Climate Modeling

Spring 2013 ATS 421/521 CRN 58877

4 Credits

Lectures: Mo, We, Fr 9:00-9:50, Wlkn 207

Programming Labs: Th 9:00-9:50, StAG 324

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Recommended Prerequisites

- ATS 420/520
  - for those who haven't taken ATS 420/520 or Fluid Earth I recommend reading chapter 1 in online textbook

Content

- Numerical (computer) models of the physics, chemistry, and biology of Earth's climate system
- Range (hierarchy) of climate models from a simple, single equation to complex, state-of-the-science systems used for future projections
- Theoretical concepts linked to practical applications through hands-on programming exercises and data analysis

Measureable Student Learning Outcome

- Explain fundamental principles and theoretical concepts of simulating Earth’s climate system, its components and interactions between them
- Analyze large datasets of complex climate model simulations using FERRET
- Understand problems, challenges and uncertainties in climate modeling
- Simulate climate using a range of computer programs
- Know basic UNIX / LINUX commands

Additionally ATS521 students will be able to

- Evaluate the ability of climate models to reproduce observed variables
- Create simple numerical models using FORTRAN

Some homeworks and exam questions will be different for undergraduate students

Script will be distributed as we go

Text Book

Goosse, H., P.Y. Barriat, W. Lefebvre, M.F. Loutre and V. Zunz, "Introduction to climate dynamics and climate modelling" an online textbook. http://www.climate.be/textbook

Evaluation of Student Performance

- 50% homeworks
- 30% exams (10% mid-term, 20% final)
- 20% participation in discussions
  - each student should lead one discussion by presenting the main results and figures of the paper (this will count 10%)

Schedule ATS 421/521 Spring 2013
L: lectures
C: computer lab
D: discussion
HW: Homeworks due Mondays as noted in green

Week	*Date*	*Topic*
1	Mo Apr 1	L01: Introduction, History of Climate Modeling
	We Apr 3	L02: Components of Earth's Climate System, Energy Fluxes, The Zero-Dimensional (0D) Energy Balance Model (EBM), Ice-Albedo Feedback
	Th Apr 4	C01: Basic UNIX commands, Introduction to FORTRAN, work on HW1
	Fr Apr 5	D01: Hansen et al. (1981)
2	Mo Apr 8	L03: Multiple Equilibria, Stability Analysis, Temporal Discretization, Time-Stepping Schemes, Initial Conditions, HW1 due
	We Apr 10	L04: Stochastic Climate Models, Spectral Analysis (Periodogram)
	Th Apr 11	C02: Introduction to FERRET and PCMDI, work on HW2
	Fr Apr 12	D02: Hasselmann (1976), Huybers and Curry (2006)
3	Mo Apr 15	L05: Climate Sensitivity, The 1D Zonally Averaged EBM, Meridional Transport, Spatial Discretization, Spatial Boundary Conditions, HW2 due
	We Apr 17	L06: Numerics 1, Introduction, General Issues, Schemes for the Advection Equation, Euler, Leapfrog, von Neumann Stability Analysis
	Th Apr 18	C03: work on HW3
	Fr Apr 19	L07: Numerics 2, CFL Criterion, Upwind Scheme, Schemes for the Diffusion Equation
4	Mo Apr 22	no class
	We Apr 24	L08: 2D EBM, Radiative Convective Models, HW3 due
	Th Apr 25	C04: work on HW4
	Fr Apr 26	D04: Manabe and Strickler (1964), Pierrehumbert (2012)
5	Mo Apr 29	L09: Hadley Cell (Held & Hou, 1980), Review, HW4 due
	We May 1	L10: General Circulation Models I, Grids and Coordinate Systems, Spectral Method, Parameterizations
	Th May 2	C05: Review, work on HW5
	Fr May 3	Mid Term Exam
	Fr May 3	Mid Term Exam
6	Mo May 6	L11: GCMs II, Non-Linear Dynamics, Chaos and the Lorenz Model (Lorenz 1963), HW5 due
	We May 8	L12: Box Model of the Thermohaline Ocean Circulation (Stommel, 1961)
	Th May 9	C06: work on HW6
	Fr May 10	D06: Held and Hou (1980), Lorenz (1963), Stommel (1961)
7	Mo May 13	L13: Ice Sheets (Oerlemans, 1981), Sea Ice, HW6 due
	We May 15	L14: Vegetation Feedbacks and Daisyworld (Watson & Lovelock, 1983)
	Th May 16	C07: work on HW7
	Fr May 17	D07: Oerlemanns (1981), Watson and Lovelock (1983)
8	Mo May 20	L15: State-Of-The-Art Dynamic Vegetation Models (Guest lecture by Fred Saltre) , HW7 due
	We May 22	L16: Ocean Ecosystem and Carbon Cycle Models, HW7 due
	Th May 23	C08: work on HW8
	Fr May 24	D08: Friedlingstein et al. (2006)
9	Mo May 27	Memorial Day Holiday
	We May 29	L17: Regional Climate Models, Reanalyses, HW8 due
	Th May 30	C09: work on HW9
	Fr May 31	D09: Balmaseda et al. (2013), Meehl et al. (2011)
10	Mo Jun 3	L18: Evaluation of Climate Models, HW9 due
	Th Jun 5	L19: Future Projections
	We Jun 6	D10:
	Fr Jun 7	Review
11	Mo Jun 10	18:00 Final Exam

Homeworks

- You'll write your own climate models
- You'll analyze model output from comprehensive climate models
- Label all axes of your plots correctly including units ! (I will subtract points if not)

Computer Labs

- You learn UNIX, FORTRAN, FERRET
- You learn how to download data from PCMDI*
- You work on your homework
- You can work in teams and help each other
- Exchange tips and tricks

***Action Item:**

goto http://pcmdi9.llnl.gov/esgf-web-fe/ and create an account

Discussions

- We select a paper (or two). You're welcome to choose your own paper. The next slide has some suggestions.
- All read the paper and make notes (e.g. what was important, what was unclear)
- One student presents the main results and figures (powerpoint) and leads the discussion

Possible Papers

- Hansen et al. (1981) projections CO2
- Hasselmann (1976), Huybers and Curry (2006) stochastic CM, spectra
- Budyko (1969), Sellers (1969) 1D-EBM
- Turco (1983) Nuclear Winter
- Lorenz (1963) Chaos
- Manabe & Strickler (1964) Radiat.-convect.
- Pierrehumbert (2011) infrared radiation
- Held and Hou (1980), Lindzen and Hou (’88)
- Stommel (1961) box model of THC

- Schmittner (2011, JClim) Effects of mountains and ice sheets on MOC
- Meehl (2011) ocean heat uptake / hiatus
- Balmaseda (2013) ocean reanalysis / hiatus
- Saenko (2002) Holland (2006) Sea ice
- Oerlemans (1981) Pollard (2009) Ice sheet
- Watson (1983) Daisyworld
- Cox (2000) Friedlingstein (2006) veget resp to warming, climate carbon cycle feedback
- Hargreaves (2012) Paleo / Climate Sensit.
- Bouttes (2011) ocean biogeochem. isot. paleo

Reading

For Wednesday:

- Chapters 1, 2.1, and 2.2 in script
- Chapter 1 in online textbook (not necessary if you took ATS 420/520 or Fluid Earth)

For Friday:

- Hansen et al. (1981)
  - who wants to lead the discussion ?
  - others: choose a paper for your discussion

Brief History of Climate Modeling

- Early 20th century: Vilhelm Bjerknes develops the “primitive equations” for weather prediction
- 1922 Lewis Richardson develops first numerical weather forecasting (NWF) system His Attempt to calculate weather for a single eight-hour period took six weeks and ended in failure.
- 1940: John von Neumann and Jules Charney run first NWF
- 1954: Carl-Gustaf Rossby starts first operational NWFs

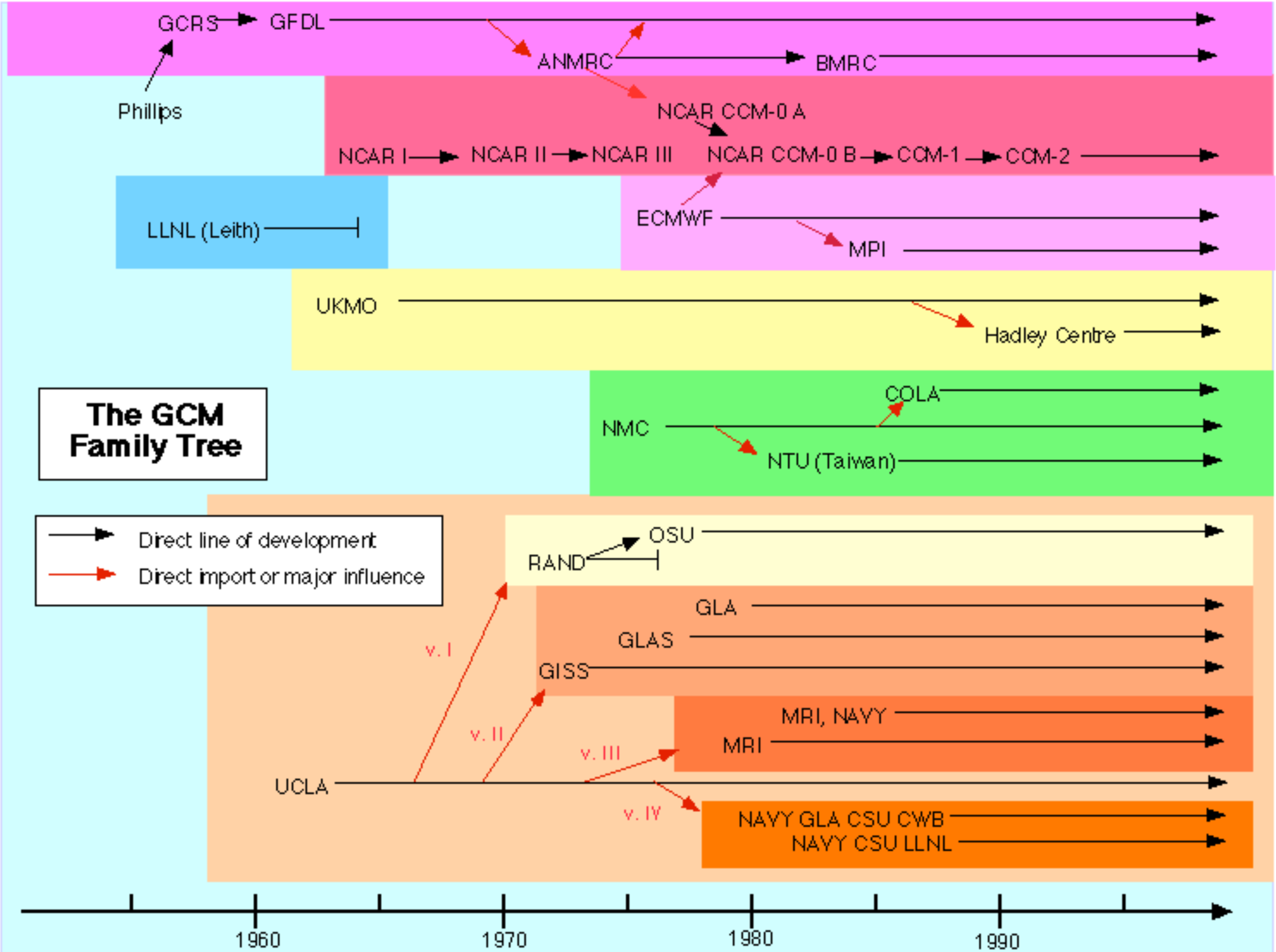
Vilhelm Bjerknes

http://pne.people.si.umich.edu/sloan/intro.html

F. Nebeker, *Calculating the Weather: Meteorology in the 20th Century* (New York: Academic Press, 1995).

- 1955 Norman Phillips: 2-layer, hemispheric, quasi-geostrophic model
- 1950s
  - GFDL: J. Smagorinsky, S. Manabe
  - UCLA: Y. Mintz, A. Arakawa
- 1960s
  - LLNL: C. Leith
  - NCAR: A. Kasahara, Warren Washington
  - Stommel (1961) Box model of thermohaline ocean circulation
  - Lorenz (1963): limits to predictability
  - Budyko and Sellers' Energy Balance Models
  - First coupled ocean-atmosphere model (Manabe & Bryan 1969 JAS)

Suki Manabe



http://pne.people.si.umich.edu/sloan/intro.html

Evolution of Climate Models

Earth System Models

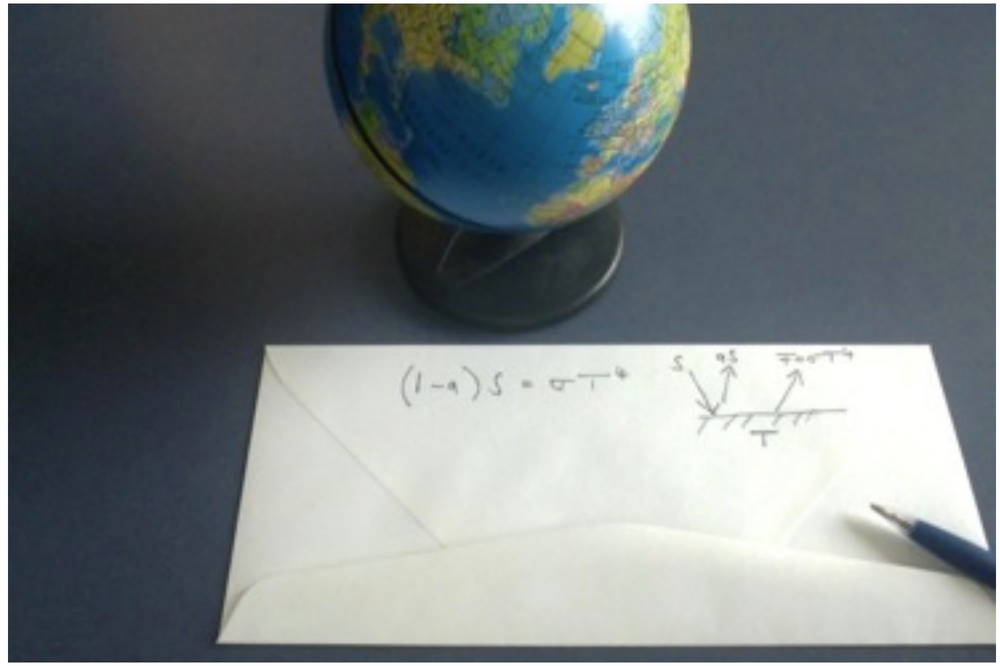
IPCC 2007

Assessment of Human Effects on Climate

- 1979 “Charney Report” NAS
- 1990 IPCC 1st AR
- 1995 IPCC 2nd AR
- 2001 IPCC 3rd AR
- 2007 IPCC AR4
- 2013 IPCC AR5 (September)

Hierarchy of Climate Models

- Back-on-the-envelope 0D EBM
- 1D EBM
- 1D radiative convective
- 2D EBM
- Earth System Models of Intermediate Complexity (EMICs)
- Coupled 3D GCMs run on supercomputers
- Reanalyses, data assimilation



Weather Prediction vs Climate Models

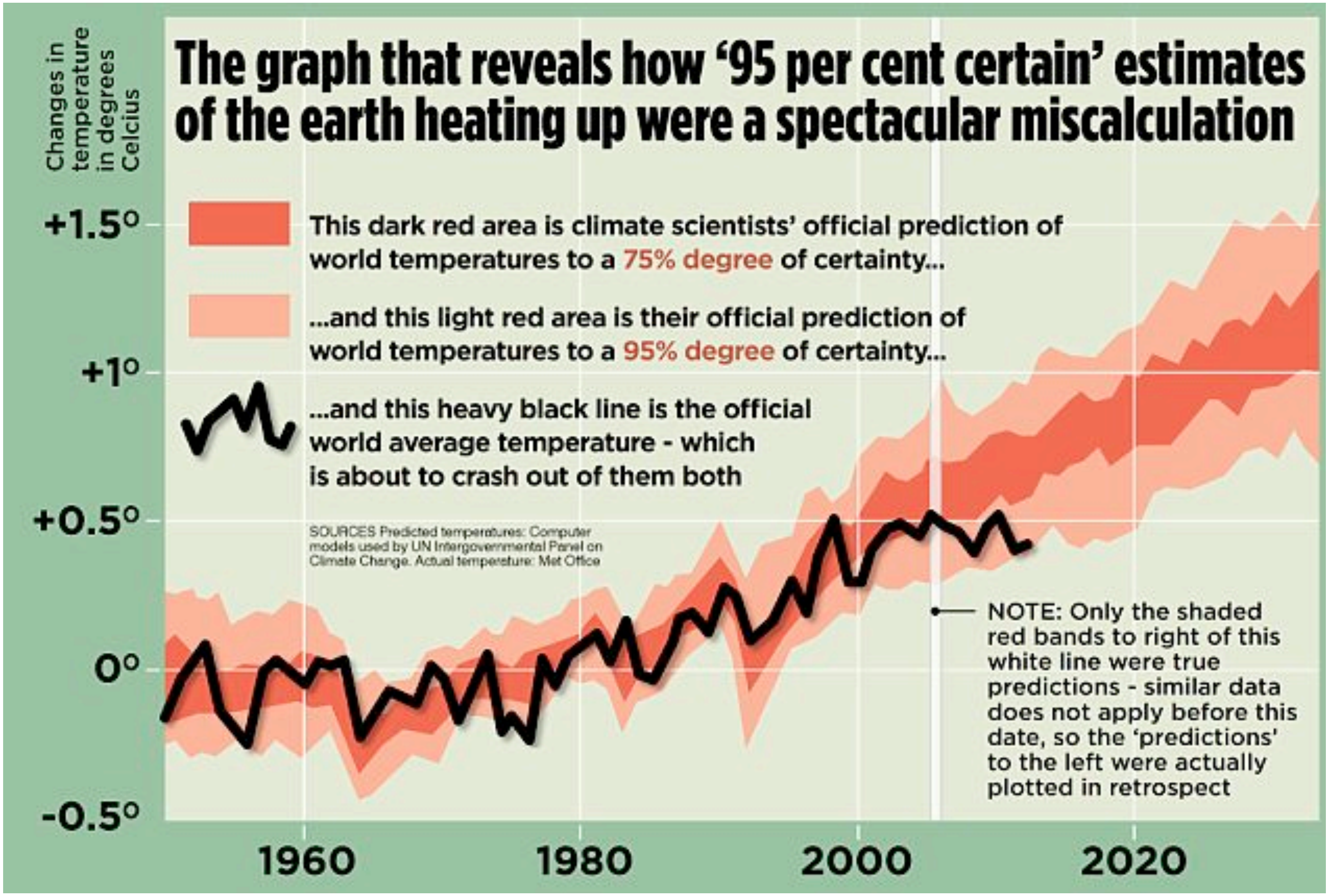
- Weather prediction models are
  - initialized with observations then run for 1-2 weeks
  - do not need to strictly conserve energy
  - do not need ocean component
- Climate models
  - are used for long-term simulations (decades to centuries and more)
  - need to conserve energy
  - need ocean component
- Reanalyses are models run with data assimilation
  - ERA, NCEP/NCAR, ...

What are climate models used for?

To prove they're wrong and global warming is a scam

The Daily Mail

Mar 16, 2013



http://www.dailymail.co.uk/news/article-2294560/The-great-green-1-The-hard-proof-finally-shows-global-warming-forecasts-costing-billions-WRONG-along.html

What are climate models used for?

- Better understanding how the complex climate system works
- Projections of future climate change
- Detection and attribution of climate change (e.g. human vs natural causes)
- Paleoclimate research

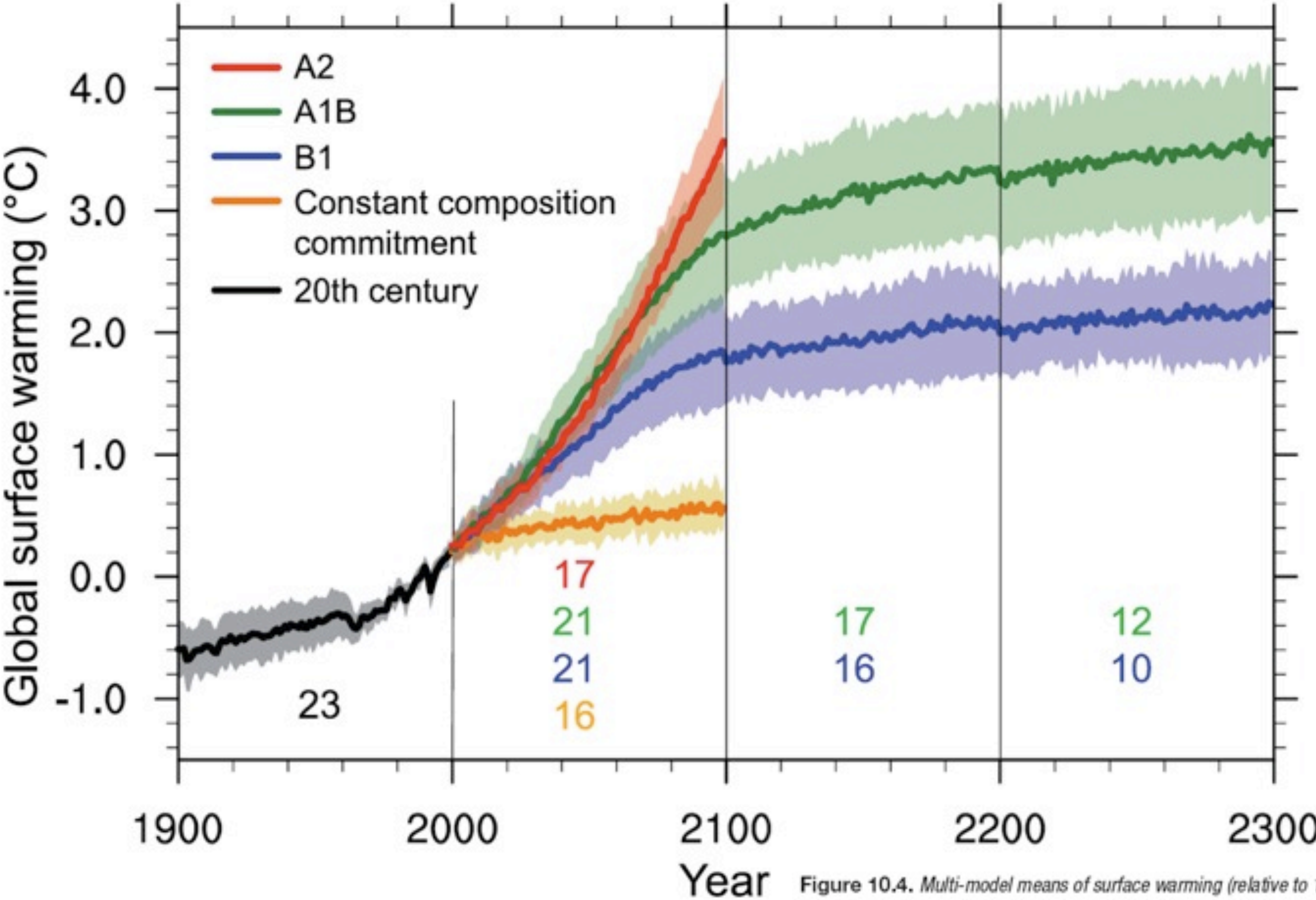
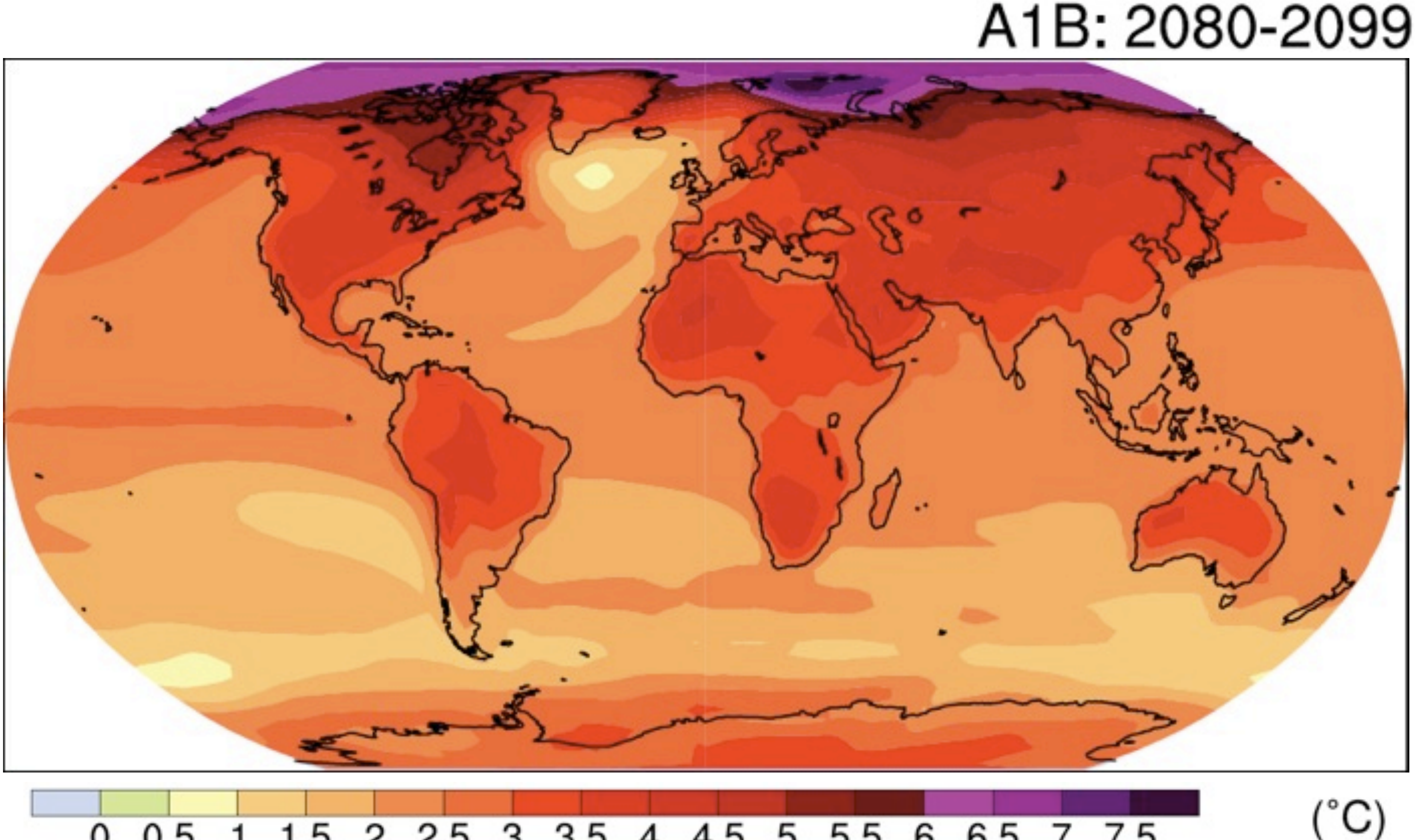


Figure 10.4. *Multi-model means of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th-century simulation. Values beyond 2100 are for the stabilisation scenarios (see Section 10.7). Linear trends from the corresponding control runs have been removed from these time series. Lines show the multi-model means, shading denotes the ±1 standard deviation range of individual model annual means. Discontinuities between different periods have no physical meaning and are caused by the fact that the number of models that have run a given scenario is different for each period and scenario, as indicated by the coloured numbers given for each period and scenario at the bottom of the panel. For the same reason, uncertainty across scenarios should not be interpreted from this figure (see Section 10.5.4.6 for uncertainty estimates).*

Future Projections IPCC AR4

Surface air temperature change



Multi-model mean

a) Precipitation

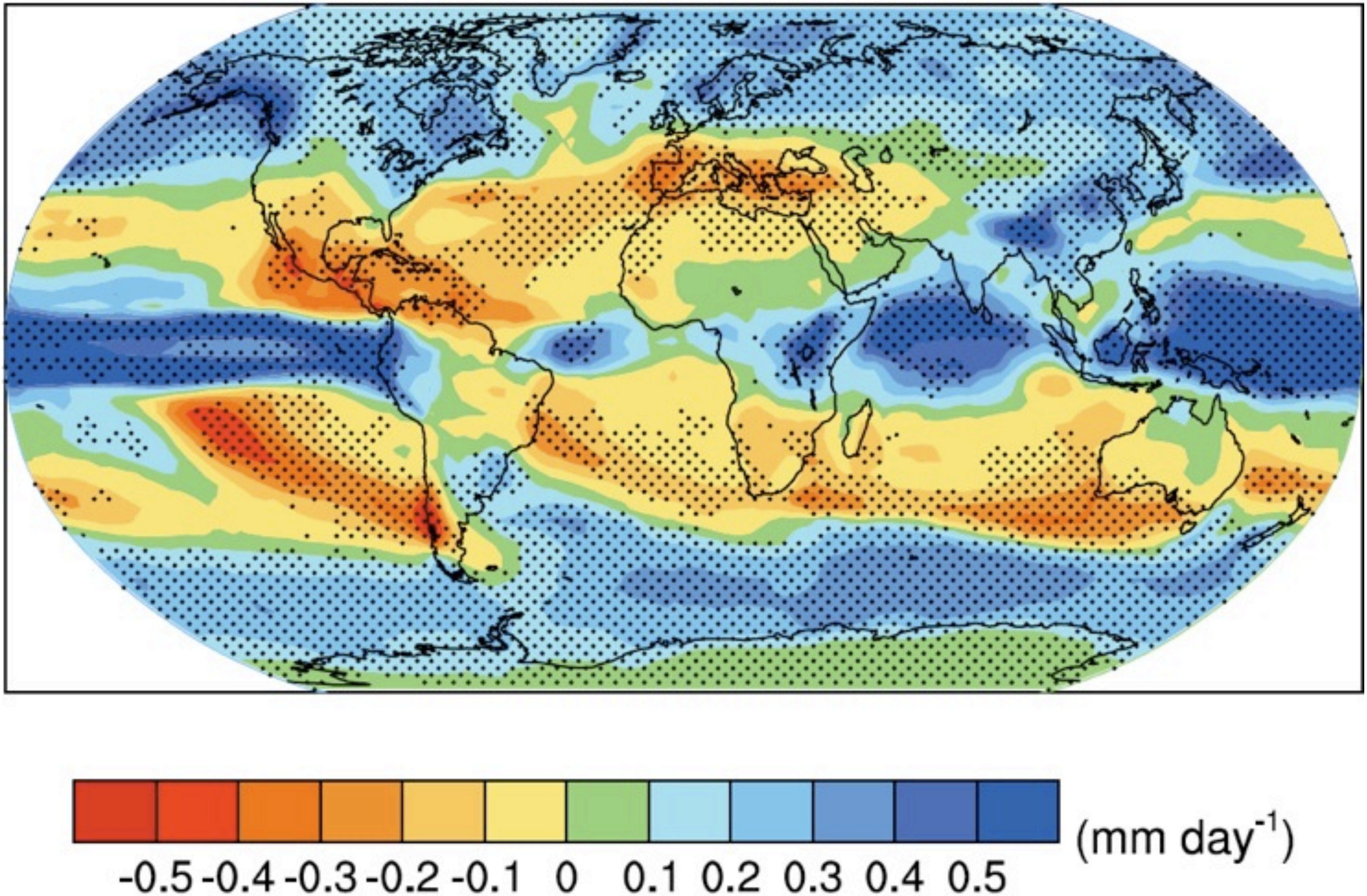
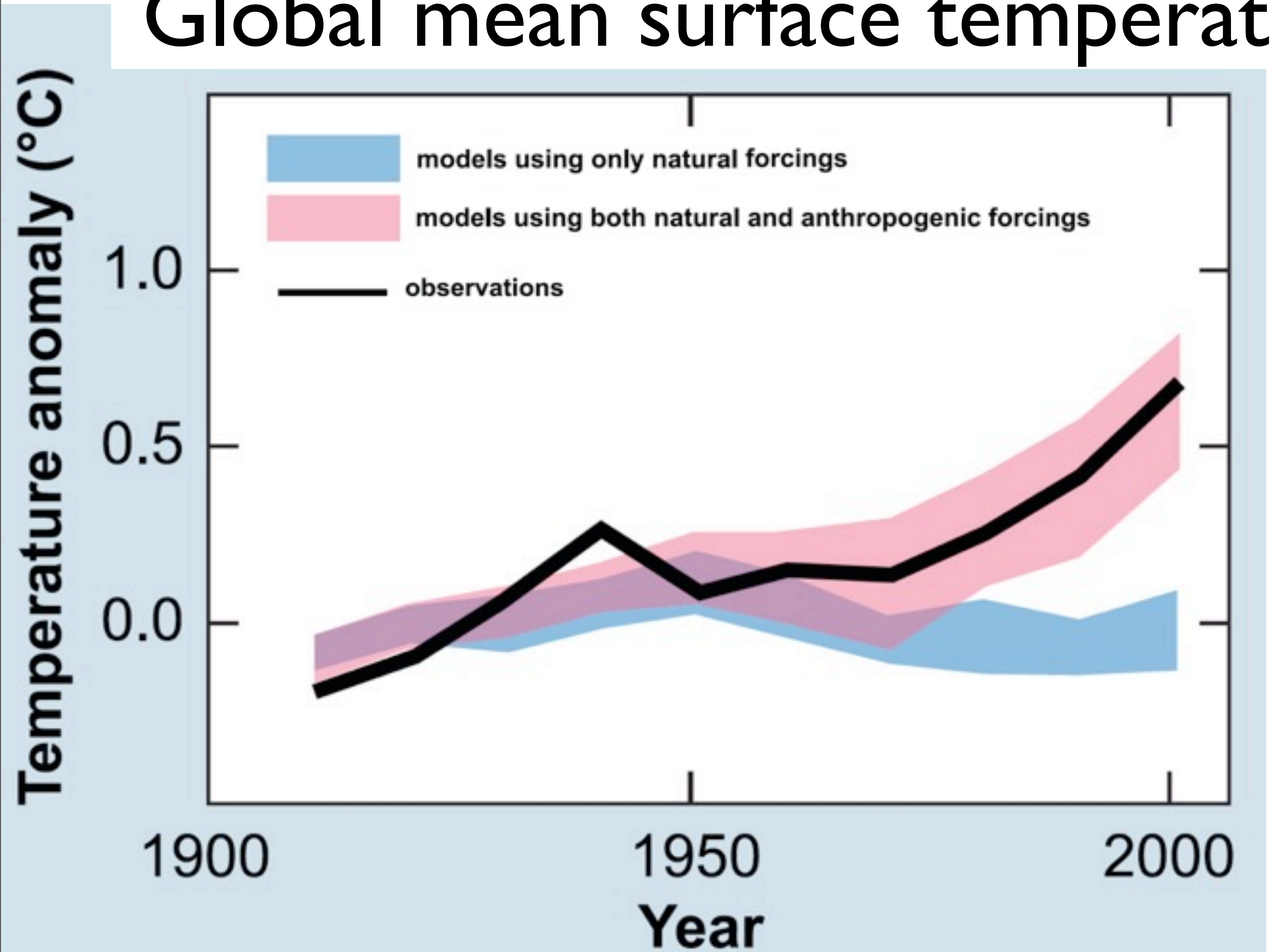


Figure 10.12. *Multi-model mean changes in (a) precipitation (mm day^{-1}), (b) soil moisture content (%), (c) runoff (mm day^{-1}) and (d) evaporation (mm day^{-1}). To indicate consistency in the sign of change, regions are stippled where at least 80% of models agree on the sign of the mean change. Changes are annual means for the SRES A1B scenario for the period 2080 to 2099 relative to 1980 to 1999. Soil moisture and runoff changes are shown at land points with valid data from at least 10 models. Details of the method and results for individual models can be found in the Supplementary Material for this chapter.*

Detection and Attribution
Global mean surface temperature



IPCC 2007

“essentially, all models are wrong, but some are useful”

George E. P. Box (1991)