How do we know if climate change influenced an extreme event?

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The nature of extreme events

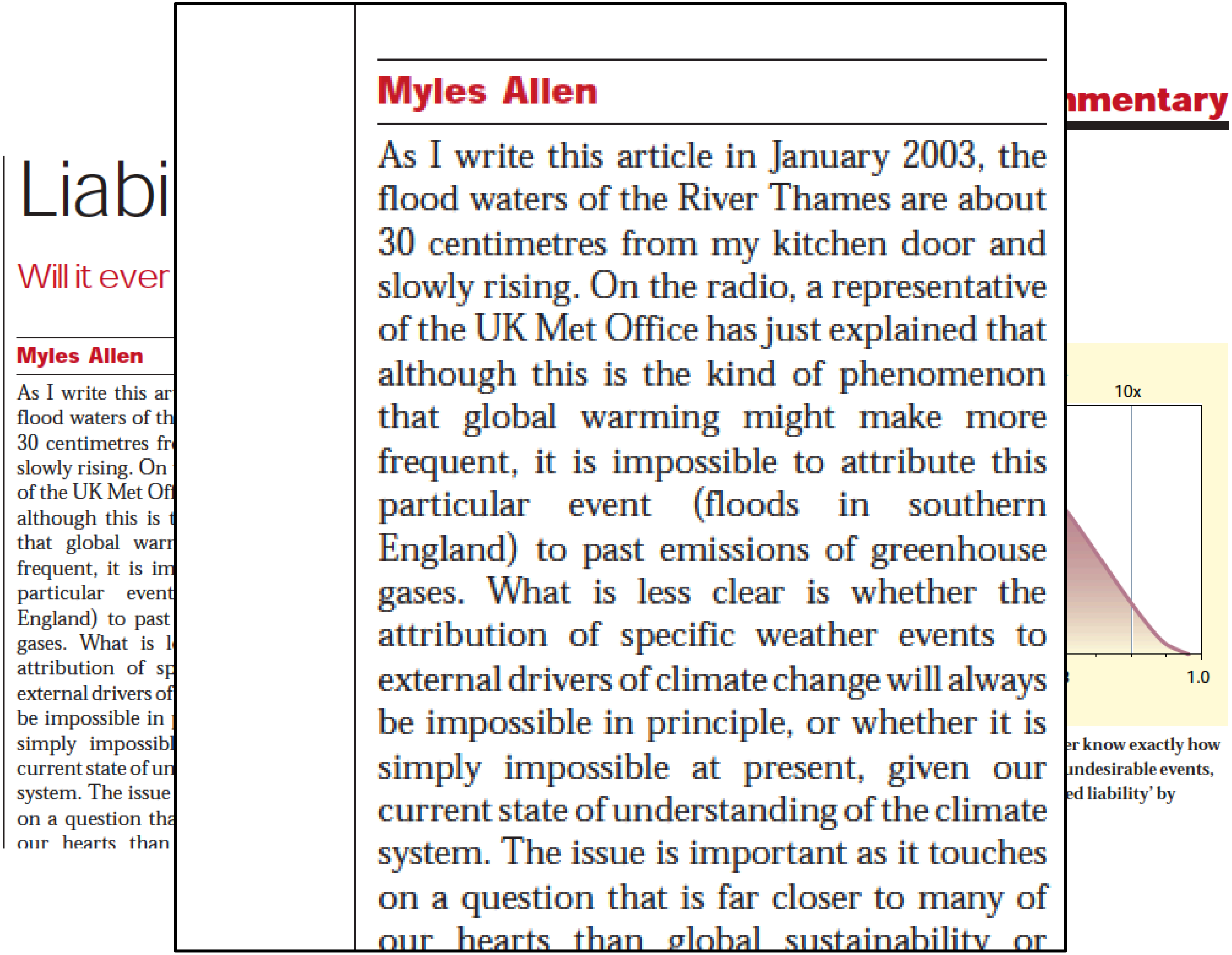
- Extreme weather and climate-related events occur in a particular place, by definition, infrequently.
- It may even refer to events such as the occurrence of a daily maximum temperature that exceeds the 90th percentile of daily variability as estimated from a climatological base period – not very extreme!
- It may refer to rare events that lie in the far tails of the distribution of the phenomenon of interest.

Understanding extremes

- Extremes are understood within a context
  - seasonal or annual means may be “extreme”
  - an unusual short-term event, such as a daily precipitation accumulation, may be extreme.
- Most D&A research on long-term changes in the probability and frequency of extremes has focused on short duration events
  - can be monitored using long records of local daily temperature and precipitation observations
  - indices that document the frequency or intensity of extremes in the observed record
  - not so much focus on individual rare events
- Event attribution studies seek to determine to what extent anthropogenic climate change has altered the probability or magnitude of particular events.

Attribution of events to causes - very challenging

- The frequency and intensity of extremes can be affected by
  - the internal variability of the climate system
  - external forcing
- Mechanisms involved can be
  - direct (e.g., via a change in the local energy balance)
  - indirect (e.g., via circulation changes).
- For example, Precipitation
  - The increased ability of the atmosphere to hold water in a warming climate – *the Thermodynamic effect*
  - A warmer climate can also lead to changes in the atmospheric circulation patterns and trigger nonlinear dynamical changes in the atmospheric processes that cause extreme precipitation – *the Dynamic effect*



Myles Allen

As I write this article in January 2003, the flood waters of the River Thames are about 30 centimetres from my kitchen door and slowly rising. On the radio, a representative of the UK Met Office has just explained that although this is the kind of phenomenon that global warming might make more frequent, it is impossible to attribute this particular event (floods in southern England) to past emissions of greenhouse gases. What is less clear is whether the attribution of specific weather events to external drivers of climate change will always be impossible in principle, or whether it is simply impossible at present, given our current state of understanding of the climate system. The issue is important as it touches on a question that is far closer to many of our hearts than global sustainability or

NATURE, V. 421, FEBRUARY 2003

Fractional Attributable Risk (FAR)

- Define a scalar, $p_0 = \psi(q_0)$, to be the probability of some … n some refere … q_0.
- p_1 is th … ew state produ … forcing q_1.
- An inc … event occurr … , as compared to the … ibuted to the chang

$$\mathrm{far} = \frac{p_1 - p_0}{p_1} = 1 - \frac{p_0}{p_1}$$

"The End-to-end Attribution Problem: From Emissions To Impacts", DA´ITHI´ A. STONE and MYLES R. ALLEN. Climatic Change (2005) 71: 303–318

Fractional Attributable Risk (FAR)

- In the real world, we cannot know either p_0 or p_1 ex
- W he fo te
- Th he climate system
- Employing periments with these mod s of our uncertainti the relevant probability density functions (PDFs).

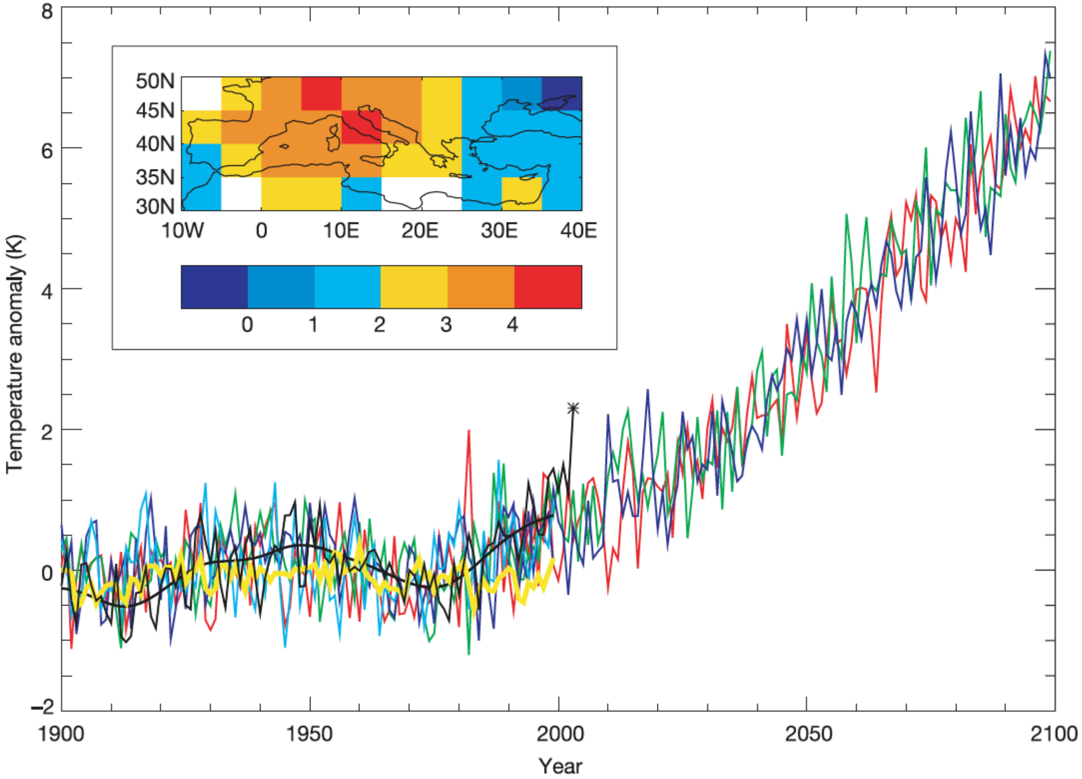
$$P_0 = \psi(q_0) + E_\psi(q_0)$$

$$P_1 = \psi(q_1) + E_\psi(q_1).$$

$$\mathrm{FAR} = 1 - \frac{P_0}{P_1}.$$

“The End-to-end Attribution Problem: From Emissions To Impacts”, DA´ITHI´ A. STONE and MYLES R. ALLEN. Climatic Change (2005) 71: 303–318

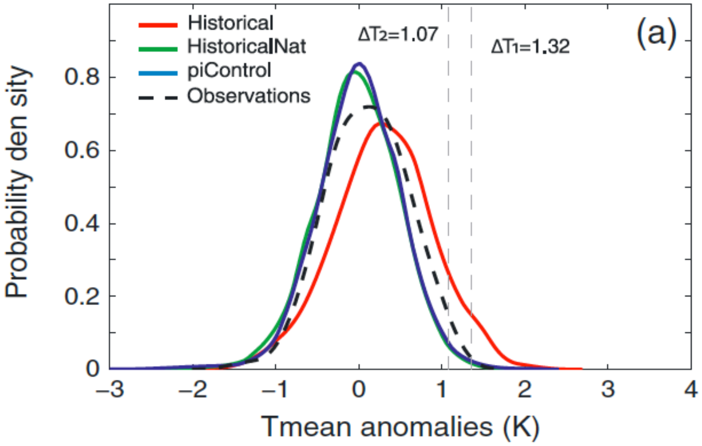
European heatwave 2003



June–August temperature anomalies (relative to 1961–90 mean, in °K) over the region shown in inset. Shown are observed temperatures (black line, with low-pass filtered temperatures as heavy black line), modelled temperatures from four HadCM3 simulations including both anthropogenic and natural forcings to 2000 (red, green, blue and turquoise lines), and estimated HadCM3 response to purely natural natural forcings (yellow line). The observed 2003 temperature is shown as a star. Also shown (red, green and blue lines) are three simulations (initialized in 1989) including changes in greenhouse gas and sulphur emissions according to the SRES A2 scenario to 2100. The inset shows observed summer 2003 temperature anomalies, in °K.

Human contribution to the European heatwave of 2003 Peter A. Stott, D. A. Stone, & M. R. Allen. Nature (2004)

Australia's Record Summer Temperature 2013



$$\mathrm{FAR} = 1 - \frac{P_{\mathrm{NAT}}}{P_{\mathrm{ALL}}}$$

Attributable increase in risk = P_{ALL}/P_{NAT}

(a) Probability density functions for Australian summer T_{mean} anomalies (relative to 1911– 1940) for observations (dashed black, all years shown), historical (red, 1976– 2005 only), historicalNat (green, all years shown), and piControl (dark blue, all years shown relative to long-term mean) simulations. Vertical dashed lines show observed 2013 anomaly (Δ T1) and threshold of the second hottest summer on record (Δ T2). (b) As for Figure 2a, but for RCP8.5 experiment (black, 2006– 2020 only). (c) The fraction of attributable risk of extreme summer Australian temperatures exceeding Δ T2 for the historical (red) and RCP8.5 simulations (black). Solid (dashed) vertical lines indicate mean (90th percentile) FAR estimates for each experiment.

"Anthropogenic contributions to Australia's record summer temperatures of 2013" Sophie C. Lewis and David J. Karoly. Geophysical Research Letters, VOL. 40, 3705–3709, doi:10.1002/grl.50673, 2013

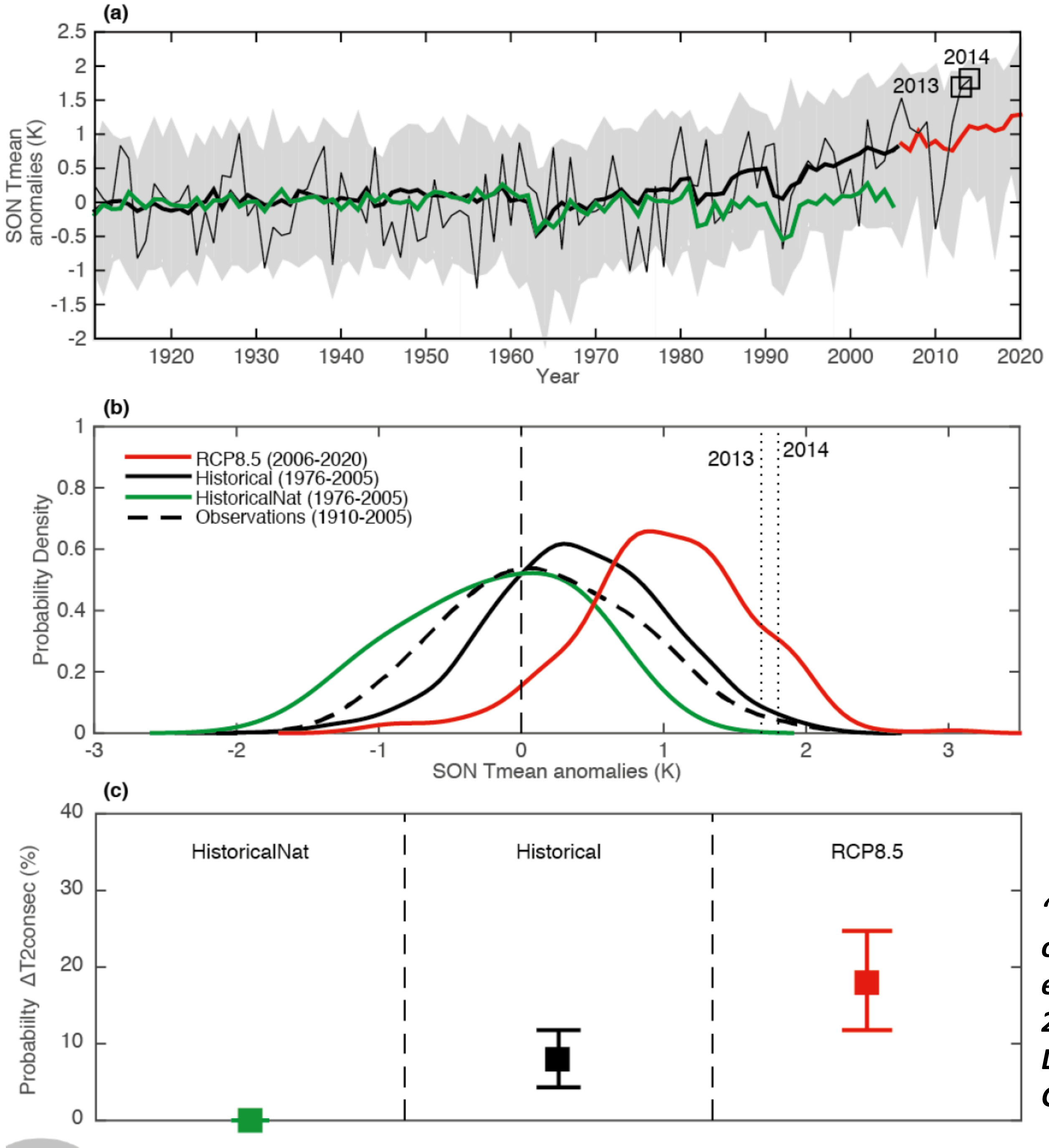


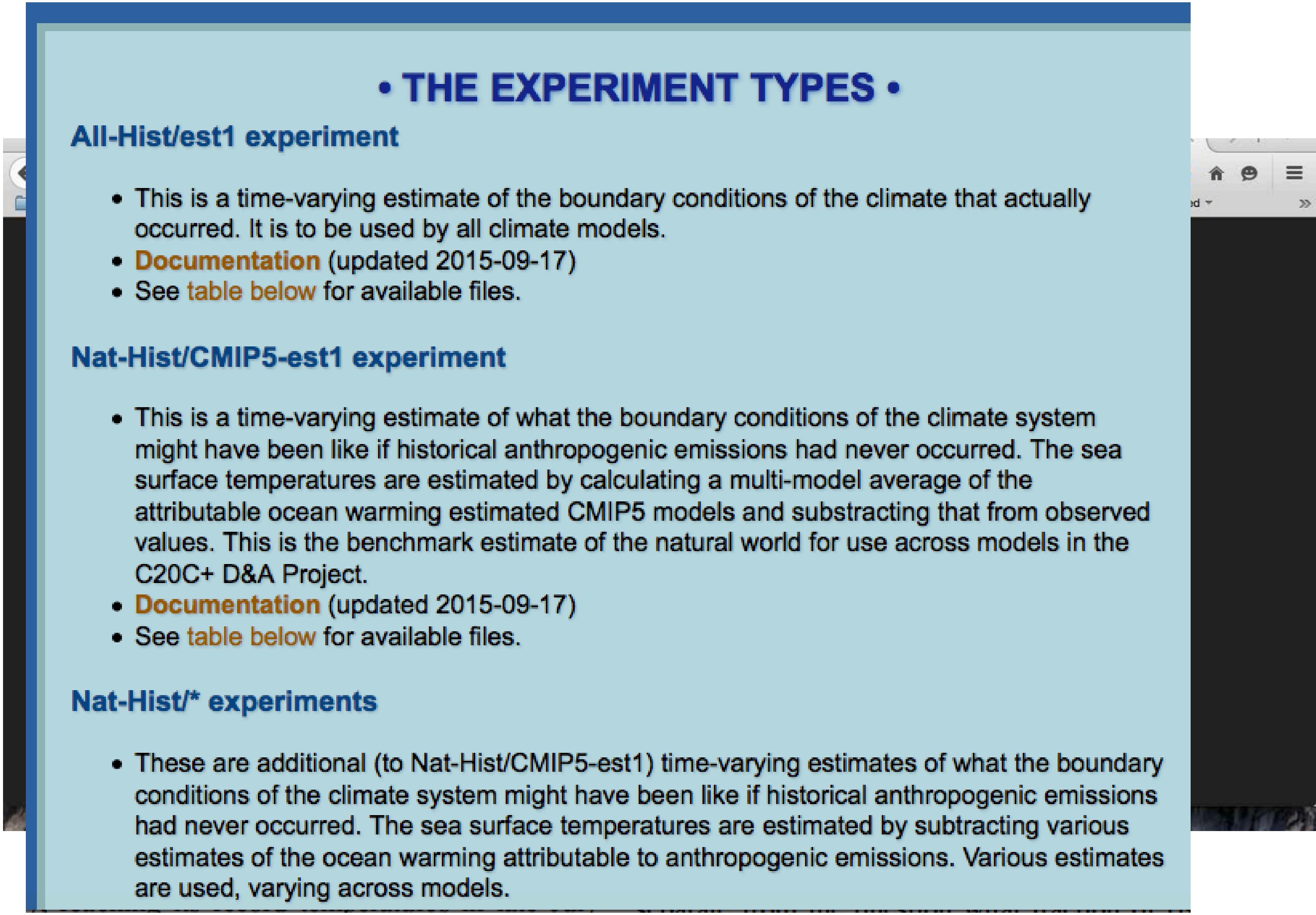
Figure 4. (a) Australian SON *Tmean* anomalies (K) for observations (thin black), historicalNat (green), historical (black) and RCP8.5 (red) multimodel mean. The grey plume indicates the 5th–95th percentile simulated range of SON temperatures across historical model ensemble members. (b) Probability density estimates for Australian average SON anomalies for observations (years 1910–2014, dashed black), compared with historicalNat (green, years 1976-2005), historical (black, years 1976-2005) and RCP8.5 (red, years 2006-2020). Vertical dashed lines show the observed 2013 (*ΔT2*) and 2014 (*ΔT1*) anomalies. (c) Probability (%) of consecutive extreme (each year > *ΔT4*) Australian-average SON *Tmean* anomalies occurring in historicalNat (green, years 1976-2005), historical (black, years 1976-2005) and RCP8.5 (red, years 2006-2020) simulations.

"Stochastic and anthropogenic influences on repeated record-breaking temperature extremes in Australian spring of 2013 and 2014" Ailie J. E. Gallant and Sophie C. Lewis
GRL (2016) doi: 10.1002/2016GL067740

Met Office Hadley Centre Attribution System

- This is based on HadGEM3-A (1.25° longitude X 1.875° latitude and 38 vertical levels)
- 100-member ensemble of model simulations forced with observed SSTs and sea ice and current levels of greenhouse gases
- Compared with two 100-member ensembles in which
  - human influence has been subtracted from the SSTs and sea ice
  - GHGs and aerosols are reduced to preindustrial levels
- Estimates of the change in SST due to human influence are derived from transient simulations of three coupled climate models, HadGEM1, HadGEM2-ES, and HadCM3.

Nikolaos Christidis, Peter A. Stott, Adam A. Scaife, Alberto Arribas, Gareth S. Jones, Dan Copsey, Jeff R. Knight, and Warren J. Tennant, 2013: A New HadGEM3-A-Based System for Attribution of Weather- and Climate-Related Extreme Events. J. Climate, 26, 2756–2783. doi: http://dx.doi.org/10.1175/JCLI-D-12-00169.1



• THE EXPERIMENT TYPES •

All-Hist/est1 experiment

- This is a time-varying estimate of the boundary conditions of the climate that actually occurred. It is to be used by all climate models.
- **Documentation** (updated 2015-09-17)
- See table below for available files.

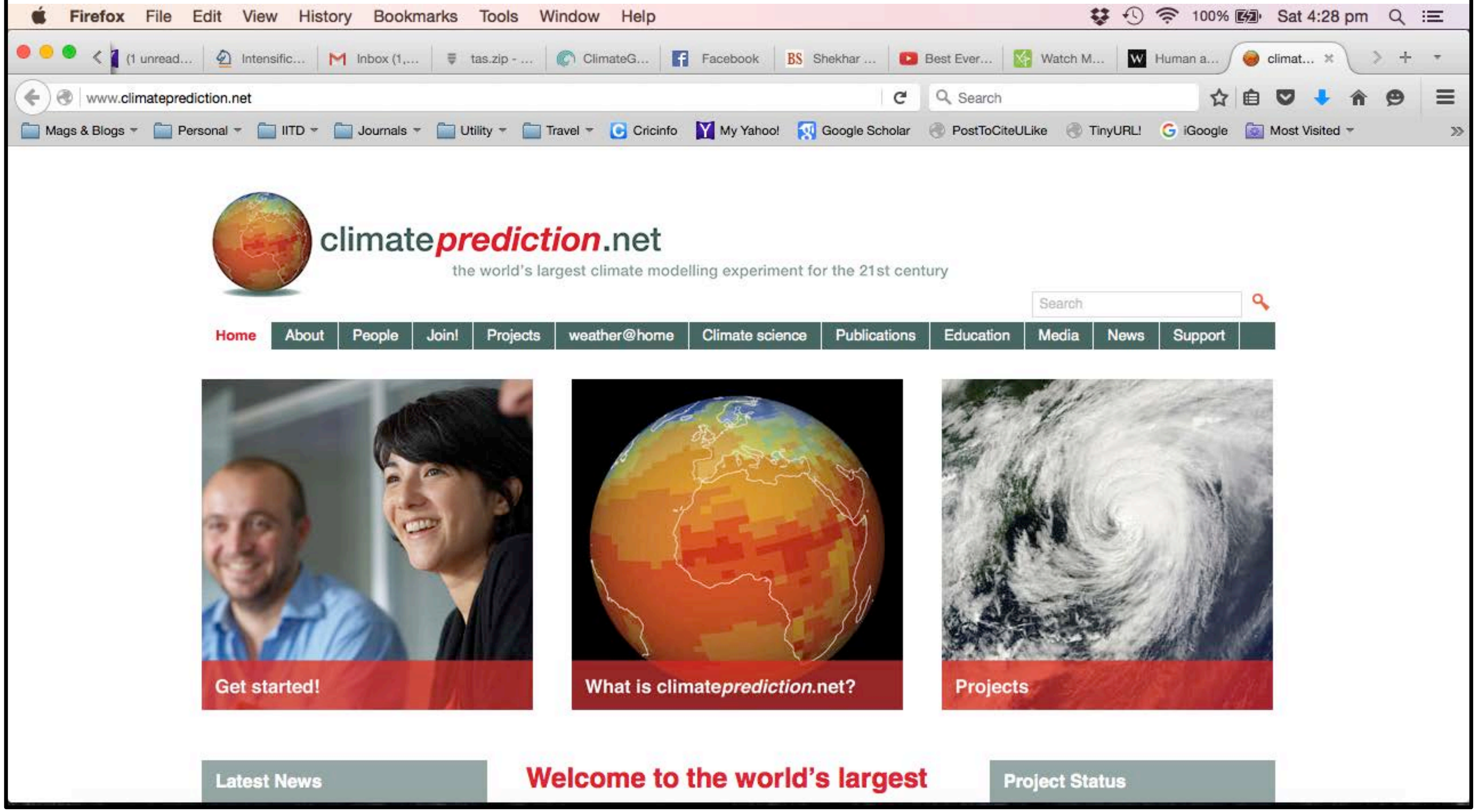
Nat-Hist/CMIP5-est1 experiment

- This is a time-varying estimate of what the boundary conditions of the climate system might have been like if historical anthropogenic emissions had never occurred. The sea surface temperatures are estimated by calculating a multi-model average of the attributable ocean warming estimated CMIP5 models and substracting that from observed values. This is the benchmark estimate of the natural world for use across models in the C20C+ D&A Project.
- **Documentation** (updated 2015-09-17)
- See table below for available files.

Nat-Hist/* experiments

- These are additional (to Nat-Hist/CMIP5-est1) time-varying estimates of what the boundary conditions of the climate system might have been like if historical anthropogenic emissions had never occurred. The sea surface temperatures are estimated by subtracting various estimates of the ocean warming attributable to anthropogenic emissions. Various estimates are used, varying across models.

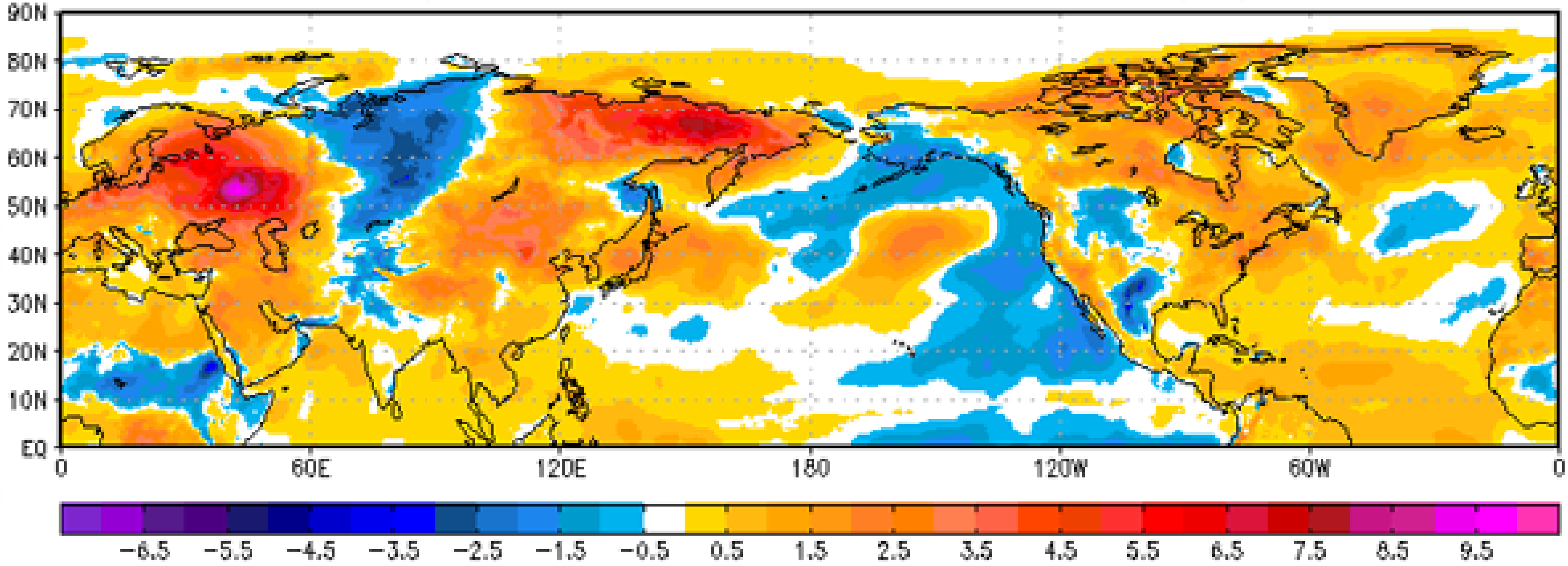
1000+ simulations available



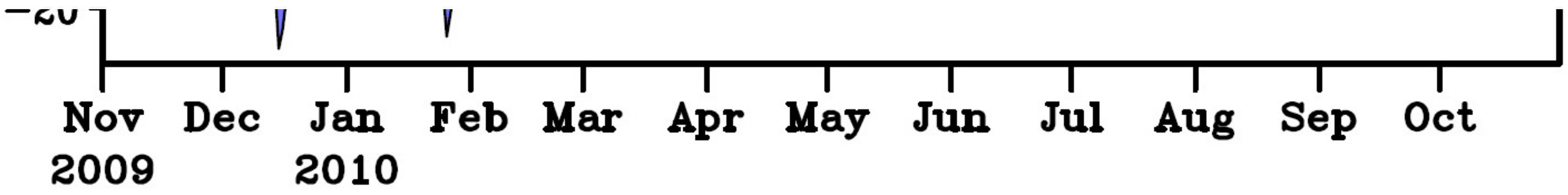
weather@home utilises the climateprediction.net volunteer distributed computing network to compute very large ensembles of the HadRM3P regional climate model driven by the HadAM3P atmosphere-only global climate model (AGCM).

"weather@home – development and validation of a very large ensemble modelling system for probabilistic event attribution" N. Massey, R. Jones, F. E. L. Otto, T. Aina, S. Wilson, J. M. Murphy, D. Hassell, Y. H. Yamazaki and M. R. Allen Q. J. R. Meteorol. Soc. 141: 1528–1545, July 2015

Russia Heatwave 2010



July 2010 2m Temperature Anomalies (°C)



- Contradiction?

Comparison of the return time of a 2010-like heat wave in a 1200 member ensemble of model runs for the 2000s with the return period of such an event in an 1600 member ensemble representing the 1960s.

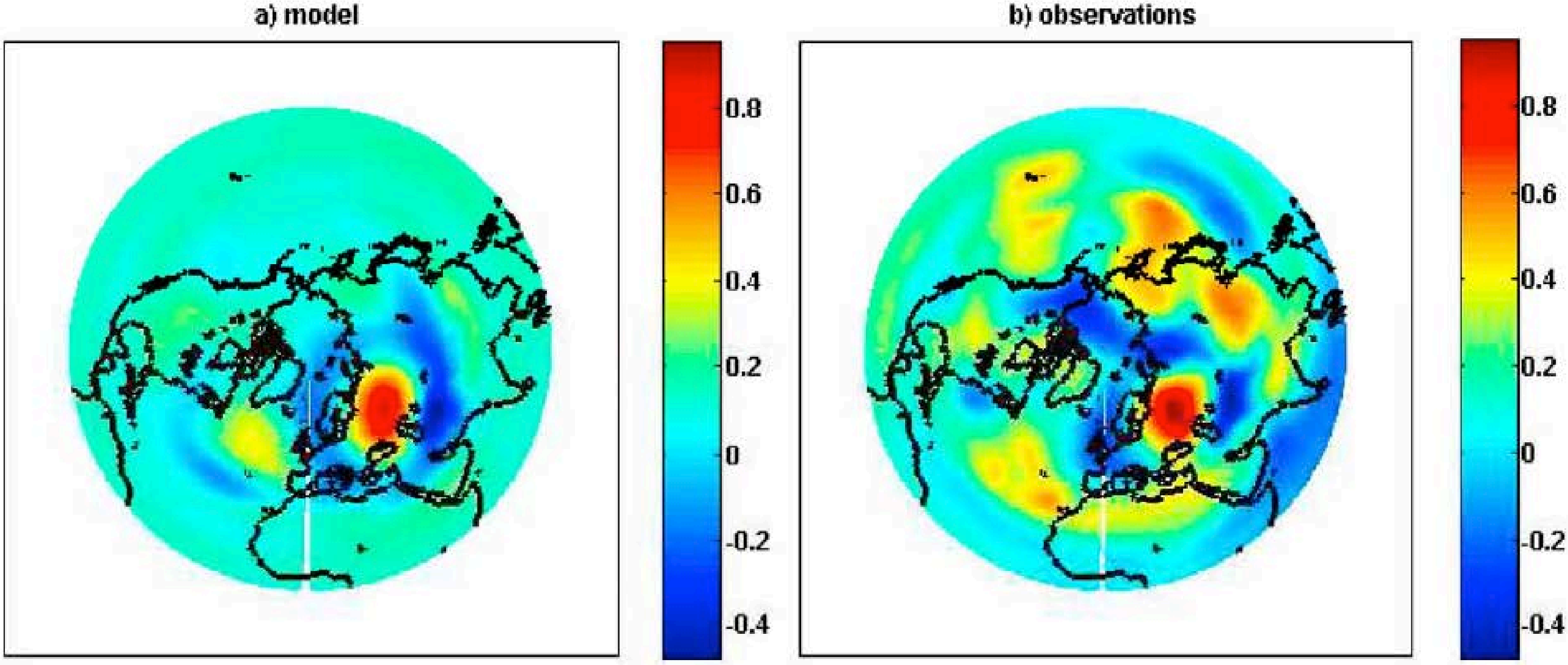
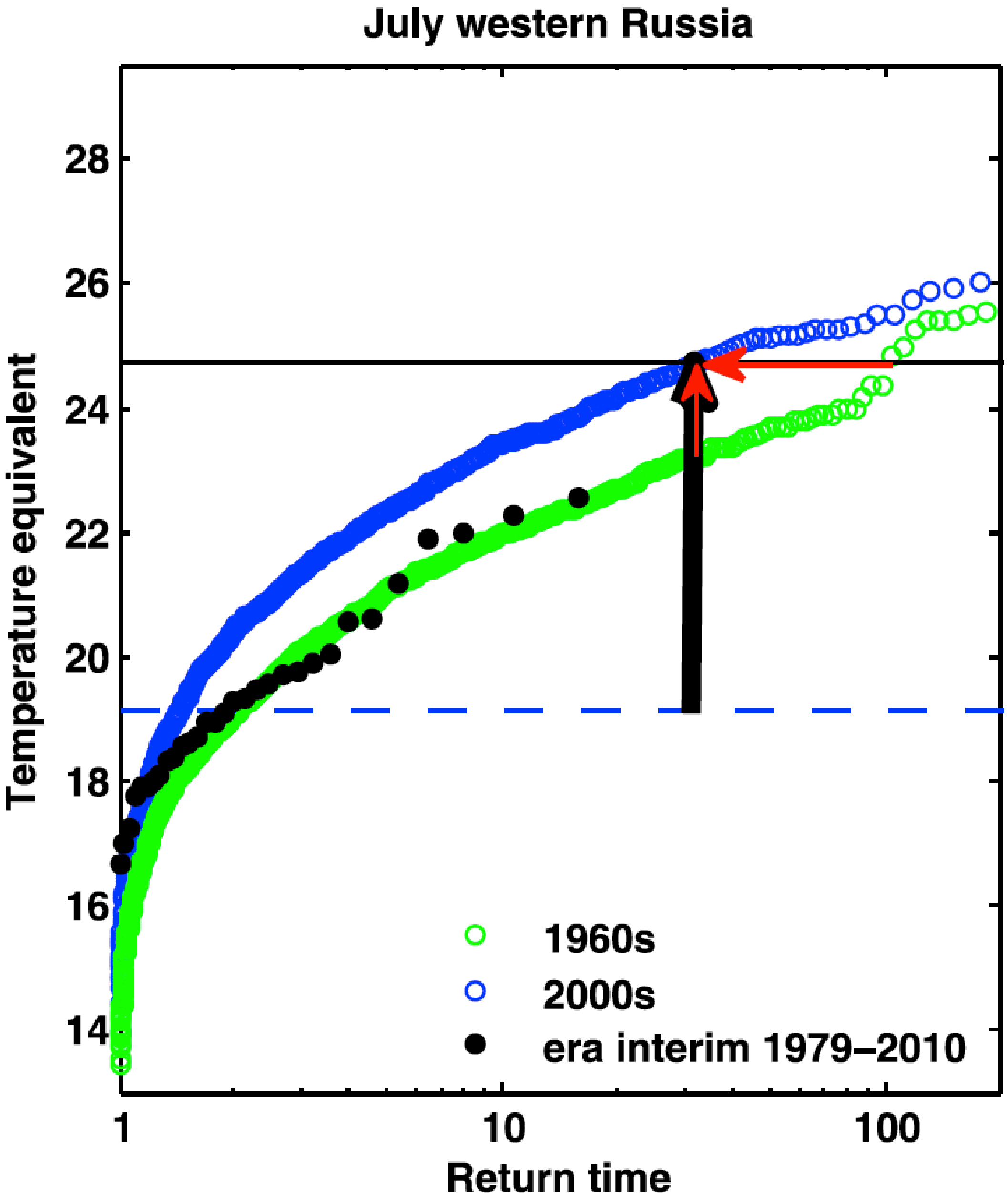


Figure 2. Regression maps on synoptic structure of northern hemisphere 500 hPa geopotential height patterns associated with July mean temperatures in (a) the model and (b) observations.

"Reconciling two approaches to attribution of the 2010 Russian heat wave": F. E. L. Otto, N. Massey, G. J. van Oldenborgh, R. G. Jones, and M. R. Allen. Geophysical Research Letters, VOL. 39, L04702, doi:10.1029/2011GL050422, 2012

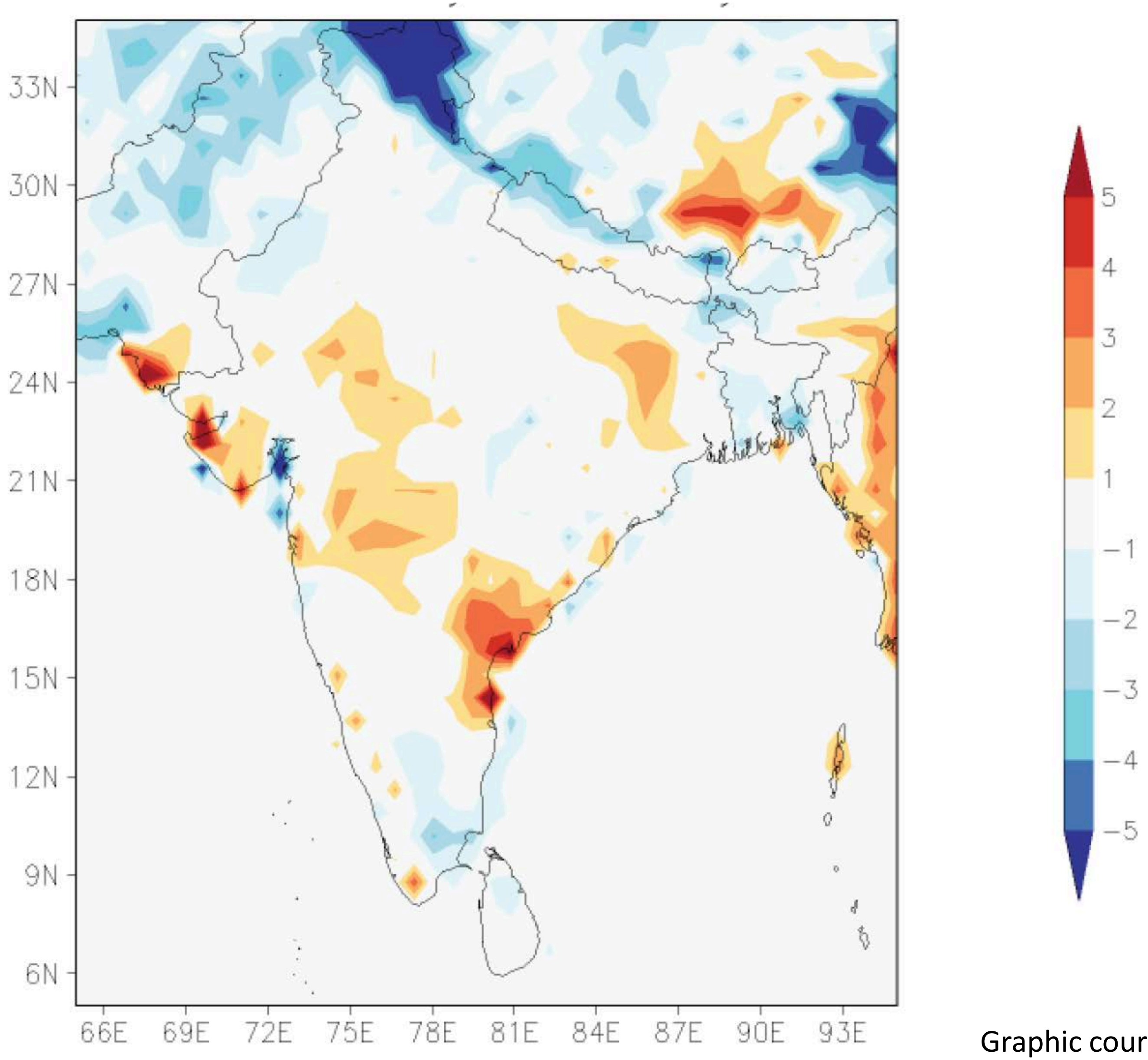


- The event was " mainly natural" in terms of magnitude (as in Dole et al 2011.)
- There is a three-fold increase in the risk of the 2010 threshold being exceeded, supporting the assertion that the risk of the event occurring was mainly attributable to the external trend (as in Rahmstorf & Camou 2011)

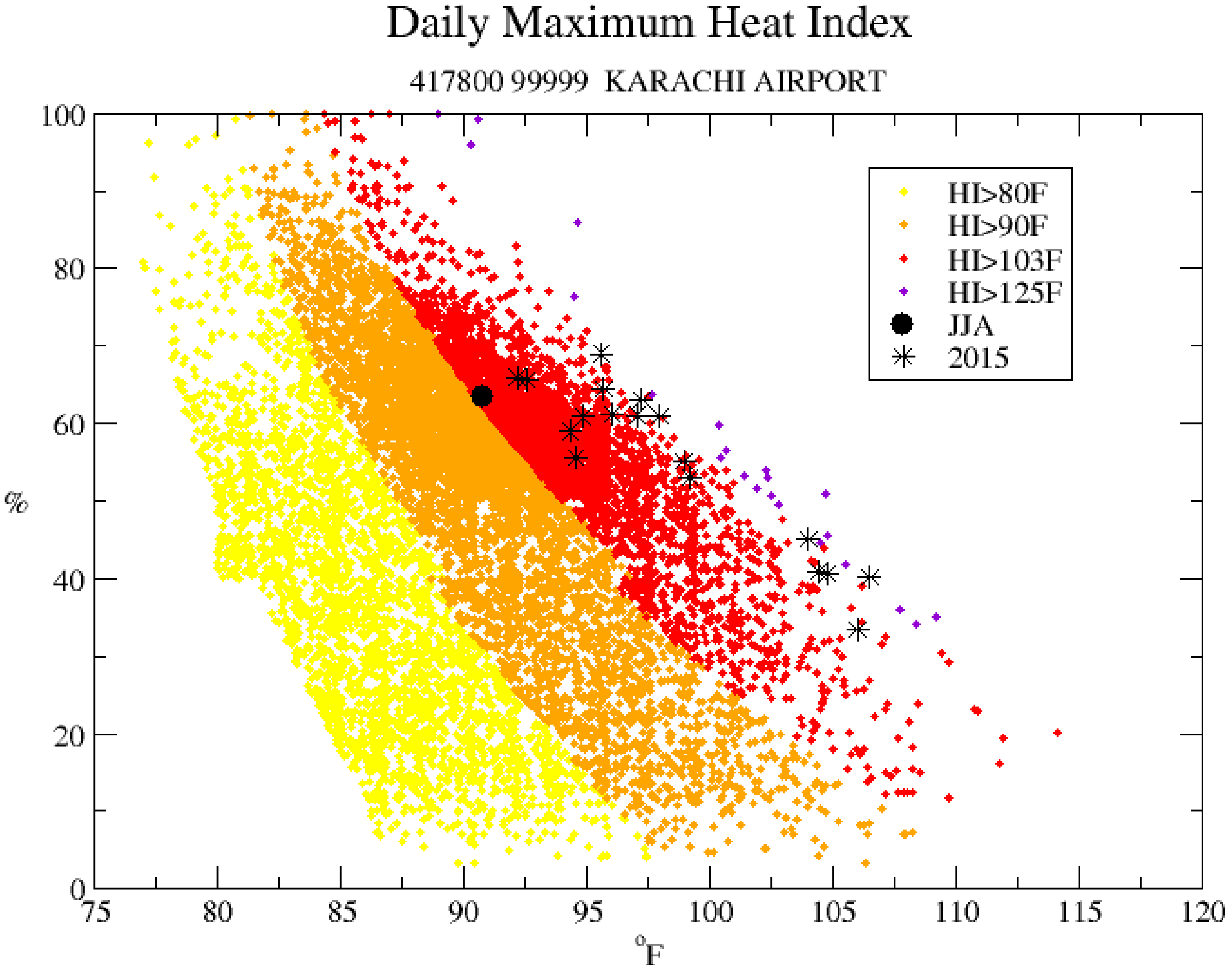
Figure 4. Return periods of temperature-geopotential height conditions in the model for the 1960s (green) and the 2000s (blue) and in ERA-Interim for 1979–2010 (black). The vertical black arrow shows the anomaly of the Russian heat wave 2010 (black horizontal line) compared to the July mean temperatures of the 1960s (dashed line). The vertical red arrow gives the increase in the magnitude of the heat wave due to the shift of the distribution whereas the horizontal red arrow shows the change in the return period.

"Reconciling two approaches to attribution of the 2010 Russian heat wave": F. E. L. Otto, N. Massey, G. J. van Oldenborgh, R. G. Jones, and M. R. Allen. Geophysical Research Letters, VOL. 39, L04702, doi:10.1029/2011GL050422, 2012

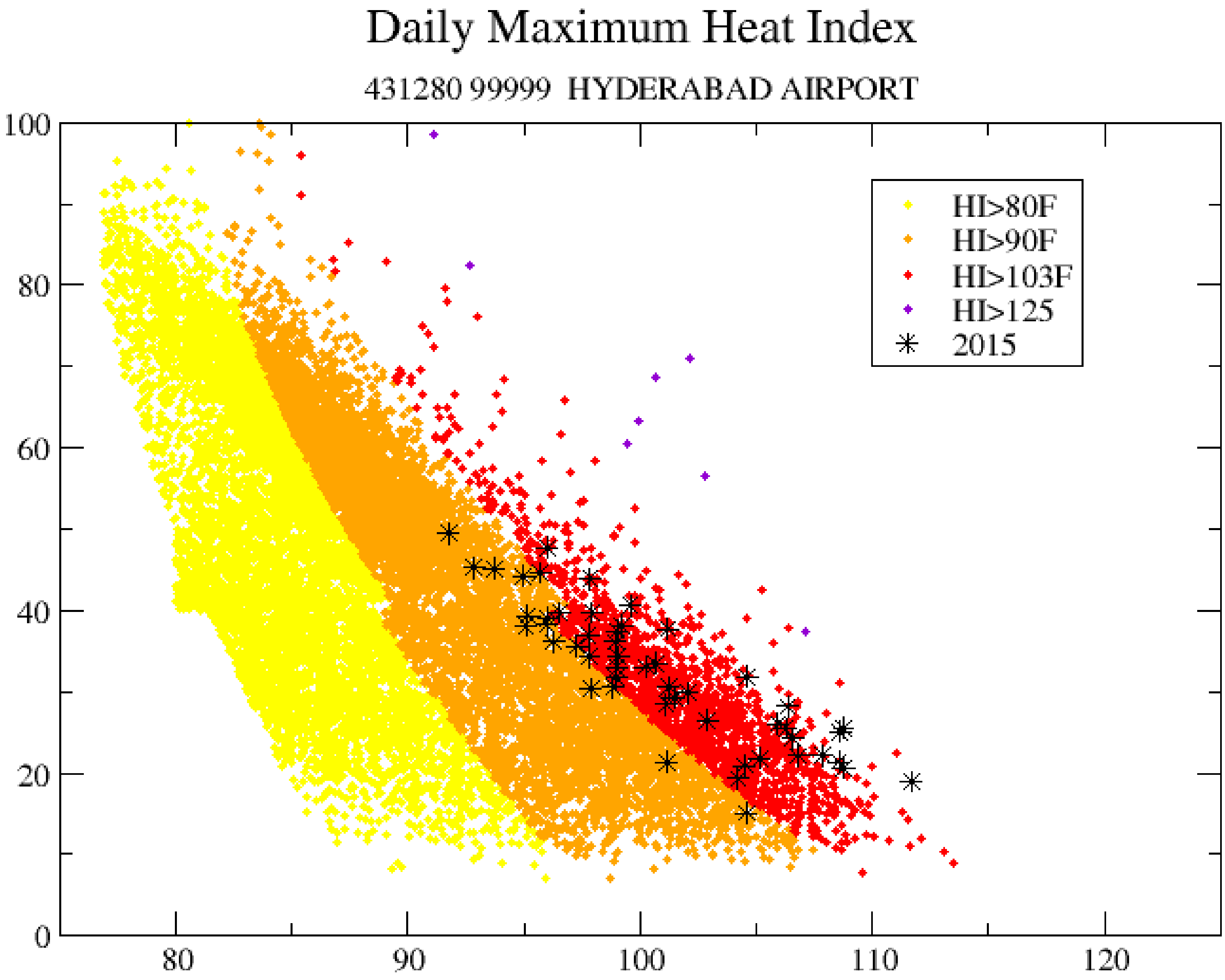
Monthly Maximum of daily T_{max} – Climatology (1981-2010) May 2015 (ERA-Interim)



Graphic courtesy: Geert Jan van Oldenburgh



Graphic courtesy: Michael Wehner, LBNL



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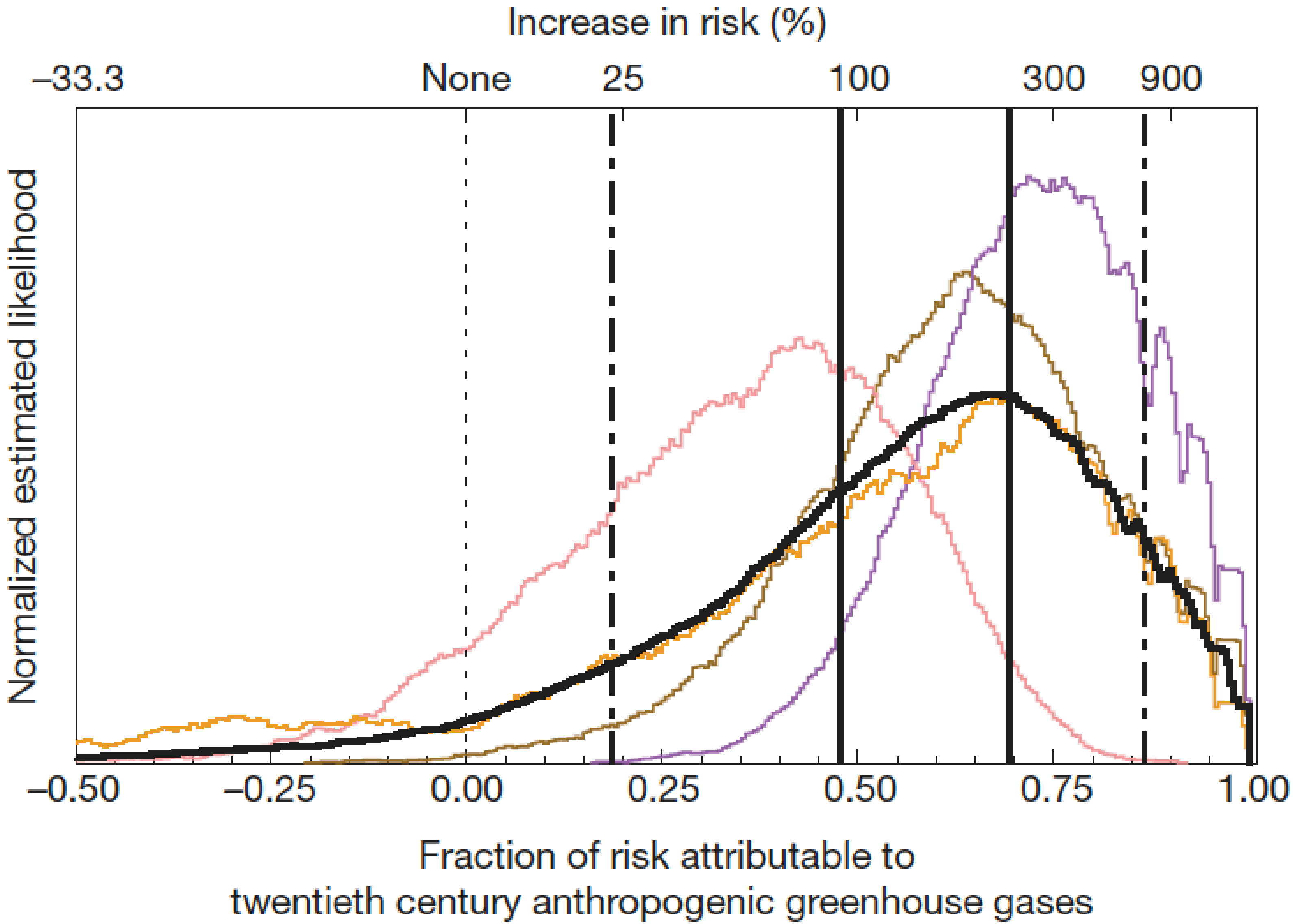
Thanks



“Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000” Pardeep Pall, Tolu Aina, Da´ithı´A. Stone, Peter A. Stott, ToruNozawa, ArnoG. J. Hilberts, Dag Lohmann & Myles R. Allen. NATURE V 470, 2011

volunteer distributed computing (VDC) is used.
CPDN uses the Berkeley Open Infrastructure for Network Computing (BOINC; Anderson, 2004) to leverage the idle computing power of volunteers in a client/server model.
climateprediction.net (CPDN)uses VDC to generate very large ensembles of coupled slab layer-ocean and atmosphere models (Stainforth et al., 2005), high-resolution atmosphere-only models (Pall et al., 2011) and coupled atmosphere–ocean models (Rowlands et al., 2012).

HadAM3P/RM3P requires a number of inputs, which must be supplied to the volunteers' computers
initial condition of the model and, as the model is atmosphere-only, forcings are required at the sea-surface boundary, in the form SST and sea-ice fraction (SIF). Atmospheric concentrations of the well-mixed greenhouse gases are required, including carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and the halocarbons (CFC113, CFC11, CFC12, HCFC22, HFC124 and HFC134A). Ozone (O3) concentrations are required as zonal averages at each model level and the inputs to the sulphur cycle are also required.

CPDN scientists control the project's servers, which hand out workunits to volunteers' client computers. Each workunit contains all the information needed by the climate models
to run an experiment for a certain period ofmodel time, under a specified climate scenario.
weather@home builds upon CPDN's success to use the same infrastructure to compute large-ensemble simulations using the HadAM3P/RM3P models.

Rainfall extremes

- The increased ability of the atmosphere to hold water in a warming climate – *the Thermodynamic effect*
- A warmer climate can also lead to changes in the atmospheric circulation patterns and trigger nonlinear dynamical changes in the atmospheric processes that cause extreme precipitation – *the Dynamic effect*
- For either mechanism — thermodynamic or dynamic — attribution of an individual extreme weather event to climate change is challenging: we do not have the observations of what the world would have been like without human influence.

"Attribution of extreme weather", Friederike E. L. Otto, Nature Geoscience, Vol. 8, 2015