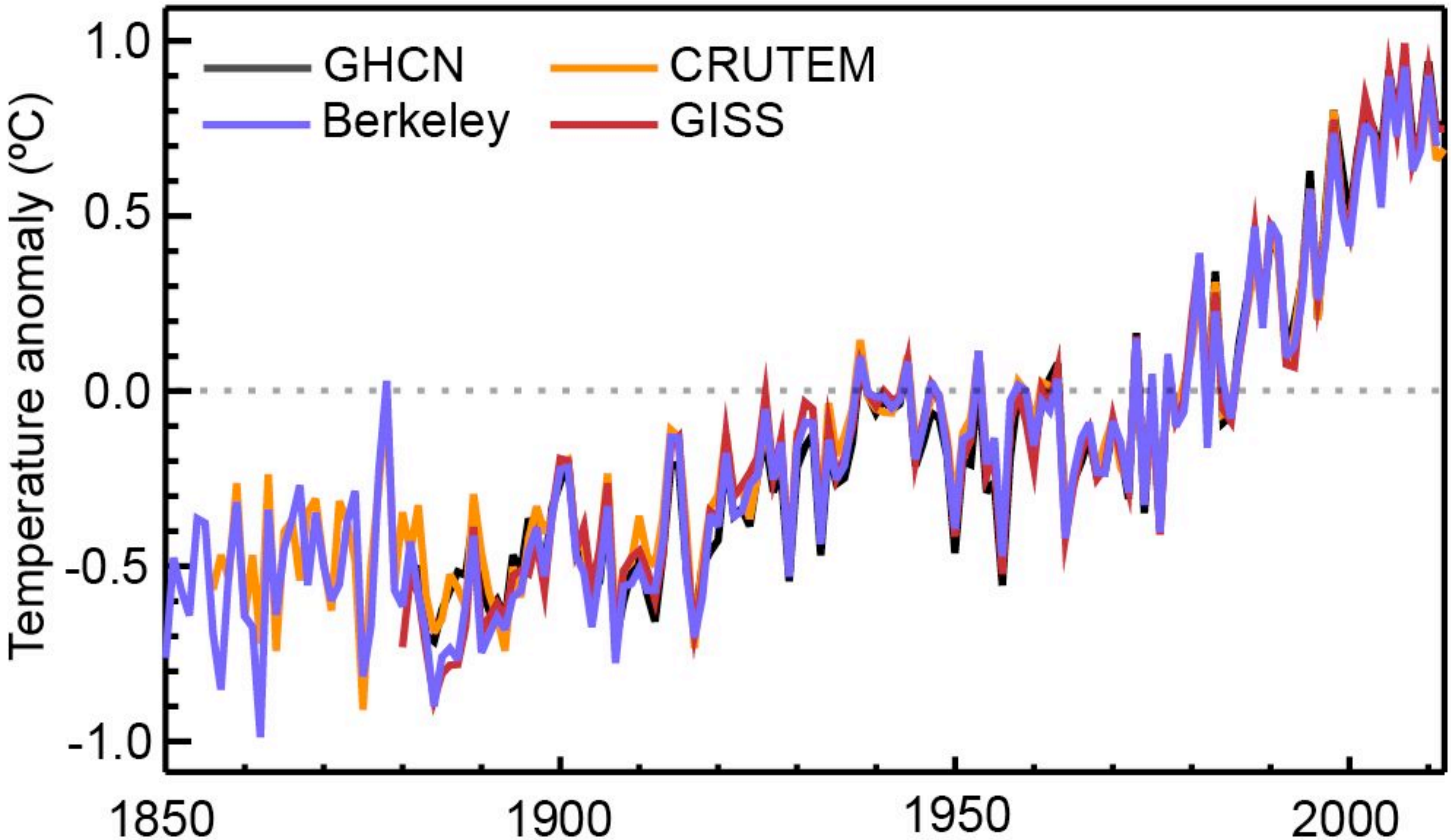


Figure 2.14 | Global annual average land-surface air temperature (LSAT) anomalies relative to a 1961–1990 climatology from the latest versions of four different data sets (Berkeley, CRUTEM, GHCN and GISS). http://www.climatechange2013.org/images/report/WG1AR5_Chapter02_FINAL.pdf

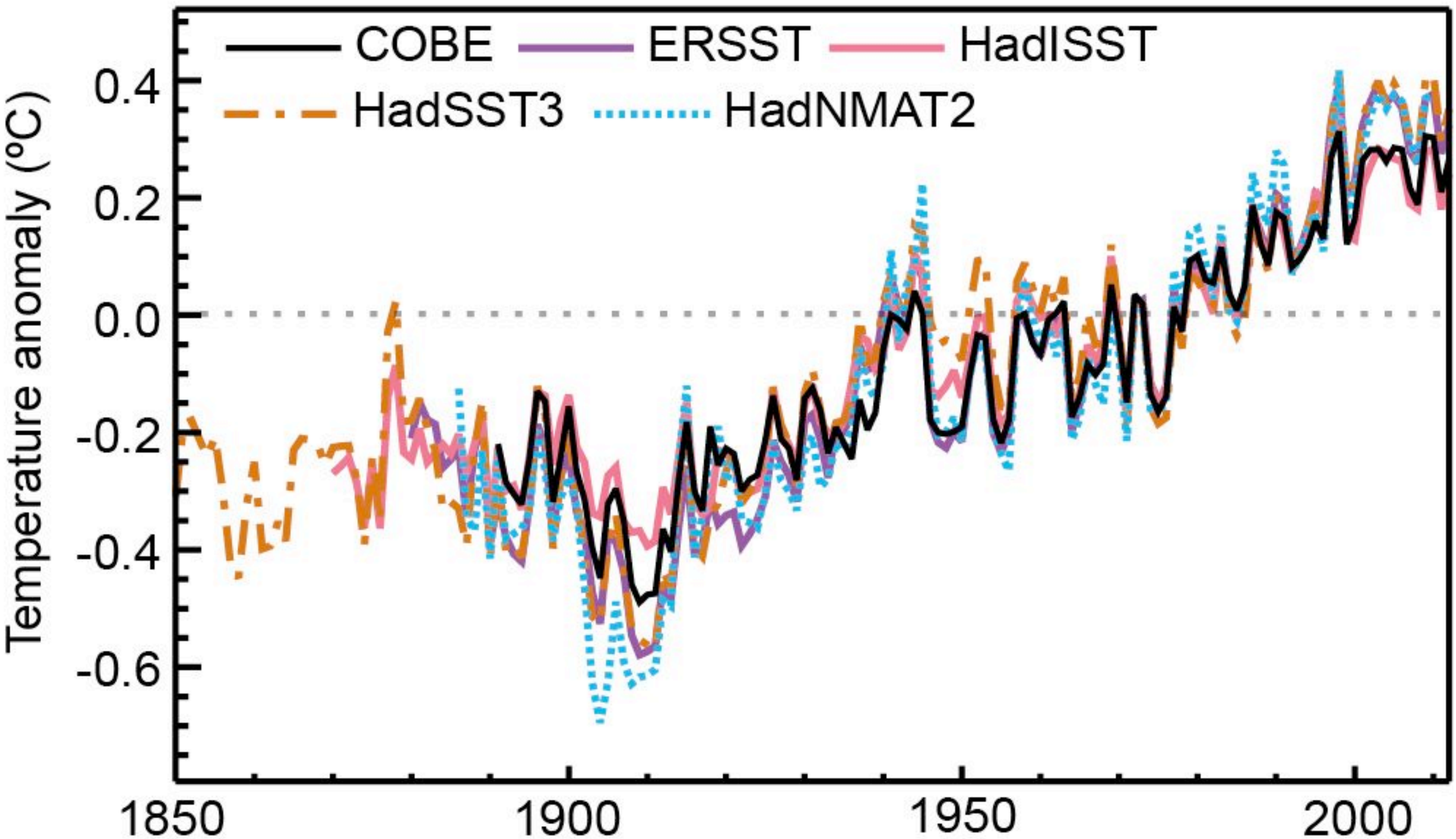
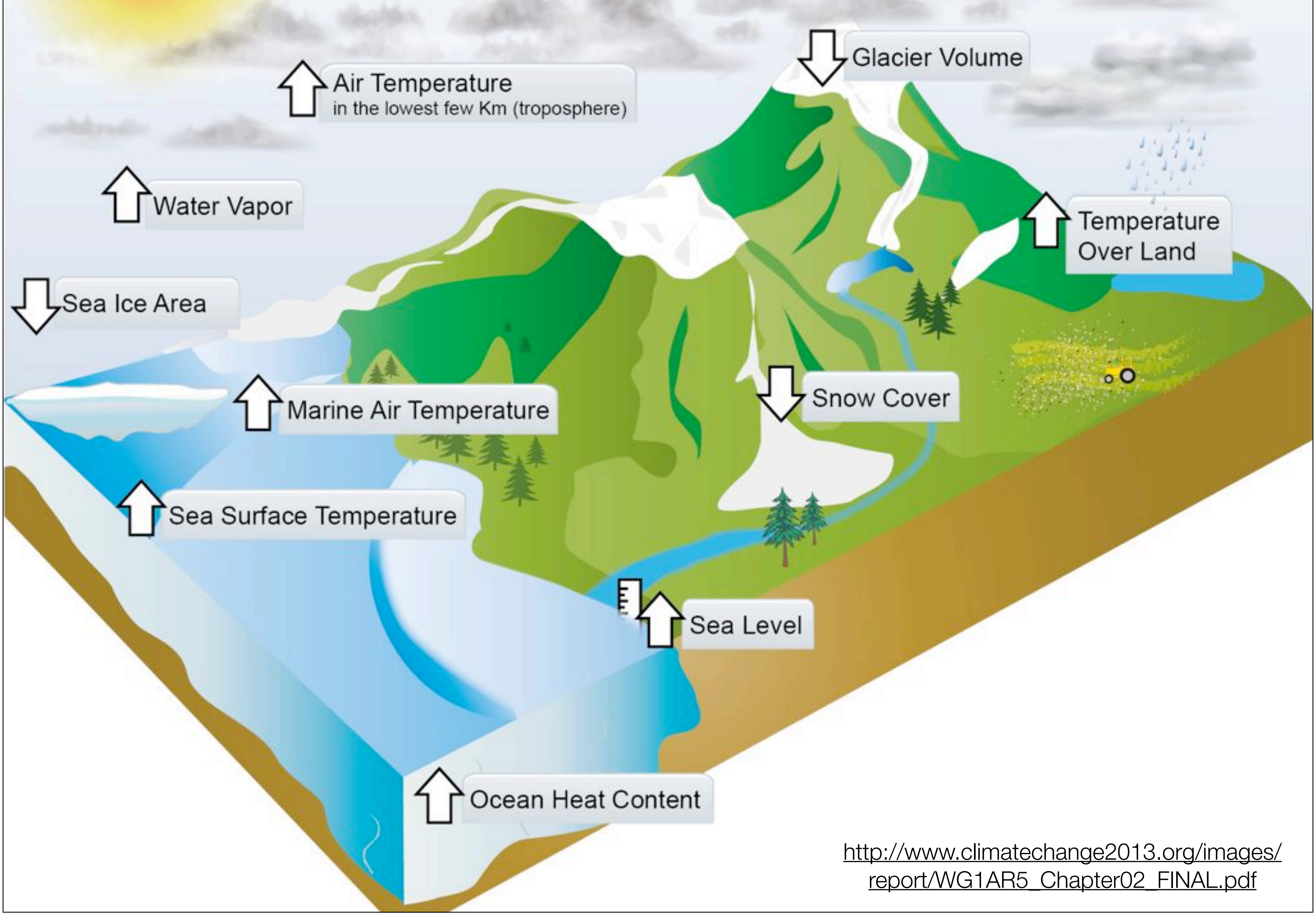


Figure 2.18 | Global annual average sea surface temperature (SST) and Night Marine Air Temperature (NMAT) relative to a 1961–1990 climatology from state of the art data sets. Spatially interpolated products are shown by solid lines; non-interpolated products by dashed lines.
http://www.climatechange2013.org/images/report/WG1AR5_Chapter02_FINAL.pdf

How Do We Know the World Has Warmed?



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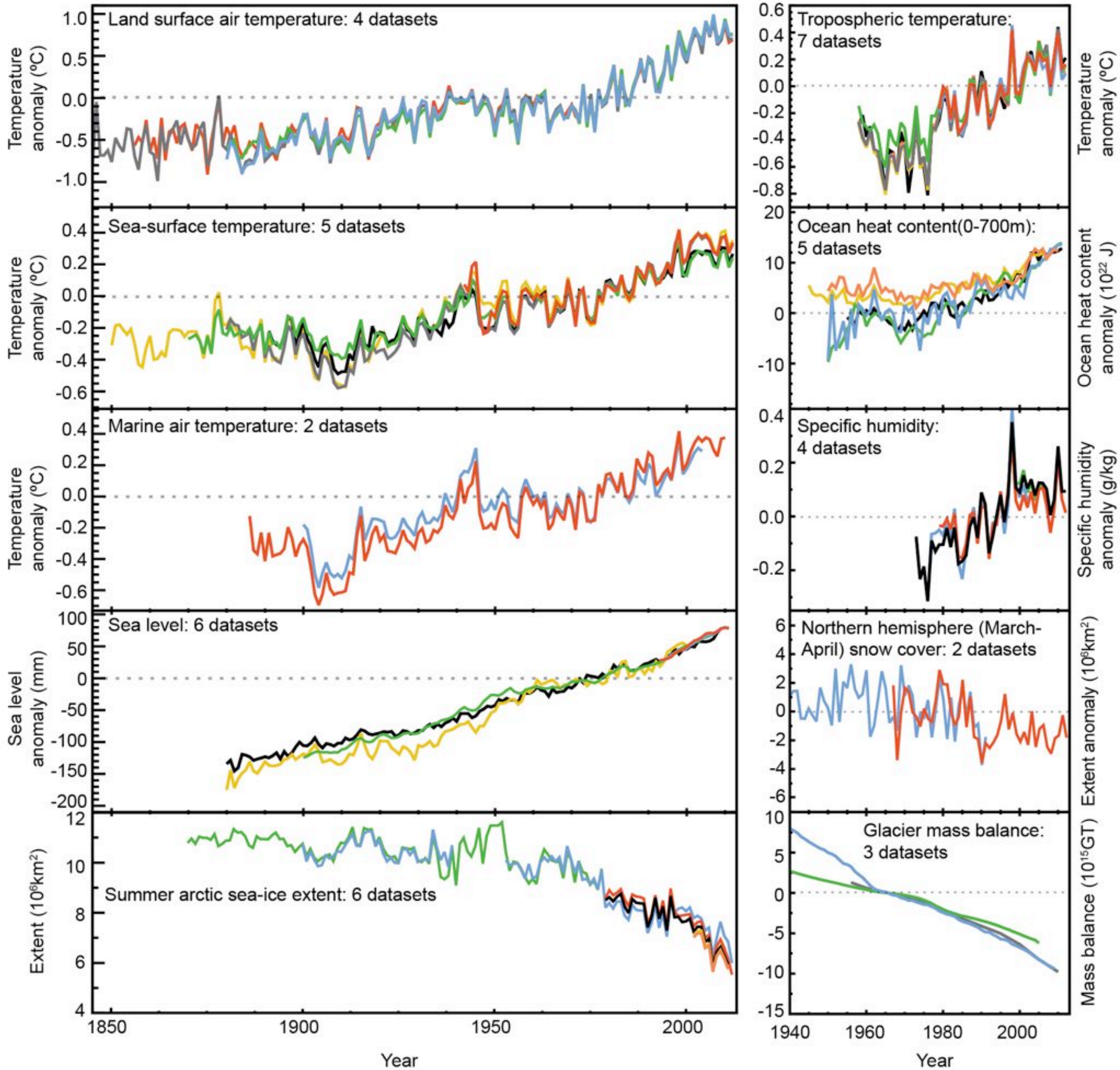


http://www.climatechange2013.org/images/figures/WGI_AR5_FigFAQ2.1-2.jpg

“Low Confidence”

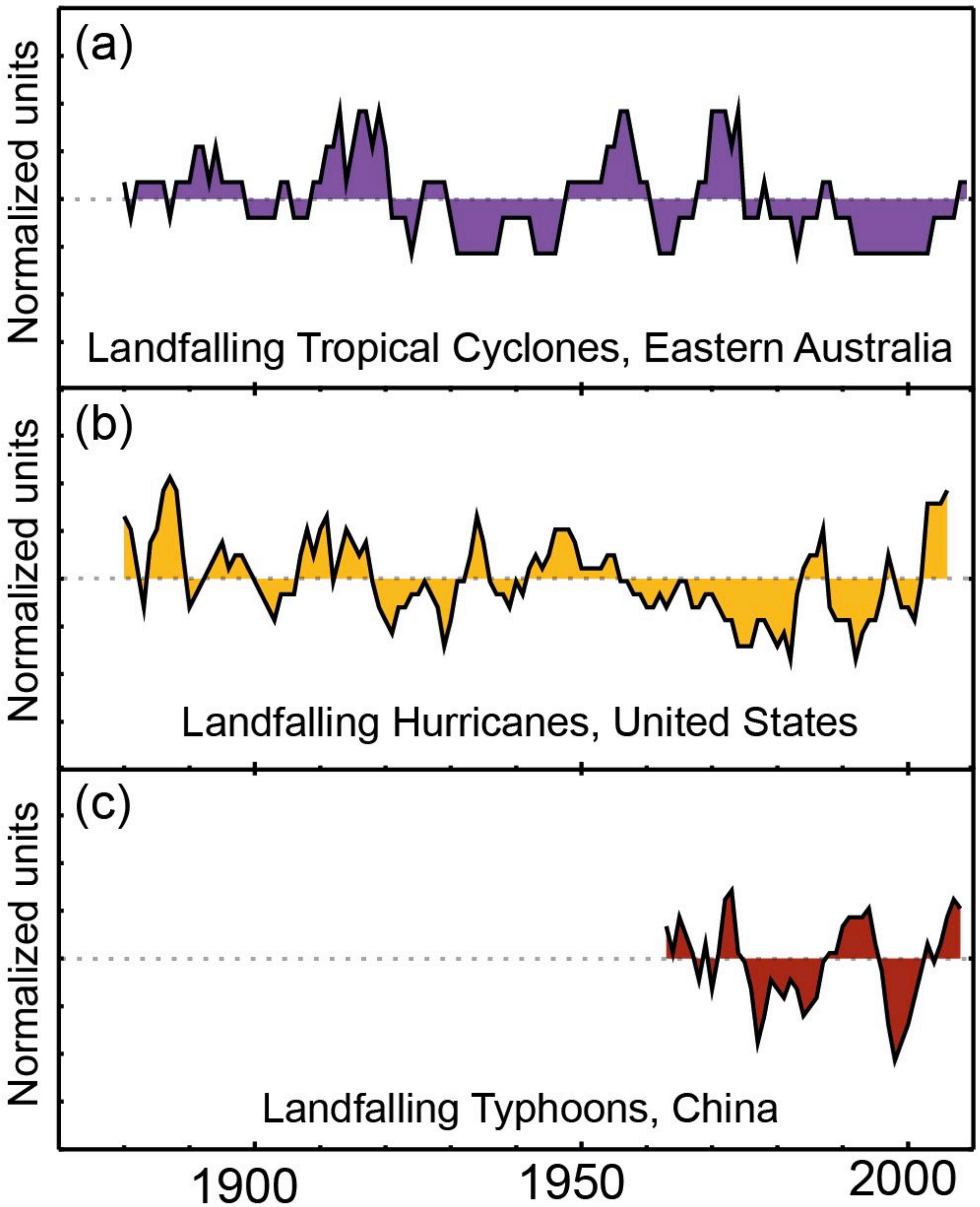
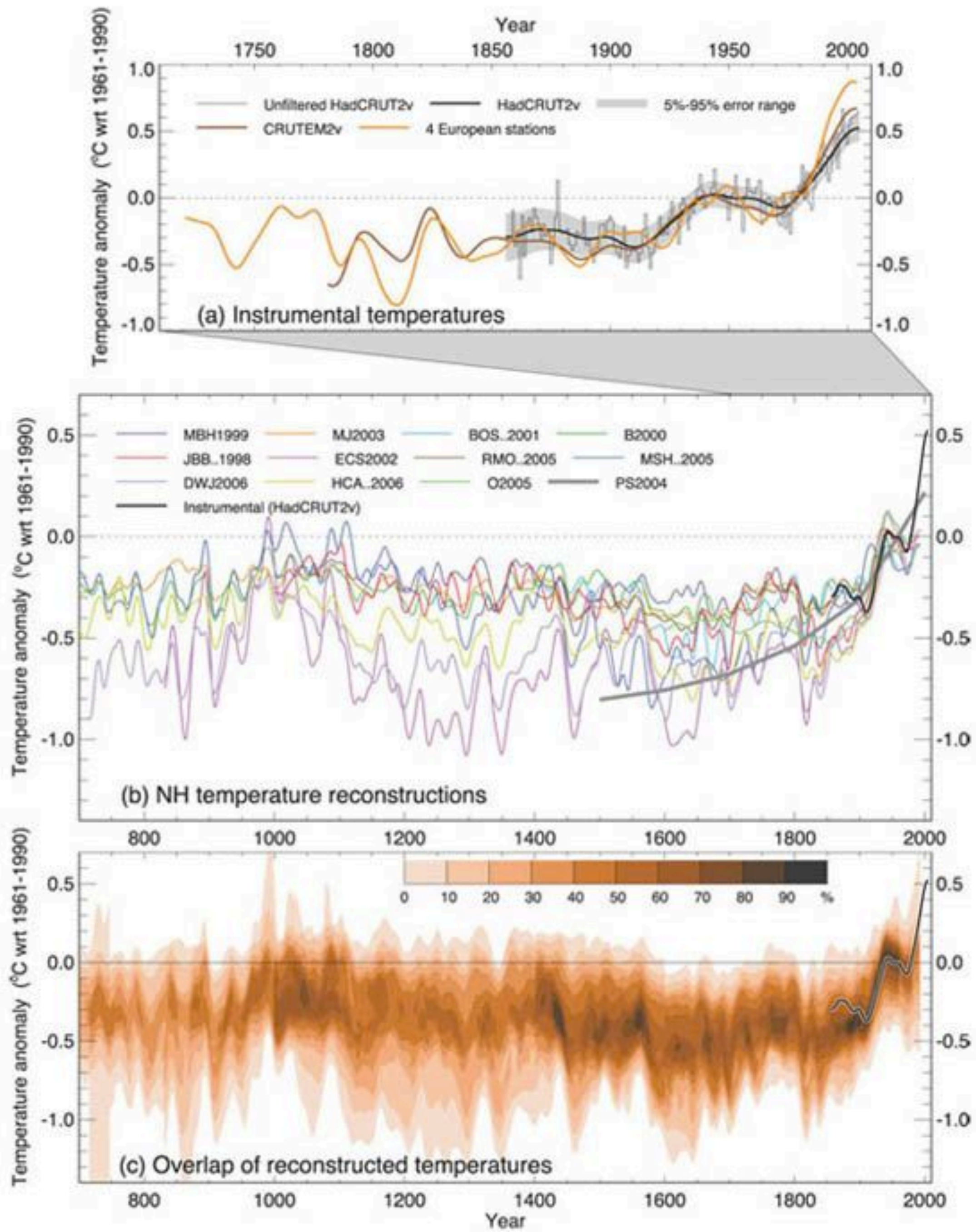


Figure 2.34 | Normalized 5-year running means of the number of (a) adjusted land falling eastern Australian tropical cyclones (adapted from Callaghan and Power (2011) and updated to include 2010//2011 season) and (b) unadjusted land falling U.S. hurricanes (adapted from Vecchi and Knutson (2011) and (c) land-falling typhoons in China (adapted from CMA, 2011). Vertical axis ticks represent one standard deviation, with all series normalized to unit standard deviation after a 5-year running mean was applied.



Clear increase in temperature over last 150 years of instrument readings

Can add in other sources of data (e.g., tree rings, isotopic ratios, abundance of temperature-sensitive species) to extend time series

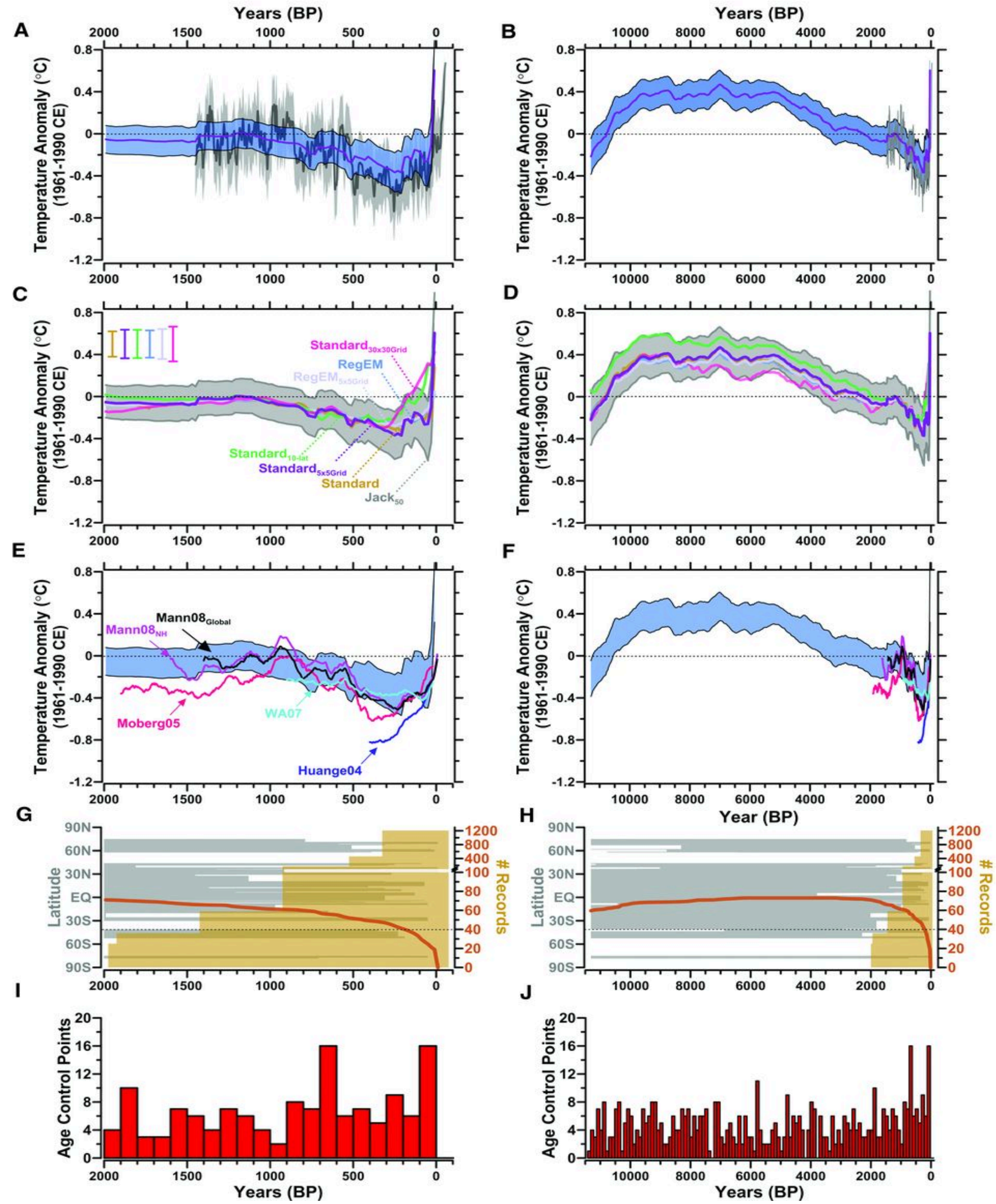
Last 20 years warmer than previous ~1,300!

From SimUText & refs therein

Fig. 1 Comparison of different methods and reconstructions of global and hemispheric temperature anomalies.

Used 73 globally distributed temperature records
Variety of paleotemperature proxies

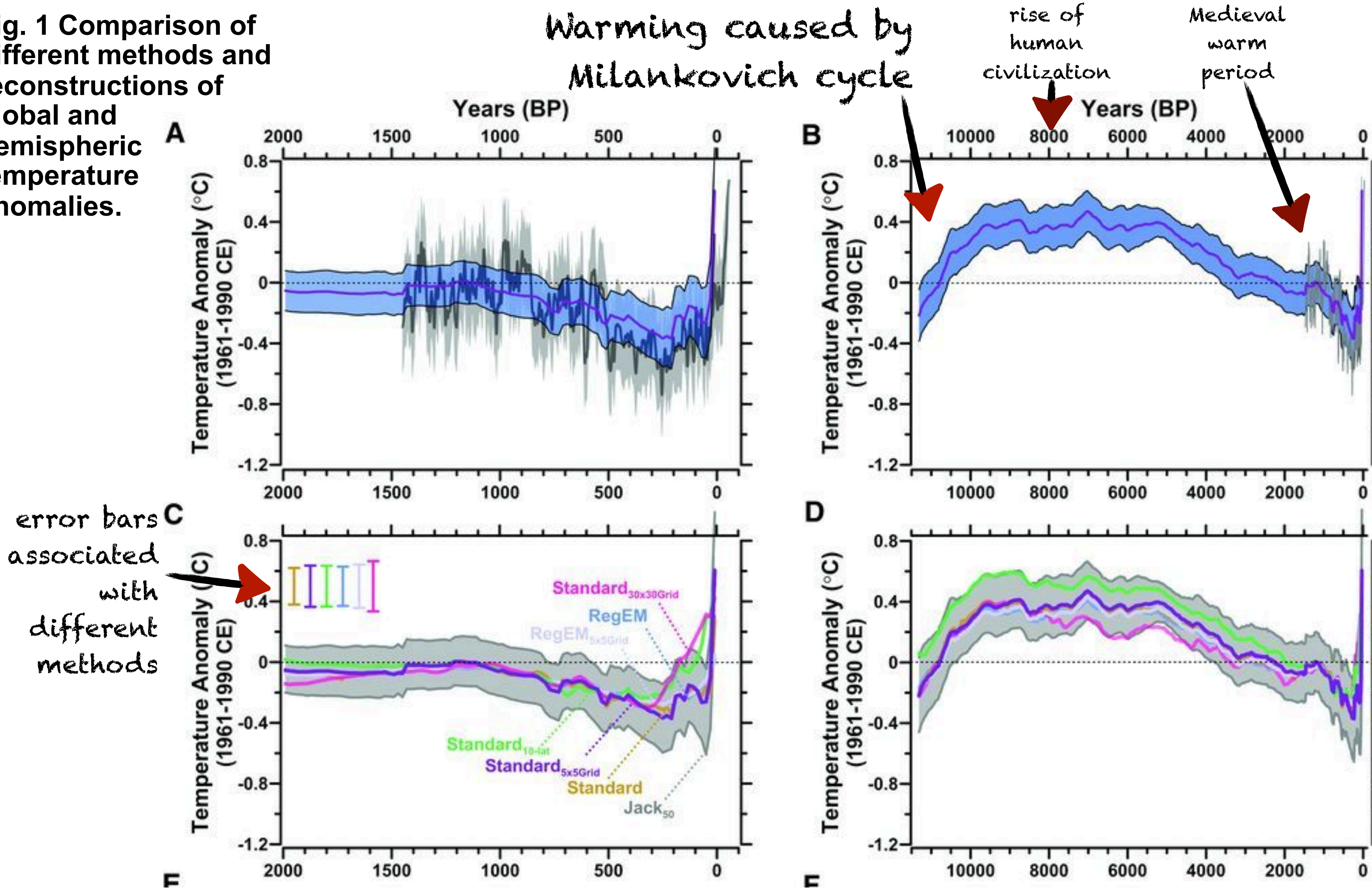
- alkenone (n=31)
- planktonic foraminifera Mg/Ca (n=19)
- TEX86 (n=4)
- fossil chironomid transfer function (n=4)
- fossil pollen modern analog technique (MAT) (n=4)
- ice-core stable isotopes (n=5)
- other microfossil assemblages
- (n=5)
- Methylation index of Branched Tetraethers (MBT) (n=1).



Published by AAAS

S A Marcott et al. Science 2013;339:1198-1201

Fig. 1 Comparison of different methods and reconstructions of global and hemispheric temperature anomalies.



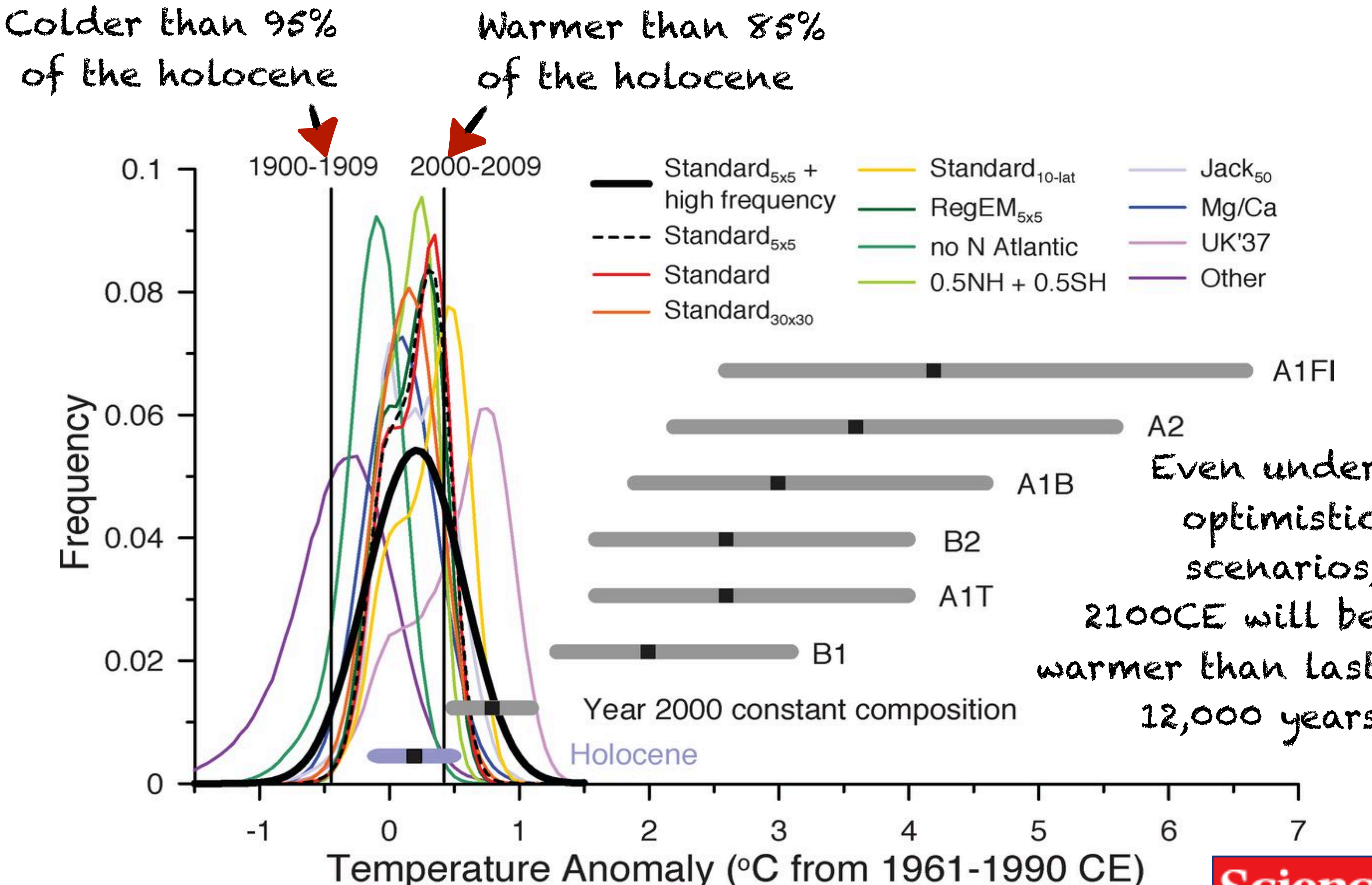
Recent decade warmest in ~4000 years!

Science AAAS

S A Marcott et al. Science 2013;339:1198-1201

Published by AAAS

Fig. 3 Holocene temperature distribution compared to modern temperature and future projections.



Published by AAAS

S A Marcott et al. Science 2013;339:1198-1201

Qori Kalis glacier (part of Quelccaya ice cap) in Peru from 1978 to 2011

Newly exposed plants ~6298 yr B.P.

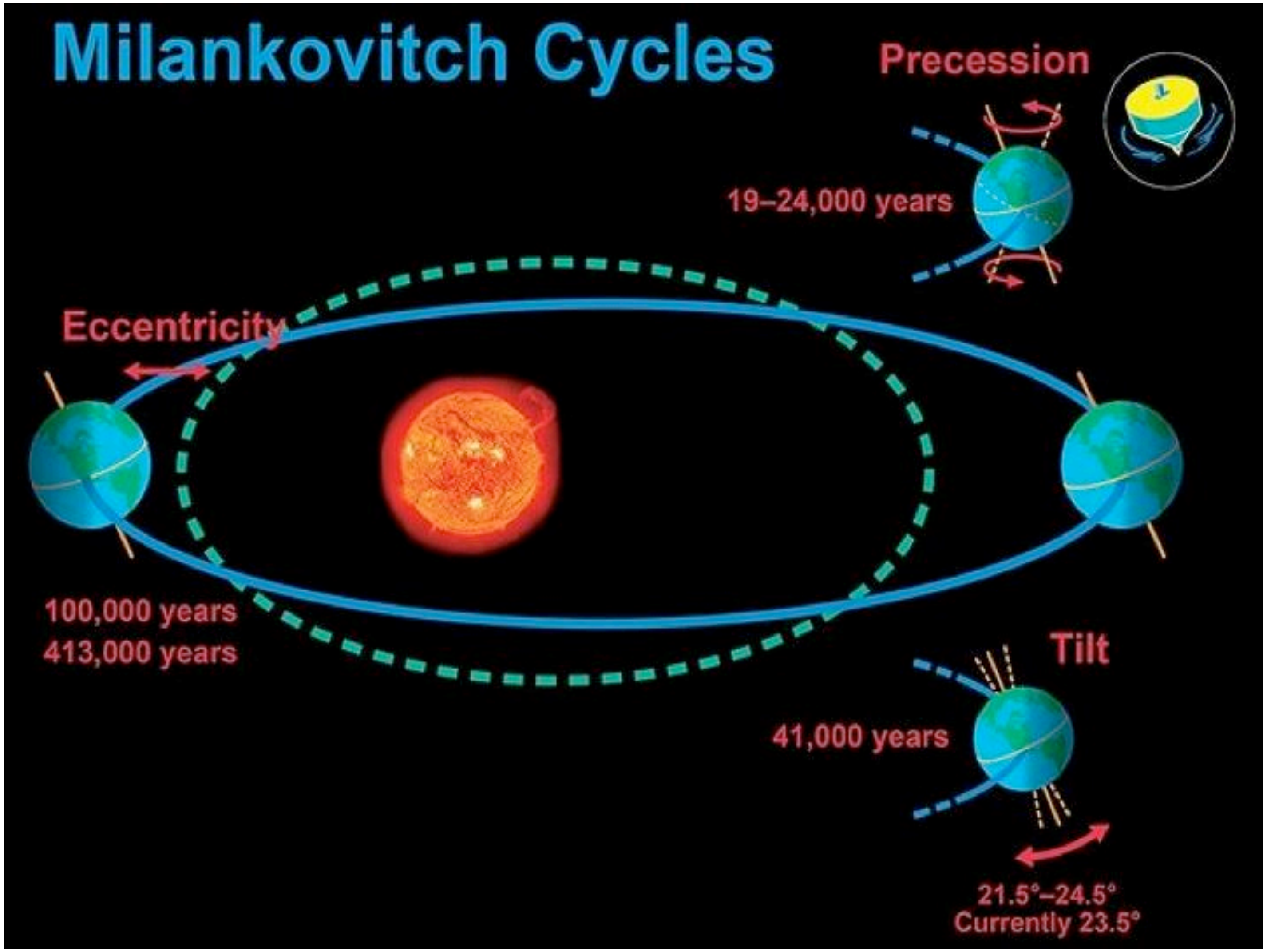
Quelccaya is now smaller than it was 6000 years ago

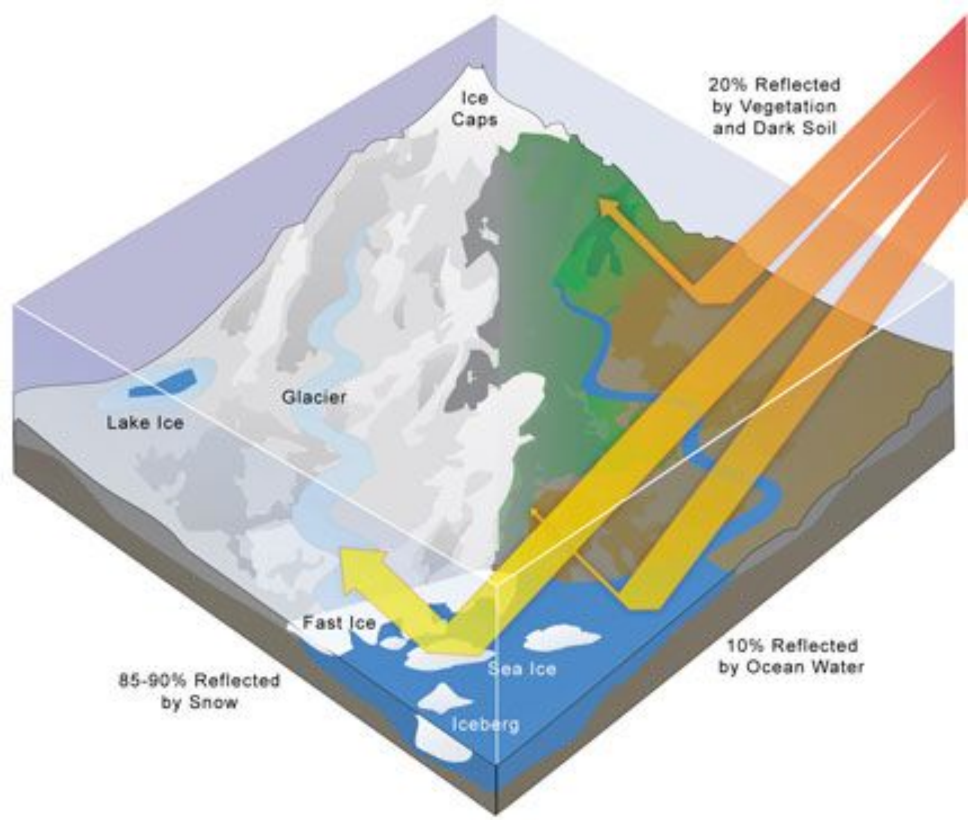
Annually Resolved Ice Core Records of Tropical Climate Variability over the Past ~1800 Years

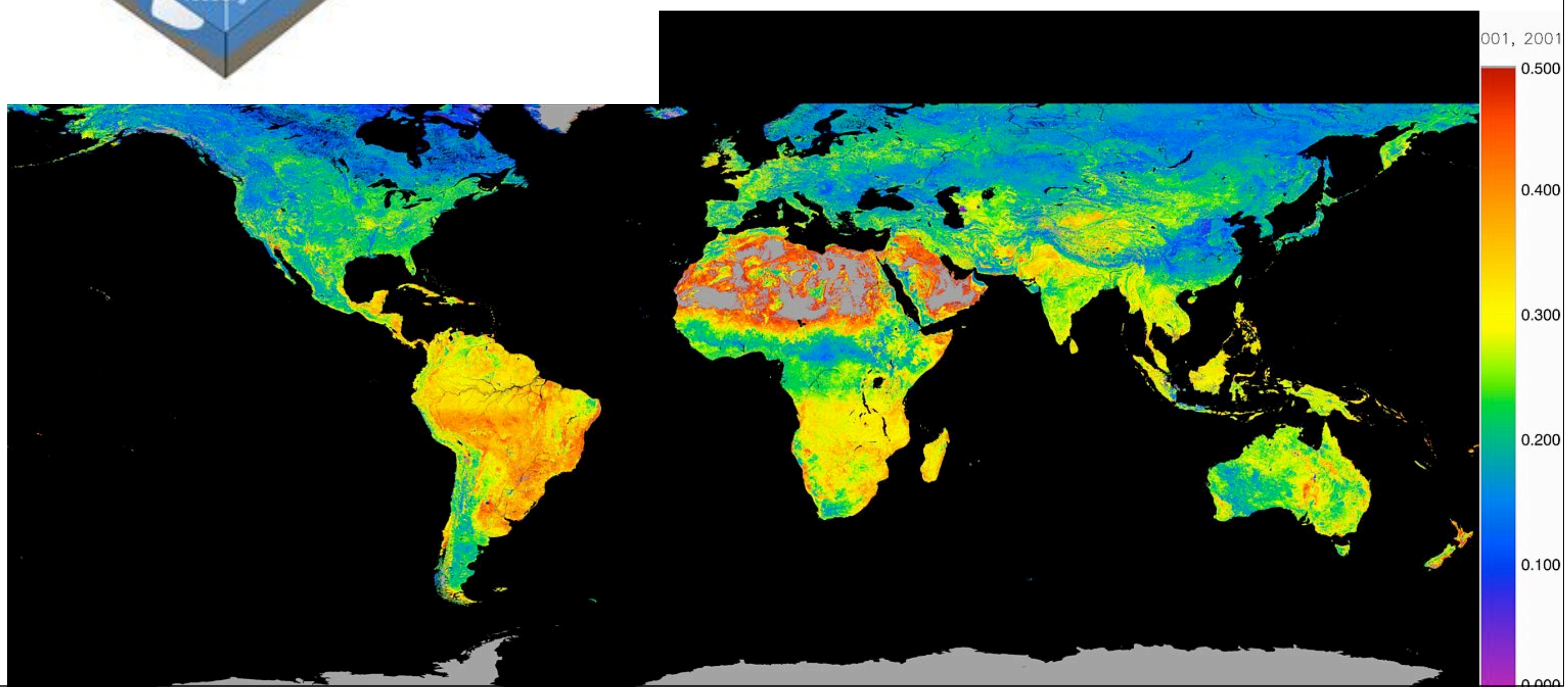
L. G. Thompson,[1,2]* E. Mosley-Thompson,[1,3] M. E. Davis,[1] V. S. Zagorodnov,[1] I. M. Howat,[1,2] V. N. Mikhalenko,[4] P.-N. Lin[1]

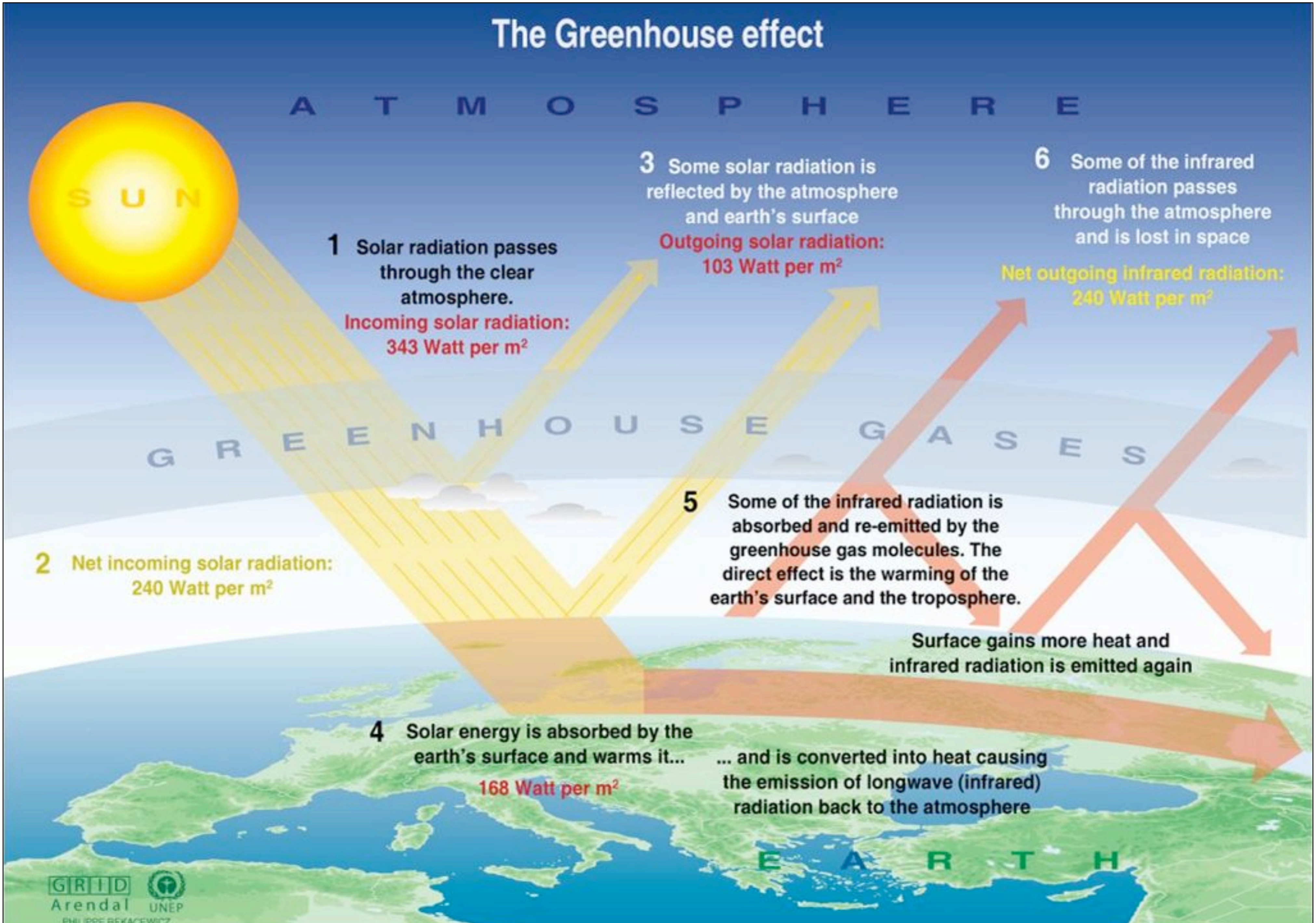
SCIENCE VOL 340 24 MAY 2013

http://www.nytimes.com/2013/04/05/world/americas/1600-years-of-ice-in-perus-andes-melted-in-25-years-scientists-say.html

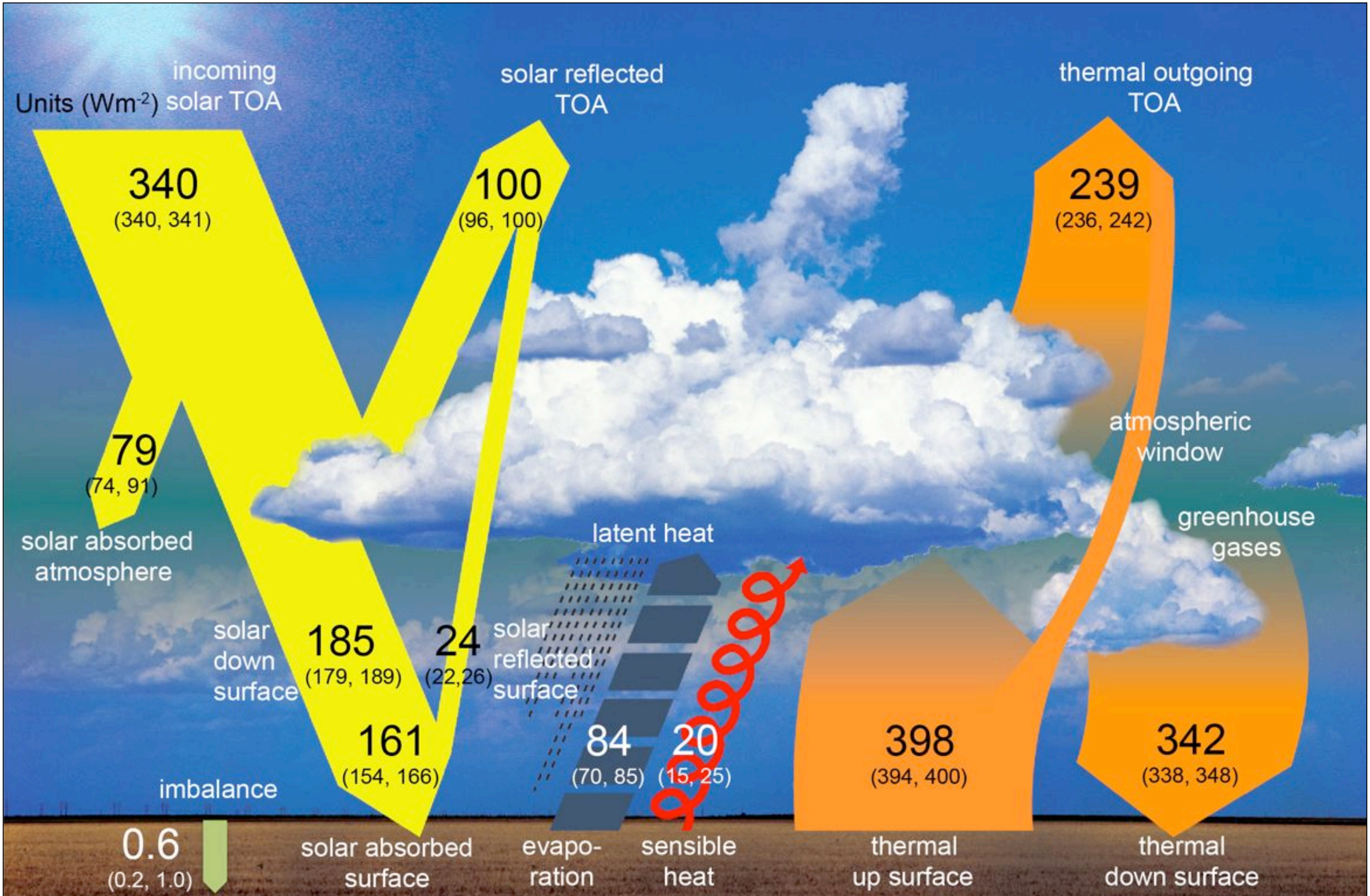

Milankovitch Cycles
Precession
19–24,000 years
Eccentricity
100,000 years
413,000 years
Tilt
41,000 years
21.5°–24.5°
Currently 23.5°


Ice Caps
20% Reflected by Vegetation and Dark Soil
Glacier
Lake Ice
Fast Ice
Sea Ice
85-90% Reflected by Snow
10% Reflected by Ocean Water
Iceberg


0.500
0.400
0.300
0.200
0.100



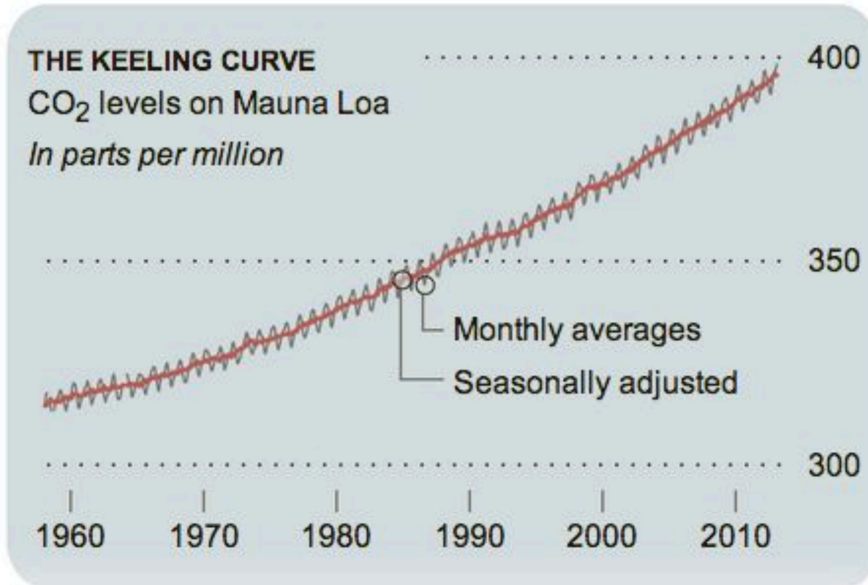
Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

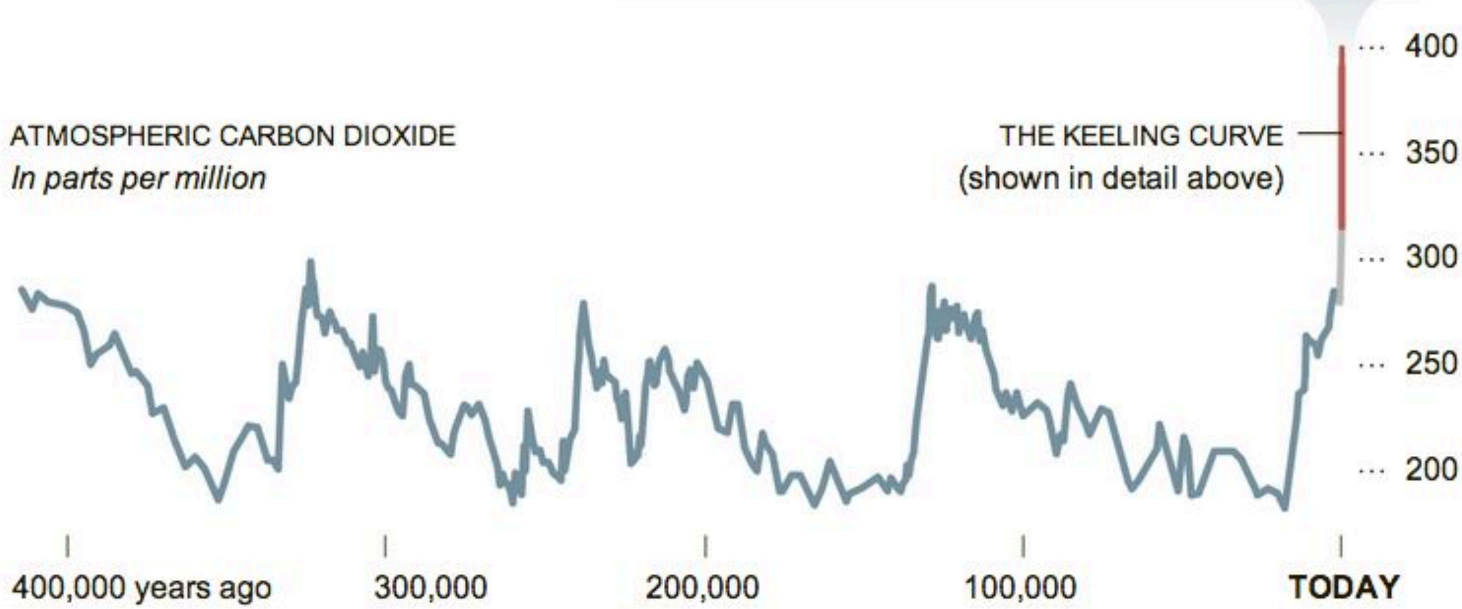


http://www.ipcc.ch/report/ar5/wg1/

Carbon dioxide in the atmosphere was measured at just above 400 p.p.m. on Thursday, the highest daily average ever recorded at the flagship Mauna Loa station.

Preindustrial levels of carbon dioxide, as measured in ice bubbles, tended to oscillate between 180 and 280 p.p.m.





http://www.nytimes.com/interactive/2013/05/10/science/crossing-a-line.html?ref=earth

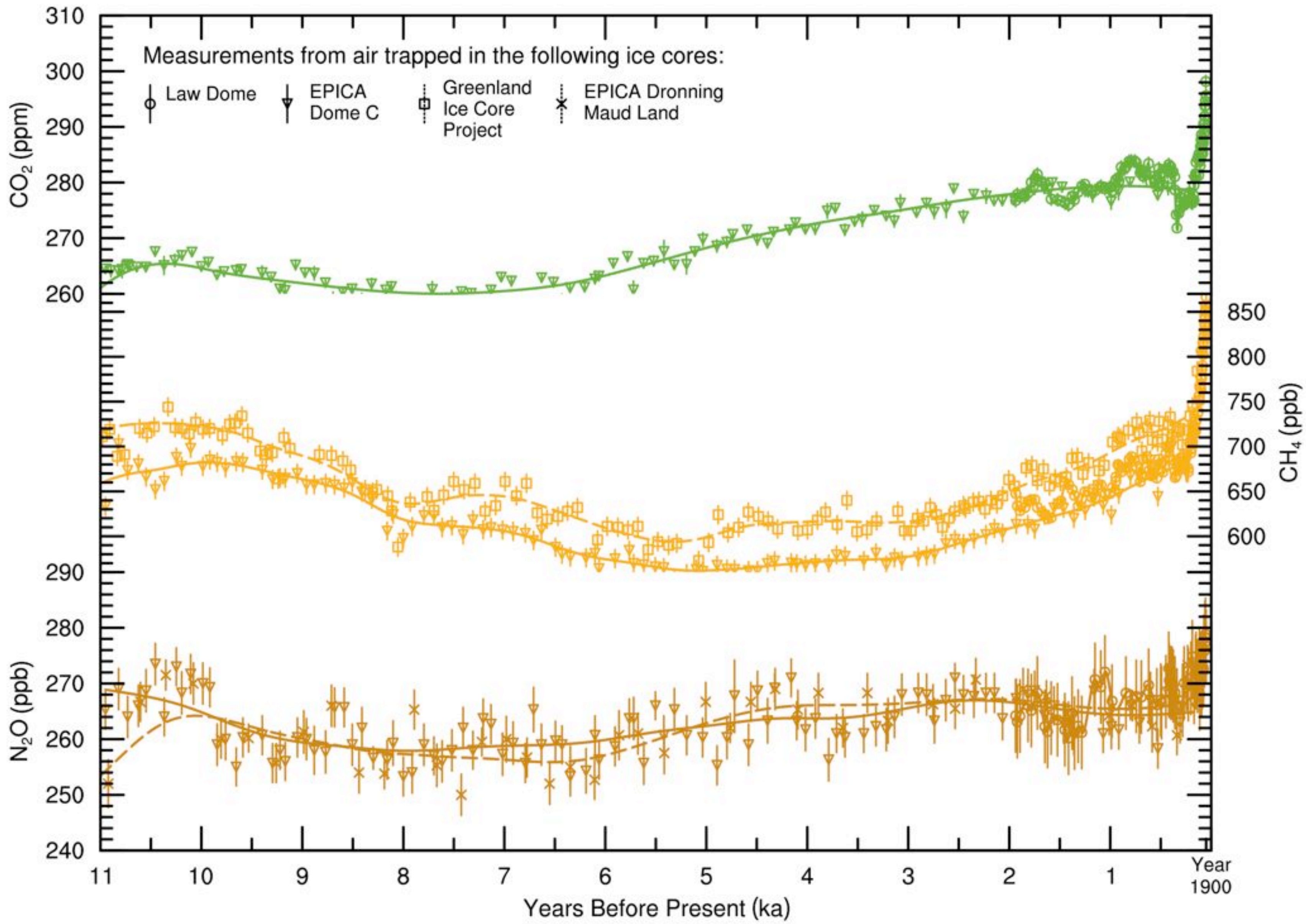


Figure 6.7 I Variations of CO_2, CH_4, and N_2O during 900–1900 from ice cores. The data are for Antarctic ice cores: Law Dome (Etheridge et al., 1996; MacFarling-Meure et al., 2006), circles; West Antarctic Ice Sheet (Mitchell et al., 2011; Ahn et al., 2012), triangles; Dronning Maud Land (Siegenthaler et al., 2005a), squares. Lines are spline fits to individual measurements. http://www.climatechange2013.org/images/report/WG1AR5_Chapter06_FINAL.pdf

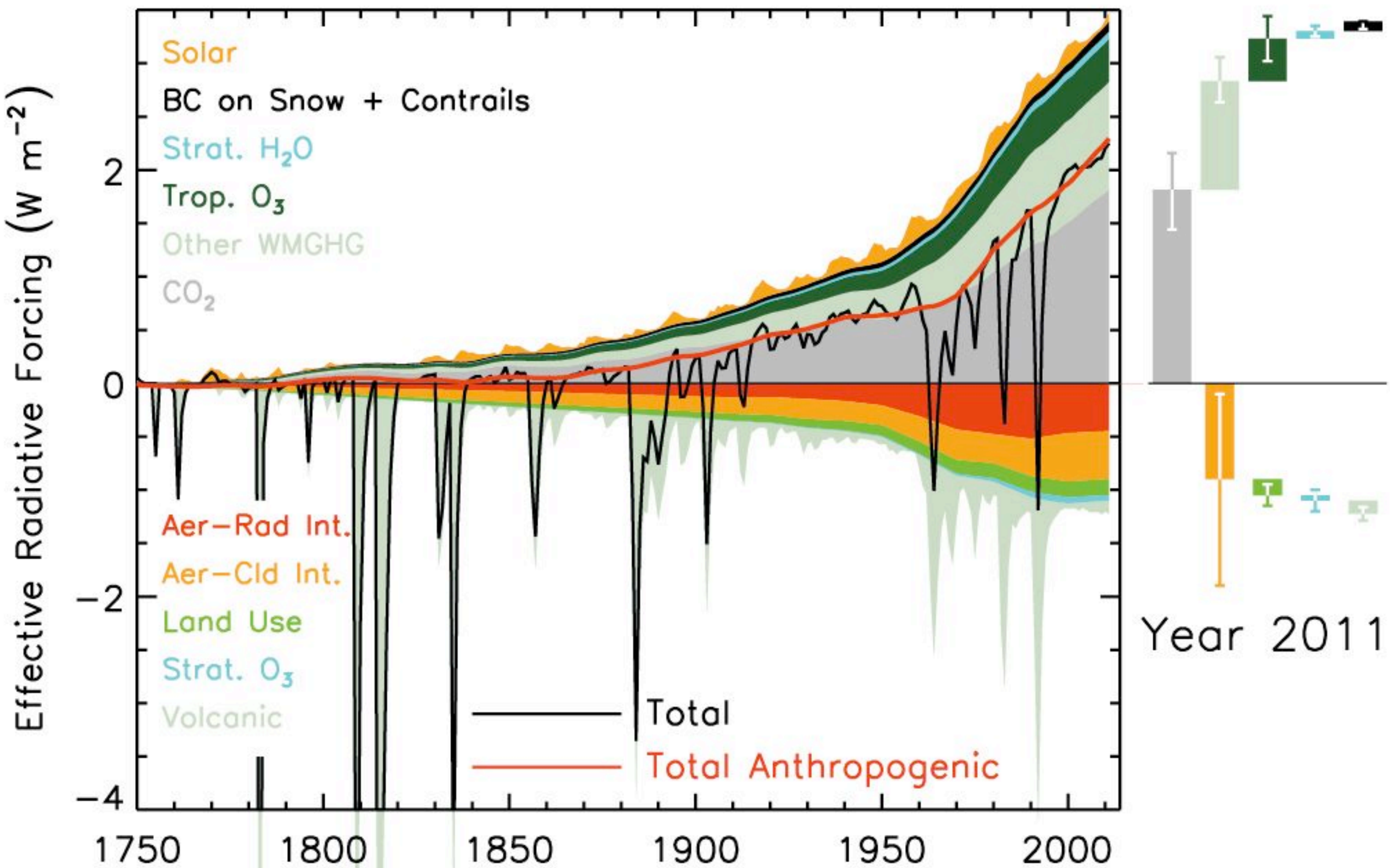


Figure 8.18 | Time evolution of forcing for anthropogenic and natural forcing mechanisms. Bars with the forcing and uncertainty ranges (5 to 95% confidence range) at present are given in the right part of the figure. For aerosol the ERF due to aerosol– radiation interaction and total aerosol ERF are shown.

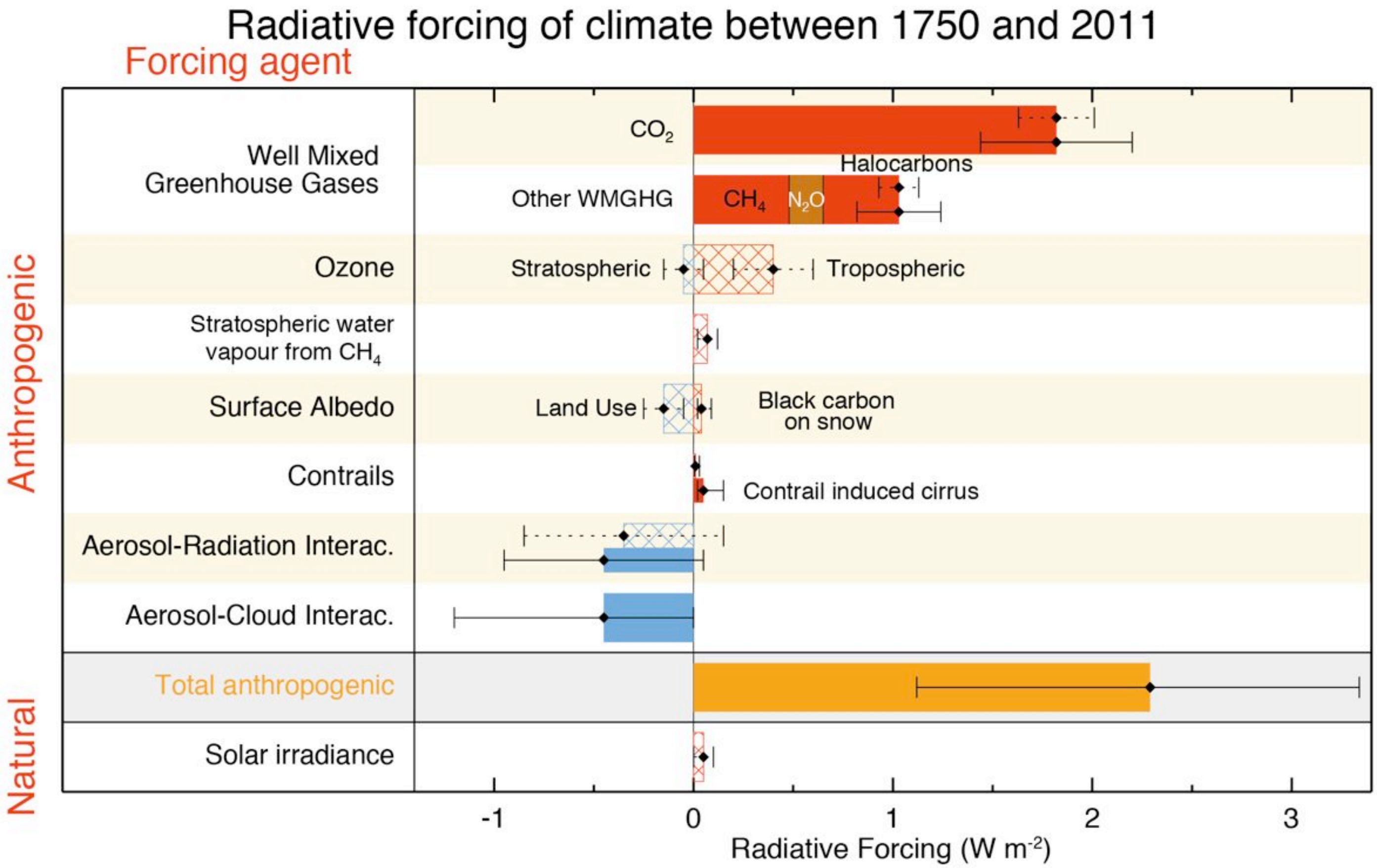
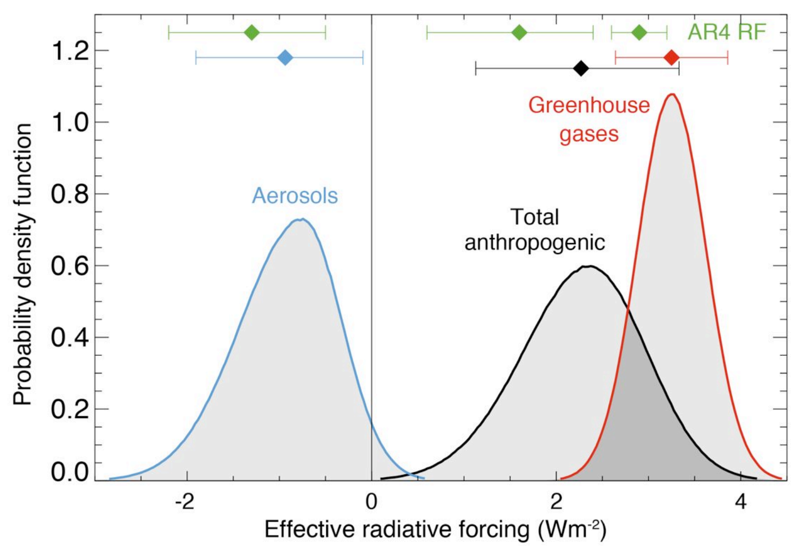
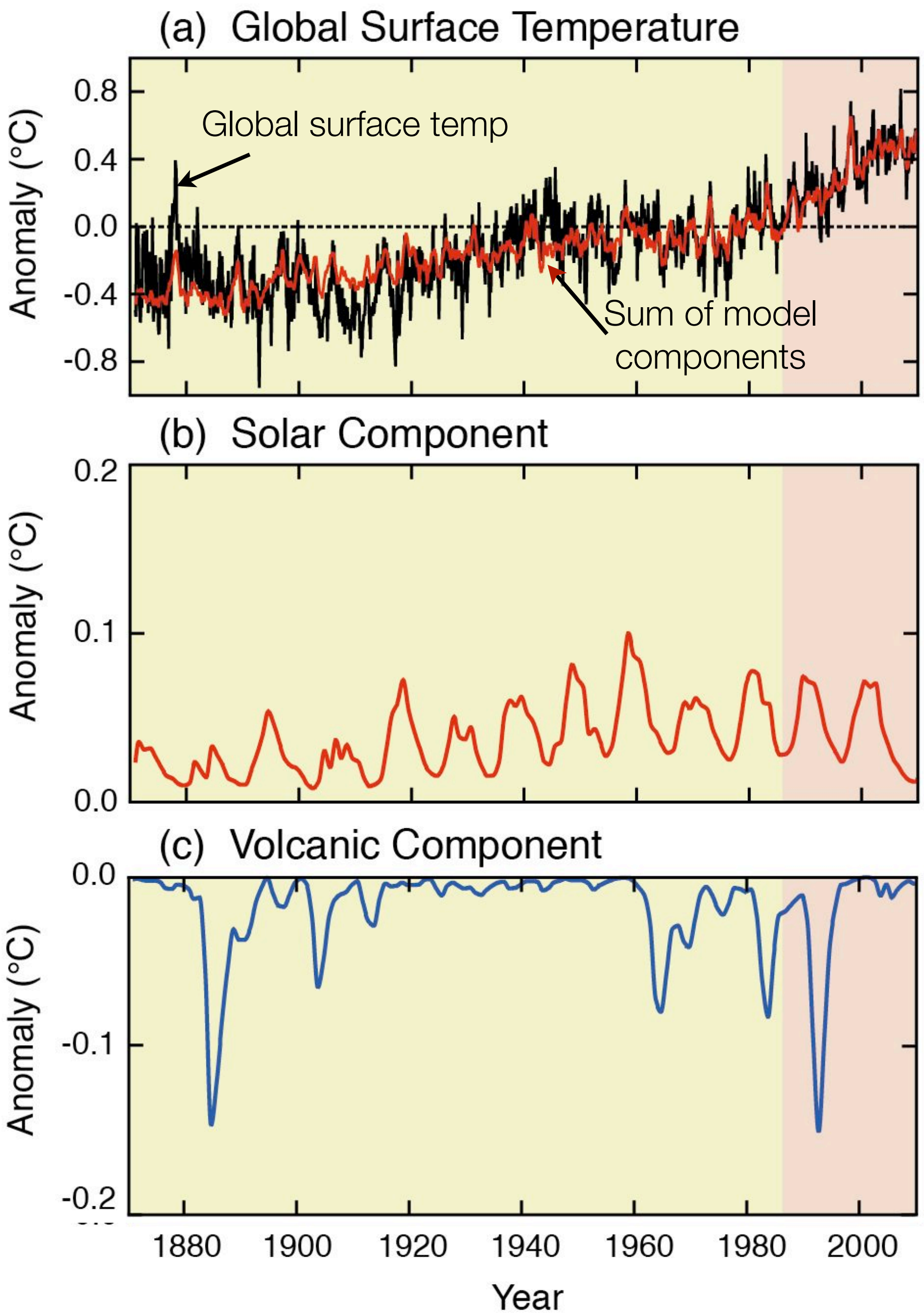


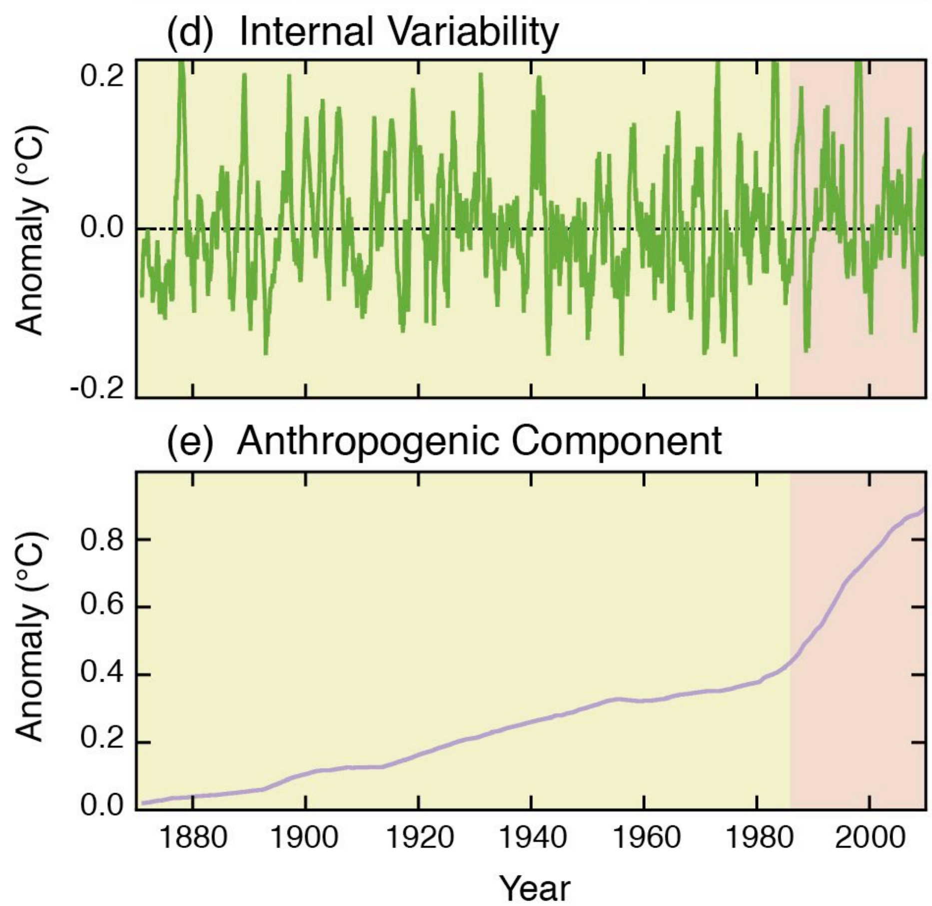
Figure 8.15 l Bar chart for RF (hatched) and ERF (solid) for the period 1750–2011, where the total ERF is derived from Figure 8.16. Uncertainties (5 to 95% confidence range) are given for RF (dotted lines) and ERF (solid lines).



http://www.climatechange2013.org/images/report/WG1AR5_Chapter08_FINAL.pdf

FAQ 5.1, Figure 1 | Global surface temperature anomalies from 1870 to 2010, and the natural (solar, volcanic, and internal) and anthropogenic factors that influence them.





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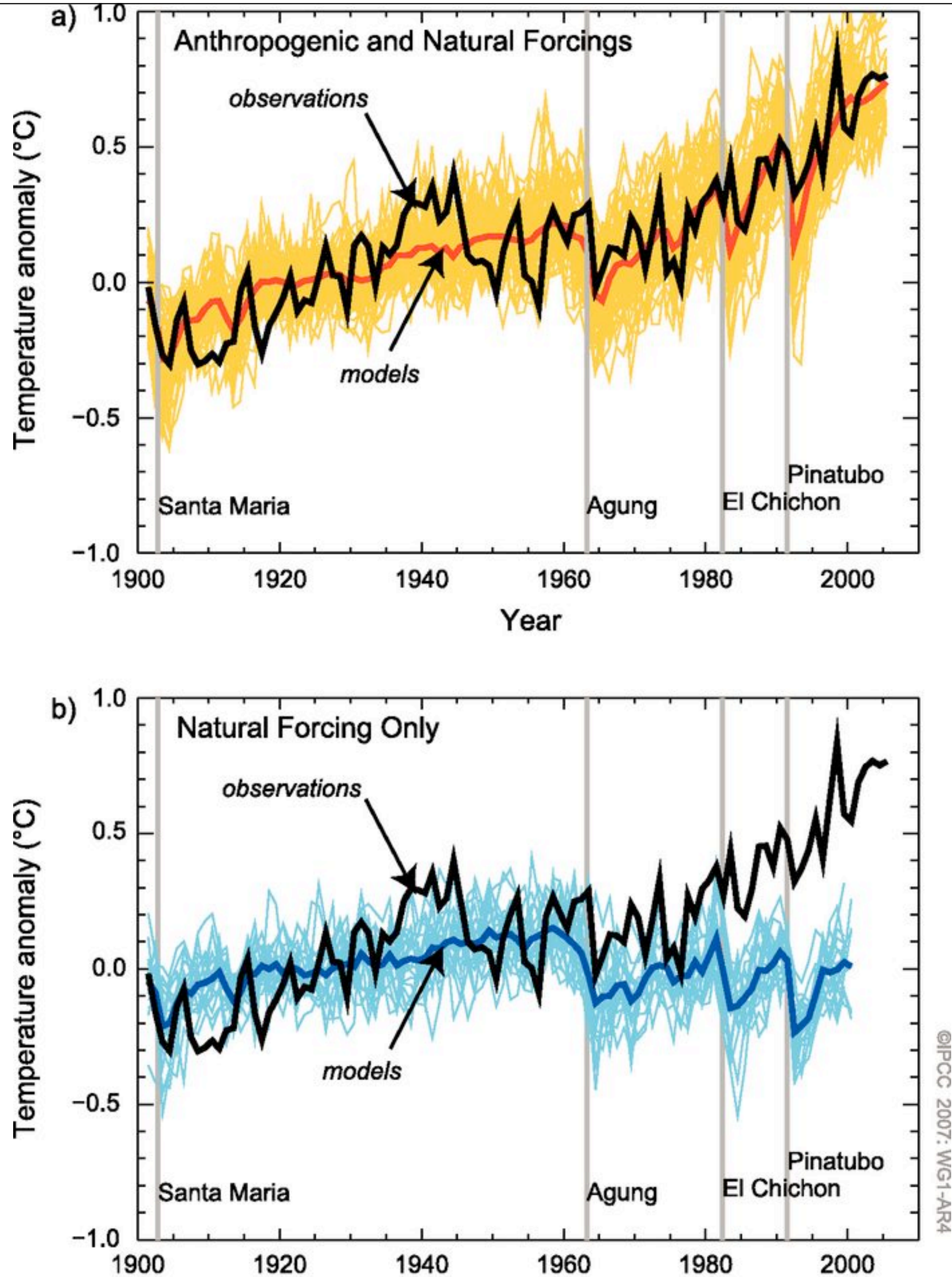
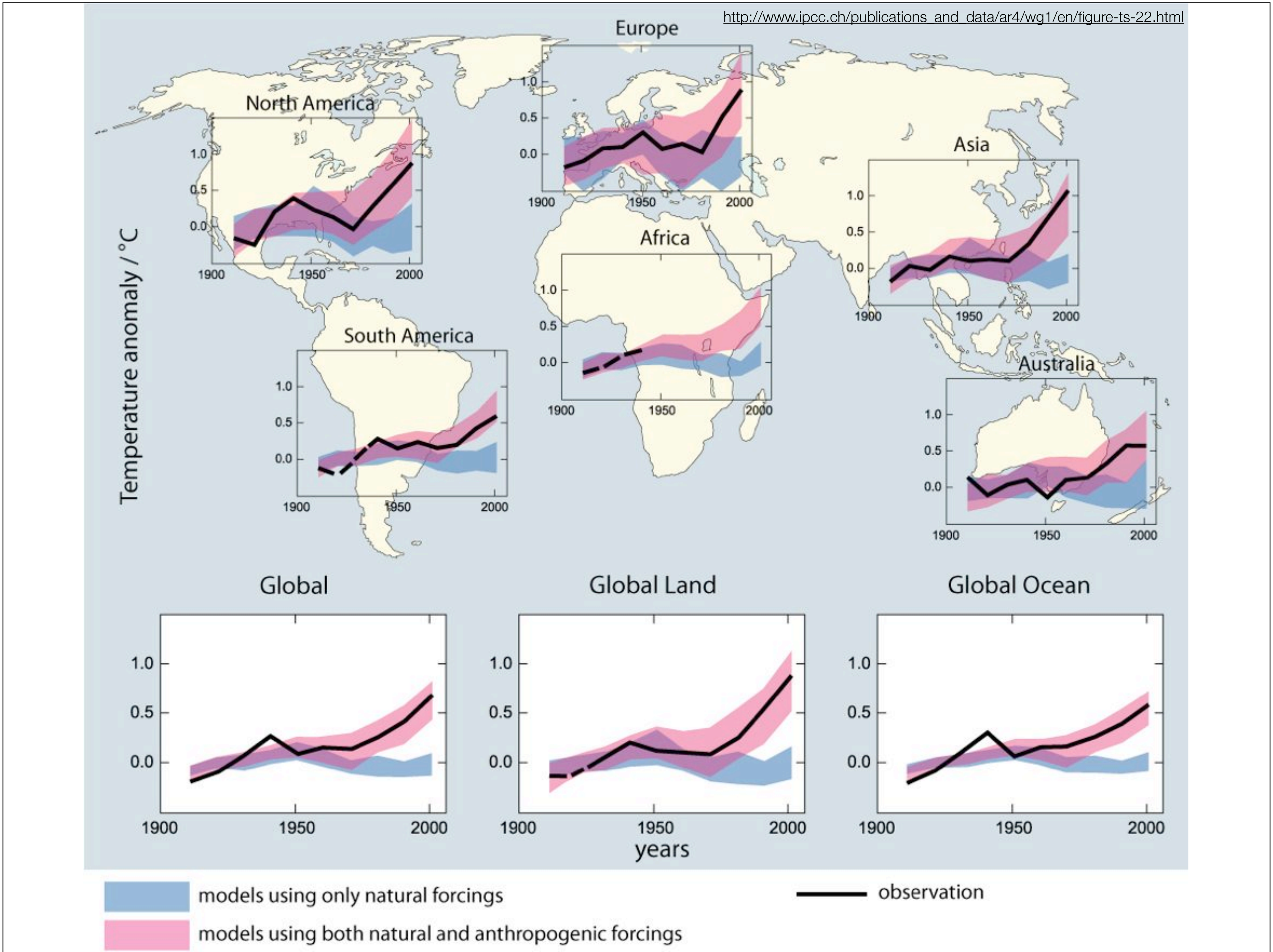


http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-ts-23.html

Are climate models getting better?

...So, yes, climate models are getting better, and we can demonstrate this with quantitative performance metrics based on historical observations. Although future climate projections cannot be directly evaluated, climate models are based, to a large extent, on verifiable physical principles and are able to reproduce many important aspects of past response to external forcing. In this way, they provide a scientifically sound preview of the climate response to different scenarios of anthropogenic forcing.

http://www.climatechange2013.org/images/report/WG1AR5_Chapter09_FINAL.pdf Page 825



http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-ts-22.html
Temperature anomaly / °C
North America
Europe
Asia
Africa
South America
Australia
Global
Global Land
Global Ocean
1.0
0.5
0.0
1900
1950
2000
years
models using only natural forcings
models using both natural and anthropogenic forcings
observation

Climate Panel Cites Near Certainty on Warming

Tim Wimborne/Reuters

A new report from the Intergovernmental Panel on Climate Change states that the authors are now 95 percent to 100 percent confident that human activity is the primary influence on planetary warming.

By JUSTIN GILLIS
Published: August 19, 2013 1020 Comments

What constitutes support for a hypothesis?

Loosely based on Bradford Hill's criteria for causation

Strength of the association

Quality of the data

- measurement
- experimental data

Quantity of the data

Consistency between studies

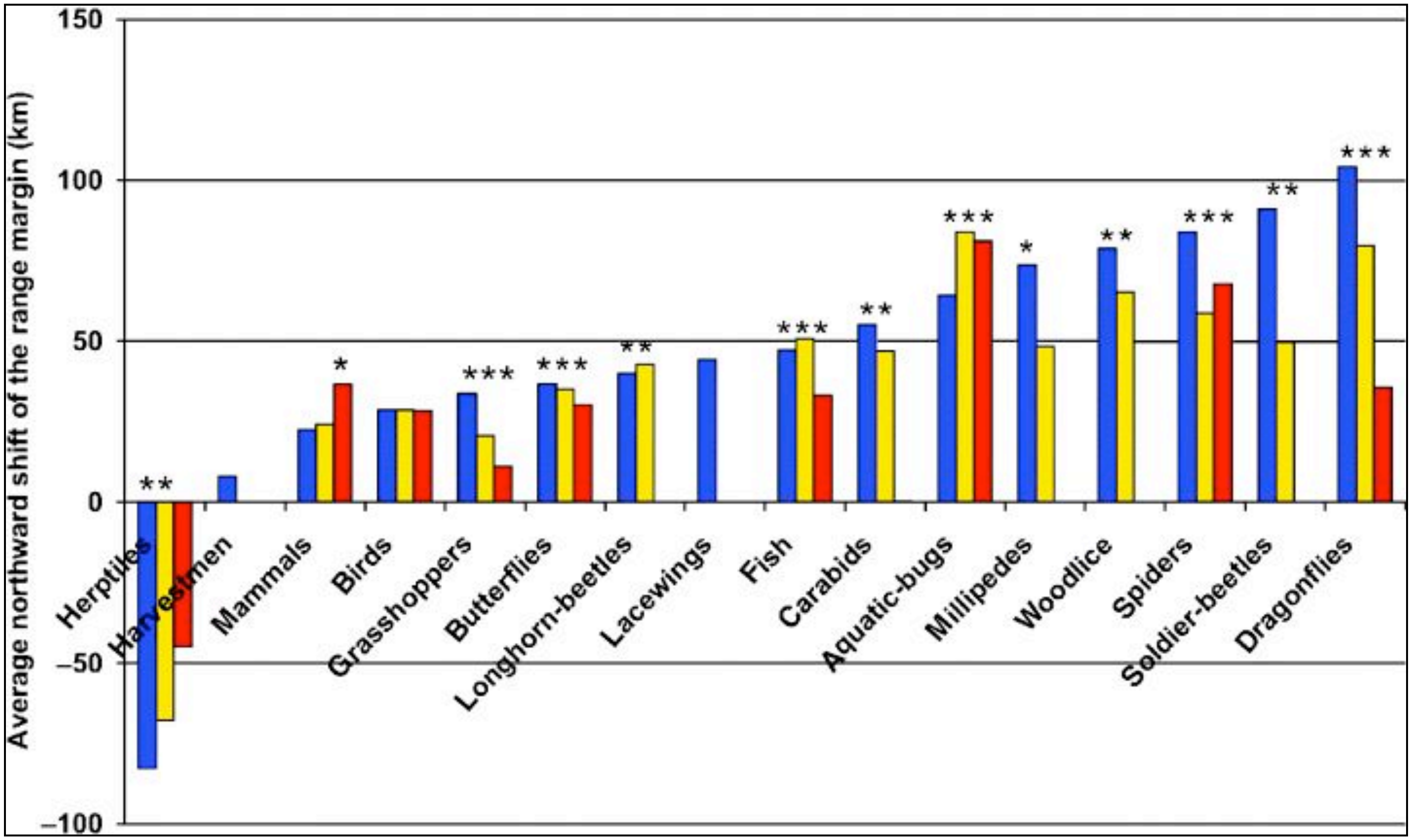
Coherence between different types of data

Plausibility of mechanism

- Analogy/similarity in other systems

Specificity of the predictions

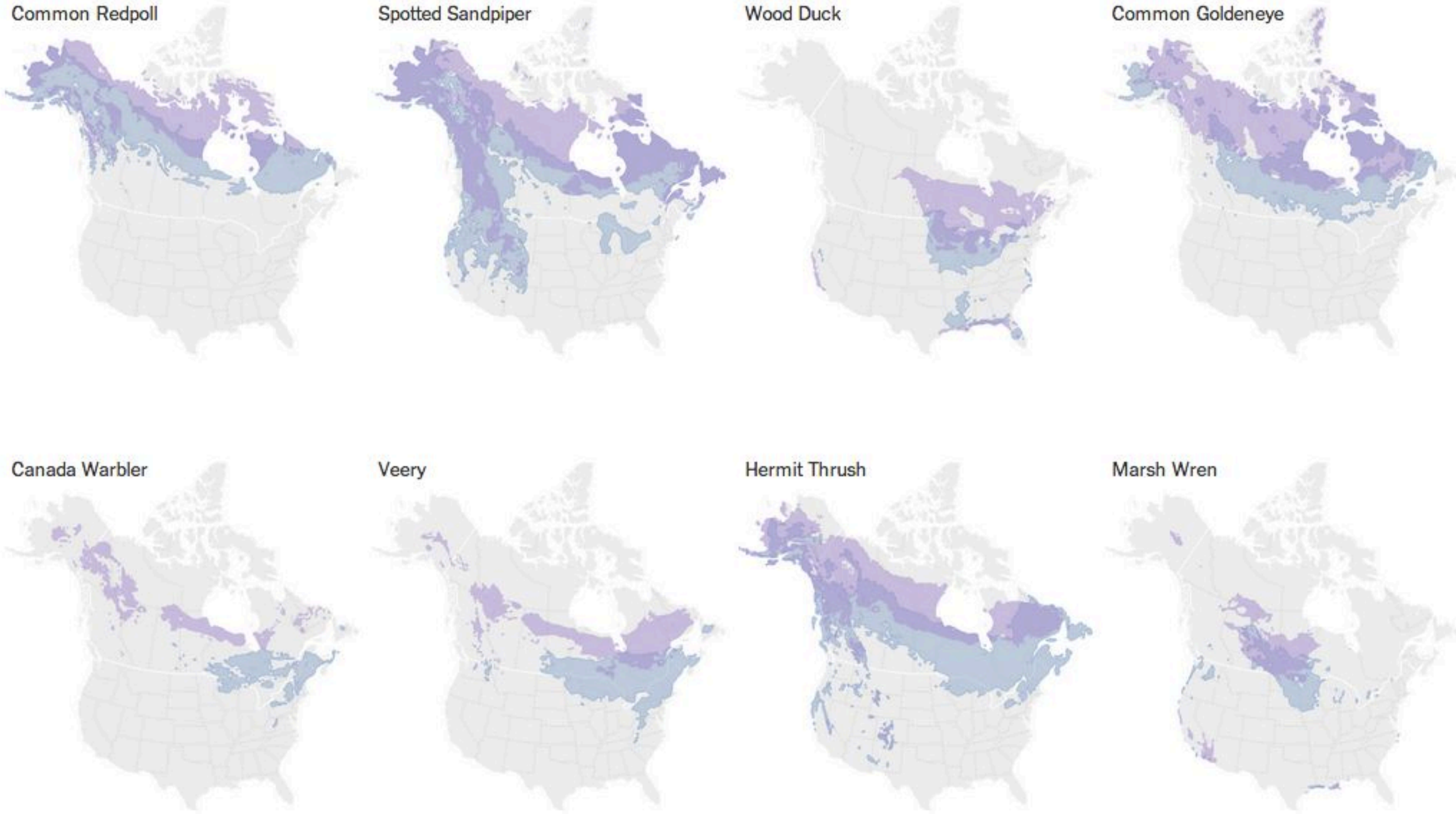
The distributions of a wide range of taxonomic groups are expanding polewards



Global Change Biology
Volume 12, Issue 3, pages 450-455, 7 MAR 2006 DOI: 10.1111/j.1365-2486.2006.01116.x
http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2006.01116.x/full#f2

. . . and many species will be pushed farther and farther north.

Maps show the core areas **where birds live now** and where similar climate conditions **could exist in 2080.**



http://www.nytimes.com/2014/09/09/us/climate-change-will-disrupt-half-of-north-americas-bird-species-study-says.html

Climate-driven changes in northeastern US butterfly communities

nature climate change

PUBLISHED ONLINE: 19 AUGUST 2012 | DOI: 10.1038/NCLIMATE1663

Greg A. Breed[1]*, Sharon Stichter[2] and Elizabeth E. Crone[1]

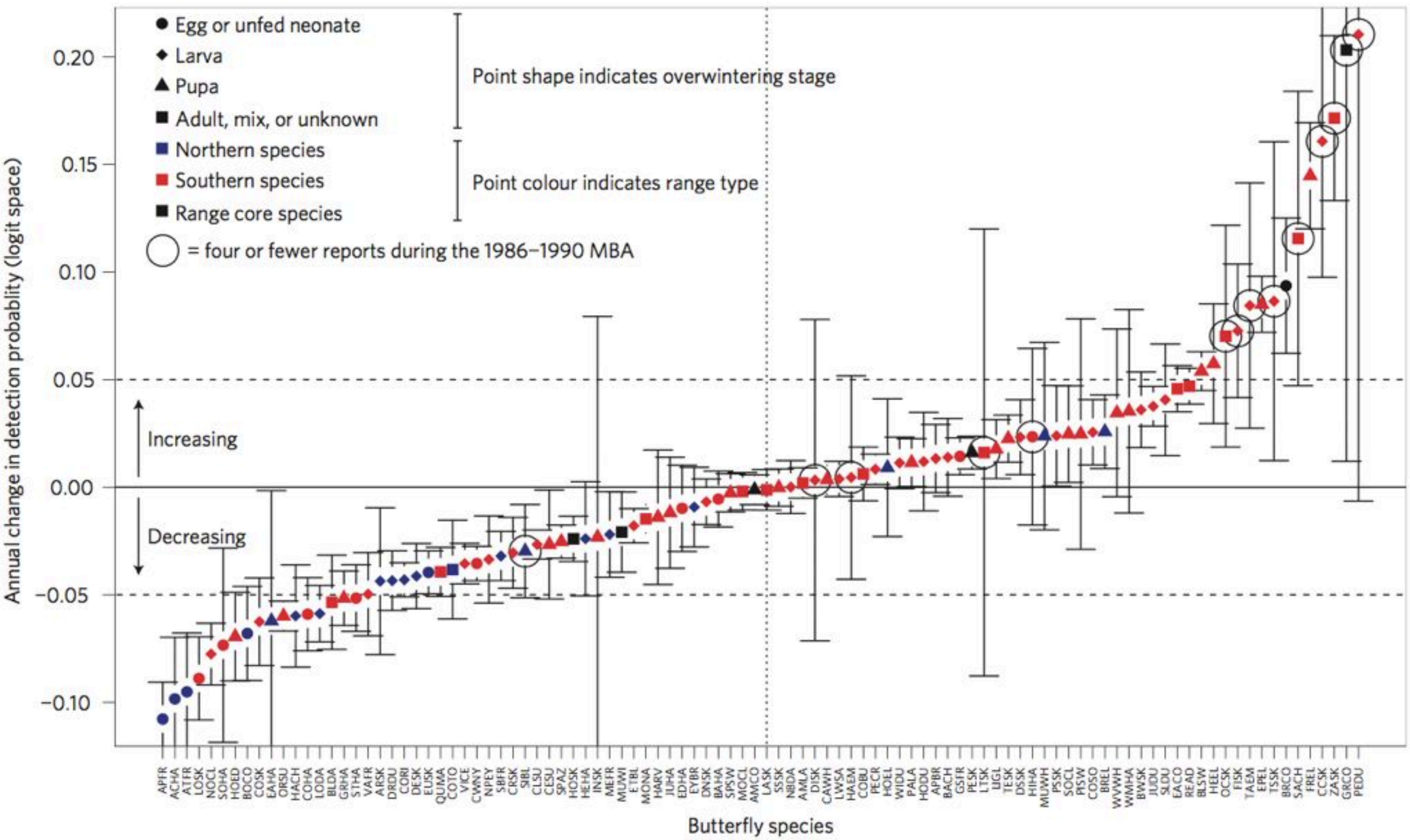


Figure 1 | Population trajectories with 90% confidence intervals for butterfly species in Massachusetts, with range type (northerly versus southerly, symbol colour) and overwintering stage (symbol shape) superimposed. Species that were rare or not present in the 1986–1990 MBA are circled. The

Climate-driven changes in northeastern US butterfly communities

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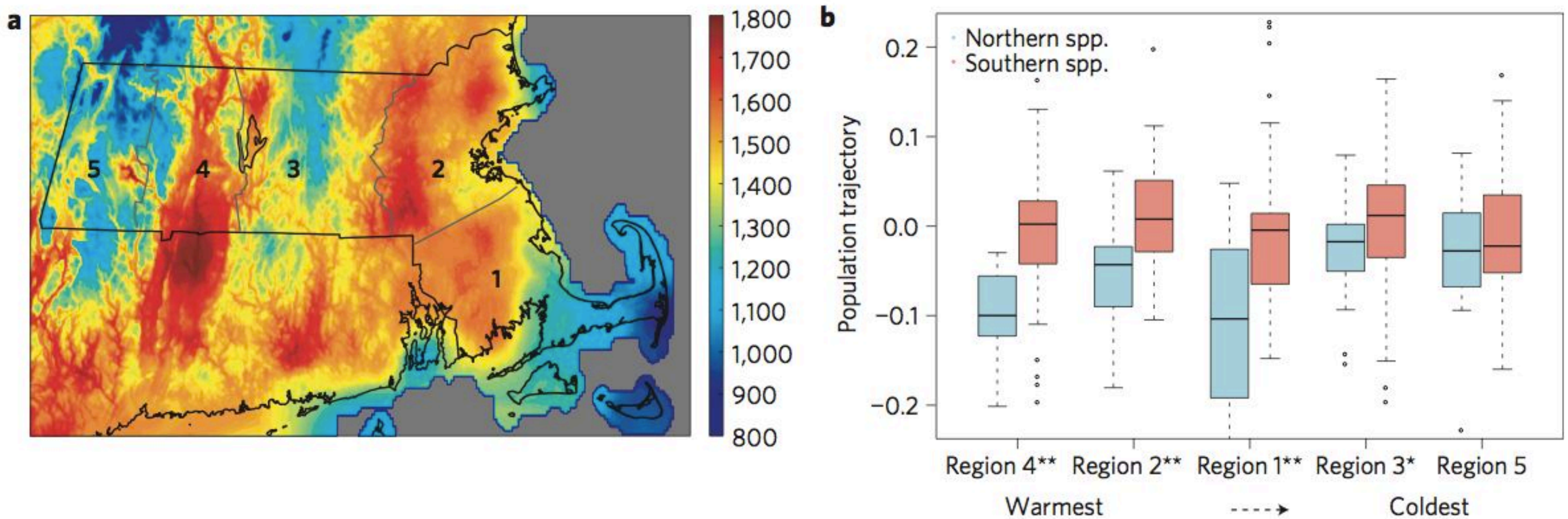
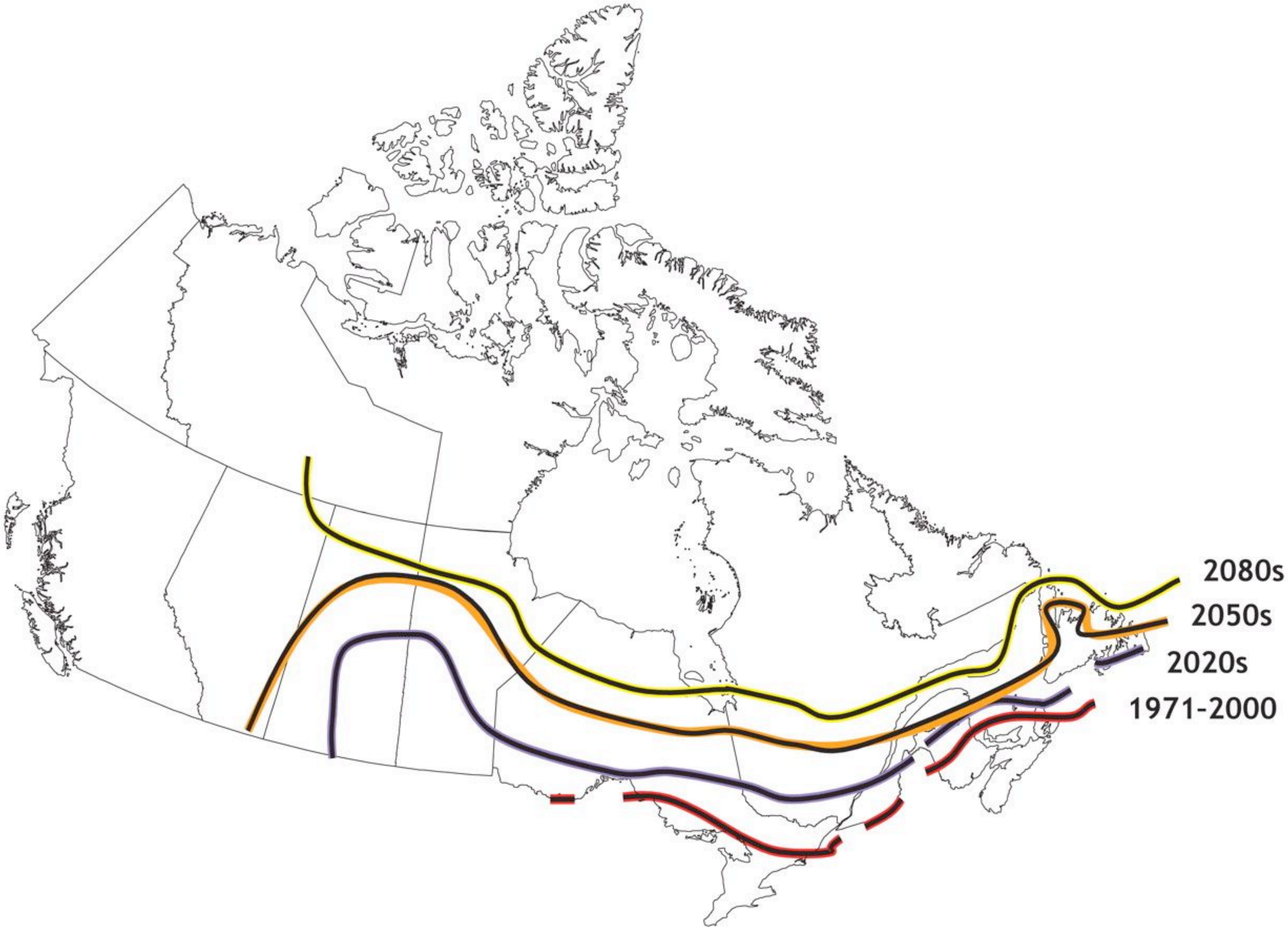


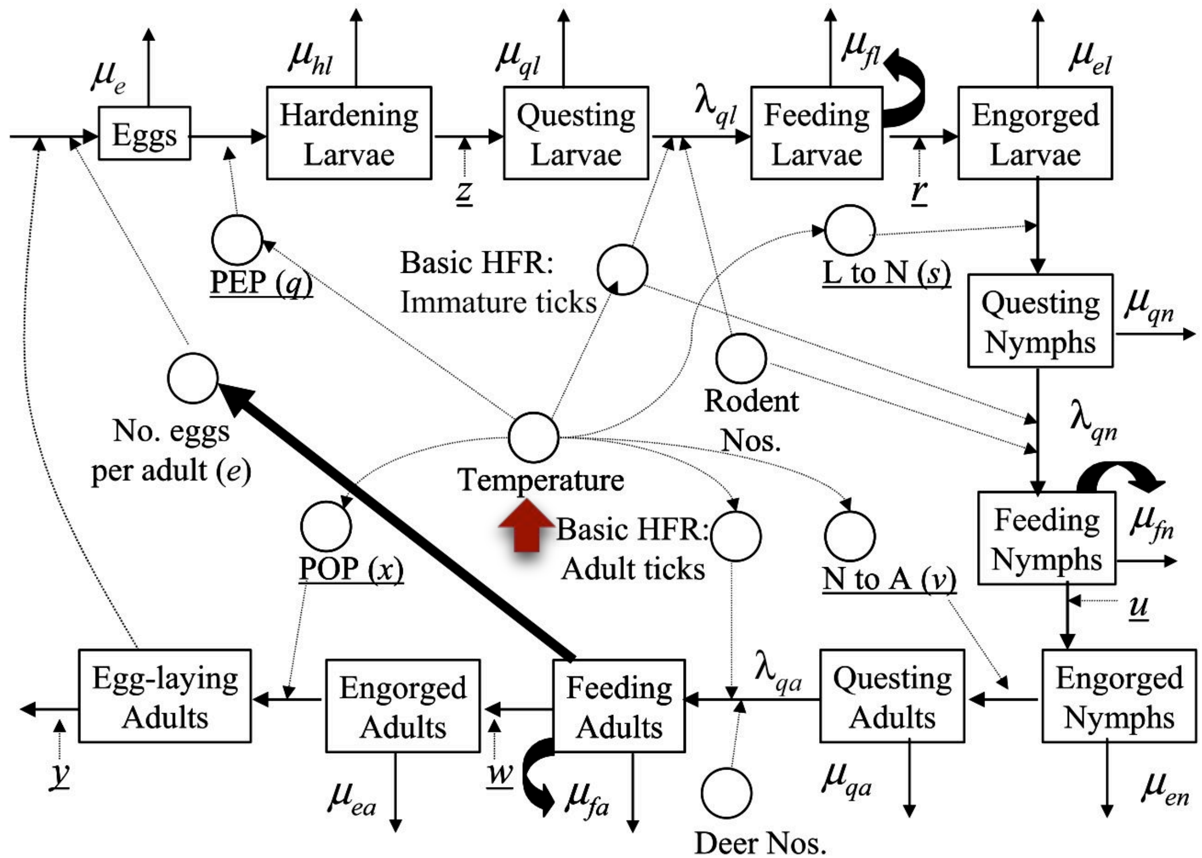
Figure 2 | Regional analysis. Region 1: Cape Cod/Long Island terminal moraines and Narragansett/Bristol Lowland; region 2: Metro Boston; region 3: Worcester Plateau; region 4: Connecticut River Valley; region 5: Berkshire Mountains. **a**, Regional divisions superimposed over a state map of 30-year mean 15 °C degree days. The colour scale indicates annual accumulated degree days above 15 °C (data from ref. 29). **b**, Northerly distributed butterflies are declining much faster in warmer regions of Massachusetts (**regions 1,2,4: $p = 0.0055$, $p = 0.0053$, $p < 0.0001$, respectively). *Region 3, which is cooler and higher, had only marginally significant declining trends in northerly species ($p = 0.0530$) and region 5, which is mountainous and much cooler, had no trend ($p = 0.4346$). The open circles are outliers.

Figure 2: Upper temperature limits for Ixodes scapularis establishment in Canada, based on mathematical models.

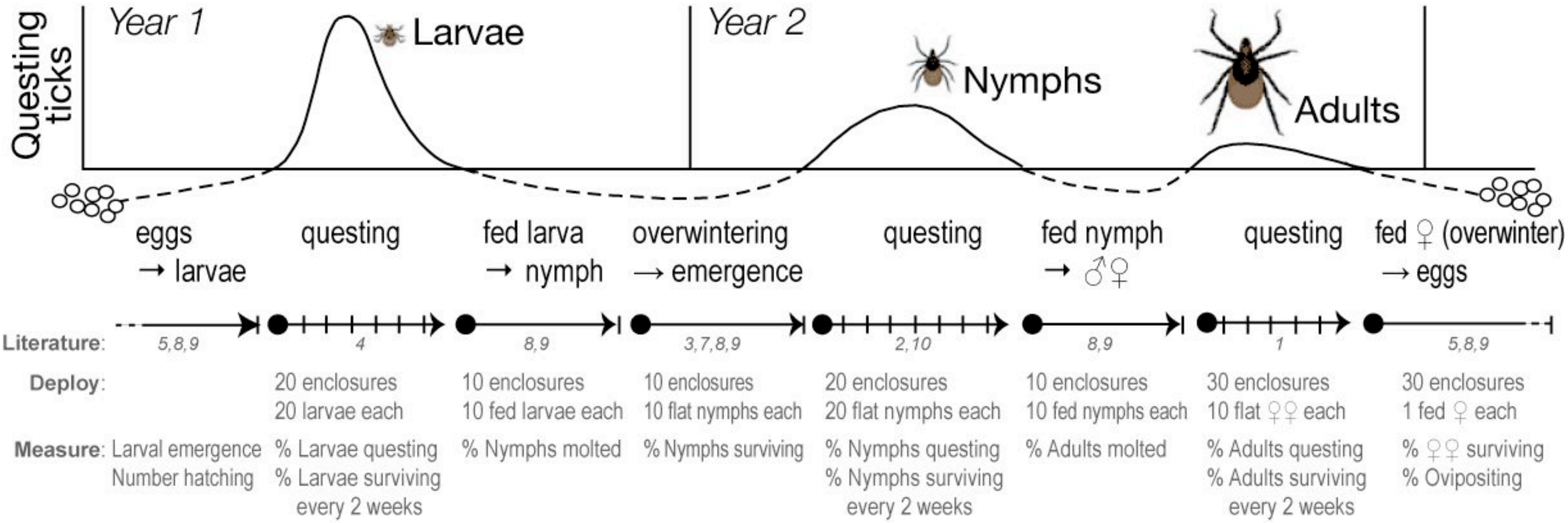


Greer, Amy et al. CMAJ 2008;178:715-722

CMAJ·JAMC



μ_e
Eggs
μ_{hl}
Hardening Larvae
μ_{ql}
Questing Larvae
λ_{ql}
μ_{fl}
Feeding Larvae
μ_{el}
Engorged Larvae
z
r
PEP (q)
Basic HFR: Immature ticks
L to N (s)
Questing Nymphs
μ_{qn}
Rodent Nos.
λ_{qn}
No. eggs per adult (e)
Temperature
Feeding Nymphs
μ_{fn}
POP (x)
Basic HFR: Adult ticks
N to A (v)
u
Egg-laying Adults
Engorged Adults
Feeding Adults
λ_{qa}
Questing Adults
Engorged Nymphs
y
μ_{ea}
w
μ_{fa}
Deer Nos.
μ_{qa}
μ_{en}



Certain conditions (e.g., warmer temperatures) might be good for some stages (e.g., faster development of larvae), but bad for others (e.g., lower nymphal survival)

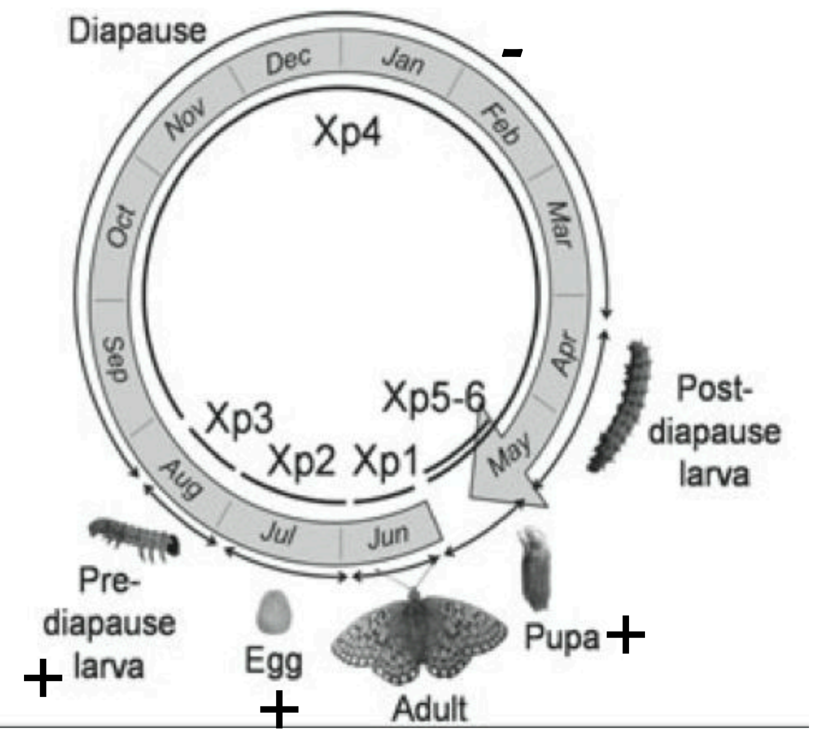
Have to consider the whole lifecycle of the organism

Journal of Animal Ecology

Journal of Animal Ecology 2012 doi: 10.1111/j.1365-2656.2012.02029.x

Each life stage matters: the importance of assessing the response to climate change over the complete life cycle in butterflies

Viktoriia Radchuk*, Camille Turlure and Nicolas Schtickzelle



Journal of Animal Ecology

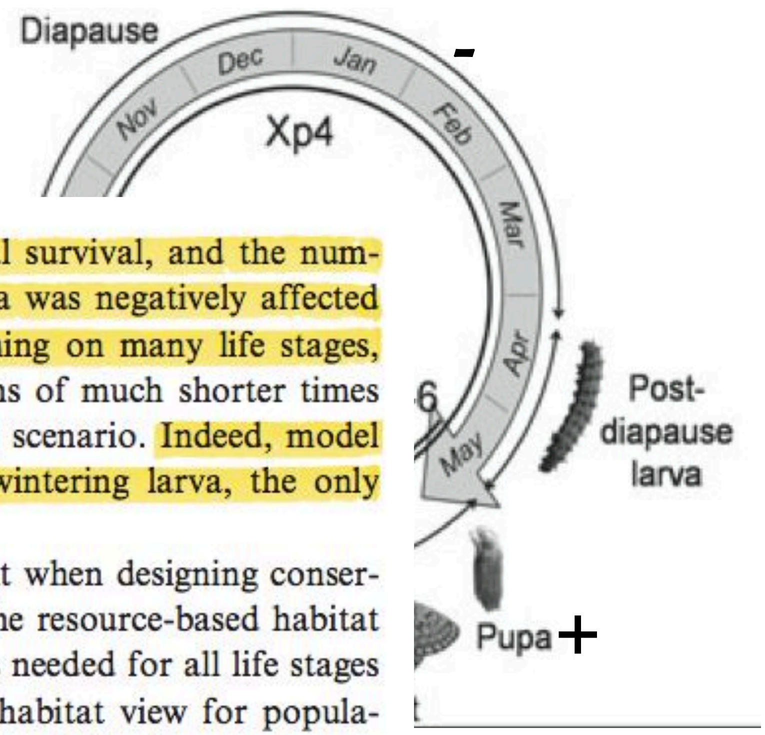
British Ecological Society

Journal of Animal Ecology 2012

doi: 10.1111/j.1365-2656.2012.02029.x

Each life stage matters: the importance of assessing the response to climate change over the complete life cycle in butterflies

Viktoriia Radchuk*, Camille Turlure and Nicolas Schtickzelle



explored the impact of several climate change scenarios.

4. Temperature positively affected egg, pre-diapause larva and pupal survival, and the number of eggs laid by a female; only the survival of overwintering larva was negatively affected by an increase in temperature. Despite the positive impact of warming on many life stages, population viability was reduced under all scenarios, with predictions of much shorter times to extinction than under the baseline (current temperature situation) scenario. Indeed, model predictions were the most sensitive to changes in survival of overwintering larva, the only stage negatively affected by warming.

5. A proper consideration of every stage of the life cycle is important when designing conservation guidelines in the light of climate change. This is in line with the resource-based habitat view, which explicitly refers to the habitat as a collection of resources needed for all life stages of the species. We, therefore, encourage adopting a resource-based habitat view for population viability analysis and development of conservation guidelines for butterflies, and more generally, other organisms. Life stages that are cryptic or difficult to study should not be forsaken as they may be key determinants in the overall response to climate change, as we found with overwintering *Boloria eunomia* larvae.

Mountain pine beetle (*Dendroctonus ponderosae*)

Coleoptera: Curculionidae, Scolytinae

Native to North America

Infests all species of pines within their range (but especially ponderosa, lodgepole, western white, sugar, and limber pines)

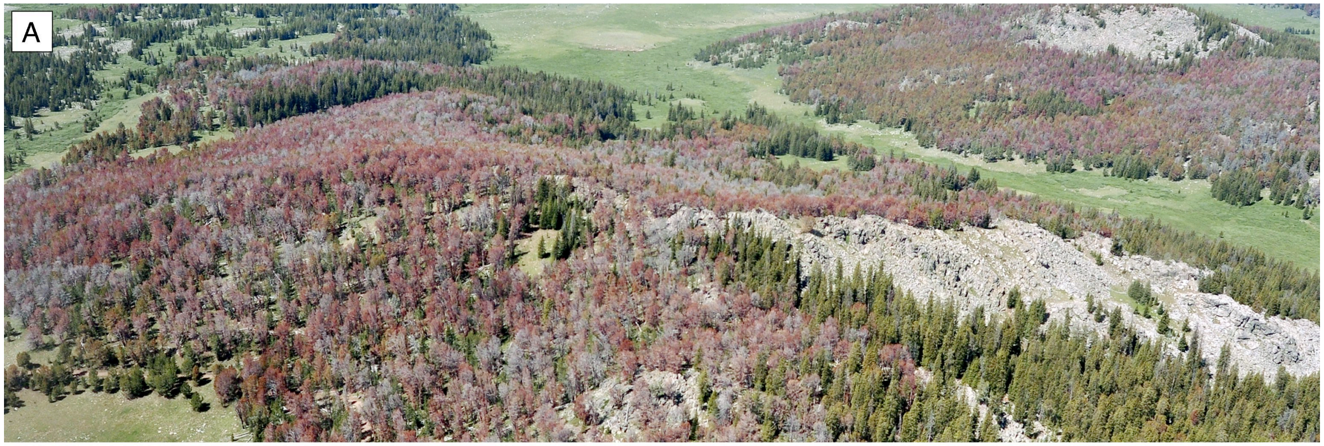
Attacking beetles introduce spores of several fungi, which alters resin and water flow, preventing tree response

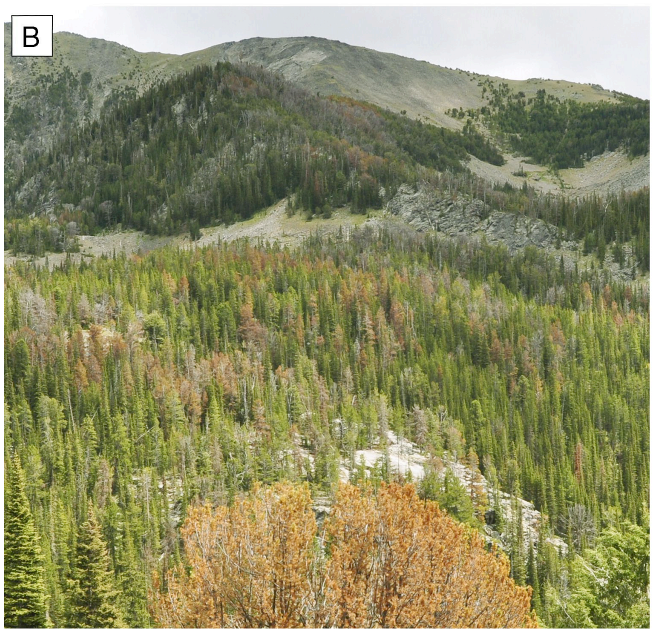
Girdles trees

Large outbreaks can affect ≥80% of trees in a stand

www.fs.fed.us/rm/landscapes/Solutions/Pinebeetlebrood.shtml

www.uwyo.edu/uwag/News/May2011/pine-beetle-devastation.jpg





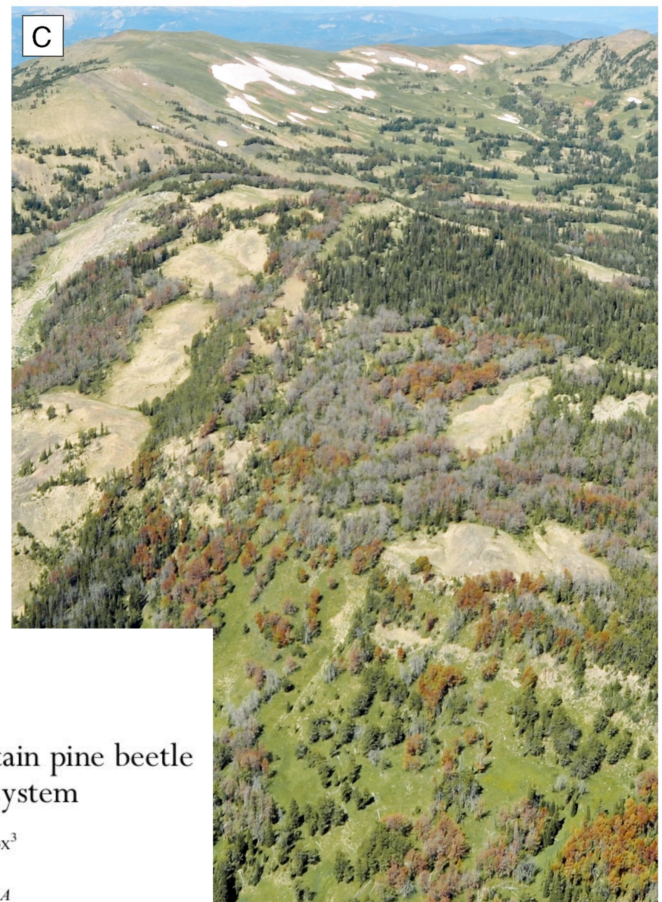


Plate 1. In these photographs, the trees with red needles were killed during the previous summer; the gray "ghost trees" remain after the needles drop, beginning the second summer after the tree is killed: (A) near Union Pass, Gros Ventre Range, Bridger-Teton National Forest, south-central GYE (Greater Yellowstone Ecosystem, USA); (B) Wisconsin Creek, Tobacco Root Range, Beaverhead National Forest, northwest GYE; (C) two miles southwest of Electric Peak, Gallatin Range, Yellowstone National Park, north-central GYE. Photo credits: W. W. Macfarlane.

Ecological Applications, 20(4), 2010, pp. 895–902

Whitebark pine vulnerability to climate-driven mountain pine beetle disturbance in the Greater Yellowstone Ecosystem

Jesse A. Logan,[1,4] William W. Macfarlane,[2] and Louisa Willcox[3]

[1]*USDA Forest Service, Box 482, Emigrant, Montana 54927 USA*
[2]*GeoGraphics, Incorporated, 90 West Center Street, Logan, Utah 84321 USA*
[3]*Natural Resources Defense Council, Box 70, Livingston, Montana 59047 USA*

Cold hardening in Mountain Pine Beetles

○ Habitat within the bark can drop below –35°C
○ MPB are not freeze tolerant!
○ Lower their supercooling point (SCP), the temp at which ice crystals spontaneously form

Steps:

1. rid body of ice-nucleating agents such as food in gut, large proteins in hemolymph (lowers SCP by 10–20°C!)
2. Accumulate cryoprotectants (e.g. glycerol) and antifreeze proteins (lowers SCP by an additional 10°C)

This is a process of *acclimation*, so early cold snaps = bad news

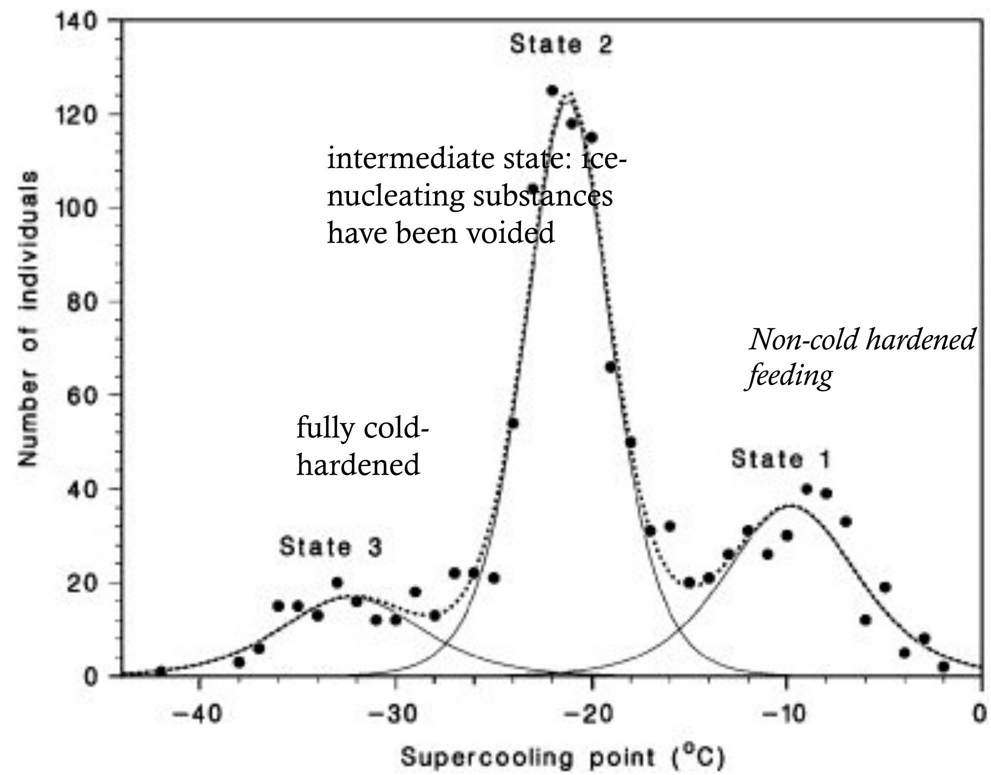
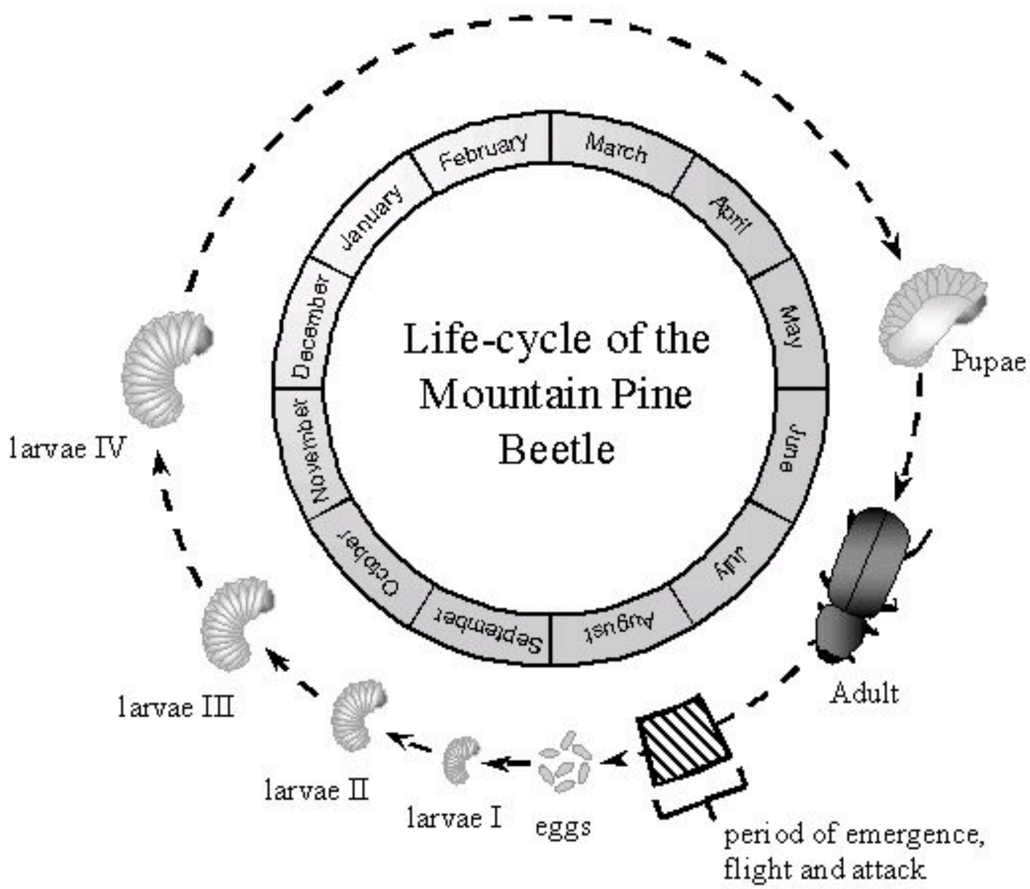


Fig. 3. Pooled frequency of all larval SCP (1 °C classes). Eq. (1) (solid lines: for each state; dotted line: combined) fitted by non-linear logistic regression to pooled observations of SCP among *Dendroctonus ponderosae* larvae (●).



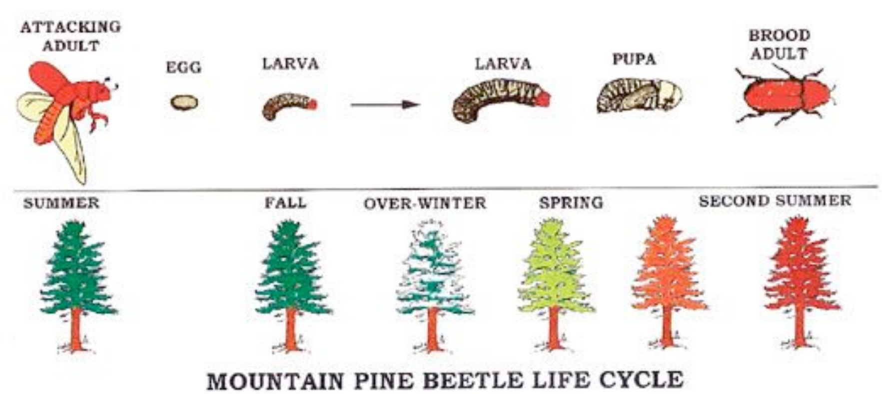
www.realclimate.org/index.php/archives/2010/10/seeing-red/

All but a few days that are spent flying and attacking trees MPB are in inner bark and phloem

Adults bore into tree, mate, and lay eggs

Generally has a one year life cycle at low elevations, maybe two at higher elevations

Note: mass attacks are much more successful, so synchronous emergence is important



csfs.colostate.edu/images/graphics/barkbeetlefadergraphic.jpg

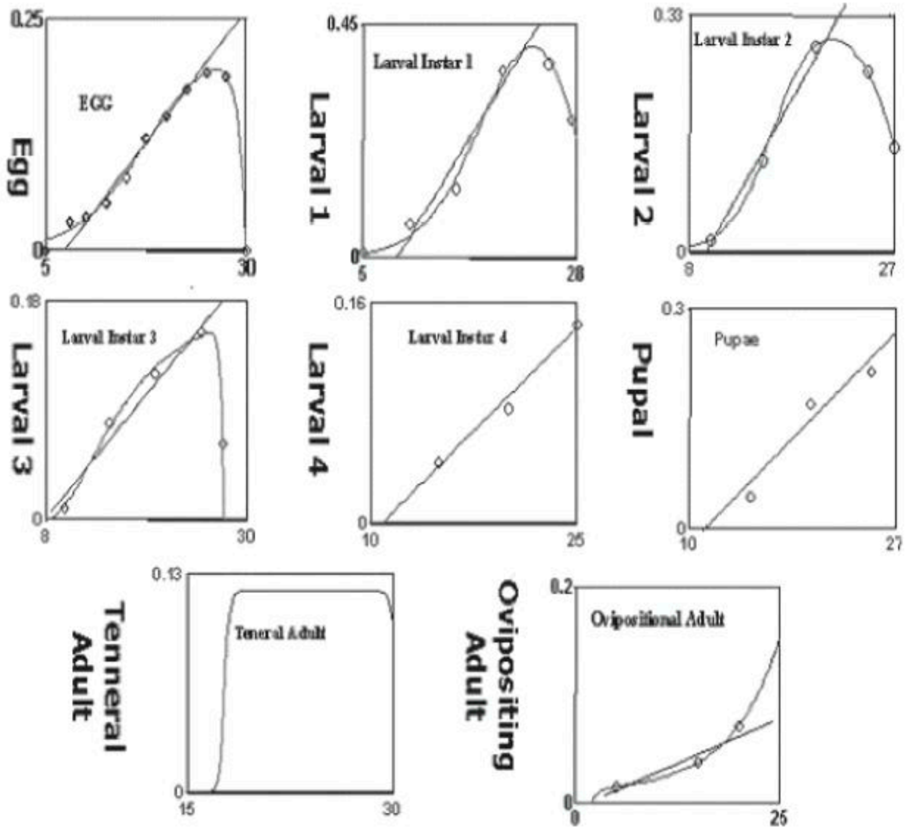


Figure 1. Rate curves for the mountain pine beetle. In all curves, the vertical axis is measured in development/day and the horizontal axis is temperature in centigrade. Data points determined by rearing at controlled temperatures are depicted as open circles.

Modelling Mountain Pine Beetle Phenological Response to Temperature

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In T.L. Shore, J.E. Brooks, and J.E. Stone, editors. Mountain Pine Beetle Symposium: Challenges and Solutions, October 30-31, 2003, Kelowna, British Columbia, Canada. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, Information Report BC-X-399. 298 p

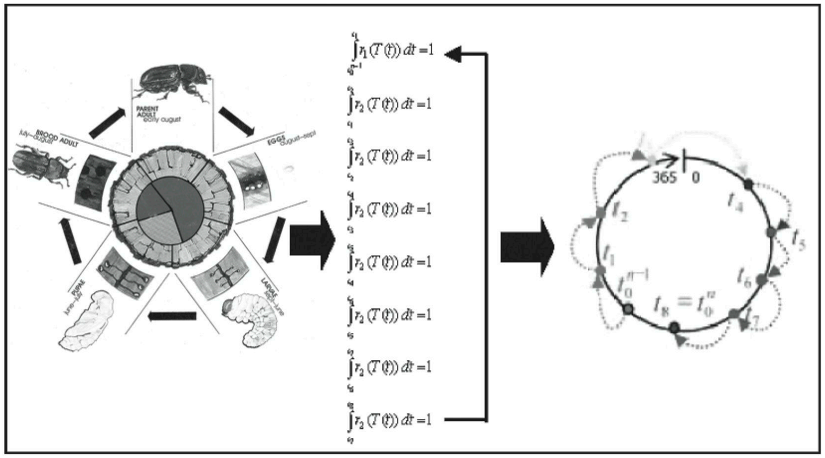

Figure 2. Schematic diagram of the mountain pine beetle model. Development for each life stage is accumulated according to the stage specific development rate curves in Fig. 1. Completion of the final life stage signals the initiation of the first life stage in the next generation. This process is mathematically represented as a circle map, analogous to the cycles of the natural world.

Ecological Applications, 20(4), 2010, pp. 895–902

Whitebark pine vulnerability to climate-driven mountain pine beetle disturbance in the Greater Yellowstone Ecosystem

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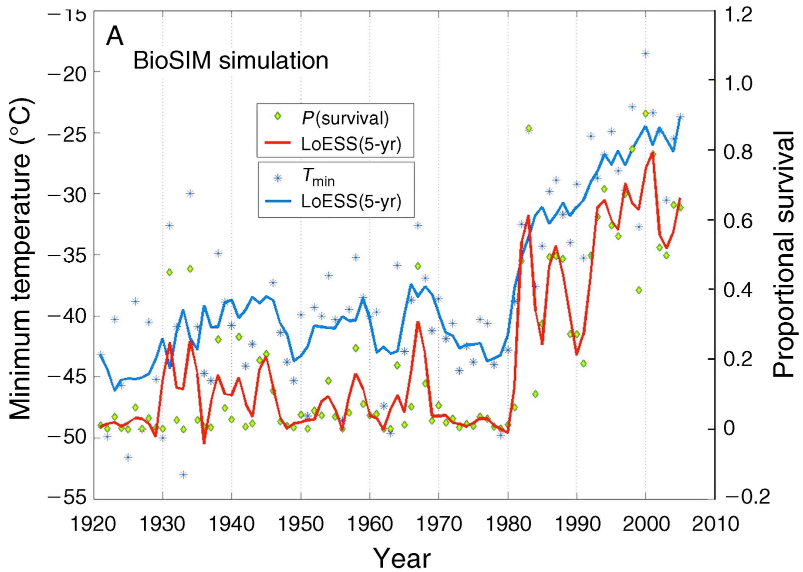
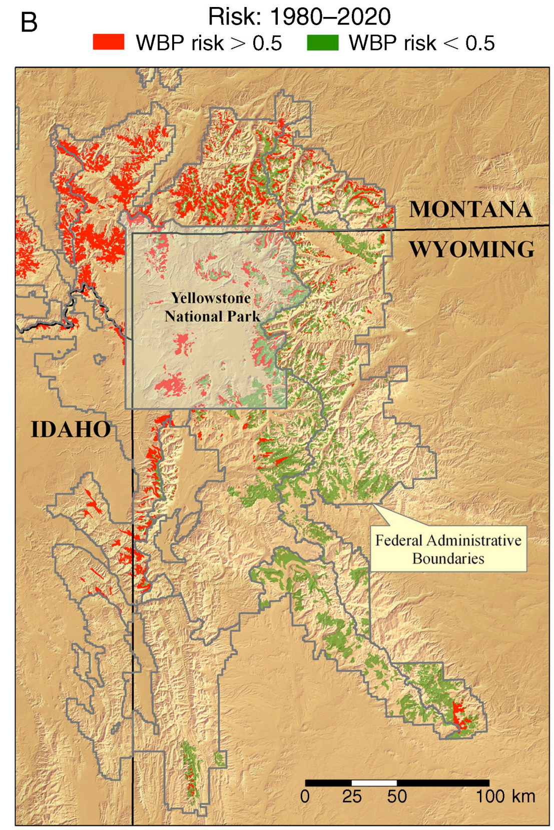
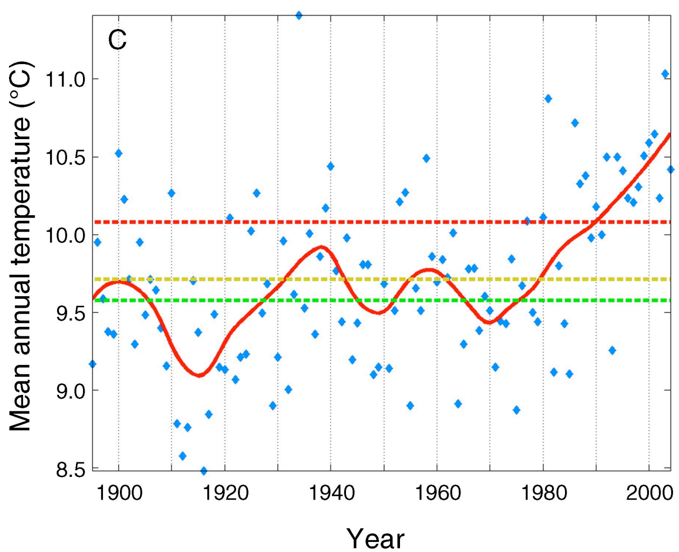


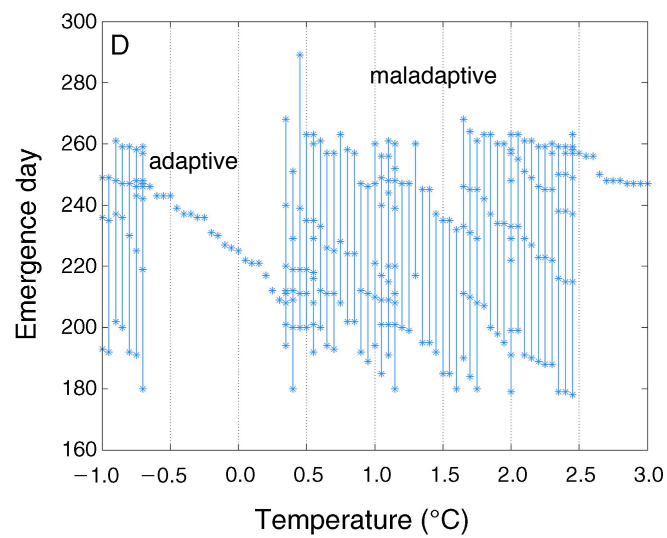


c) Mean annual temp for the 11 Western state

Grand mean ≥ 1976

Grand mean < 1976





Mountain pine beetle and forest carbon feedback to climate change

NATURE|Vol 452|24 April 2008

W. A. Kurz[1], C. C. Dymond[1], G. Stinson[1], G. J. Rampley[1], E. T. Neilson[1], A. L. Carroll[1], T. Ebata[2] & L. Safranyik[1]

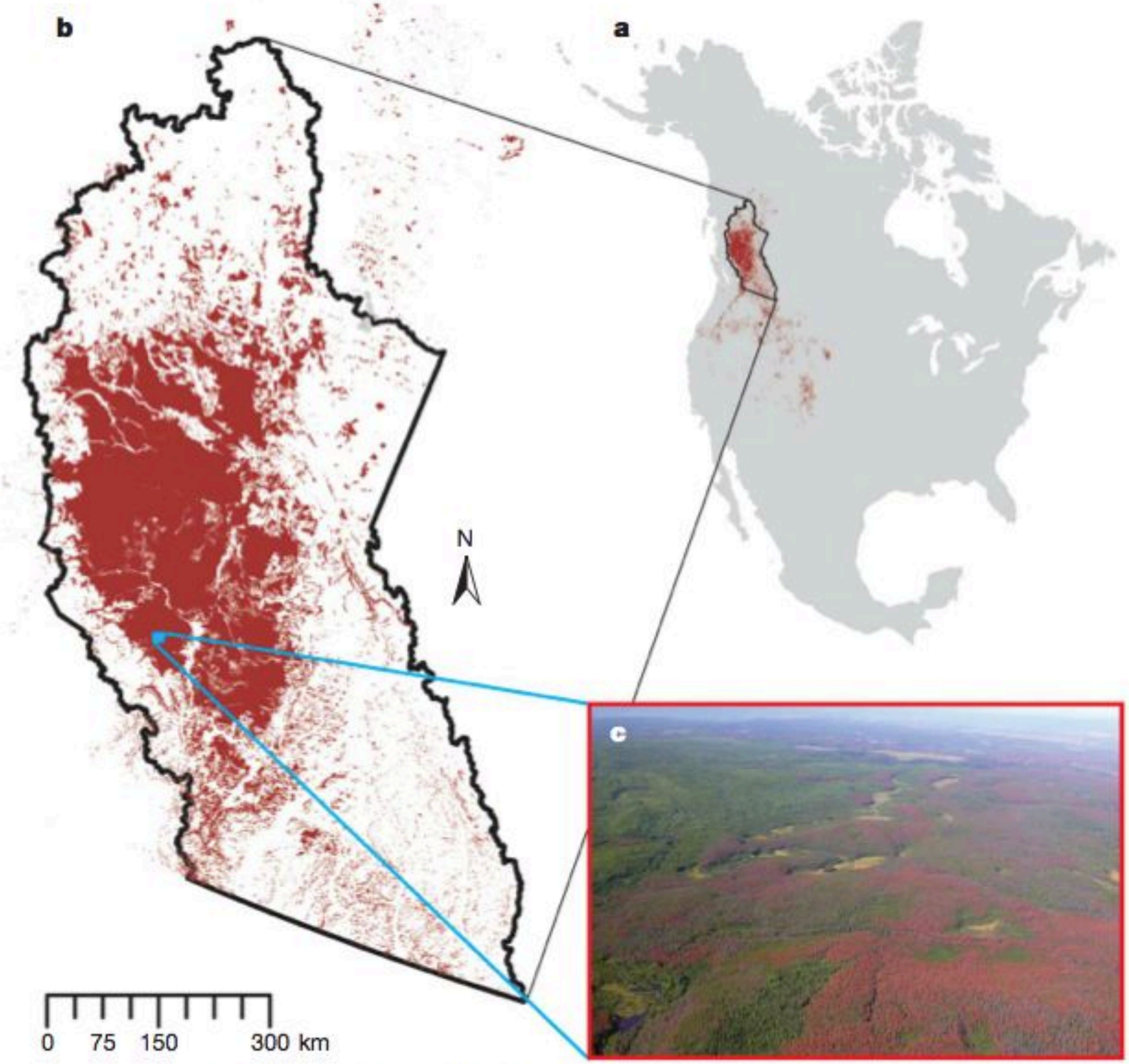
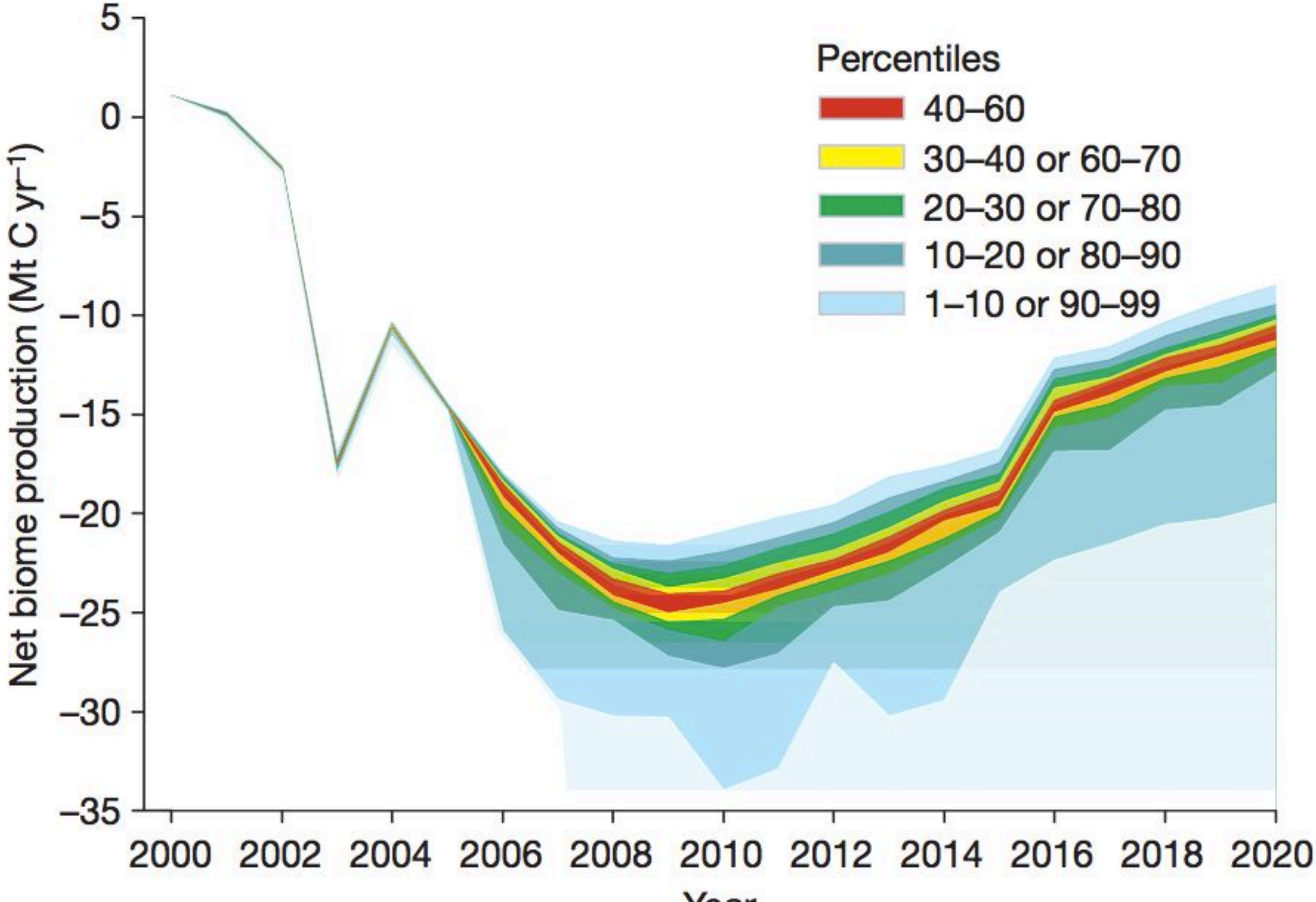


Figure 1 | Geographic extent of mountain pine beetle outbreak in North America. a, Extent (dark red) of mountain pine beetle. **b**, The study area includes 98% of the current outbreak area. **c**, A photograph taken in 2006 showing an example of recent mortality: pine trees turn red in the first year after beetle kill, and grey in subsequent years. Photo credit: Joan Westfall, Entopath Management Ltd.



Percentiles
40–60
30–40 or 60–70
20–30 or 70–80
10–20 or 80–90
1–10 or 90–99
Net biome production (Mt C yr^{-1})
5
0
−5
−10
−15
−20
−25
−30
−35
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year