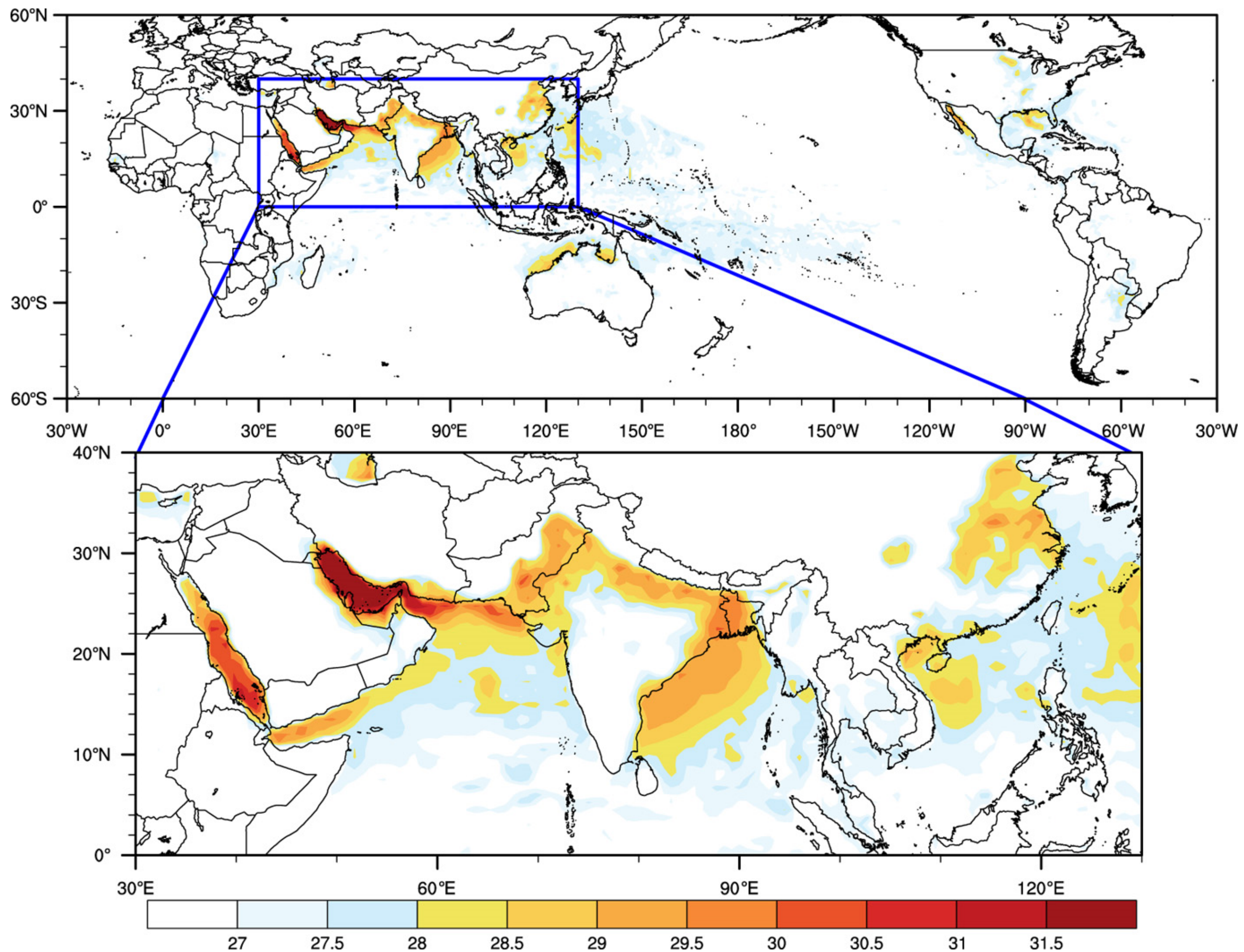
At 35°C and 100% relative humidity (Wet Bulb Temperature WBT = 35°C) the human body cannot loose heat through convection or evaporation (Sherwood and Huber 2010)

Deadly heat stress around Persian Gulf?



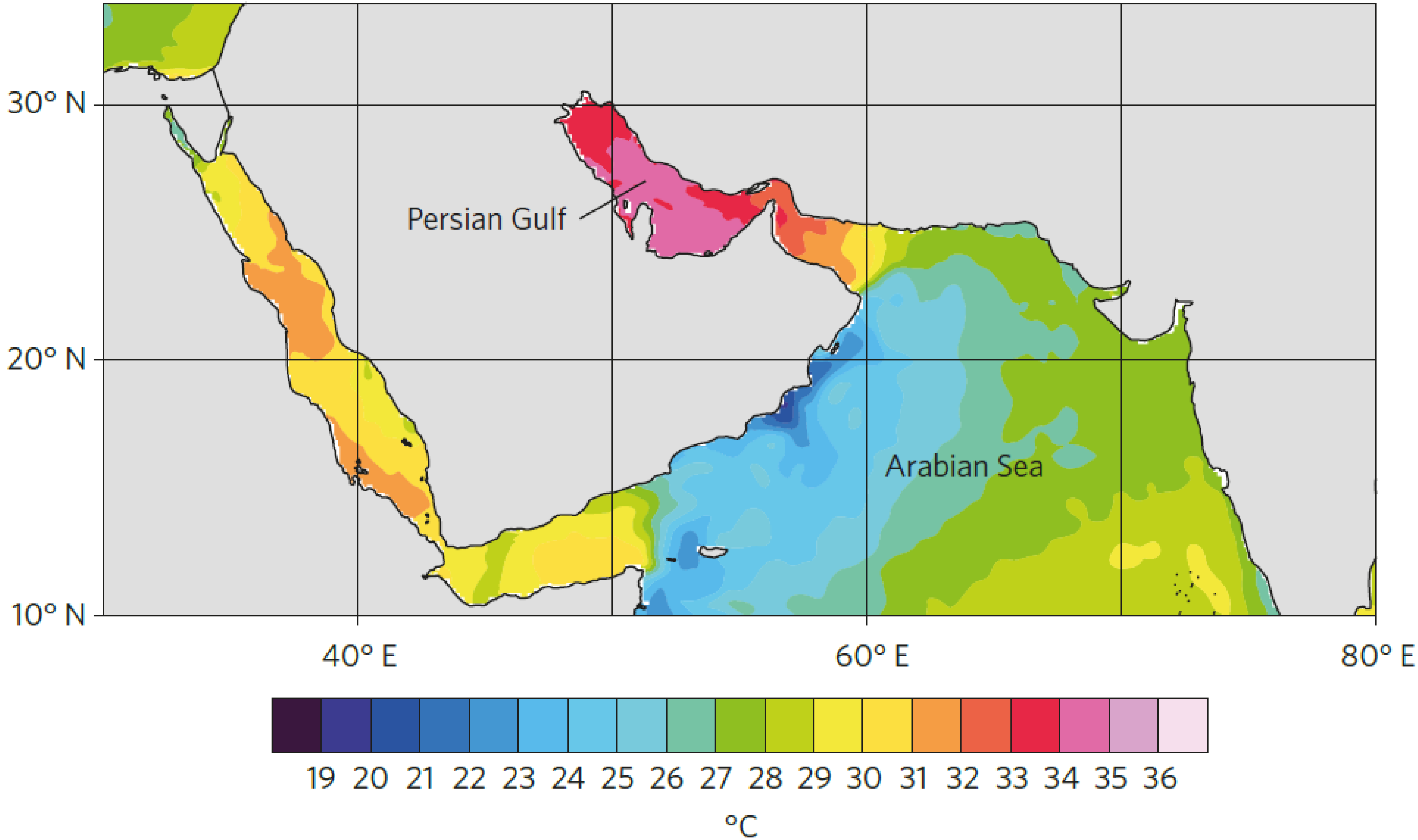
Pal and Eltahir, *Nature Climate Change* (2016)
Im et al. (2017) *Science Advances*

Highest heat stress values in 1979-2015



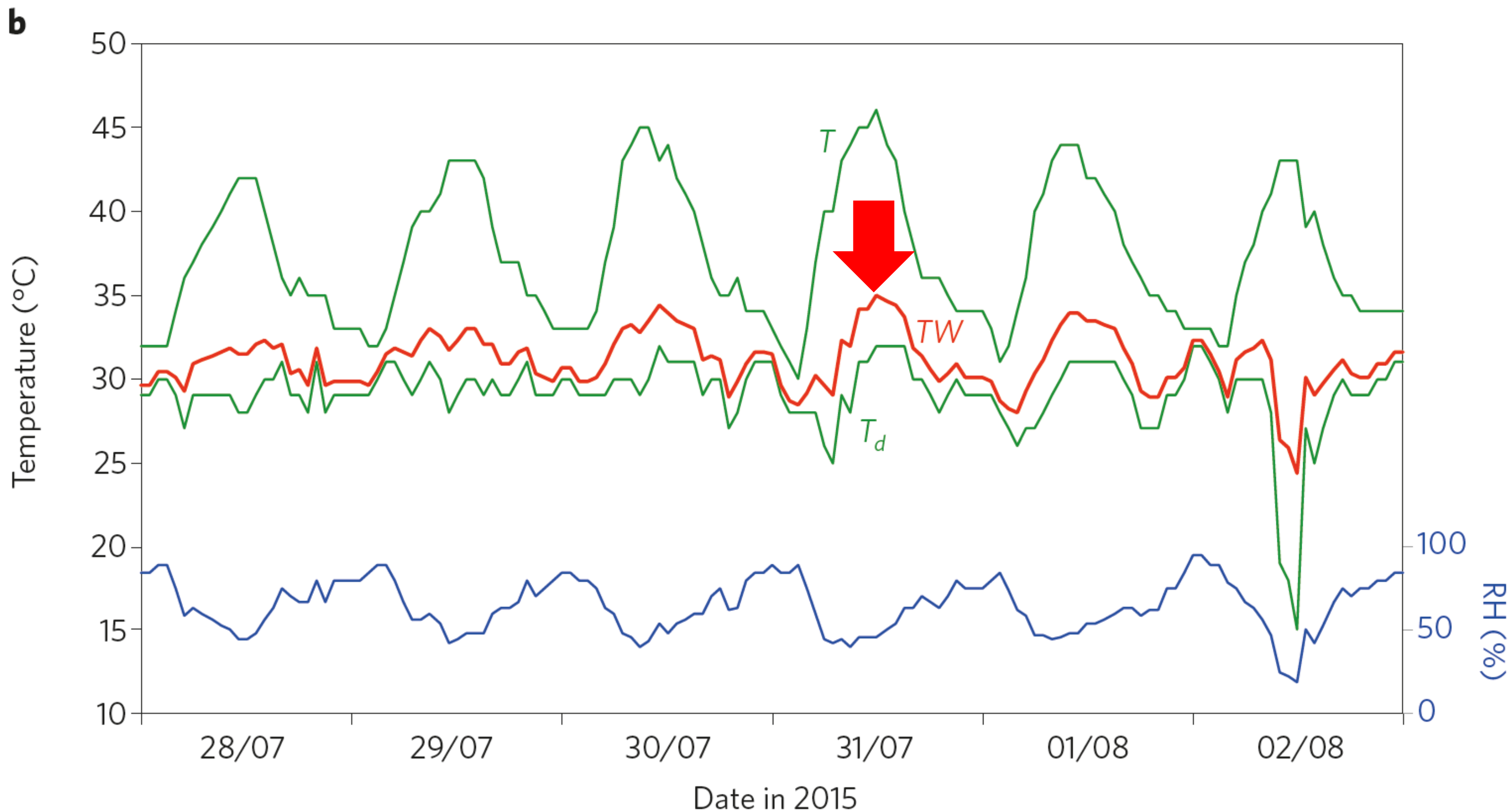
Im et al. (2017) *Science Advances*

Bandar Mahshahr, Iran, July 2015



Schär, *Nature Climate Change* (2016)

Bandar Mahshahr, Iran, July 2015



31 Juli (16:30 Ortszeit)

T: 46°C

RH: 49%

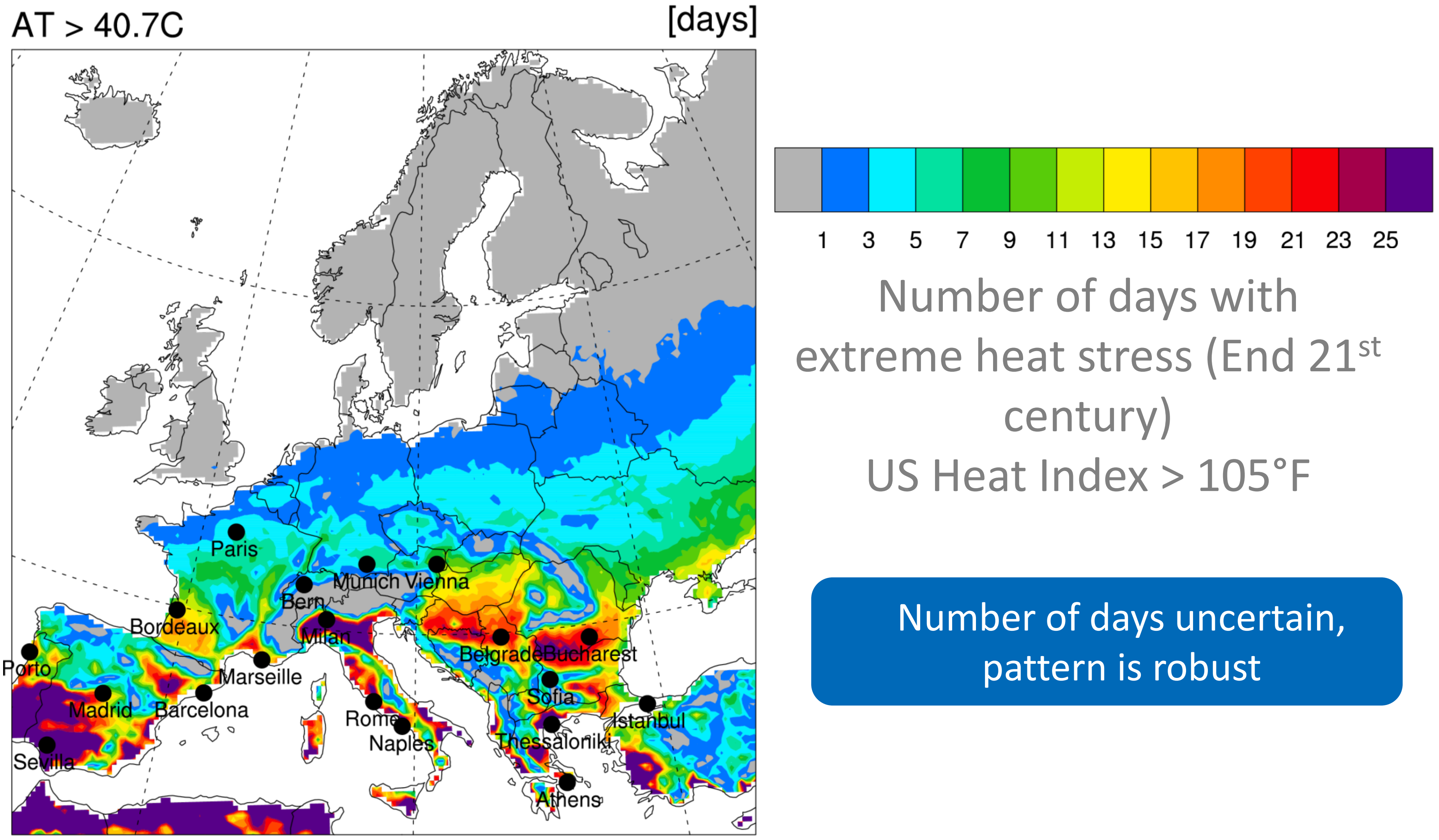
WBT: 34.6°C

At 4°C warming the limit may be reached around the Persian Gulf and along the Ganges

Schär, *Nature Climate Change* (2016)

Heat stress may be reaching levels near the **adaptation limit – excess mortality** starts already at much lower levels

Hotspots along densely populated coasts



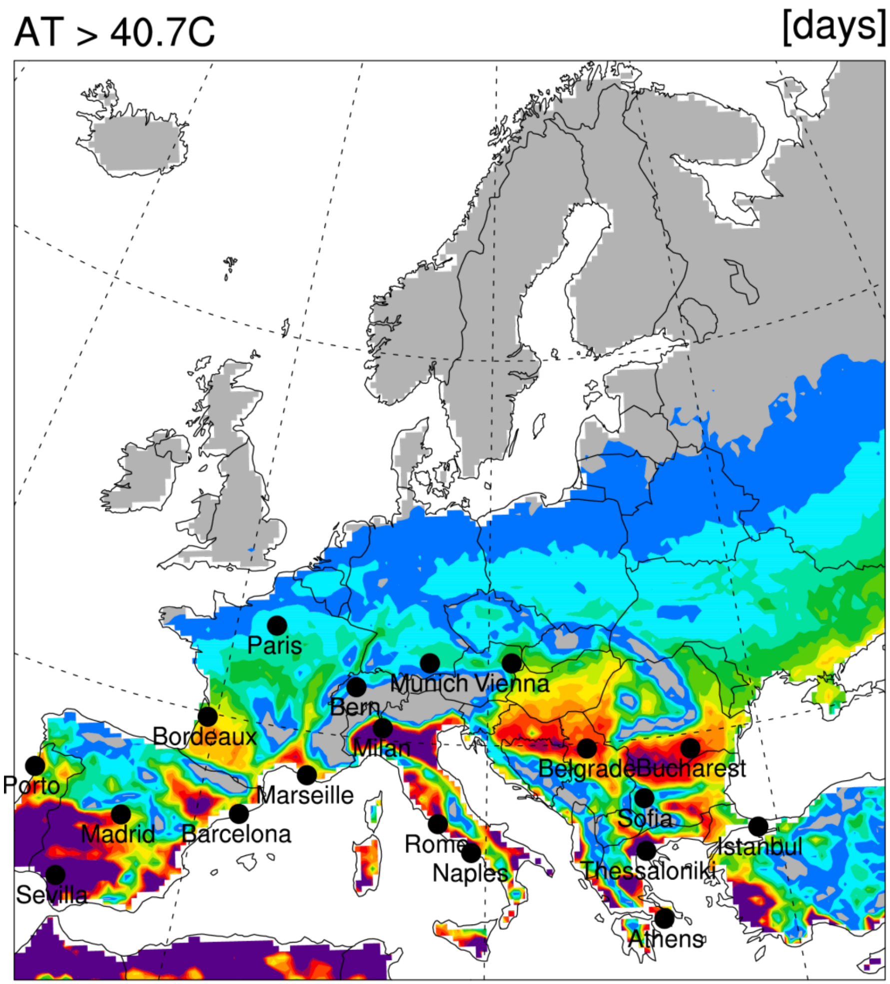
Number of days with extreme heat stress (End 21st century)

US Heat Index > 105°F

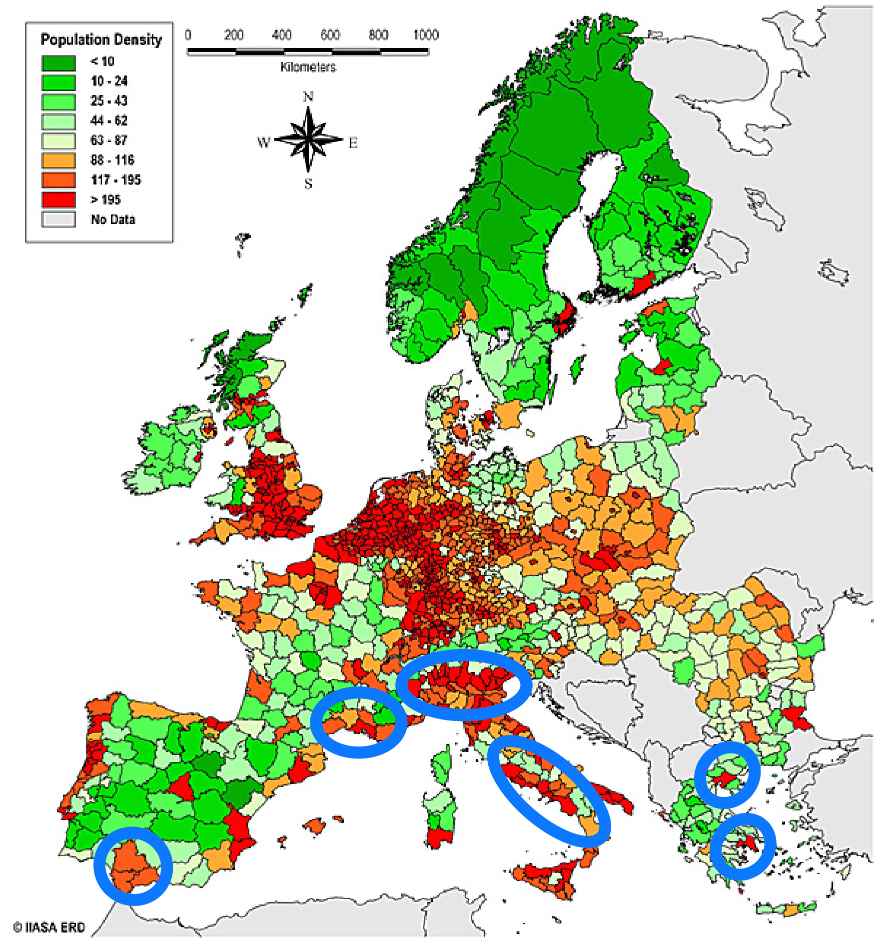
Number of days uncertain, pattern is robust

Fischer and Schär, *Nature Geoscience* (2010)

Urbanized areas most affected

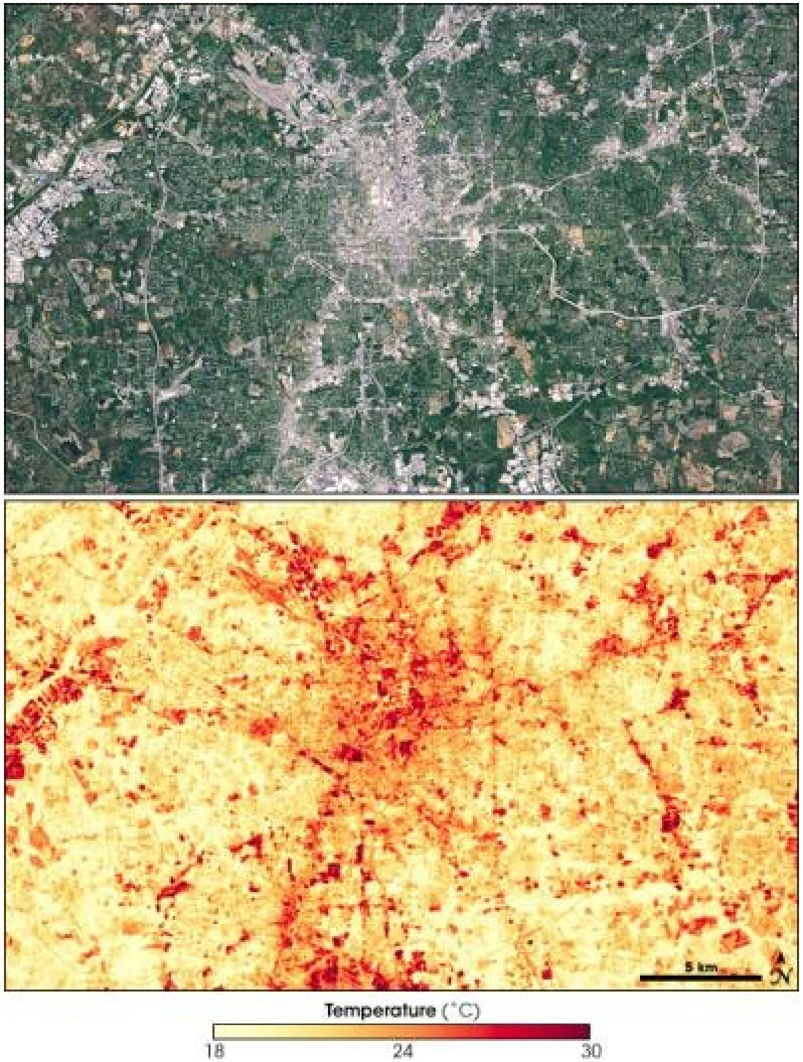


Fischer and Schär, *Nature Geoscience* (2010)



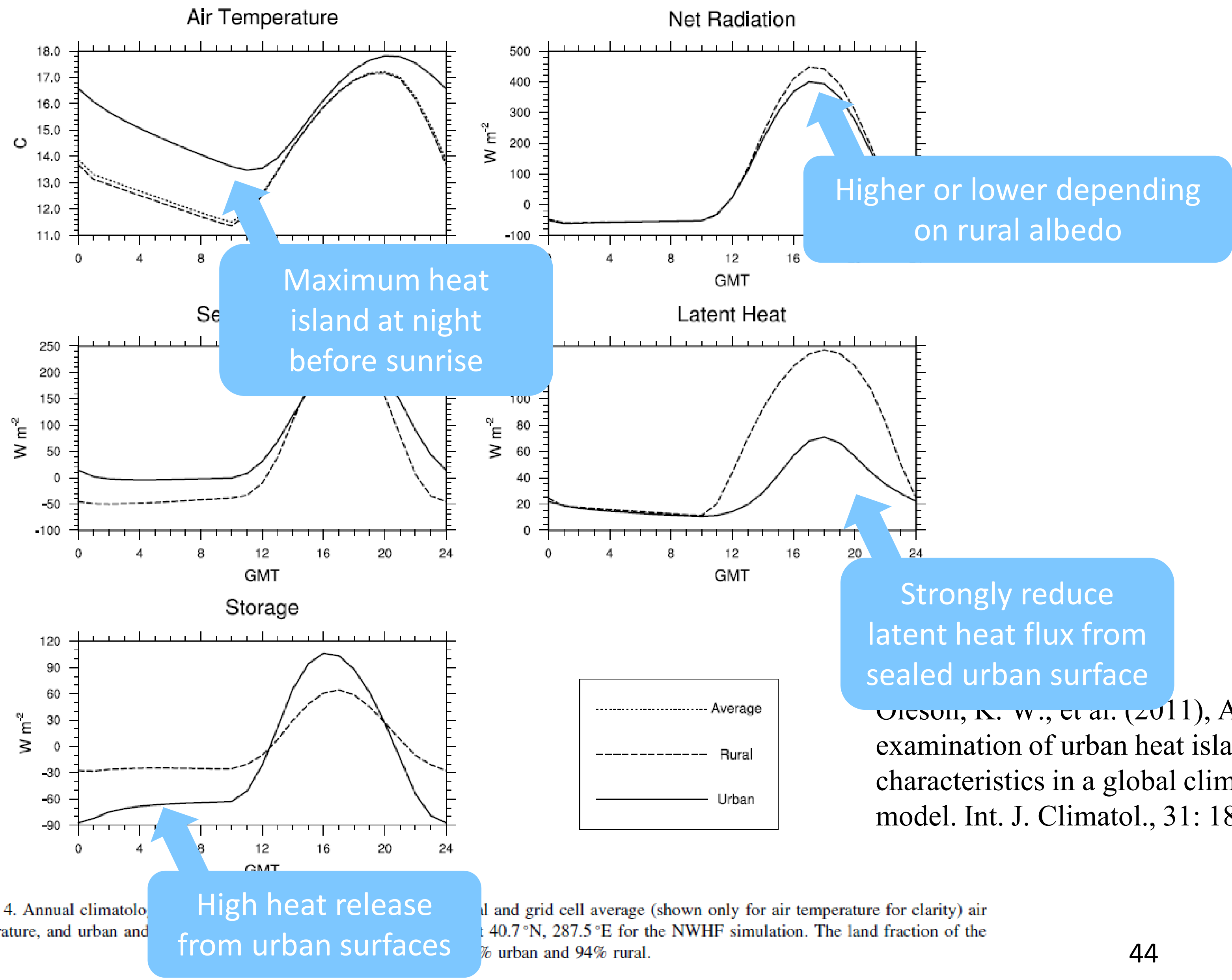
Source IIASA

Urban heat island effect



NASA 2010

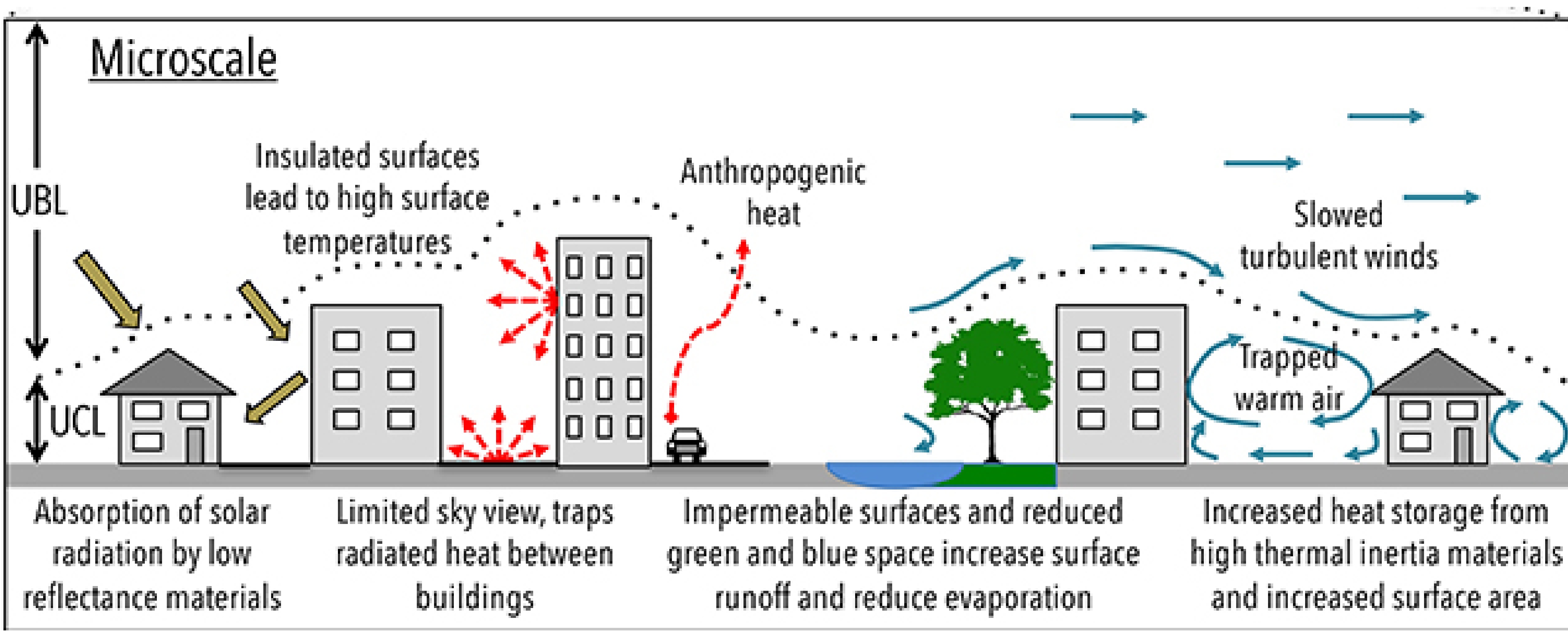
Urban heat island – simulated



Oleson, K. W., et al. (2011), An examination of urban heat island characteristics in a global climate model. Int. J. Climatol., 31: 1848–1865.

Figure 4. Annual climatolo[…] l and grid cell average (shown only for air temperature for clarity) air temperature, and urban and […] 40.7 °N, 287.5 °E for the NWHF simulation. The land fraction of the […] % urban and 94% rural.

Urban heat island over N Europe (JJA mean)

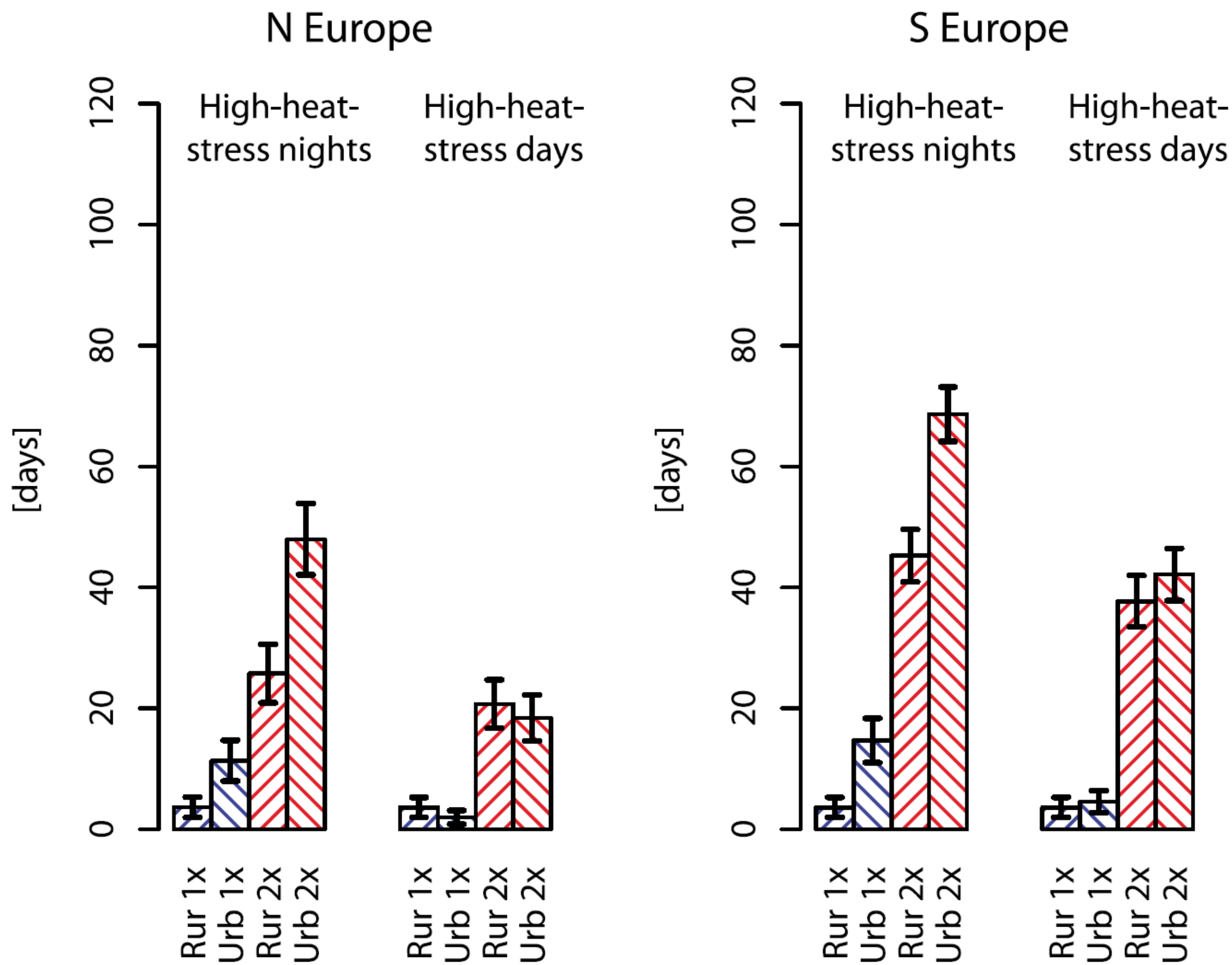


Kershaw, 2017; doi:10.1088/978-0-7503-1197-7ch4

Factors contributing to urban heat island

- Increased heat storage/release due to higher thermal admittance (ground heat flux)
- Longwave trapping due to reduced sky view factor
- Albedo contrast due to low reflectance material
- More impermeable and less green surfaces -> reduced latent heat flux
- Anthropogenic waste heat

Heat stress nights increase more over cities



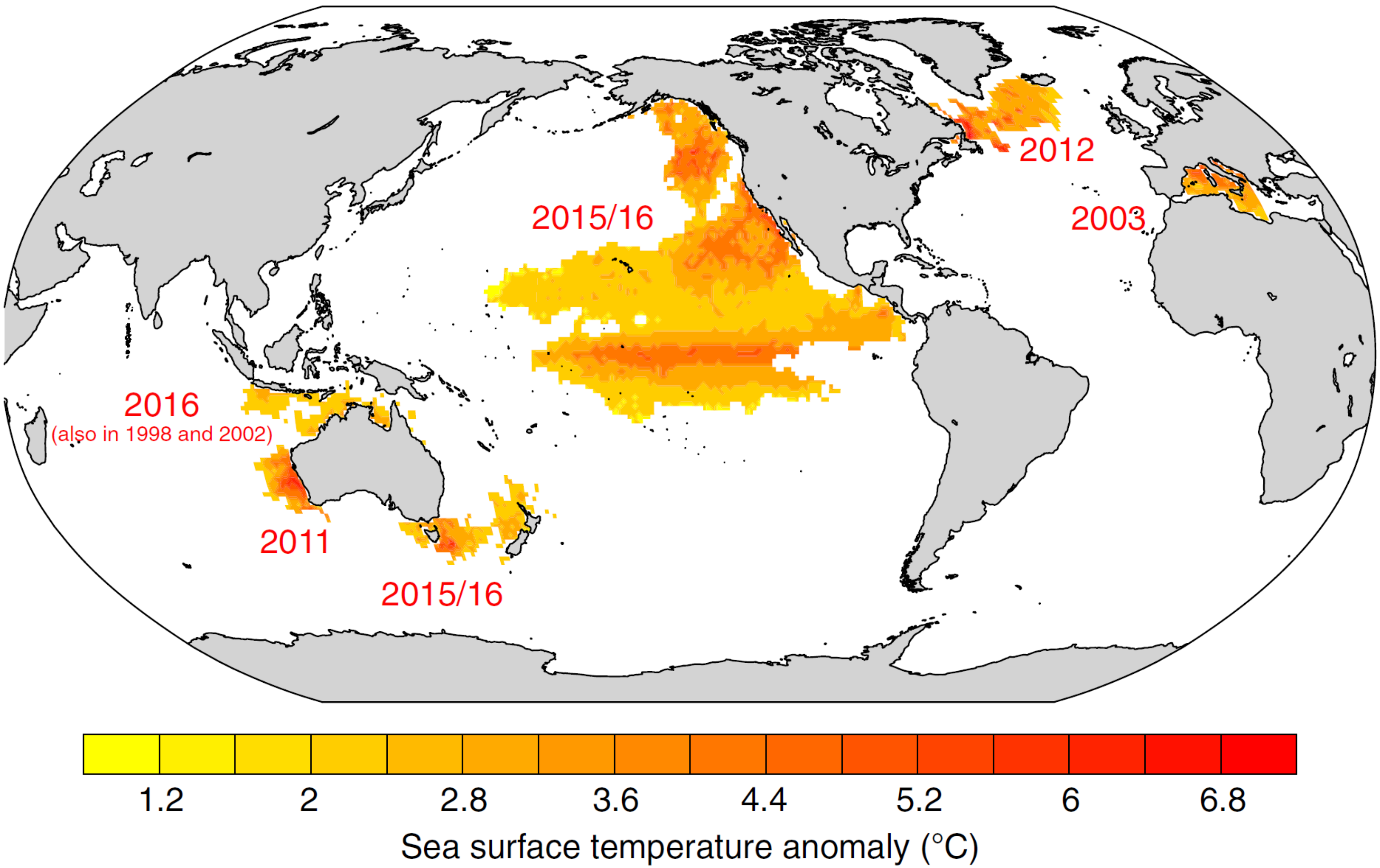
Fischer et al., 2012; *GRL*

Urban heat island effect can substantially amplify nighttime extremes

Marine heatwaves

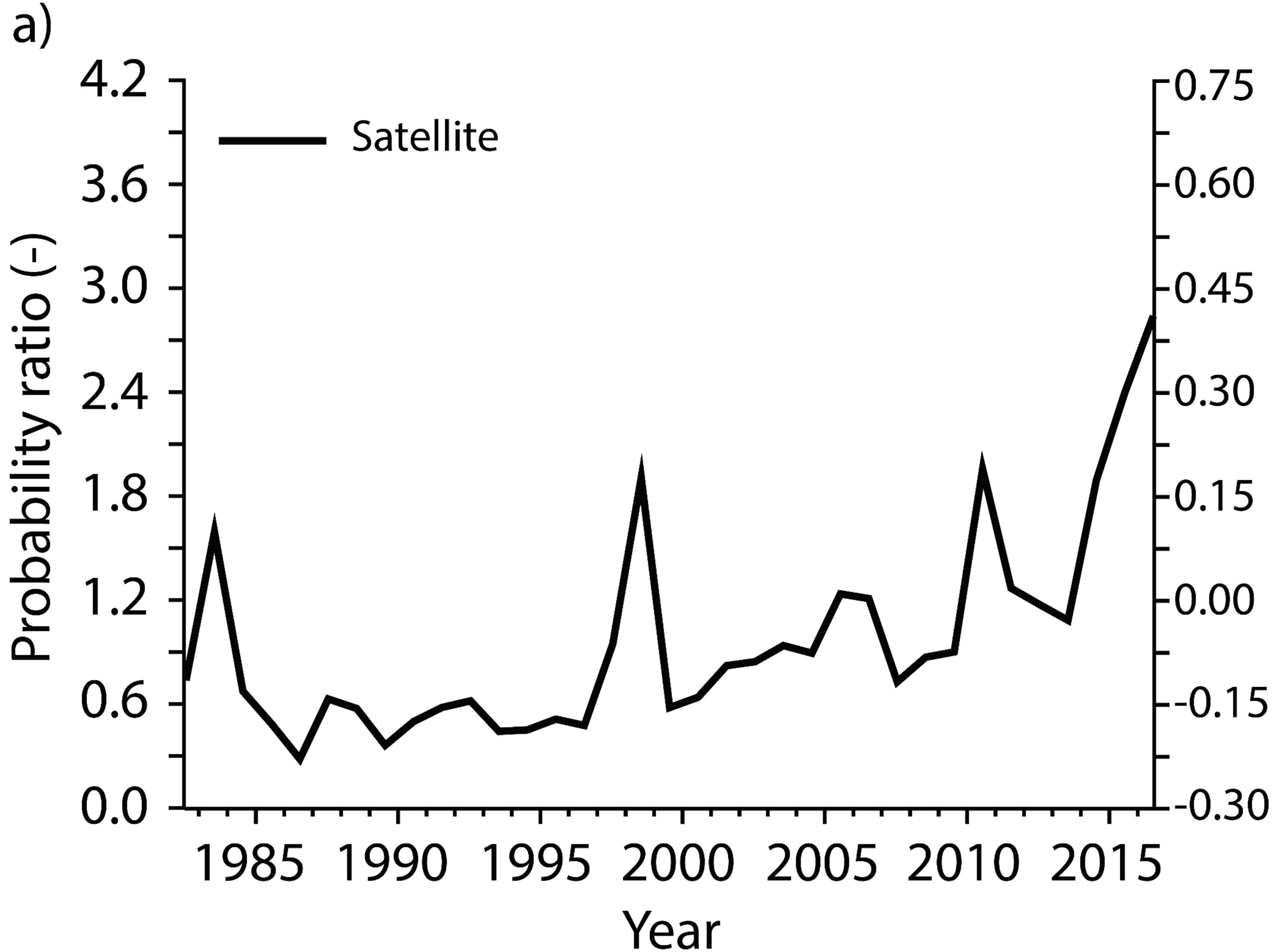
Mass coral bleaching, fish mortality, toxic algae

Recent occurrence of marine heatwaves



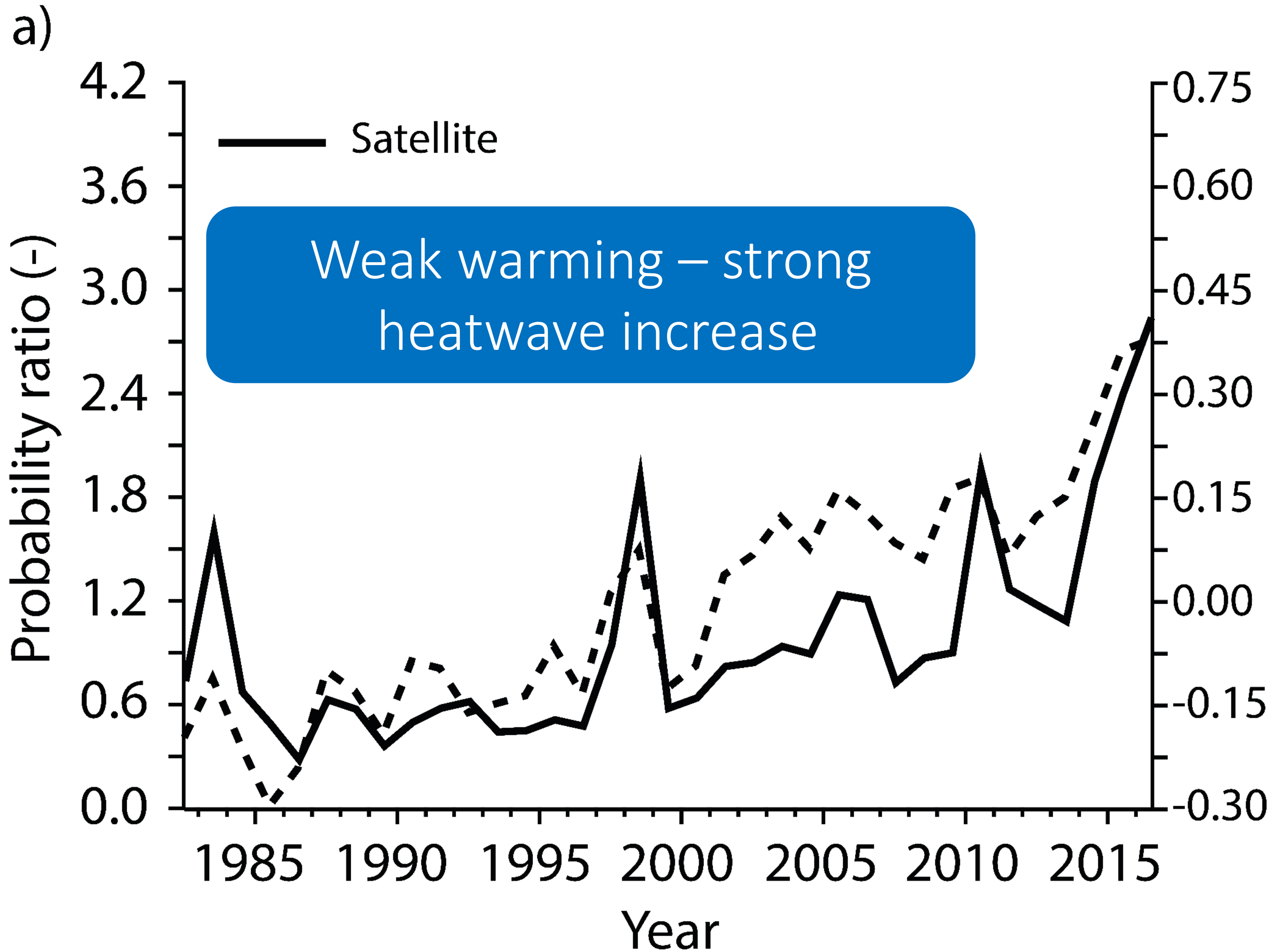
Froelicher and Laufkoetter (2018), *Nature Comm.*

Marine heatwaves have doubled



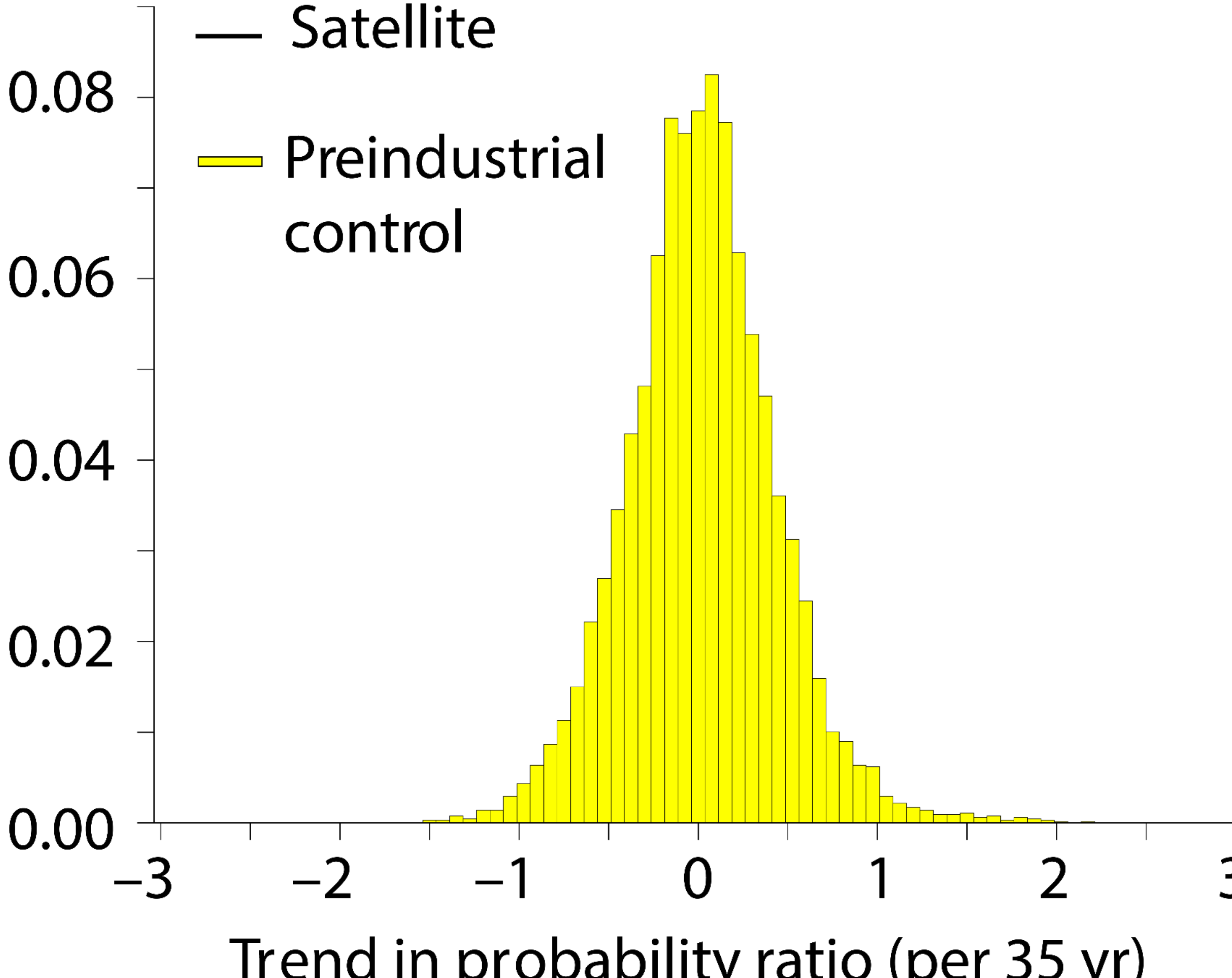
Froelicher, Fischer and Gruber (2018) *Nature*

Marine heatwaves follow the mean warming



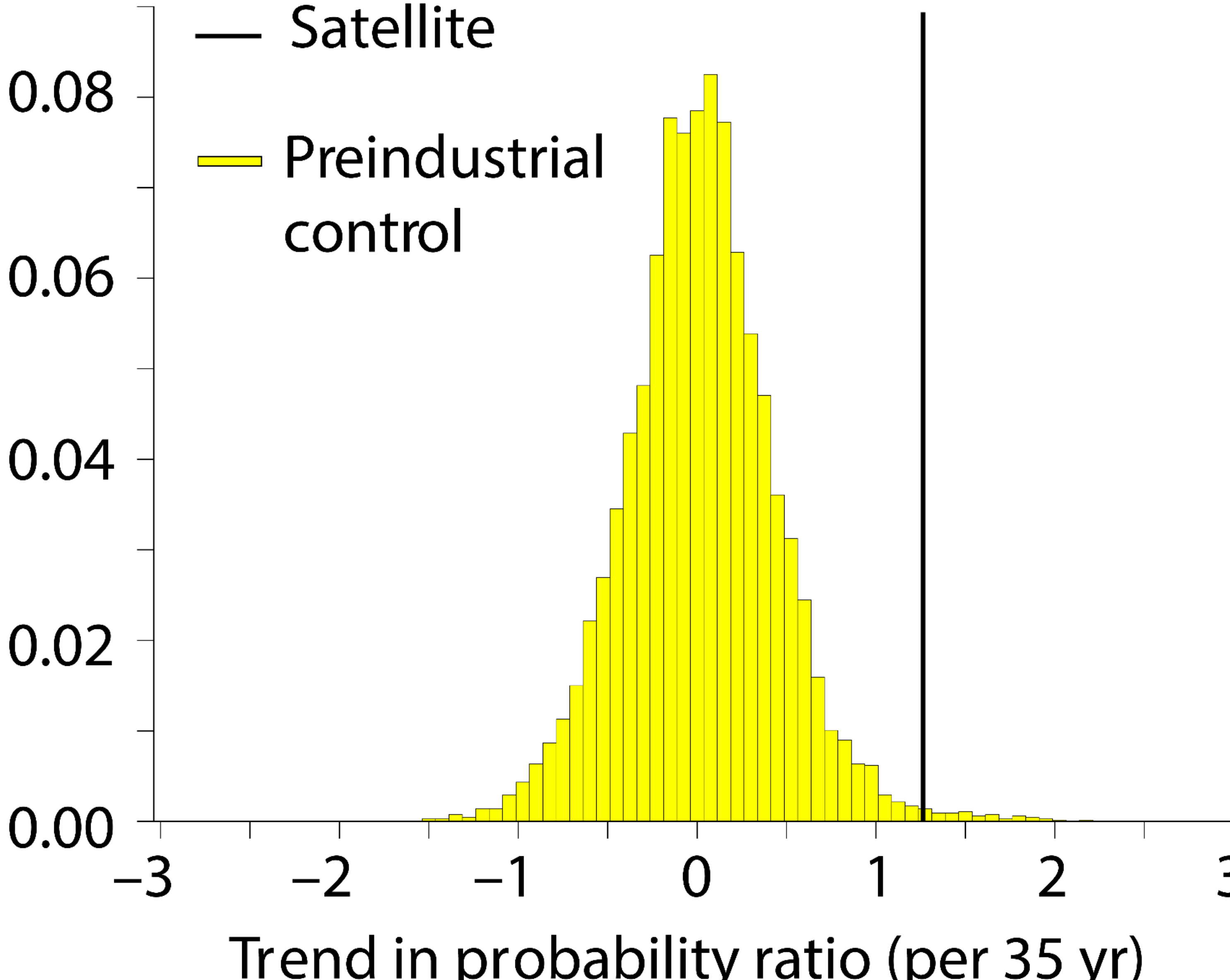
Froelicher, Fischer and Gruber (2018) *Nature*

Detection: Trend exceeds internal variability



Froelicher, Fischer and Gruber (2018) *Nature*

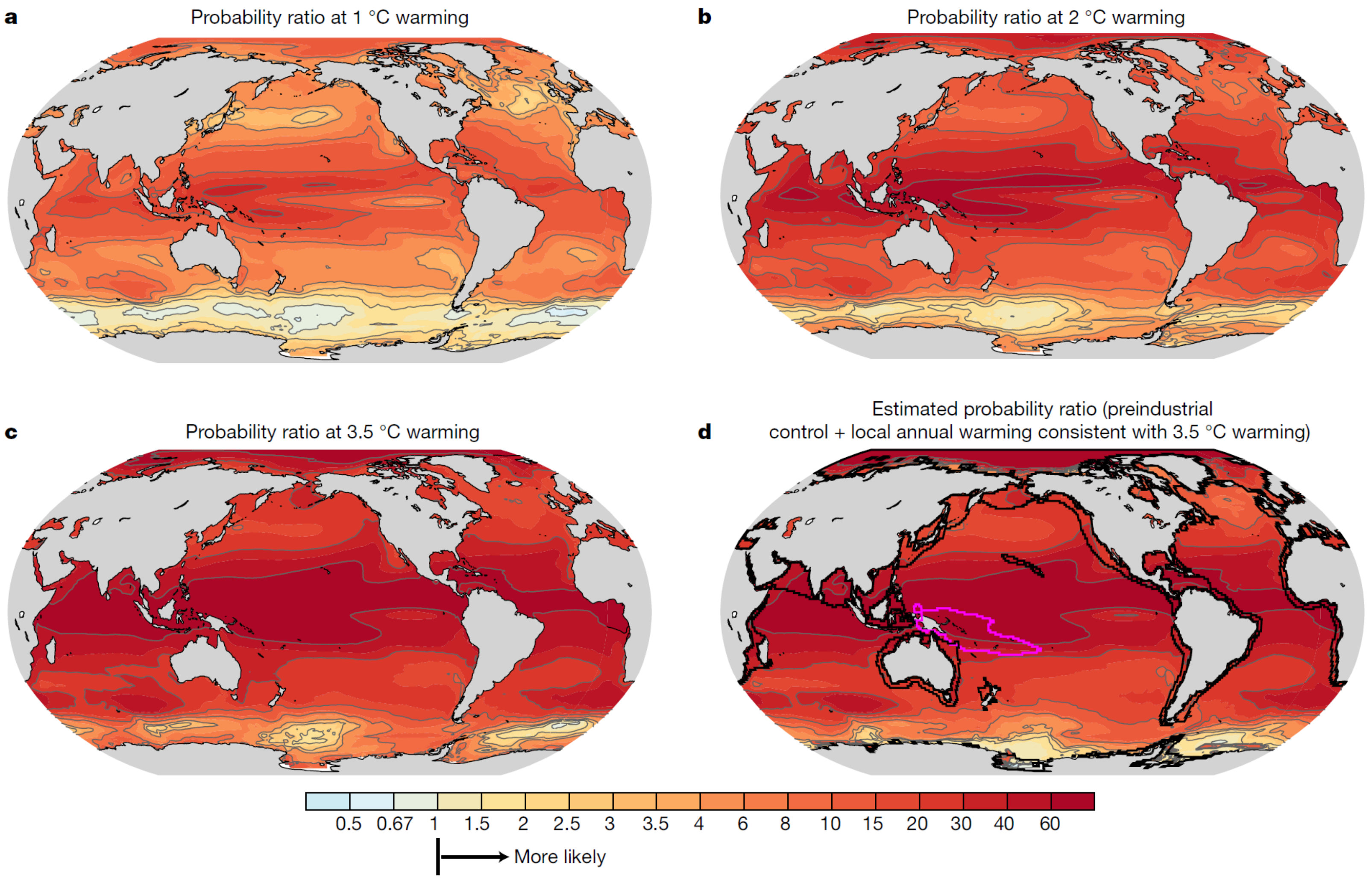
Detection: Trend exceeds internal variability



Froelicher, Fischer and Gruber (2018) *Nature*

Changes in marine heatwave follow mean

CMIP5 mean change in marine heatwave probability



Froelicher, Fischer and Gruber (2018) *Nature*

Marine heatwaves

rapidly increase with warming

Conclusions

- Heat stress is a multivariate problem
- Urban heat island can substantially amplify nighttime temperatures
- Marine heatwaves increase faster despite less warming over ocean than land