



Making Better Scientific Graphics



Doug McNeall

Met Office Hadley Centre
betterfigures.org @dougmcneall



Ed Hawkins

University of Reading
climate-lab-book.ac.uk @ed_hawkins



What is different about scientific graphics?

Anscombe's quartet

I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89



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Anscombe's quartet

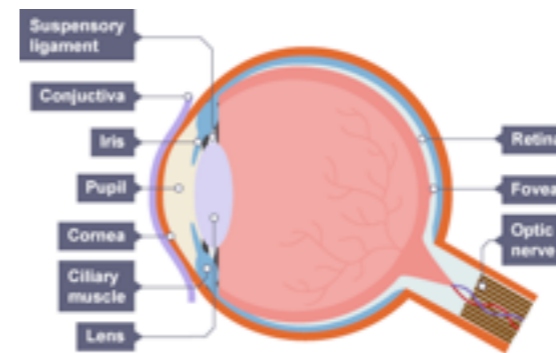
I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
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13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
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x	y	x	y	x	y	x	y
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9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
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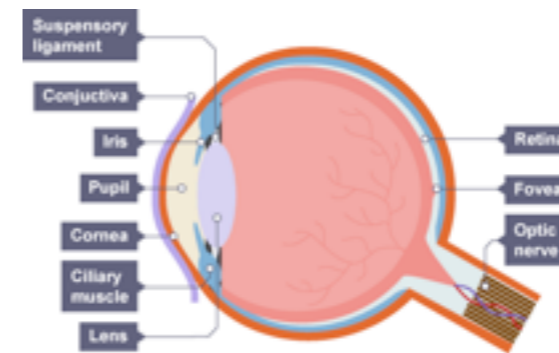


What is different about scientific graphics?

LAZY



BIASED



Anscombe's quartet

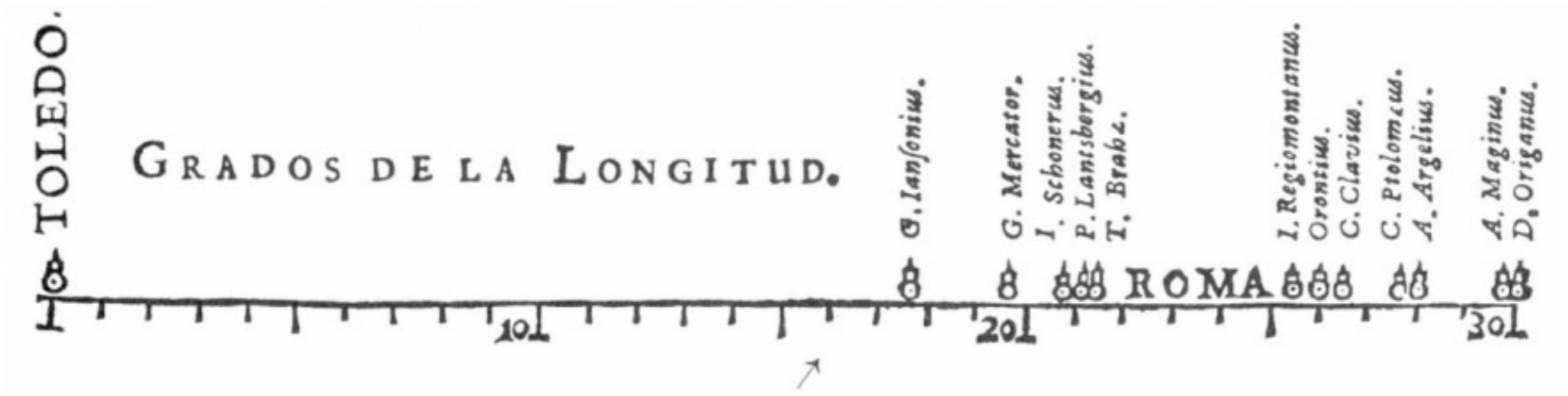
I		II		III		IV	
x	y	x	y	x	y	x	y
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11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
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5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89



What worked in the past?

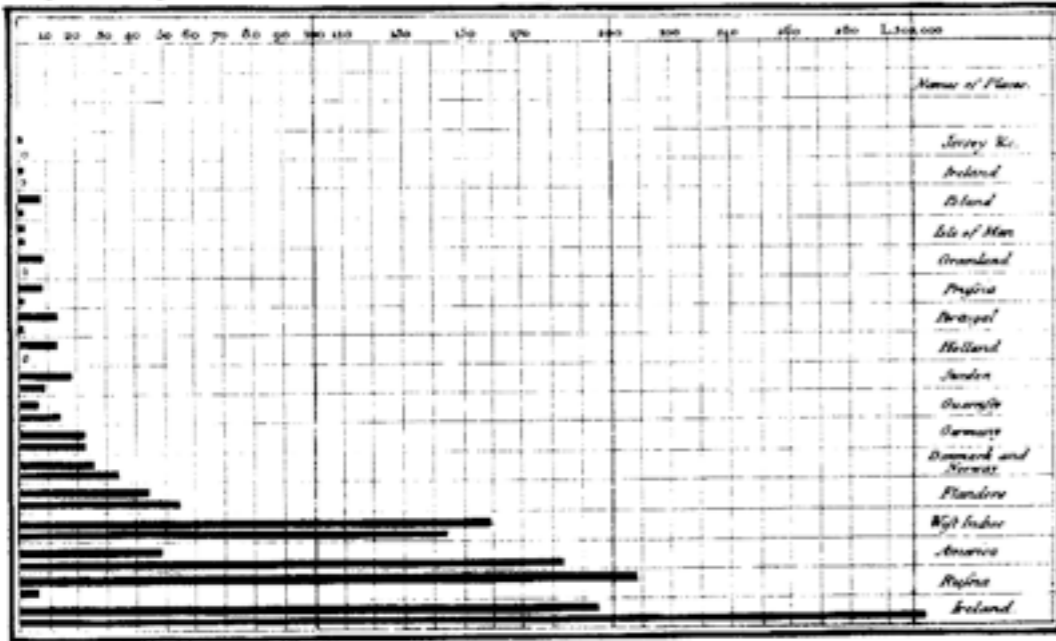
[A very short history of statistical graphics]

1643 - First statistical graphic



1643 First graphical representation of statistical data by Flemish cartographer [Michaël Florent van Langren \(Langrenus\)](#) - longitudinal distances from Toledo in Spain to Rome in Italy.

Exports and Imports of SCOTLAND to and from different parts for one Year from Christmas 1784 to Christmas 1785.



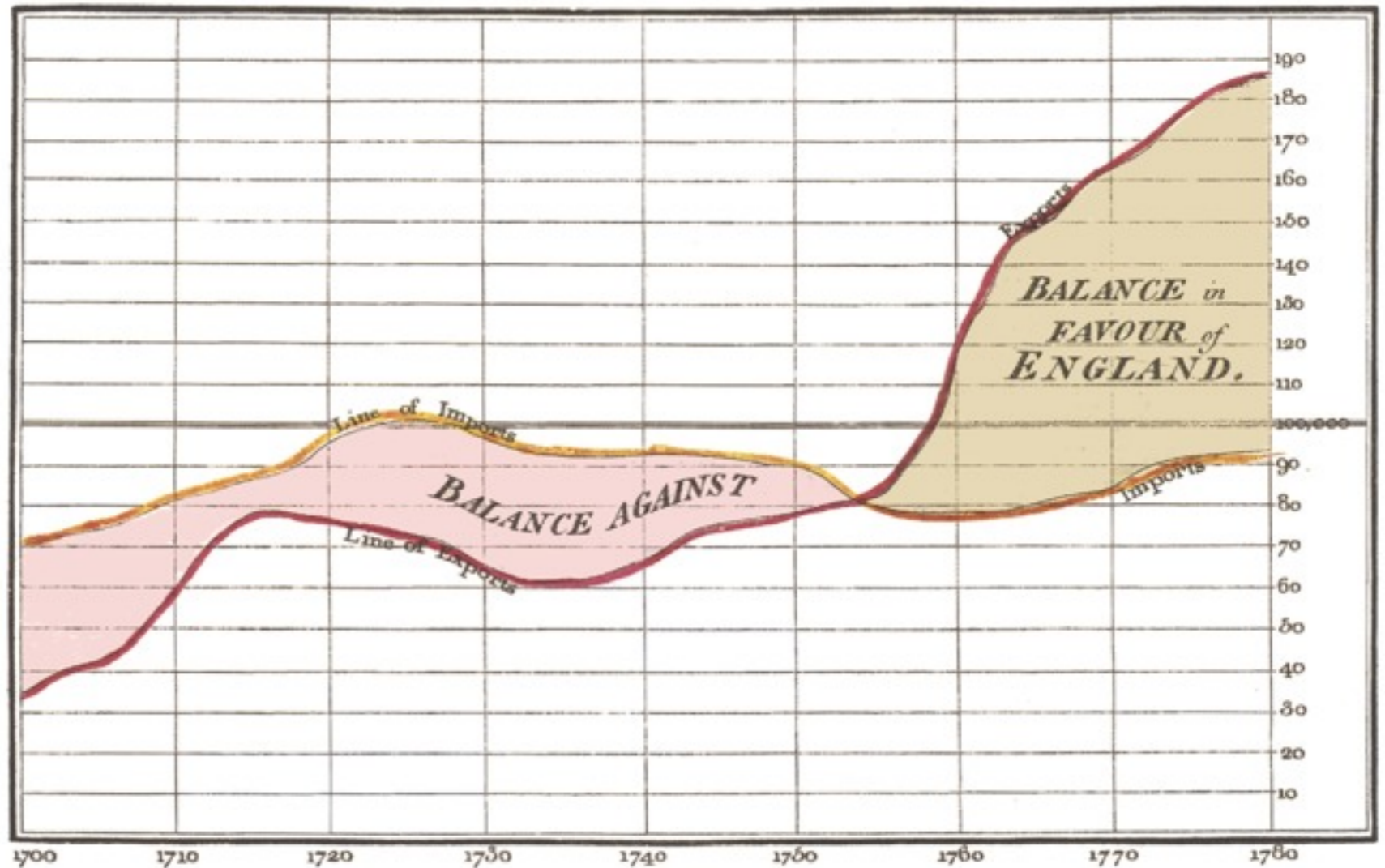
The Upright divisions are Ten Thousand Pounds each. The Black Lines are Exports the Ribbon-like Imports.
 Published in the Act ditto, June 7th 1786 by W^m Playfair
 Made and sold at 352 Strand, London.

Bar Chart

Late 18th Century - William Playfair (1759-1823) invents Microsoft Excel

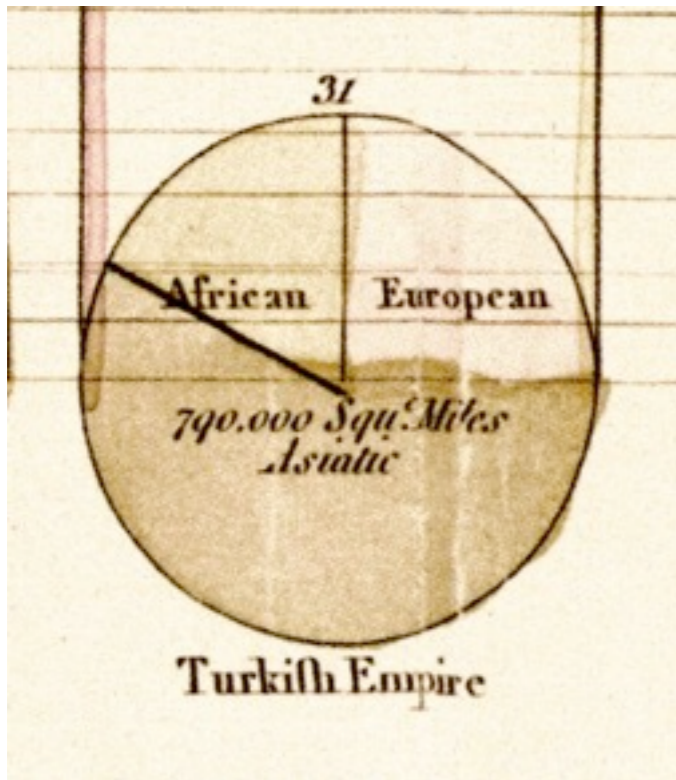
Time series

Exports and Imports to and from DENMARK & NORWAY from 1700 to 1780

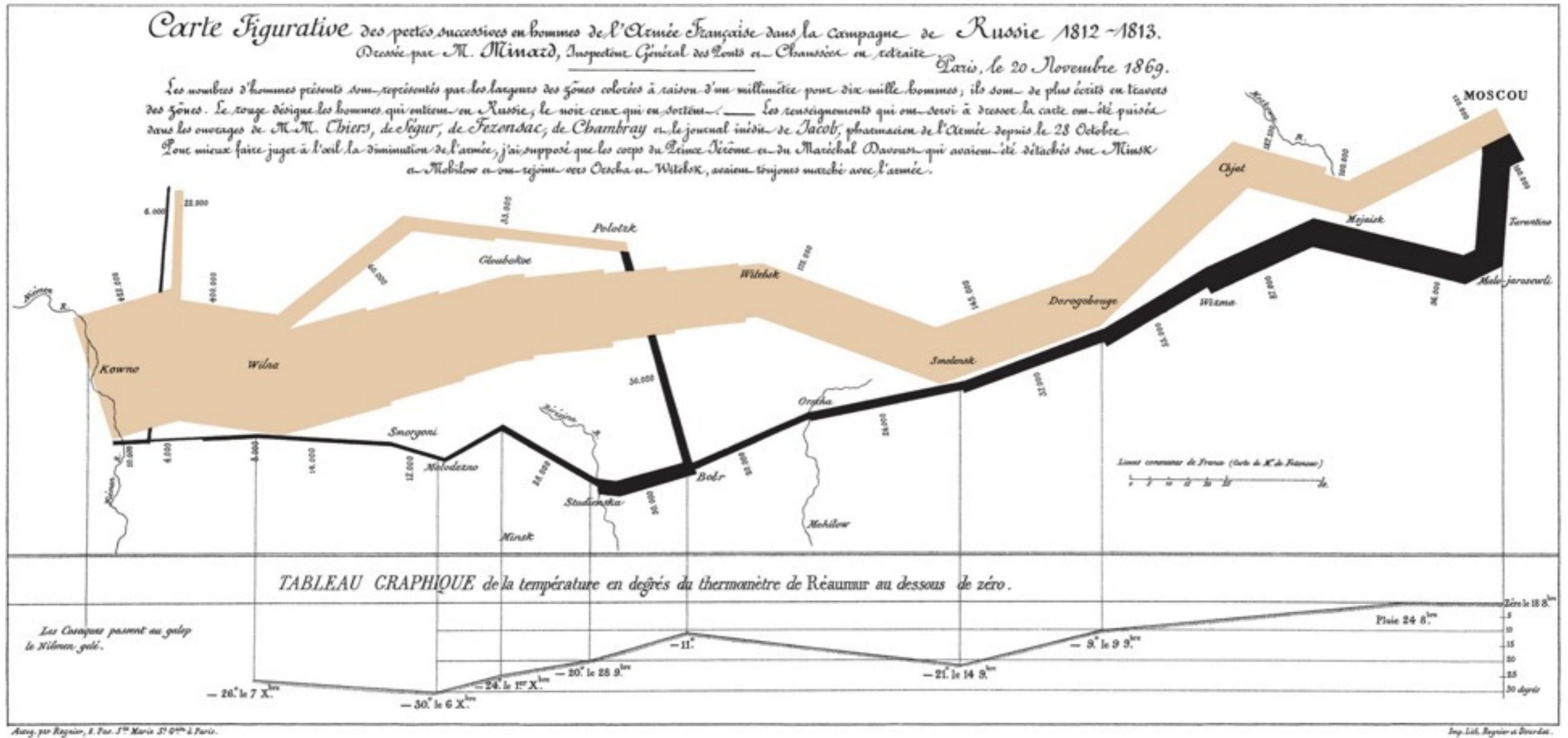


The Bottom line is divided into Years, the Right hand line into £10,000 each.
 Published in the Act ditto, 1st May 1786, by W^m Playfair
 Made and sold at 352 Strand, London.

Pie chart

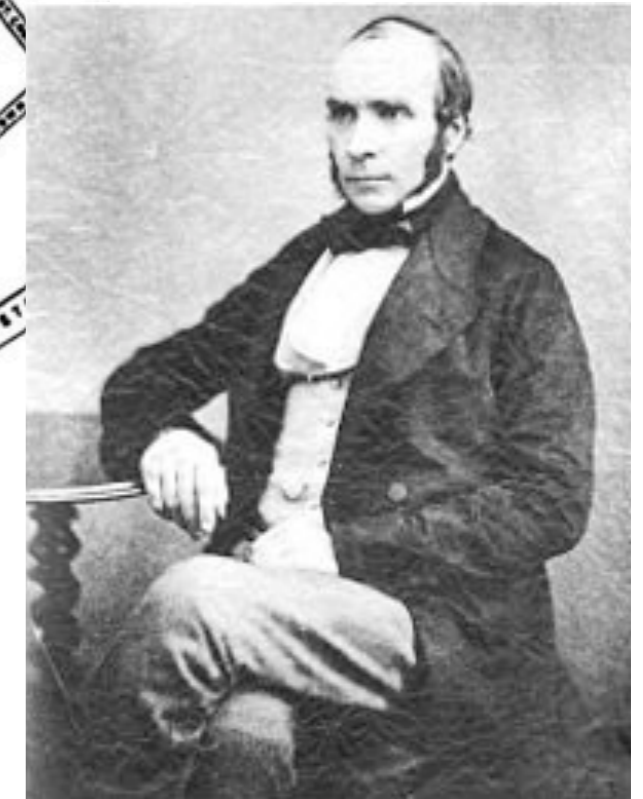
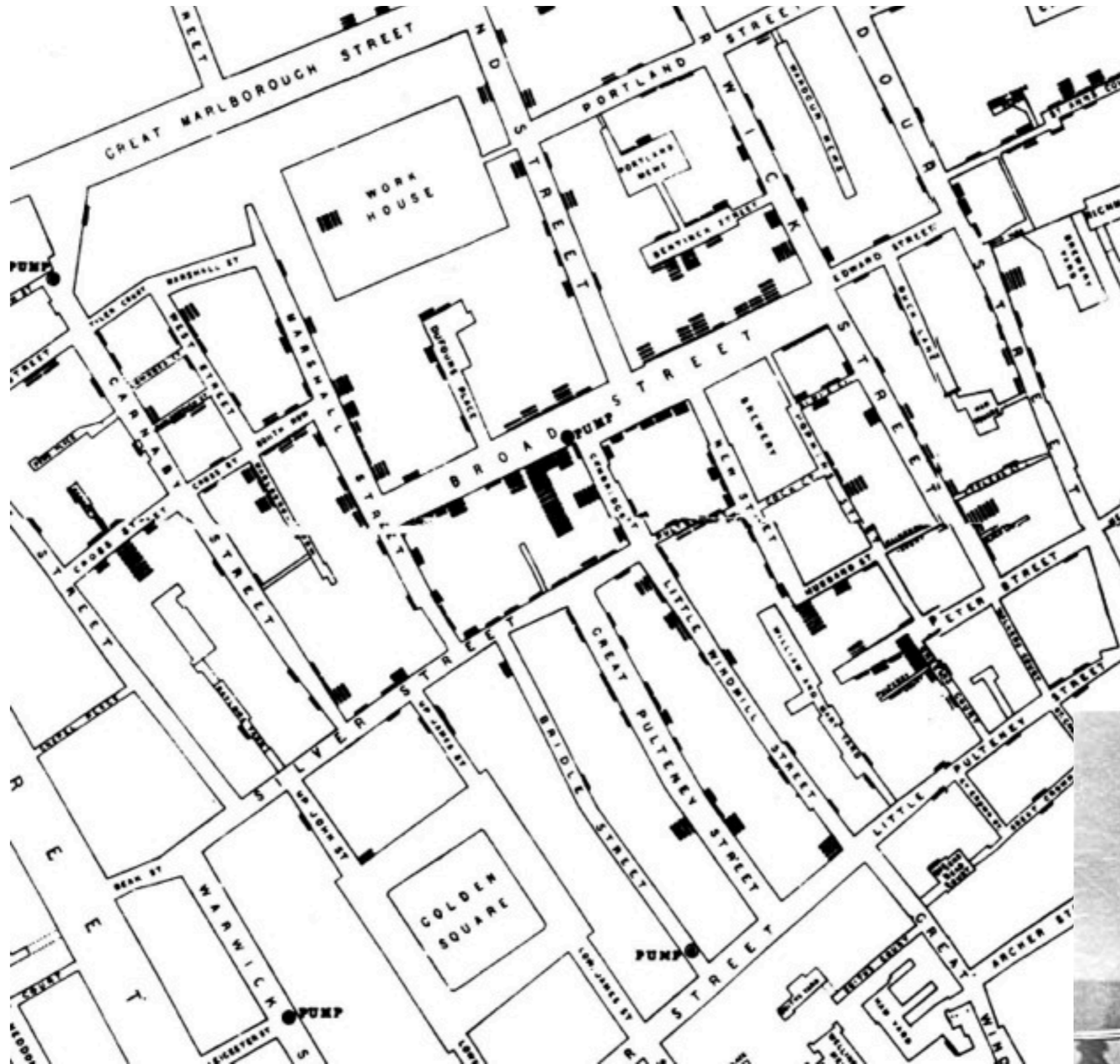


[later, Sankey diagram]

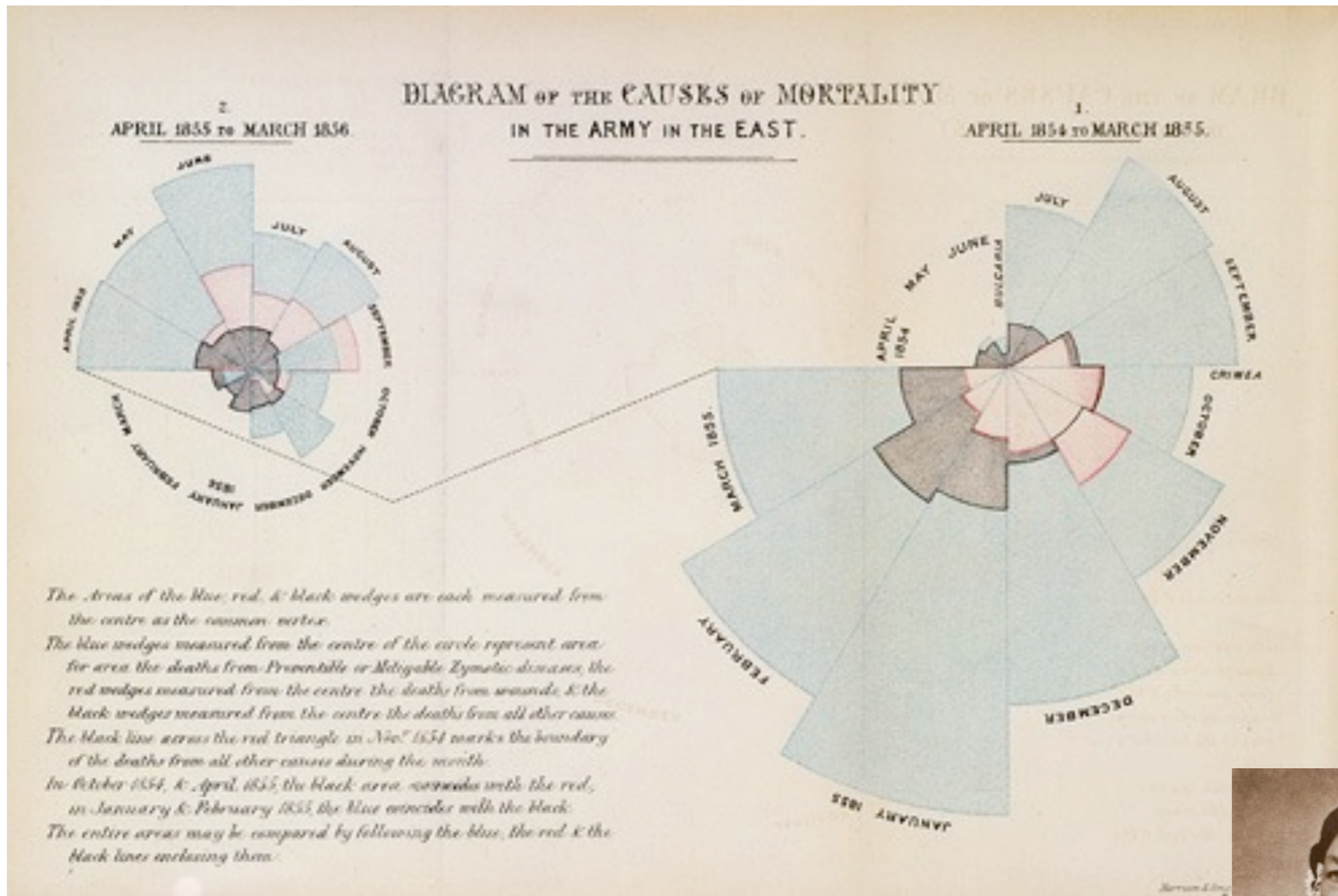


Mid 19th Century - Charles Joseph Minard (1781-1870) maps the disaster of Napoleon's Russian campaign

Source: <http://en.wikipedia.org/wiki/File:Minard.png>



1854 - Statistical graphics does epidemiology.
John Snow & the Broad Street cholera outbreak



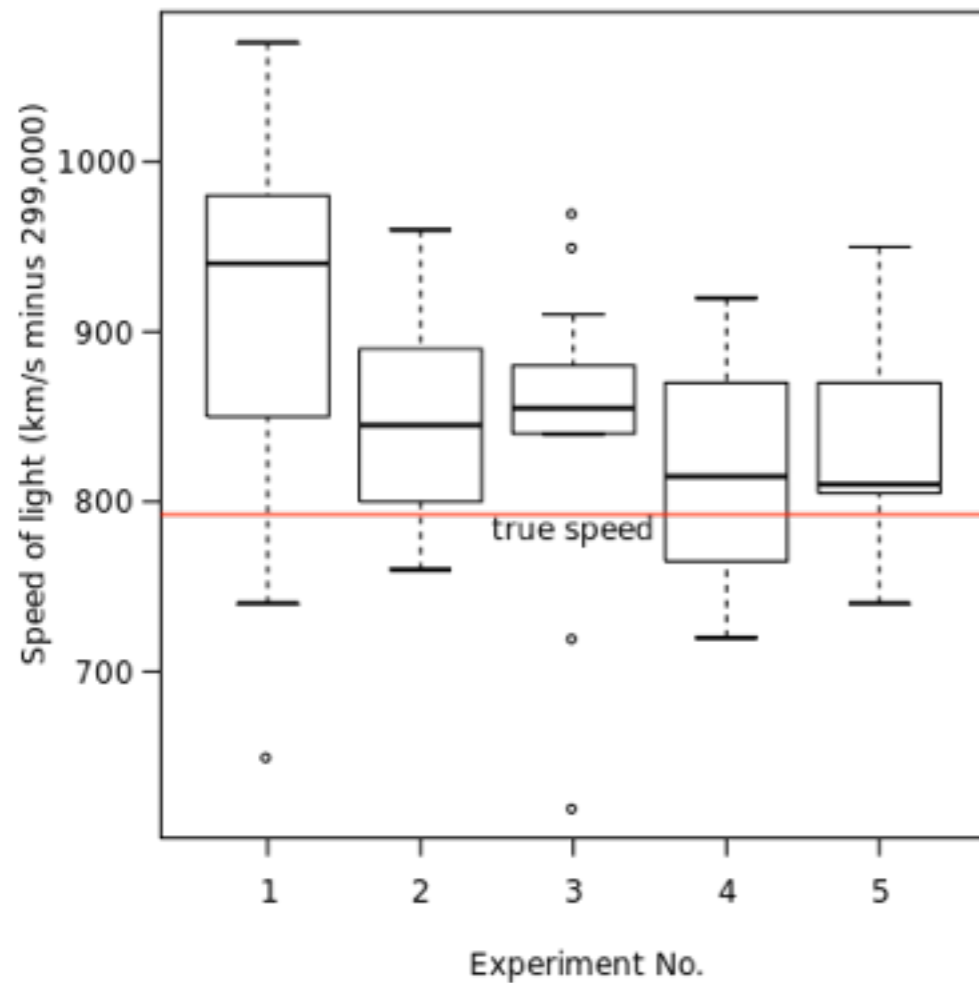
<http://understandinguncertainty.org/coxcombs>

Mid 19th Century - Florence Nightingale campaigns to improve sanitation for soldiers.



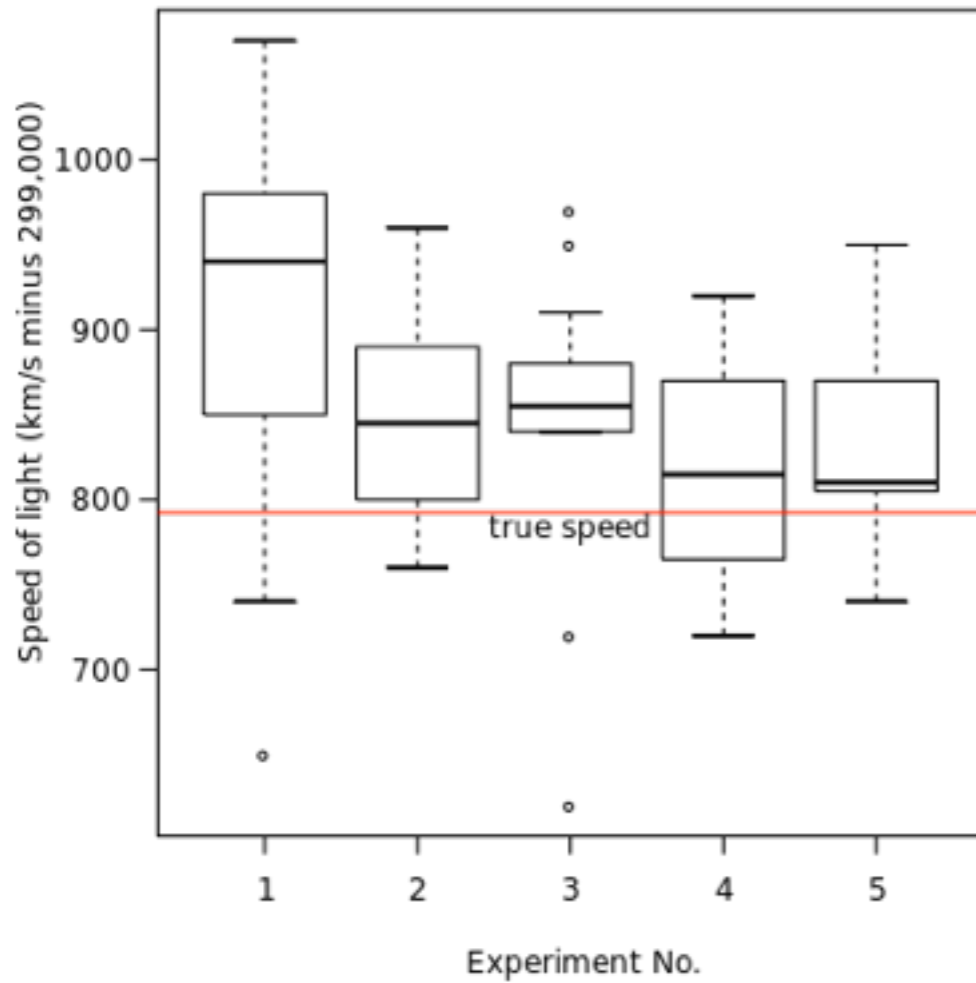
http://en.wikipedia.org/wiki/File:Florence_Nightingale_CDV_by_H_Lenthall.jpg

Late 20th Century - computing power enables high dimensional analysis, fast exploration

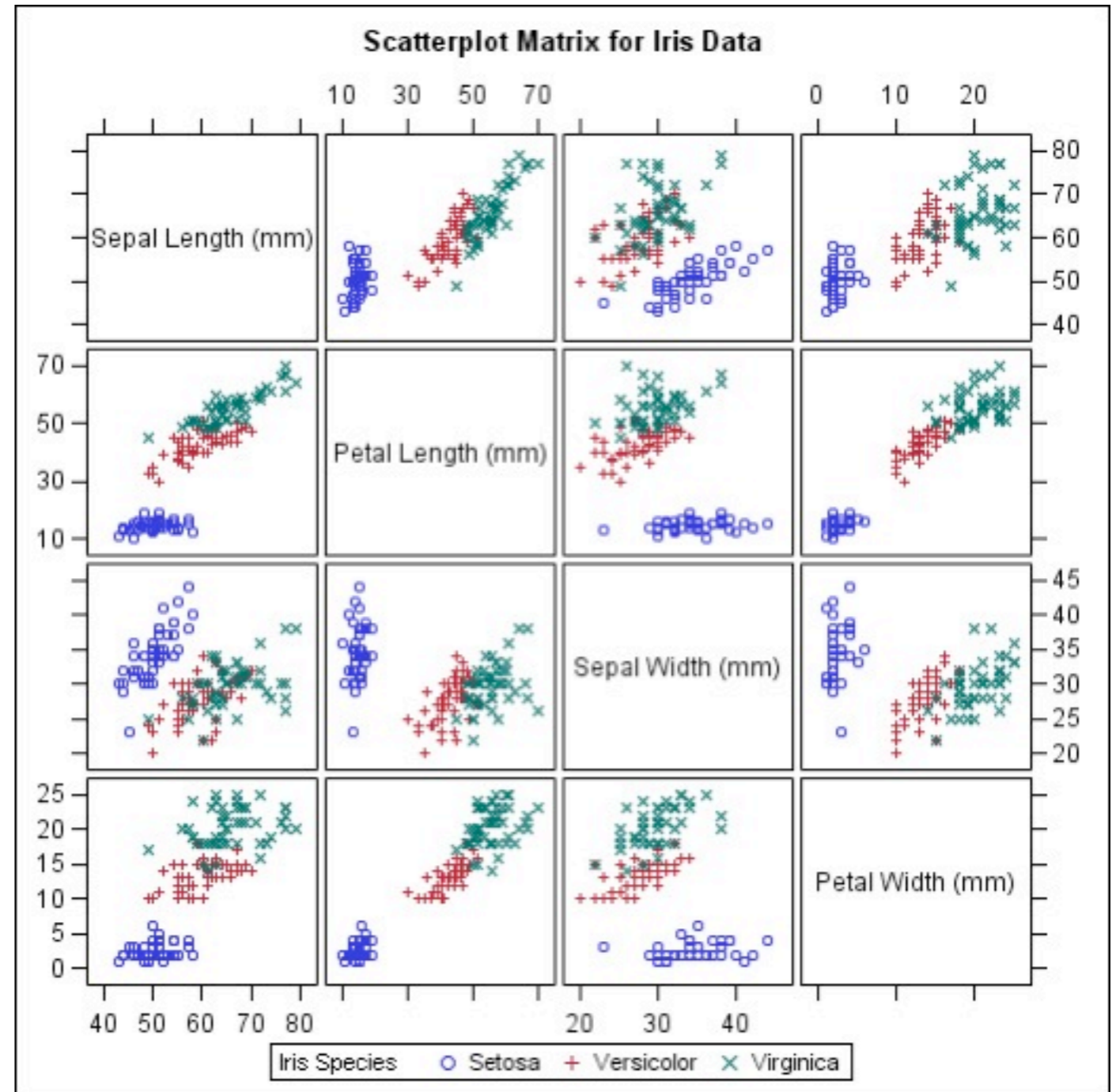


Tukey, John Wilder. (1962). The future of data analysis. *Annals of Mathematical Statistics*. 33. 1-67 and 81.

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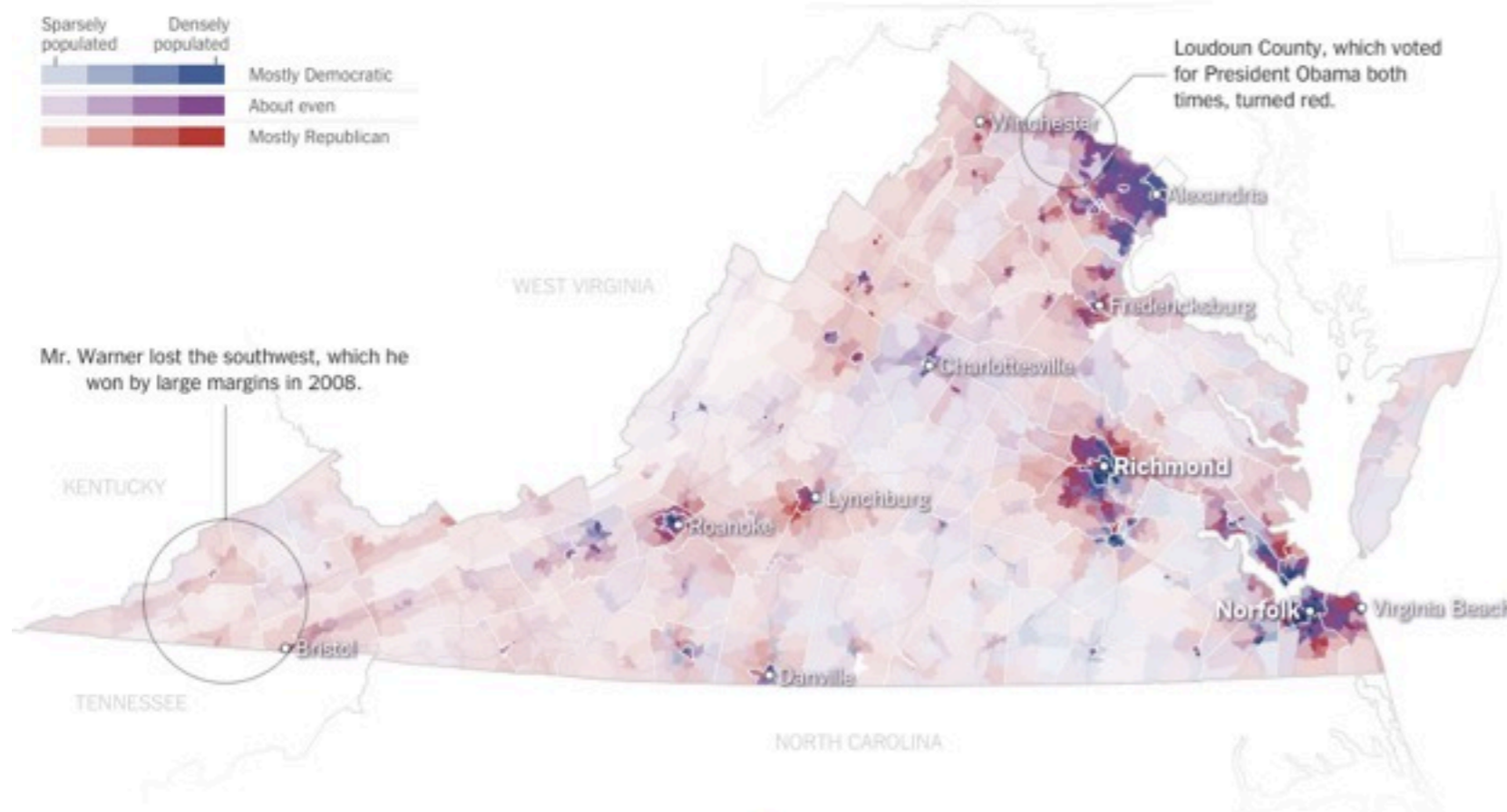
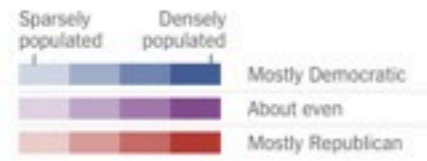


Tukey, John Wilder. (1962). The future of data analysis. *Annals of Mathematical Statistics*. 33. 1-67 and 81.



Virginia

Dem. Mark Warner 49.2%
Rep. Ed Gillespie 48.4%



Mike Bostock d3.js

North Carolina

Rep. Thom Tillis 49.0%
Dem. Kay Hagan 47.3%



Hans Rosling, Gapminder

March 1861

March 1875

have described were regarded as about the same which have yet taken place there.

THE WEATHER.

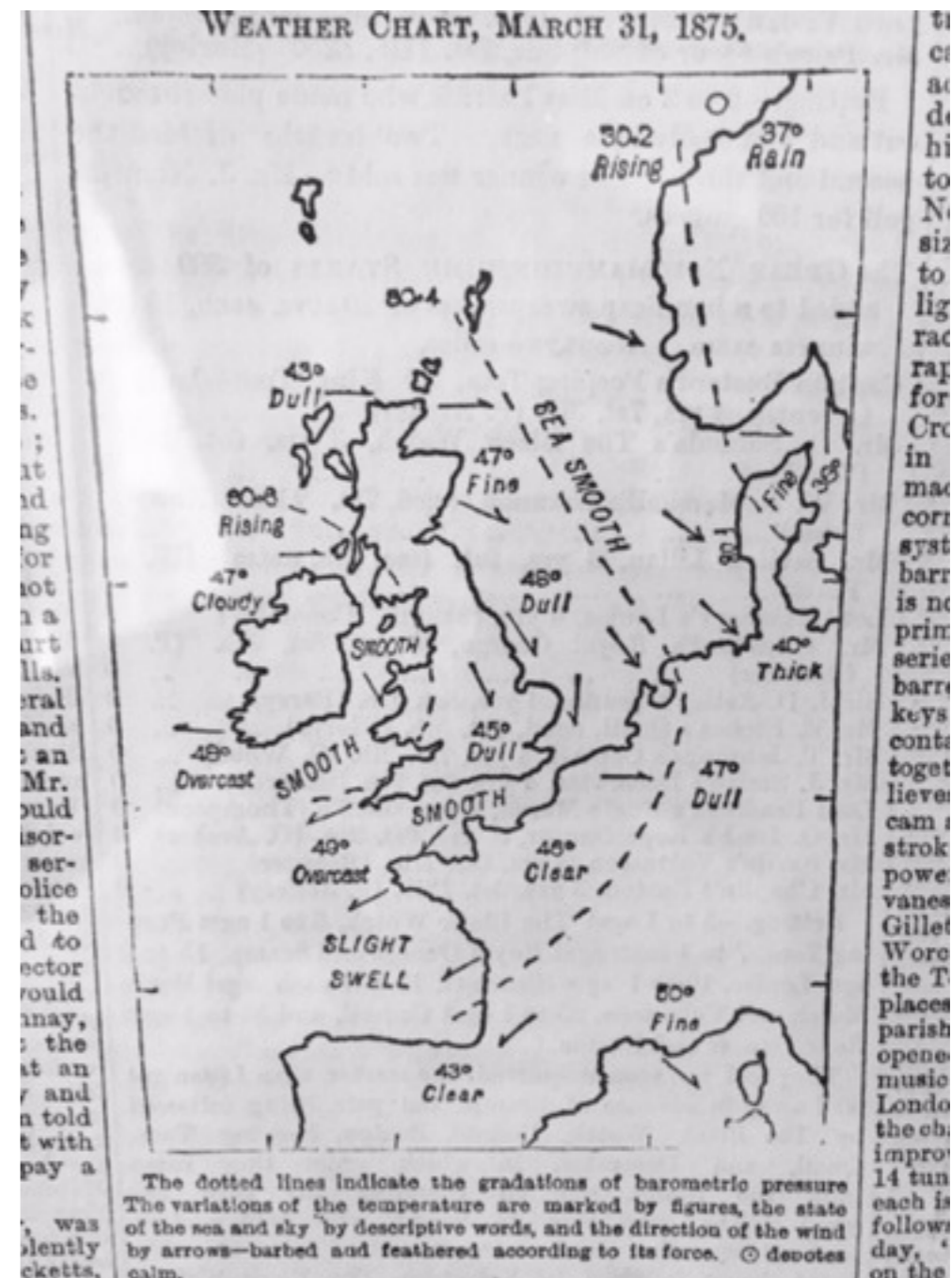
METEOROLOGICAL REPORTS.

Wednesday, July 31, 8 to 9 a.m.	B.	E.	M.	D.	F.	C.	I.	S.
Nairn.. ..	29.54	57	56	W.S.W.	6	9	o.	3
Aberdeen.. ..	29.60	59	54	S.S.W.	5	1	b.	3
Leith.. ..	29.70	61	55	W.	3	5	c.	2
Berwick.. ..	29.69	59	55	W.S.W.	4	4	c.	2
Ardrossan.. ..	29.73	57	55	W.	5	4	c.	5
Portrush.. ..	29.72	57	54	S.W.	2	2	b.	2
Shields.. ..	29.80	59	54	W.S.W.	4	5	o.	3
Galway.. ..	29.83	65	62	W.	5	4	c.	4
Scarborough.. ..	29.85	59	56	W.	3	6	c.	2
Liverpool.. ..	29.91	61	56	S.W.	2	8	c.	2
Valentia.. ..	29.87	62	60	S.W.	2	5	o.	3
Queencstown.. ..	29.88	61	59	W.	3	5	c.	2
Yarmouth.. ..	30.05	61	59	W.	5	2	c.	3
London.. ..	30.02	62	58	S.W.	3	2	b.	—
Dover.. ..	30.04	70	61	S.W.	3	7	o.	2
Portsmouth.. ..	30.01	61	59	W.	3	6	o.	2
Portland.. ..	30.03	63	59	S.W.	3	2	c.	3
Plymouth.. ..	30.09	62	59	W.	5	1	b.	4
Penzance.. ..	30.04	61	60	S.W.	2	6	c.	3
Copenhagen.. ..	29.94	64	—	W.S.W.	2	6	c.	3
Helder.. ..	29.99	63	—	W.S.W.	6	5	c.	3
Brest.. ..	30.09	60	—	S.W.	2	6	c.	5
Bayonne.. ..	30.13	68	—	—	—	9	m.	5
Lisbon.. ..	30.18	70	—	N.N.W.	4	3	b.	2

General weather probable during next two days in the—
 North—Moderate westerly wind; fine.
 West—Moderate south-westerly; fine.
 South—Fresh westerly; fine.

Explanation.
 B. Barometer, corrected and reduced to 32° at mean sea level; each 10 feet of vertical rise causing about one-hundredth of an inch diminution, and each 10° above 32° causing nearly three-hundredths increase. E. Exposed thermometer in shade. M. Moistened bulb (for evaporation and dew-point). D. Direction of wind (true—two points left of magnetic). F. Force (1 to 12—estimated). C. Cloud (1 to 9). I. Initials:—b., blue sky; c., clouds (detached); f., fog; h., hail; l., lightning; m., misty (hazy); o., overcast (dull); r., rain; s., snow; t., thunder. S. Sea disturbance (1 to 9).

TO THE EDITOR OF THE TIMES.



Robert FitzRoy and the first public weather forecasts

G.S. Callendar measures the changing temperature of Earth, 1938

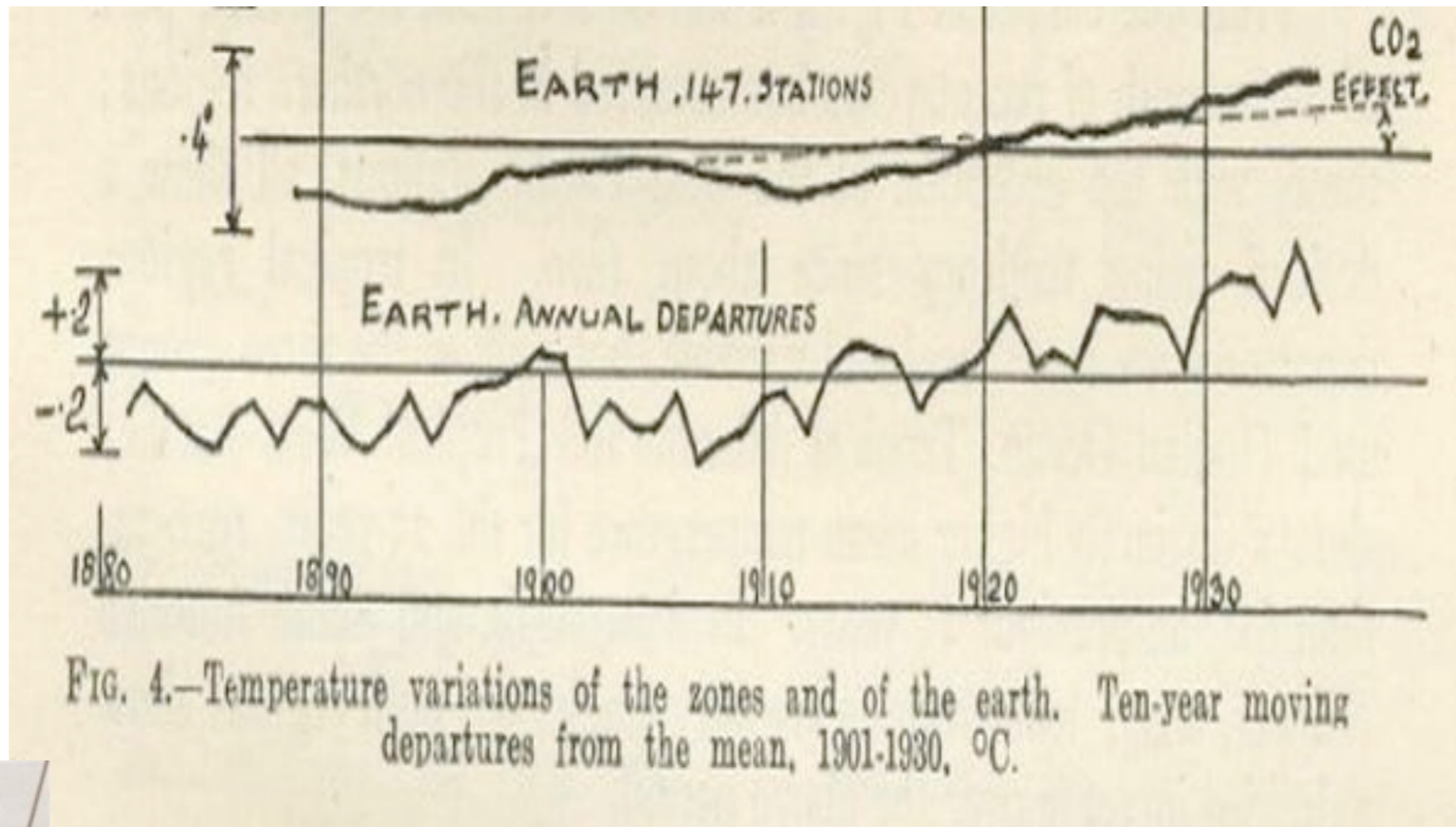


FIG. 4.—Temperature variations of the zones and of the earth. Ten-year moving departures from the mean, 1901-1930, °C.



Some principles

“Graphical displays should;

See also Tufte’s rules http://www.sealthreinhold.com/tuftes-rules/rule_one.php

Quotes from Edward Tufte: The Visual Display of Quantitative Information

“Graphical displays should;

show the data,

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rather than about methodology, graphic design, the
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Present many numbers in a small space,

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See also Tufte's rules [http://www.sealthreinhold.com/
tuftes-rules/rule_one.php](http://www.sealthreinhold.com/tuftes-rules/rule_one.php)

[Quotes from Edward Tufte: The Visual Display of
Quantitative Information](#)

“Graphical displays should;

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reveal the data at several levels of detail, from a broad overview to the fine structure,

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serve a reasonably clear purpose: description, exploration, tabulation, or decoration,

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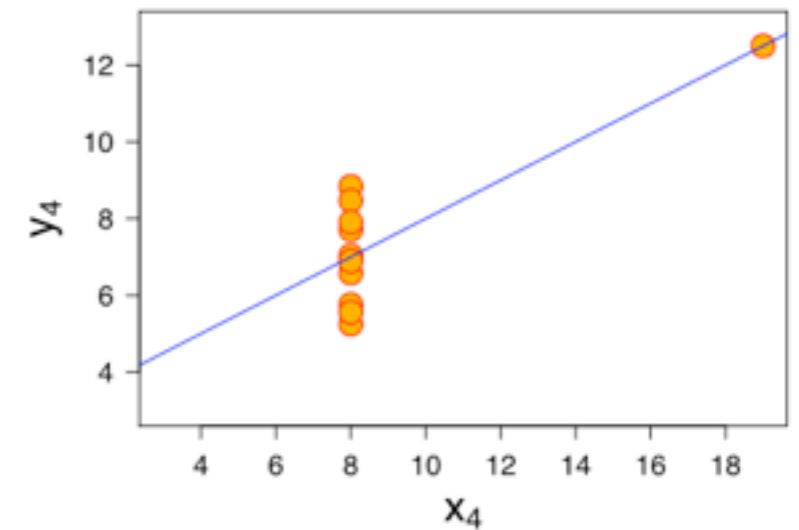
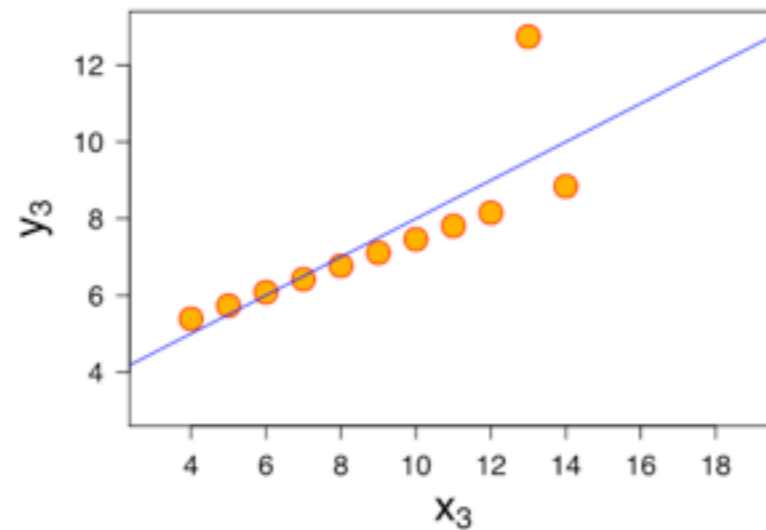
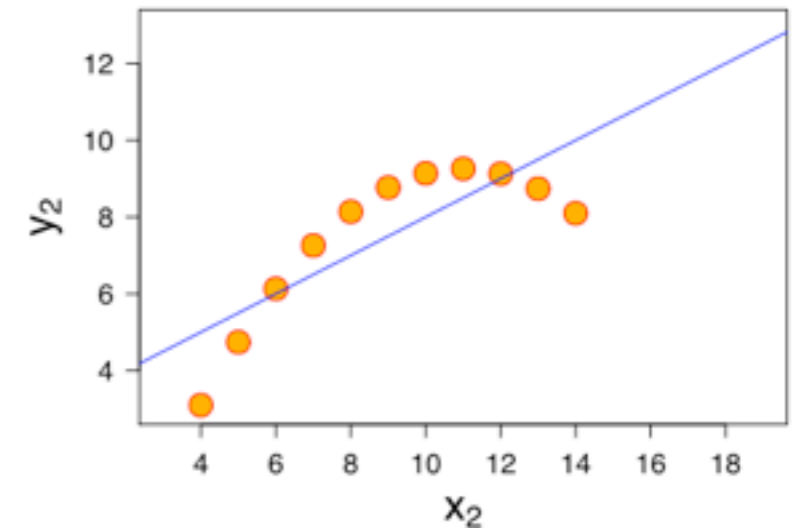
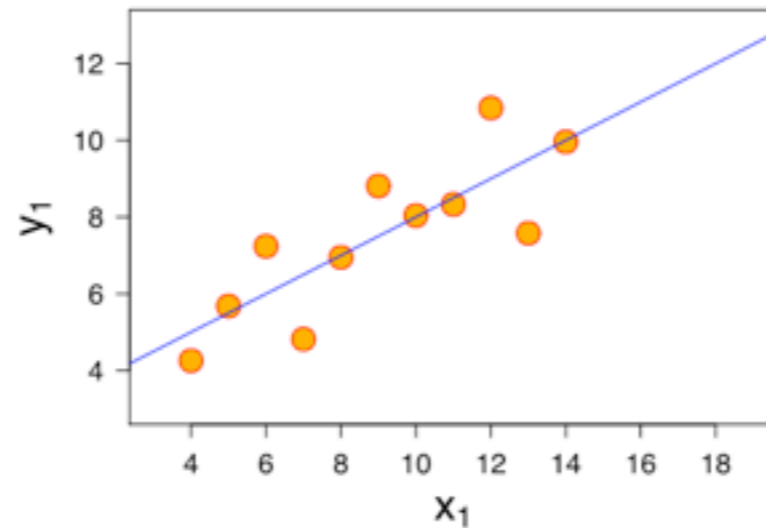
serve a reasonably clear purpose: description, exploration, tabulation, or decoration,

be closely integrated with the statistical and verbal descriptions of a data set.”

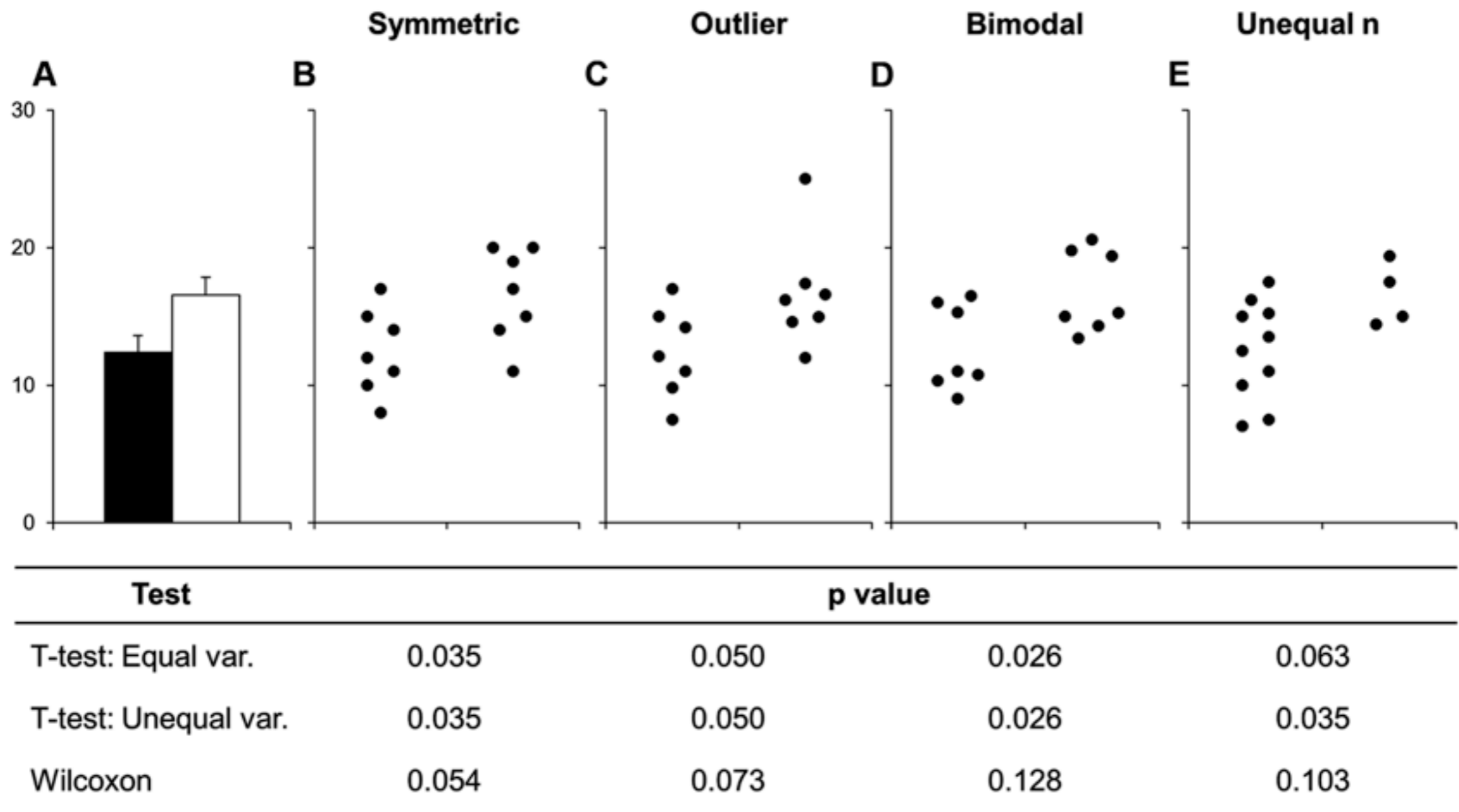
Show the data

Anscombe's quartet

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14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
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All these data sets have the same:
Means, Variances,
Correlation, Regression line



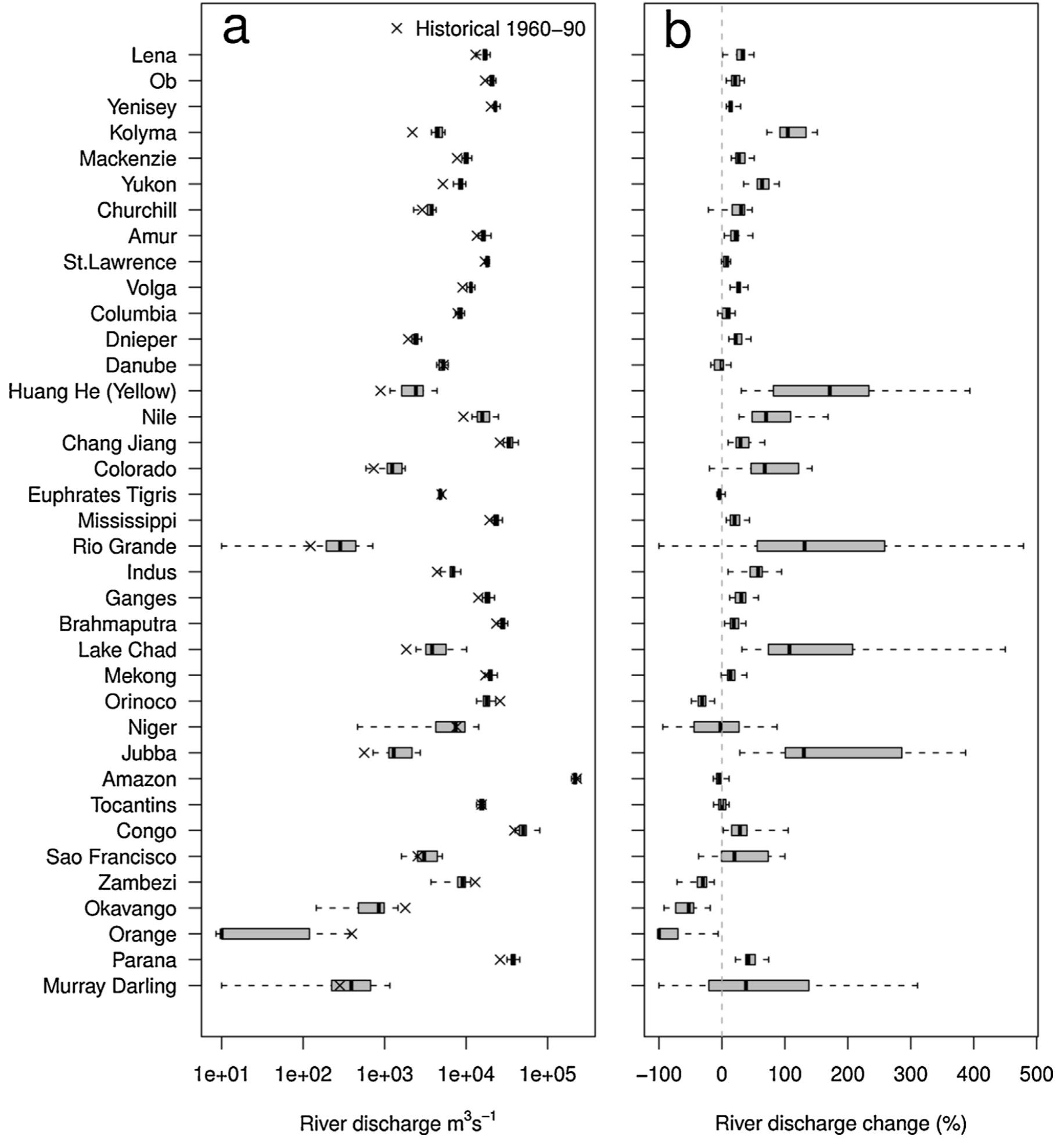
Beyond Bar and Line Graphs: Time for a New Data Presentation Paradigm

- 1 Tracey L. Weissgerber,
- 2 Natasa M. Milic,
- 3 Stacey J. Winham,
- 4 Vesna D. Garovic

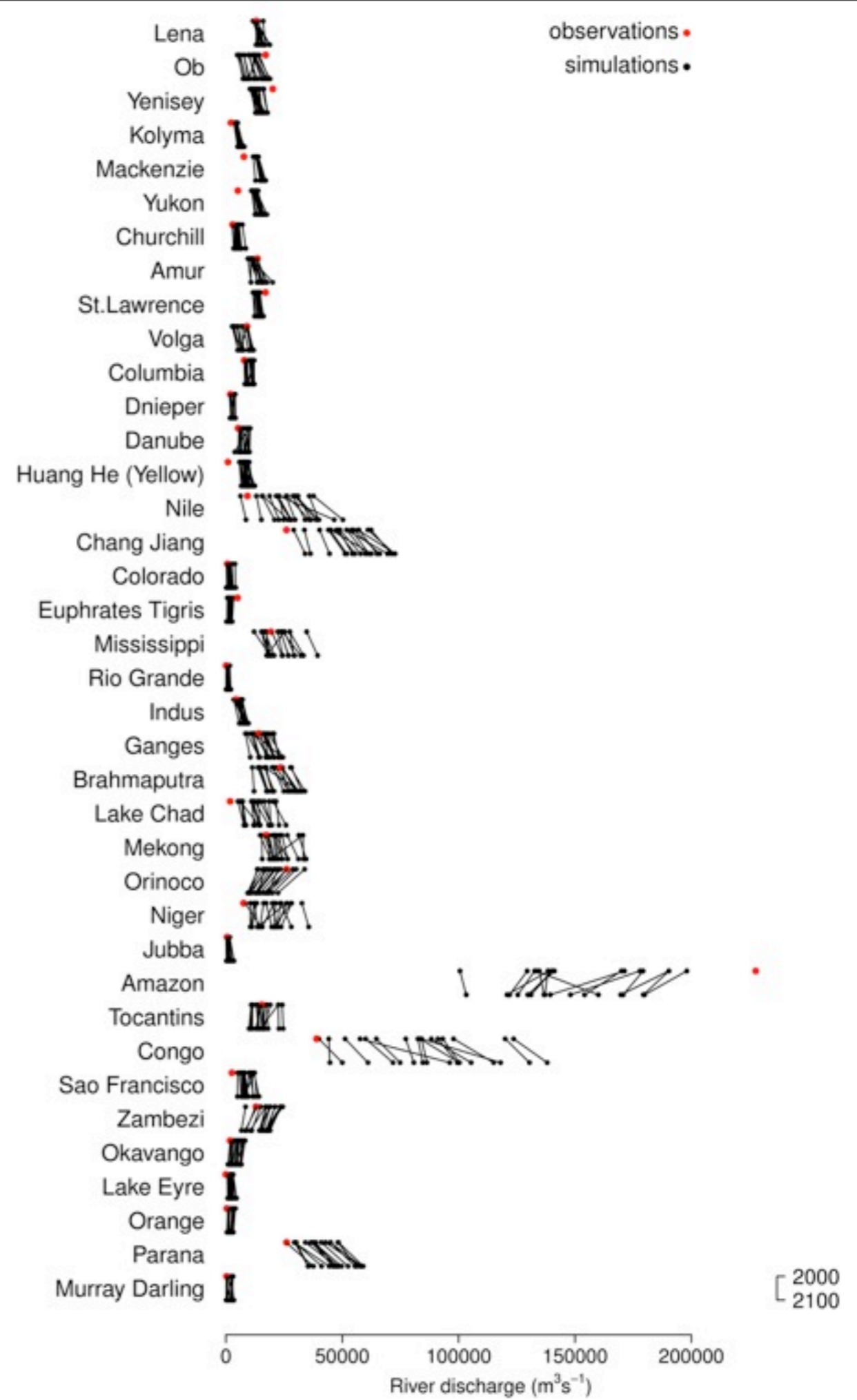
- Published: April 22, 2015
- DOI: 10.1371/journal.pbio.1002128

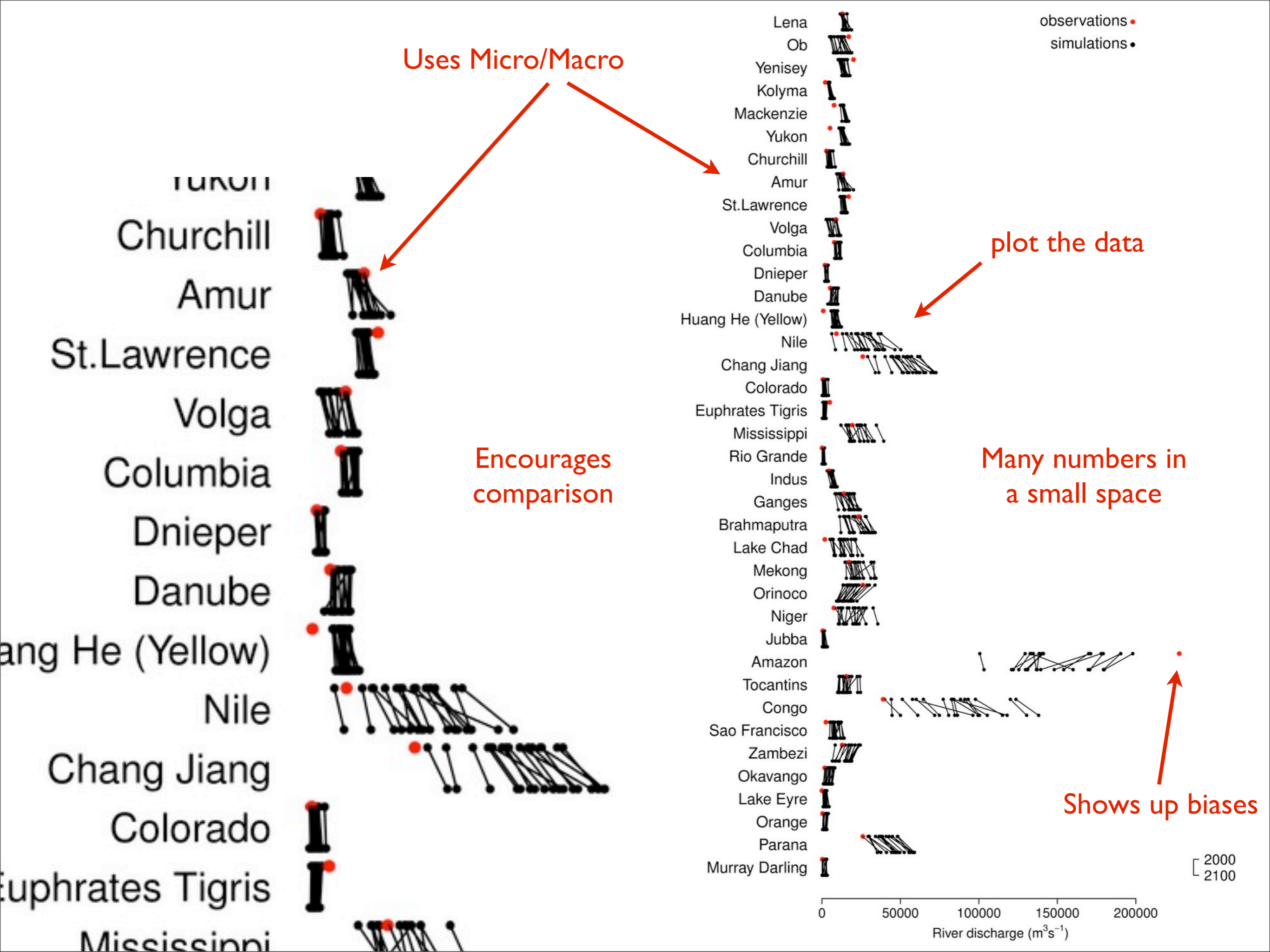
River discharge

Absolute and relative change, compared to observations



Wiltshire *et al.* (2013), Global Environmental Change





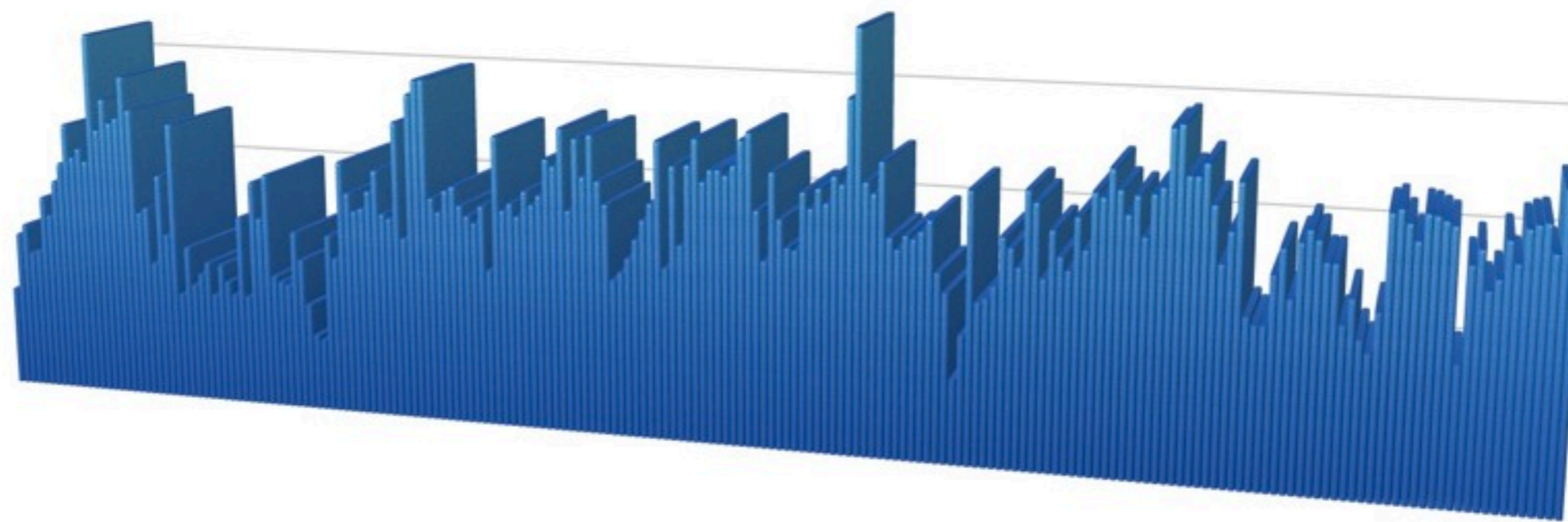
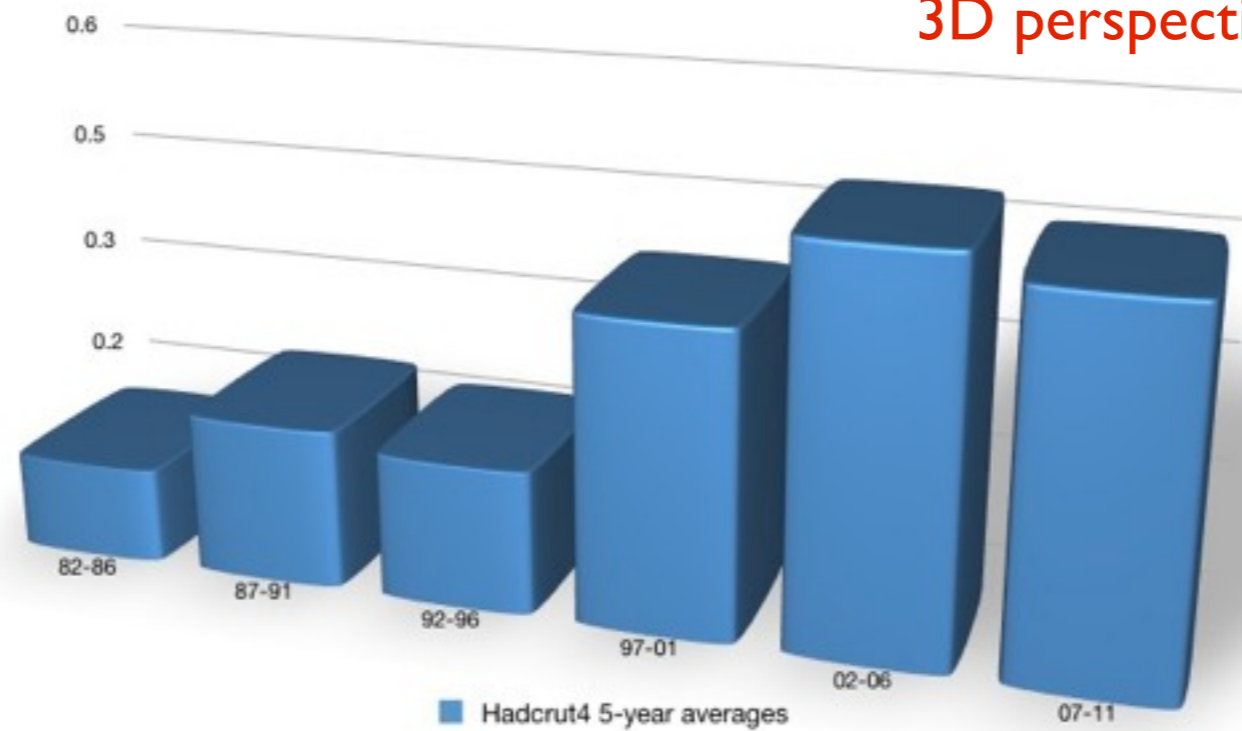
Minimize chartjunk

3D bars add no information

3D perspective masks trends

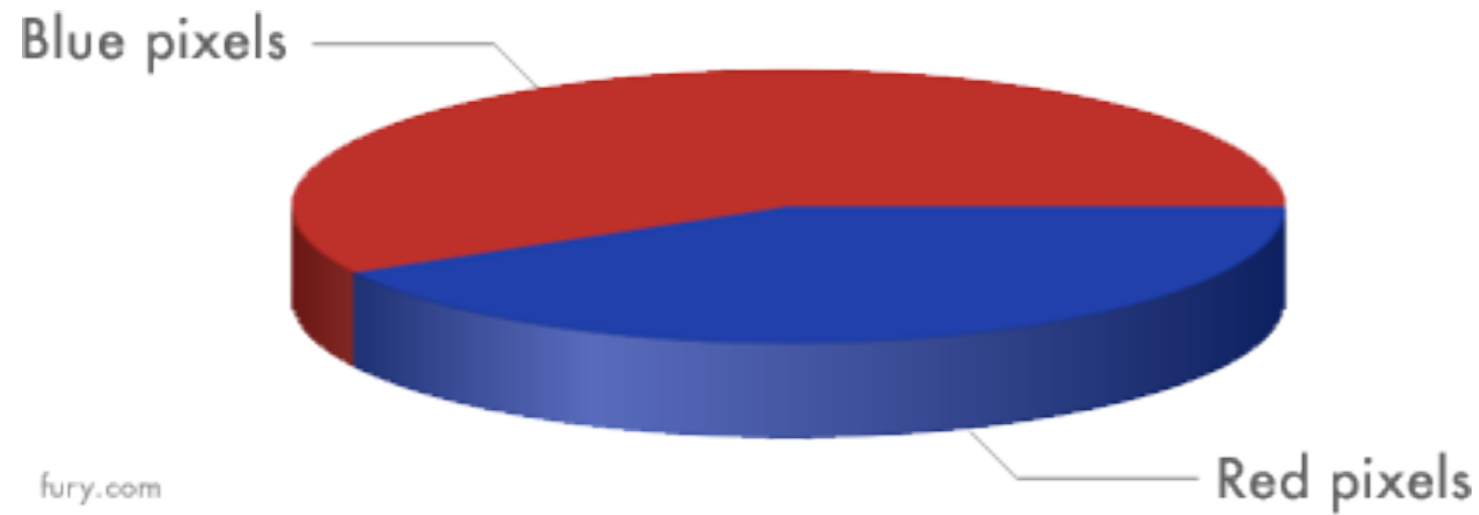
Unnecessary drop shadow

Tiny or missing labelling



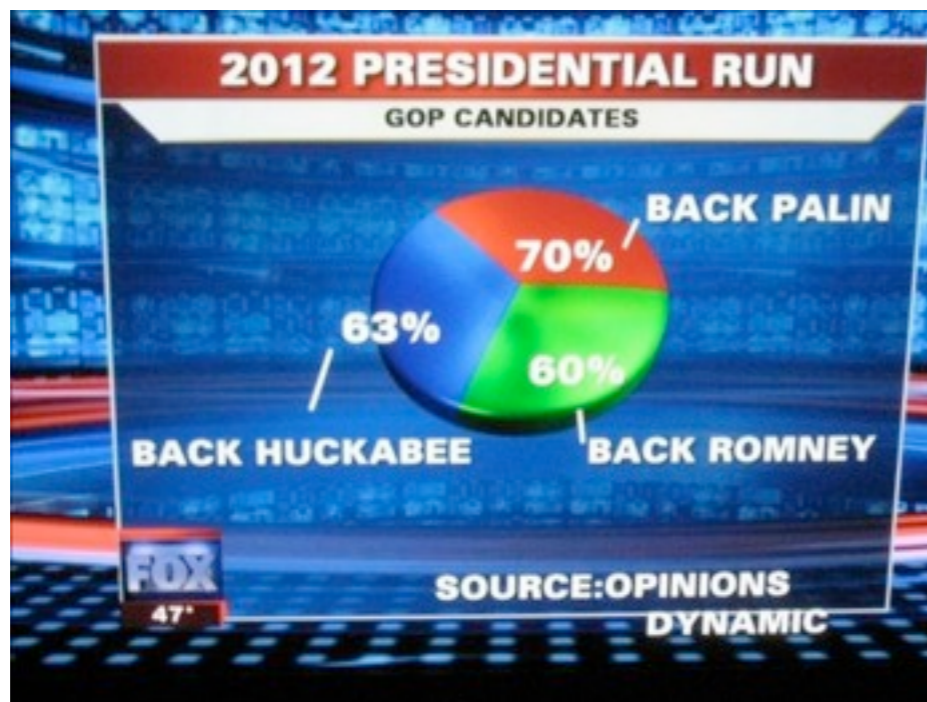
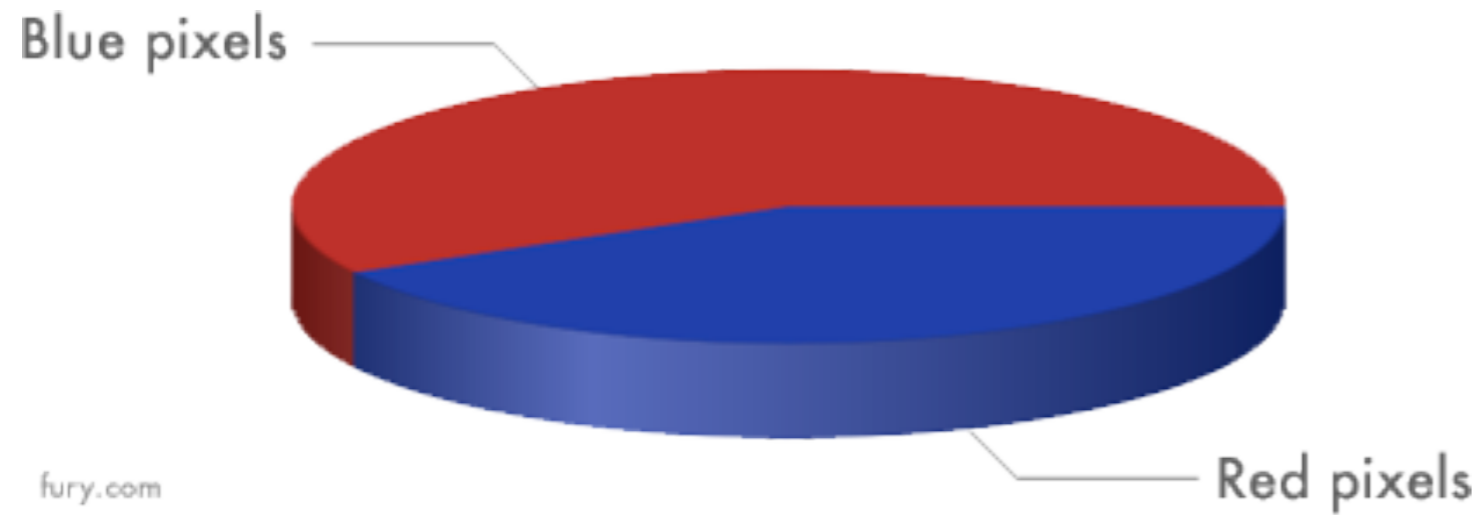
Avoid distorting what the data have to say

Why 3d pie charts are bad



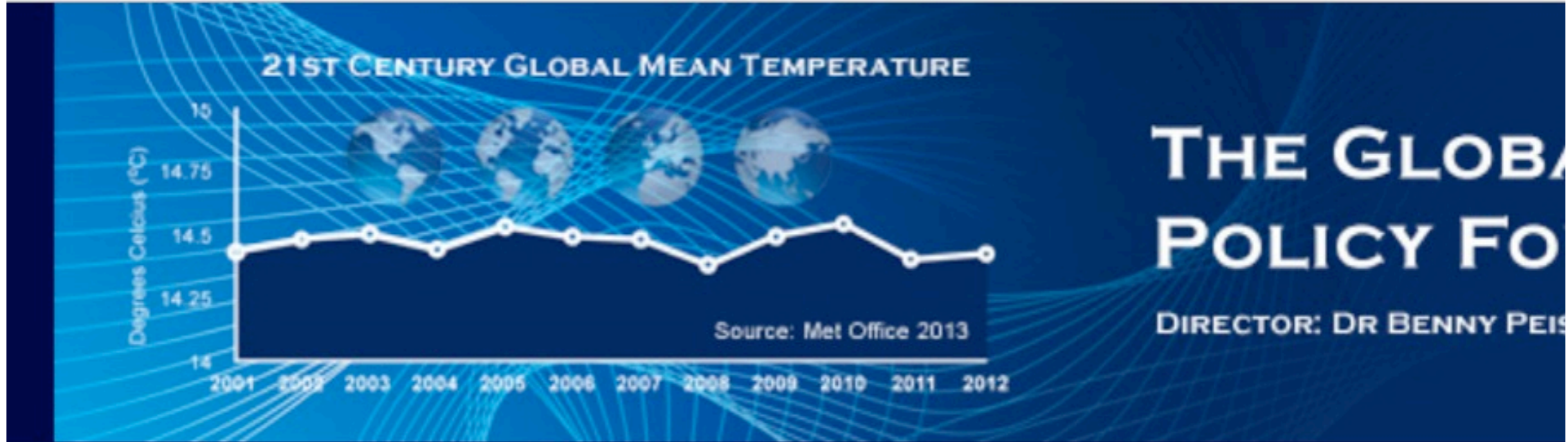
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Why 3d pie charts are bad



Being plain wrong

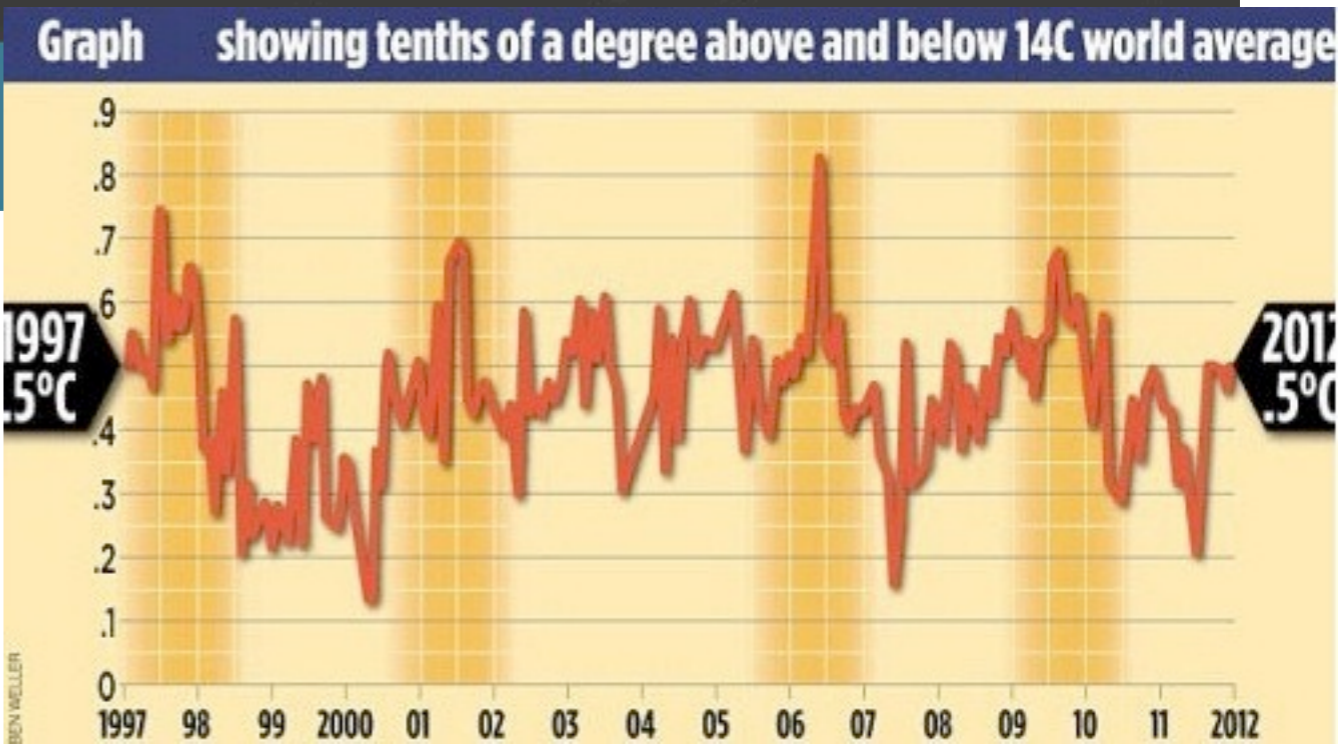
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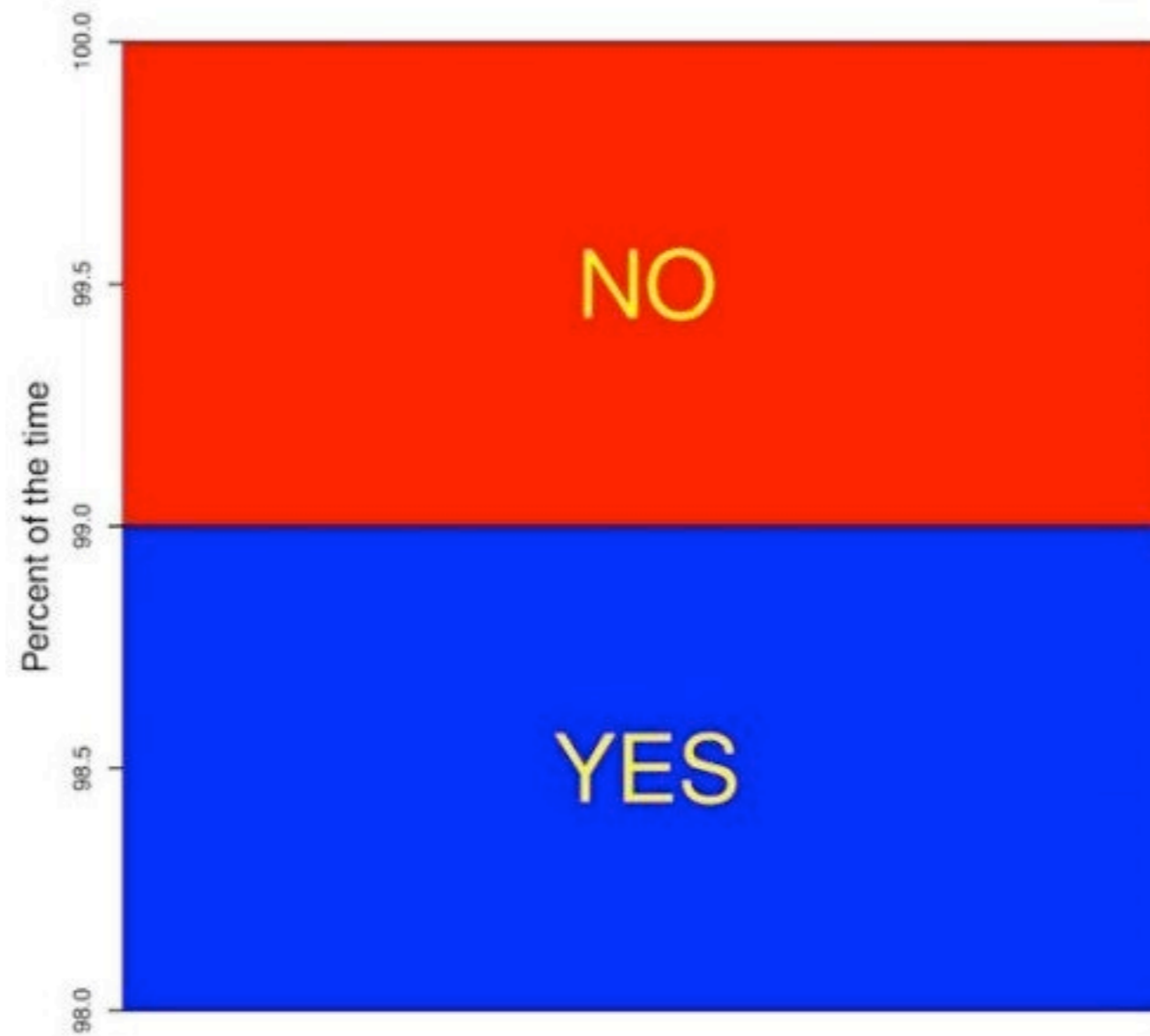
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BEST OF BLOGS



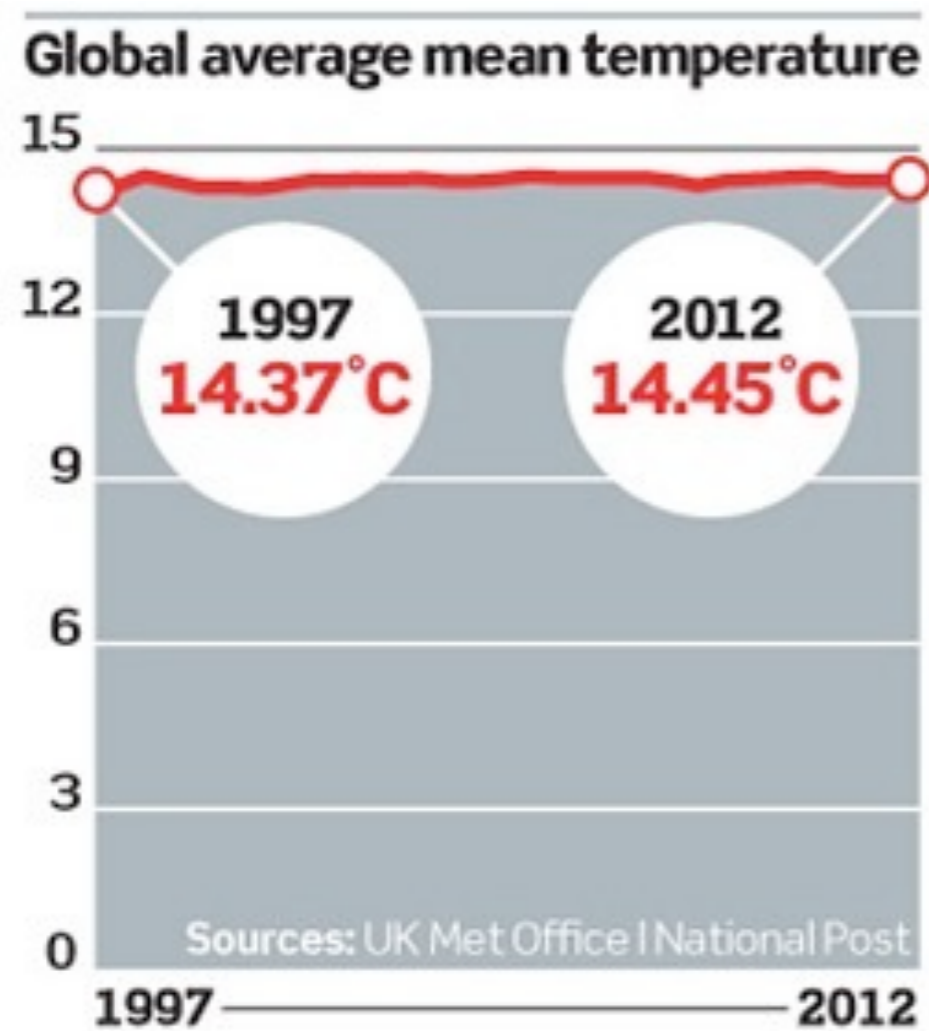
Cherry picking

Is truncating the Y-axis misleading?



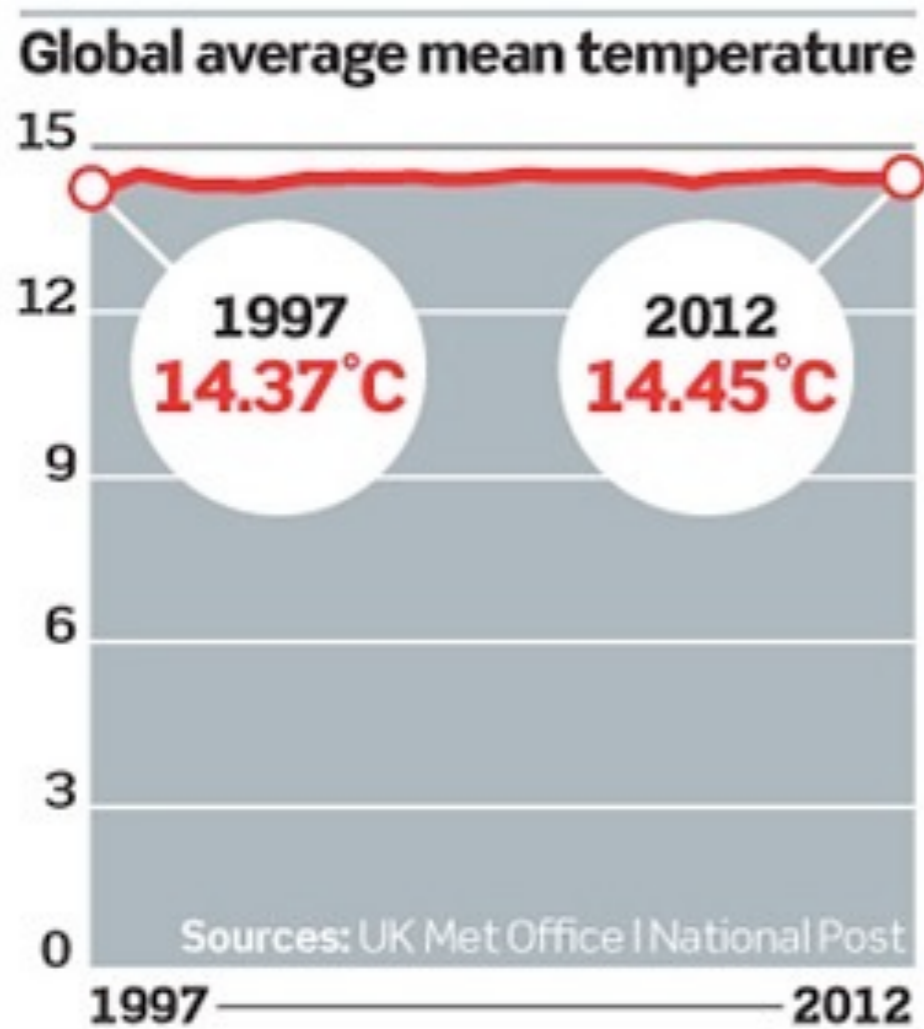
By [Russell Christopher @russch](#)

Creative y-axis selection

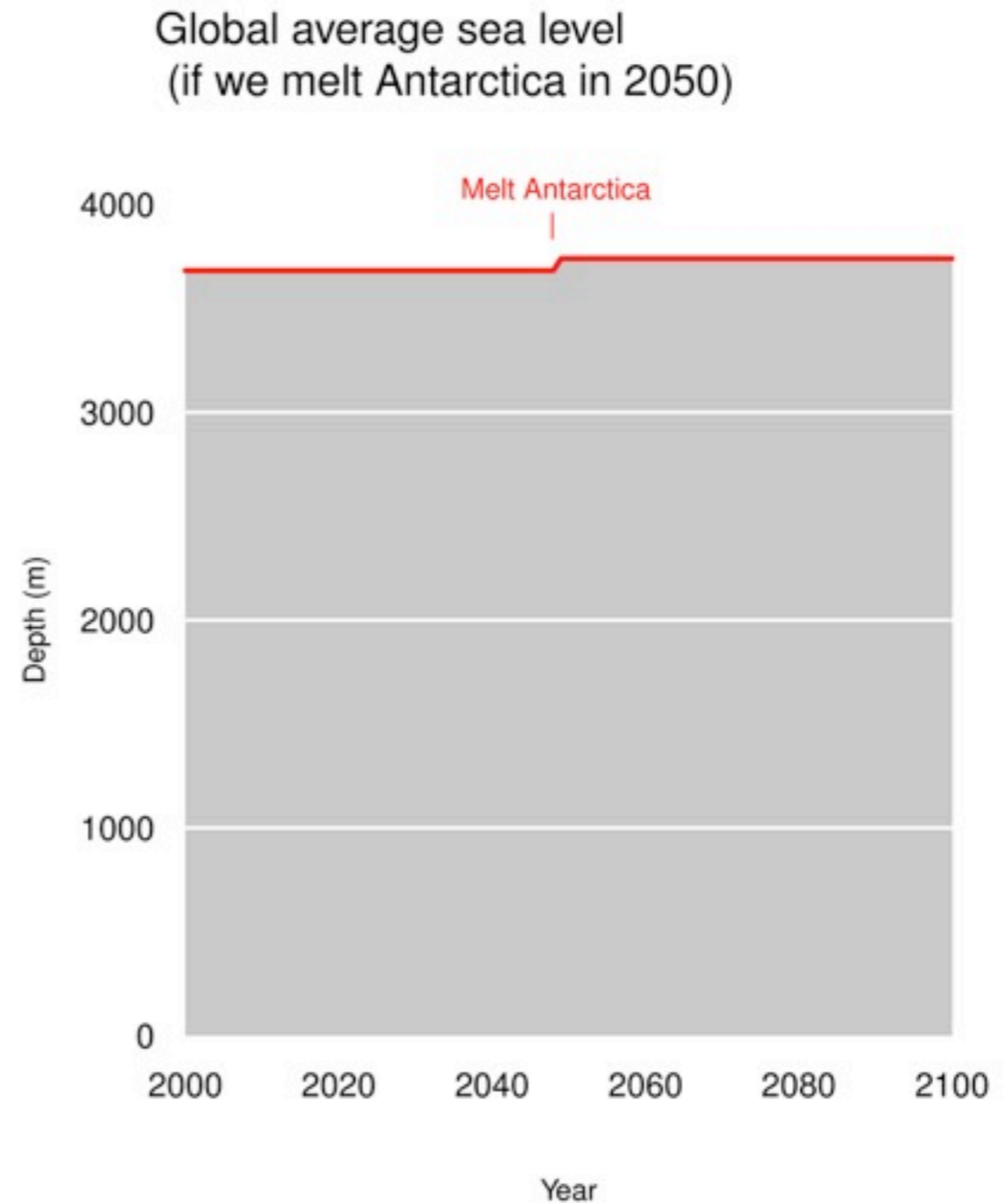


Source: Christopher Booker, The Telegraph

Creative y-axis selection

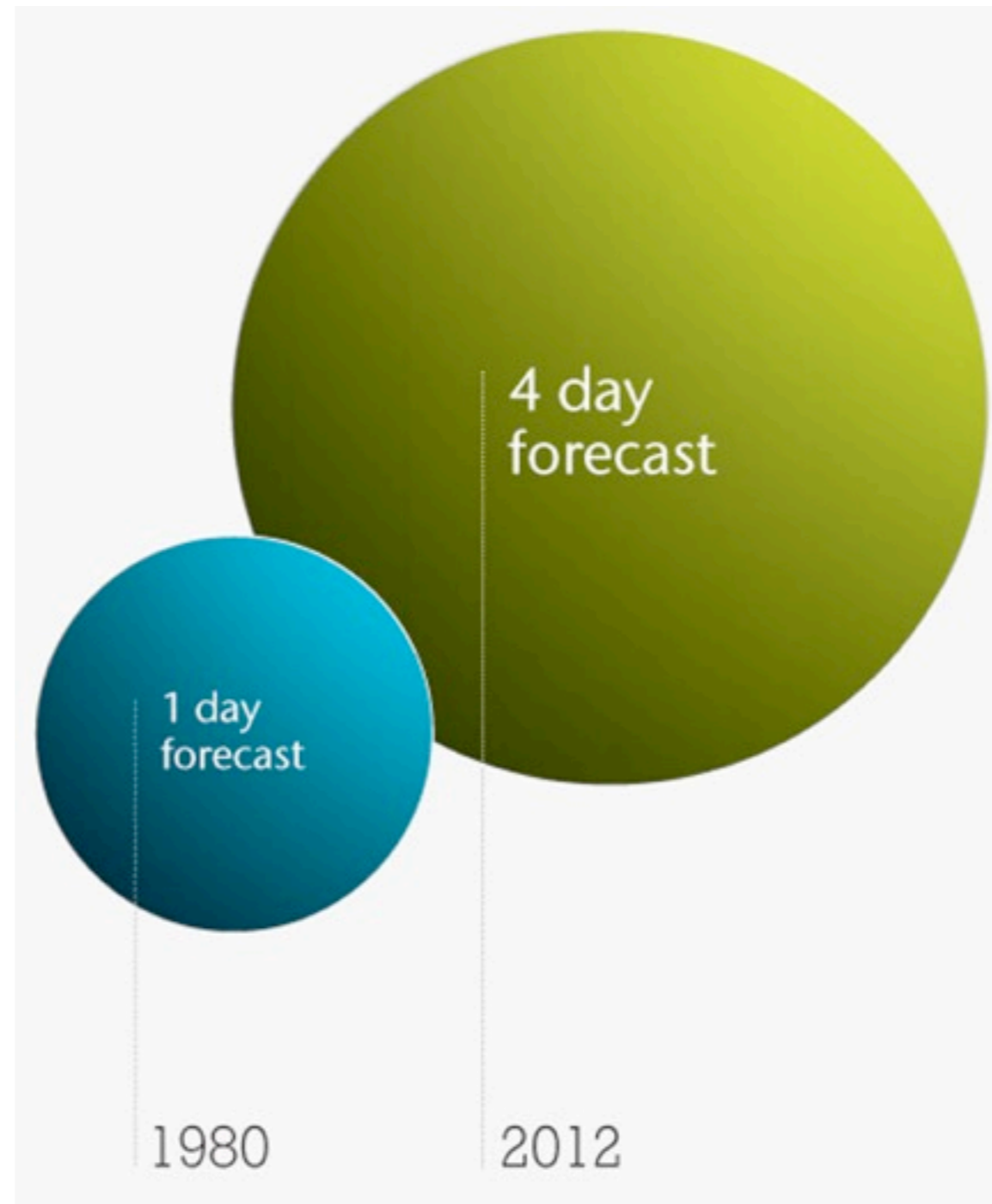


Source: Christopher Booker, The Telegraph



58 metres of sea level rise.
Source: betterfigures.org

Even the Met Office can get it wrong sometimes...



Source: Barometer Magazine

"Our four day forecasts today are as accurate as our one-day forecasts in 1980."

- Choose a message
- Minimise work for the reader
- Don't trust defaults
- Remove non-data ink (pixels) where possible

$$\textit{Data-ink ratio} = \frac{\textit{data-ink}}{\textit{total ink used}}$$

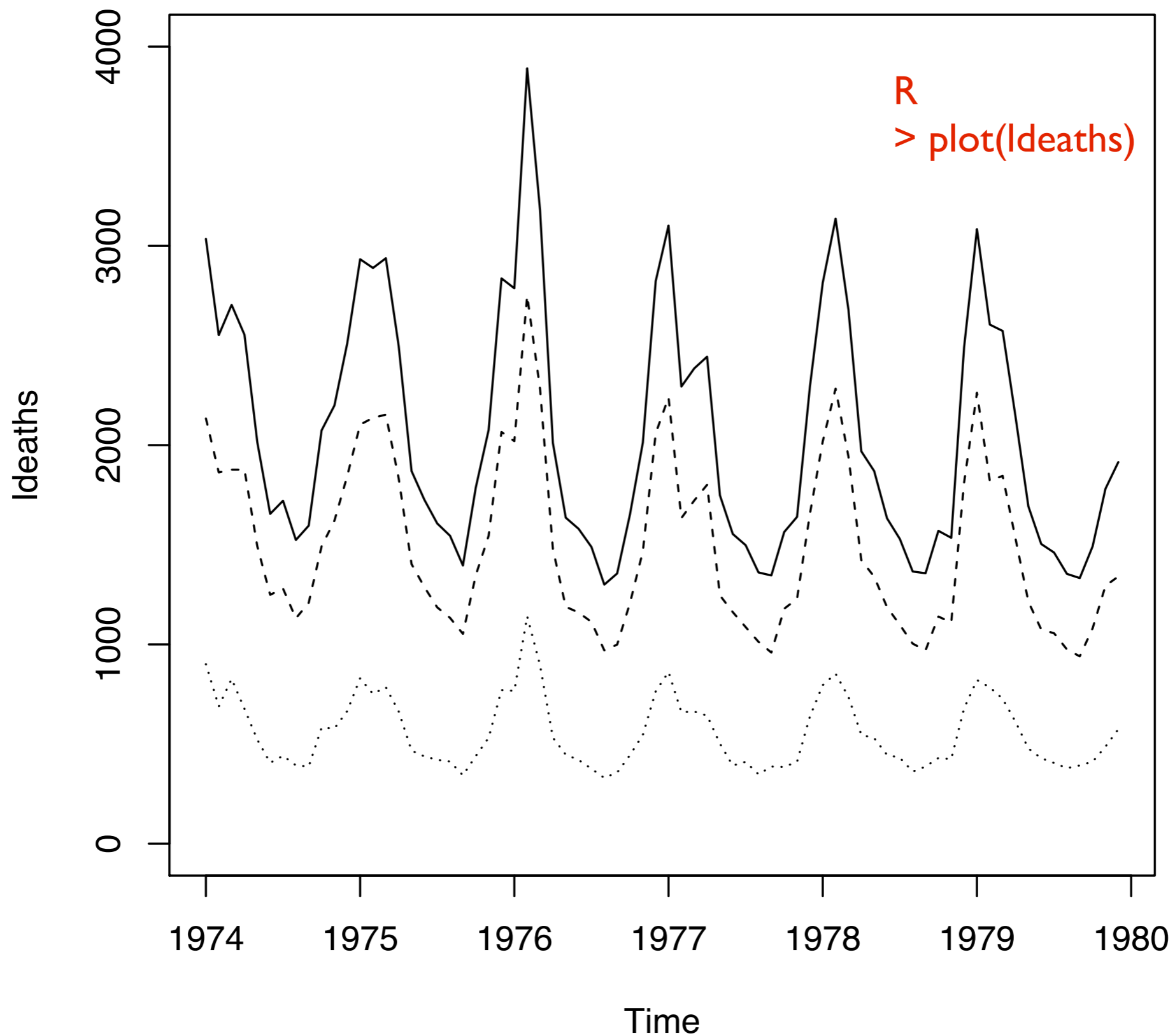
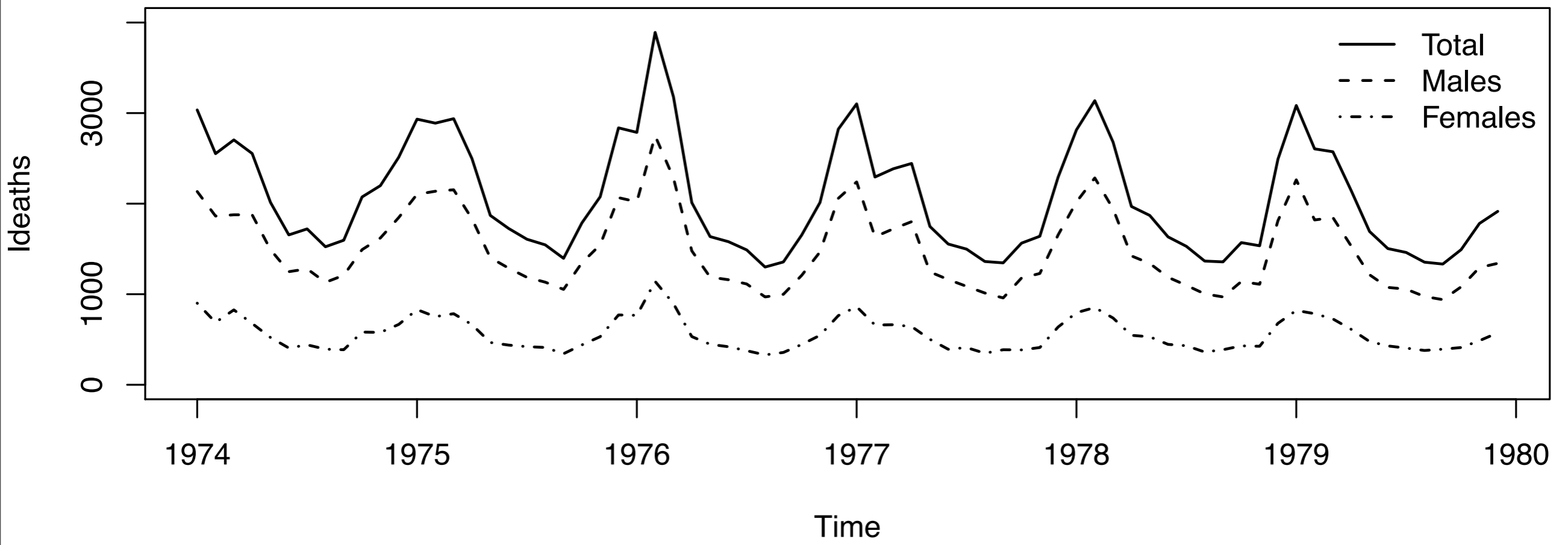
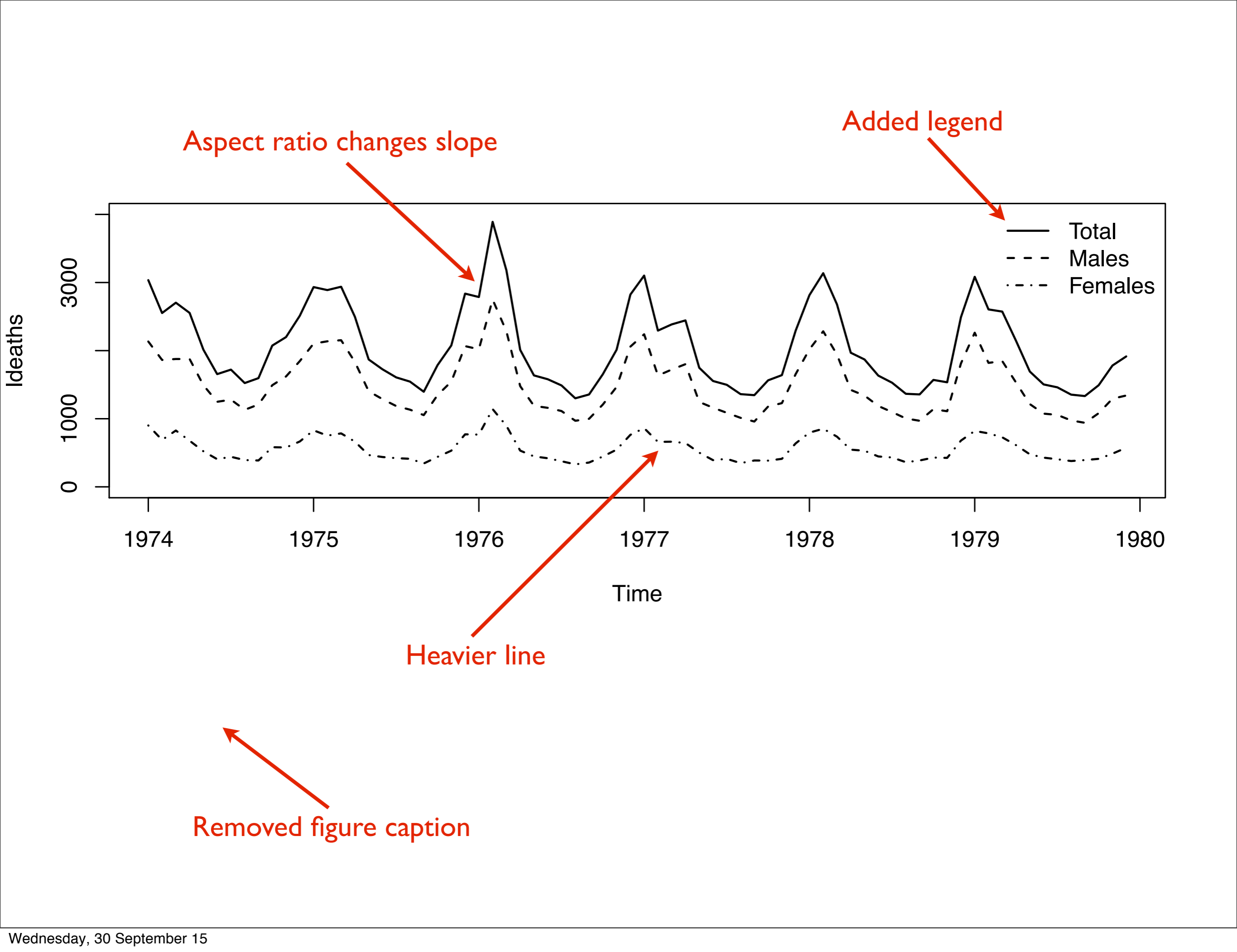


Fig 1. Monthly deaths due to lung disease in the UK. The dotted line shows number of female deaths, the dashed line shows male deaths, with the total shown by the solid line.





Aspect ratio changes slope

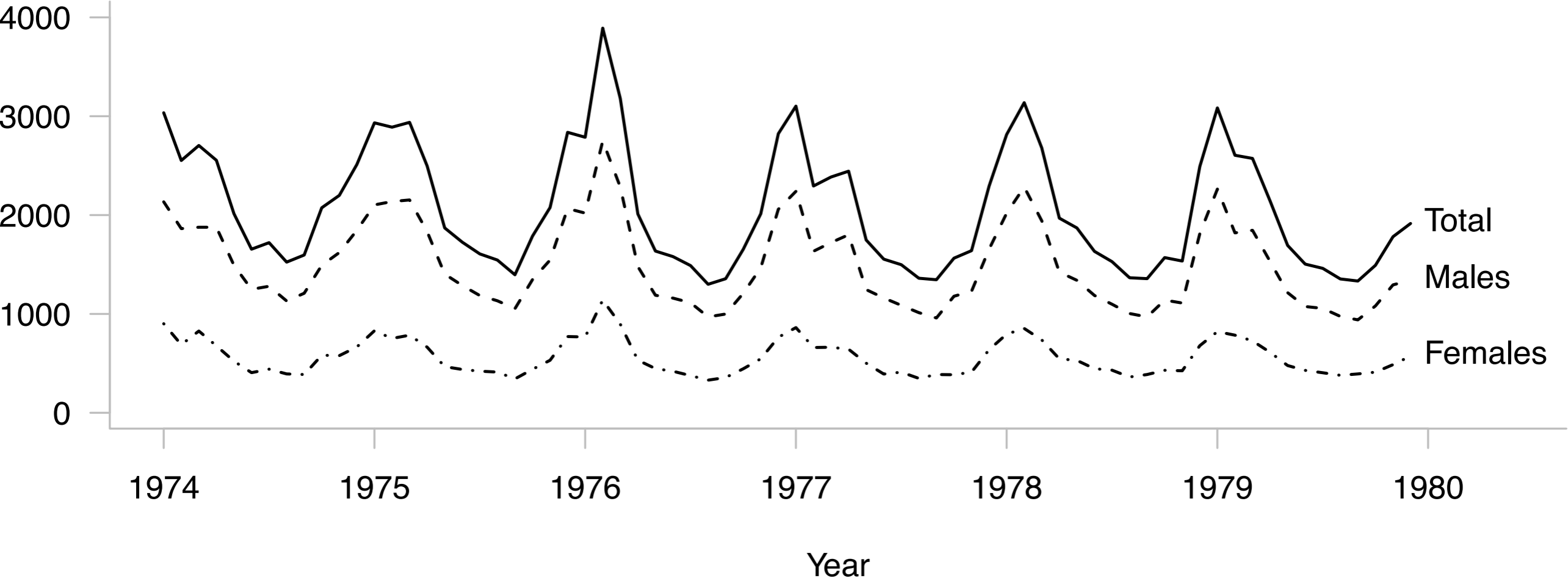
Added legend

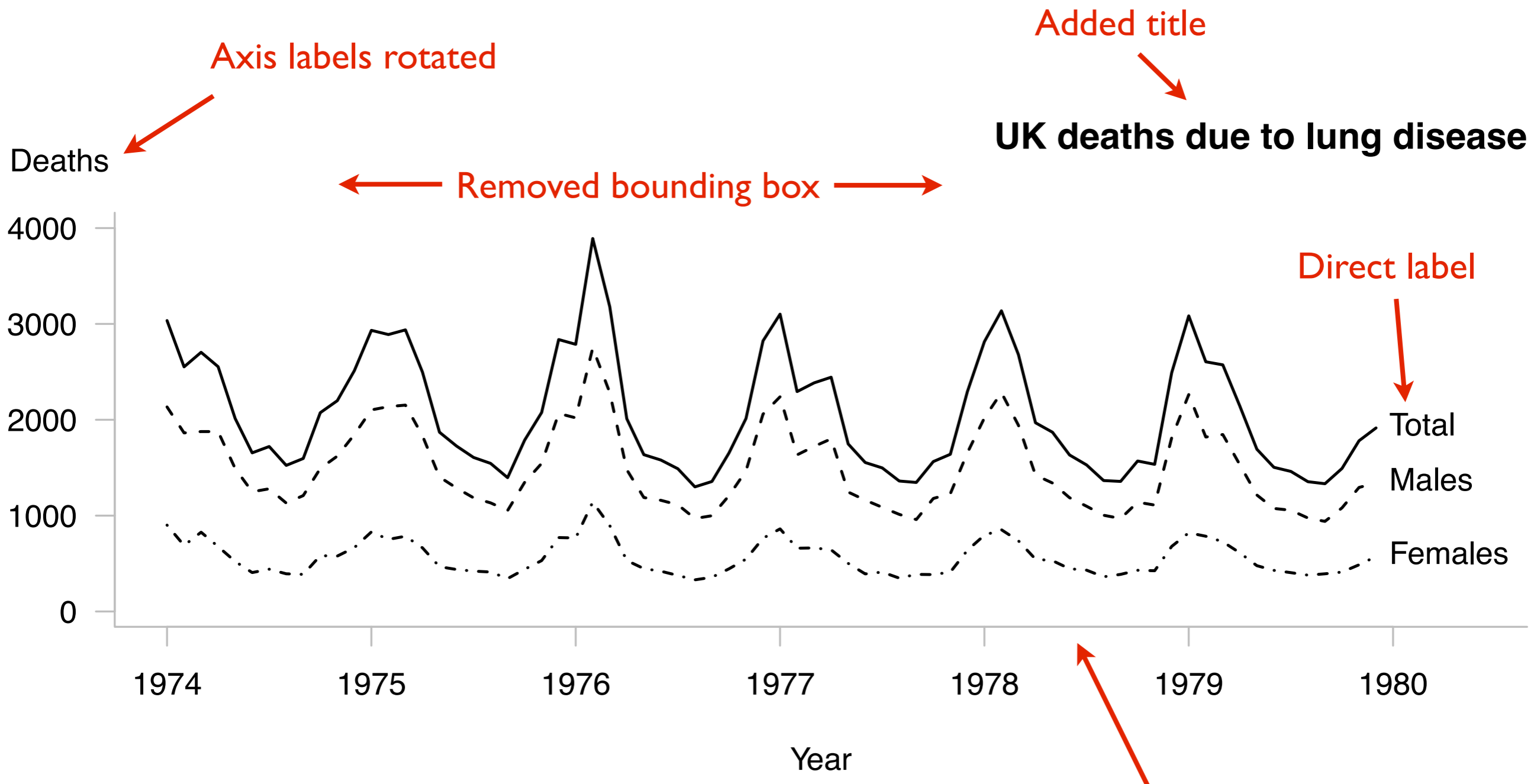
Heavier line

Removed figure caption

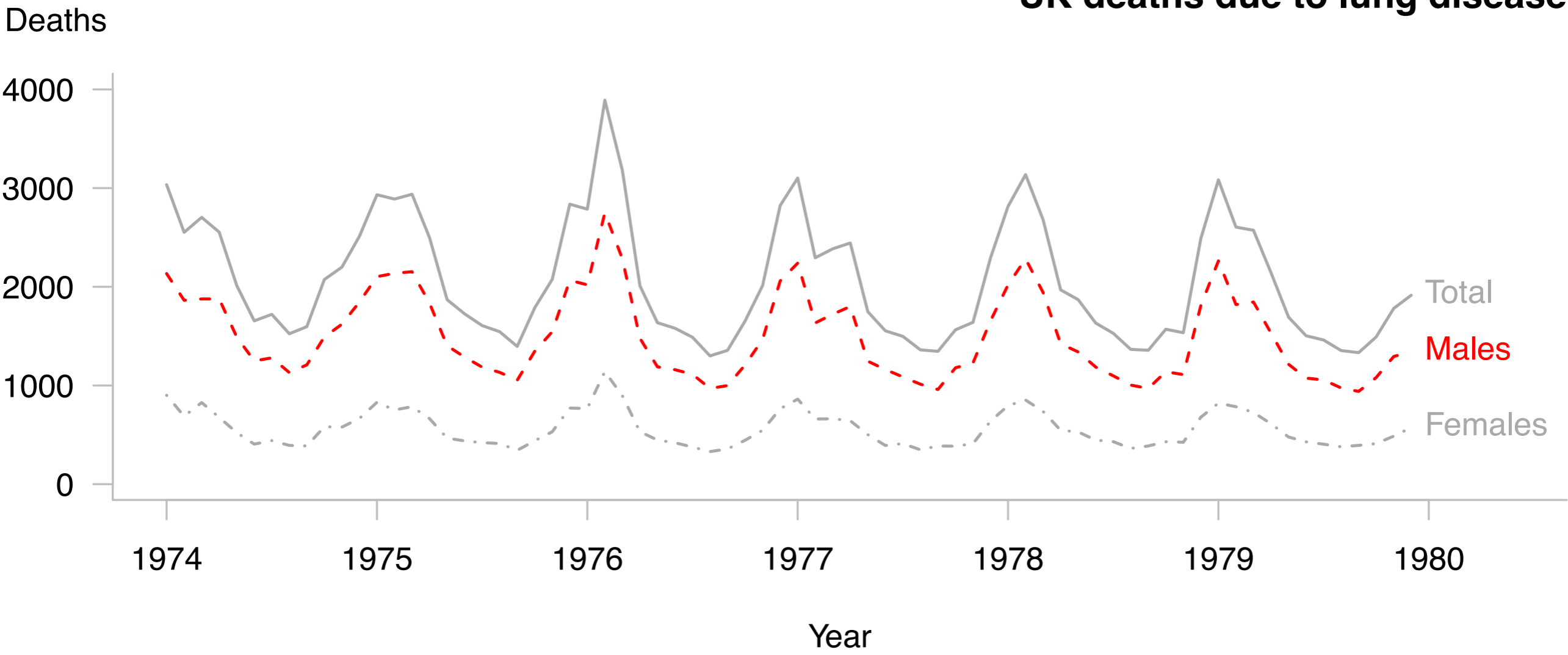
UK deaths due to lung disease

Deaths

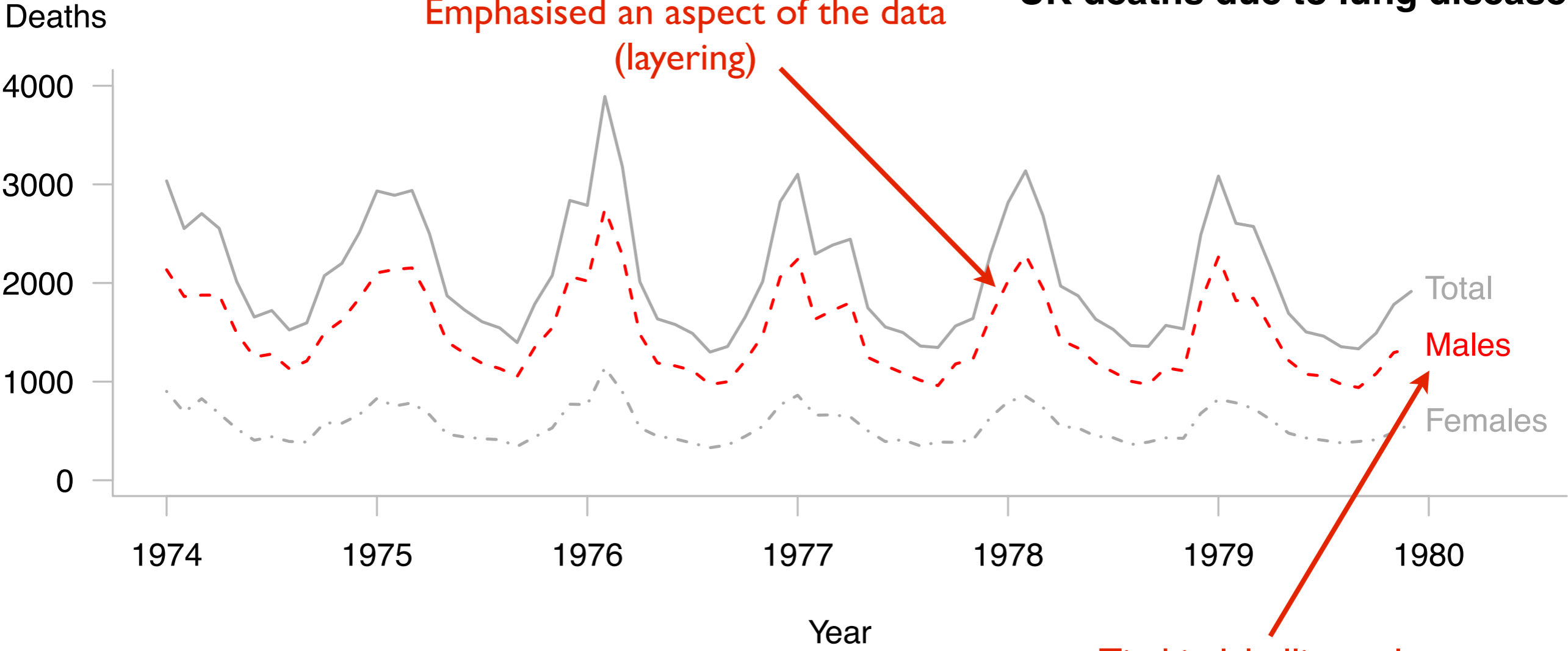




UK deaths due to lung disease



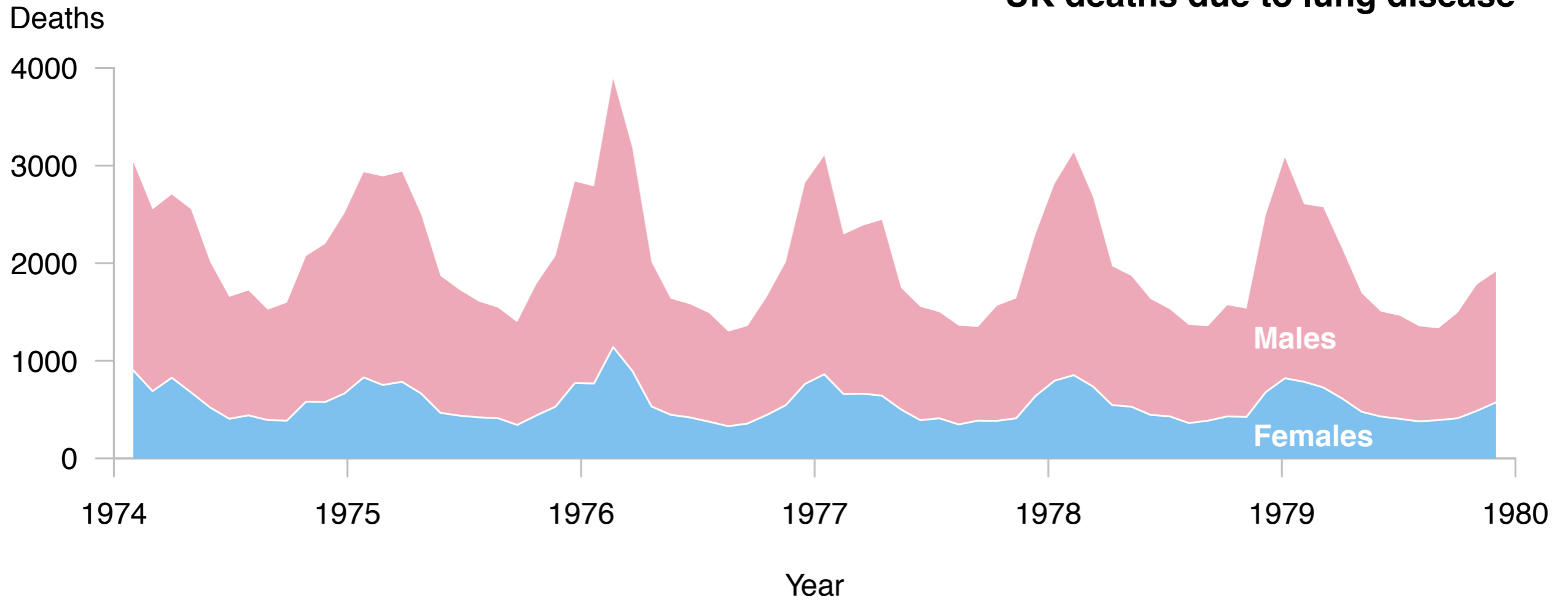
UK deaths due to lung disease



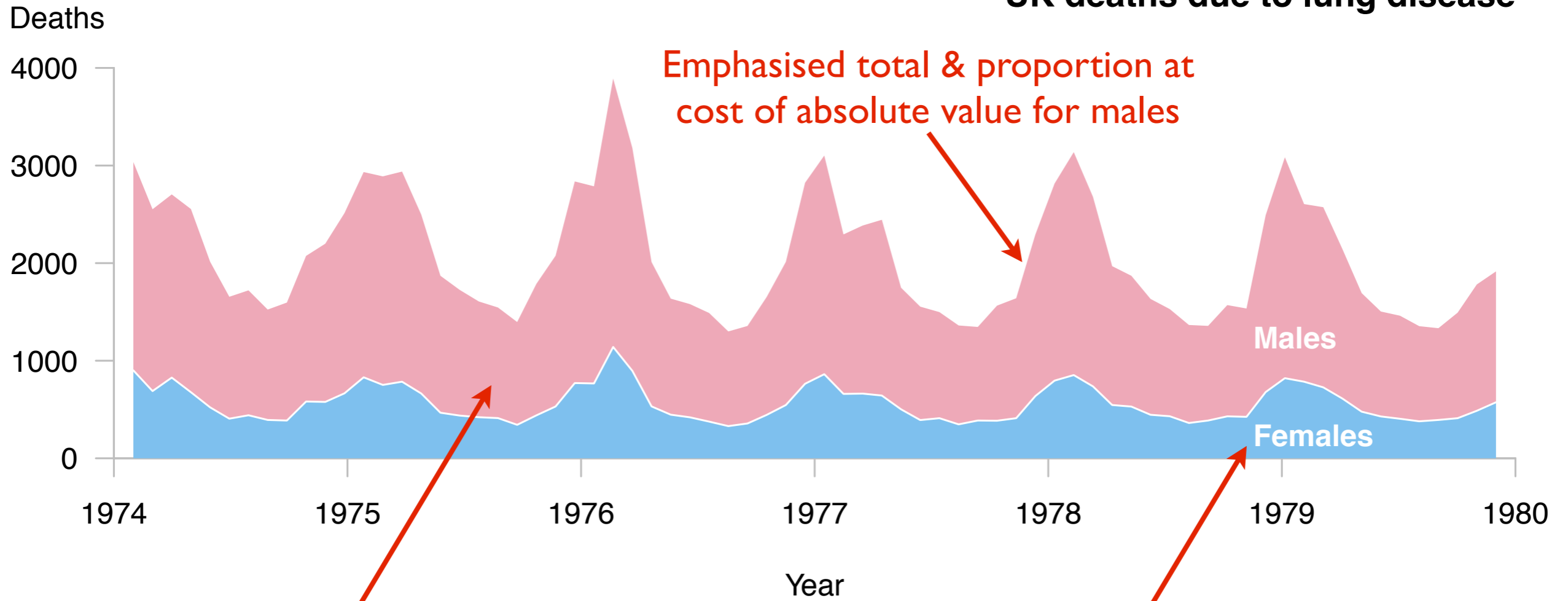
Emphasised an aspect of the data
(layering)

Tied in labelling colour

UK deaths due to lung disease



UK deaths due to lung disease



Emphasised total & proportion at cost of absolute value for males

Culturally appropriate colour scheme

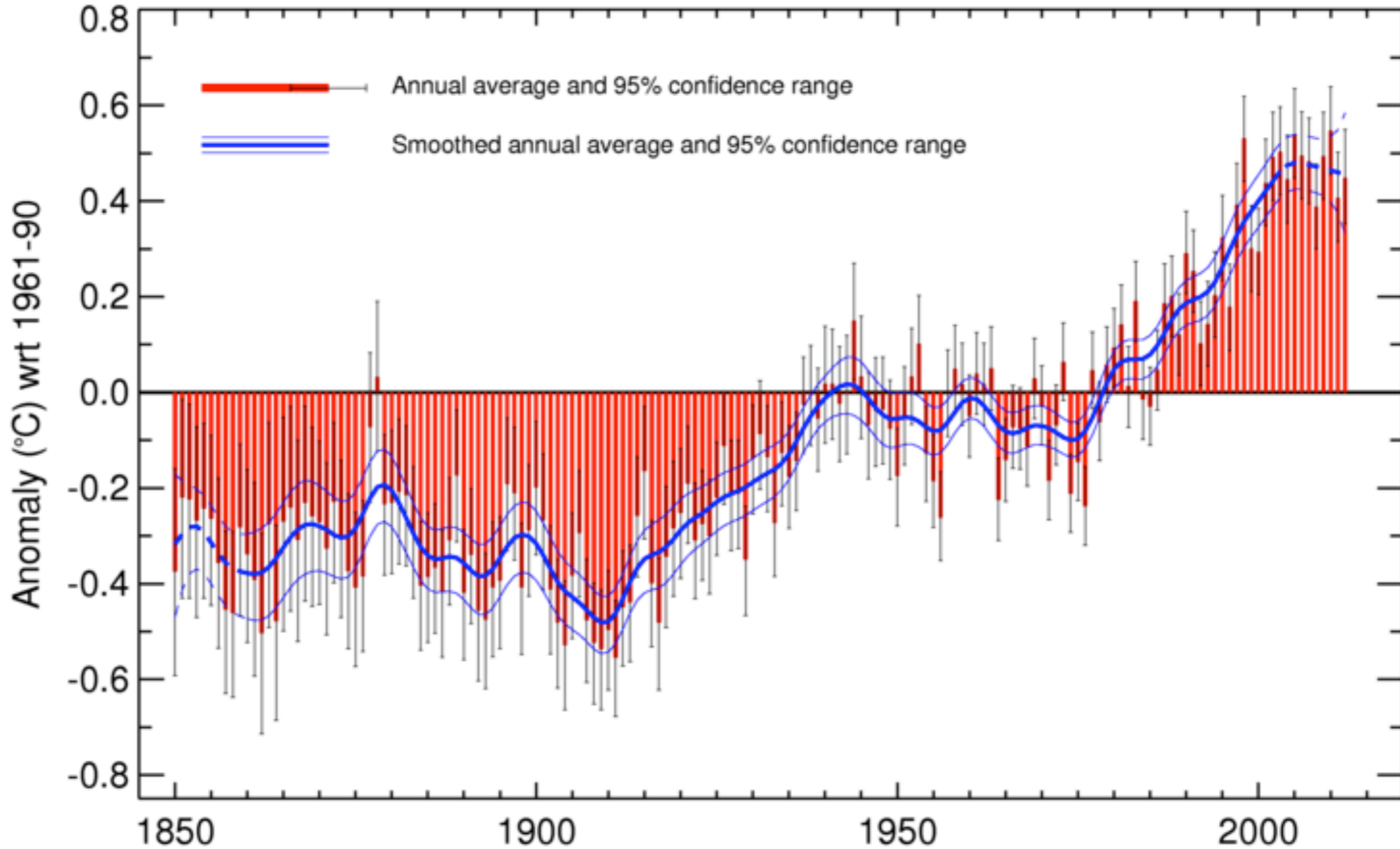
Contrasting direct labelling

Old Skool Bar



Global average temperature 1850-2012

Updated from Morice et al. 2012

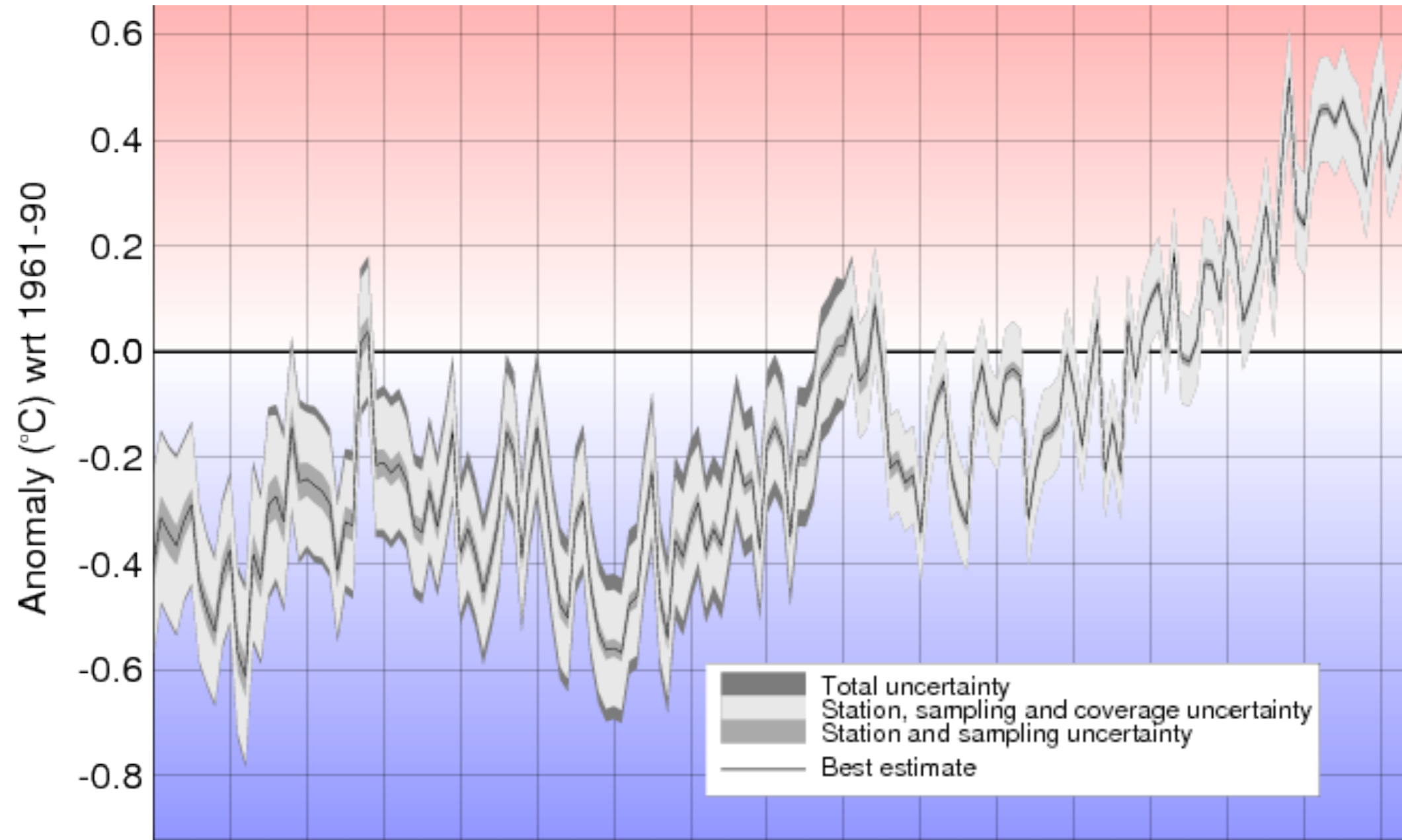


Met Office Hadley Centre

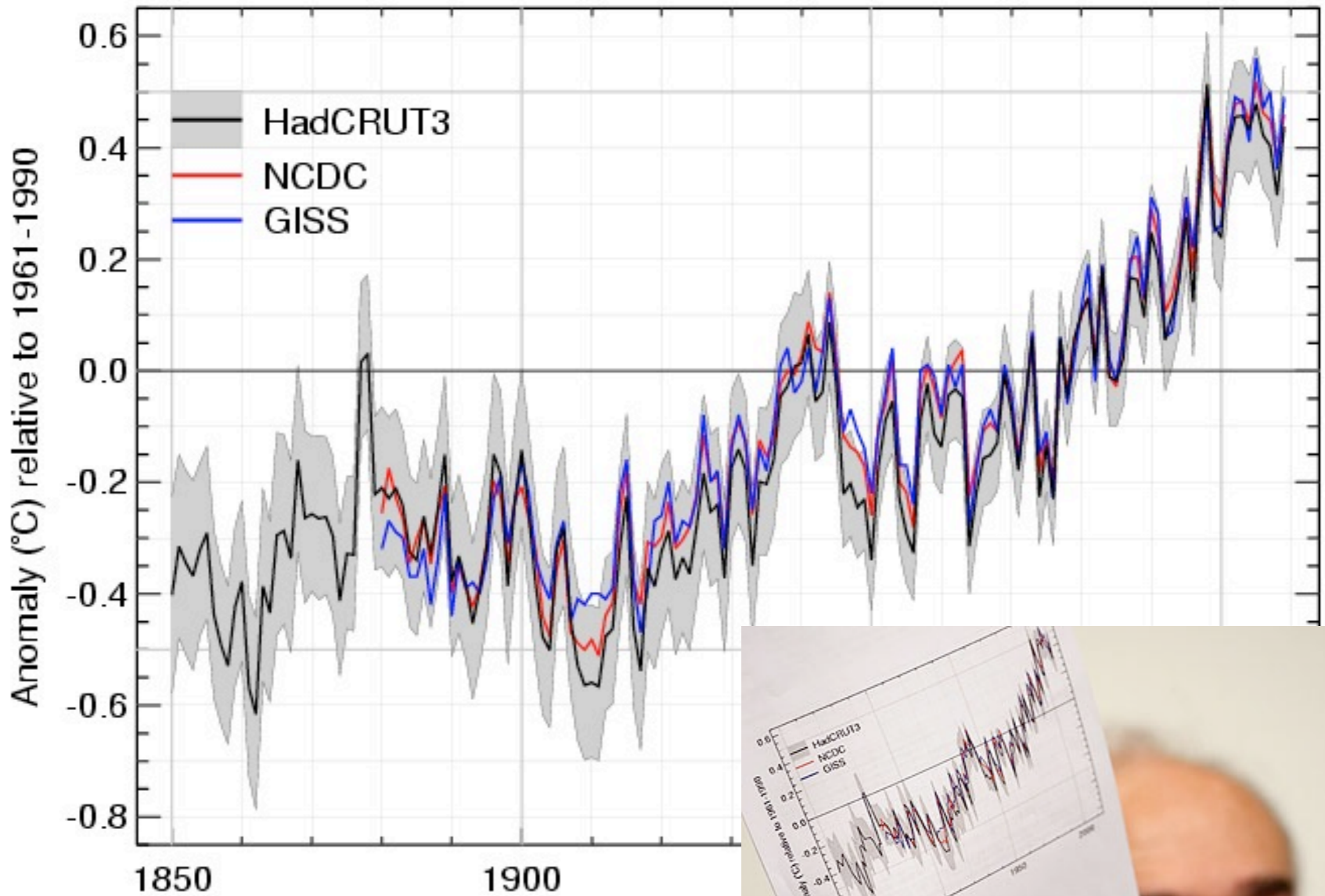
Source: www.metoffice.gov.uk/hadobs

Crown Copyright 2013

Middl Skool



L8 Middl Skool

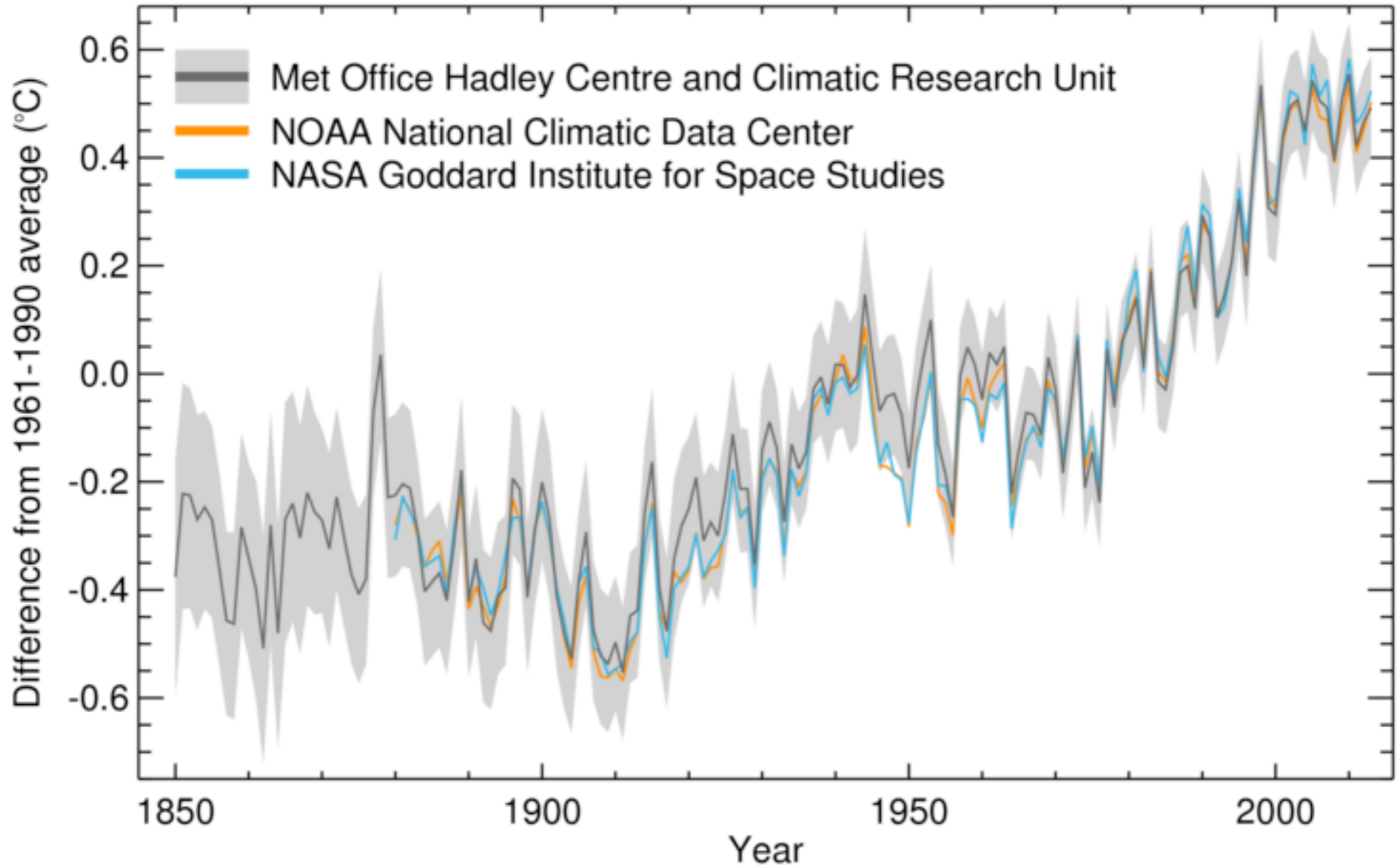


Michel Jarraud at Copenhagen

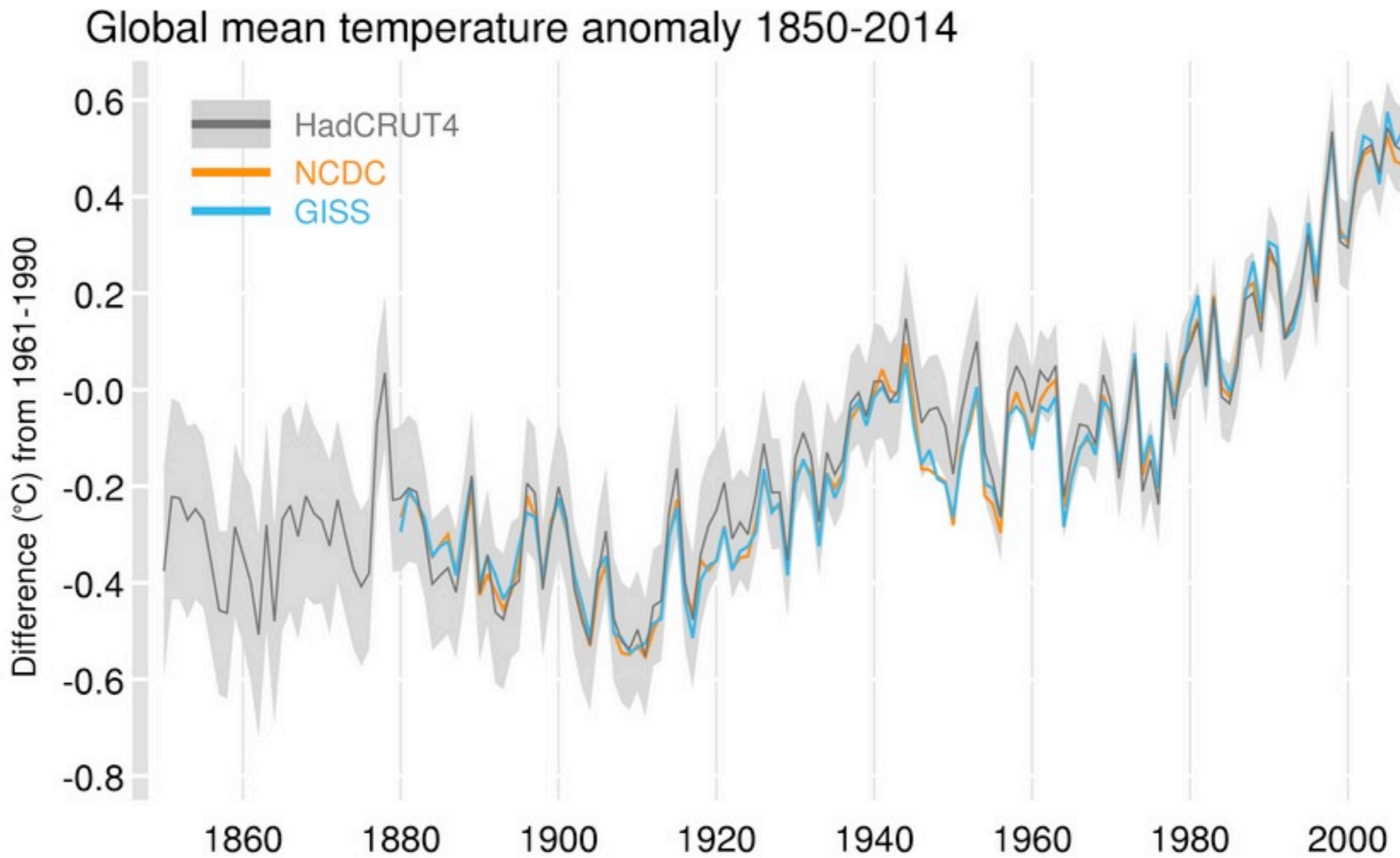
Nu Skool



Global average temperature anomaly (1850-2013)



Nu Nu Skool



Colour

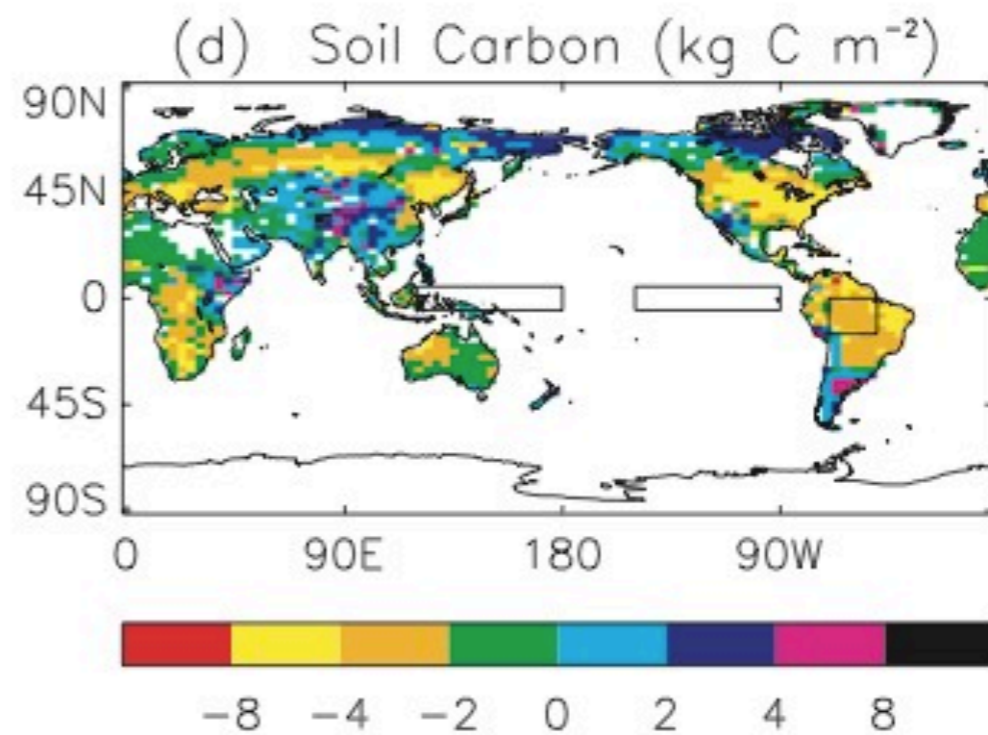
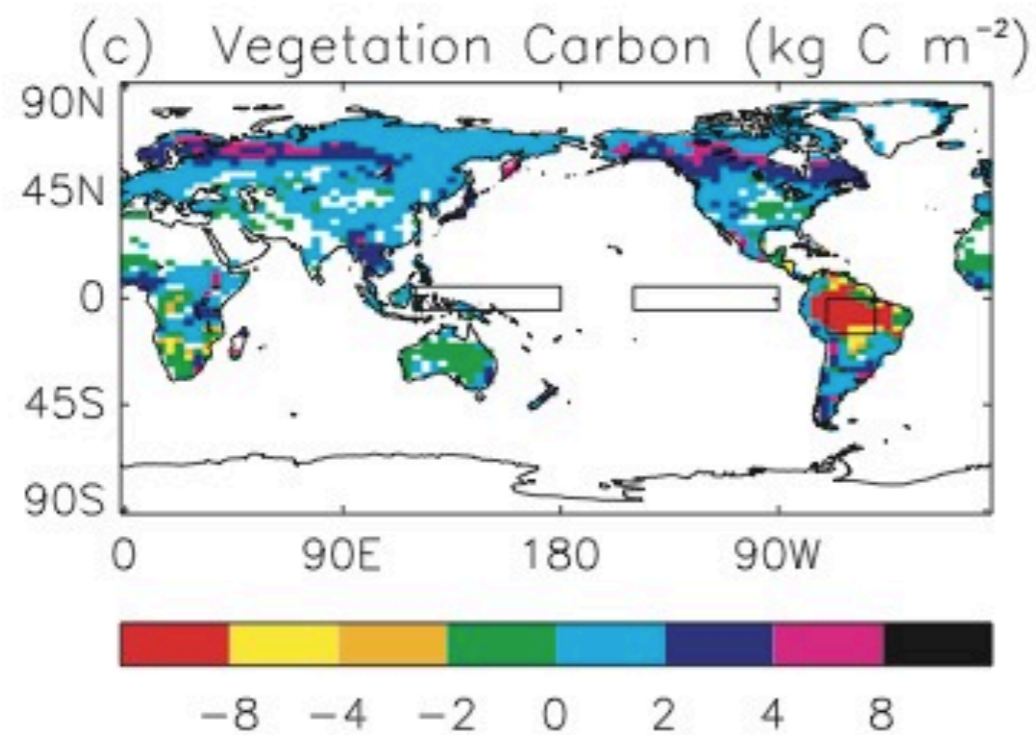
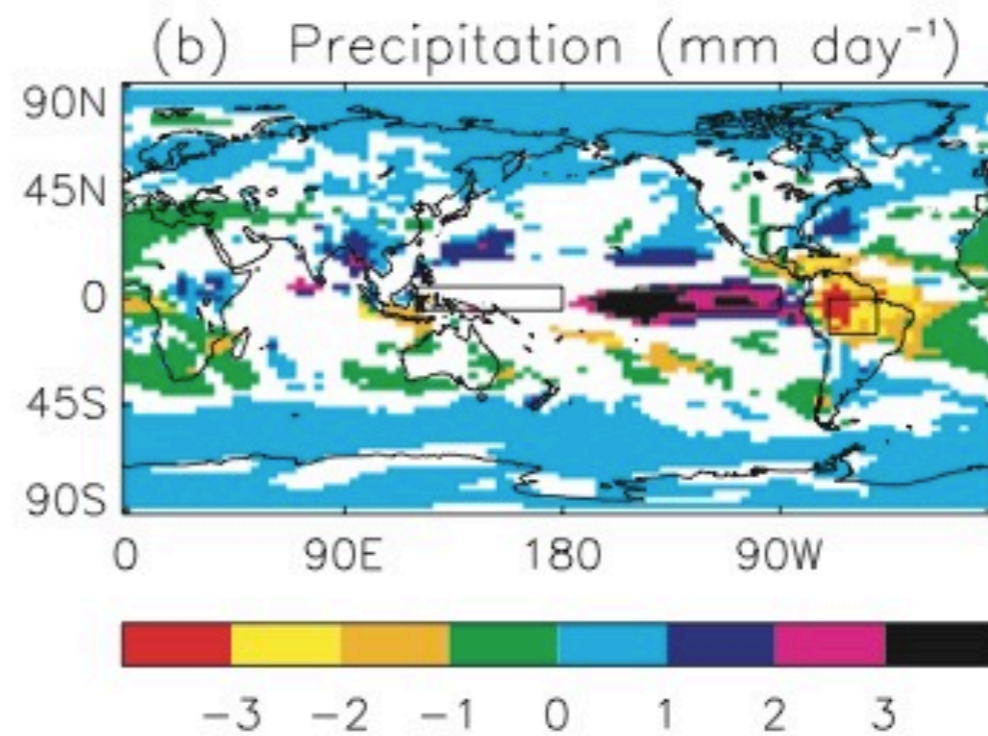
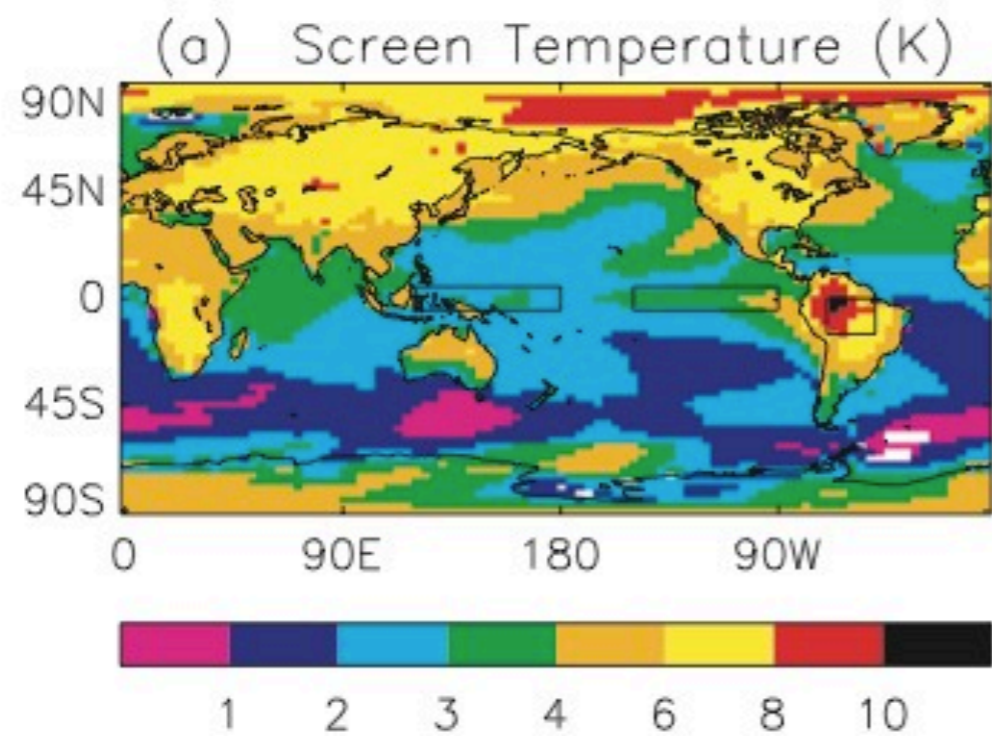


Fig. 4. Maps of changes in climate and land carbon storage over the 21st century from the fully coupled climate-carbon cycle projections. (a) Screen temperature, (b) precipitation, (c) vegetation carbon and (d) soil carbon. These maps were calculated as the differences between the means for the 2090s and the 1990s. Only areas for which the projected change is greater than 95% significant (according to a paired student t-test) are shown. In each map the box over South America represents the definition of Amazonia for the purposes of this study (70°W – 50°W , 15°S – 0°N), while the boxes over the Pacific show the NINO3 region (150°W – 90°W , 5°S – 5°N), and the western Equatorial Pacific region as used in Fig. 5 (120°E – 180°E , 5°S – 5°N)

¹ Hadley Centre for Climate Prediction, Research, Met Office, Exeter, UK

² Department of Meteorology, University of Reading, Reading, Berks, UK

³ Centre for Ecology and Hydrology, Wallingford, Oxon, UK

Amazonian forest dieback under climate-carbon cycle projections for the 21st century

P. M. Cox¹, R. A. Betts¹, M. Collins², P. P. Harris³,
C. Huntingford³, and C. D. Jones¹

With 10 Figures

Received March 28, 2003; revised August 16, 2003; accepted October 9, 2003

Published online April 27, 2004 © Springer-Verlag 2004

Summary

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[Amazonian forest dieback under climate-carbon cycle projections for the 21st century](#)

[PM Cox, RA Betts, M Collins, PP Harris... - Theoretical and Applied ..., 2004 - Springer](#)

... to derive the equilibrium vegetation state consistent with the model's pre- industrial climate (Cox et al ... et al., 1999), which has implications for the timing of Amazonian dieback (Huntingford et al., 2004). ... 2). The modelled mean air tem- perature over the **Amazon** box (25.90 C) is ...

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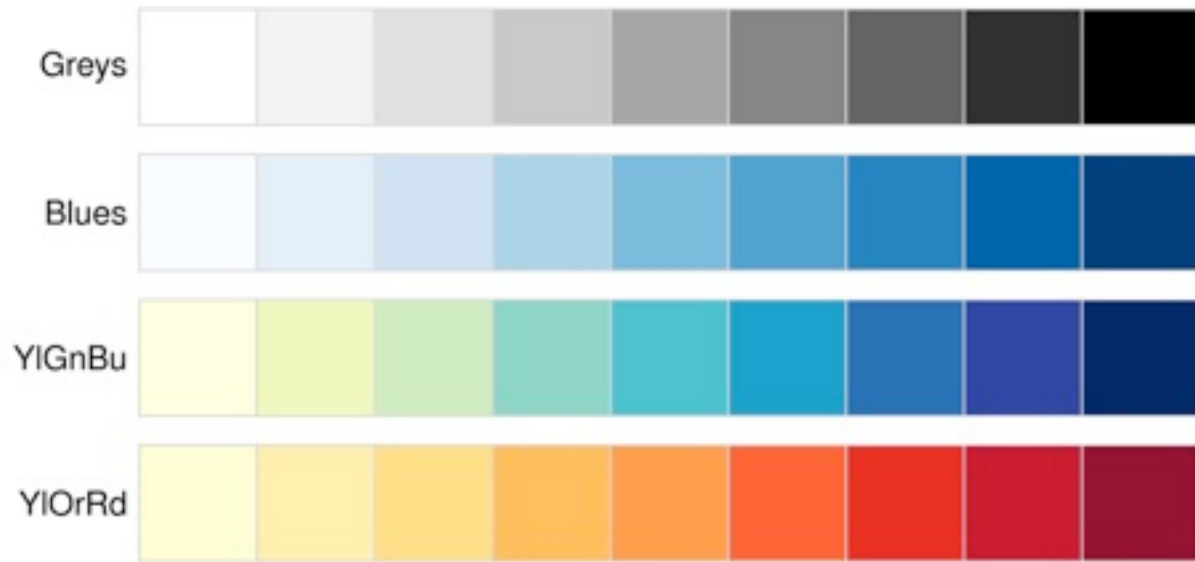
... to derive the equilibrium vegetation state consistent with the model's pre-industrial climate (Cox et al ... et al., 1999), which has implications for the timing of Amazonian dieback (Huntingford et al., 2004). ... 2). The modelled mean air temperature over the Amazon box (25.90 C) is ...

[Cited by 582 Related articles All 16 versions Cite Save More](#)

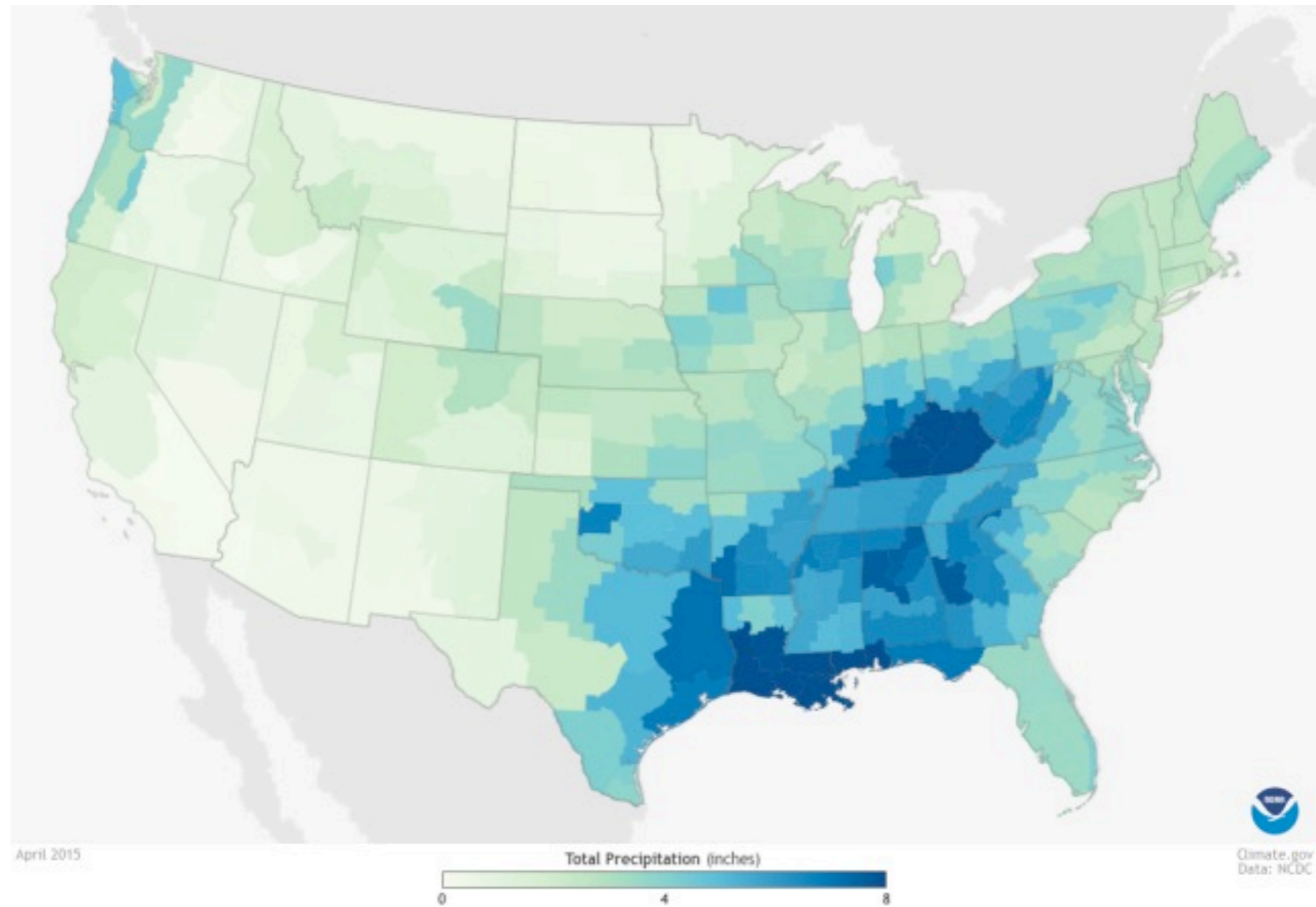
How to choose a palette?

- Ensure a perceptual relationship between the colour scale and the data. (e.g. equal steps in data are perceived as equal steps in colour space)
- Understand audience cultural expectations
- Make it accessible

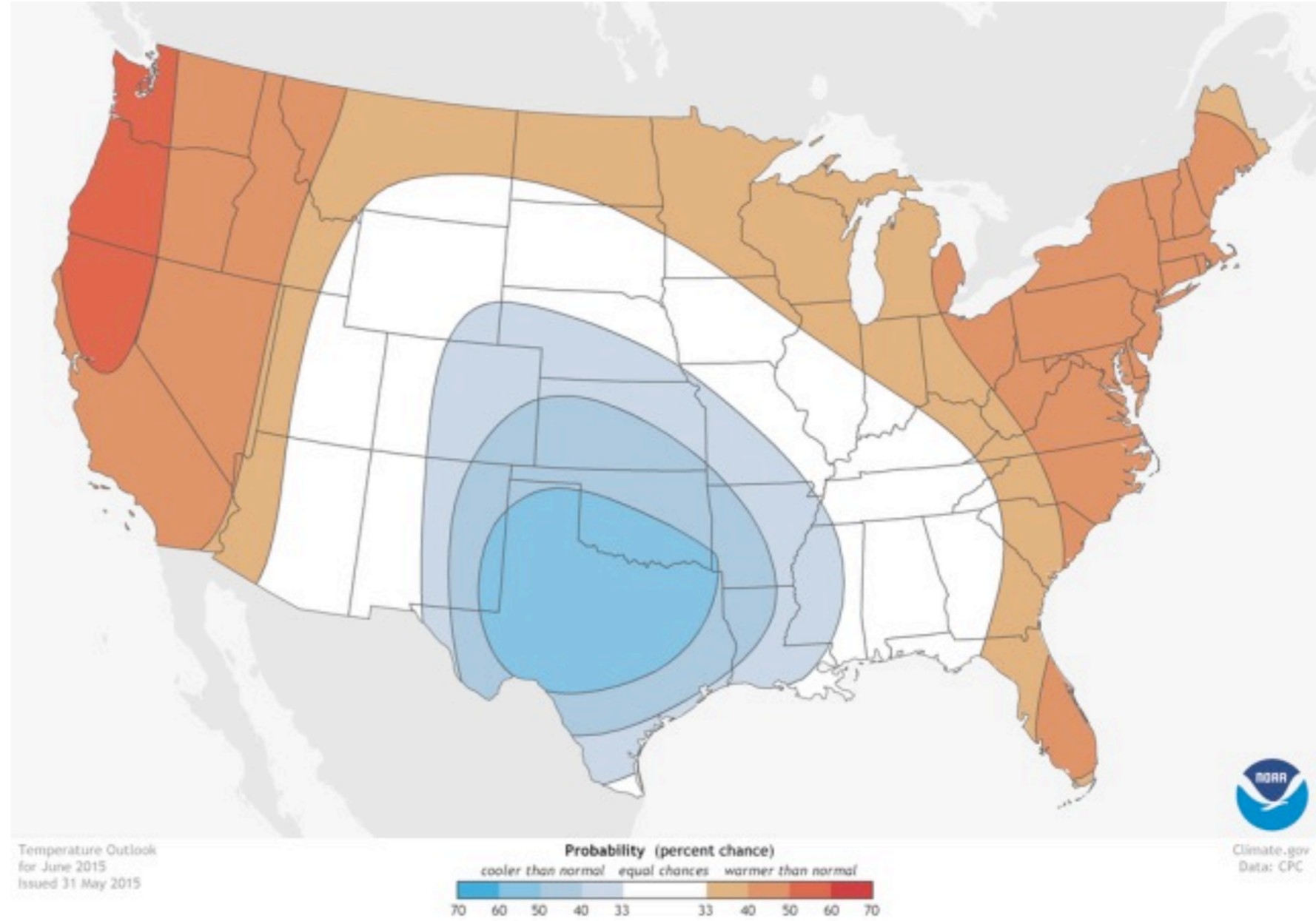
Sequential palettes



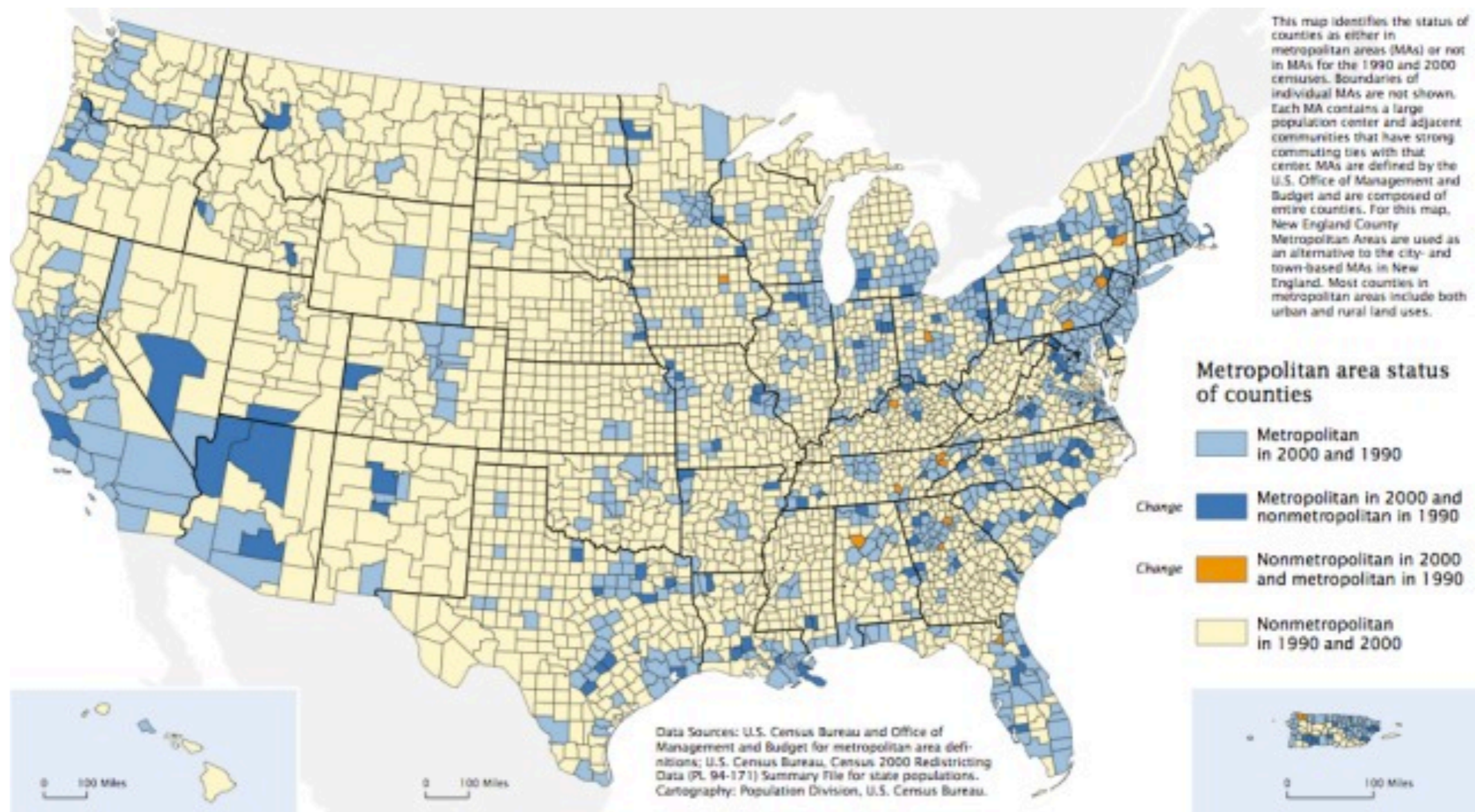
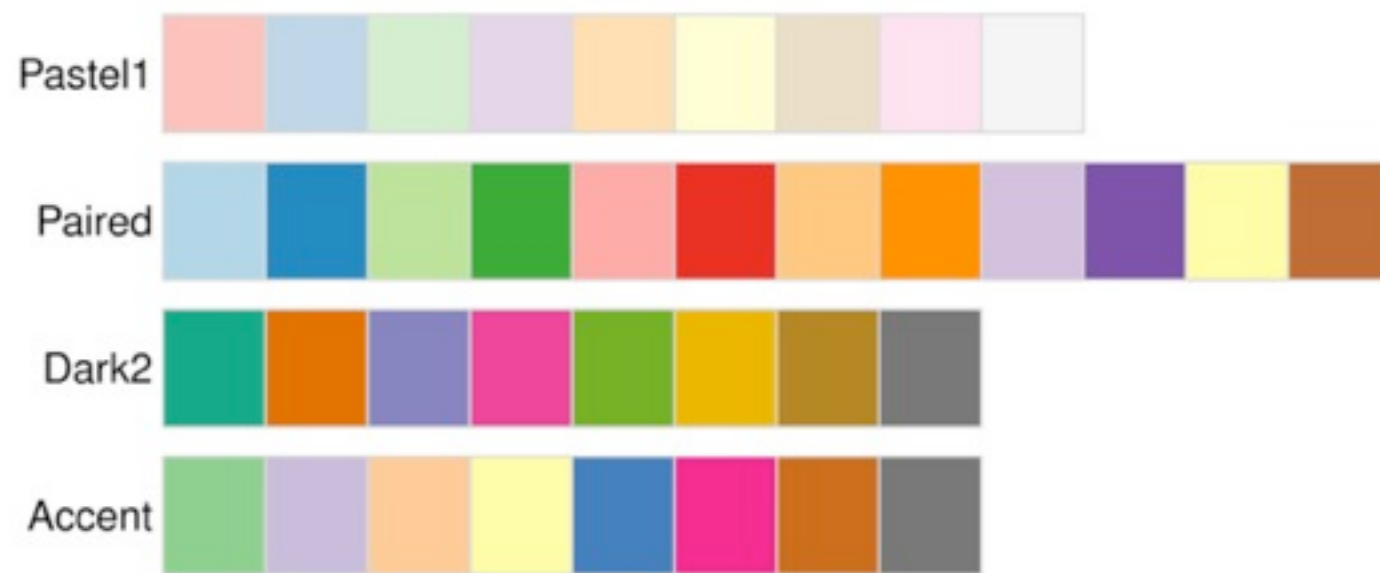
In general, darker = 'more'



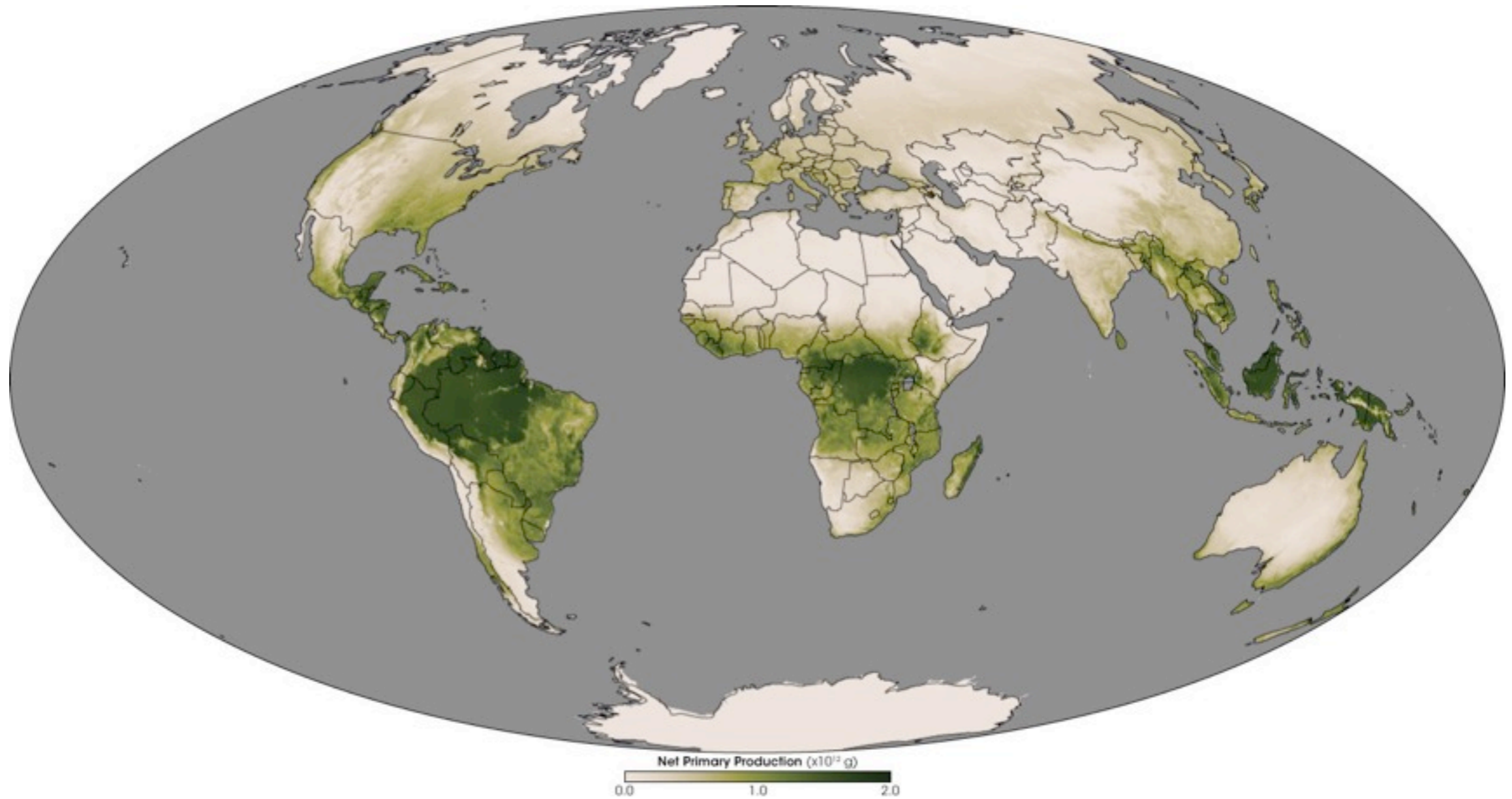
Diverging palettes



Categorical palettes



Net Primary Production, NASA



Matches cultural expectation
(plant growth = green)

We need to talk about Rainbow



Fig. 1. The rainbow color map. Know thy enemy.

#endrainbow

The end of the rainbow

Posted on [November 18, 2014](#) by [Ed Hawkins](#)

An open letter to the climate science community

[Ed Hawkins](#), [Doug McNeall](#), [David Stephenson](#), [Jonny Williams](#) & [Dave Carlson](#)

Dear colleagues,

This is a heartfelt plea.

A plea to you all to help rid climate science of colour scales that can distort, mislead and confuse. Colour scales that are often illegible to those who are colour blind.

The main culprit is, of course, the 'rainbow':



We have all likely [used it](#), and we have all certainly seen it – presentations, posters, papers, blogs and news articles full of figures with similar colour scales.

However, the most commonly used rainbow colour scales can [distort perceptions](#) of data and [alter meaning](#) by creating [false boundaries](#) between values. There are [numerous blogs and published papers](#) from visualisation experts illustrating these issues. In one example, changing to a non-rainbow scale even [improved accuracy of heart disease diagnoses](#).



License: [Climate Lab Book](#) blog pages have a Creative Commons Attribution-Share Alike 3.0 Unported License.

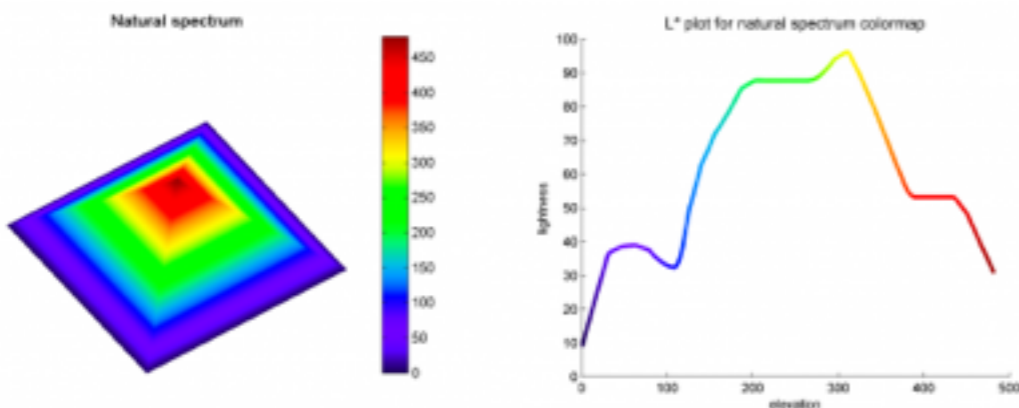
Post Categories

[Arctic](#) [Atlantic](#) [climate](#)
[sensitivity](#) [communication](#) [crops](#)
[emergence](#) [energy balance](#)
[extremes](#) [GCMs](#) [history](#)
[hysteresis](#) [IPCC AR5](#) [journals](#)
[MOC](#) [observations](#)
[precipitation](#)
[predictability](#)
[projections](#) [sea-ice](#)
[SSTs](#)
[temperature](#)
[uncertainty](#)
[variability](#)
[visualisation](#)
[weather](#)

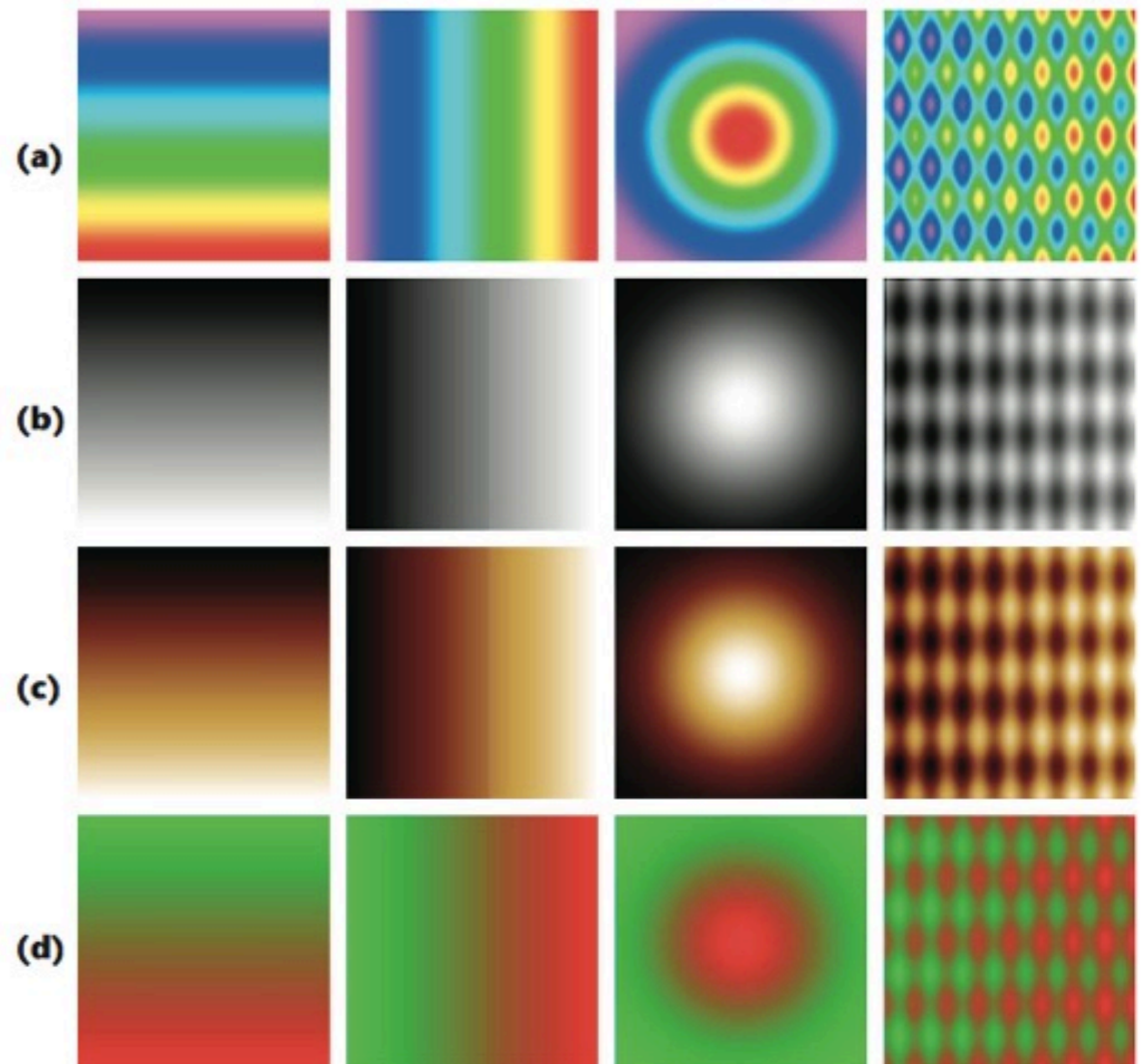
Recent Comments

- [Deep Climate](#) on [Comparing CMIP5 & observations](#)
- [Spinning the 'warmest year'](#) | [Climate Etc.](#) on [Updates to](#)

I. Rainbow palette misses features where they exist, and introduces them where they do not.

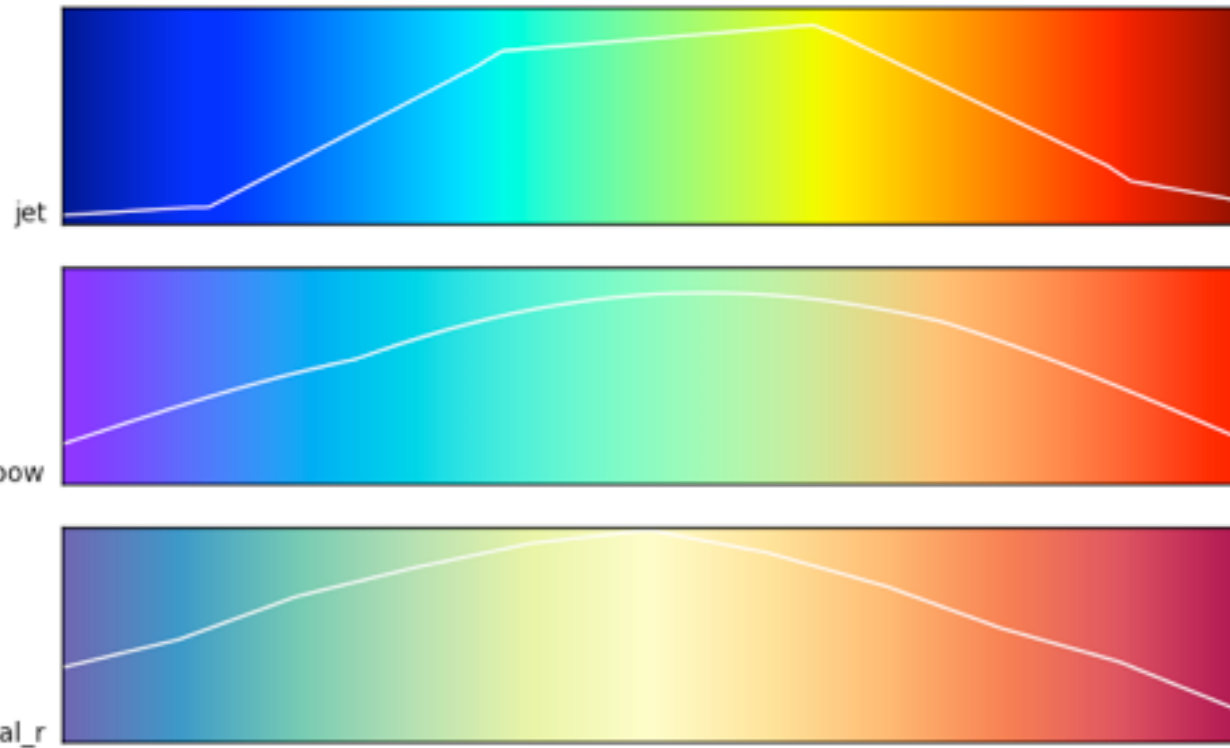


<https://mycarta.wordpress.com/2012/05/12/the-rainbow-is-dead-long-live-the-rainbow-part-1/>



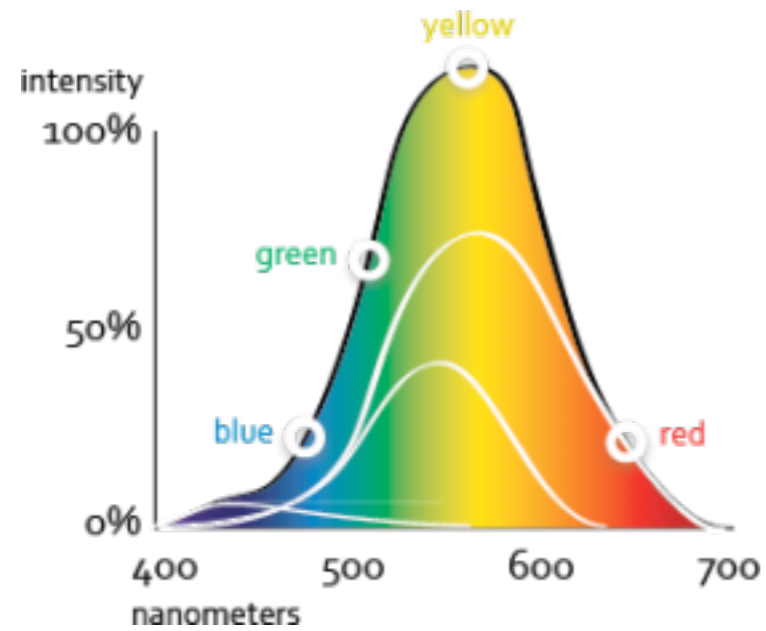
3 Four data sets visualized with (a) rainbow, (b) gray-scale, (c) black-body radiation, and (d) isoluminant green–red color maps. Apparent sharp gradients in the data in (a) are revealed as rainbow color map artifacts, not data features, by comparing this row with the same data viewed using the other color maps. Conversely, the sharp gradient found at the center of the second data set (see the second column) shown in the gray-scale and black-body radiation (and to a lesser extent, the isoluminant green–red) images is not found in the corresponding image with the rainbow color map.

Borland & Taylor (2007) Rainbow Colormap (still) considered harmful



2. Yellow is special

PUTTING IT
ALL TOGETHER



<http://blog.visual.ly/the-use-of-yellow-in-data-design/>



http://old.provizsports.com/media/catalog/category/cycling_13.jpg

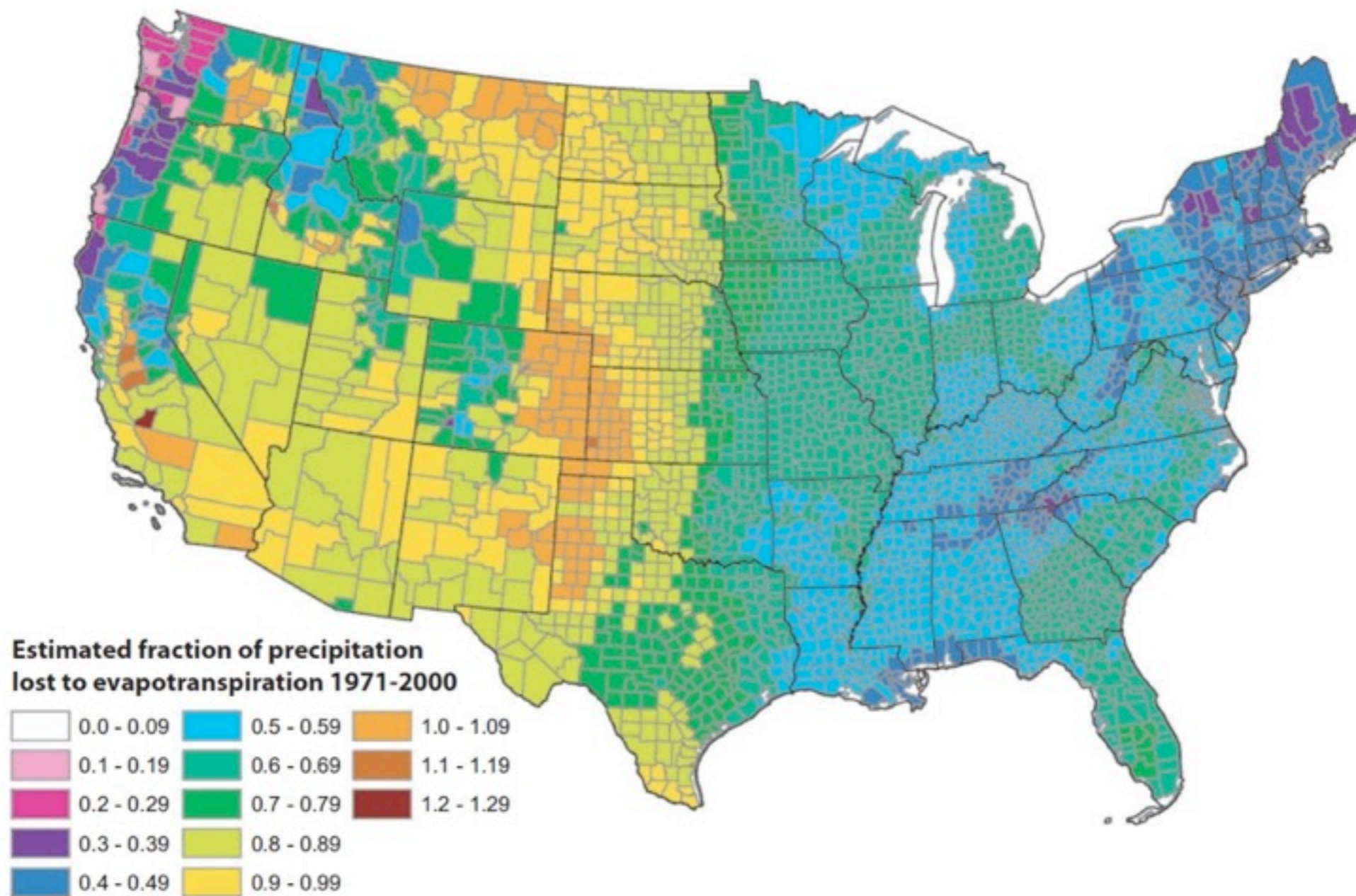
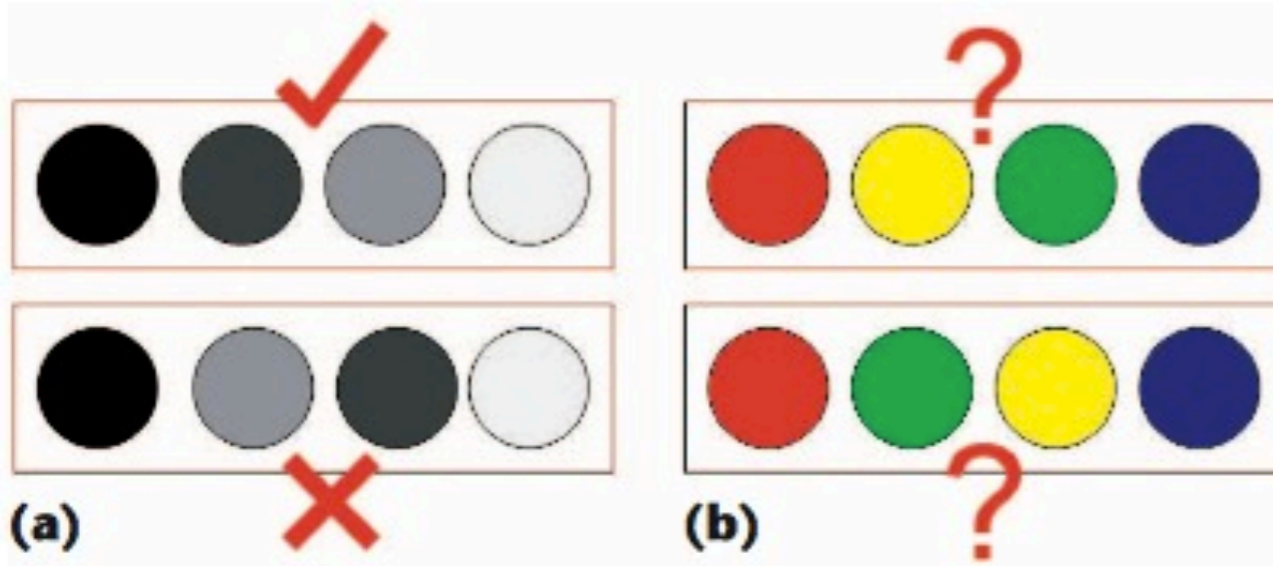
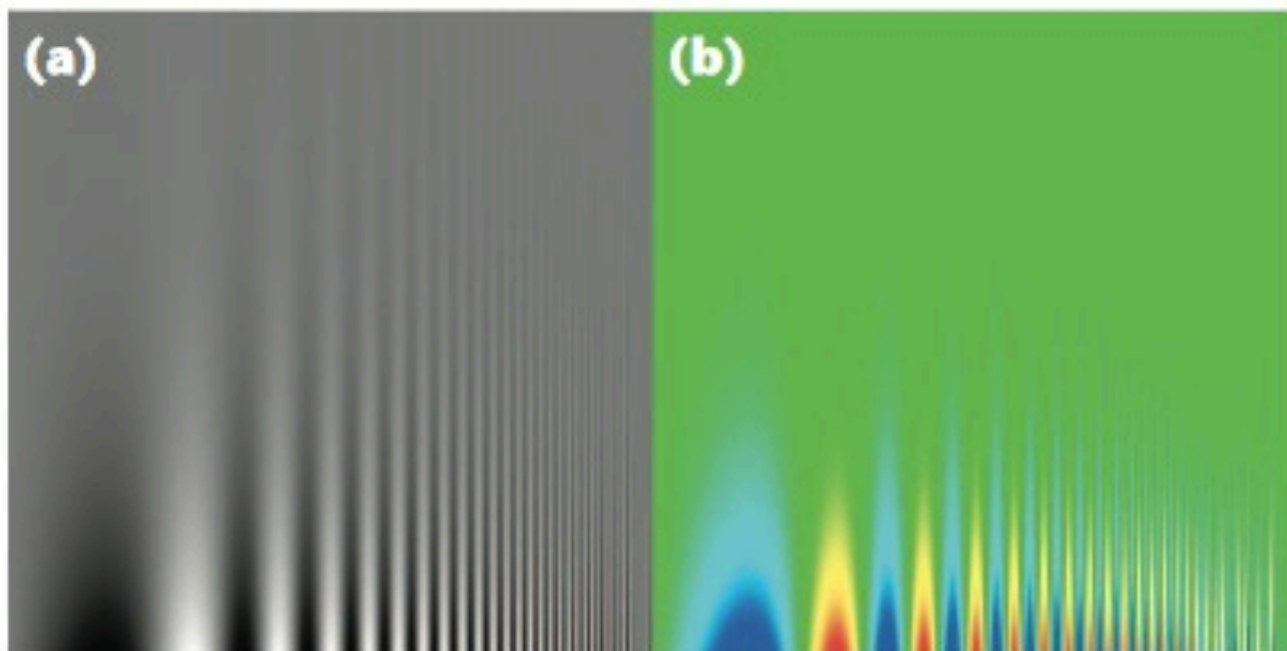


FIGURE 13. Estimated Mean Annual Ratio of Actual Evapotranspiration (ET) to Precipitation (P) for the Conterminous U.S. for the Period 1971-2000. Estimates are based on the regression equation in Table 1 that includes land cover. Calculations of ET/P were made first at the 800-m resolution of the PRISM climate data. The mean values for the counties (shown) were then calculated by averaging the 800-m values within each county. Areas with fractions >1 are agricultural counties that either import surface water or mine deep groundwater.



1 Perceptual ordering. (a) We can easily place the gray paint chips in order based on perception, (b) but cannot do this with the colored chips.



2 Spatial contrast sensitivity function. Frequency increases to the right and contrast increases toward the bottom of both images in the figure. We can see detail at much lower contrast in the (a) luminance-varying gray-scale image than with the (b) rainbow color map.

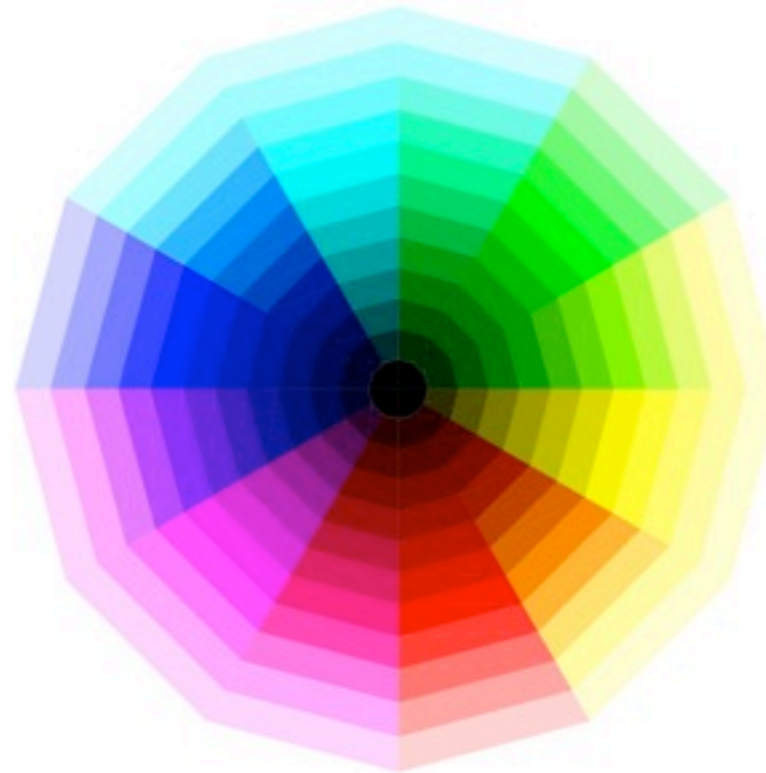
3. There is no unique intuitive perceptual ordering

4. Surprisingly, they can mask fine detail

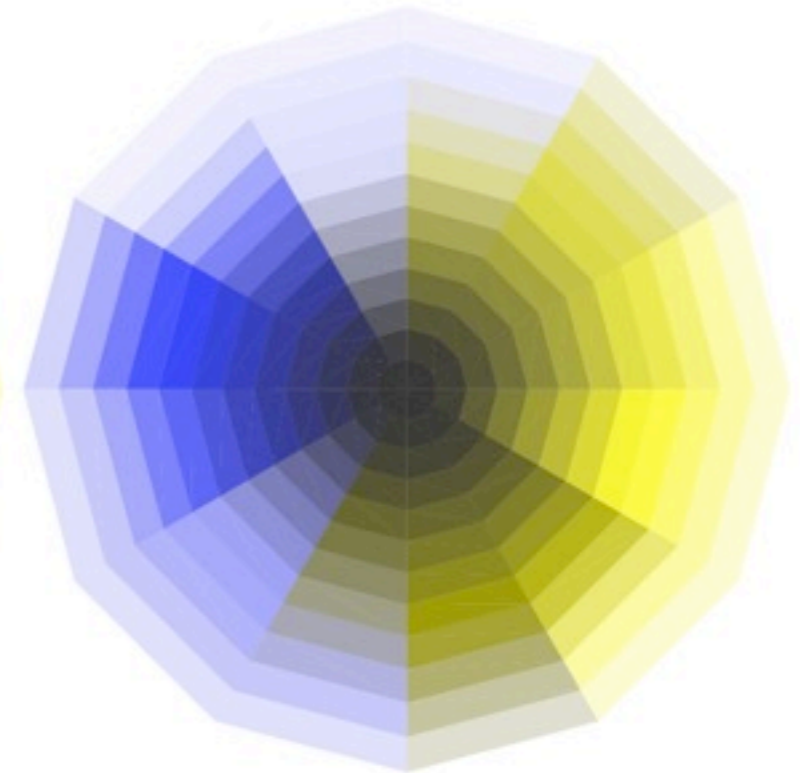
Borland & Taylor (2007) Rainbow Colormap (still) considered harmful

5. They are difficult or impossible to read if you are colourblind (8% males 0.5% females)

Colour Wheel

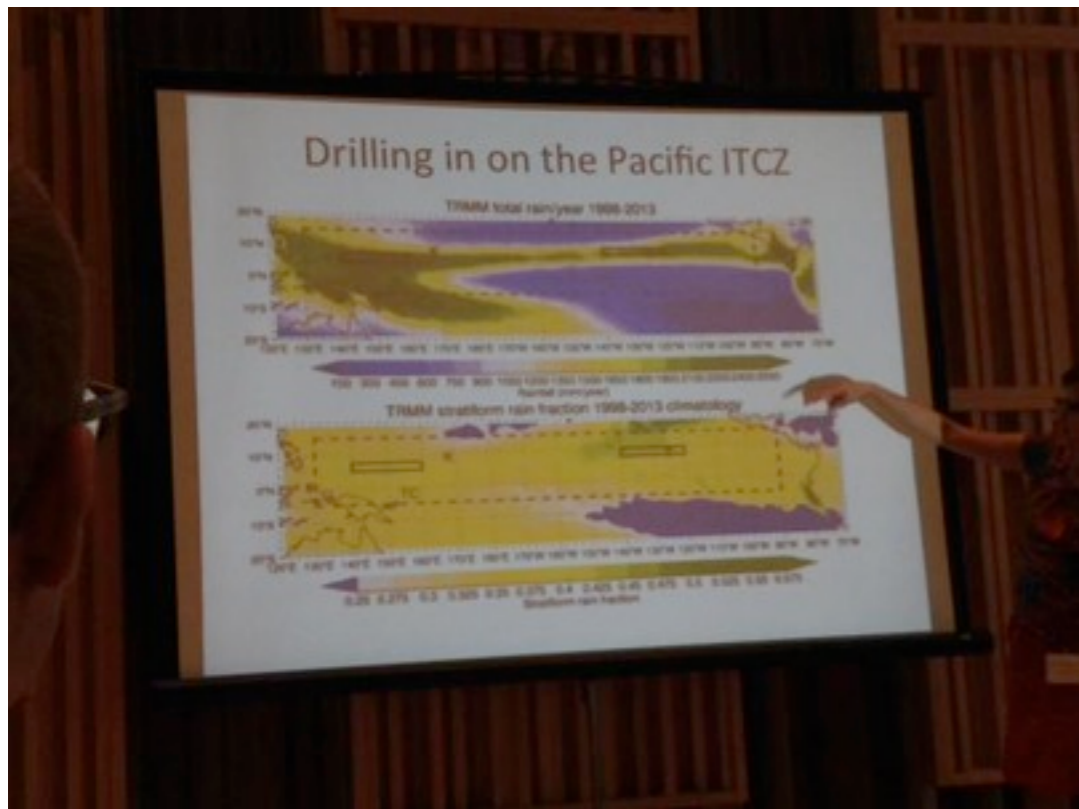


Normal colour vision

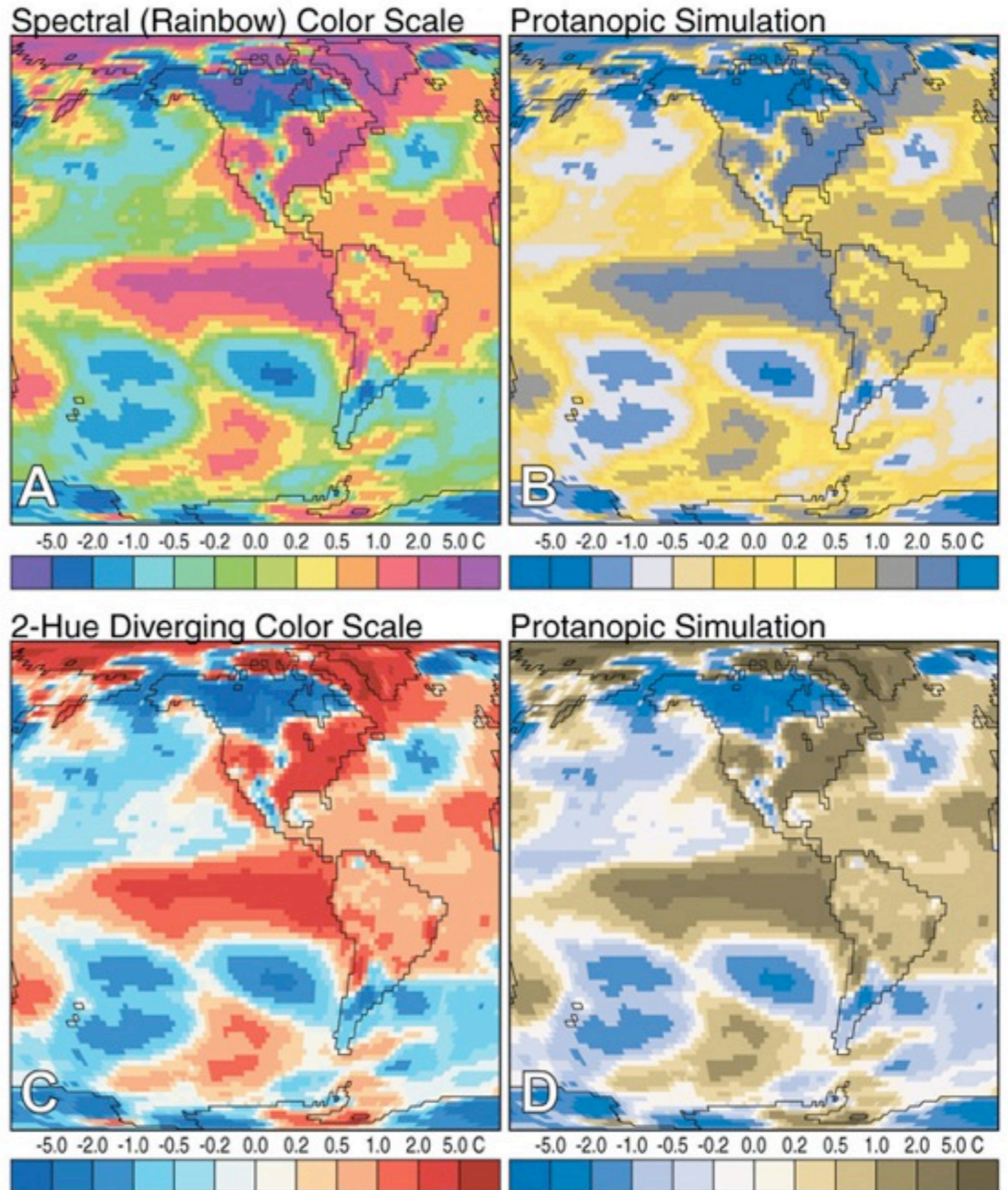


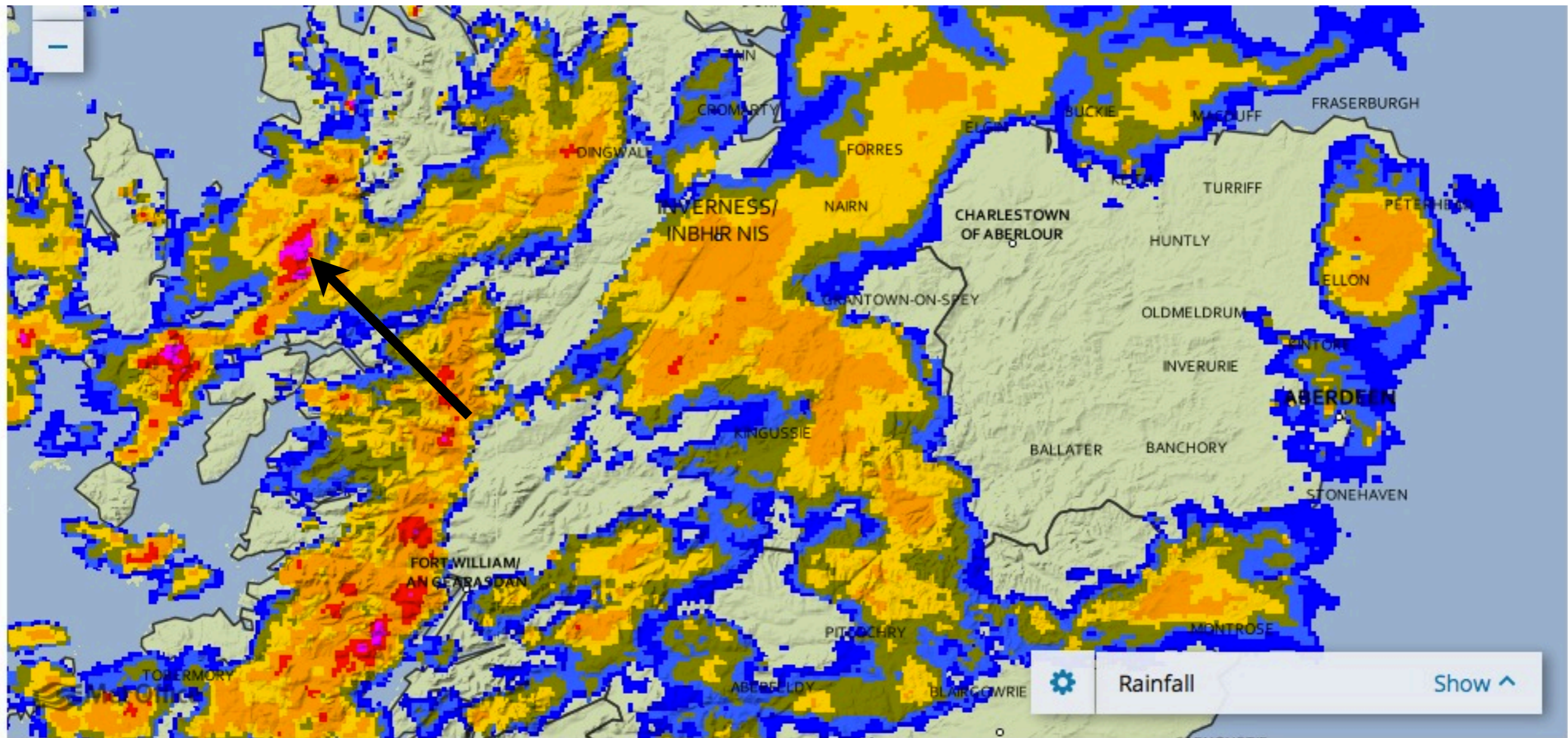
Simulation of severe deuteranopia

5. They are difficult or impossible to read if you are colourblind (8% males 0.5% females)



Pic from Julia Hargreaves @julesberry





▶ 1x >>

1145 Wed

Issued at: 1145 on Wed 10 Dec 2014

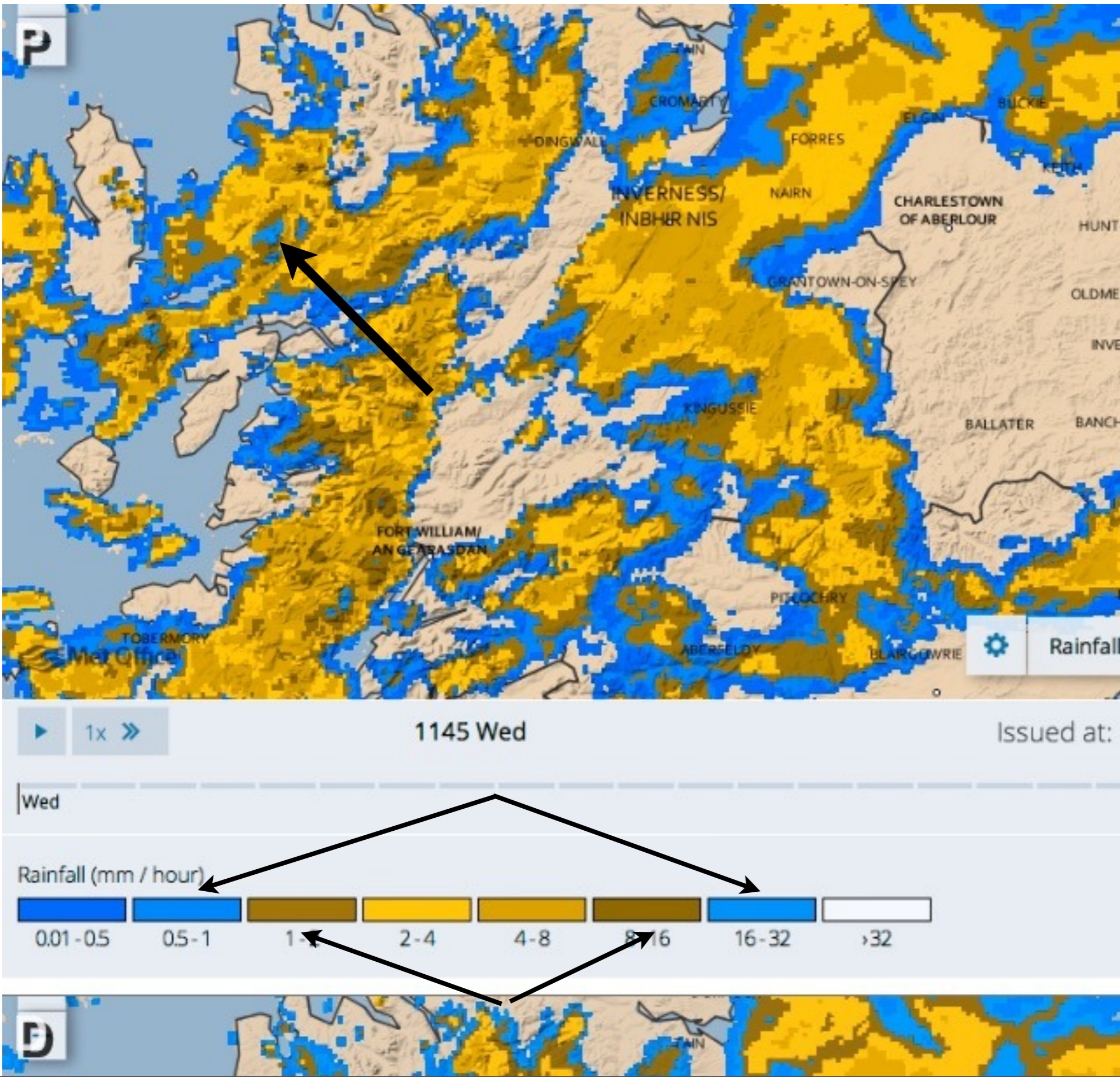
Wed

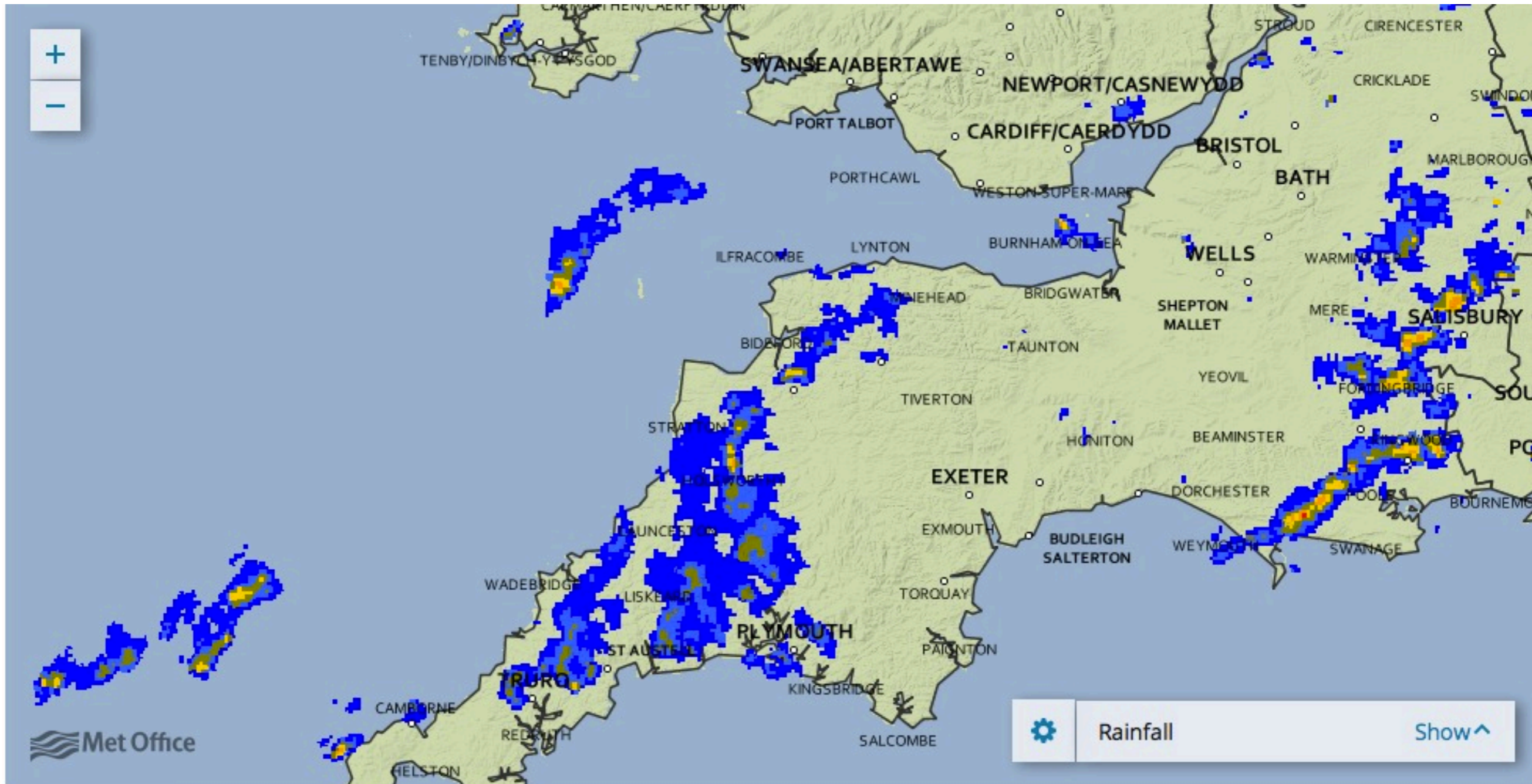
Rainfall (mm / hour)



Met Office rain radar

Protanope colourblindness simulation with CVsimulator





▶ 1x »

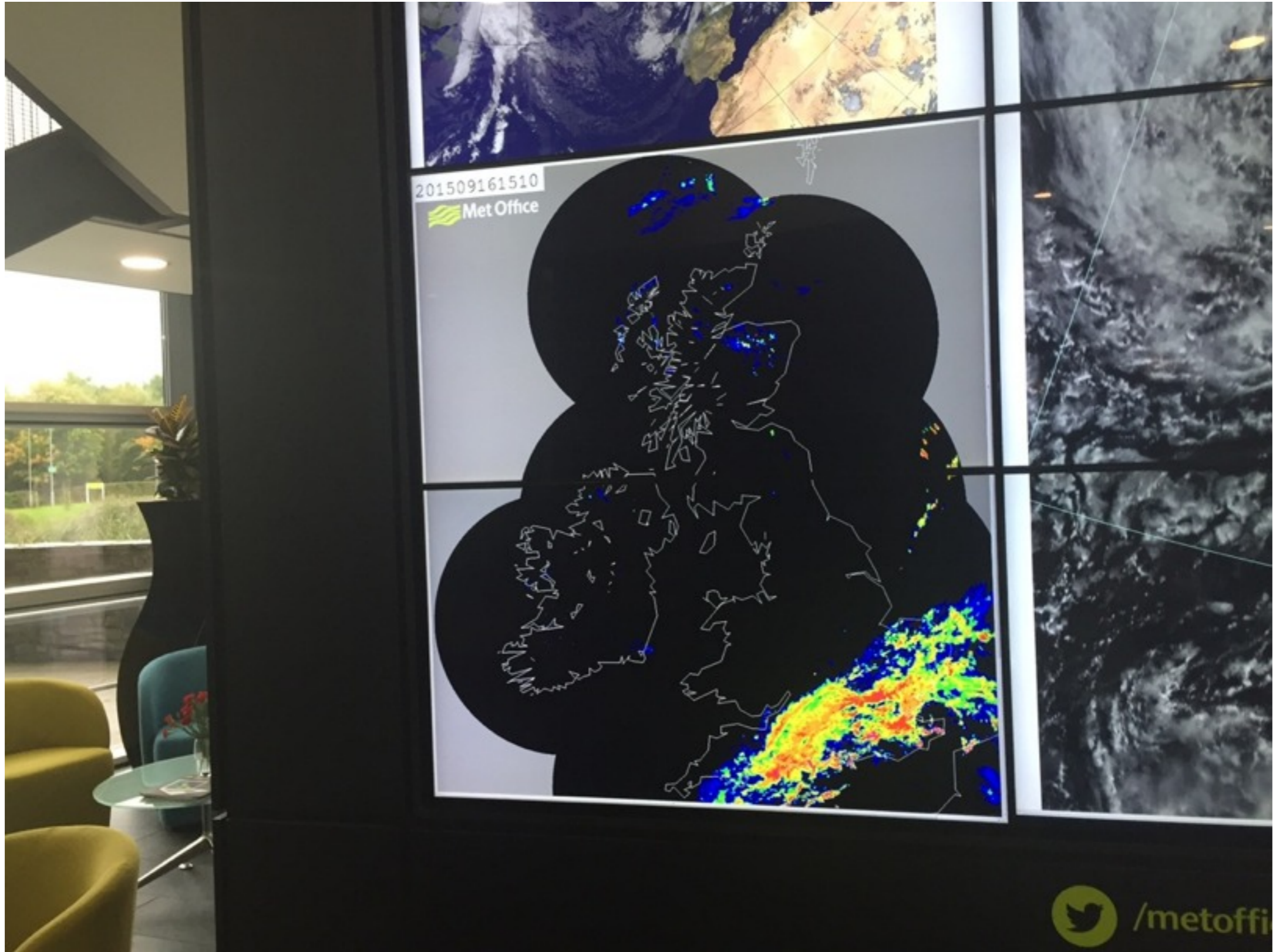
1400 Thu

Issued at: 1400 on Thu 24 Sep 2015

Thu

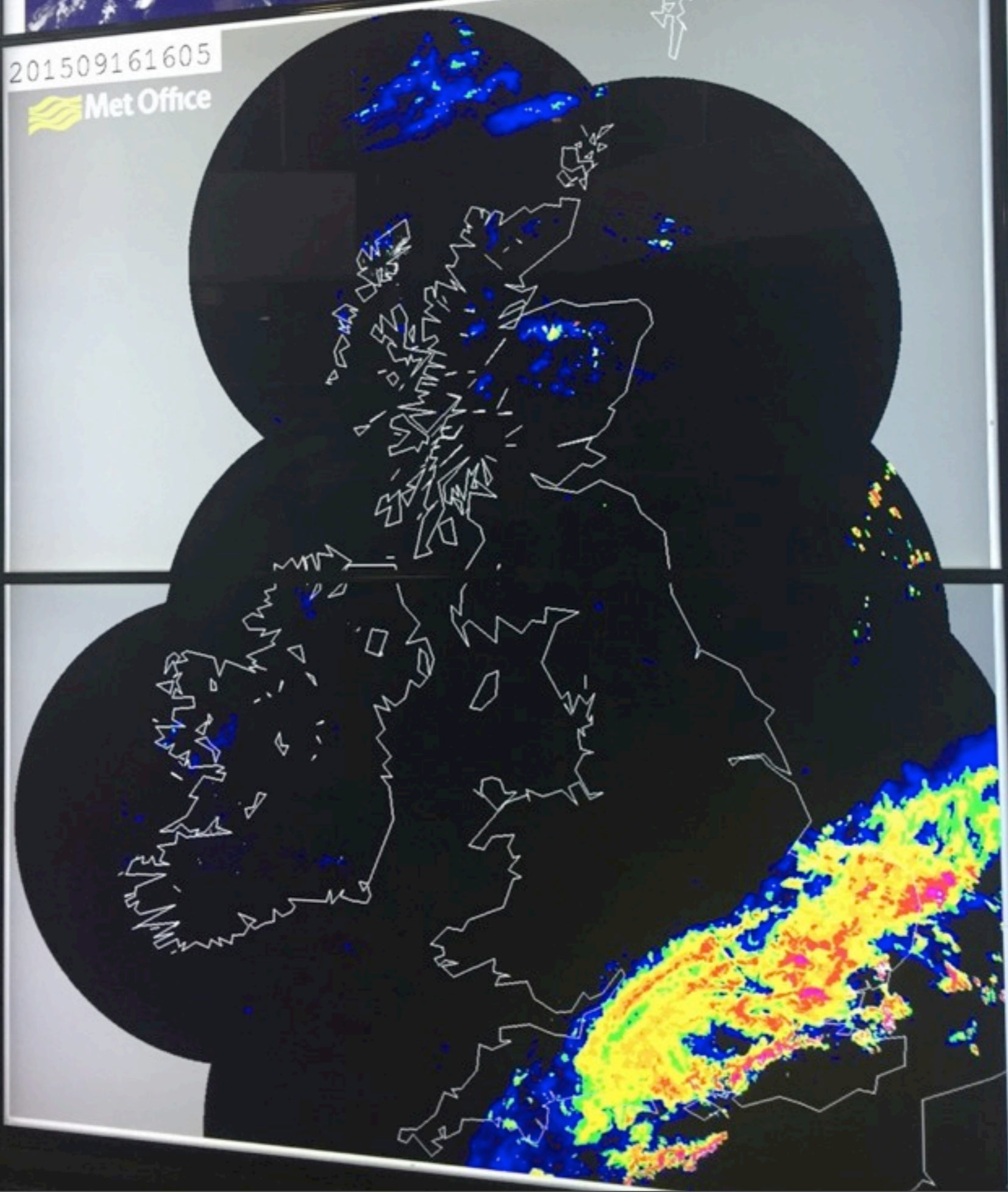
Rainfall (mm / hour)



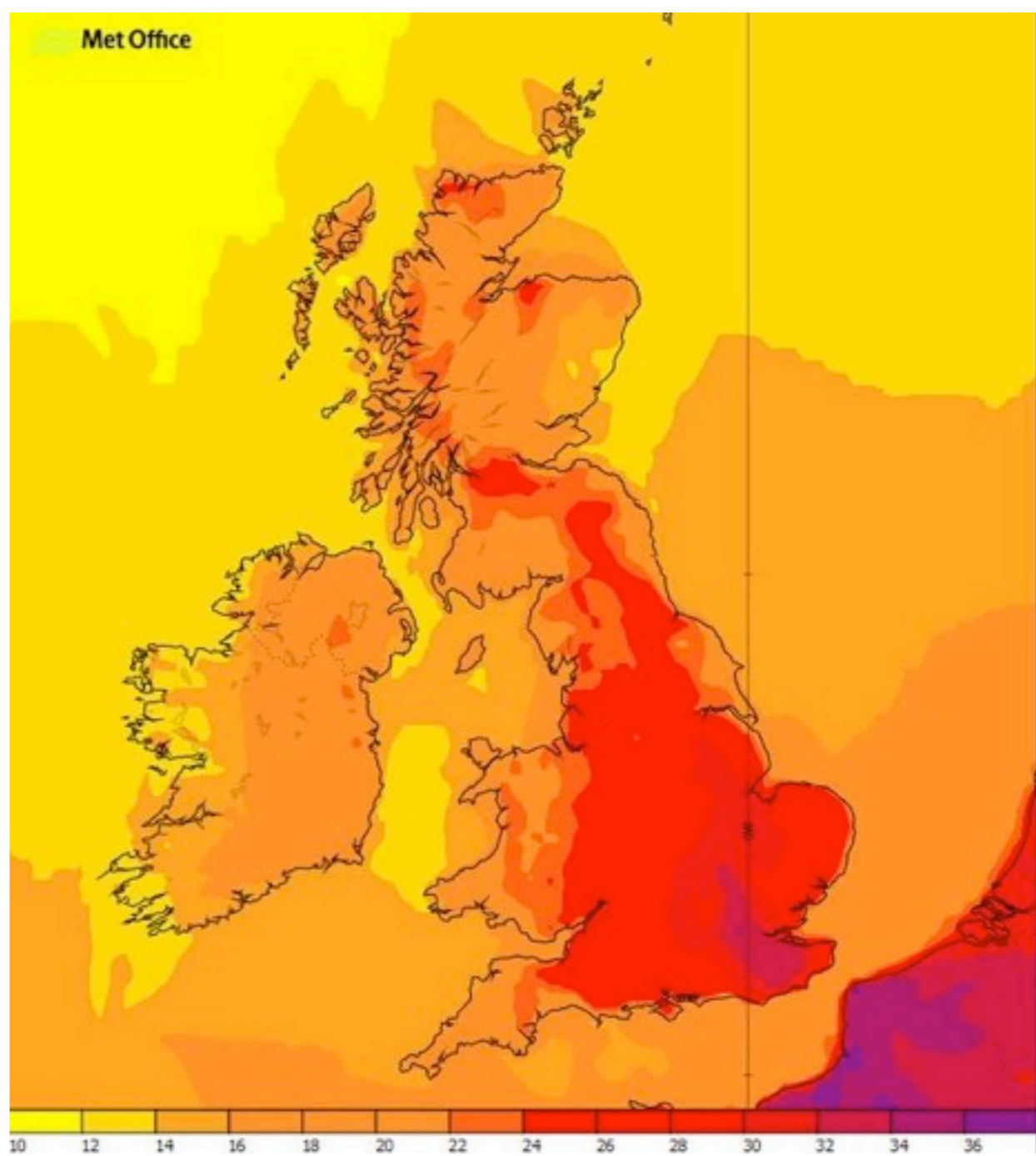
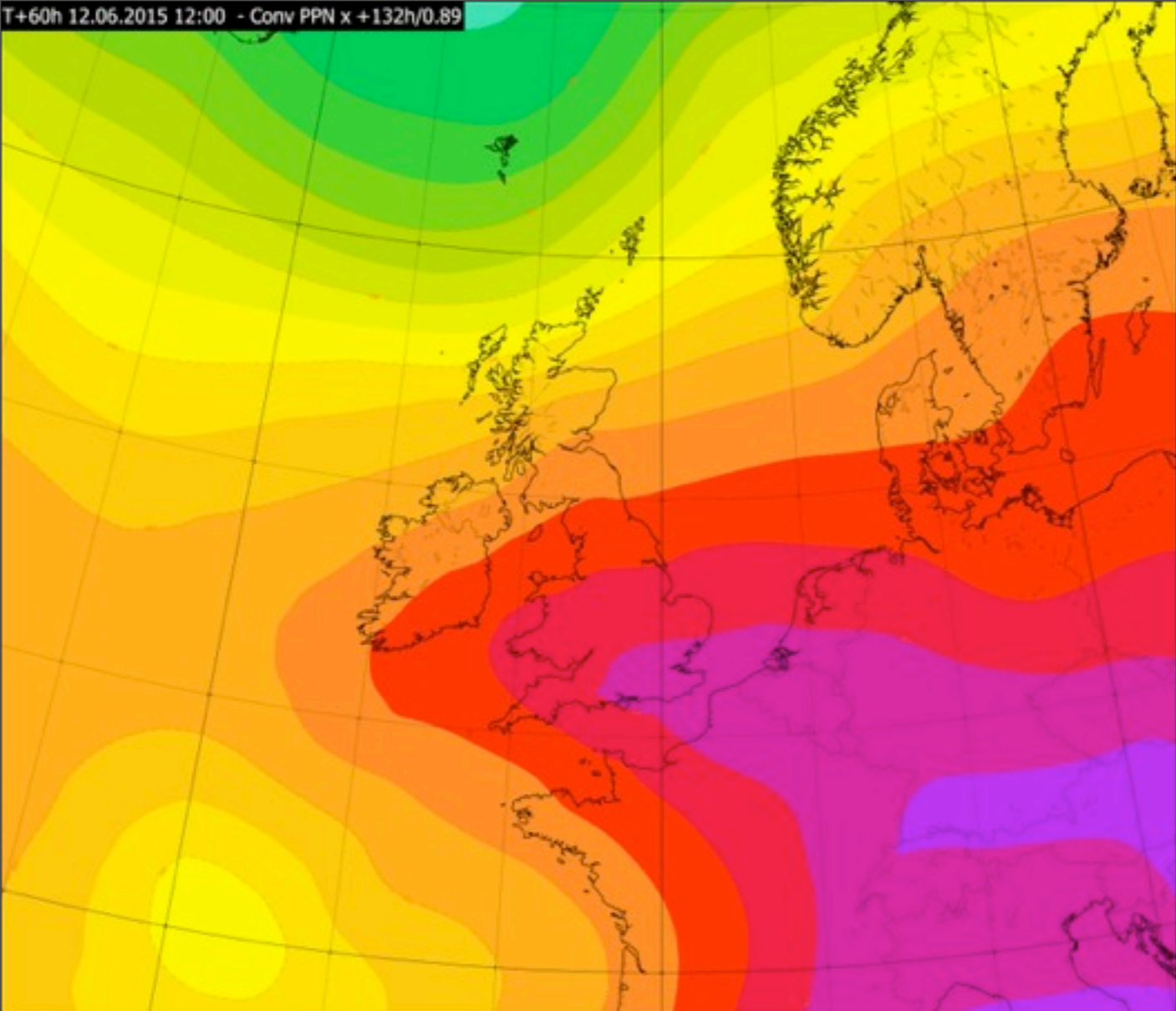


201509161605

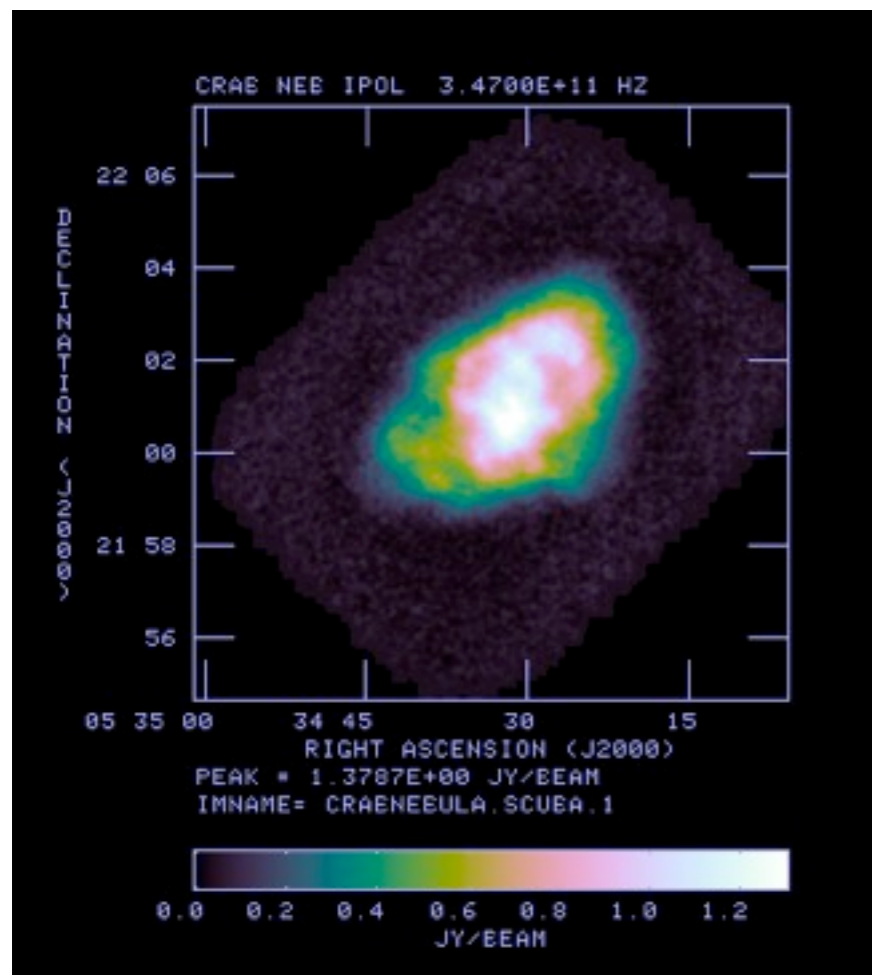
 Met Office



T+60h 12.06.2015 12:00 - Conv PPN x +132h/0.89

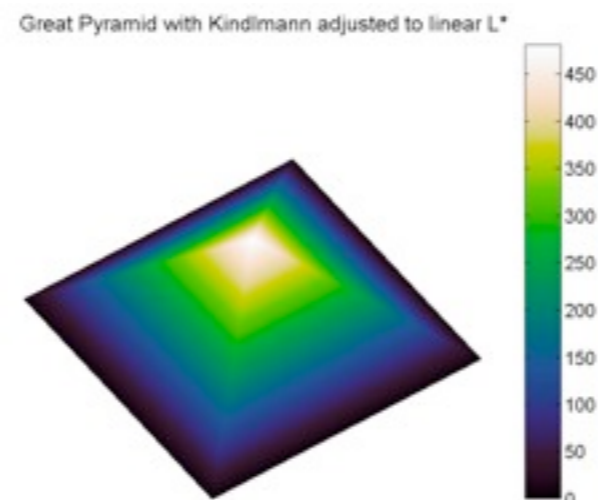


Alternative Rainbows

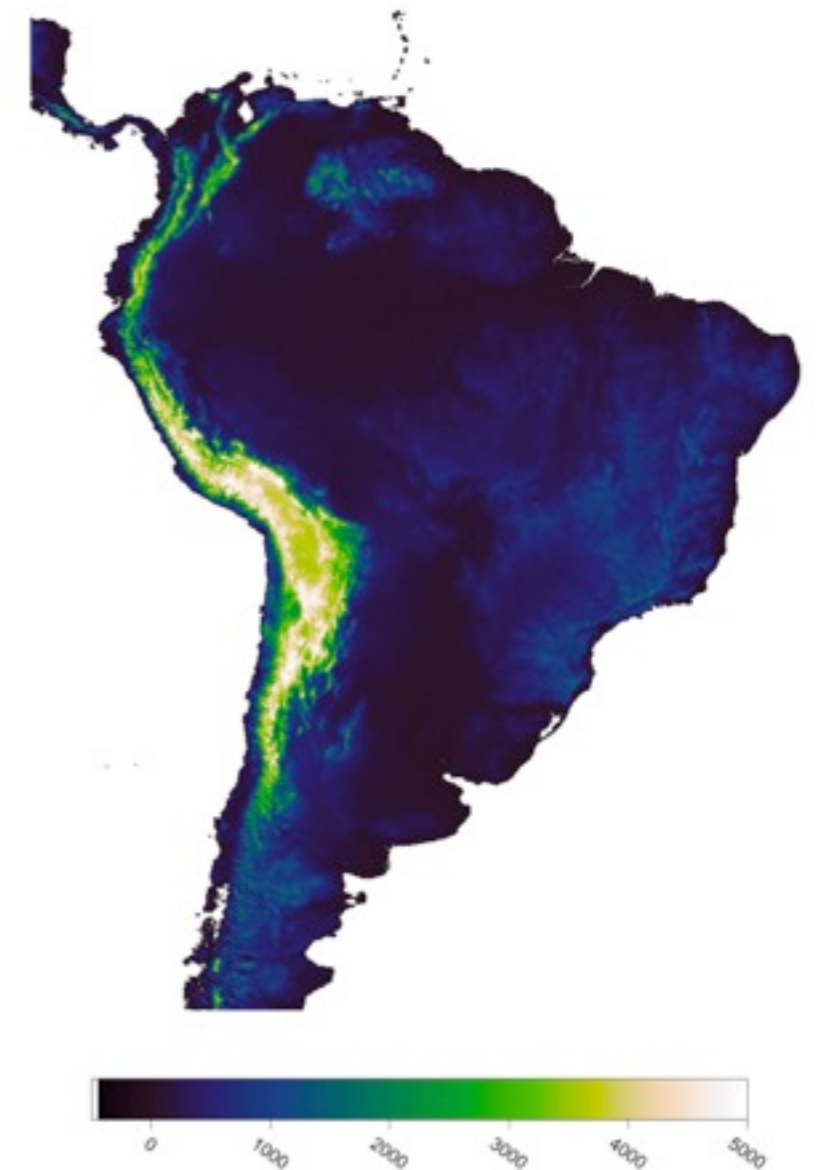


Dave Green's cubehelix

<https://www.mrao.cam.ac.uk/~dag/CUBEHELIX/>

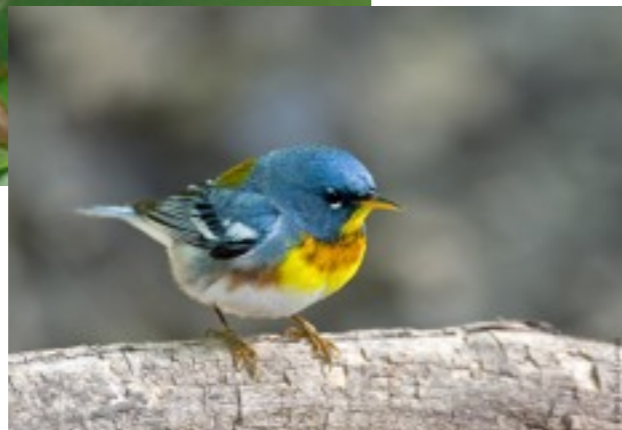


CIE Lab Linear L [Kindelmann]

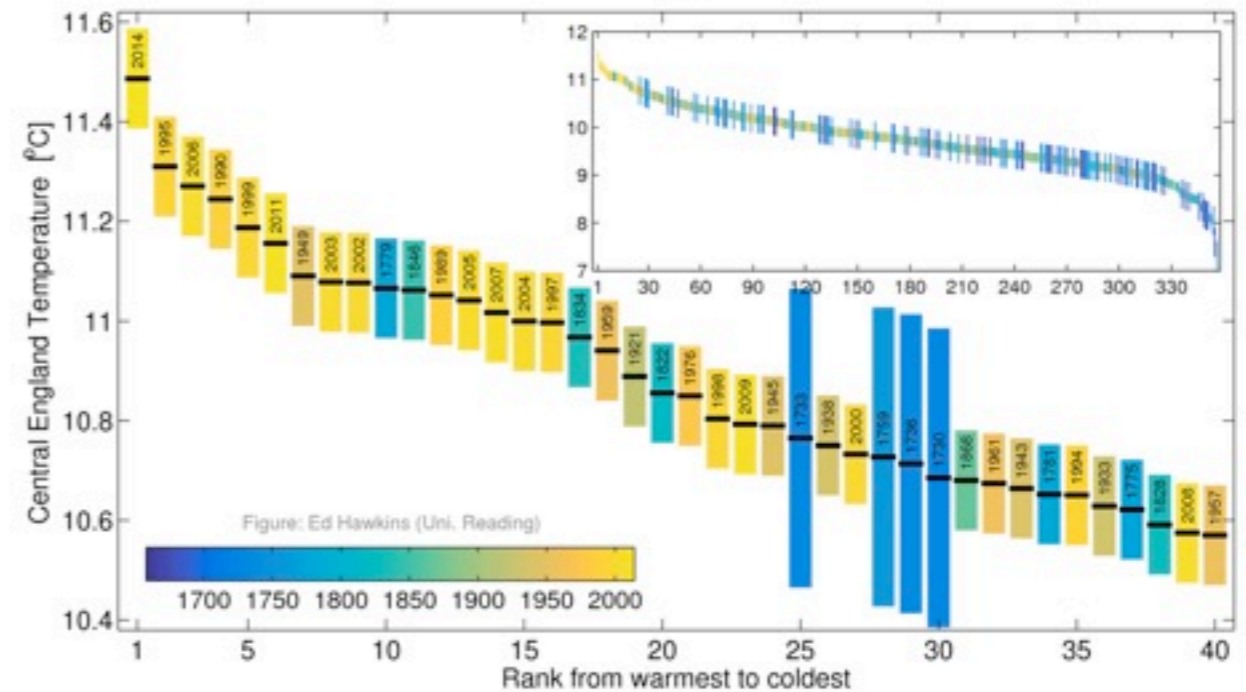
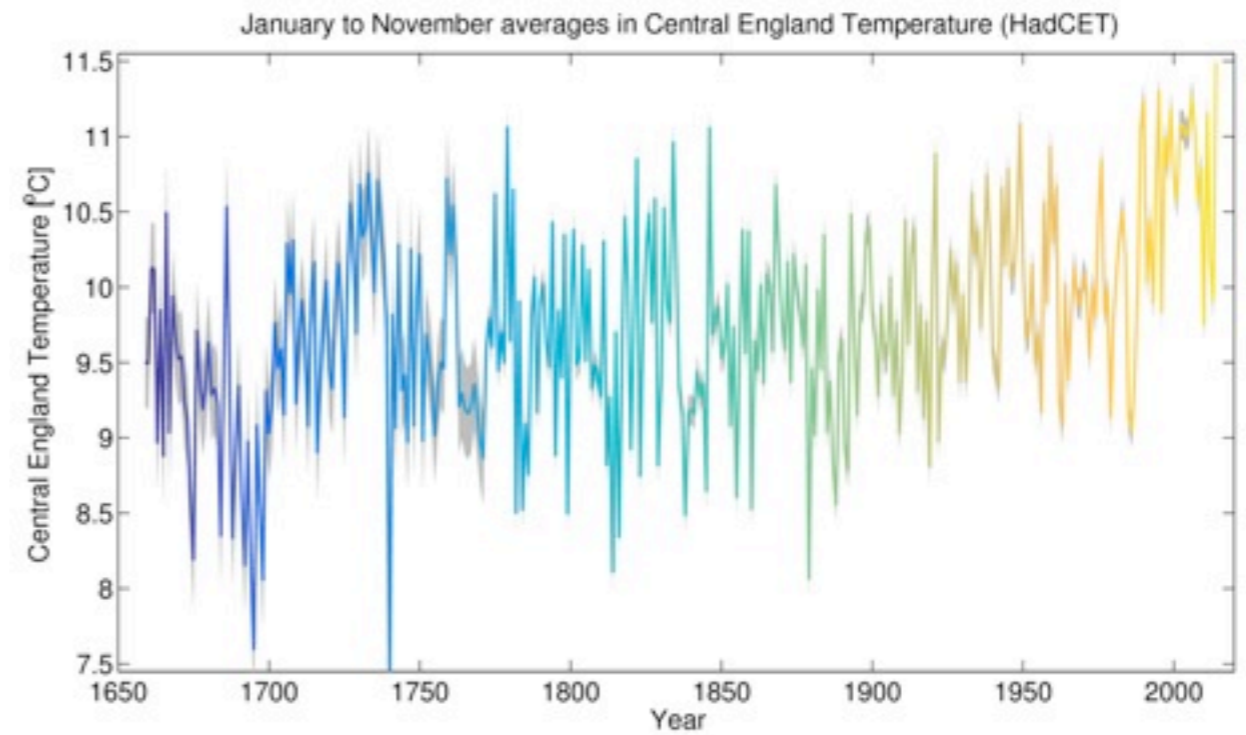
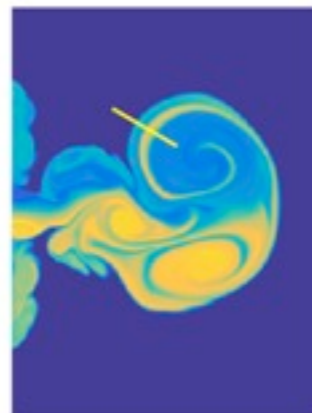
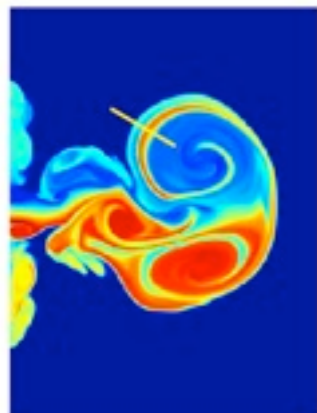


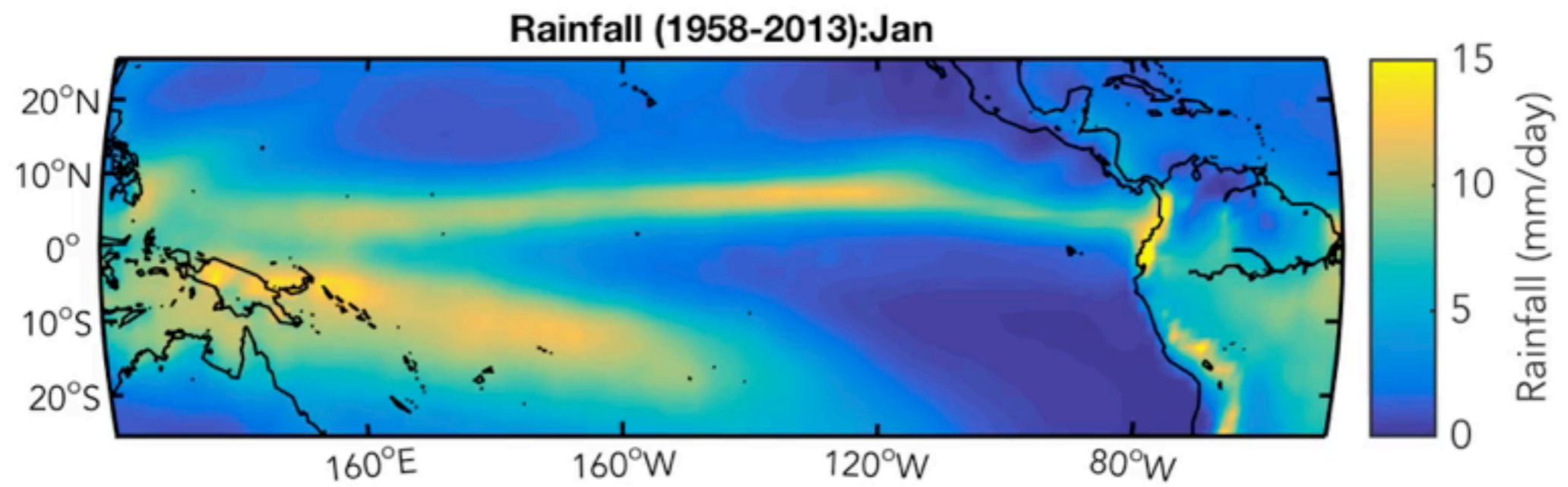
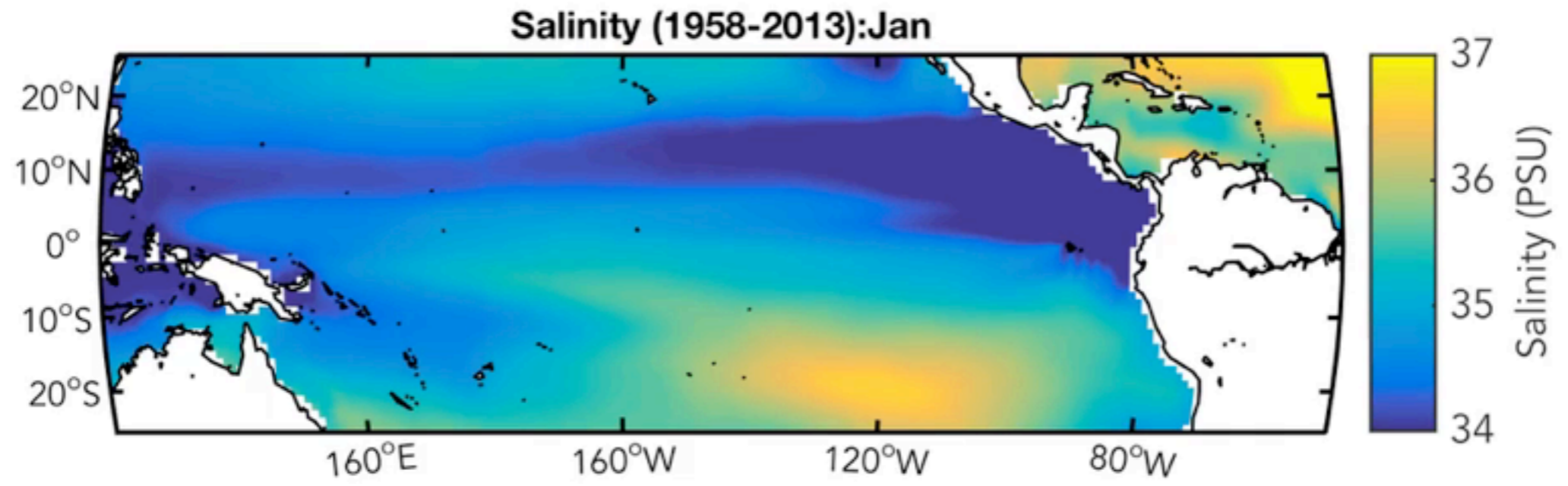
Parula (Matlab)

<http://www.larkwire.com/library/bird-sounds/1616/Northern-Parula-songs-and-calls>



http://www.lilibirds.com/gallery2/v/warblers/northern_parula/northern_parula+male+1.jpg.html

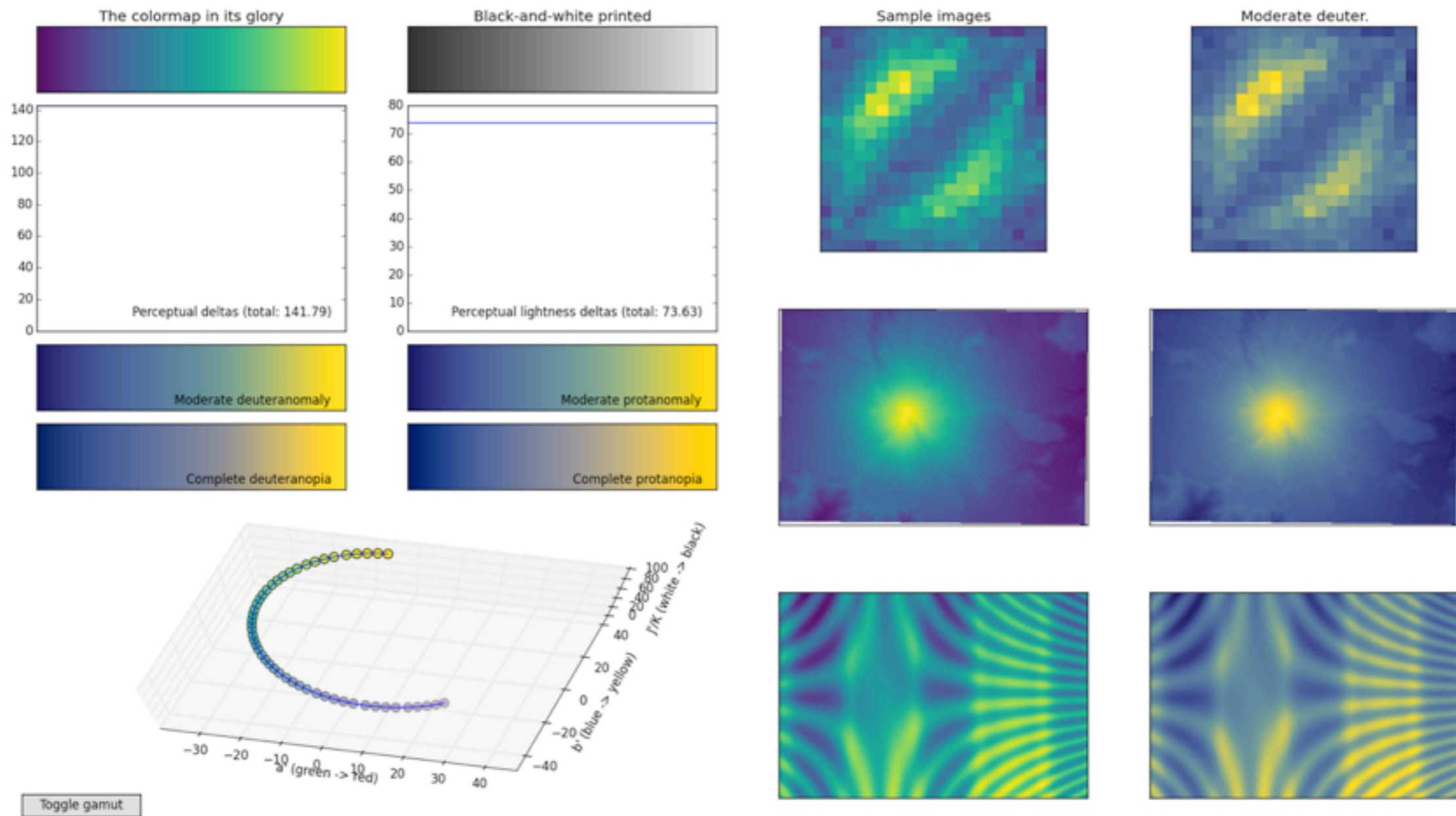




Parula figure courtesy of [Kaustubh Thirumalai @holy_kau](#)

Viridis (matplotlib)

Colormap evaluation: option_d.py



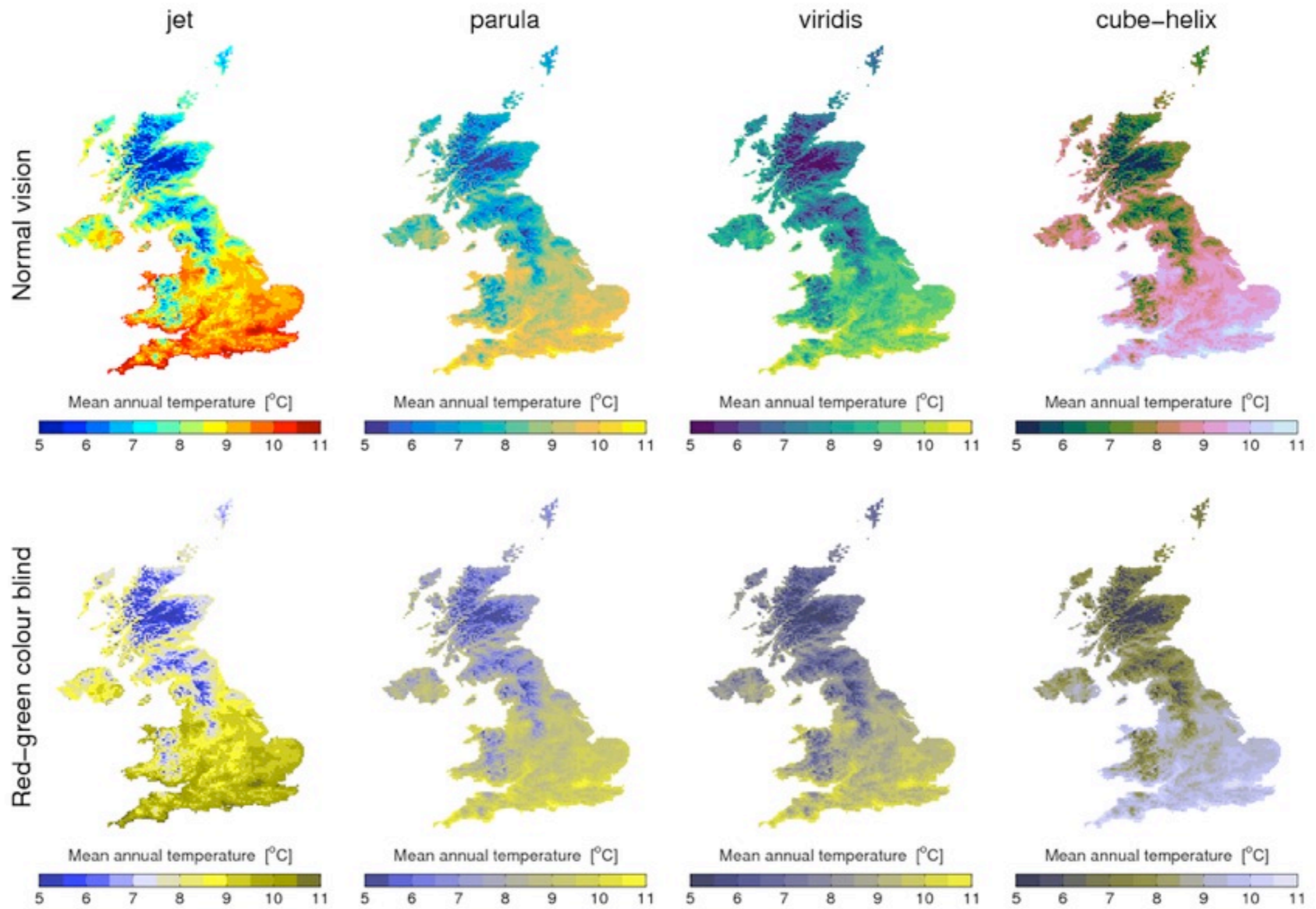
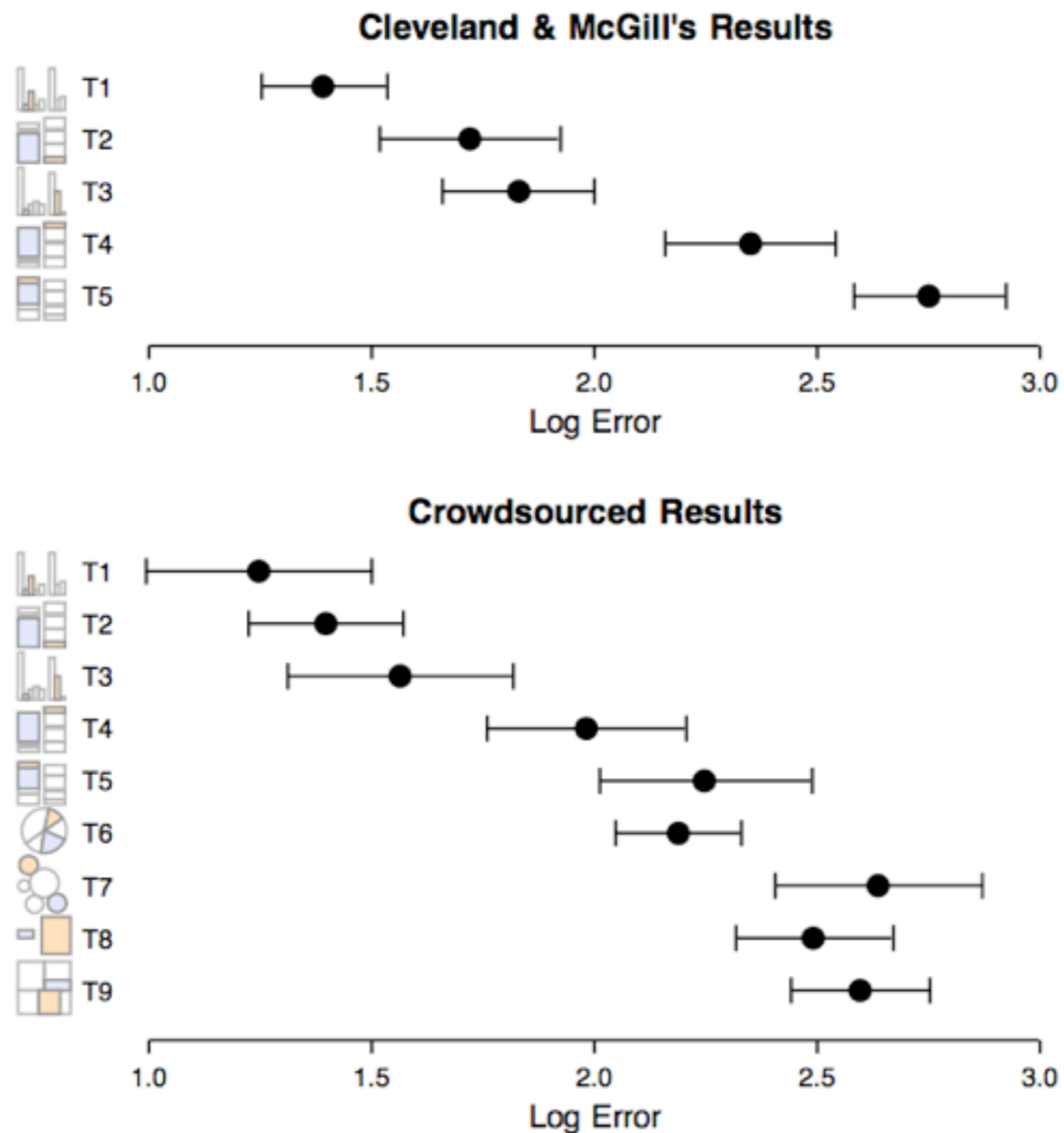


Figure by Ed Hawkins

There **is** a science of visualisation



Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design

Jeffrey Heer and Michael Bostock

Bryant et al (2014) “Useage of color scales on radar maps”

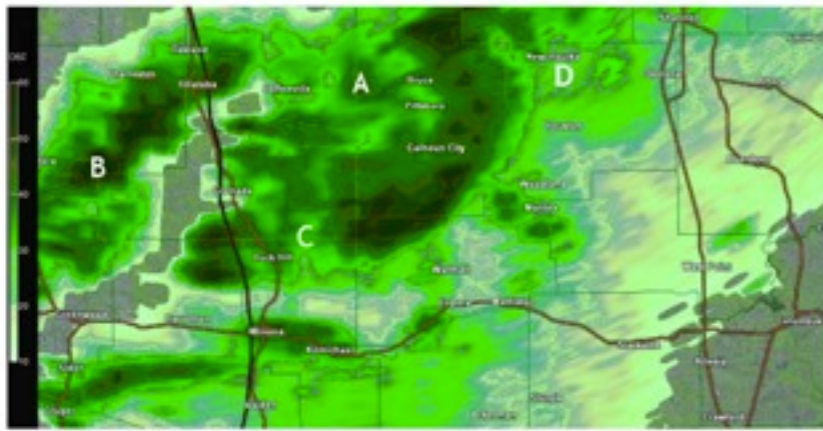


Figure 2. Same as Fig. 1 but for a green map.

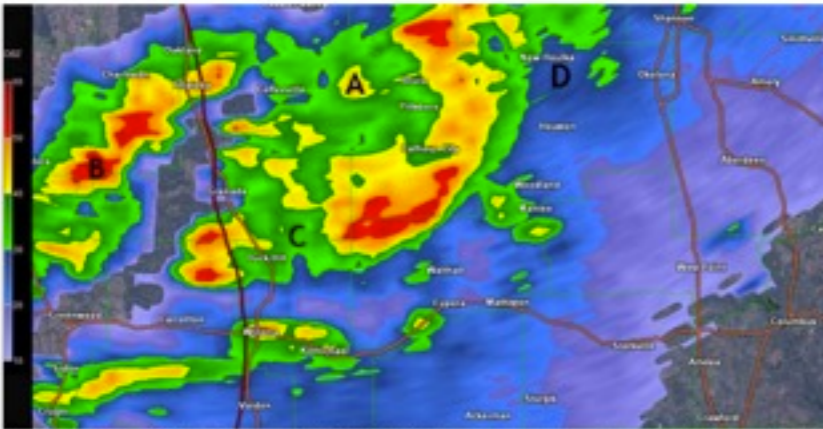


Figure 1. Radar base-reflectivity rainbow map valid 0353 UTC 17 October 2012. The area shown is approximately 100 km × 180 km. A, B, C, and D refer to locations of varying intensity. Click image for an external version; this applies to all figures hereafter.



Figure 4. Same as Fig. 3 but for a green map.



Figure 3. Storm-total precipitation rainbow map valid 0353 UTC 17 October 2012. The area shown is approximately 250 km × 100 km.

Table 1. Frequency table of accuracy (see section 3a) for the radar image (top) and the storm-total precipitation image (bottom).

Radar Image			
	Accuracy		
Radar Type	1	2	3
Green	4	37	243
Rainbow	15	57	197

Storm-Total Image			
	Accuracy		
Storm-Total Type	1	2	3
Green	3	19	253
Rainbow	9	18	252

Bryant, B., M. Holiner, R. Kroot, K. Sherman-Morris, W. B. Smylie, L. Stryjewski, M. Thomas, and C. I. Williams, 2014: Usage of color scales on radar maps. *J. Operational Meteor.*, 2 (14), 169–179, doi: <http://dx.doi.org/10.15191/nwajom.2014.0214>.



Visualisation of AMOC driven cooling by @JenniferMecking



Picture credit (and cake eating) by [@WillHomoky](#)



Visualisation of TAMSAT rainfall by @dunning_cm
(Caroline Dunning)

Doug's meta-principles of scientific data visualisation

Doug's meta-principles of scientific data visualisation

I. Know your audience, and your message

Doug's meta-principles of scientific data visualisation

1. Know your audience, and your message
2. Don't lie

Doug's meta-principles of scientific data visualisation

1. Know your audience, and your message

2. Don't lie

[3. Keep it as simple as you can get away with]

“...better to violate any principle than to put graceless or inelegant marks on paper.”

cf. Orwell “6. Break any of these rules sooner than saying something outright barbarous.”

Quotes from Edward Tufte: The Visual Display of Quantitative Information

**Tools, links and resources at
betterfigures.org**

Thanks for listening!

Favourites

- Hadley Wickham - R - ggplot2 <http://had.co.nz>
- R - googleviz <http://code.google.com/p/google-motion-charts-with-r/>
- Bostock <http://bost.ocks.org/mike/> D3 <http://d3js.org>
- Ben Fry - Processing <http://benfry.com>
- Rob Simmon <http://earthobservatory.nasa.gov/blogs/elegantfigures/>
- Hans Rosling - gapminder <http://www.gapminder.org>
- Cynthia Brewer for good palettes <http://colorbrewer2.org>
- Milestones on data viz <http://www.datavis.ca/milestones/index.php?page=home>