The dynamics of moist heat stress and their implications for future predictions

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say hi to Jon Buzan

made possible by hard work from members of the Climate Dynamics Prediction Lab

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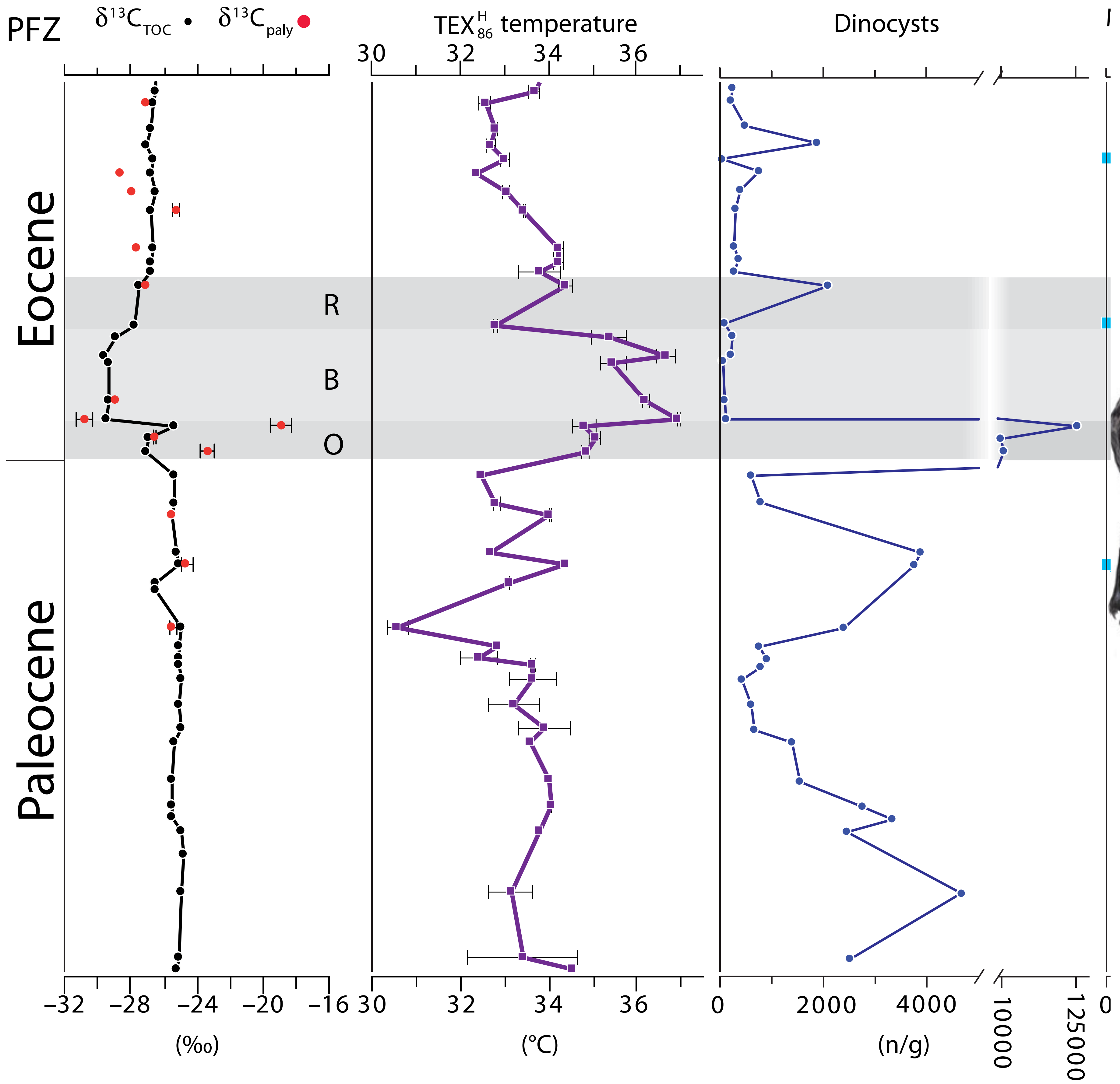
Paleocene-Eocene Thermal Maximum 55 mya

Tropical Heat Death in Nigeria



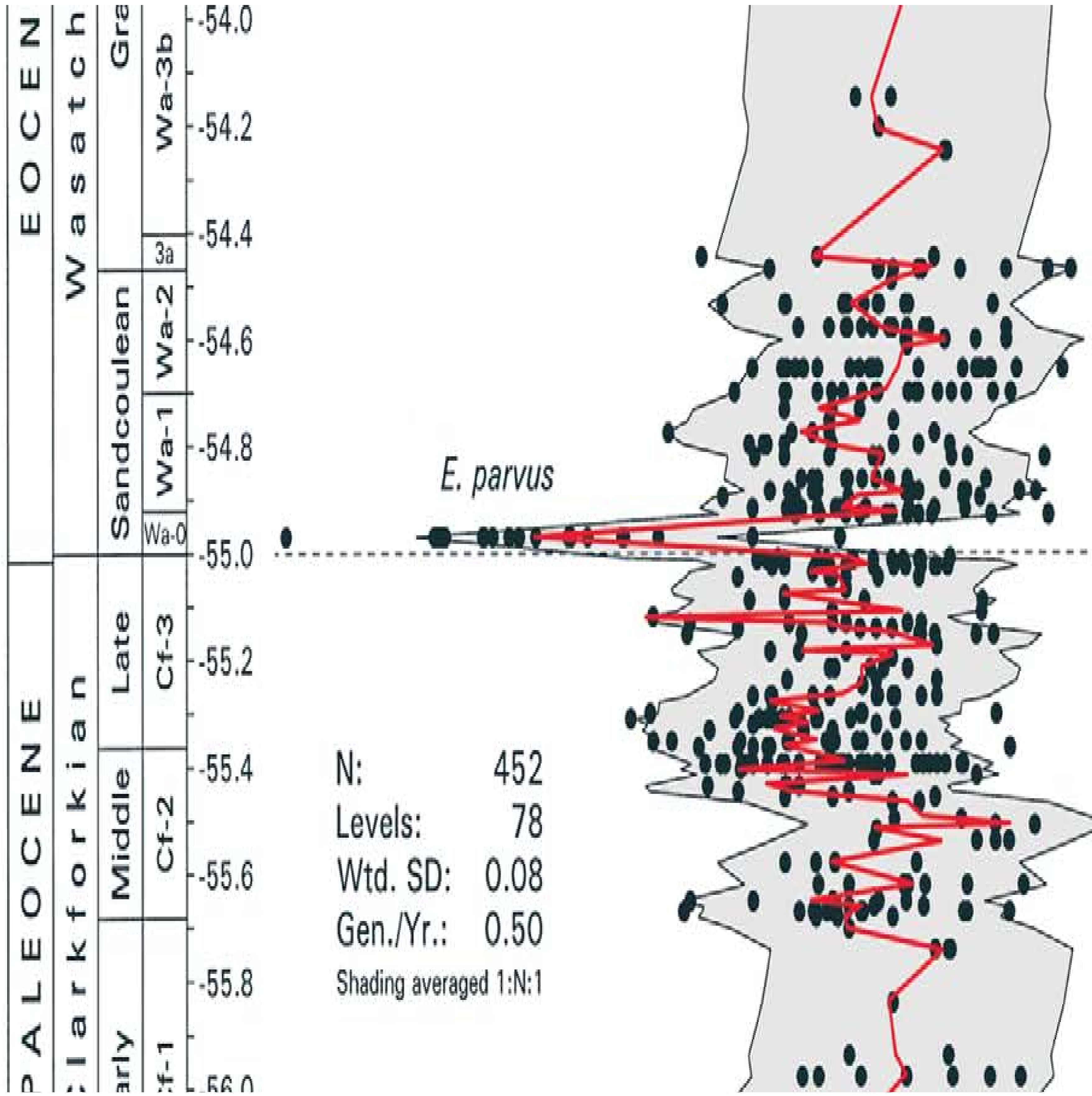
SCIENCE ADVANCES | RESEARCH ARTICLE

CLIMATOLOGY

Extreme warmth and heat-stressed plankton in the tropics during the Paleocene-Eocene Thermal Maximum

Joost Frieling,[1]* Holger Gebhardt,[2] Matthew Huber,[3] Olabisi A. Adekeye,[4] Samuel O. Akande,[4] Gert-Jan Reichart,[5,6] Jack J. Middelburg,[5] Stefan Schouten,[5,6] Appy Sluijs[1]

Transient Mammalia Dwarfing in Wyoming



dog-size horse

cat-size horse

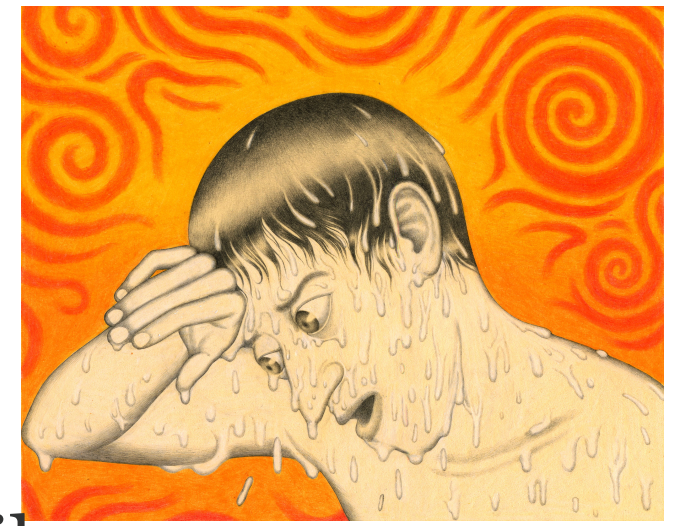
dog-size horse

Gingerich, 2006

Matthew Huber, 2017

The Deadly Combination of Heat and Humidity

By ROBERT KOPP, JONATHAN BUZAN and MATTHEW HUBER JUNE 6, 2015



New York Times SundayReview | OPINION

THE most deadly weather-related disasters aren't necessarily caused by floods, droughts or hurricanes. They can be caused by heat waves, like the sweltering blanket that's taken over 2,500 lives in India in recent weeks.

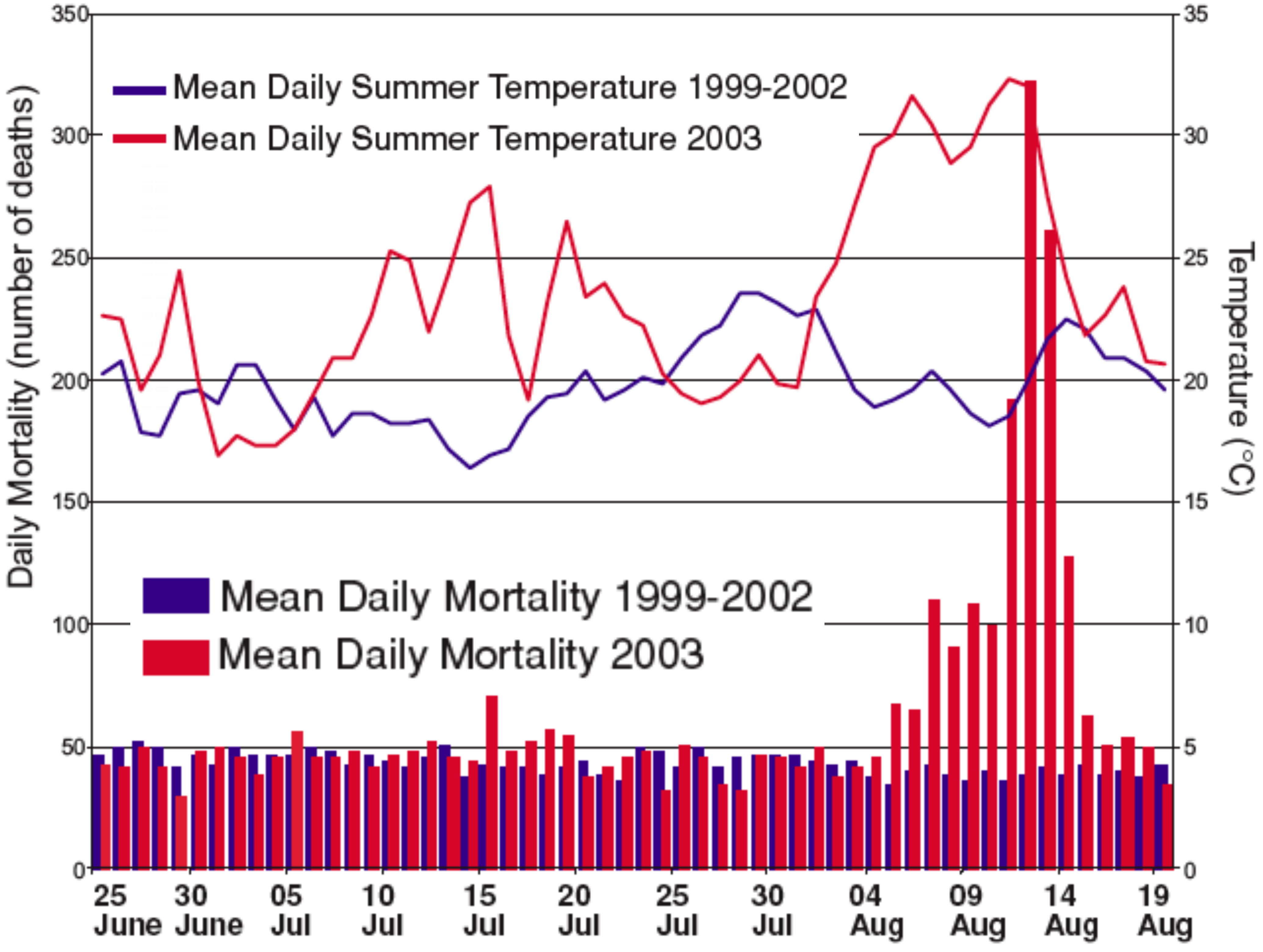
Temperatures broke 118 degrees in parts of the country. The death toll is still being tallied, and many heat-related deaths will be recognized only after the fact. Yet it's already the deadliest heat wave to hit India since at least 1998 and, by some accounts, the fourth- or fifth-deadliest worldwide since 1900.

These heat waves will only become more common as the planet continues to warm.

They don't just affect tropical, developing countries; they're a threat throughout the world. The July 1995 heat wave in the Midwest caused over 700 deaths in Chicago. The August 2003 heat wave in western Europe led to about 45,000 deaths. The July-August 2010 heat wave in western Russia killed about 54,000 people.

But as anyone who's spent a summer in the eastern United States knows, it's not just the heat; it's also the humidity. Together, they can be lethal, even if the heat doesn't seem quite so extreme.

The Paris Heatwave: Deaths and Temperatures



CCF 2005

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Haldane 1905

THE INFLUENCE OF HIGH AIR TEMPERATURES.
No. I.

BY J. S. HALDANE, M.D., F.R.S.,
Fellow of New College and University Lecturer in Physiology, Oxford.

THE aim of the following investigations was to ascertain the limits within which men can continue to exist normally, and to work, when the air temperature is abnormally high: also to study the abnormal phenomena which are produced when these limits are exceeded.

The subject is one of wide interest, not only in connection with the effects of very warm weather or tropical climates, but also because there are many industrial occupations in which men or women have to work daily in very warm air. My attention was first drawn to the subject in connection with the conditions of work in mines and in the cotton and flax textile industries. There are, however, many other occupations, such as work in the stoke-holds and engine-rooms of steamers, in drawing the ovens used for firing pottery, in the drying of salt, etc., where men are exposed to high temperatures; and the effects of even ordinary warm summer weather in producing heat-stroke, especially among soldiers, are well known.

There are many observations showing that men can remain with impunity in temperatures considerably above the body temperature. In tropical countries, for instance, the shade temperature may, if the air be dry, rise to 120° F. (49° C.) without causing much inconvenience. The experiments made by Blagden and Forsyth and by Dobson in 1775[1] prove definitely that for short periods far higher air temperatures can be borne. These observers found that they could remain for a few minutes in a room at about 250° F. (121° C.) without serious inconvenience or marked rise of body temperature, although beef-steaks exposed in the room at the same time and place could be cooked within

- "The experiments made by Blagden and Forsyth and by Dobson in 1775 prove definitely that for short period far higher air temperatures [than 49°C] can be borne. These observers found that they could remain for a few minutes in a room at about 121C) without serious inconvenience…although beefsteaks in the room at the time and place could be cooked within 13 minutes."

- "The bearing of these experiments on the question as to the rise in temperature allowable on economic or humanitarian grounds in places where persons have to work continuously will be sufficiently evident."

- "It is clear that in still and warm air what matters to the persons present is neither the temperature of the air, nor its relative saturation, nor the absolute percentage of aqueous vapour present, **but the temperature shown by the wet-bulb thermometer**. "

- "If this exceeds a certain point (about 78° F. or 25.5° C.) continuous hard work becomes impracticable; and beyond about 88° F. or 31° C. it becomes impracticable for ordinary persons even to stay for long periods in such air."

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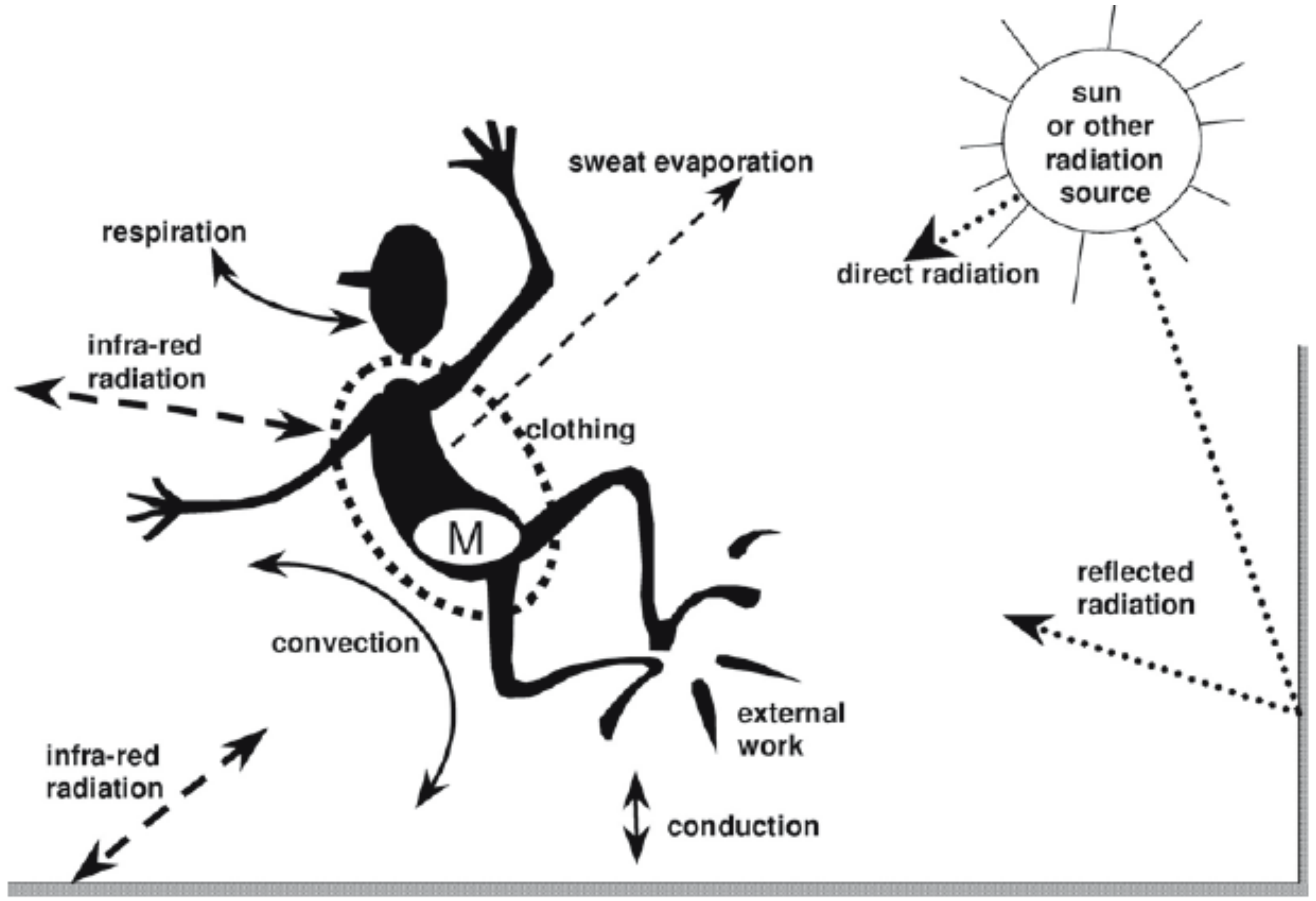

Schematic representation of the pathways for heat loss from the body. M = metabolic heat production (reproduced with permission, Havenith, 1999)

Human Energy Balance

- A resting human body generates ~100 W of metabolic heat which (in addition to any absorbed solar heating) must be carried away via a combination of heat conduction, evaporative cooling, and net infrared radiative cooling. Conductive cooling is inhibited by high temperature, and evaporation by high relative humidity.
- Net (latent+sensible) cooling can occur only if an object is warmer than the environmental <u>wet-bulb temperature</u> T_W, measured by covering a standard thermometer bulb with a wetted cloth and fully ventilating it.
- The second law of thermodynamics does not allow an object to lose heat to an environment whose TW exceeds the object's temperature, no matter how wet or well-ventilated.

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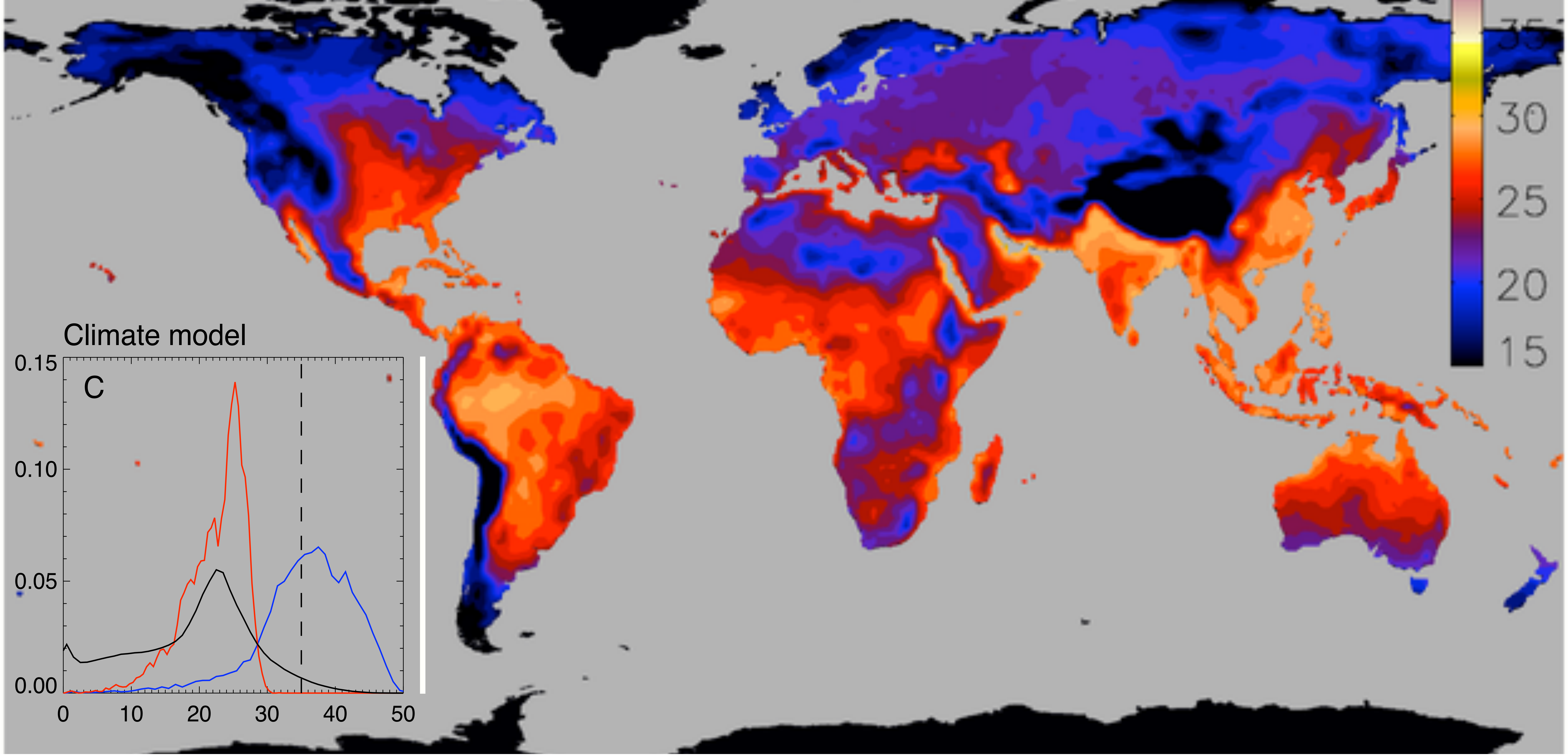
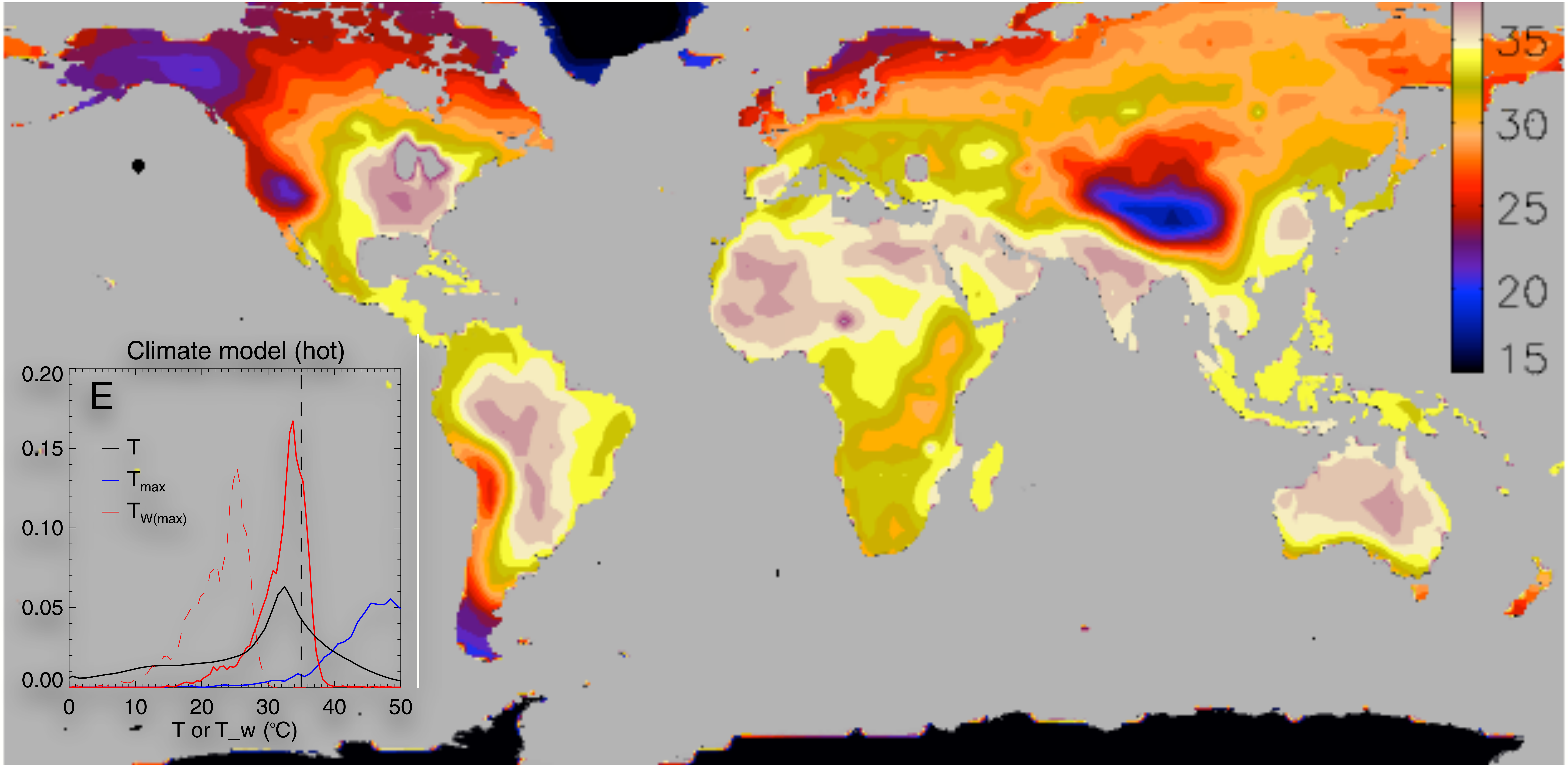


Modern maximum wetbulb temperature

Sherwood and Huber, 2010

Matthew Huber, 2017



Future maximum wetbulb temperature

Sherwood and Huber, 2010

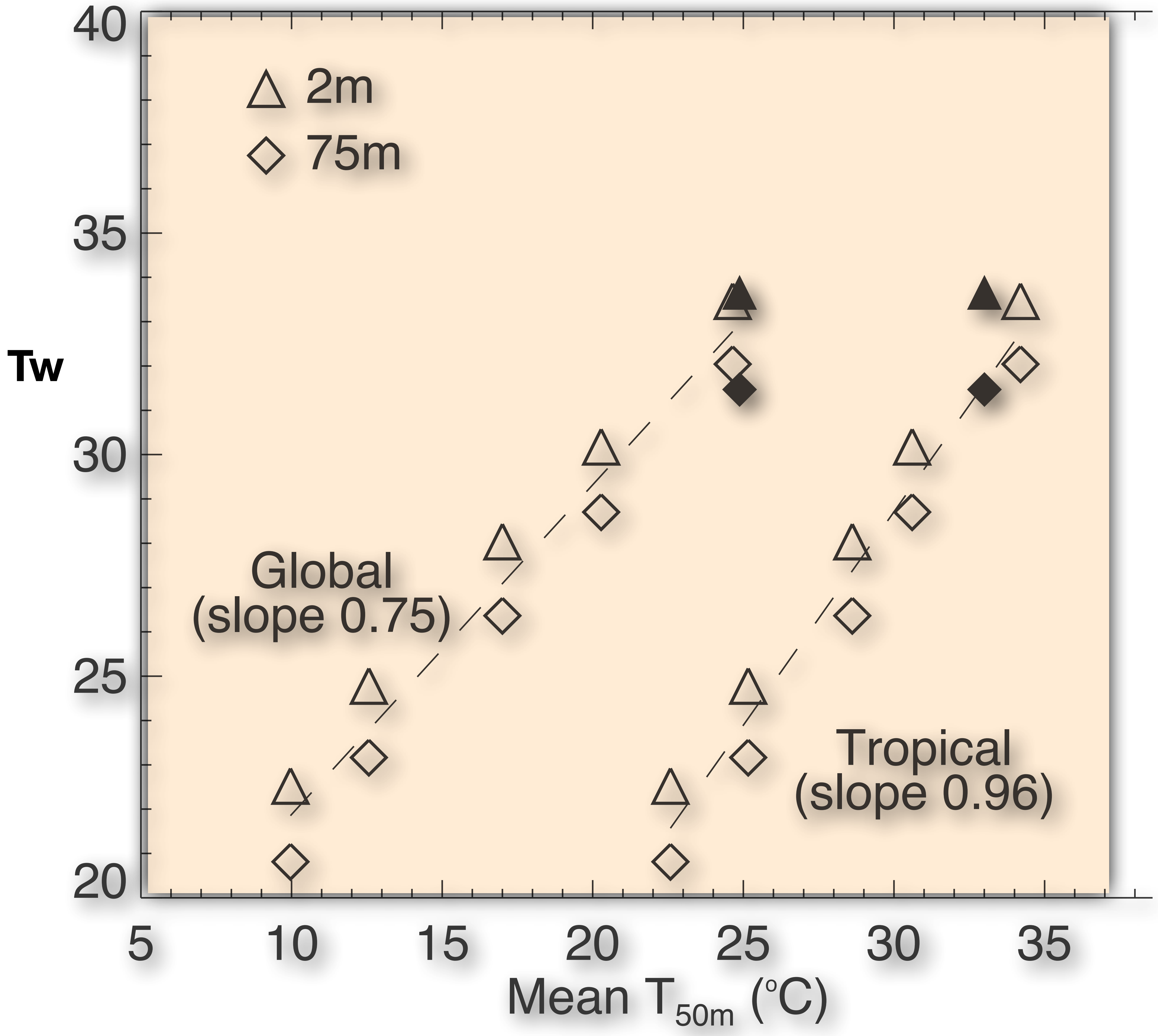
Matthew Huber, 2017

Scaling for Maximum wetbulb temperature

- Scales linearly with tropical mean temperature-- probably robust result

- For a large, but feasible warming, regions with >50% of the worlds current population will experience lethal temperatures

- Should also be true in the past (Eocene)



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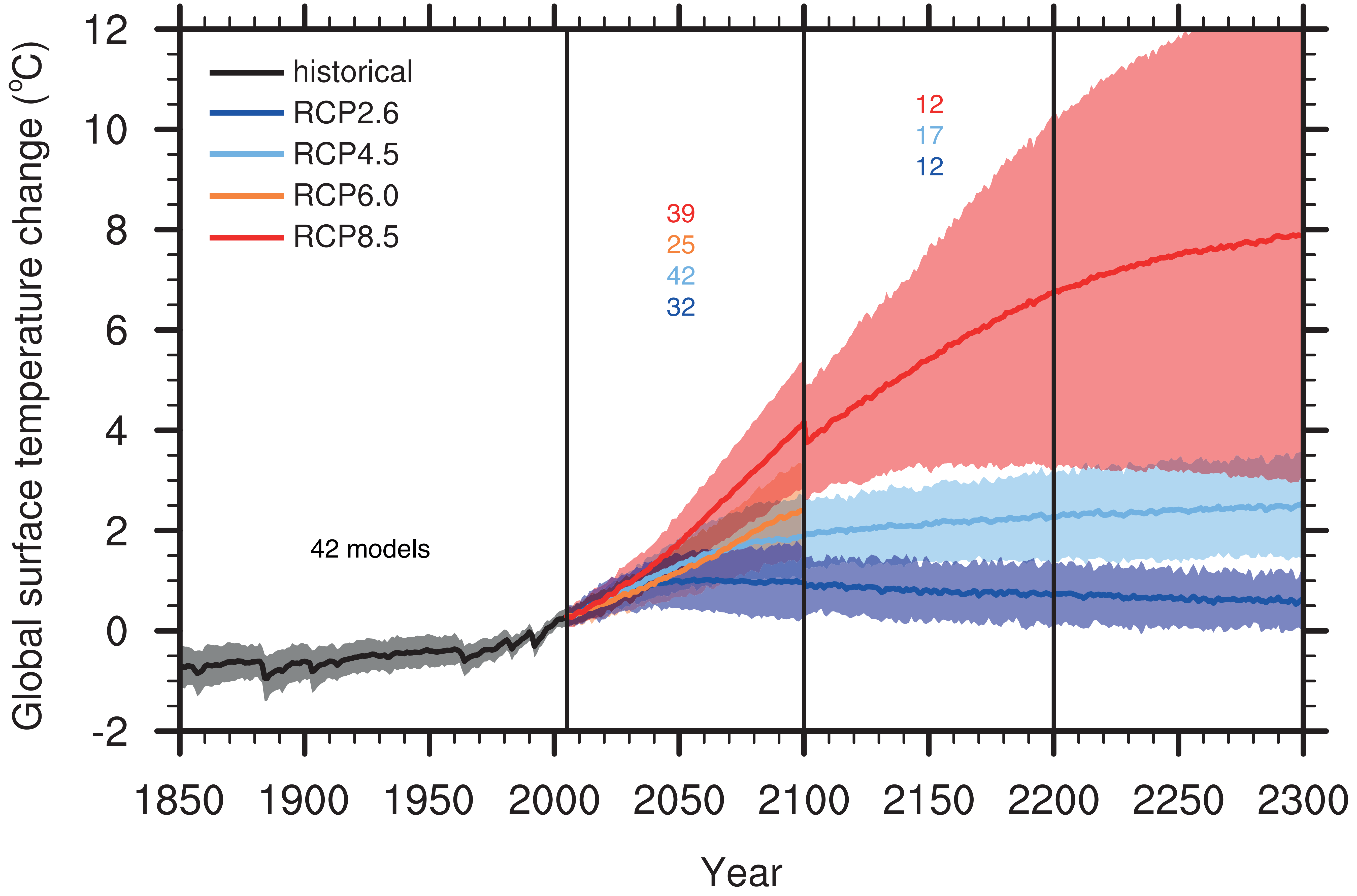
12 Long-term Climate Change: Projections, Commitments and Irreversibility

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.



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		RCP2.6 (Δ*T* in °C)	RCP4.5 (Δ*T* in °C)	RCP6.0 (Δ*T* in °C)	RCP8.5 (Δ*T* in °C)
Global:	2046–2065	1.0 ± 0.3 (0.4, 1.6)	1.4 ± 0.3 (0.9, 2.0)	1.3 ± 0.3 (0.8, 1.8)	2.0 ± 0.4 (1.4, 2.6)
	2081–2100	1.0 ± 0.4 (0.3, 1.7)	1.8 ± 0.5 (1.1, 2.6)	2.2 ± 0.5 (1.4, 3.1)	3.7 ± 0.7 (2.6, 4.8)
	2181–2200	0.7 ± 0.4 (0.1, 1.3)	2.3 ± 0.5 (1.4, 3.1)	3.7 ± 0.7 (-,-)	6.5 ± 2.0 (3.3, 9.8)
	2281–2300	0.6 ± 0.3 (0.0, 1.2)	2.5 ± 0.6 (1.5, 3.5)	4.2 ± 1.0 (-,-)	7.8 ± 2.9 (3.0, 12.6)

Community Earth System Model (CESM)

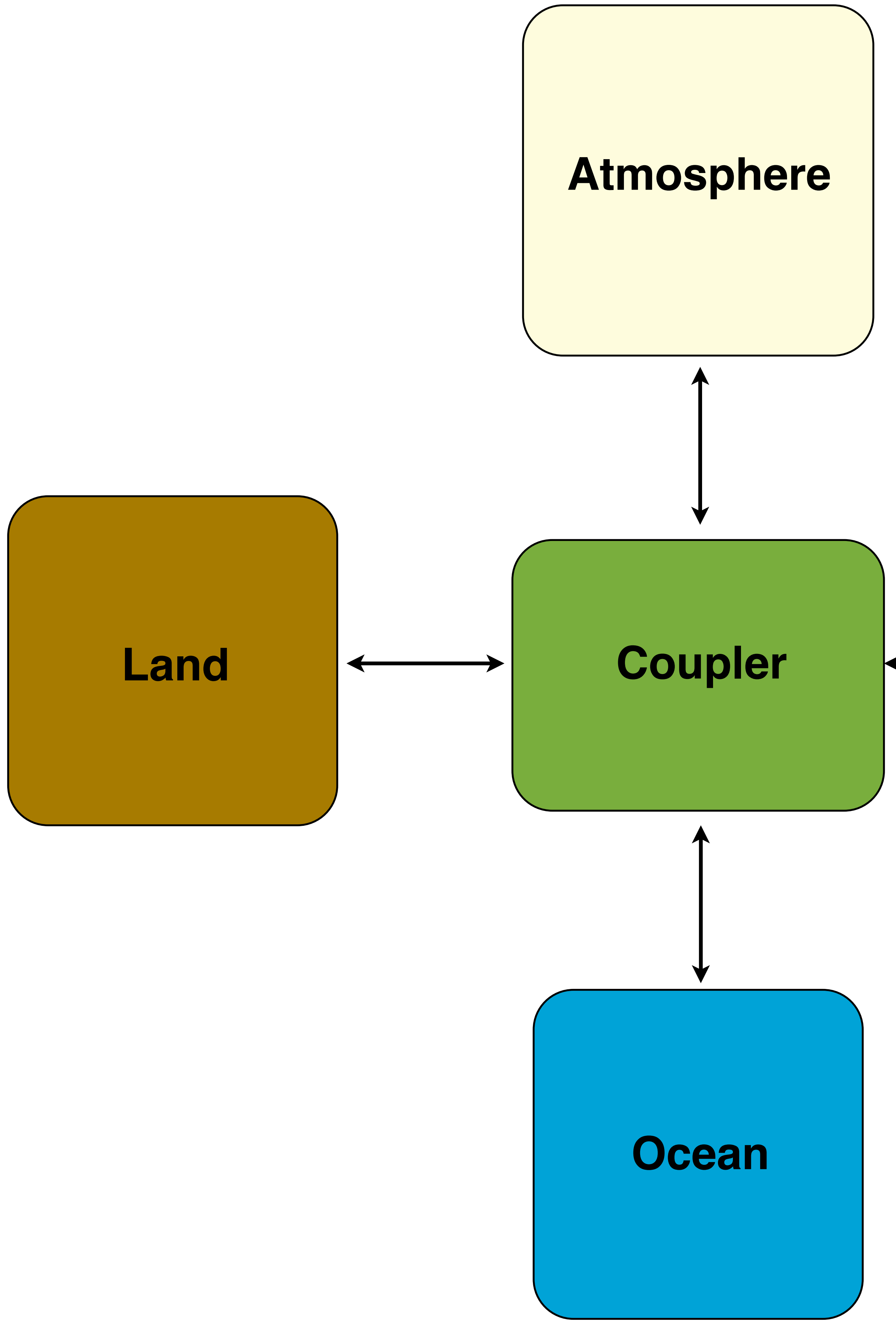
- Developed by the National Center for Atmospheric Research (NCAR) and large community
- First principle physical equations discretized to gridded environment
- open source

See Buzan et al 2015 for HumanIndexMod

Single Module with 11 Subroutines

Requires: Temperature, Pressure, Moisture, Winds

- **Wet Bulb Temperature**
- **Equivalent Pot. Temperature**
- **Equivalent Temperature**
- **Apparent Temperature**
- **NWS Heat Index**
- **Humidex**
- **Temp. Hum. Index Comfort**
- **Temp. Hum. Index Physiology**
- **Simplified WBGT**
- **Swamp Cooler Efficiency 80%**
- **Swamp Cooler Efficiency 65%**
- **Discomfort Index**



Bitz et al. 2012

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Geosci. Model Dev., 8, 151–170, 2015
www.geosci-model-dev.net/8/151/2015/
doi:10.5194/gmd-8-151-2015

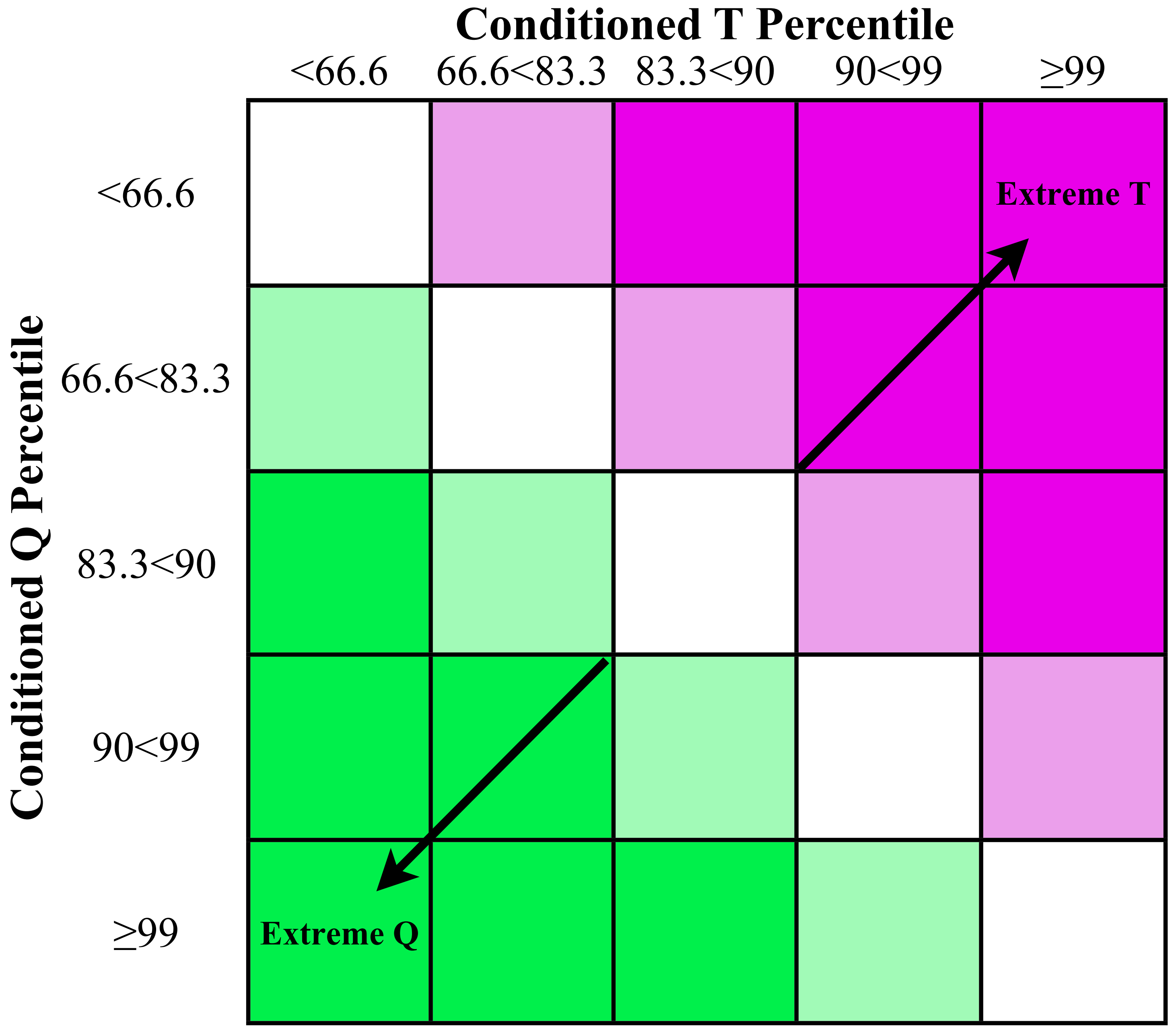
Geoscientific Model Development
Open Access

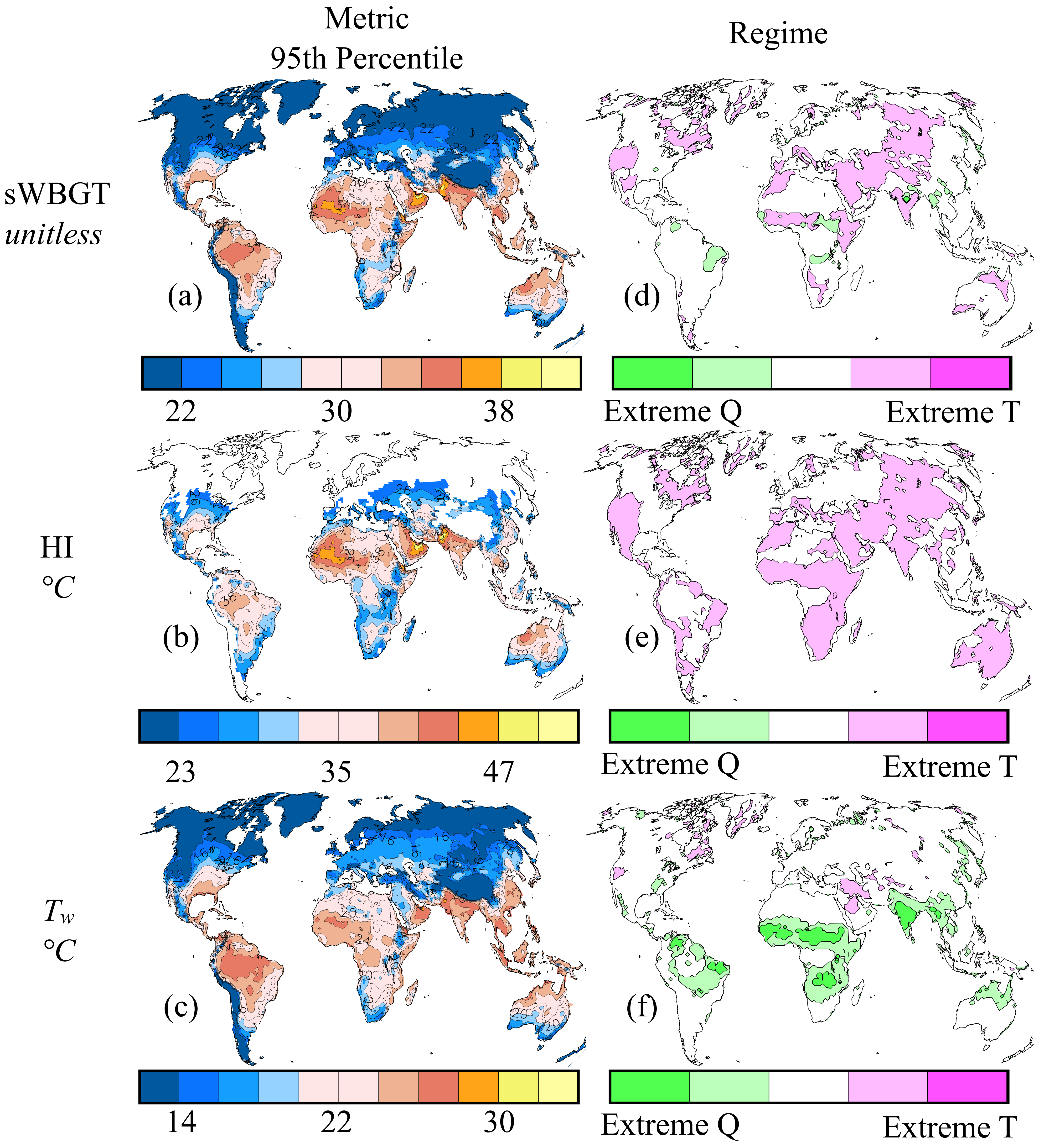
Implementation and comparison of a suite of heat stress metrics within the Community Land Model version 4.5

J. R. Buzan[1,2], K. Oleson[3], and M. Huber[1,2]

$$\mathrm{HI} = -42.379 + 2.04901523 T_{\mathrm{F}} + 10.14333127\mathrm{RH} + -0.22475541 T_{\mathrm{F}}\mathrm{RH} + -6.83783 \times 10^{-3} T_{\mathrm{F}}^{2} + -5.481717 \times 10^{-2}\mathrm{RH}^{2} + 1.22874 \times 10^{-3} T_{\mathrm{F}}^{2}\mathrm{RH} + 8.5282 \times 10^{-4} T_{\mathrm{F}}\mathrm{RH}^{2} + -1.99 \times 10^{-6} T_{\mathrm{F}}^{2}\mathrm{RH}^{2} \quad (3)$$

$$\mathrm{sWBGT} = 0.56 T_{\mathrm{C}} + \frac{0.393 e_{\mathrm{RH}}}{100} + 3.94$$





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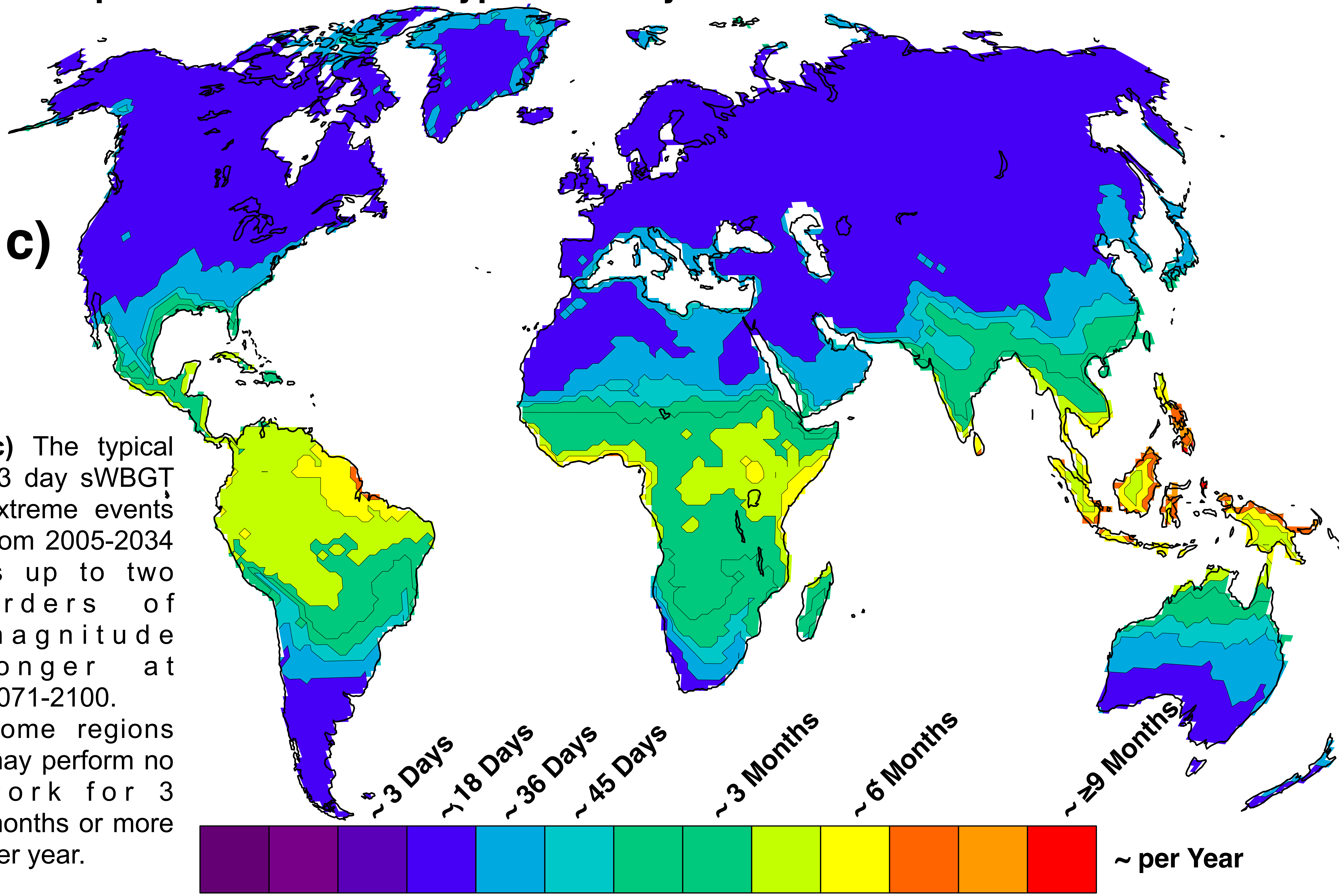
Time spent in 2071-2100 at typical ~3 day extreme sWBGT event 2005-2034



- **(c)** The typical ~3 day sWBGT extreme events from 2005-2034 is up to two orders of magnitude longer at 2071-2100.
- Some regions may perform no work for 3 months or more per year.

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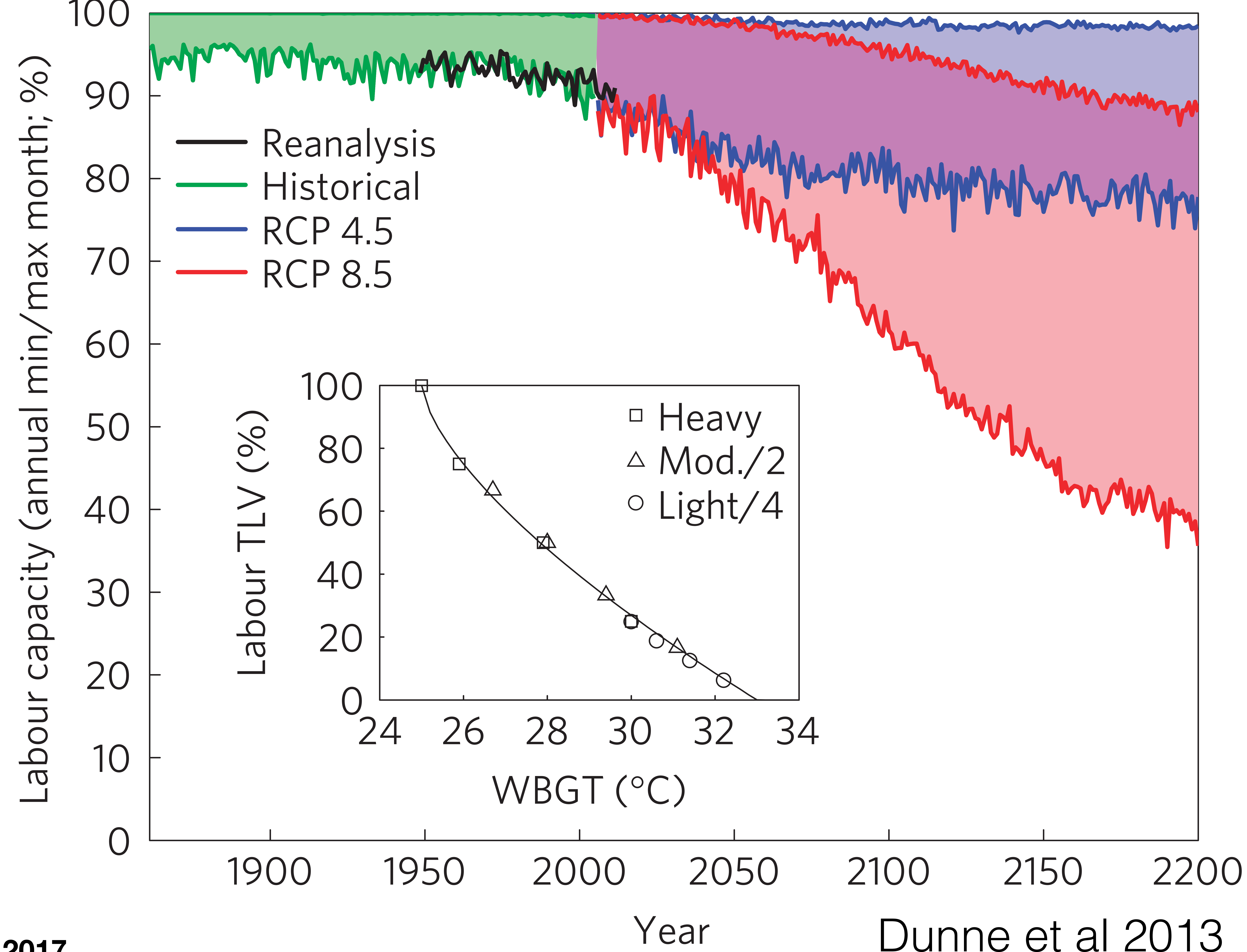

Dunne et al 2013

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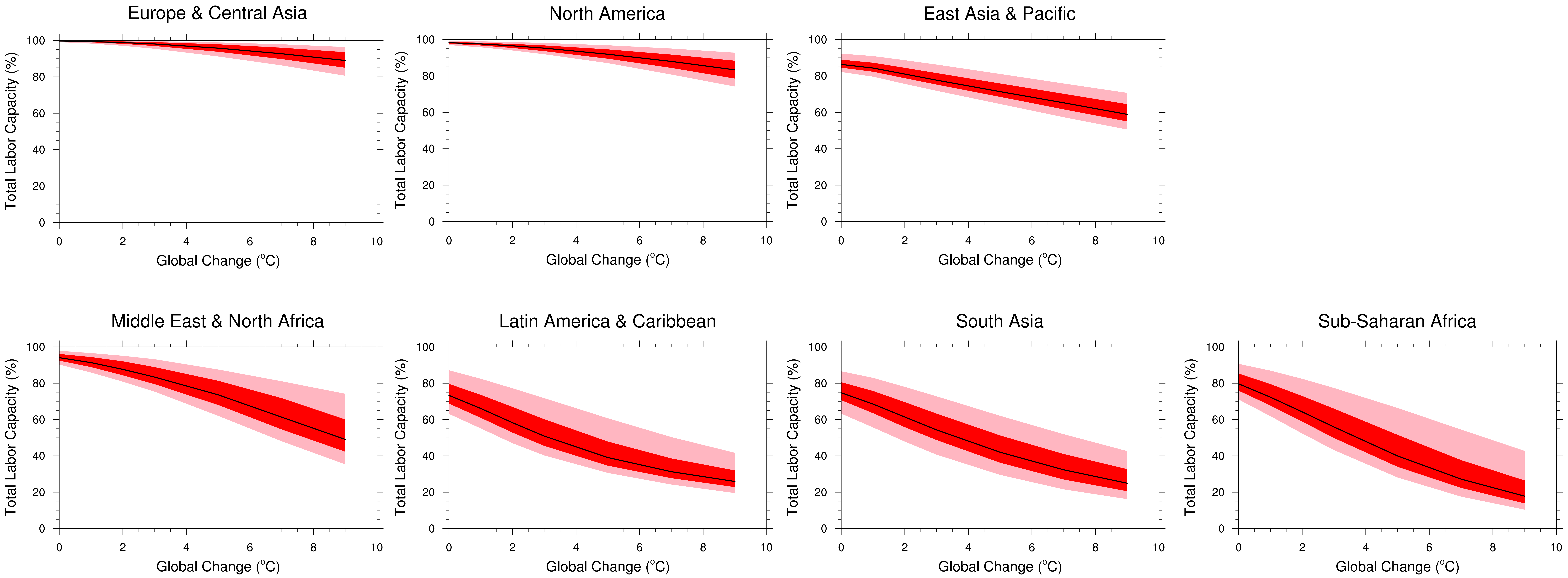
Analyzing the 18 member CMIP 5 ensemble and apply same calibration as Dunne et al

We find massive reductions in labor capacity for large warmings, especially in the ‘global South’



Matthew Huber, 2017

Conclusions

- Temperature AND humidity are important for heat stress and we have had not good general theoretical understanding of how the co-variances of these quantities might change in the future
- We must look carefully at futures that must be avoided and make a compelling case why they must be avoided
  - People (and livestock) will suffer great health and productivity losses in RCP 8.5 (i.e. for ~5°C warming) even in midlatitudes. Results unlikely to be strongly model dependent after normalizing for global temperature change (i.e. different sensitivity)
  - Labor capacity especially in warm, wet, developing nations will be reduced by ~50% with 5°C of warming
  - Warming of much greater that 5°C is distinctly possible by 2300 in RCP 8.5 extension runs and would have existential ramifications for much of human and other life over half the globe

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