Climate extremes
Motivation and guiding questions

Erich Fischer
Institute for Atmospheric and Climate Science
ETH Zurich
erich.fischer@env.ethz.ch

ETH zürich

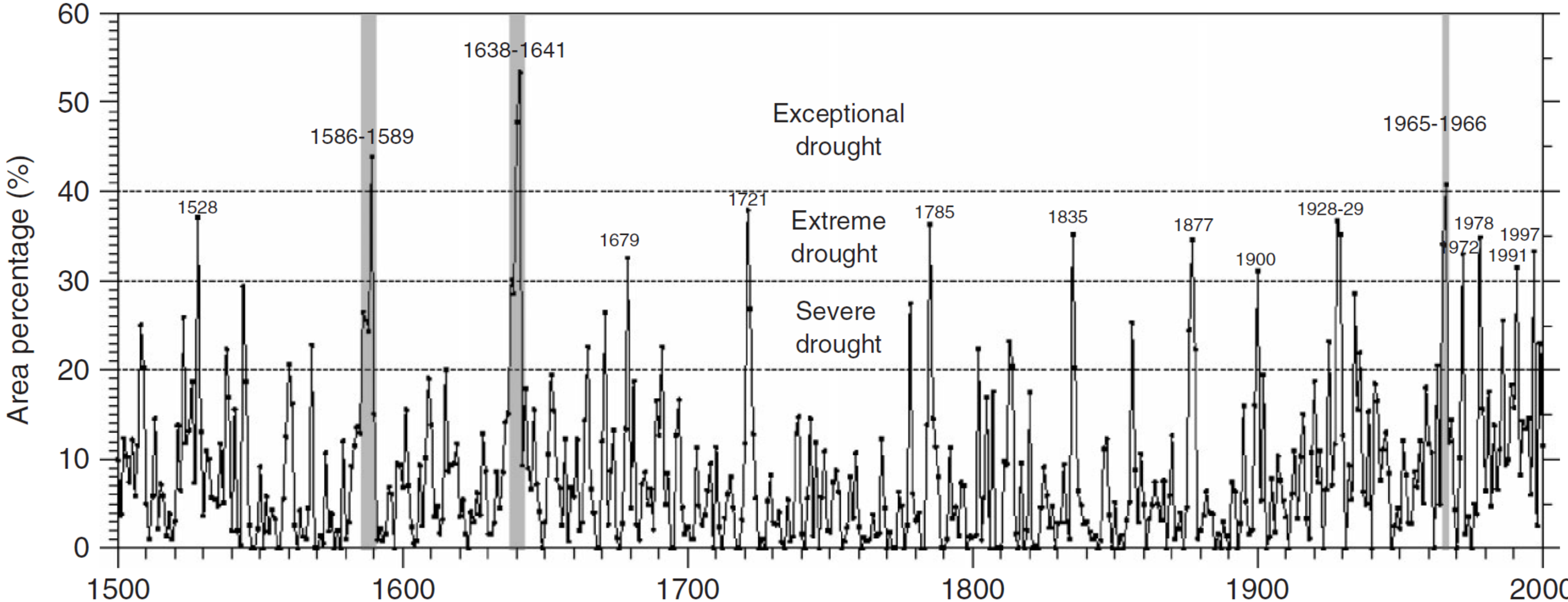
How can we **define** and **quantify** climate extremes?

Why care?

Haven't these events occurred before?

Basel, September 1852
Flooding

Estimated historical droughts in China

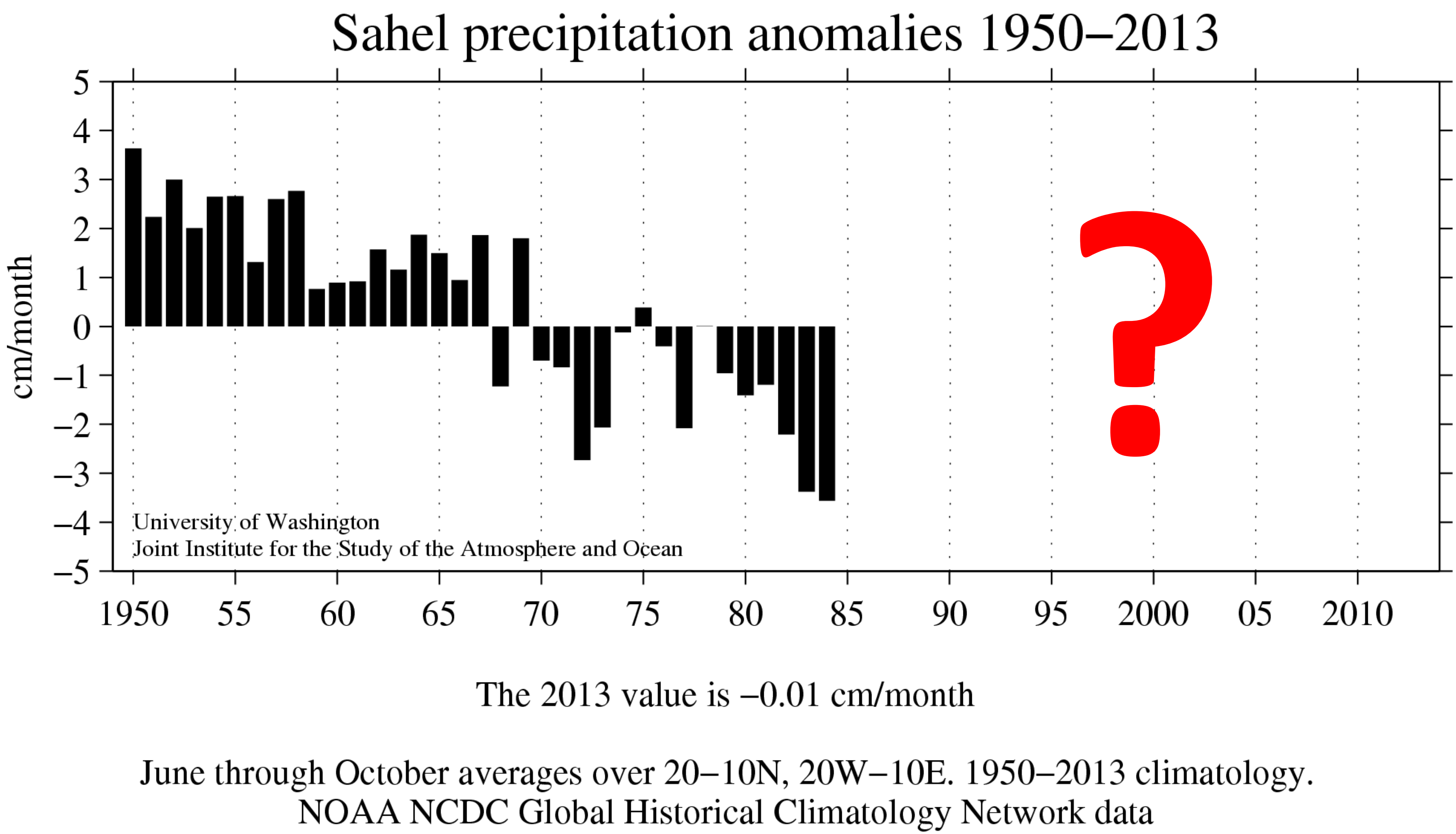


Dai et al. (2012)

Detection

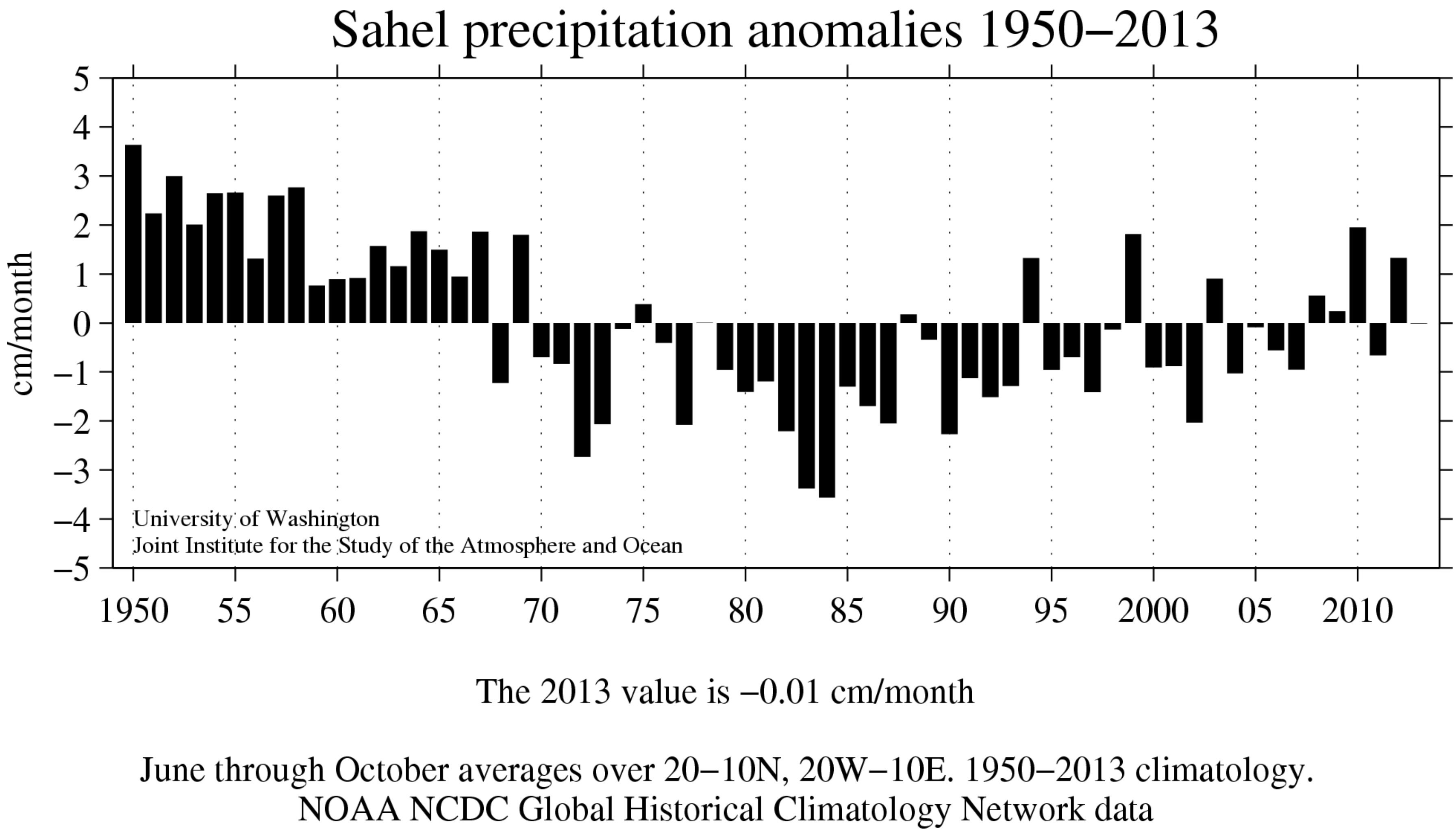
Have extremes changed more than expected by chance?

Climate change or not?



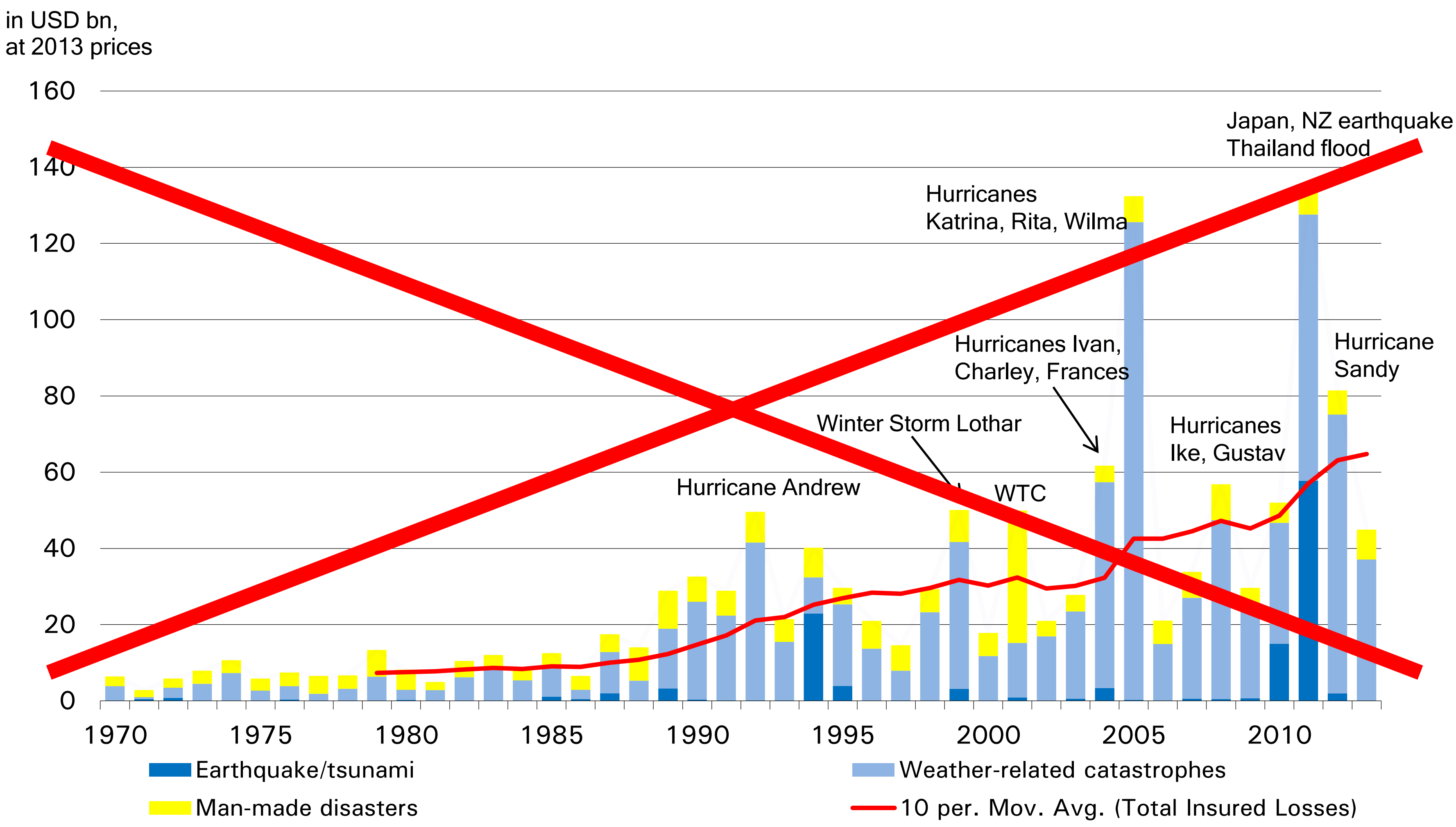
Davis and Caldeira (2010)

Climate change or not?



Davis and Caldeira (2010)

Has there been an increase in extremes?



Swiss Re (2013)

Attribution

Why have they changed?

Today’s occurrence

What is probability of extremes today and in the near future?

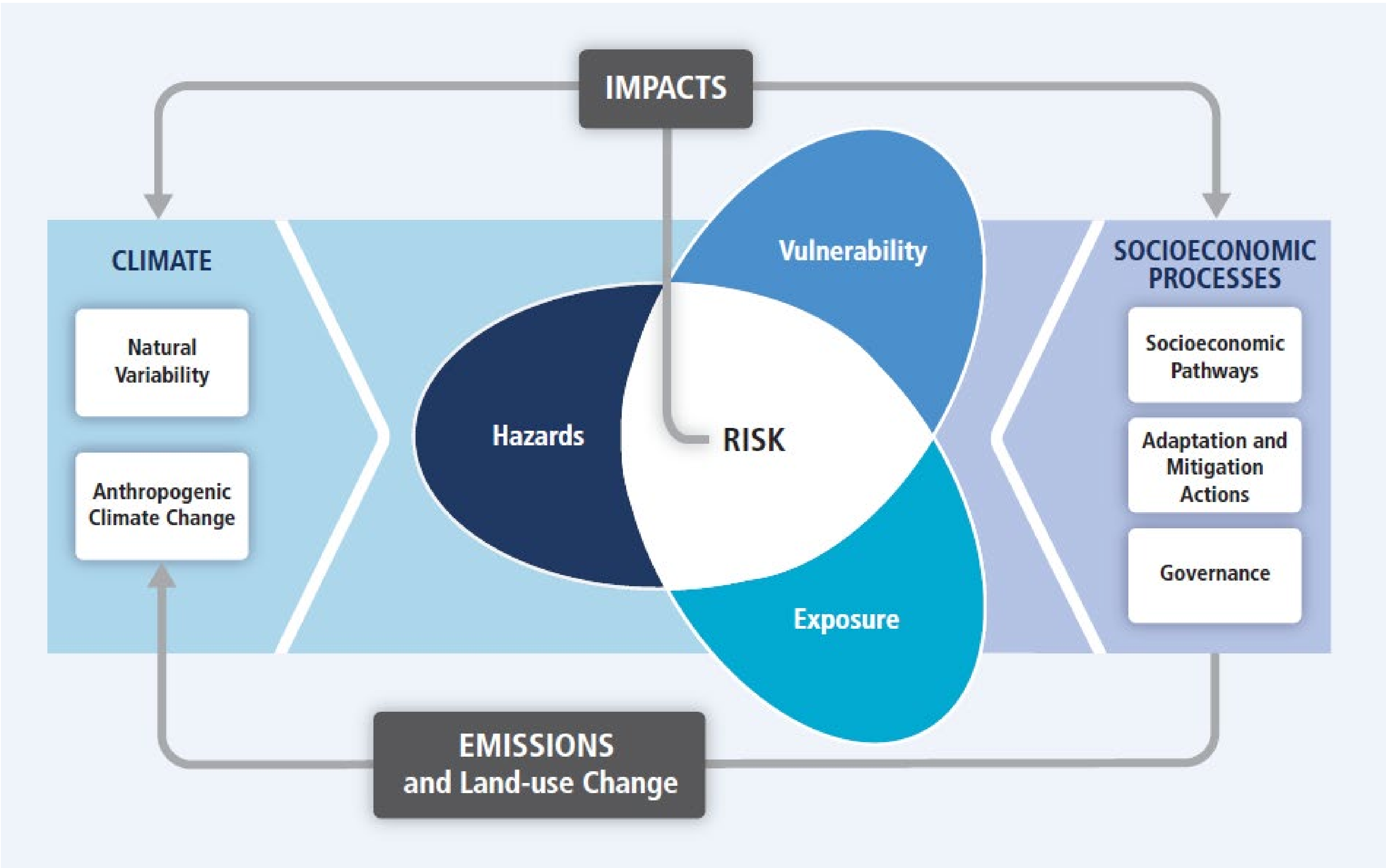
Future climate

How are extremes changing in the future? And **why**?

The risk perspective

How do we get from the hazard to the risk?

Risk is more than hazard probability



Heatwaves
Definition, metrics and drivers

Erich Fischer
Institute for Atmospheric and Climate Science
ETH Zurich
erich.fischer@env.ethz.ch

ETH zürich

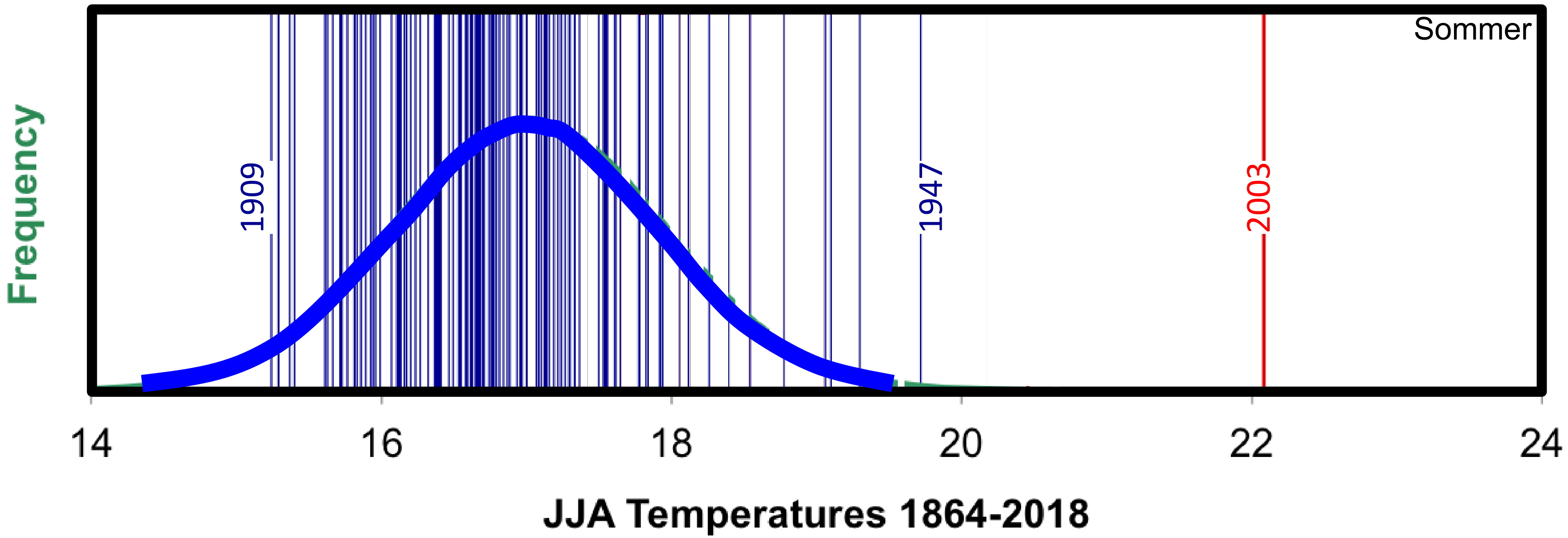
Outline

- Definition of temperature extremes
- Metrics of heatwaves
- Physical drivers of heatwaves

Definition and metrics

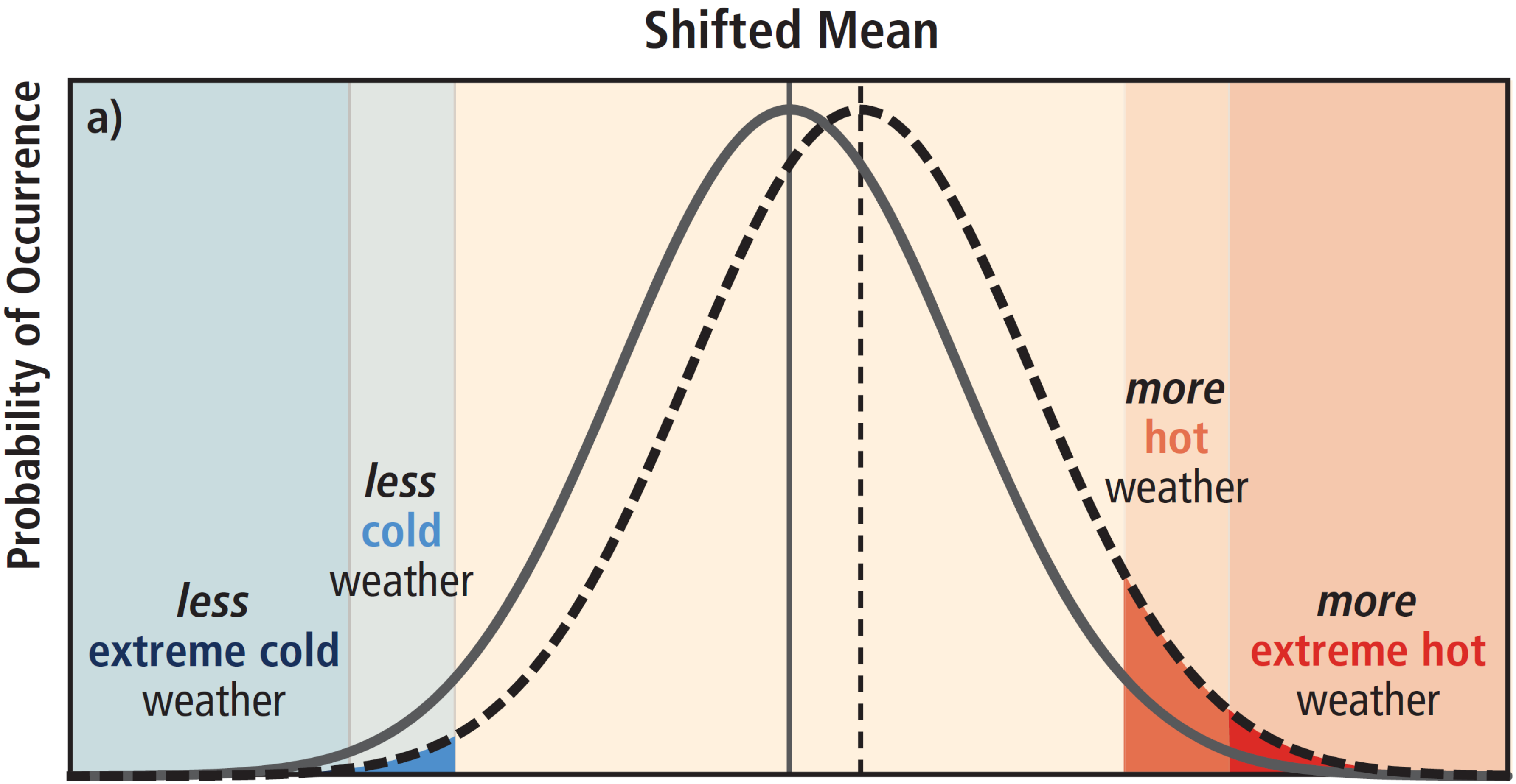
The prime example of an extreme

Average summer temperature at 4 Swiss stations



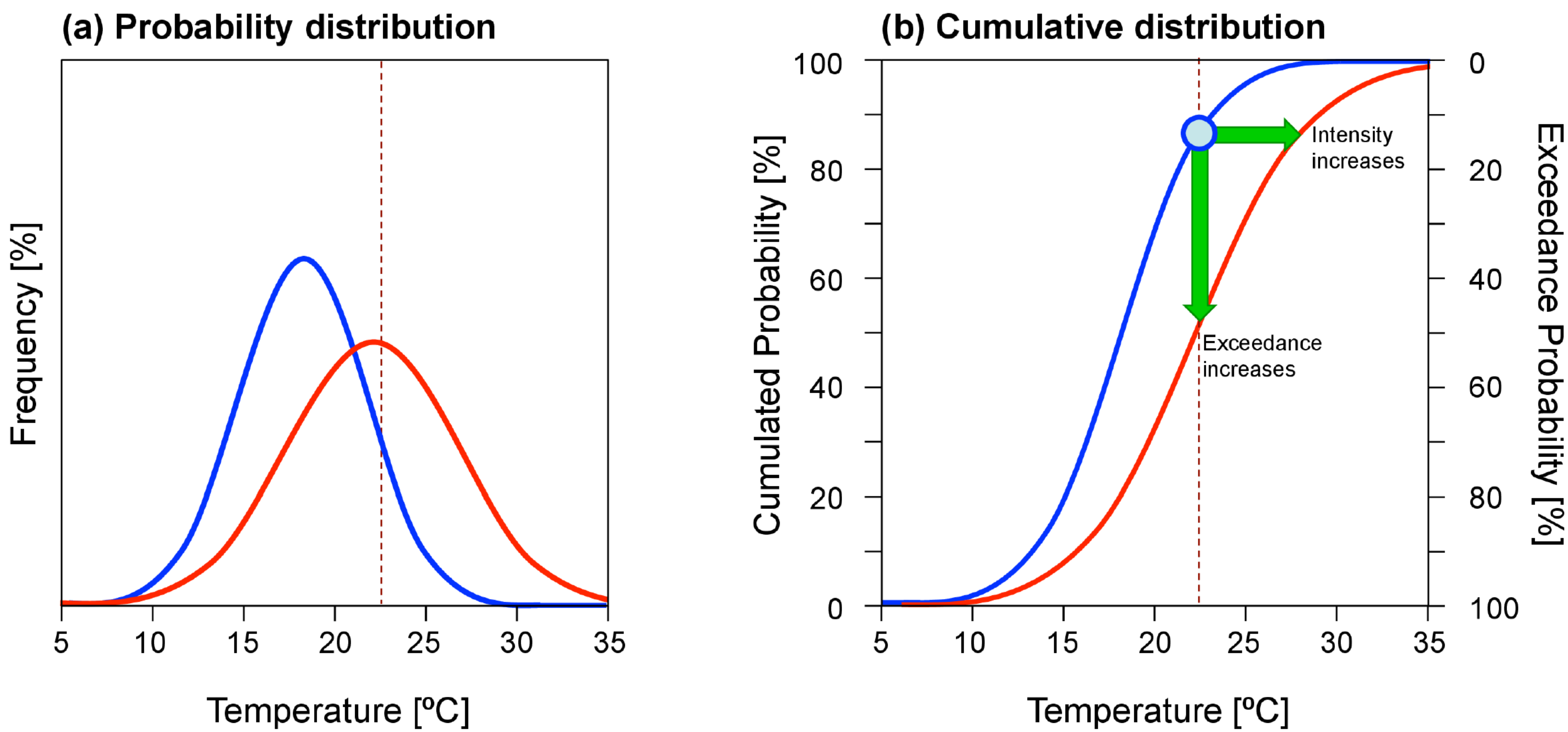
Schär et al. 2004, *Nature*

Schematic changes in temperature extremes



IPCC SREX (2012)

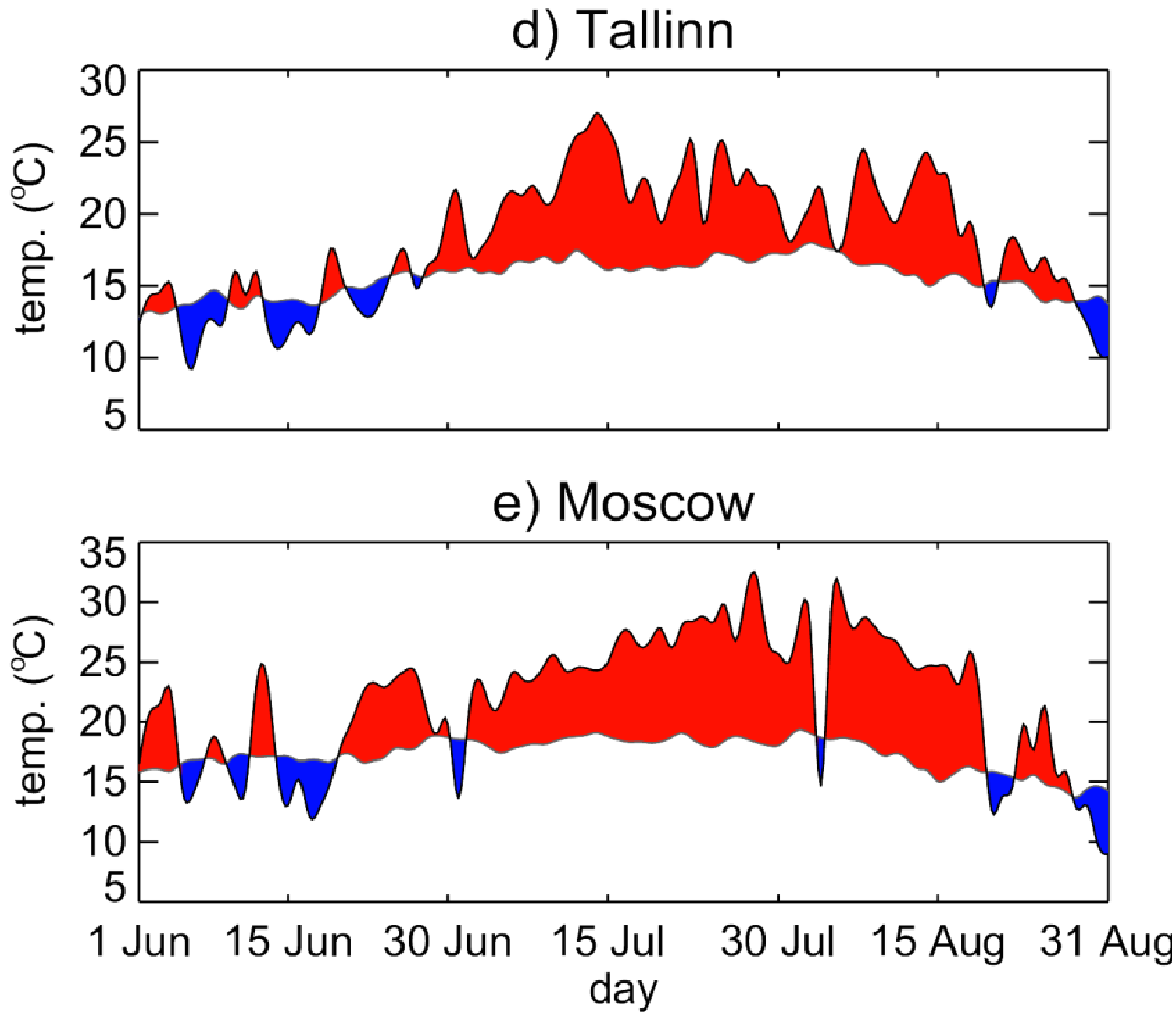
Changes beyond the mean



CH2018 Swiss National Climate Scenarios (2018)

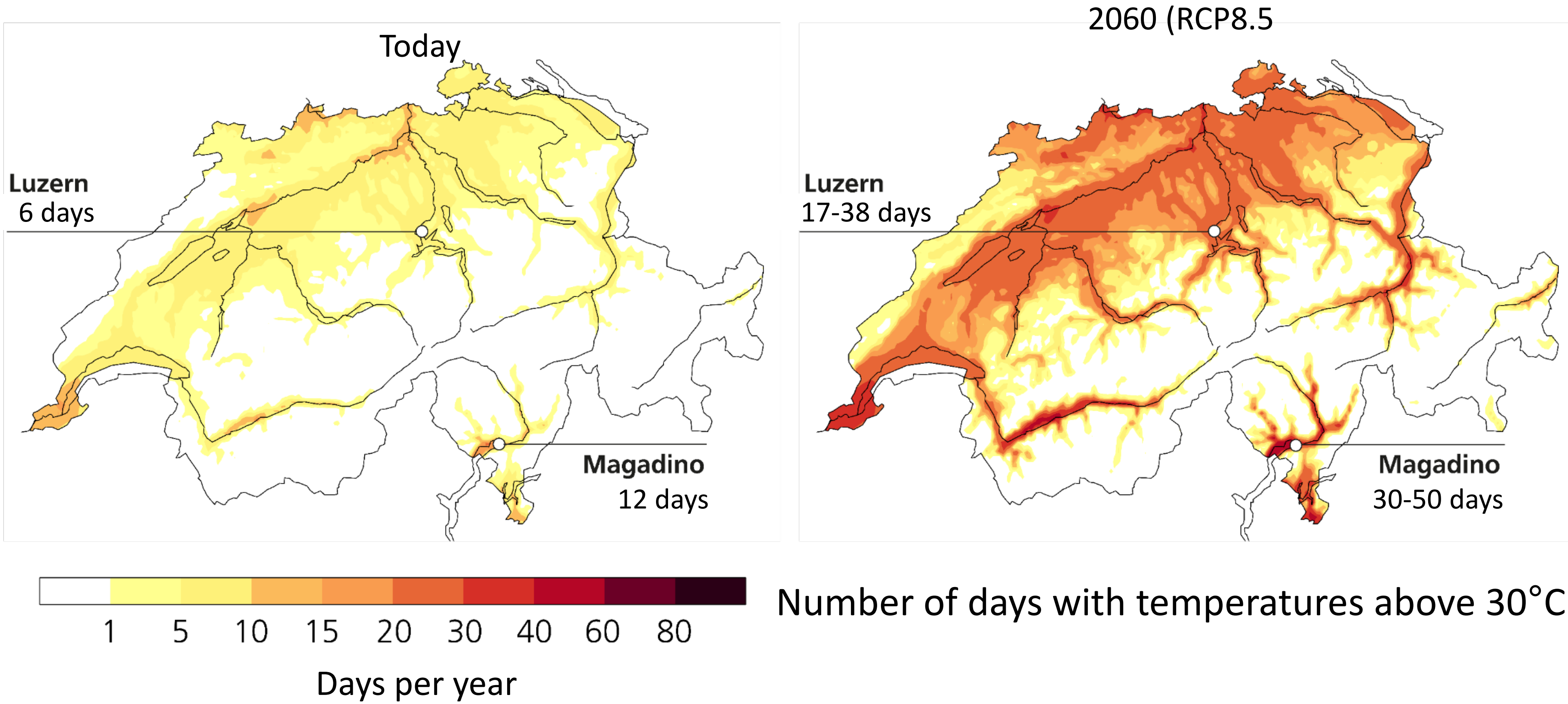
Heatwave metrics

2010 Russian heat wave



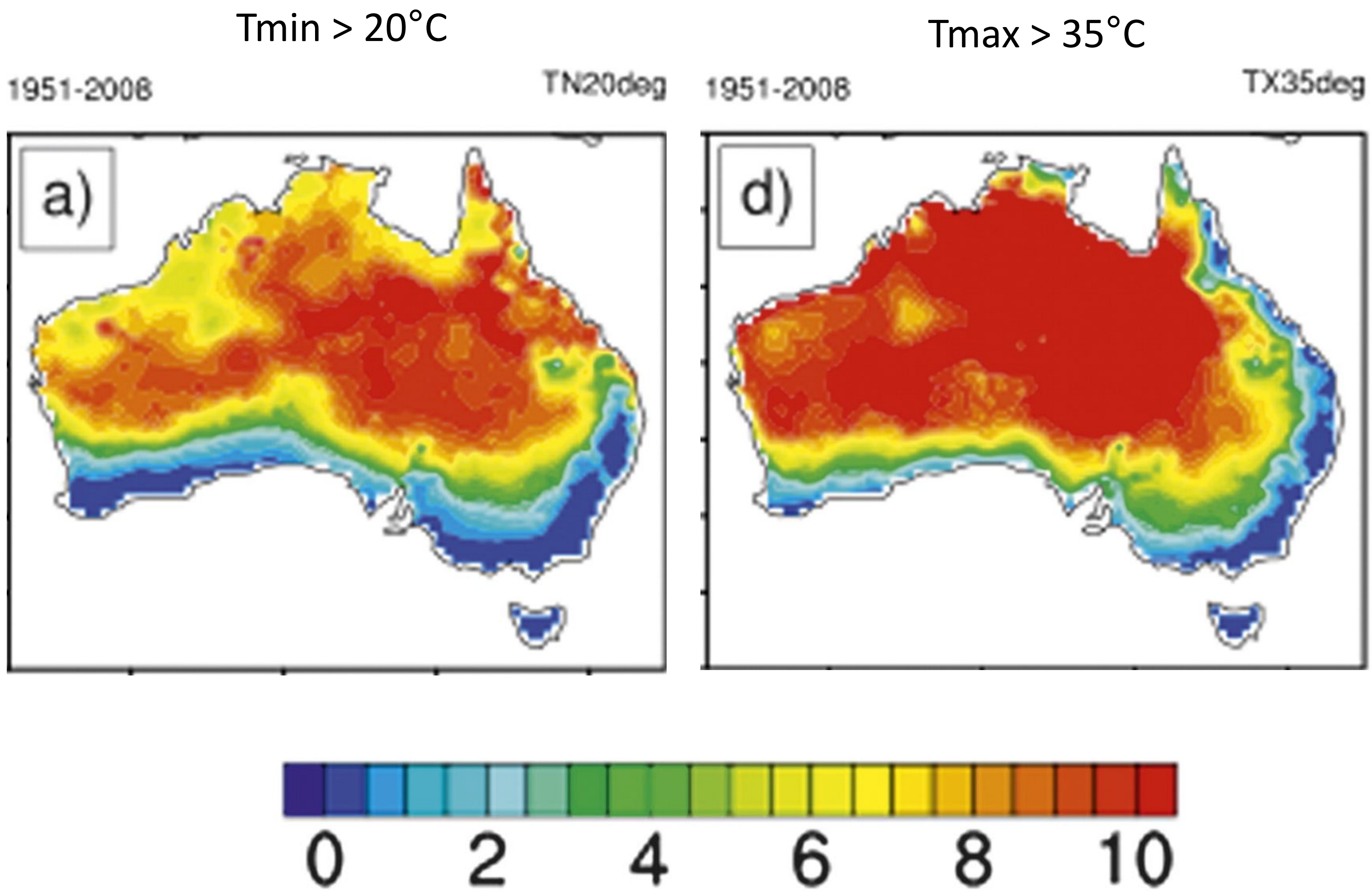
Barriopedro et al. 2011, *Science*

Fixed threshold indices – powerful communication



Number of days with temperatures above 30°C

Fixed thresholds – challenging for large regions



Perkins and Alexander 2013, *J Climate*

Fixed threshold indices

Pros:

Accessible and easy to interpret

Potentially impact-relevant

Cons:

Difficult to map across different climate zones

Zero days in one regions (e.g. mountains or polar regions) all days in others (e.g. tropics)

Ignores different adaptation level in cold and warm climates

Change depends on base state

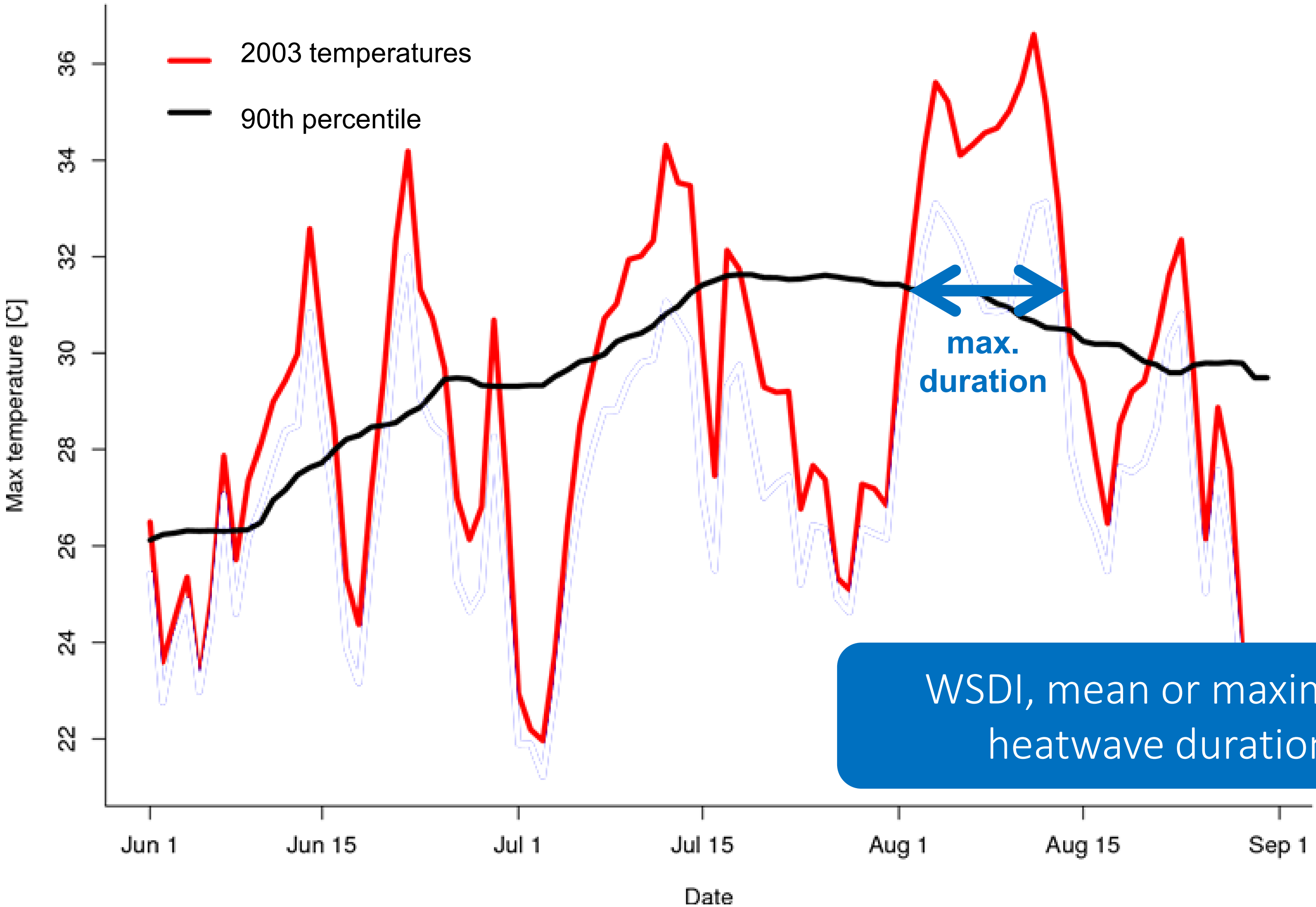
Bias-adjustment needed (sensitive to small biases in mean state)

Warm spell duration index

WSDI	Warm spell duration indicator	
Annual count when at least six consecutive days of max temperature > 90th percentile		days

Zhang et al. (2011), *WIRE*

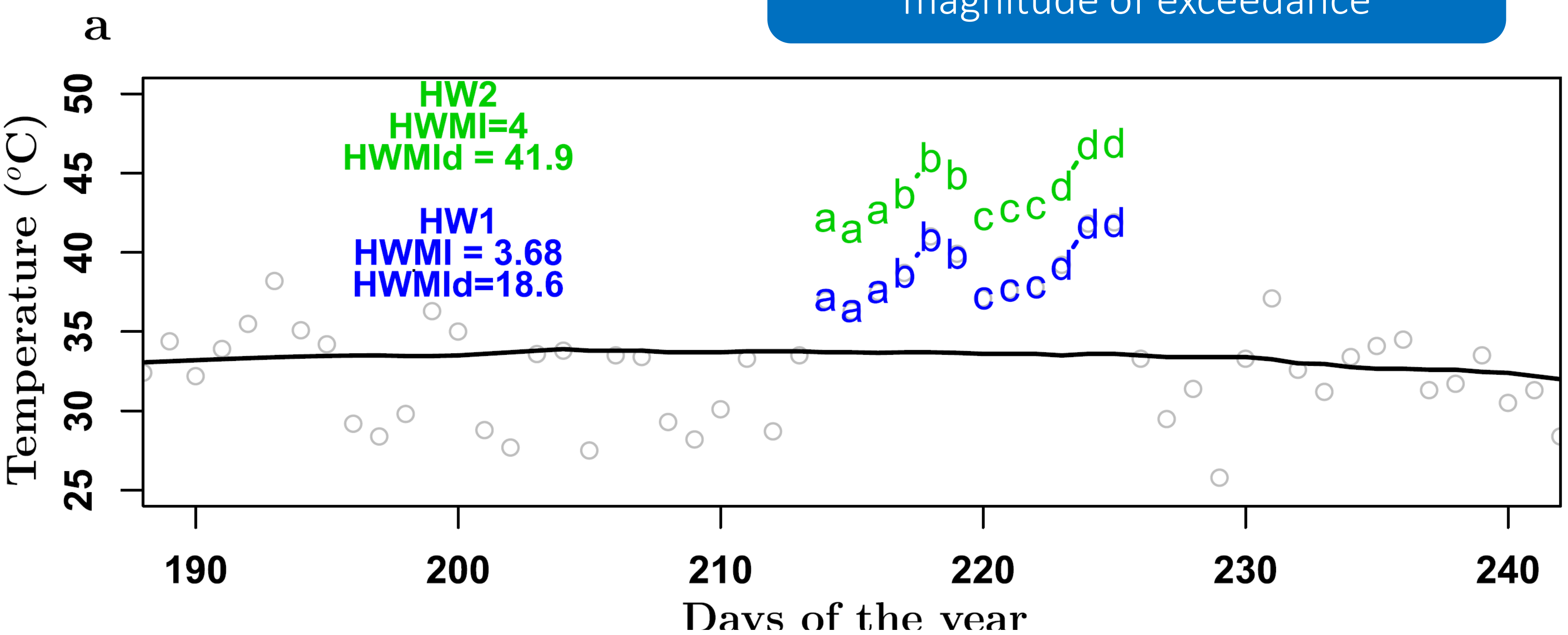
Warm spell duration index



WSDI, mean or maximum heatwave duration

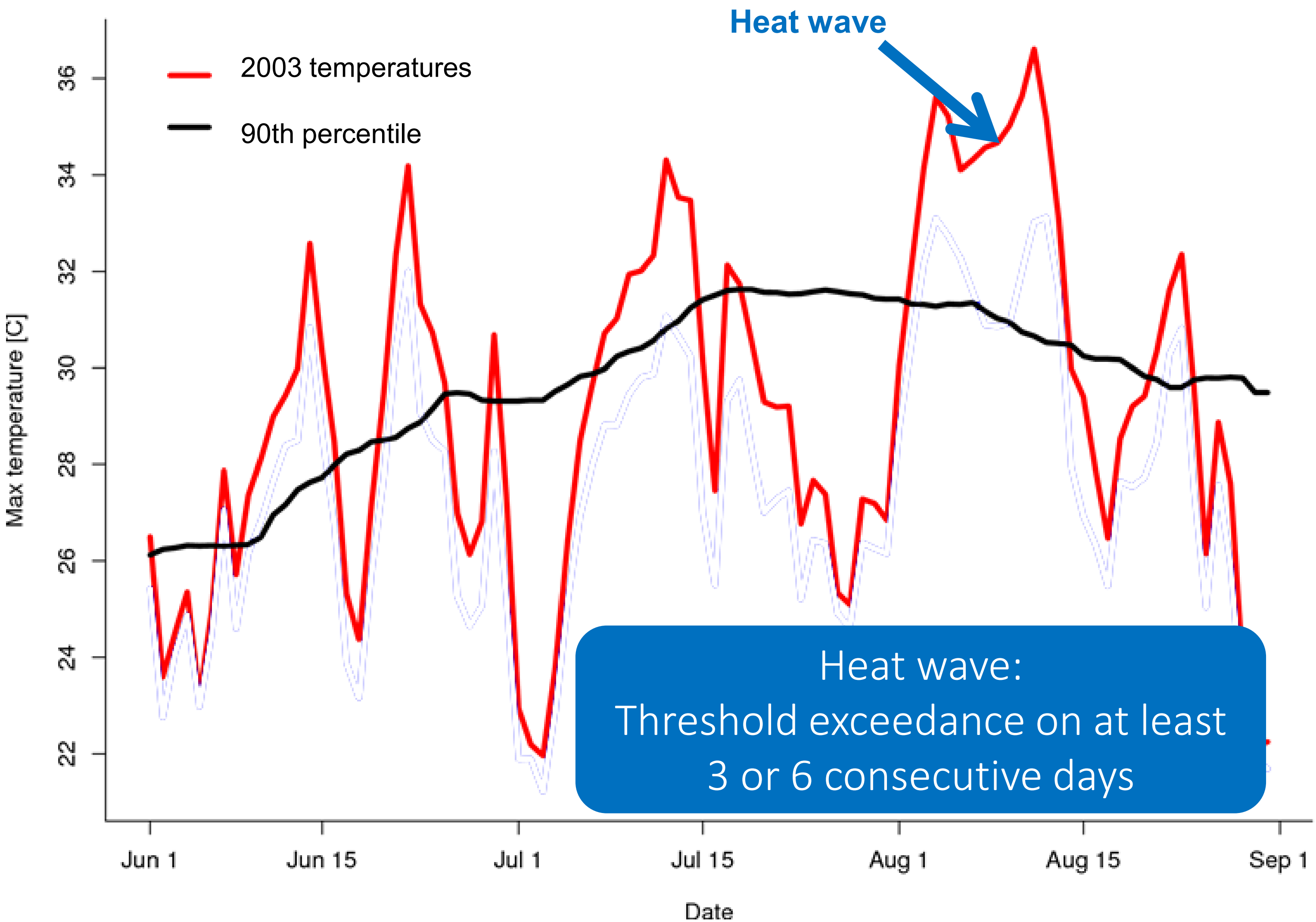
Limitations of WSDI

WSDI only quantifies duration but not magnitude of exceedance



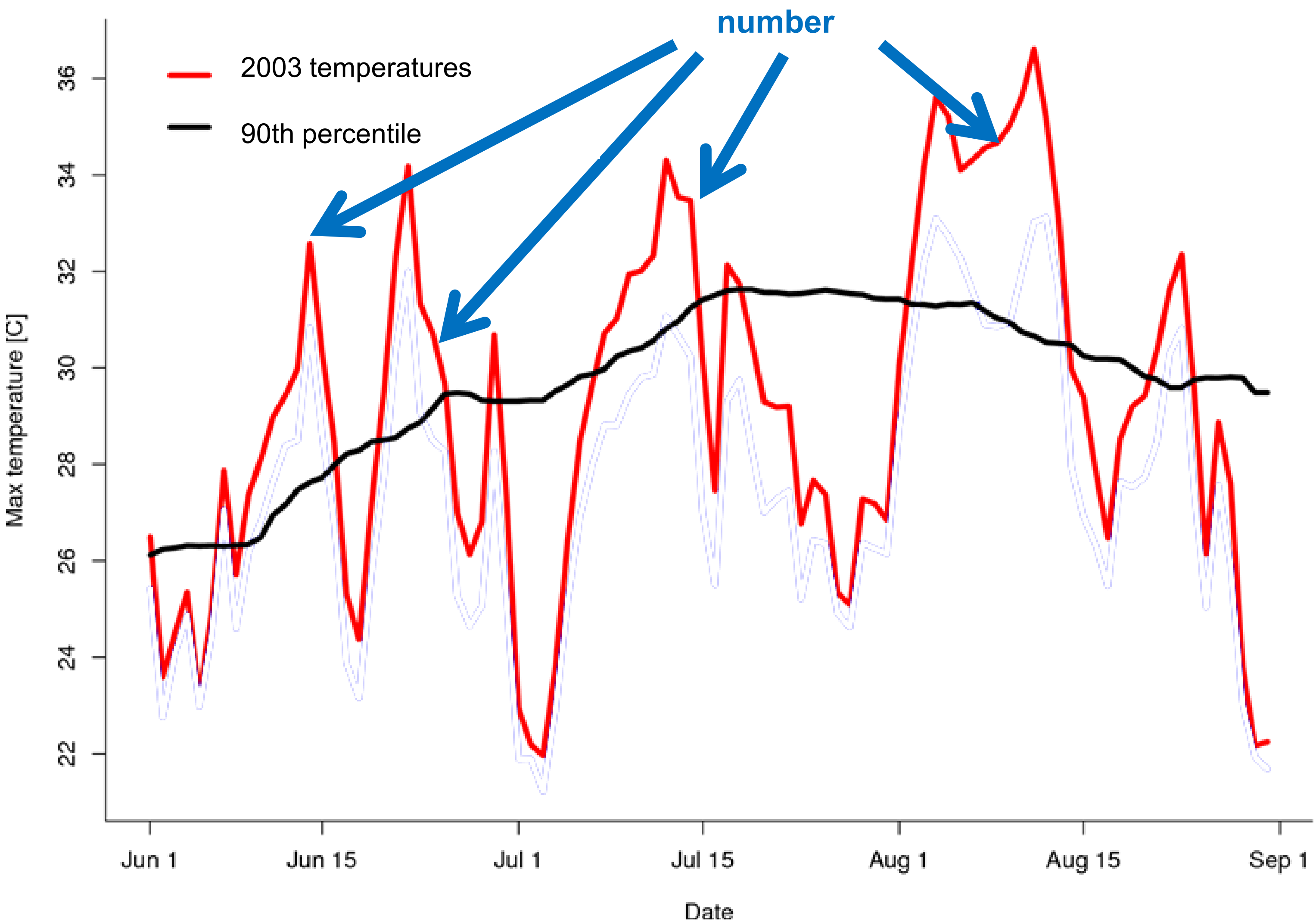
Russo et al. (2015) *ERL*

No universal heatwave definition



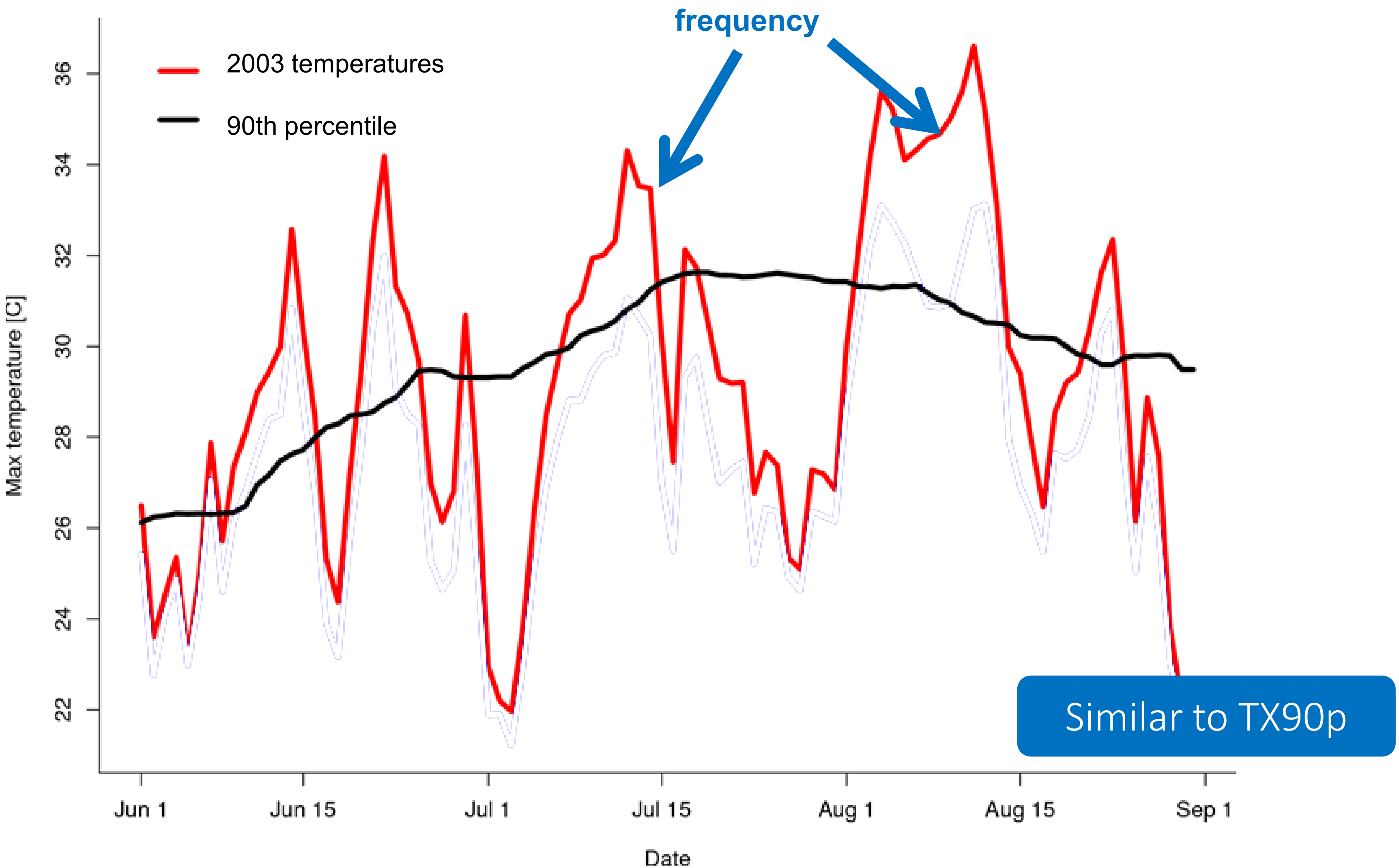
Fischer and Schär (2010), *Nature Geoscience;* Perkins and Alexander *(2013), J Climate*

Number of heatwaves



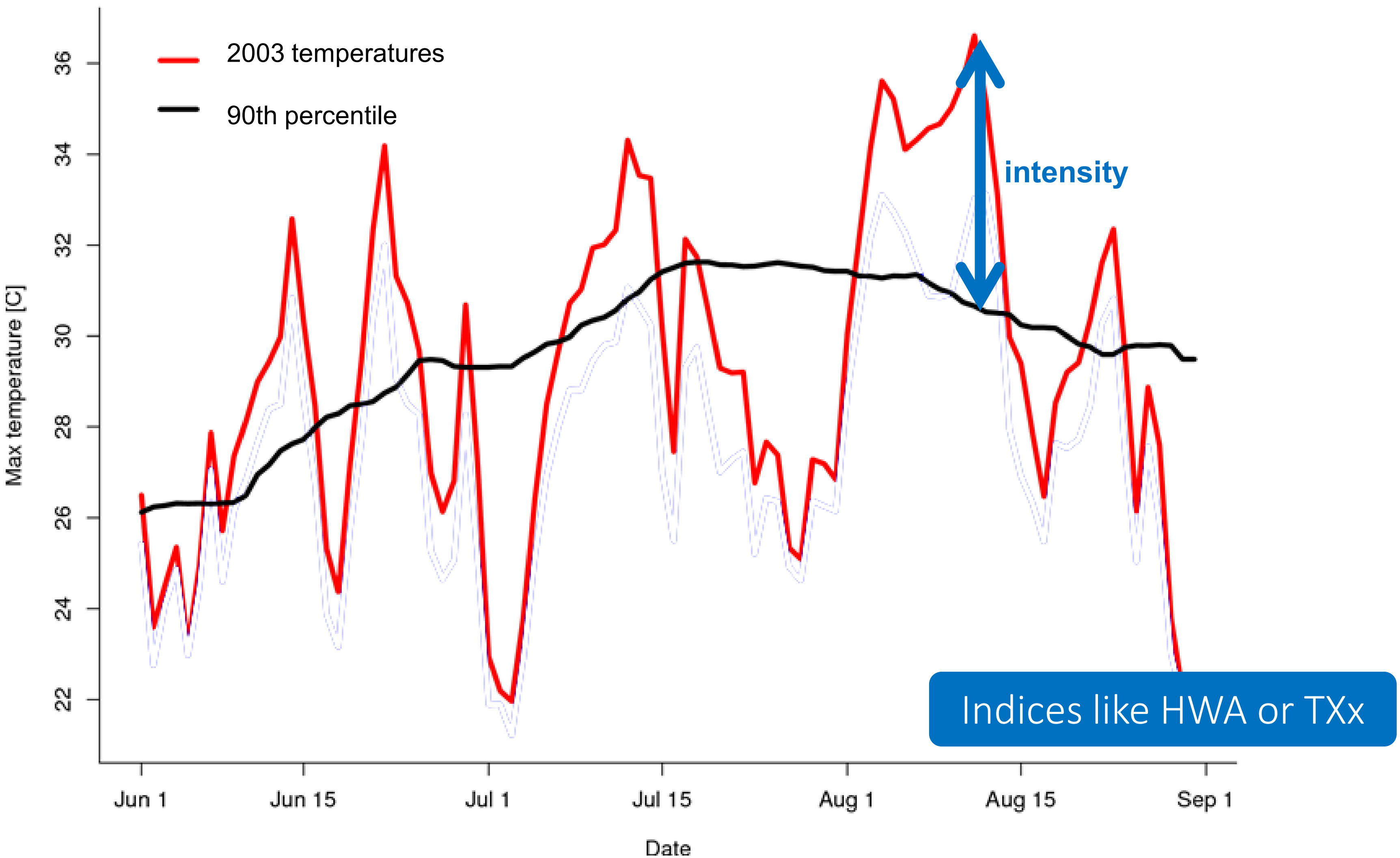
Fischer and Schär (2010), *Nature Geoscience;* Perkins and Alexander *(2013), J Climate*

Heatwave-day frequency



Fischer and Schär (2010), *Nature Geoscience;* Perkins and Alexander *(2013), J Climate*

Intensity/magnitude/amplitude of heatwave



Fischer and Schär (2010), *Nature Geoscience;* Perkins and Alexander *(2013), J Climate*

Percentile-based thresholds

Pros:

Easy to compare different models, reanalyses and observations

Applicable at global scale

Simple way of accounting for adaptation to local climate

Change is independent of base state

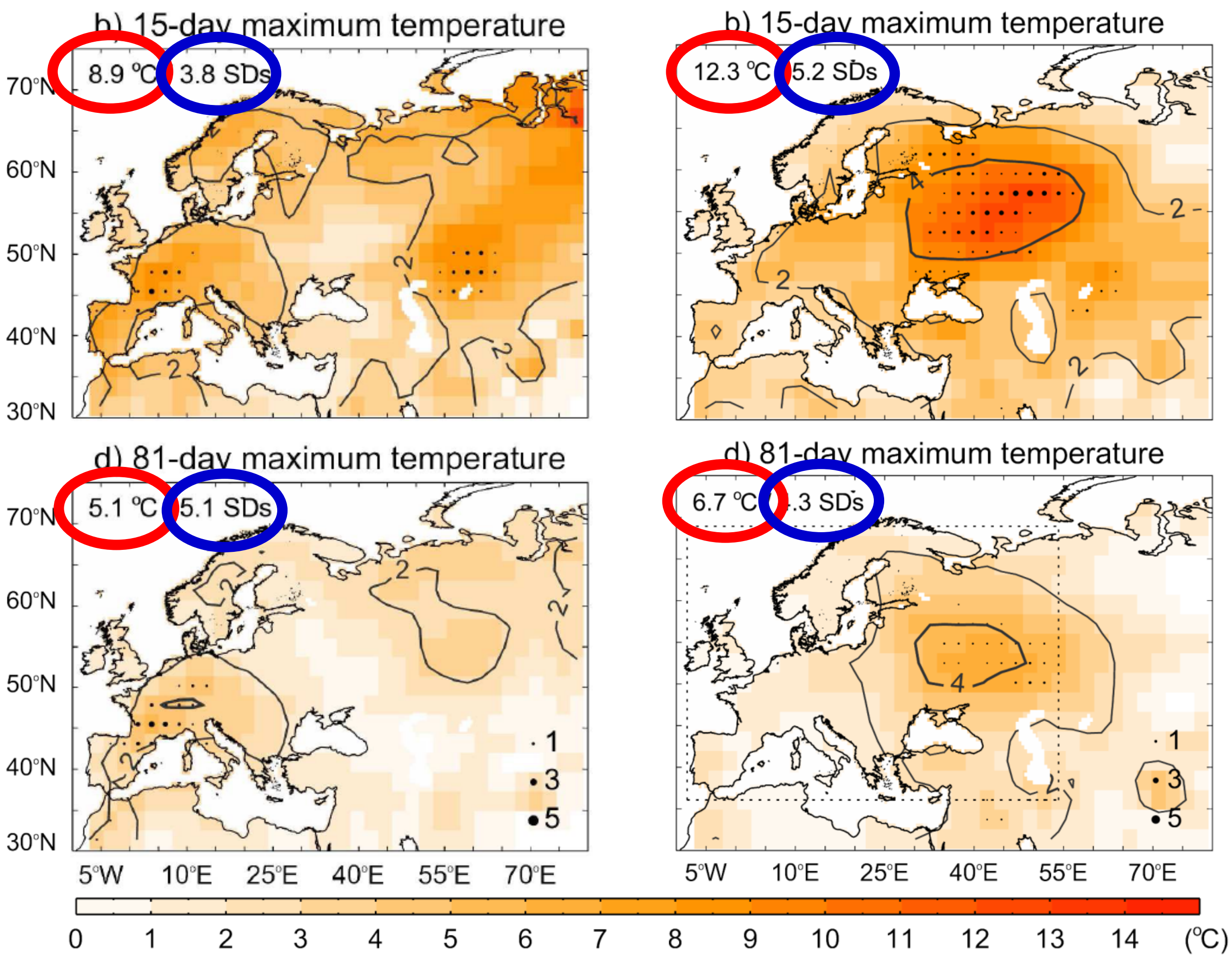
Cons:

Difficult interpret and associate with personal experience

Depends on definition of percentile (time-invariant or seasonally-varying)

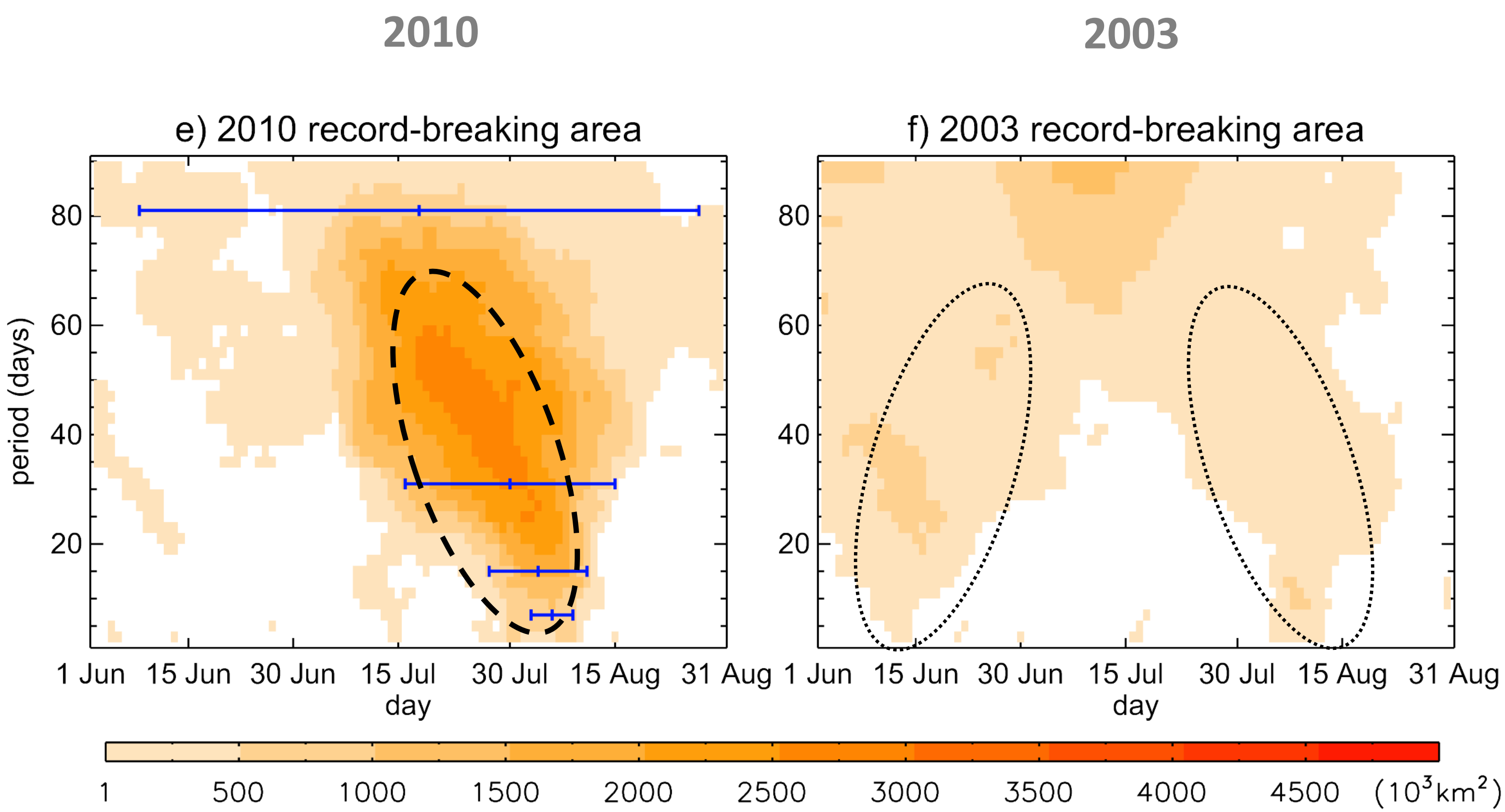
Larger or smaller? A question of definition

HW intensity 2003 | **HW intensity 2010**



Barriopedro et al. 2011, *Science*

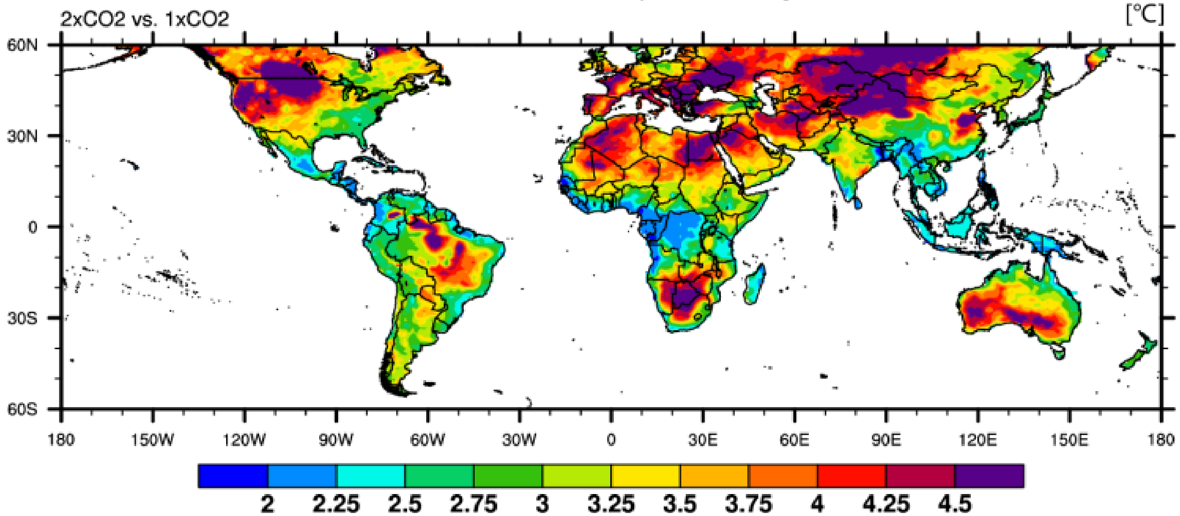
Spatial extent of record-breaking area



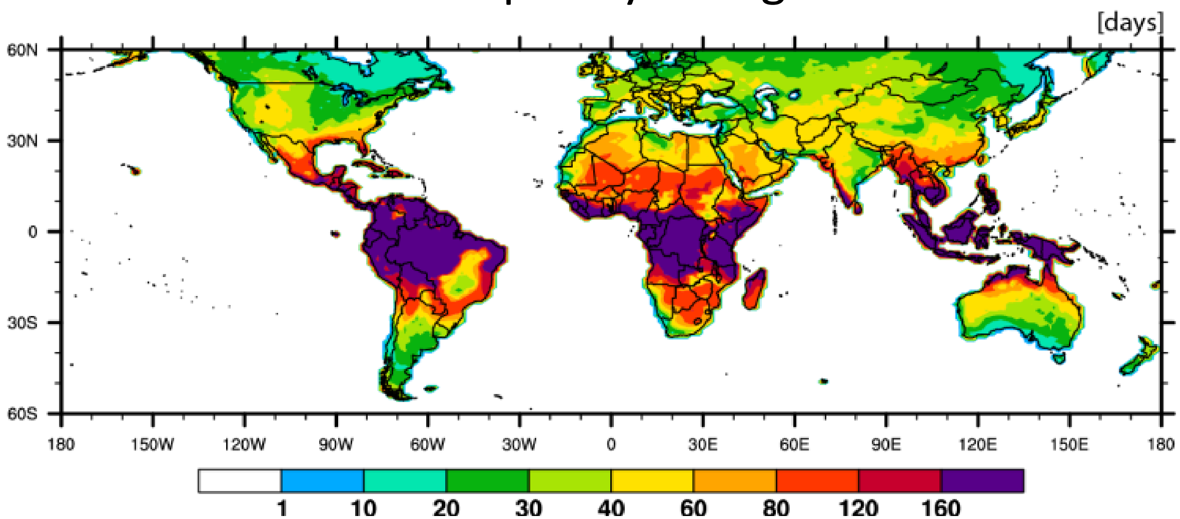
Barriopedro et al. 2011, *Science*

Indices matter: Frequency vs. intensity

(a) Intensity change

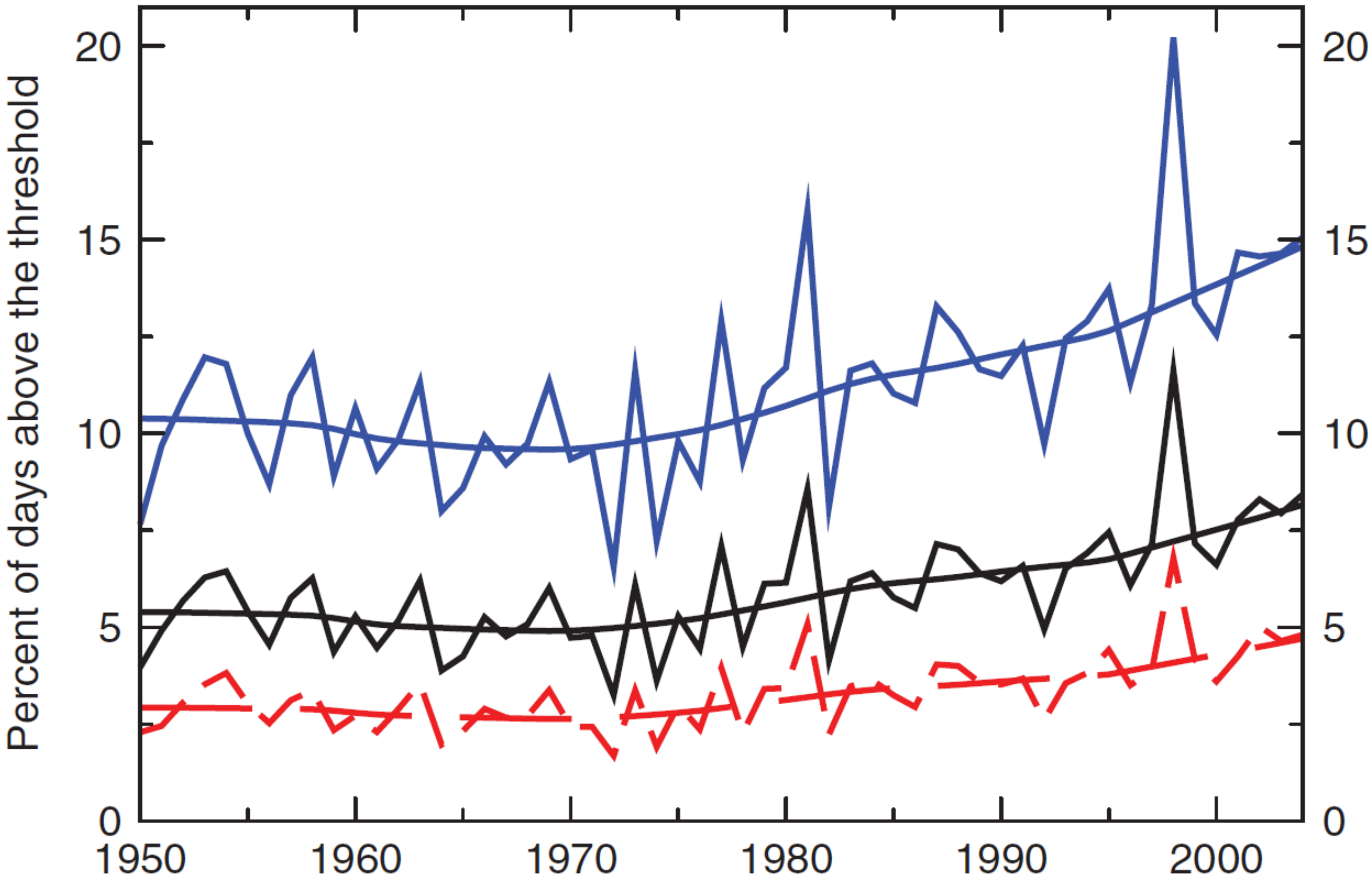


(c) Frequency change



Fischer et al. 2012, *GRL*

Changes depend on quantile



The more extreme
the higher the change

Zhang et al. 2011
Peterson et al. 2008

The quest for universal indices

Environmental Research Letters

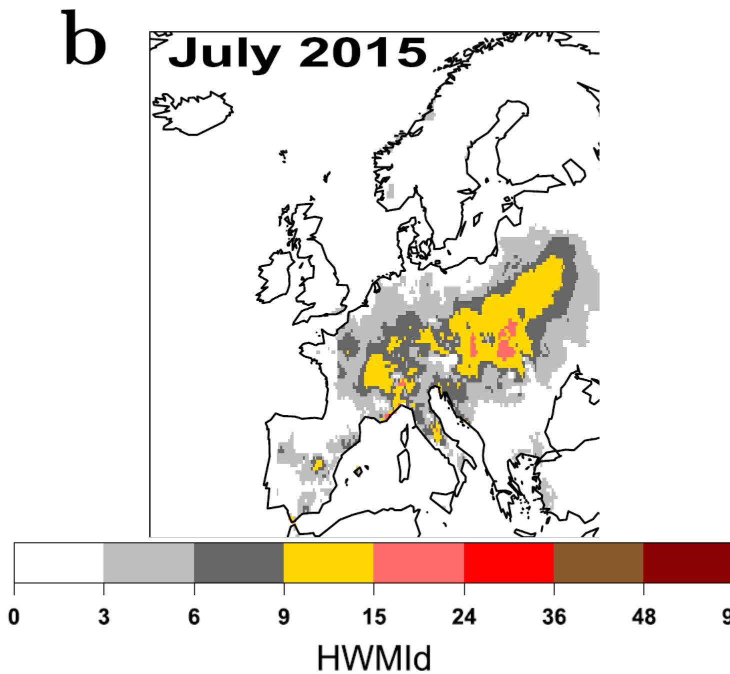
LETTER

Top ten European heatwaves since 1950 and their occurrence in the coming decades

Simone Russo[1,2], Jana Sillmann[3] and Erich M Fischer[4]

1 European Commission, Joint Research Centre, Ispra, Italy
2 Institute for Environmental Protection and Research (ISPRA), Rome, Italy

$$M_d(T_d) = \begin{cases} \dfrac{T_d - T_{30y25p}}{T_{30y75p} - T_{30y25p}} & \text{if } T_d > T_{30y25p} \\ 0 \quad \text{if } T_d \leqslant T_{30y25p} \end{cases}$$



Russo et al. (2015) *ERL*

Recommendations

- There are tradeoffs between simplicity and comprehensiveness
- Universal indices may help to identify hotspots
- Understanding the changes requires breaking down in different characteristics
- Impact studies require indices tailored to the problem

Remember that your finding may

depend on the index

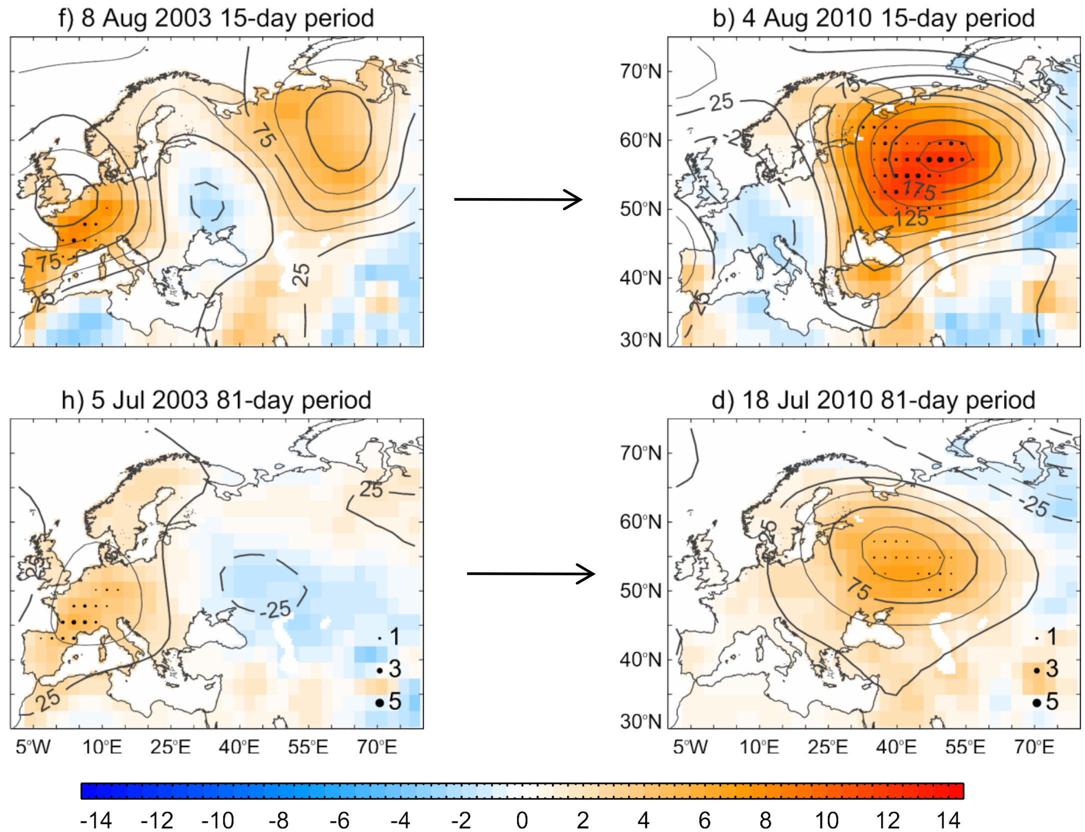
Physical drivers of heatwaves

Anticyclonic anomaly

2003 2010

15-days

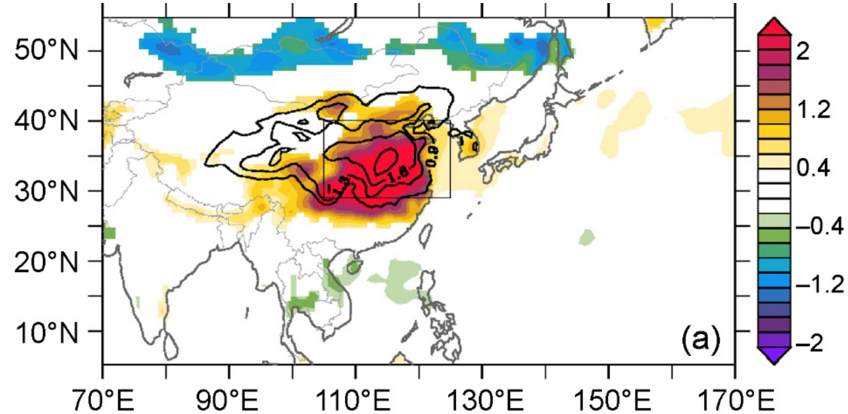
Summer



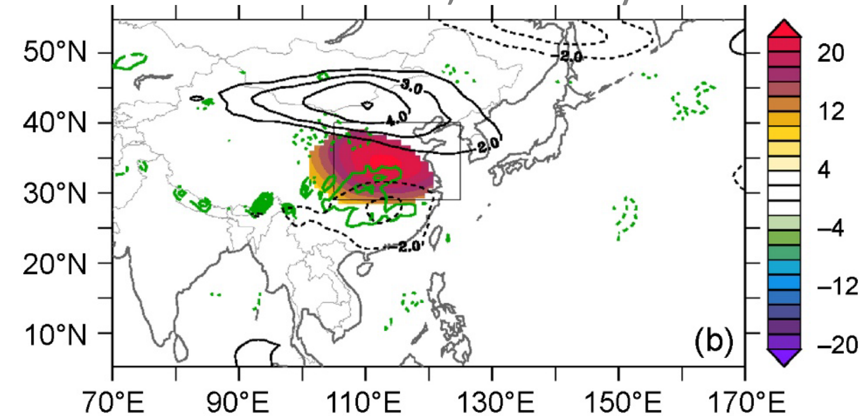
Barriopedro et al. 2011, *Science*

Same drivers in Central-Eastern China heatwaves

Min and max temp. anomaly



Z500 (colors) and U200 (black contours) anomaly

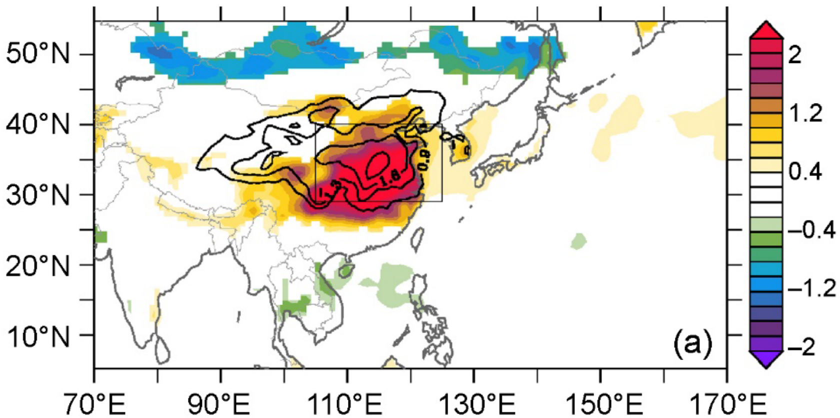


Anticyclones favor cloud-free conditions, lack of precipitation and subsidence -> adiabatic heating

Freychet et al. 2017, *ERL*

Same drivers in Central-Eastern China heatwaves

Min and max temp. anomaly



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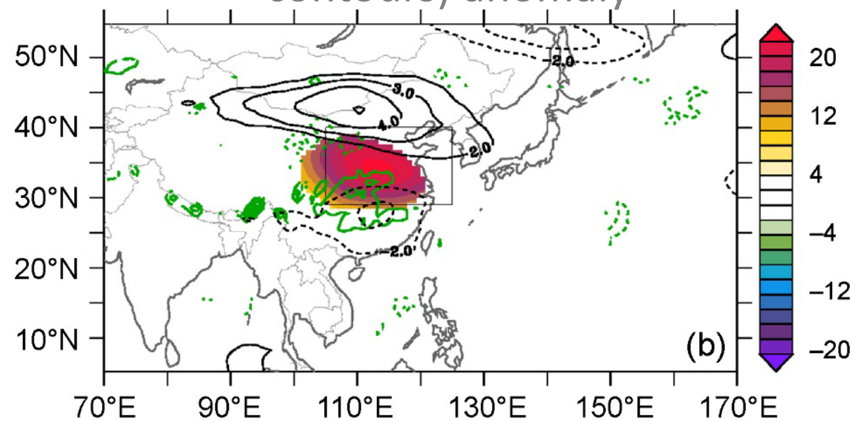
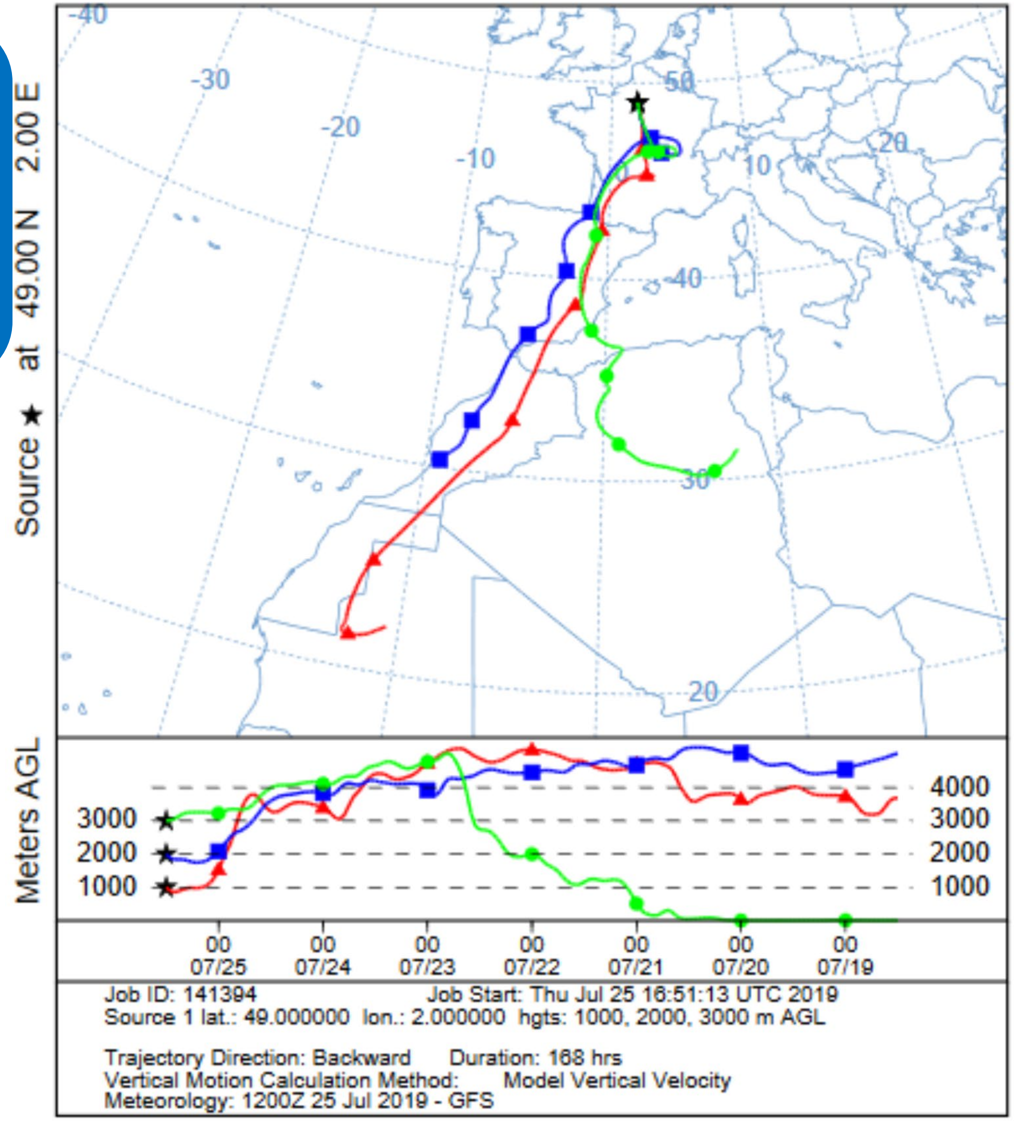


Anticyclones favor cloud-free conditions, lack of precipitation and subsidence -> adiabatic heating

Freychet et al. 2017, *ERL*

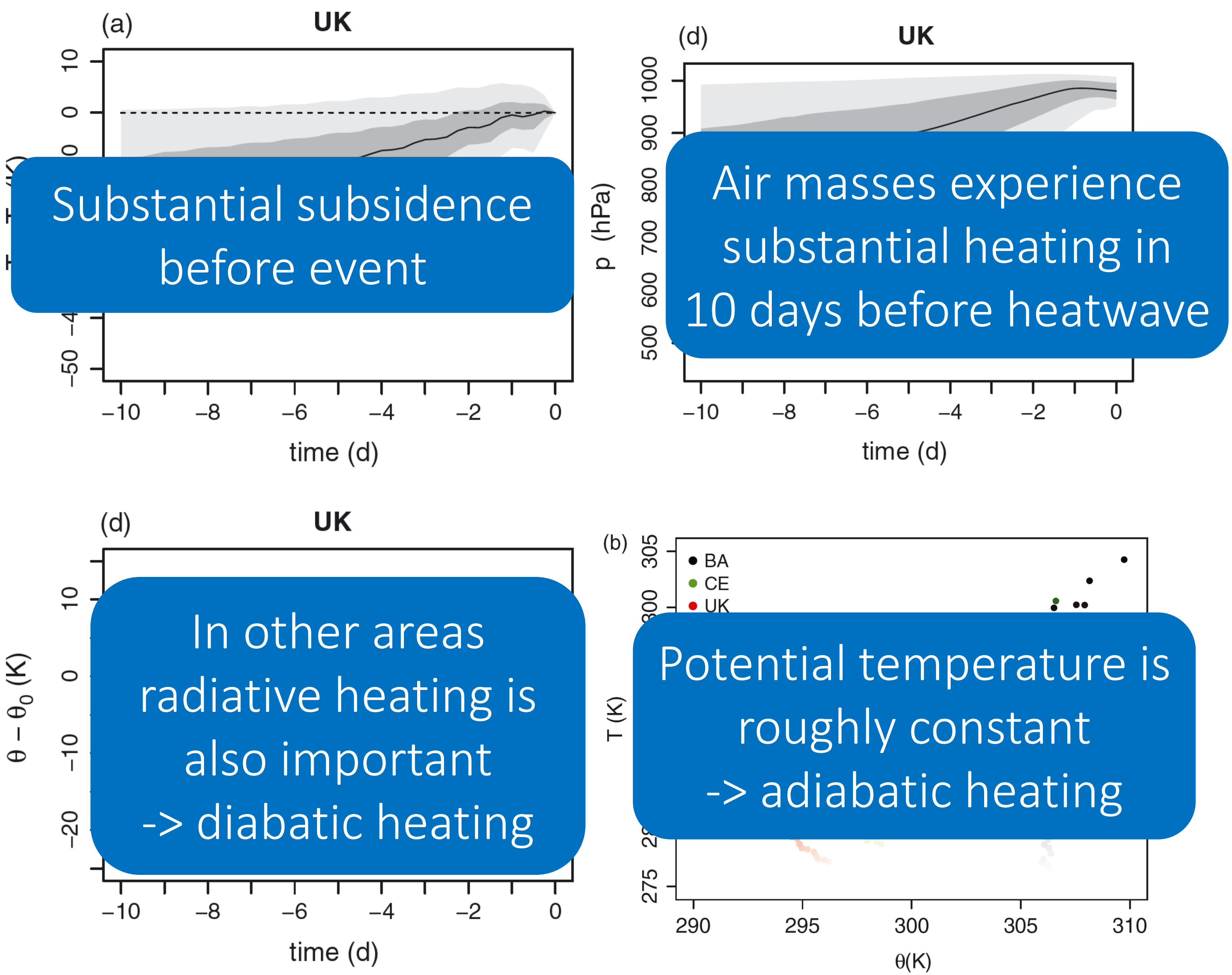
The Lagrangian perspective

Source of air masses may be remote and at higher levels (high potential temperature)



World Weather Attribution (2019)

The role of adiabatic heating



Substantial subsidence before event

Air masses experience substantial heating in 10 days before heatwave

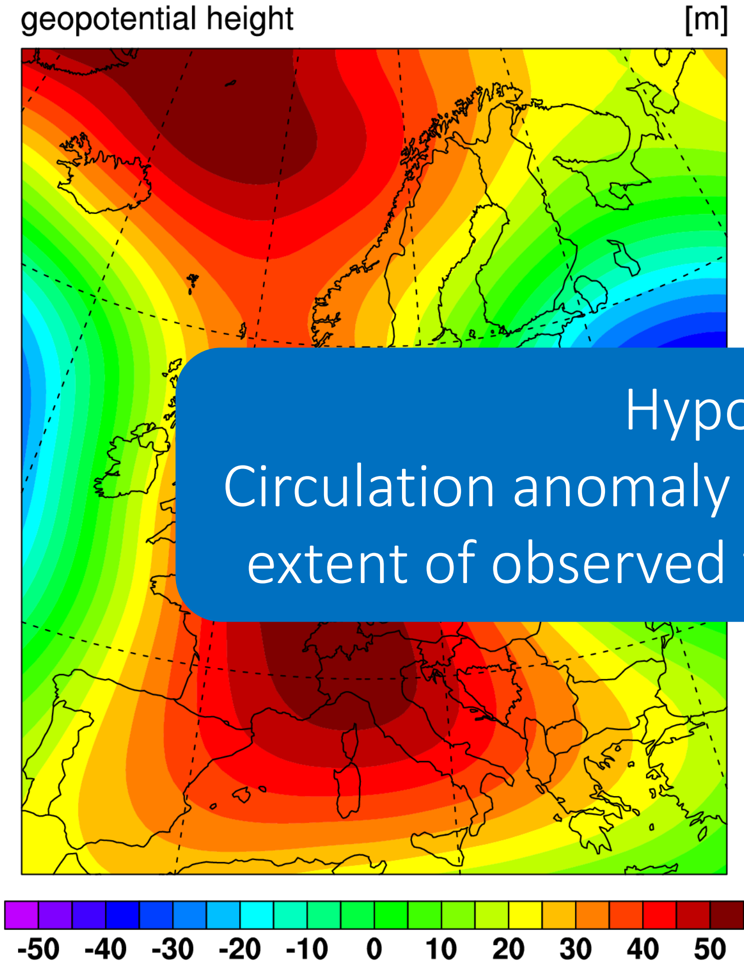
In other areas radiative heating is also important -> diabatic heating

Potential temperature is roughly constant -> adiabatic heating

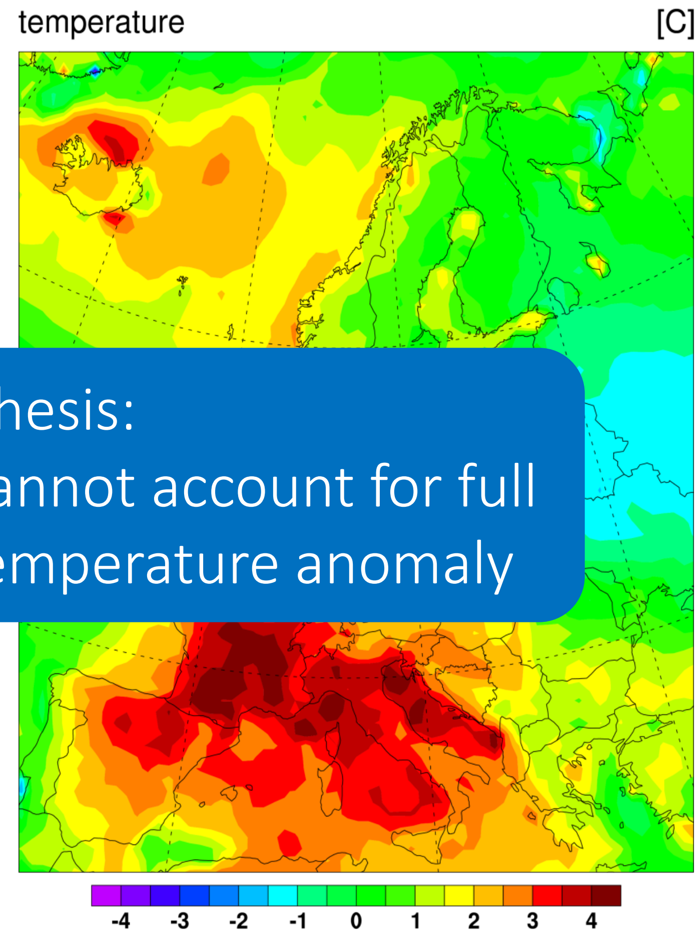
Bieli et al. (2015) *Q. J. R. Meteorol. Soc.*

Atmospheric circulation anomaly 2003

500hPa anomaly



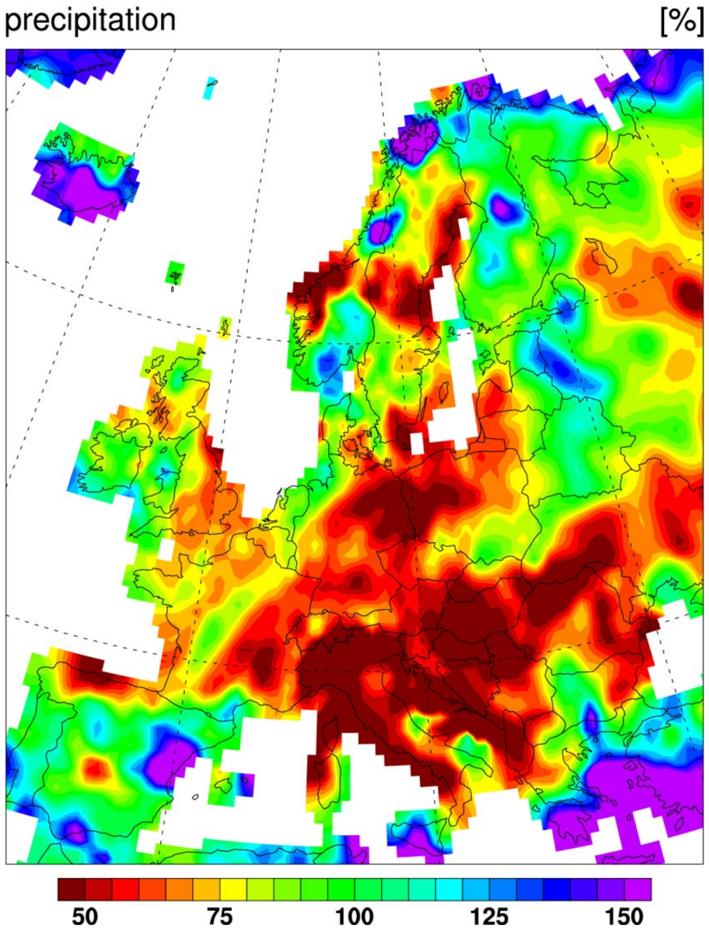
Summer temperature anomaly



Hypothesis:
Circulation anomaly cannot account for full extent of observed temperature anomaly

Dry spring 2003

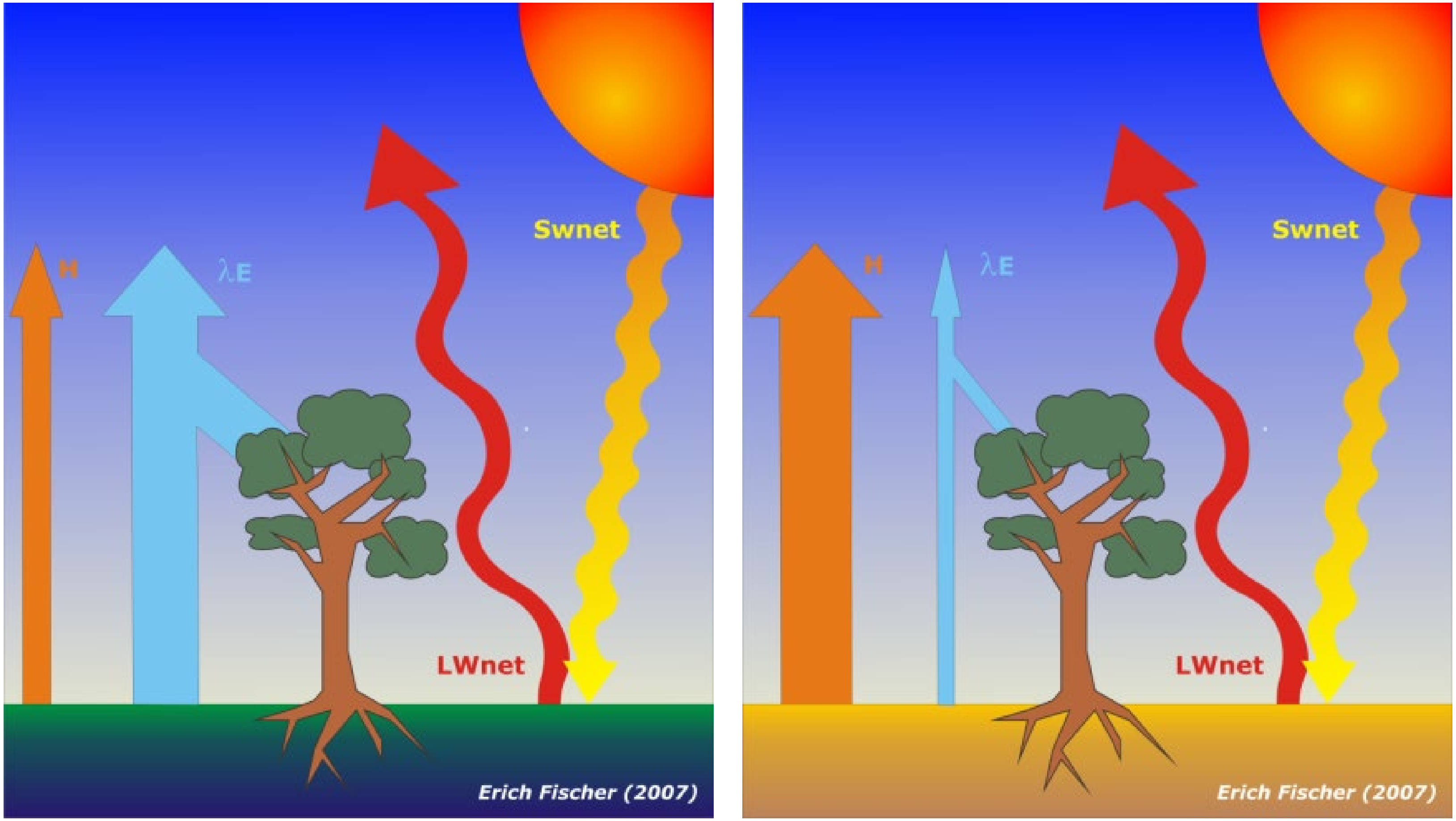
Precip anomaly FMAM 2003



Pre-conditioning through:

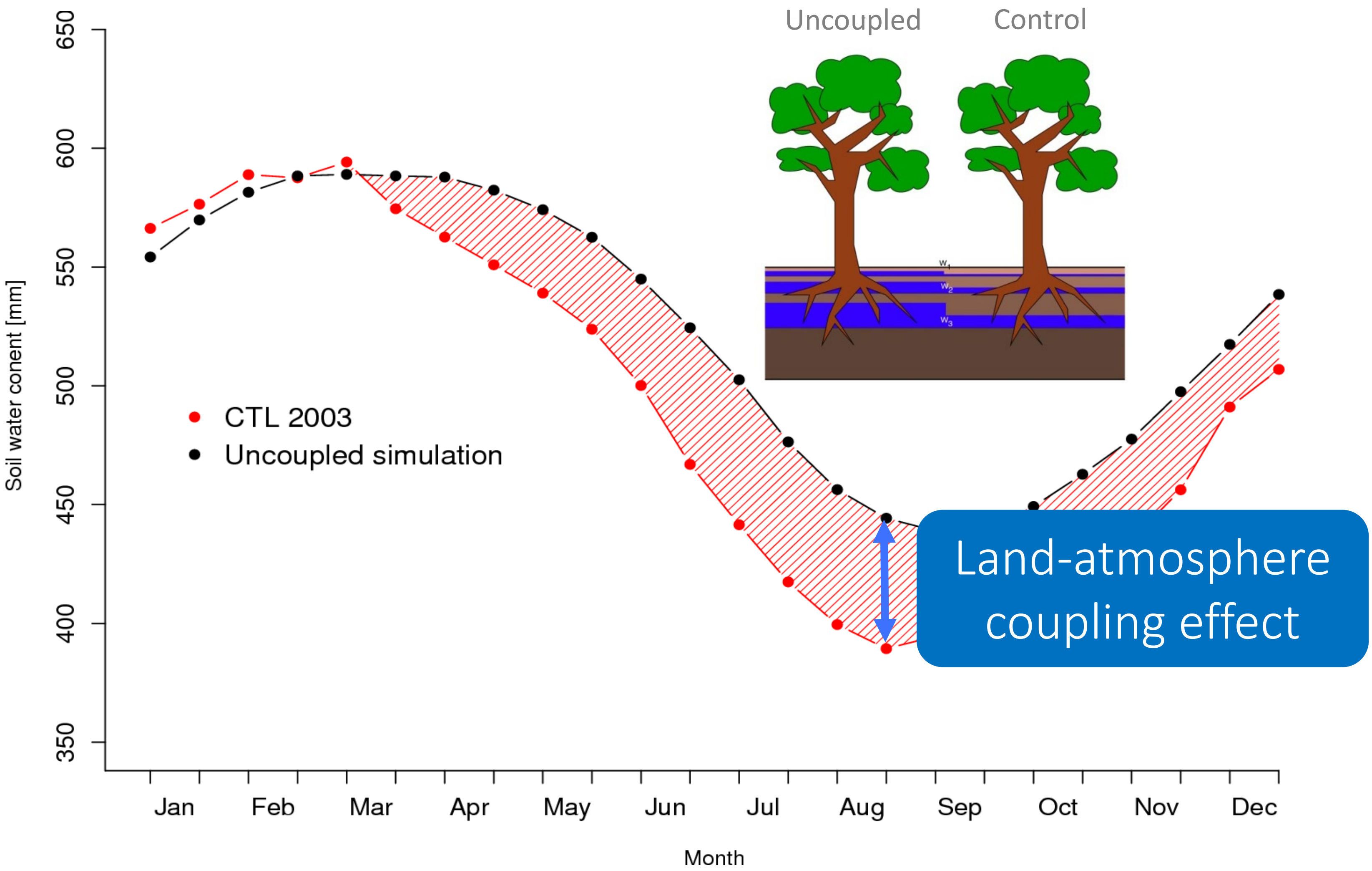
- Low spring precipitation
- Early vegetation onset -> transpiration
- Low cloudiness

Dry spring 2003

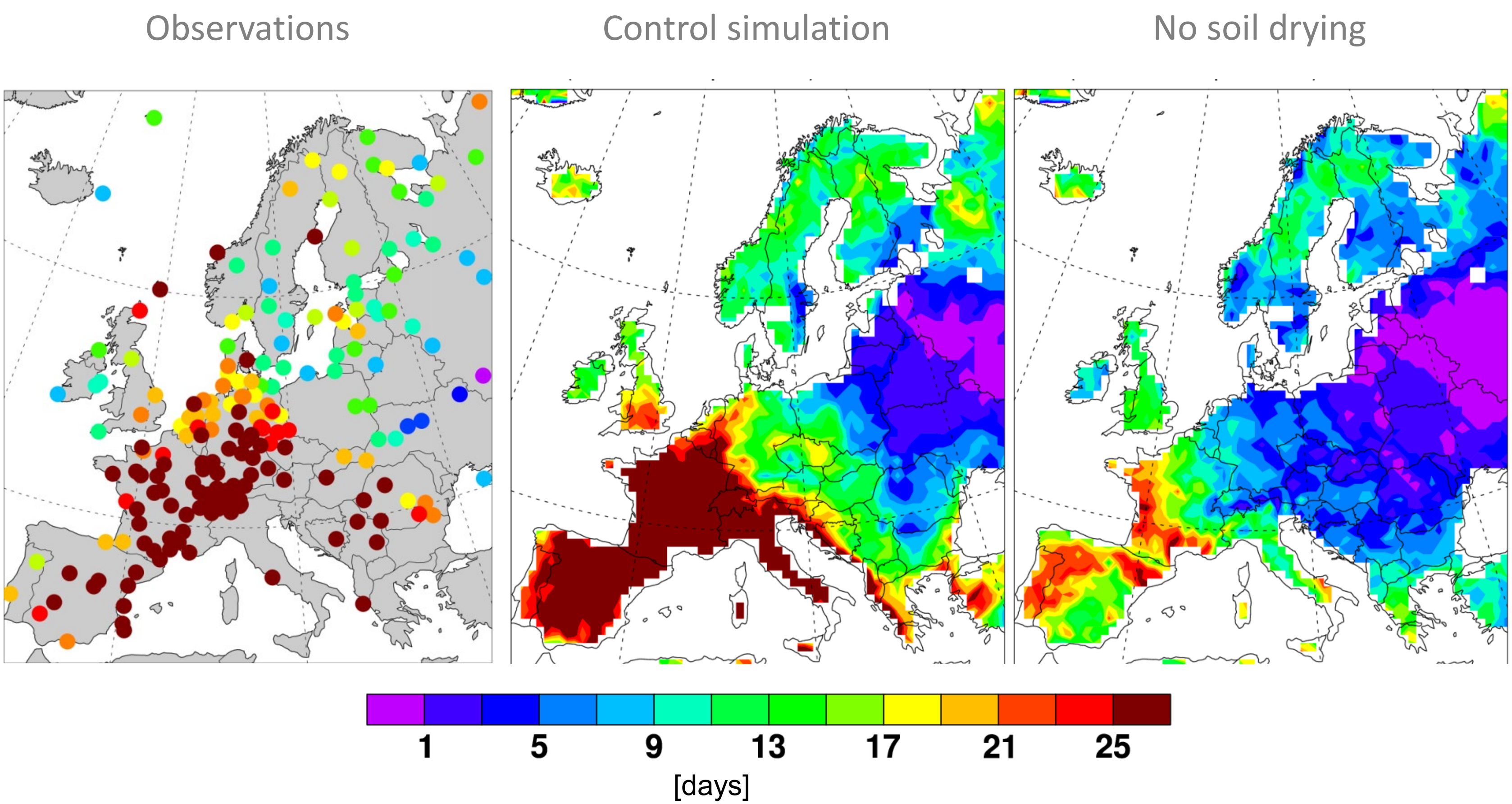


$$R_{net} = SW + LW = H + \lambda E + G$$

What is the effect of the anomalous conditions?



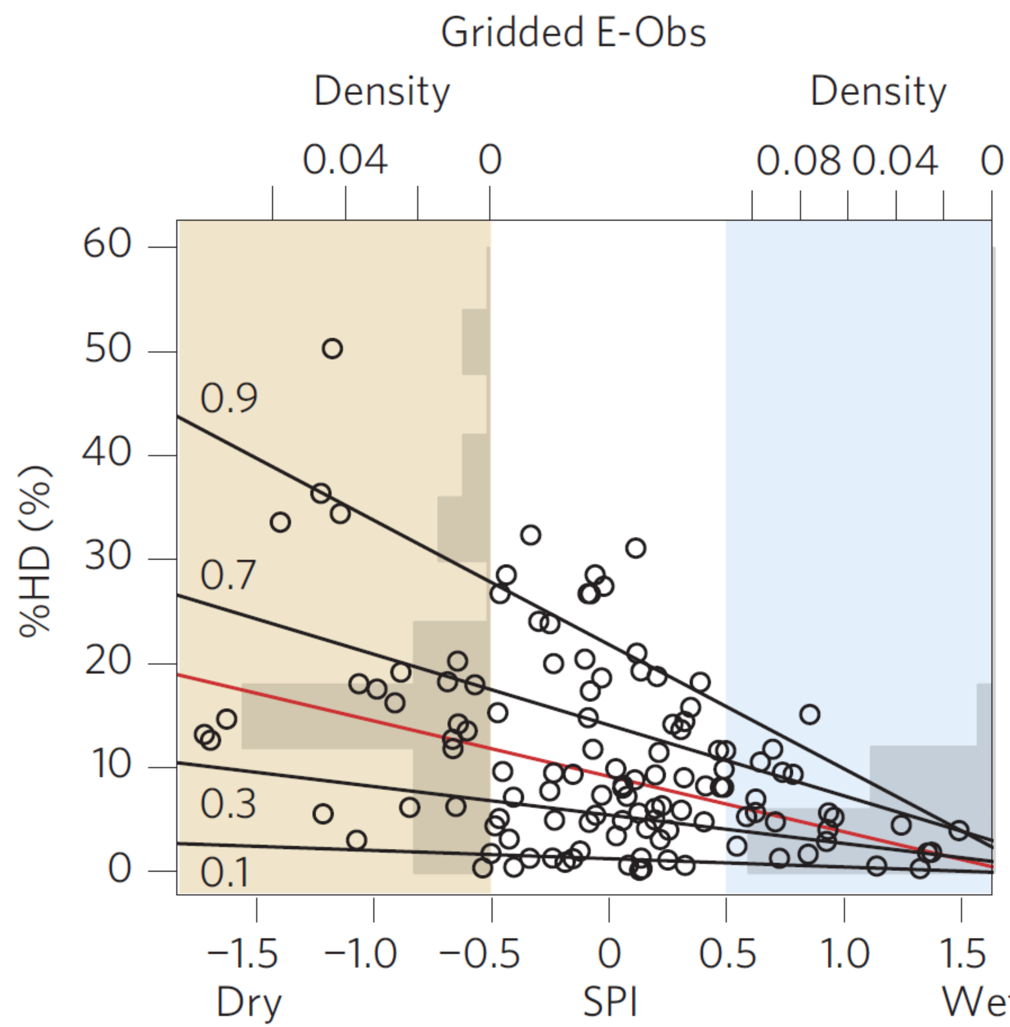
Amplification through land-atmosphere interactions



Soil drying substantially enhanced the number of hot days

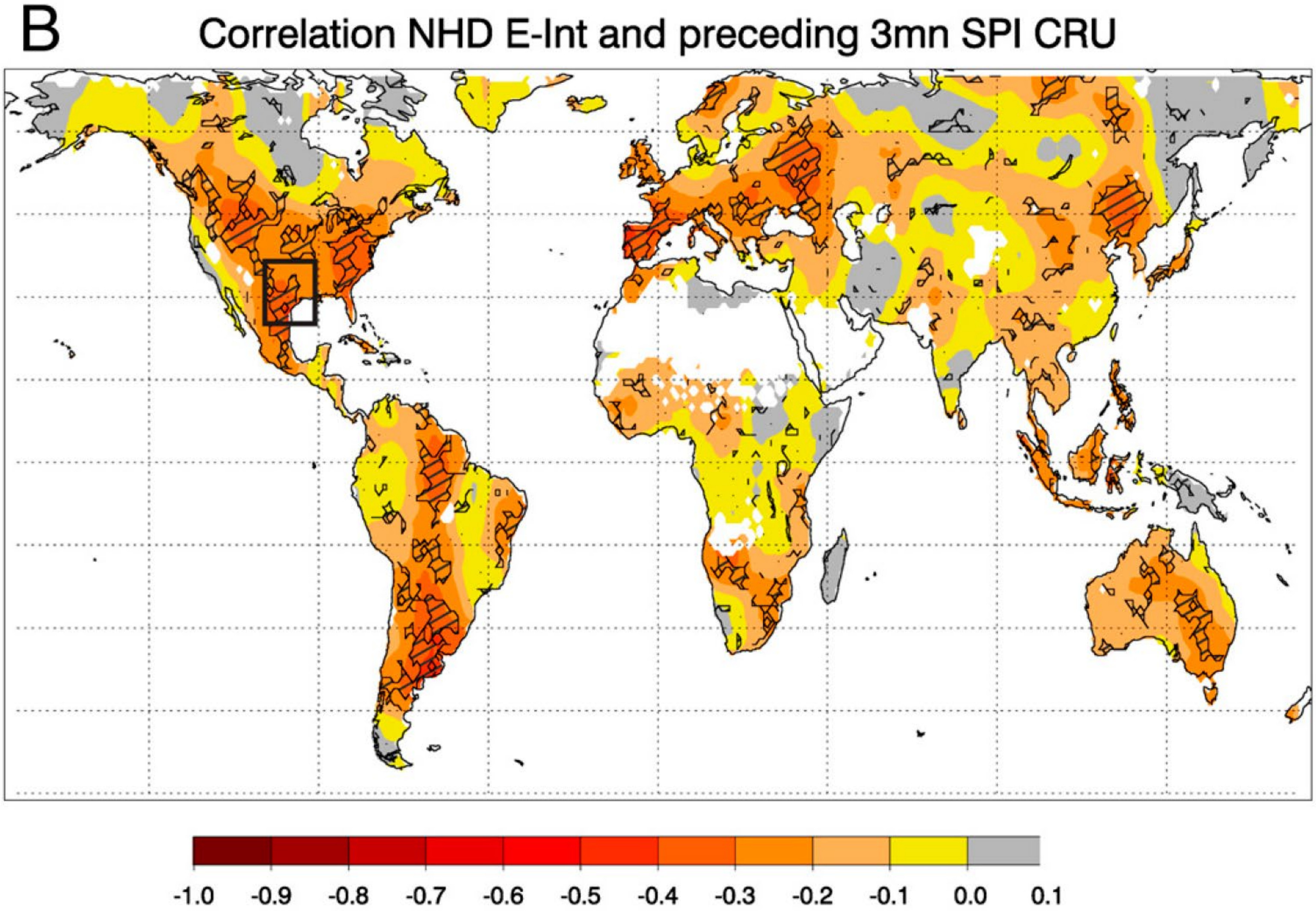
Fischer et al. 2007c, GRL

The drier the soils – the more hot days



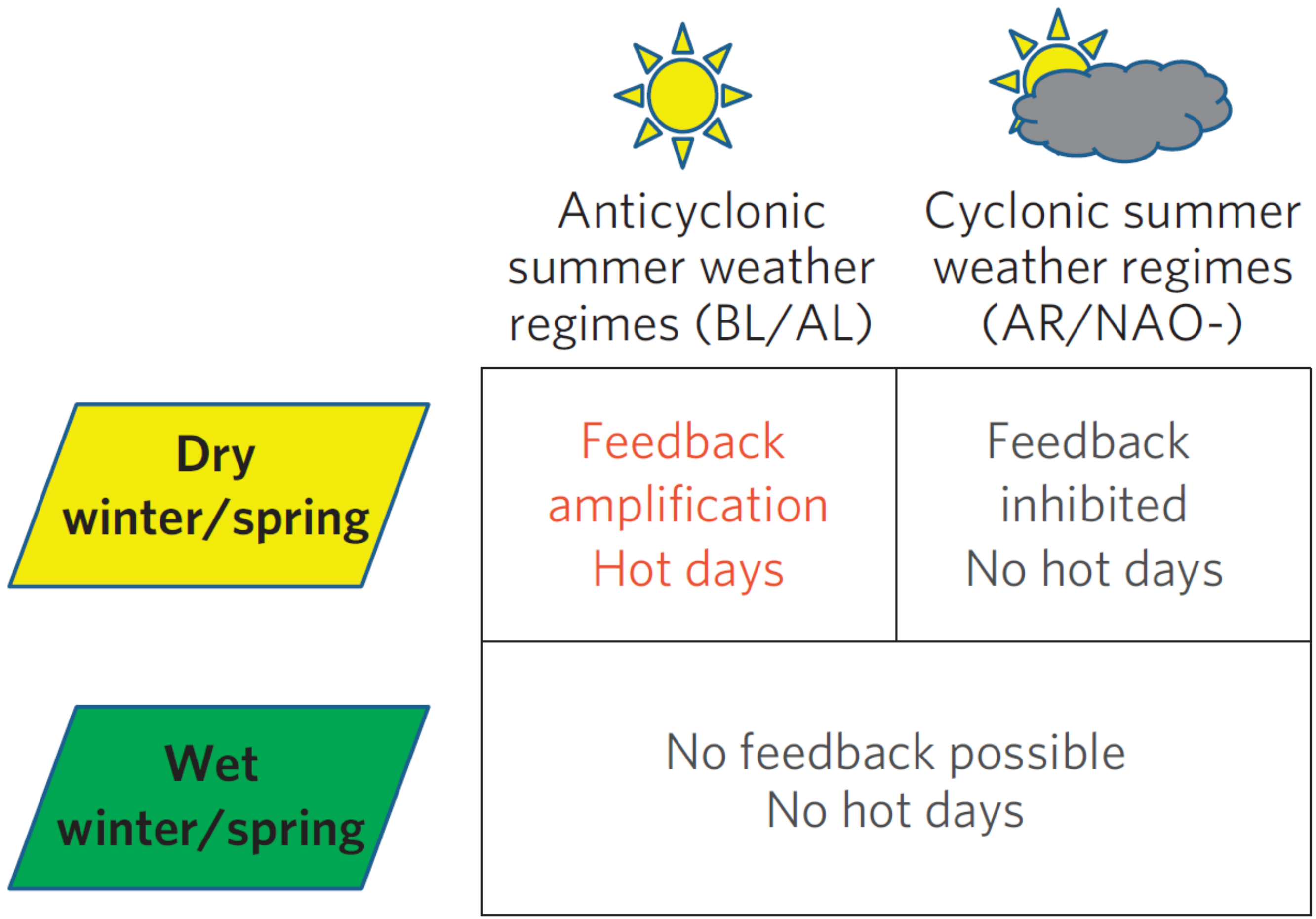
Hirschi et al. 2010, Nature Geoscience

The drier the soils – the more hot days



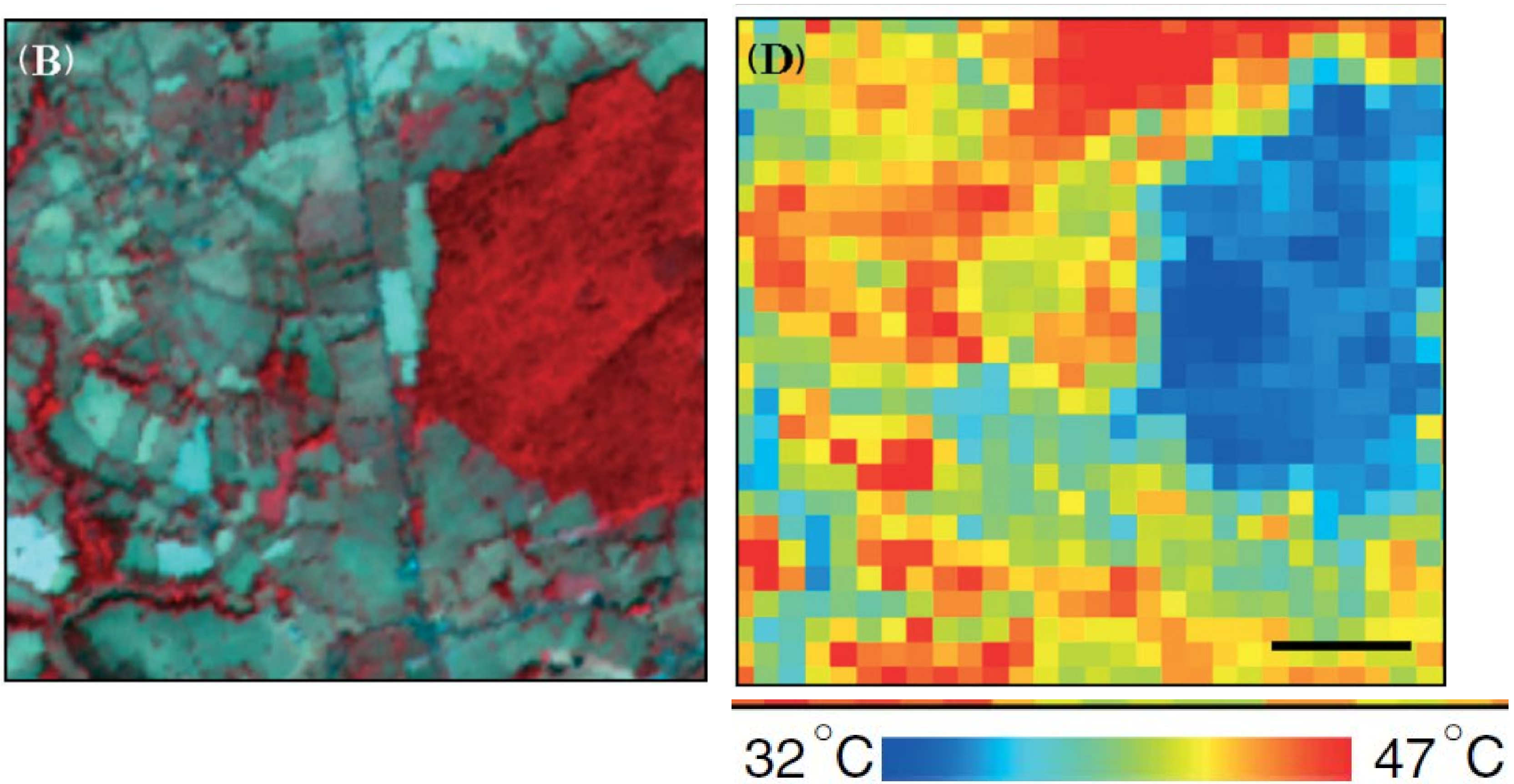
Mueller and Seneviratne 2012, *PNAS*

Dry spring – necessary but not sufficient



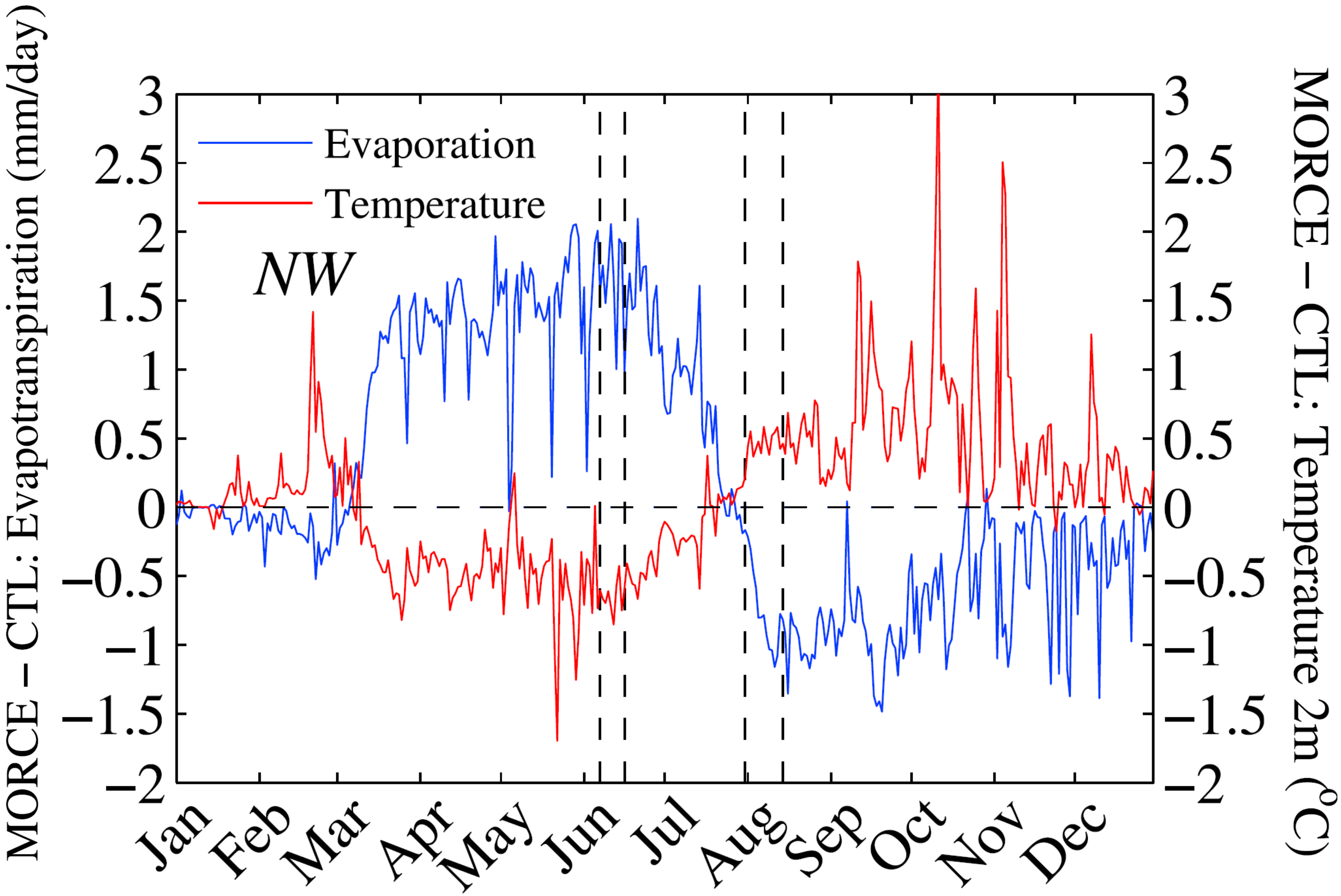
Quesada et al. 2012, Nature CC

The role of vegetation



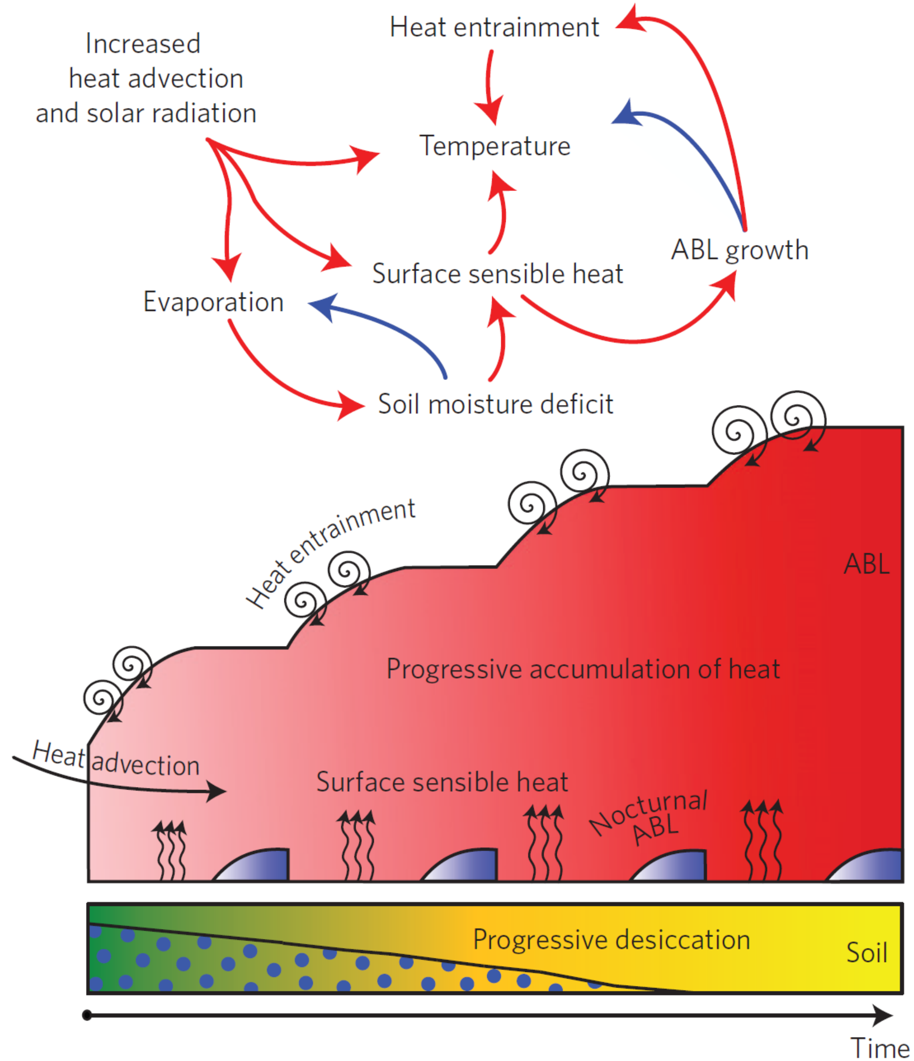
Zaitchick et al. 2006, *Int. J. Climatol.*

Dynamic vegetation vs. static vegetation



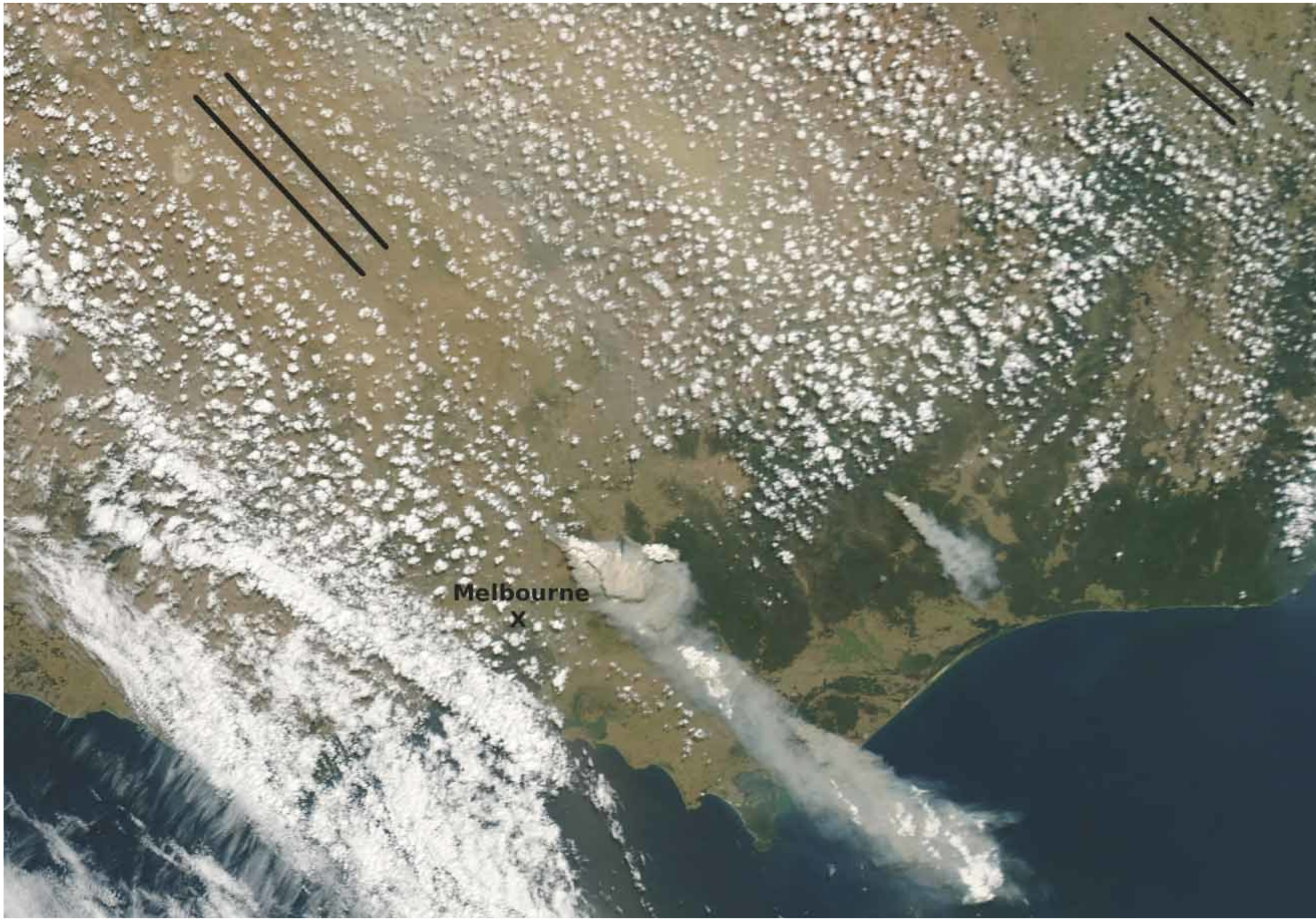
Stefanon et al. (2012) *J Geophys Res Atmos*

The built-up of a heatwave



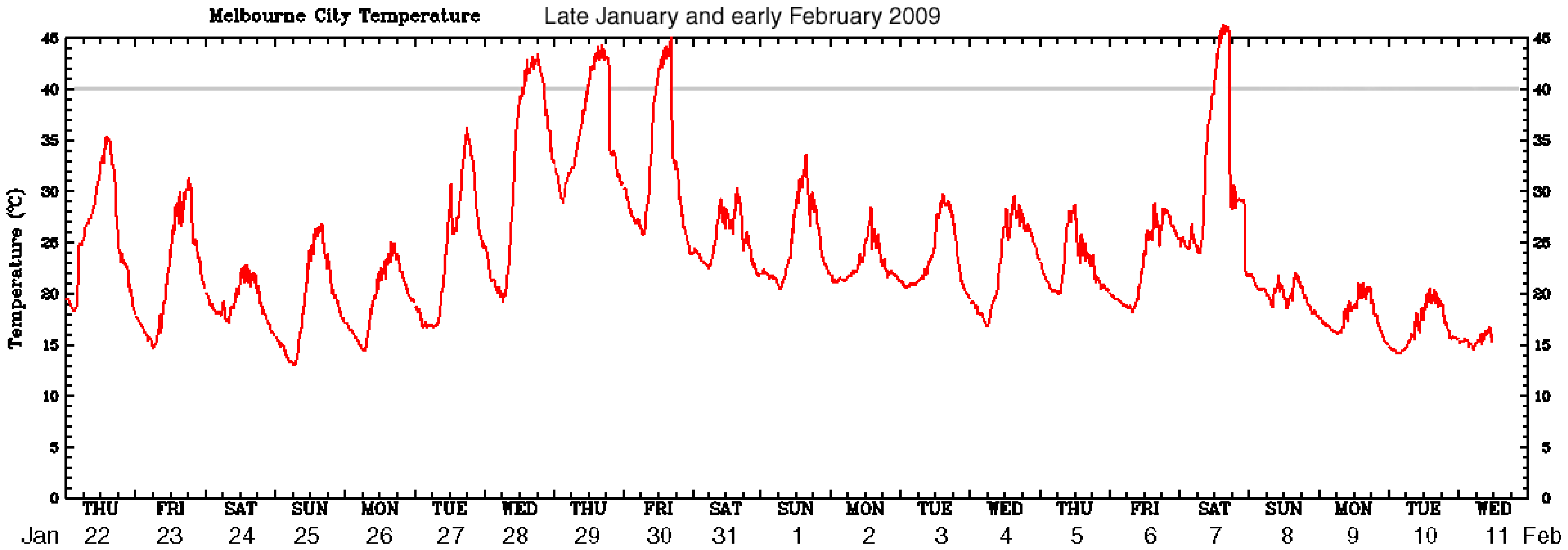
Miralles et al. 2014, *Nature Geoscience*

Case study: Black Saturday February 2009




ROAD CLOSED

Australia heatwaves – surge through advection

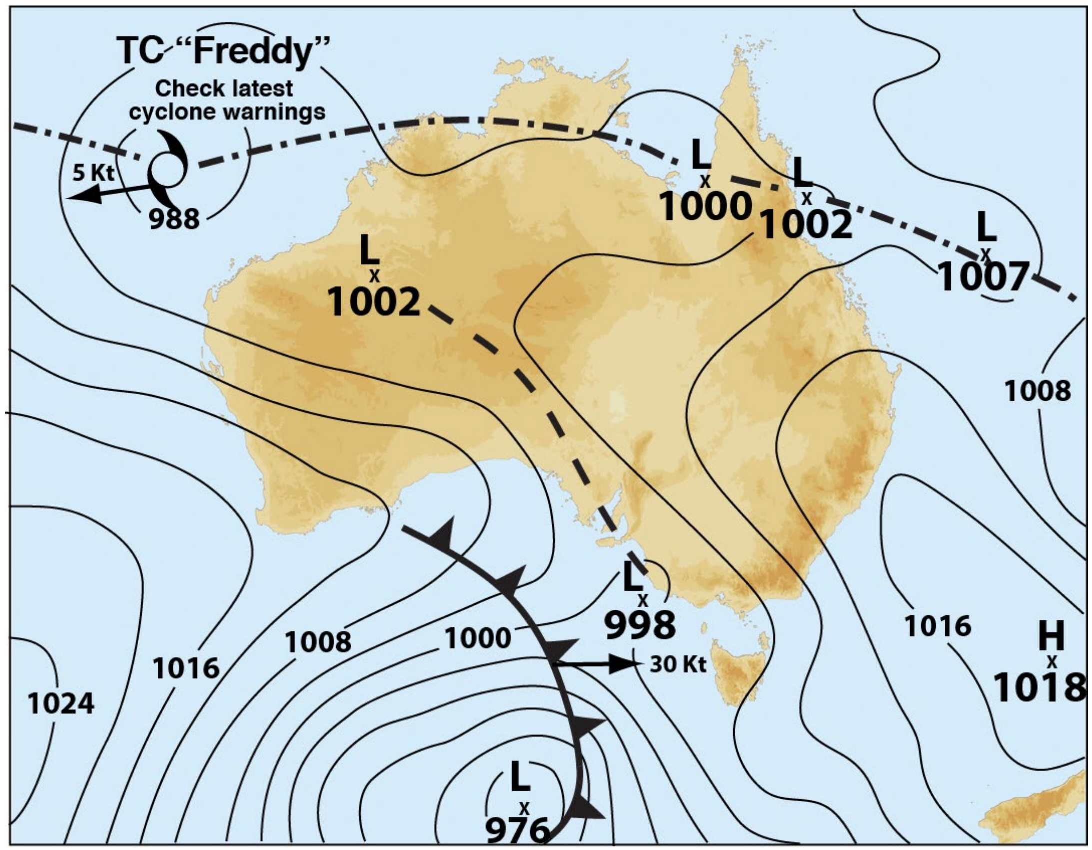


Temperature charts for Melbourne, Australia, 22 January to 10 February 2006. From 1885 to 2006, the mean maximum and minimum temperatures for this time of year were 26C and 14C respectively (79F & 57F) (www.earthsci.unimelb.edu.au/~awatkins/melbmeantemp.html). The 7 Feb peak of 46.4C (115.5F) with 5% relative humidity was the hottest in 150 years of records for any Australian capital city. Graphs by Andrew Watkins: www.earthsci.unimelb.edu.au/~awatkins/melbtemp.html With Andrew's permission, © public domain by Robin Whittle 2009-02-11.

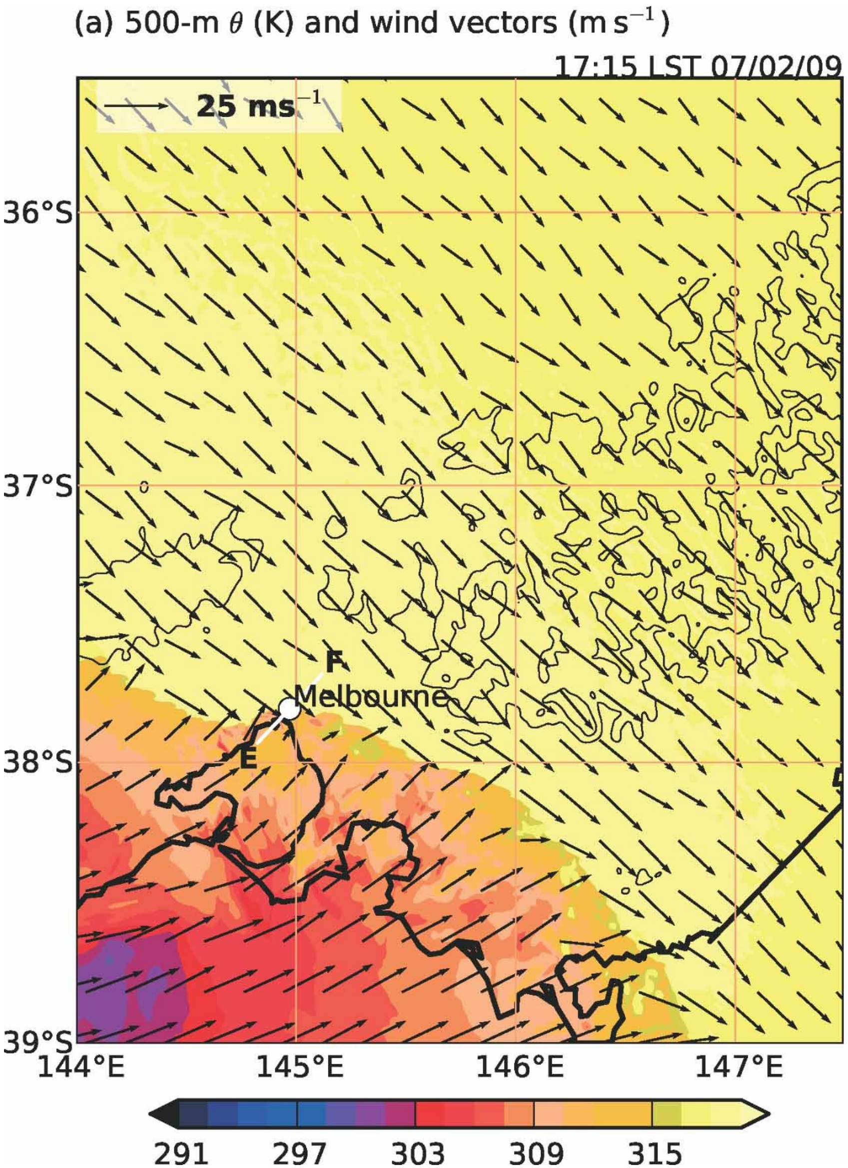
Synoptic situation – Black Friday February 2009

National Meteorological Oceanographic Centre
MSL Analysis (hPa) Valid: 00 UTC Sat, 7 February 2009
(11:00 am EDT Sat 7 February 2009)

Australian Government
Bureau of Meteorology



The desert wind



Conclusions

- Anticyclones are key drivers of heatwaves
  -> advection from subtropics, subsidence (adiabatic heating), cloud-free conditions (radiative heating)
- Land-atmosphere interactions and pre-conditioning are important amplifiers
- Build-up of heat in PBL or advection determine time scales of heatwave build-up