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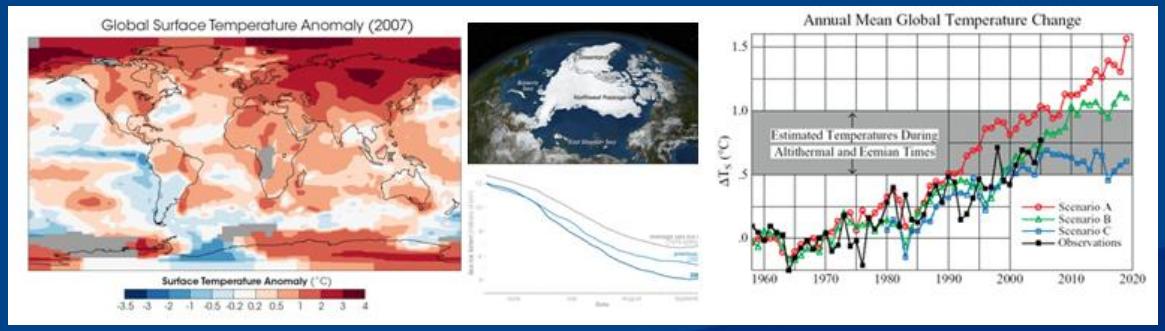

Climate Change Q&A **Seminar #2**

What future climate change scenarios are possible?

Professor Barry W. Brook

Sir Hubert Wilkins Chair of Climate Change

Director, Research Institute for Climate Change and Sustainability

School of Earth and Environmental Sciences

The University of Adelaide

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Climate Change Q&A

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6 lectures – step-by-step guide to the key questions

- 8 Aug: Is the Earth really warming?
- 22 Aug: Natural vs Human causes
- **5 Sept: Future climate change scenarios?**
- 19 Sept: Are impacts being overstated?
- 10 Oct: Will it cost the Earth to avoid this?
- 24 Oct: Greenhouse denial: the 'pretend debate'

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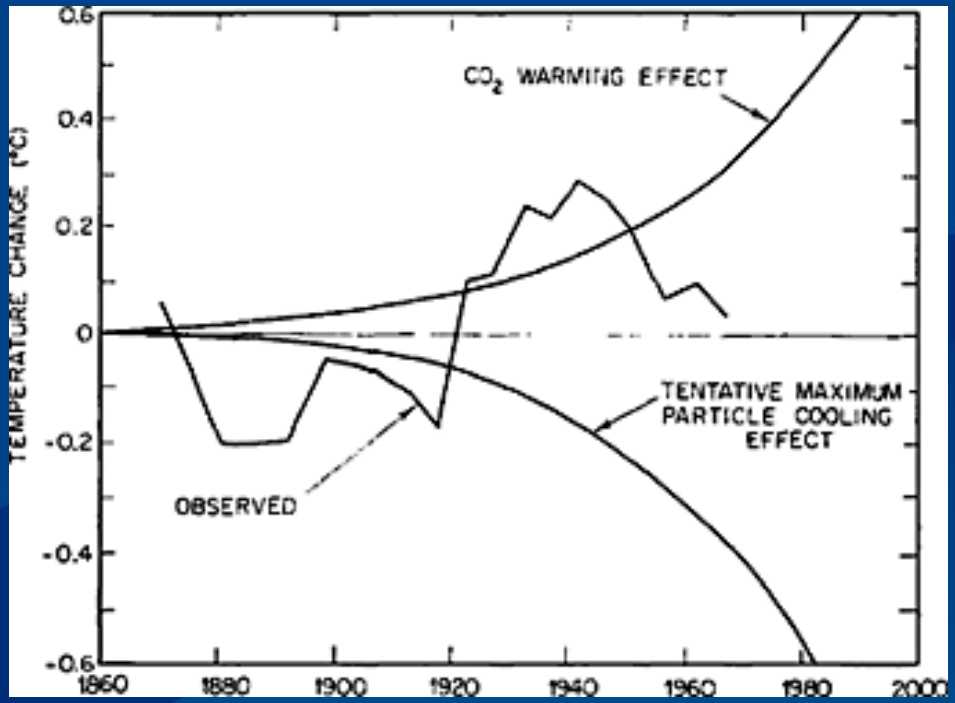
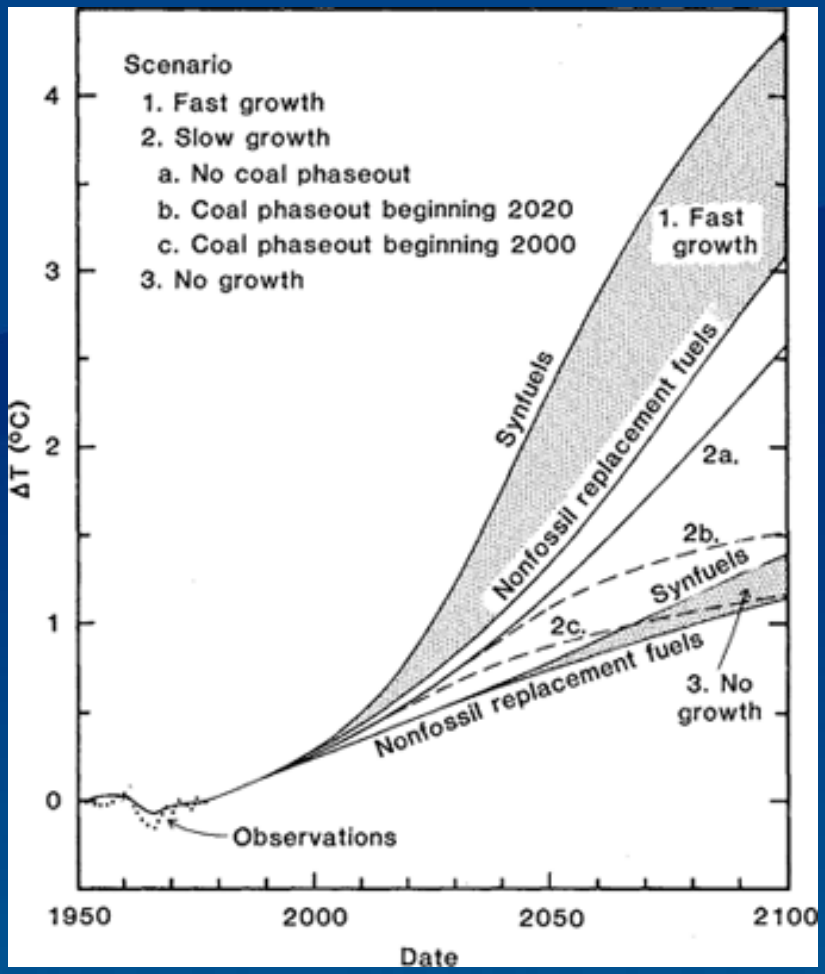
Models are unreliable!


TEMPERATURE CHANGE (°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1860
1880
1900
1920
1940
1960
1980
2000
CO_2 WARMING EFFECT
TENTATIVE MAXIMUM PARTICLE COOLING EFFECT
OBSERVED


Scenario
1. Fast growth
2. Slow growth
a. No coal phaseout
b. Coal phaseout beginning 2020
c. Coal phaseout beginning 2000
3. No growth
ΔT (°C)
4
3
2
1
0
1950
2000
2050
2100
Date
1. Fast growth
Synfuels
Nonfossil replacement fuels
2a.
2b.
Synfuels
2c.
Nonfossil replacement fuels
3. No growth
Observations

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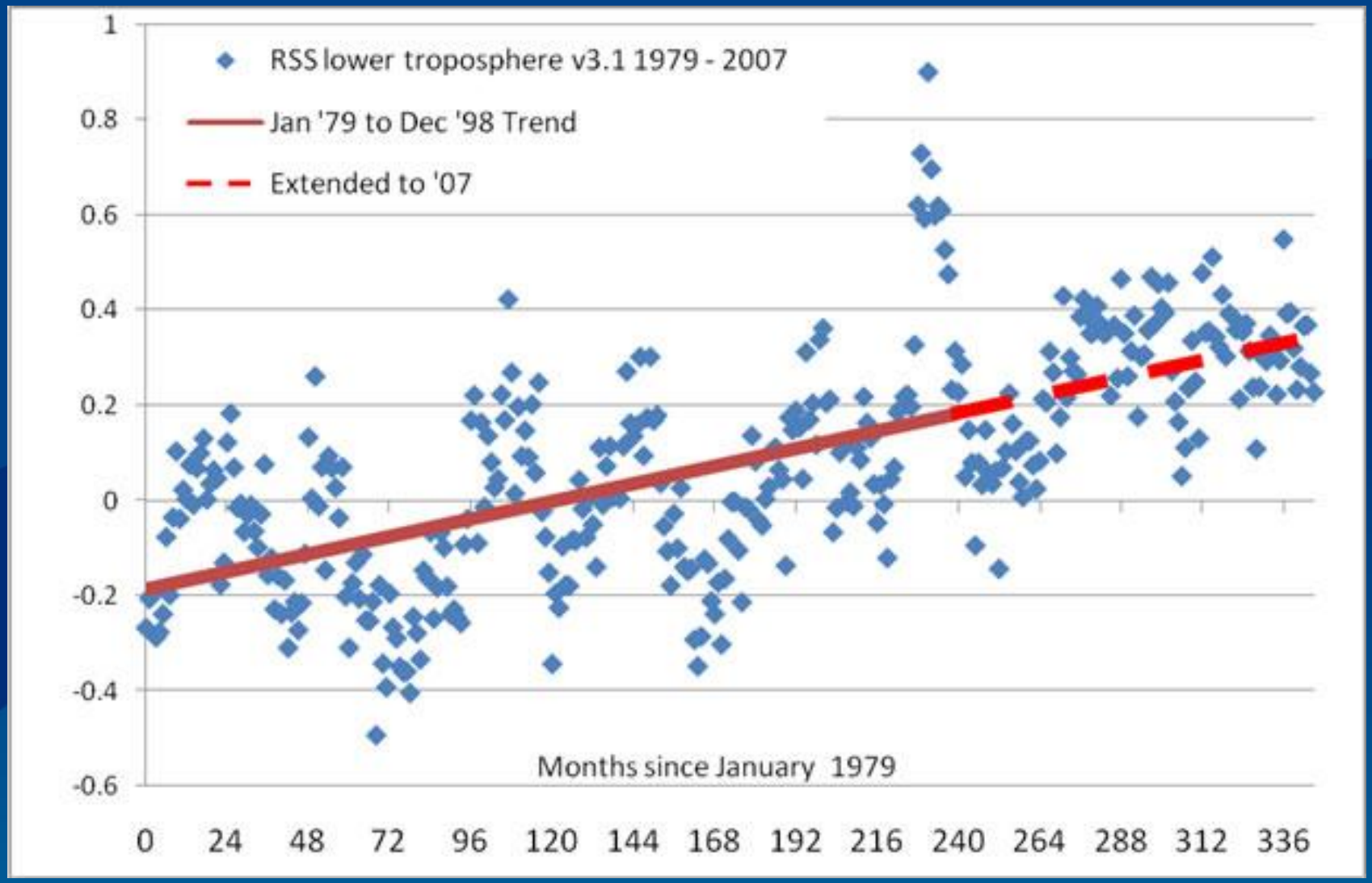

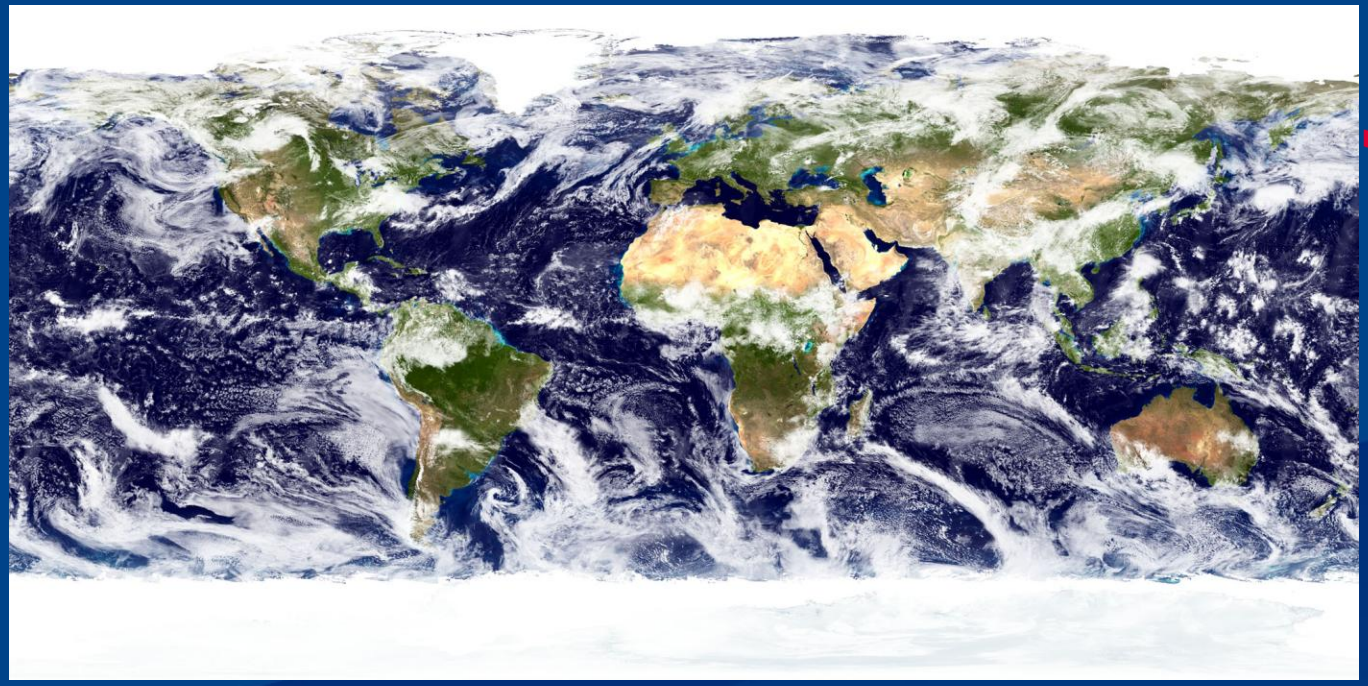

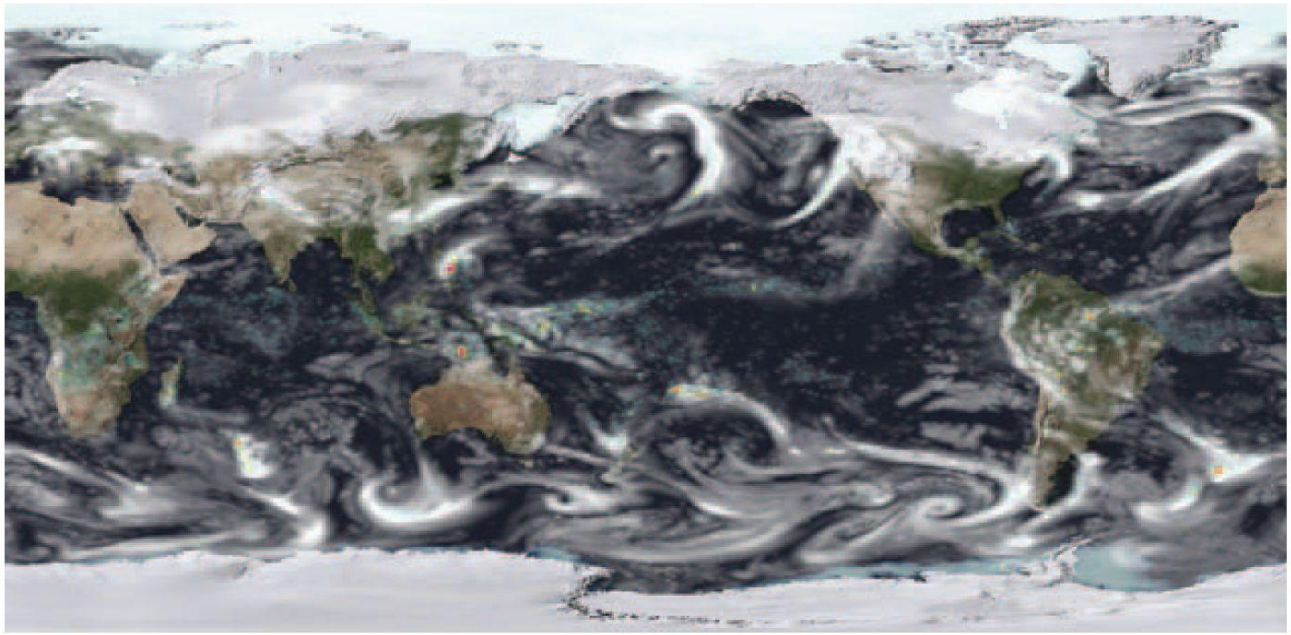

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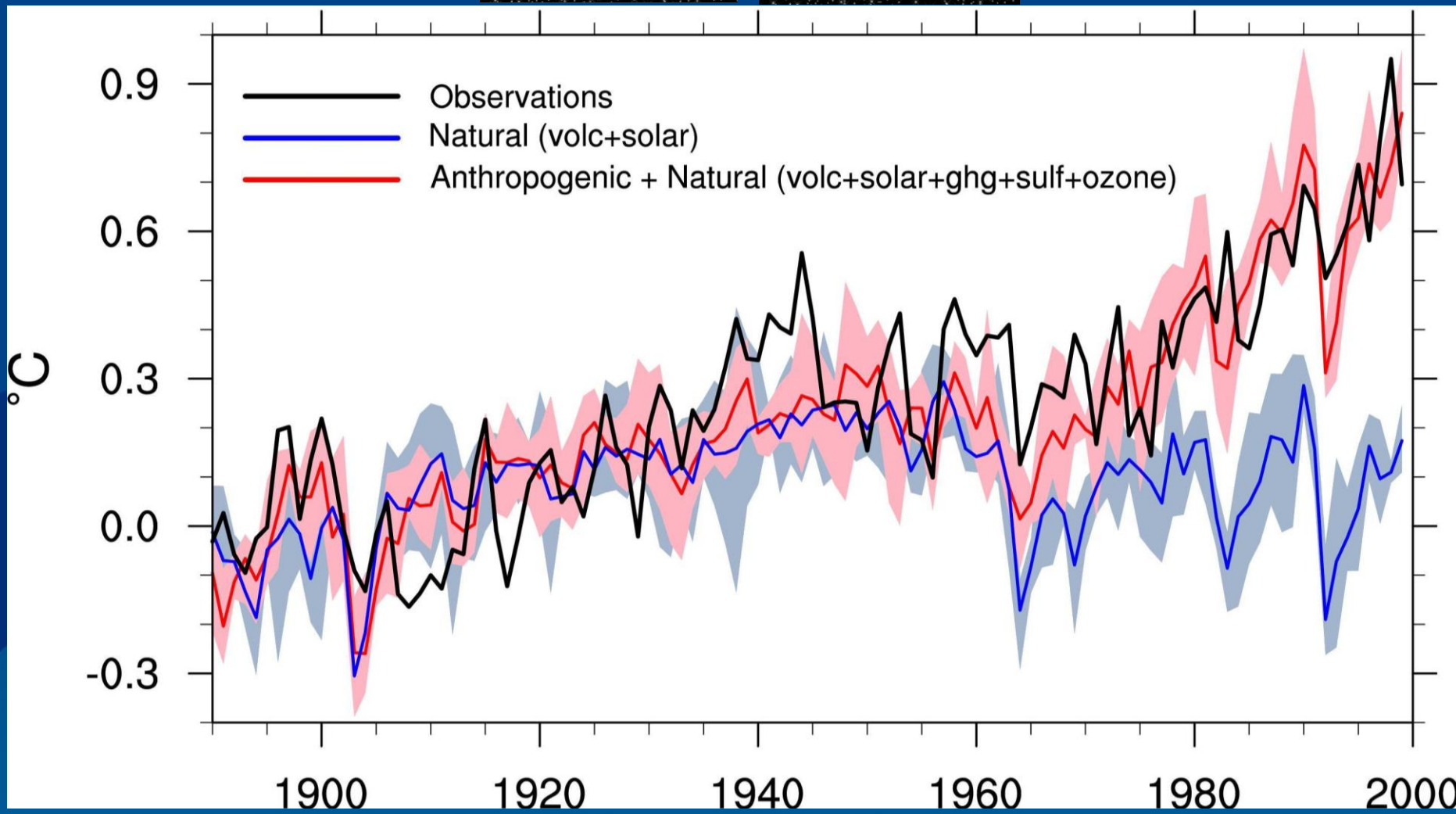

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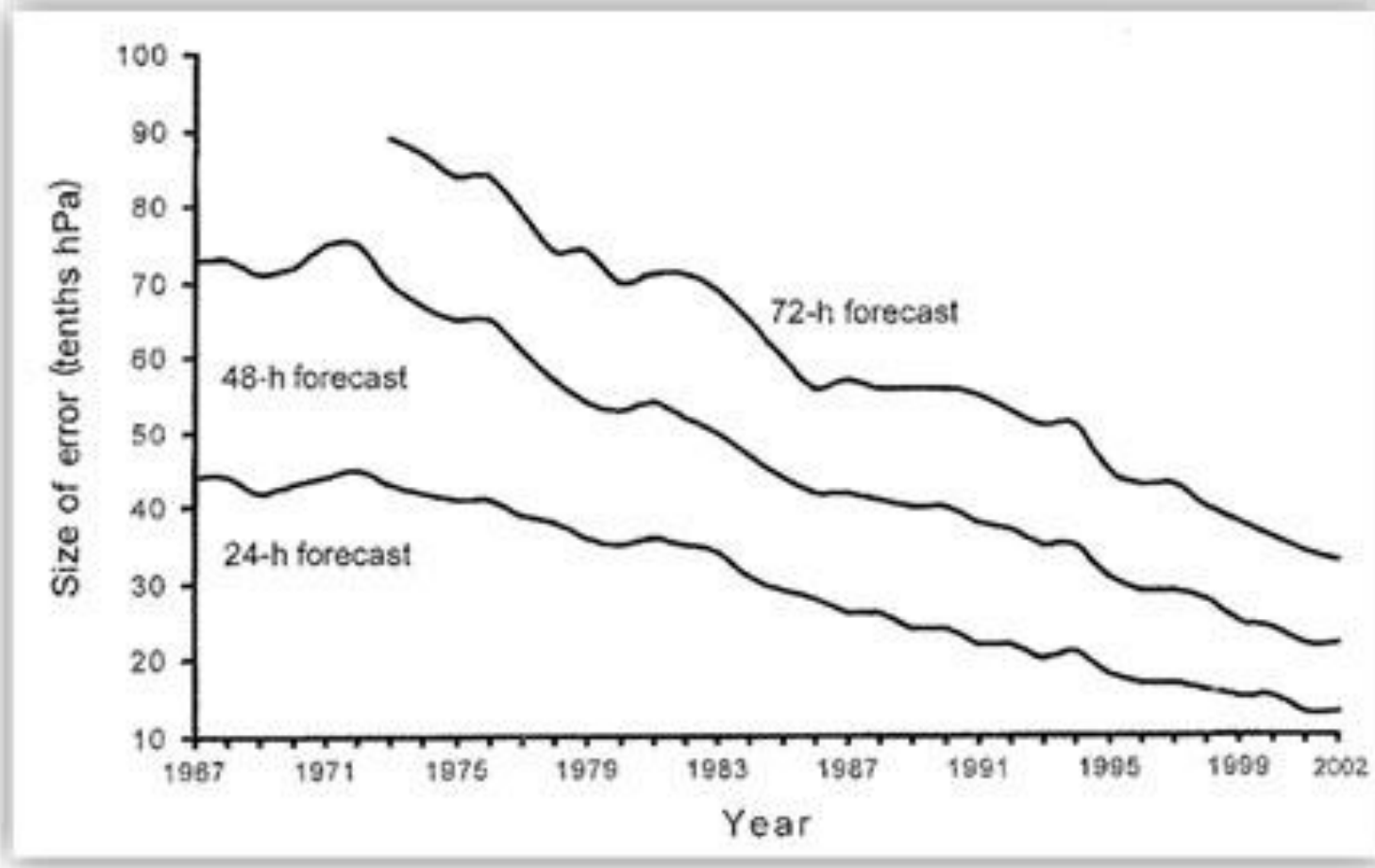
SUB CRUCE LUMEN

We can't predict the weather a week in advance, so how can we possibly predict 50 years ahead?


Size of error (tenths hPa)
100
90
80
70
60
50
40
30
20
10
72-h forecast
48-h forecast
24-h forecast
1967
1971
1975
1979
1983
1987
1991
1995
1999
2002
Year

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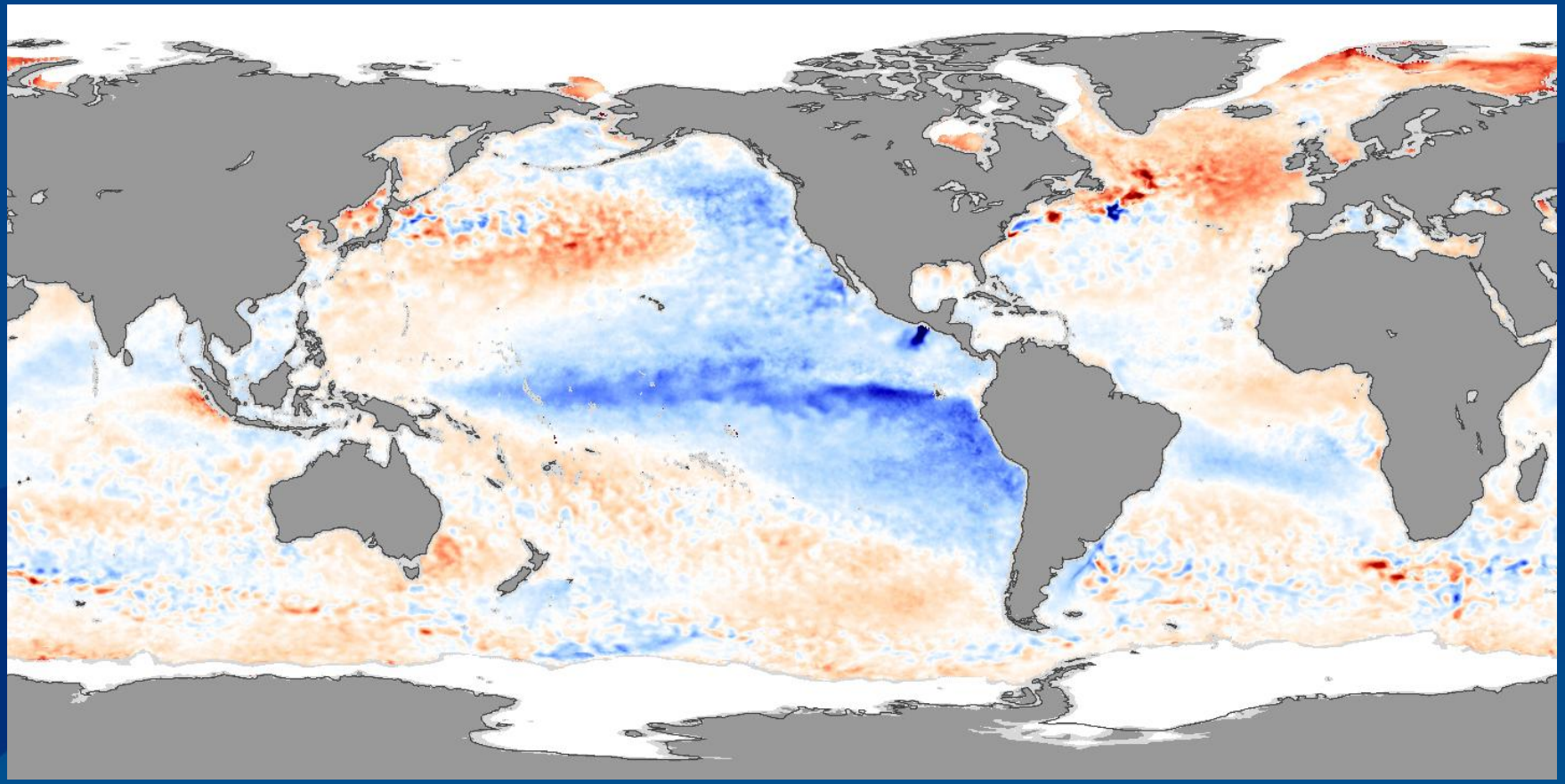
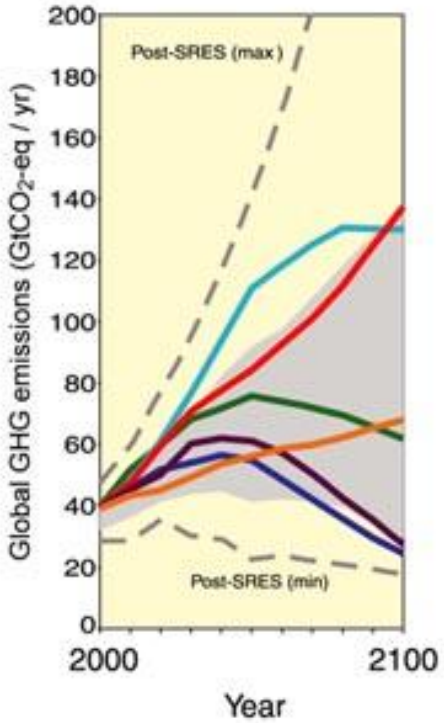
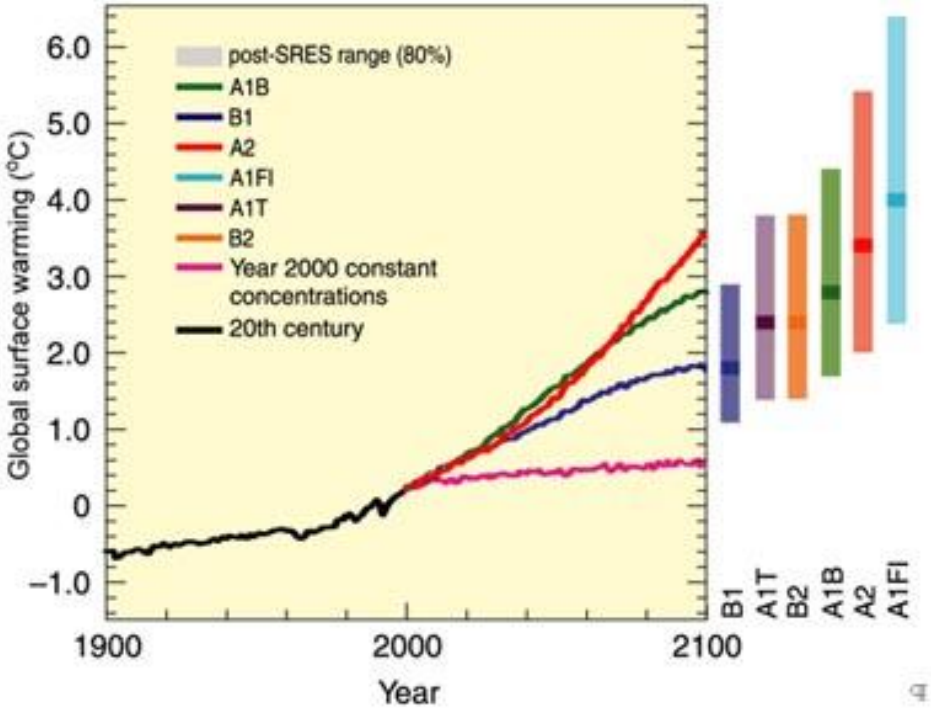


Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies) and projections of surface temperatures





Models ignore…

[*insert the thing they supposedly left out*]

Newton's second law

$$\frac{D_r u}{Dt} - \frac{uv\tan\phi}{r} - 2\Omega\sin\phi v + \frac{c_{pd}\theta}{r\cos\phi}\frac{\partial\Pi}{\partial\lambda} = -\left(\frac{uw}{r} + 2\Omega\cos\phi w\right) + S^u$$

$$\frac{D_r v}{Dt} + \frac{u^2\tan\phi}{r} + 2\Omega\sin\phi u + \frac{c_{pd}\theta}{r}\frac{\partial\Pi}{\partial\phi} = -\left(\frac{vw}{r}\right) + S^v$$

$$\frac{D_r w}{Dt} + c_{pd}\theta\frac{\partial\Pi}{\partial r} + \frac{\partial\Pi}{\partial r} = \left(\frac{u^2 + v^2}{r}\right) + 2\Omega\cos\phi u + S^w$$

mass continuity

$$\frac{D_r}{Dt}\left(\rho_d r^2\cos\phi\right) + \rho_d r^2\cos\phi\left[\frac{\partial}{\partial\lambda}\left(\frac{u}{r\cos\phi}\right) + \frac{\partial}{\partial\phi}\left(\frac{v}{r}\right) + \frac{\partial w}{\partial r}\right] = 0$$

thermodynamics

$$\frac{D_r\theta}{Dt} = S^\theta$$

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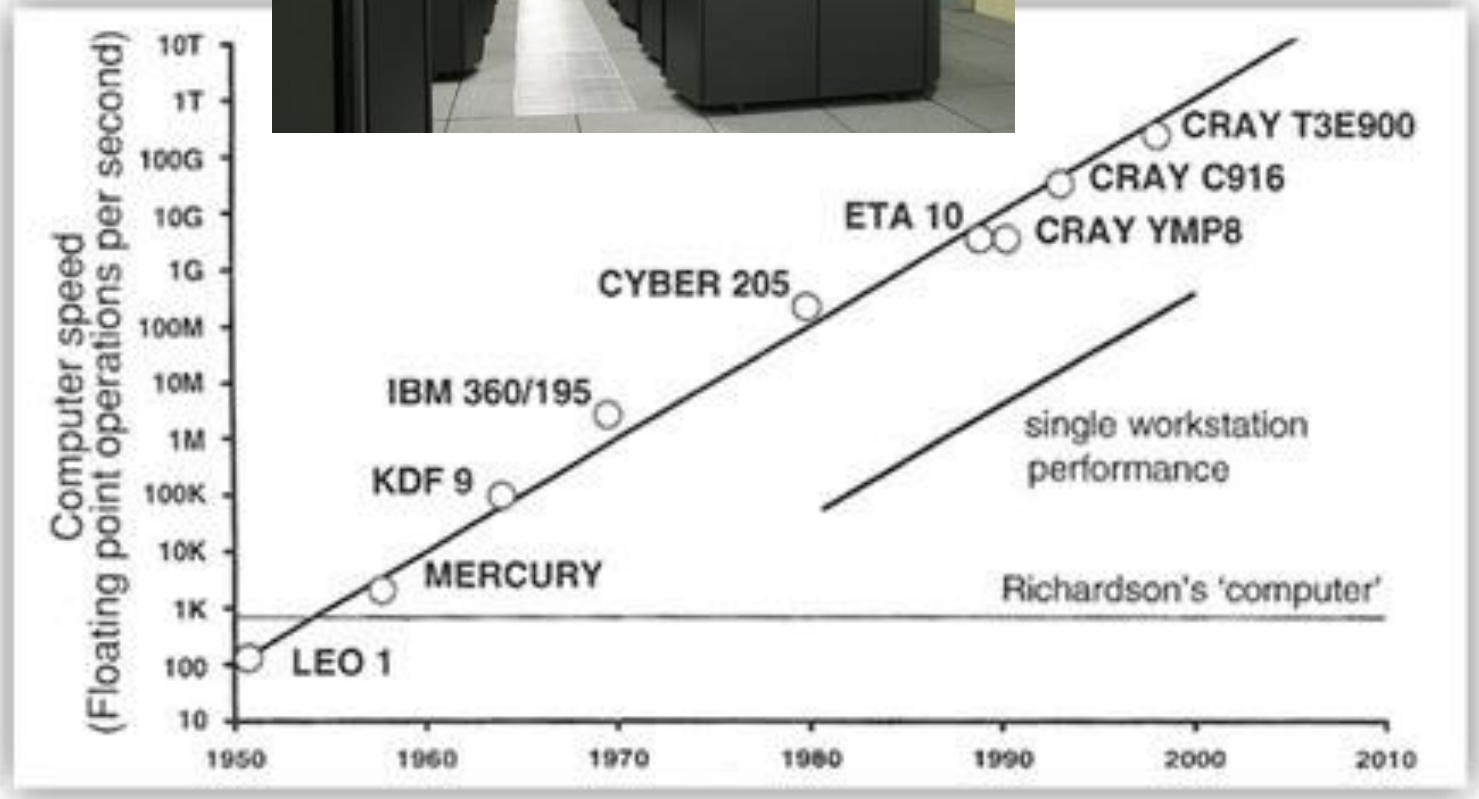
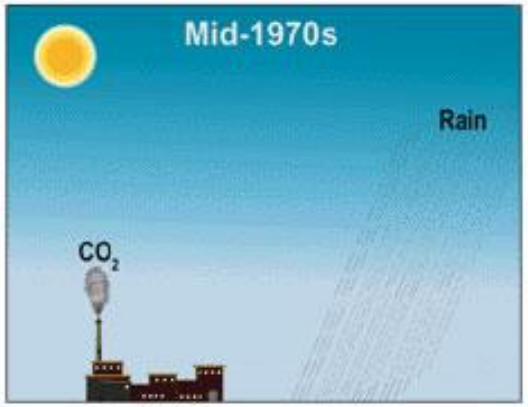
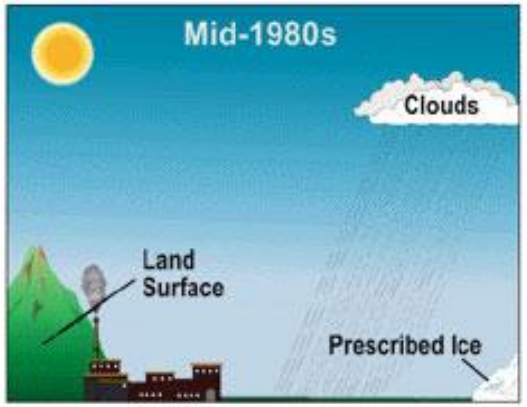
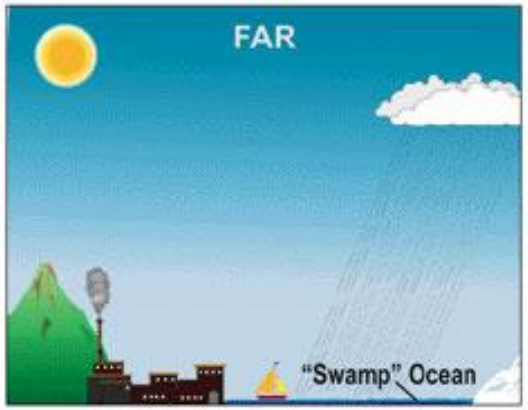
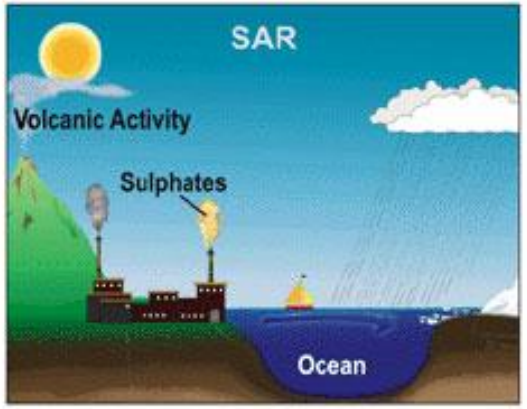


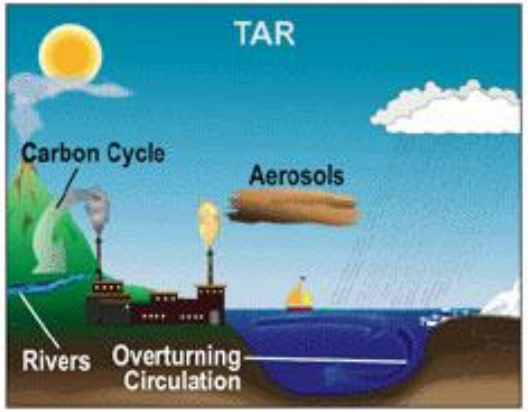
The World in Global Climate Models

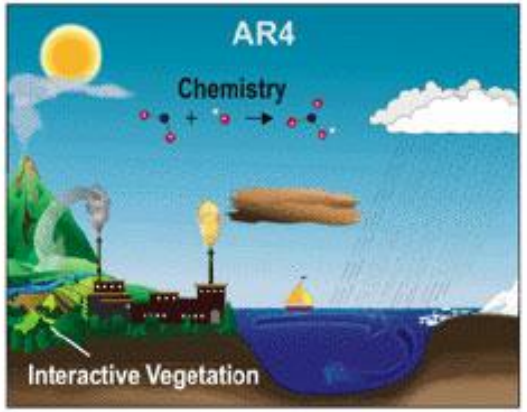


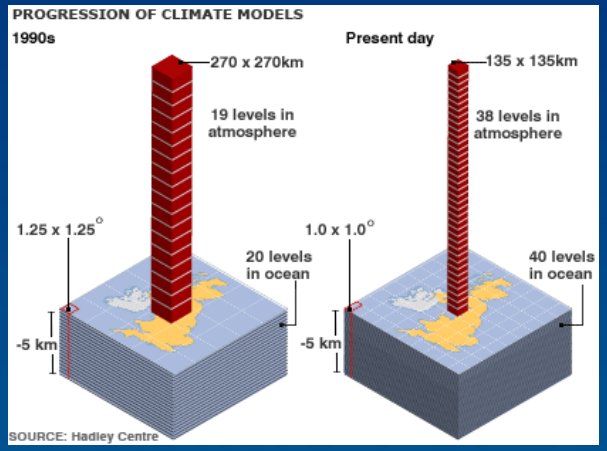


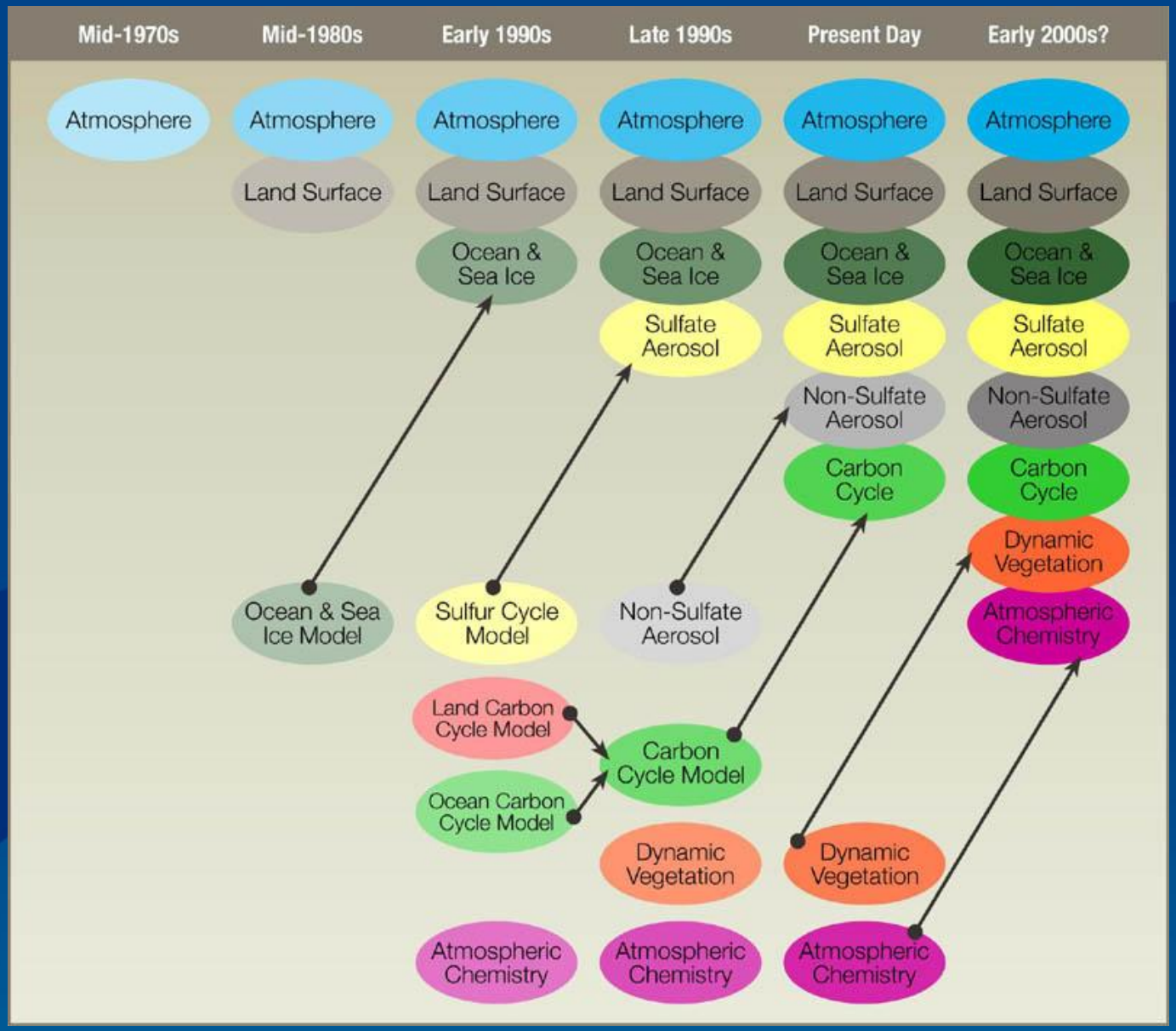


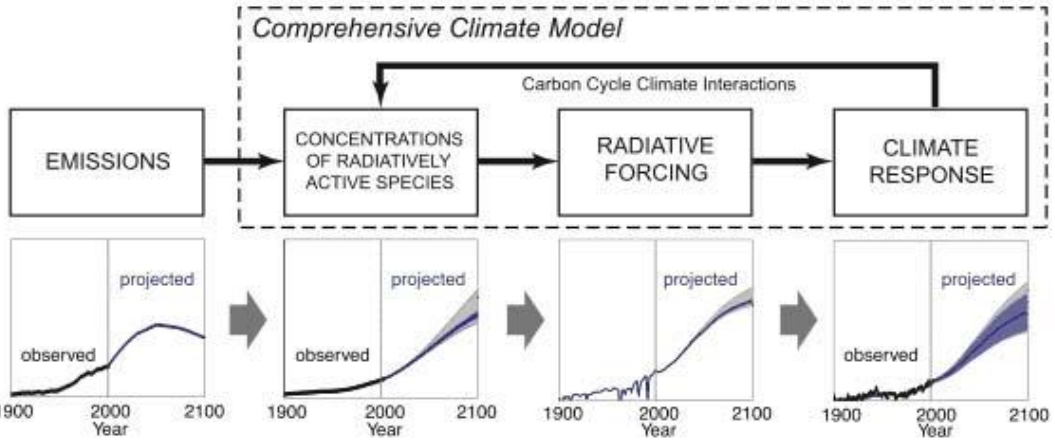


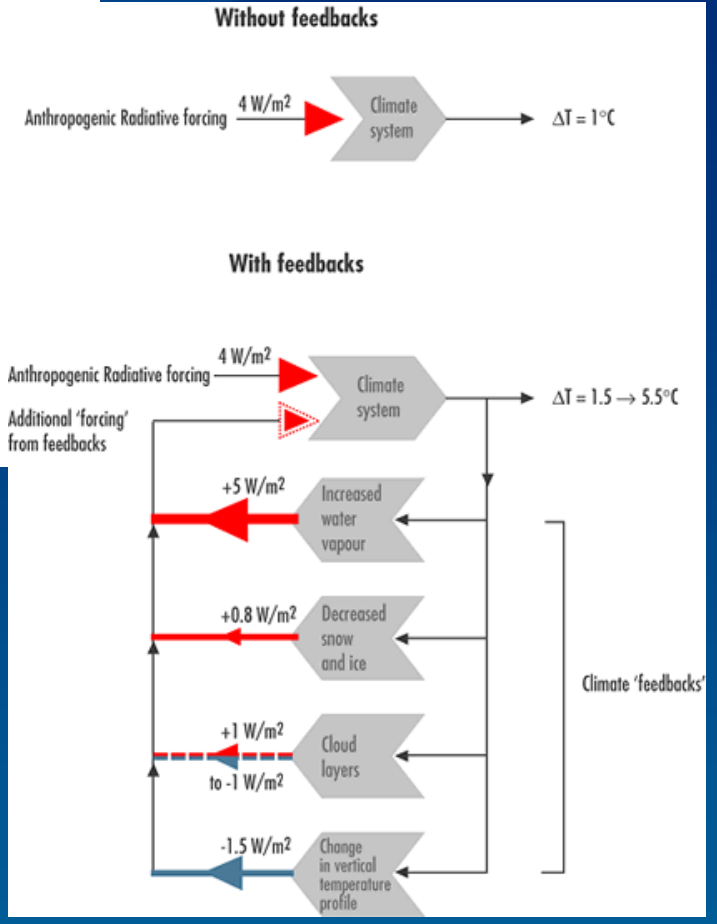


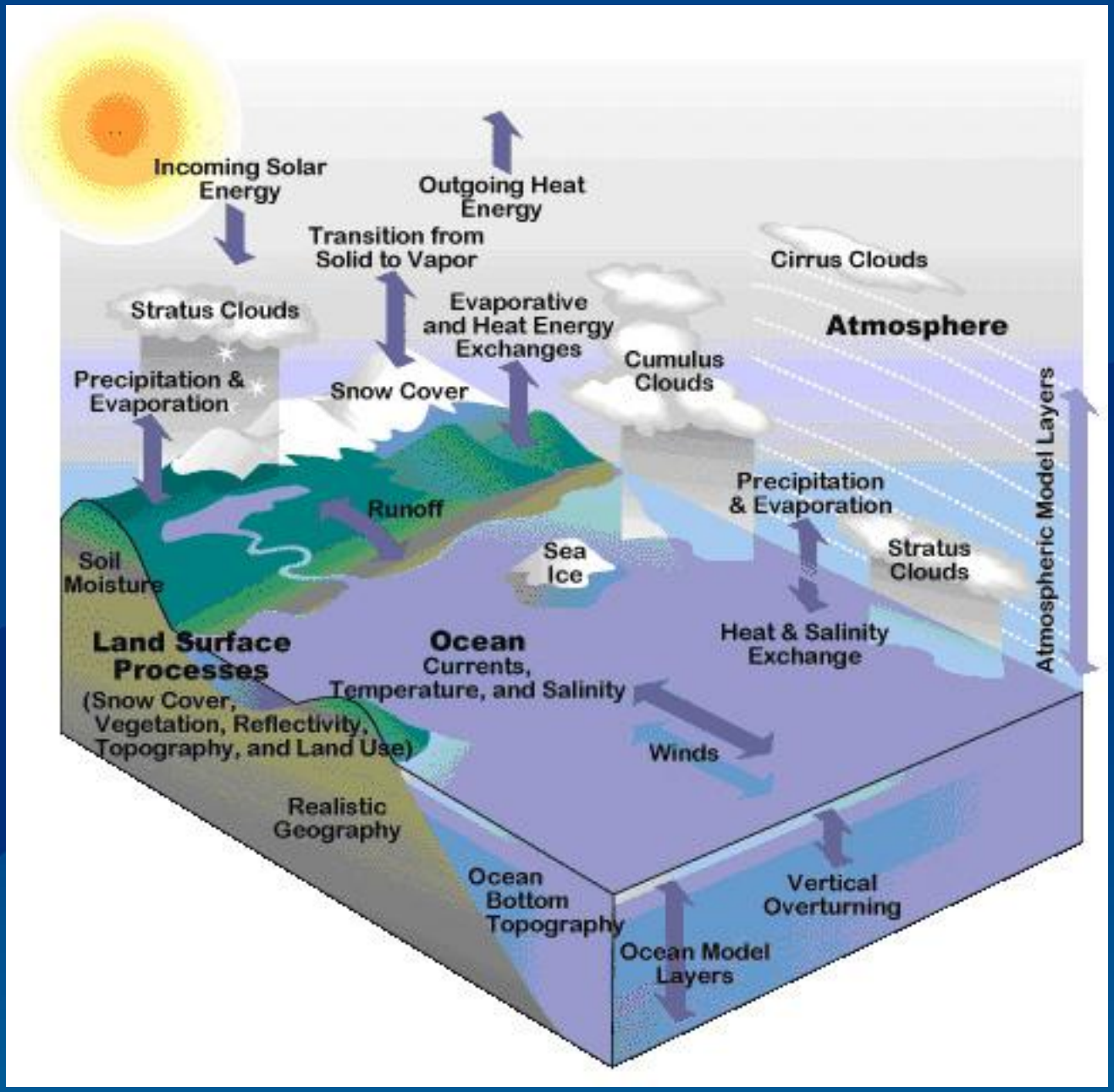





Mid-1970s
Mid-1980s
Early 1990s
Late 1990s
Present Day
Early 2000s?
Atmosphere
Land Surface
Ocean & Sea Ice
Sulfate Aerosol
Non-Sulfate Aerosol
Carbon Cycle
Dynamic Vegetation
Atmospheric Chemistry
Ocean & Sea Ice Model
Sulfur Cycle Model
Non-Sulfate Aerosol
Land Carbon Cycle Model
Ocean Carbon Cycle Model
Carbon Cycle Model
Dynamic Vegetation
Atmospheric Chemistry


Comprehensive Climate Model
Carbon Cycle Climate Interactions
EMISSIONS
CONCENTRATIONS OF RADIATIVELY ACTIVE SPECIES
RADIATIVE FORCING
CLIMATE RESPONSE
observed
projected
1900
2000
2100
Year


Without feedbacks
Anthropogenic Radiative forcing
4 W/m²
Climate system
ΔT = 1°C
With feedbacks
Anthropogenic Radiative forcing
4 W/m²
Additional 'forcing' from feedbacks
Climate system
ΔT = 1.5 → 5.5°C
+5 W/m²
Increased water vapour
+0.8 W/m²
Decreased snow and ice
+1 W/m²
to -1 W/m²
Cloud layers
-1.5 W/m²
Change in vertical temperature profile
Climate 'feedbacks'


Incoming Solar Energy
Outgoing Heat Energy
Transition from Solid to Vapor
Cirrus Clouds
Stratus Clouds
Evaporative and Heat Energy Exchanges
Atmosphere
Cumulus Clouds
Precipitation & Evaporation
Snow Cover
Atmospheric Model Layers
Precipitation & Evaporation
Runoff
Soil Moisture
Sea Ice
Stratus Clouds
Land Surface Processes
(Snow Cover, Vegetation, Reflectivity, Topography, and Land Use)
Ocean
Currents, Temperature, and Salinity
Heat & Salinity Exchange
Winds
Realistic Geography
Ocean Bottom Topography
Vertical Overturning
Ocean Model Layers

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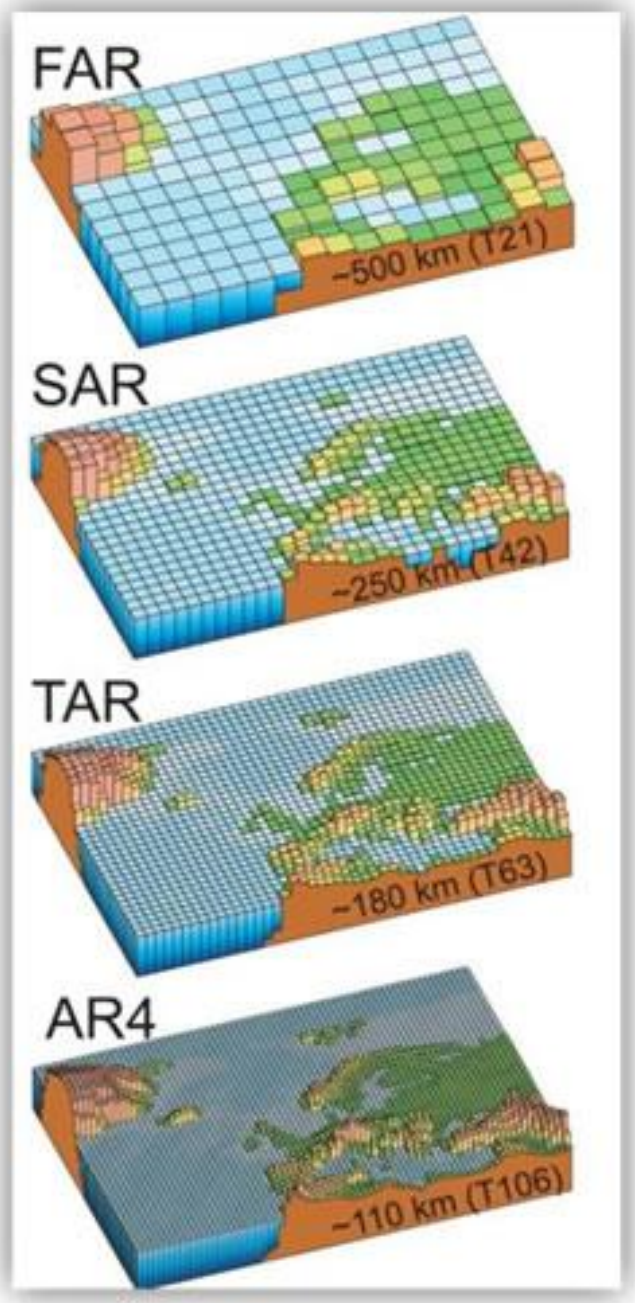
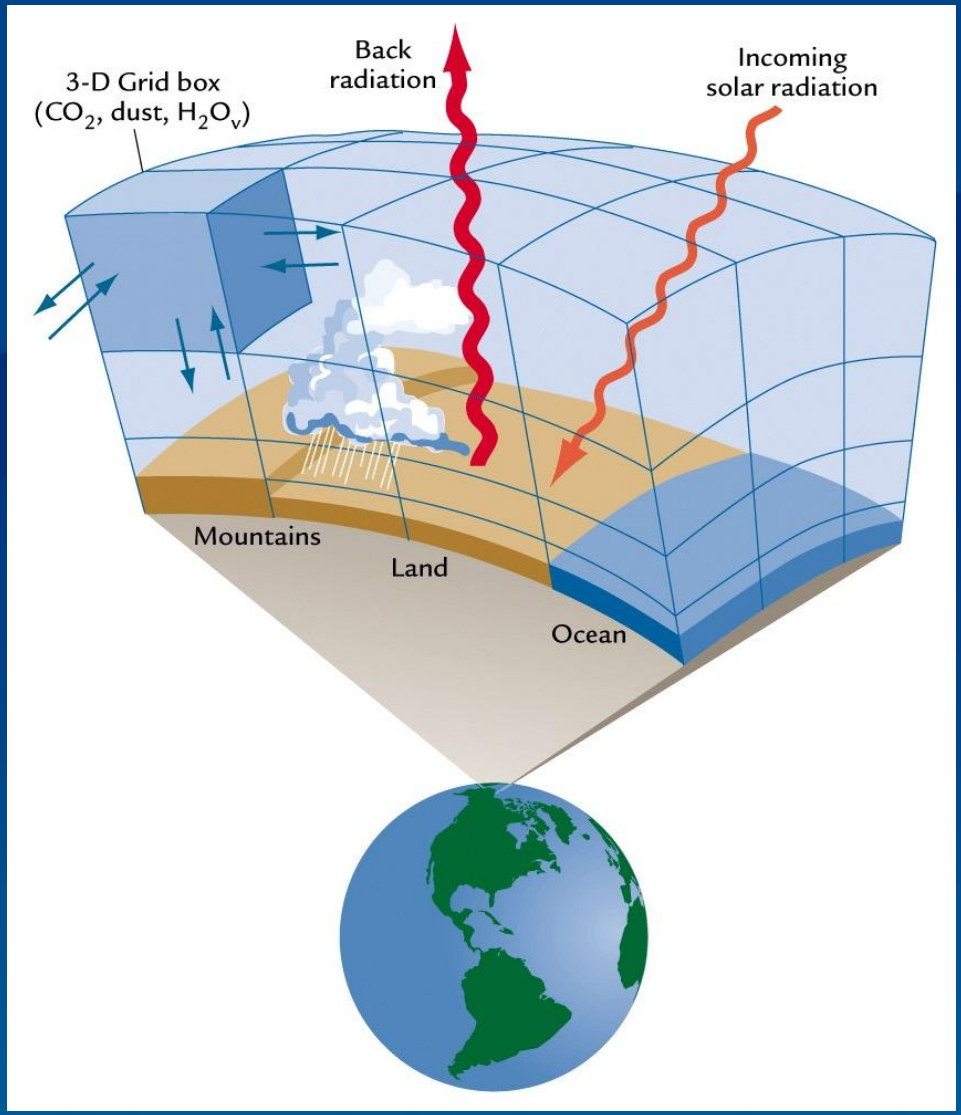
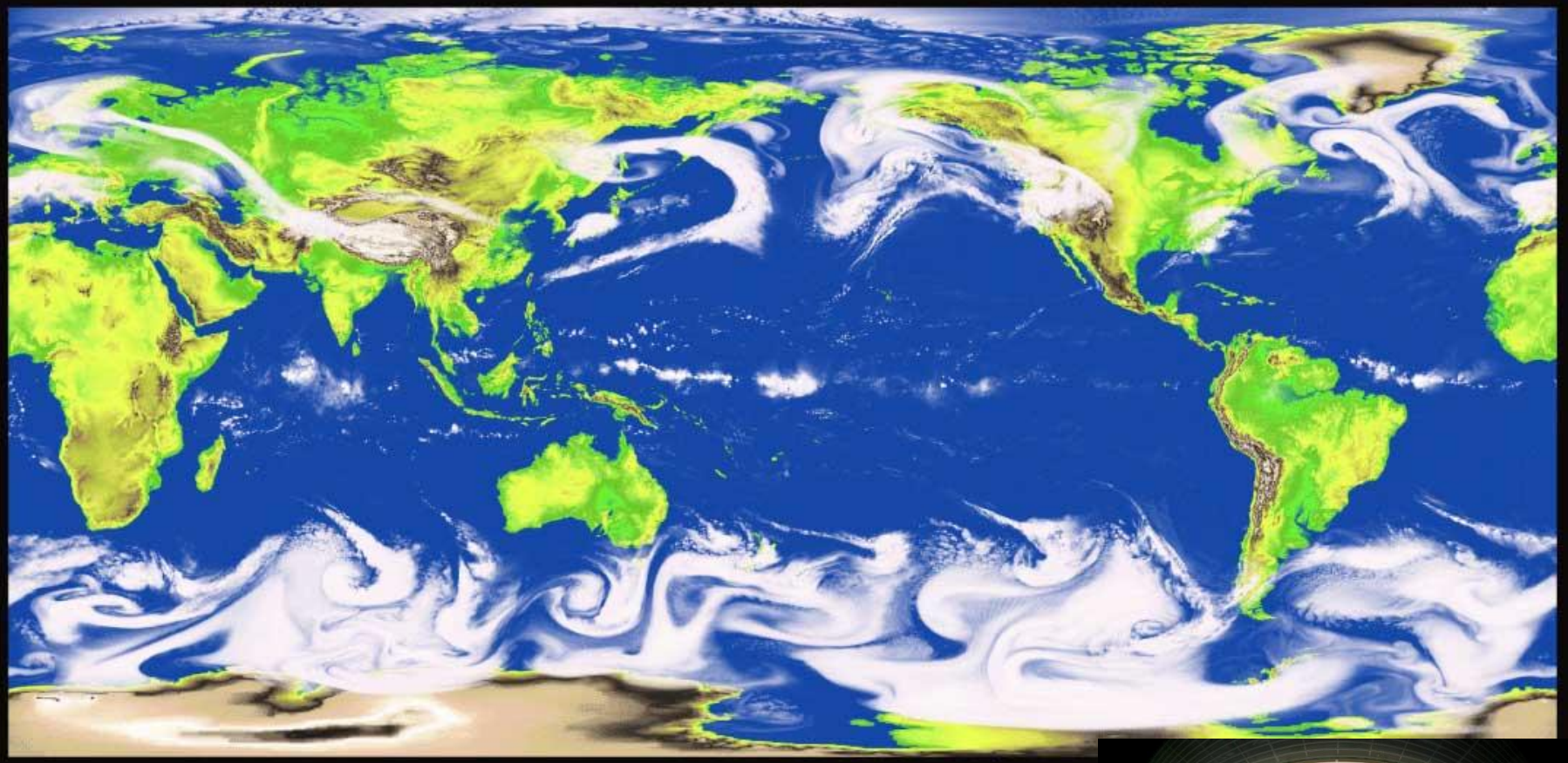




Global Mesoscale Circulation Model at GFDL



Scientists at the Geophysical Fluid Dynamics Laboratory (GFDL) have recently completed Project TERRA*. Project TERRA was co
simulation with the cloud-resolving nonhydrostatic ZETAC model. This model is the first Global Mesoscale Circulation Model (GMCN
perhaps the first global cloud-resolving model run anywhere that uses a grid resolution of 10-12Km.

Cloud distributions are of great importance in weather and climate. The correct distribution of latent heat produced by the mois
directly into the dynamics that generate weather systems. The vertical distribution of clouds is also of paramount importance in deter
characteristics of the atmosphere, which critically affect climate and climate change.

*Conceived and executed by Isidoro Orlanski and Christopher Kerr, GFDL.

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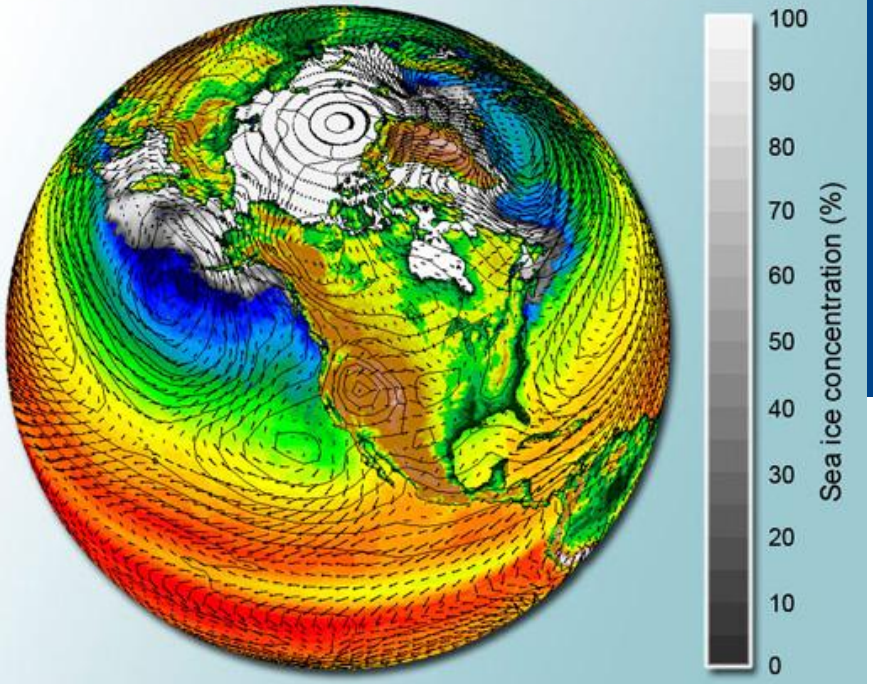
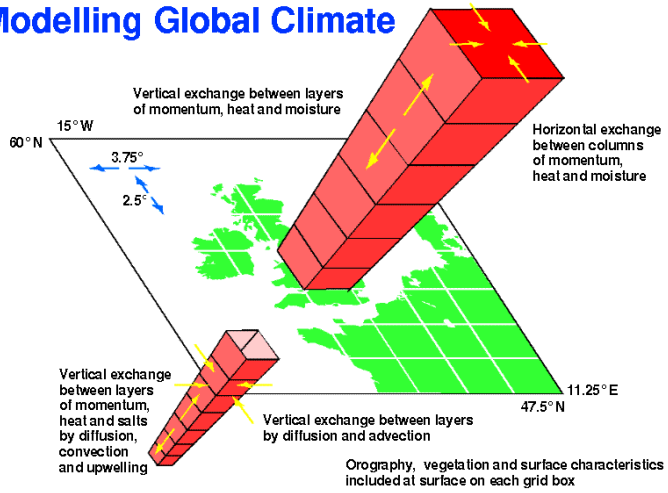
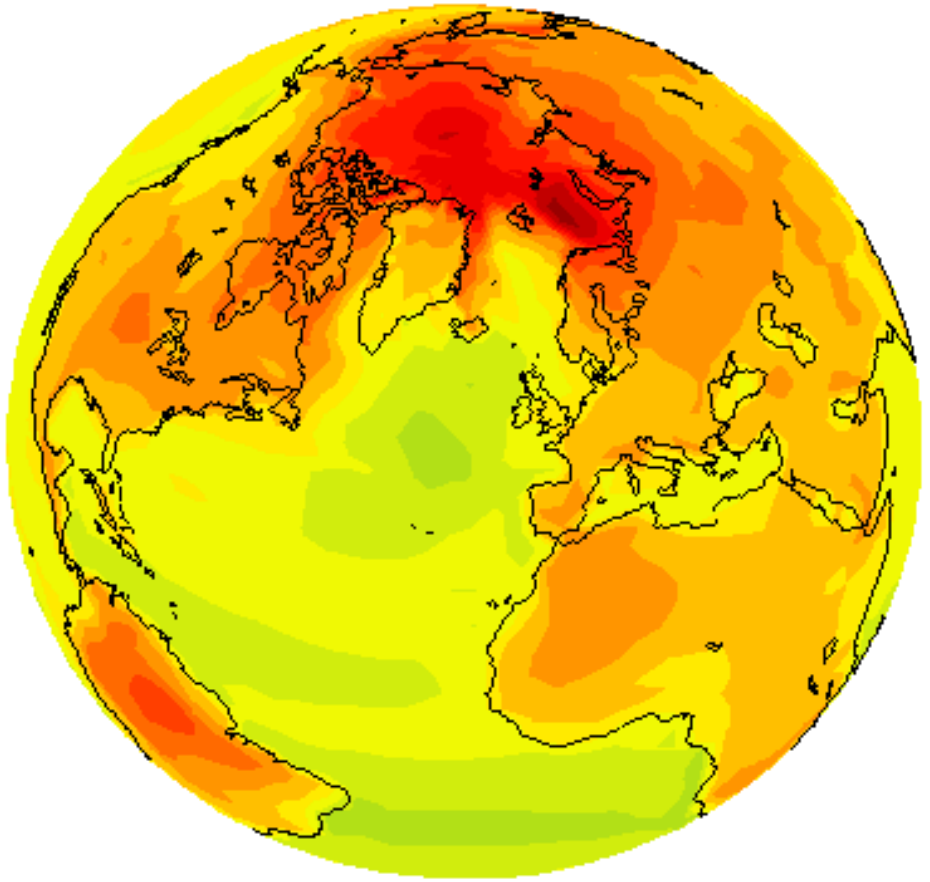


Modelling Global Climate





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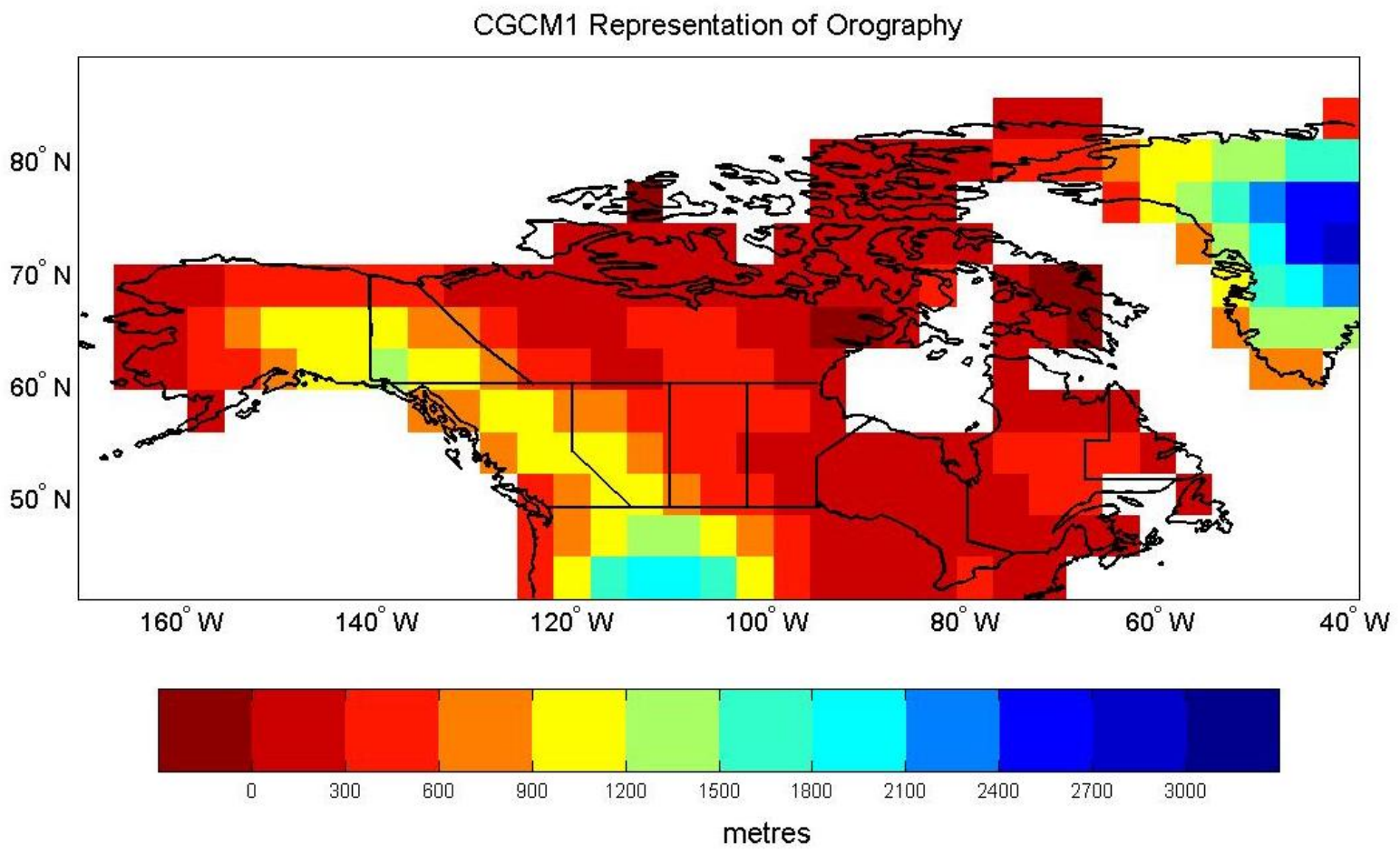

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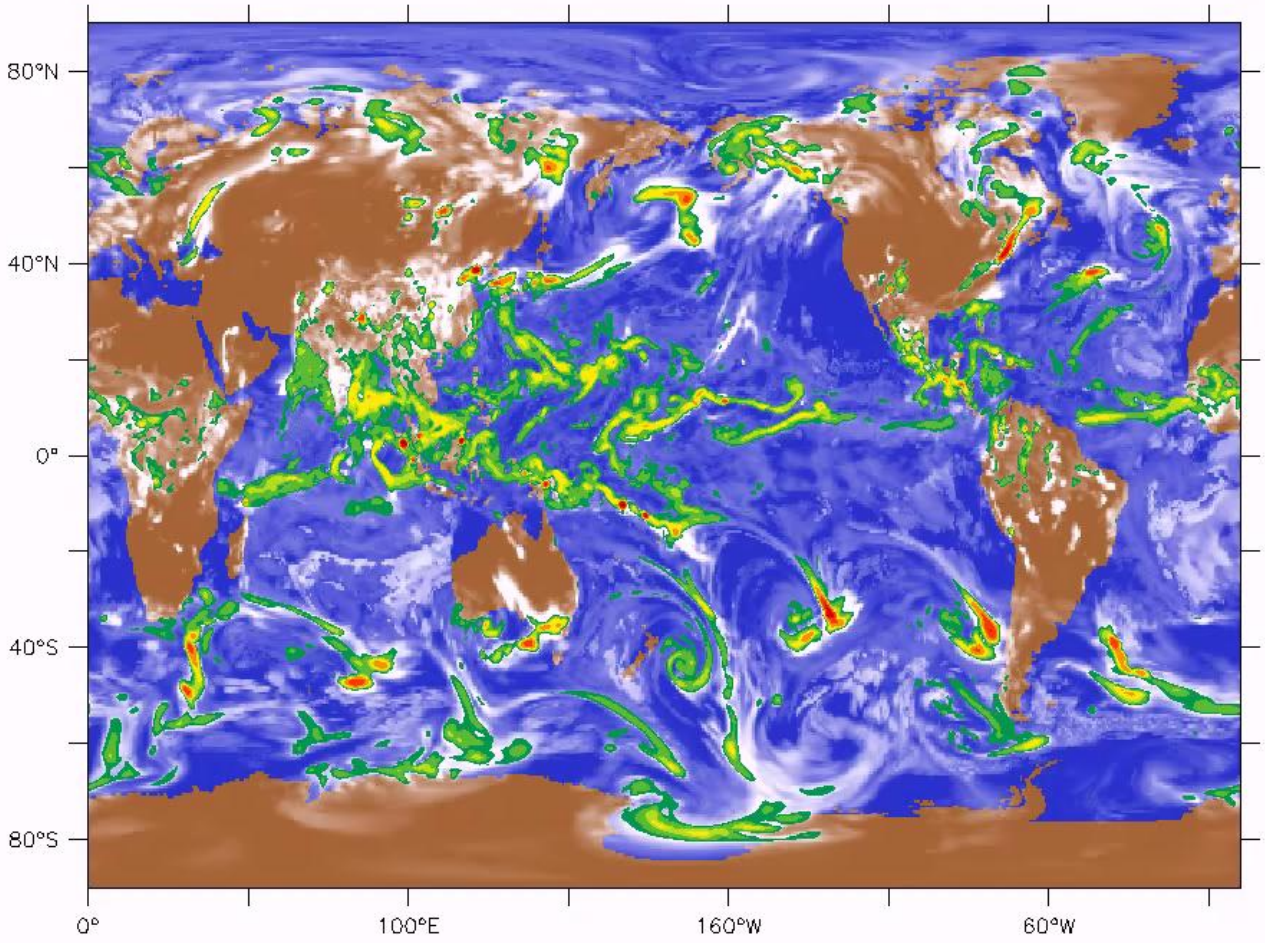
SUB CRUCE LUMEN

01–SEP



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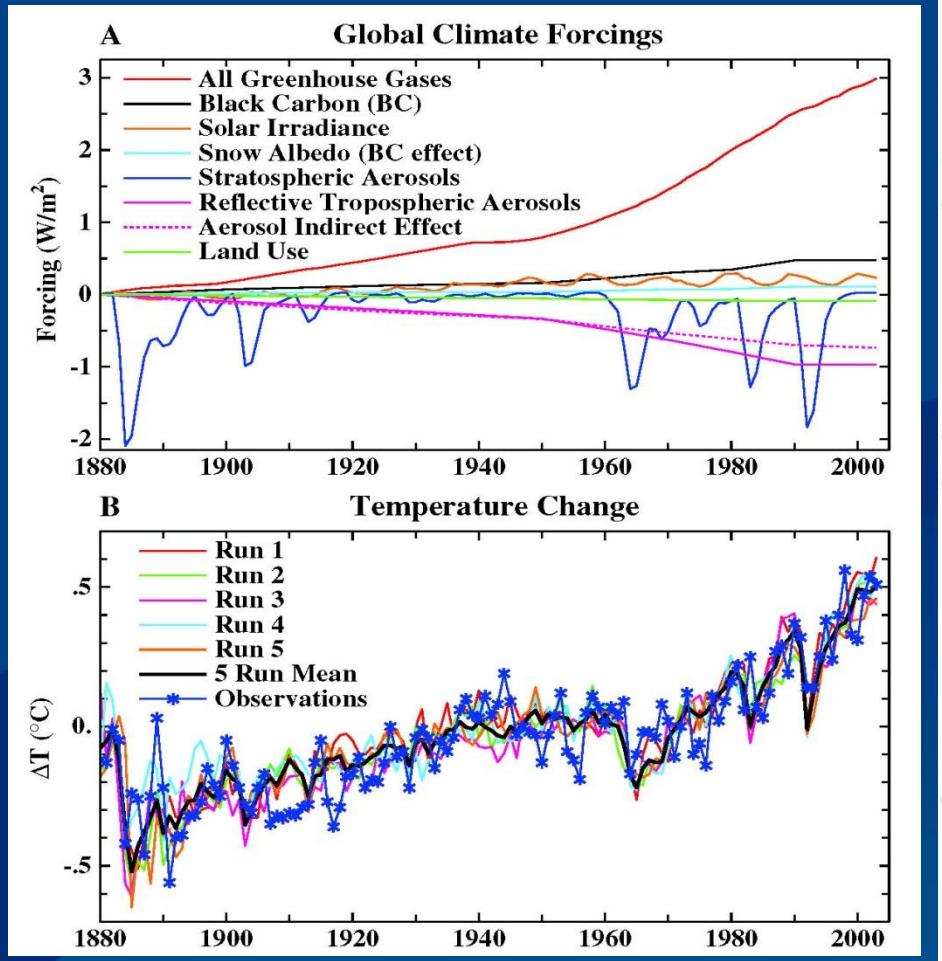
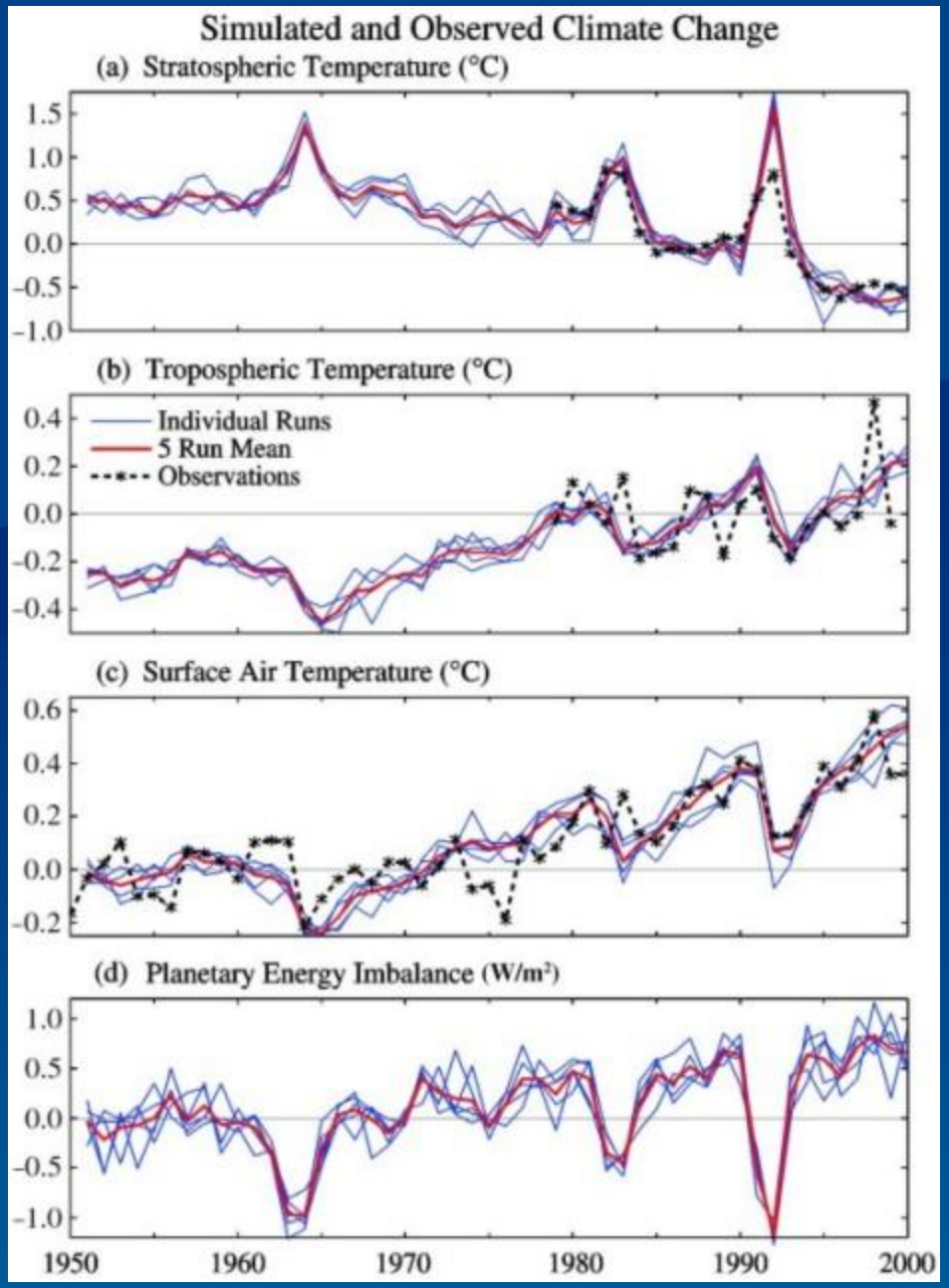
Models are unverified and ‘tuned’ to fit to past temperature change


A
Global Climate Forcings
All Greenhouse Gases
Black Carbon (BC)
Solar Irradiance
Snow Albedo (BC effect)
Stratospheric Aerosols
Reflective Tropospheric Aerosols
Aerosol Indirect Effect
Land Use
Forcing (W/m²)
3
2
1
0
-1
-2
1880
1900
1920
1940
1960
1980
2000
B
Temperature Change
Run 1
Run 2
Run 3
Run 4
Run 5
5 Run Mean
Observations
ΔT (°C)
.5
0.
-.5
1880
1900
1920
1940
1960
1980
2000


Simulated and Observed Climate Change
(a) Stratospheric Temperature (°C)
1.5
1.0
0.5
0.0
-0.5
-1.0
(b) Tropospheric Temperature (°C)
Individual Runs
5 Run Mean
Observations
0.4
0.2
0.0
-0.2
-0.4
(c) Surface Air Temperature (°C)
0.6
0.4
0.2
0.0
-0.2
(d) Planetary Energy Imbalance (W/m²)
1.0
0.5
0.0
-0.5
-1.0
1950
1960
1970
1980
1990
2000

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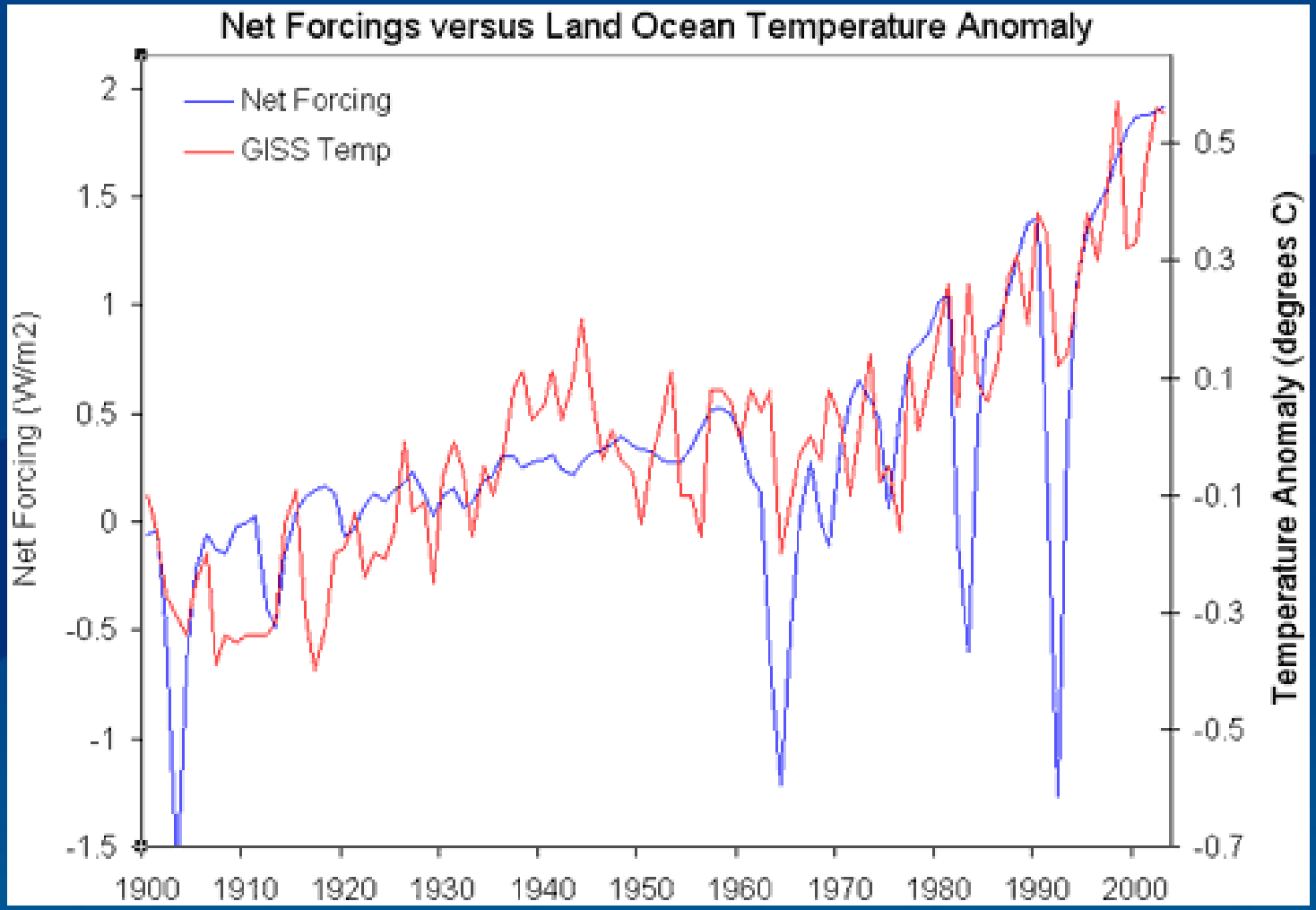

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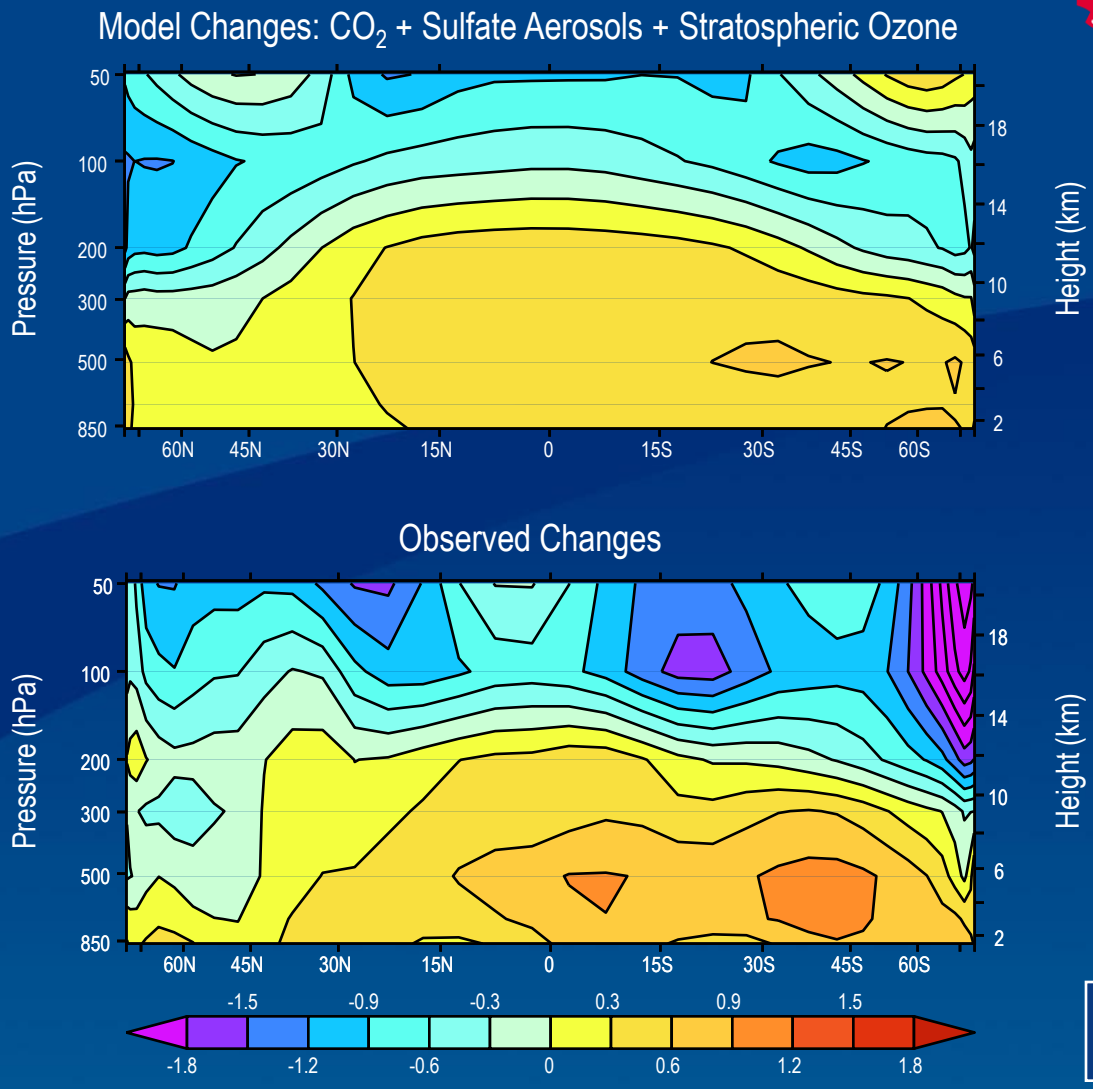
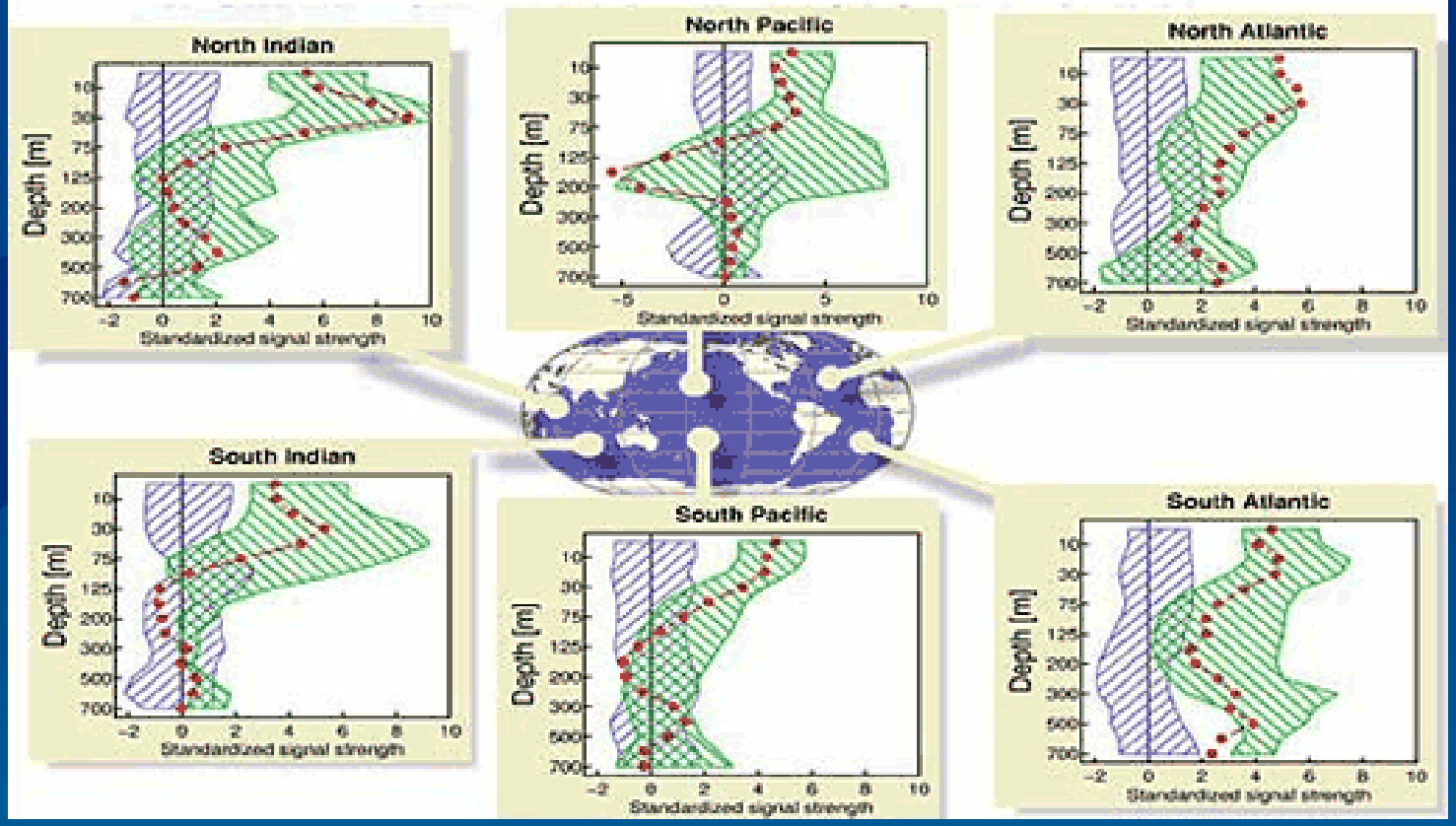


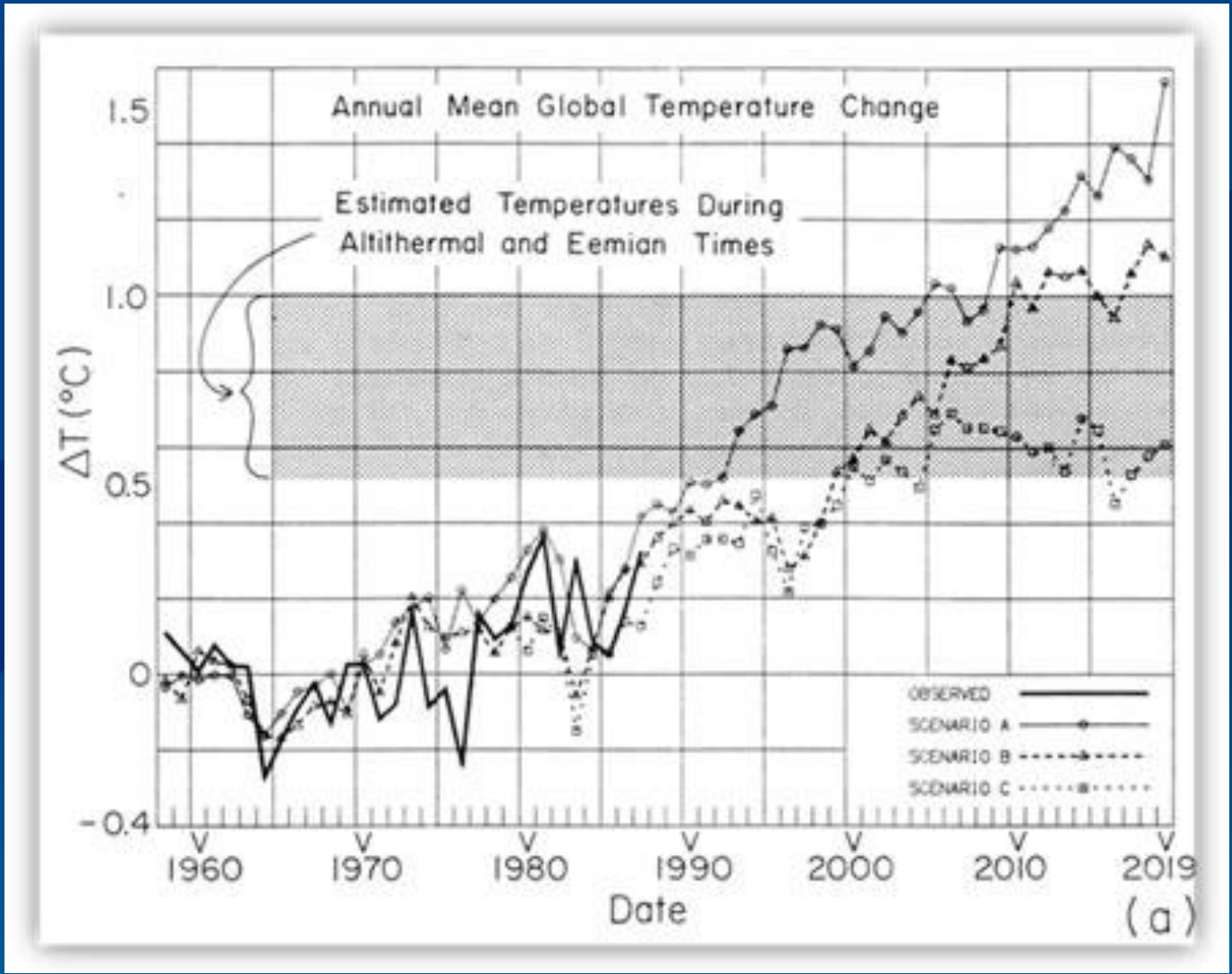
Temperature changes in ^{o}C

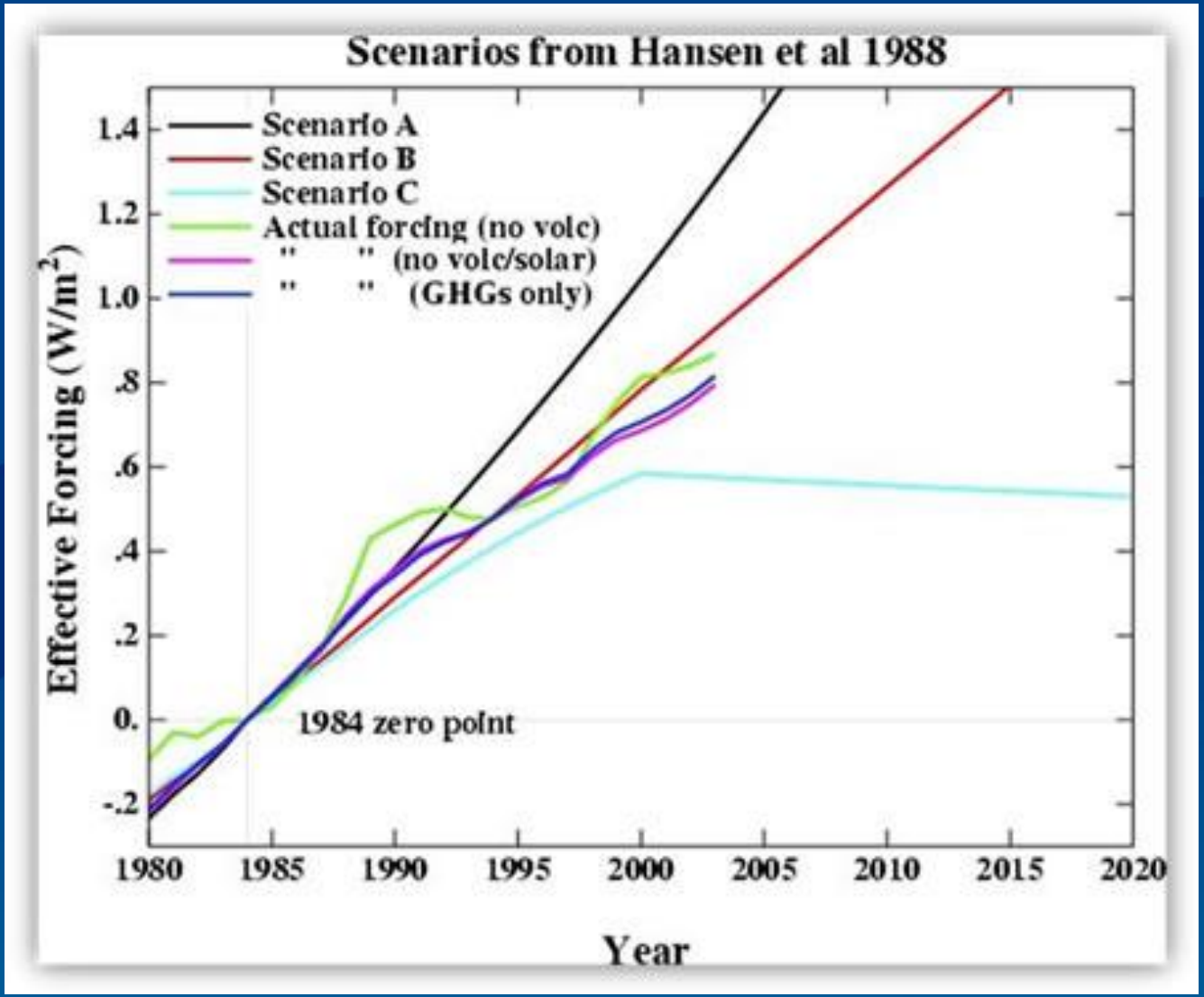
Santer *et al*., *Nature* (1996)

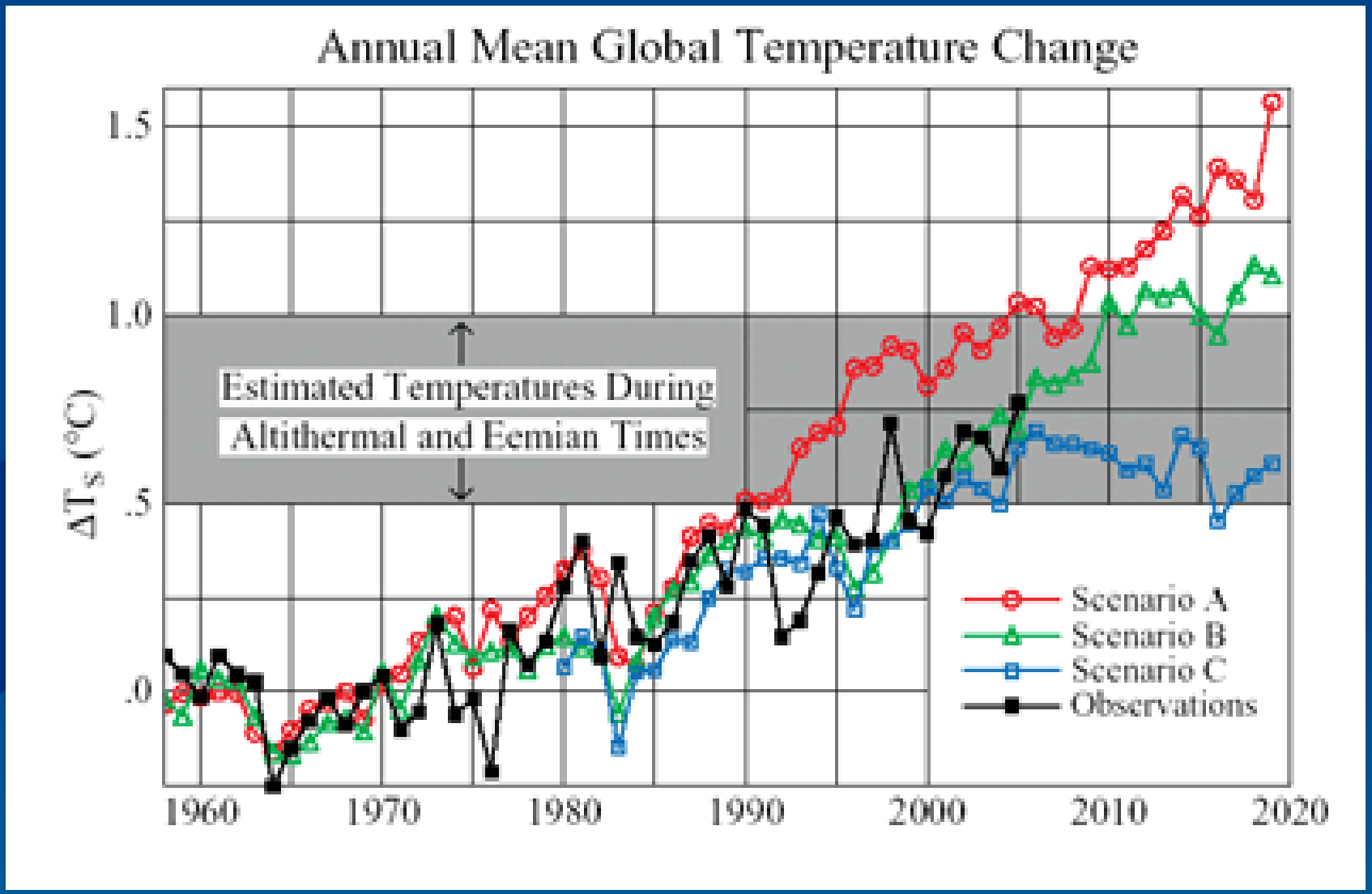
Penetration of Ocean Warming Signal (1960-1999)

RED: Observed ocean temps
GREEN Climate model with human-made greenhouse gas
BLUE Climate model without human-made greenhouse gas




Annual Mean Global Temperature Change
Estimated Temperatures During
Altithermal and Eemian Times
ΔT (°C)
1.5
1.0
0.5
0
-0.4
1960
1970
1980
1990
2000
2010
2019
Date
(a)
OBSERVED
SCENARIO A
SCENARIO B
SCENARIO C


Scenarios from Hansen et al 1988
Scenario A
Scenario B
Scenario C
Actual forcing (no volc)
" " (no volc/solar)
" " (GHGs only)
1984 zero point
Effective Forcing (W/m²)
1.4
1.2
1.0
.8
.6
.4
.2
0.
-.2
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year


Annual Mean Global Temperature Change
1.5
1.0
.5
.0
ΔTs (°C)
Estimated Temperatures During
Altithermal and Eemian Times
Scenario A
Scenario B
Scenario C
Observations
1960
1970
1980
1990
2000
2010
2020

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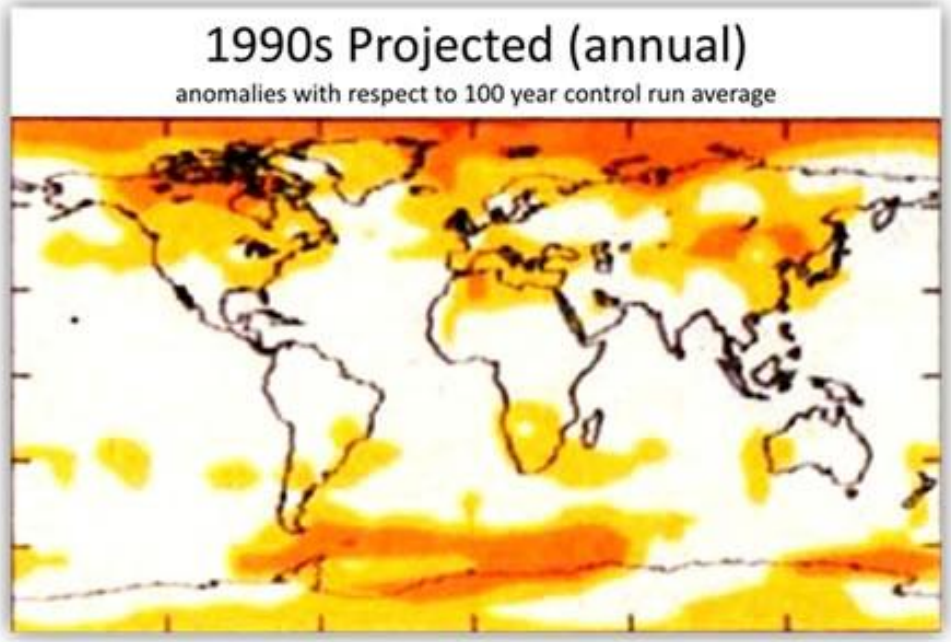
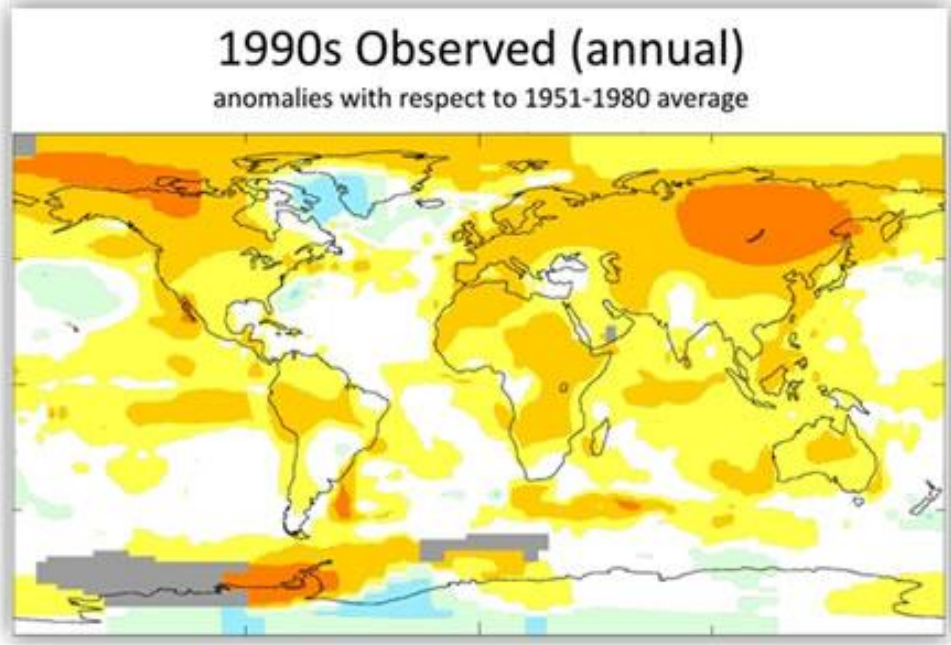
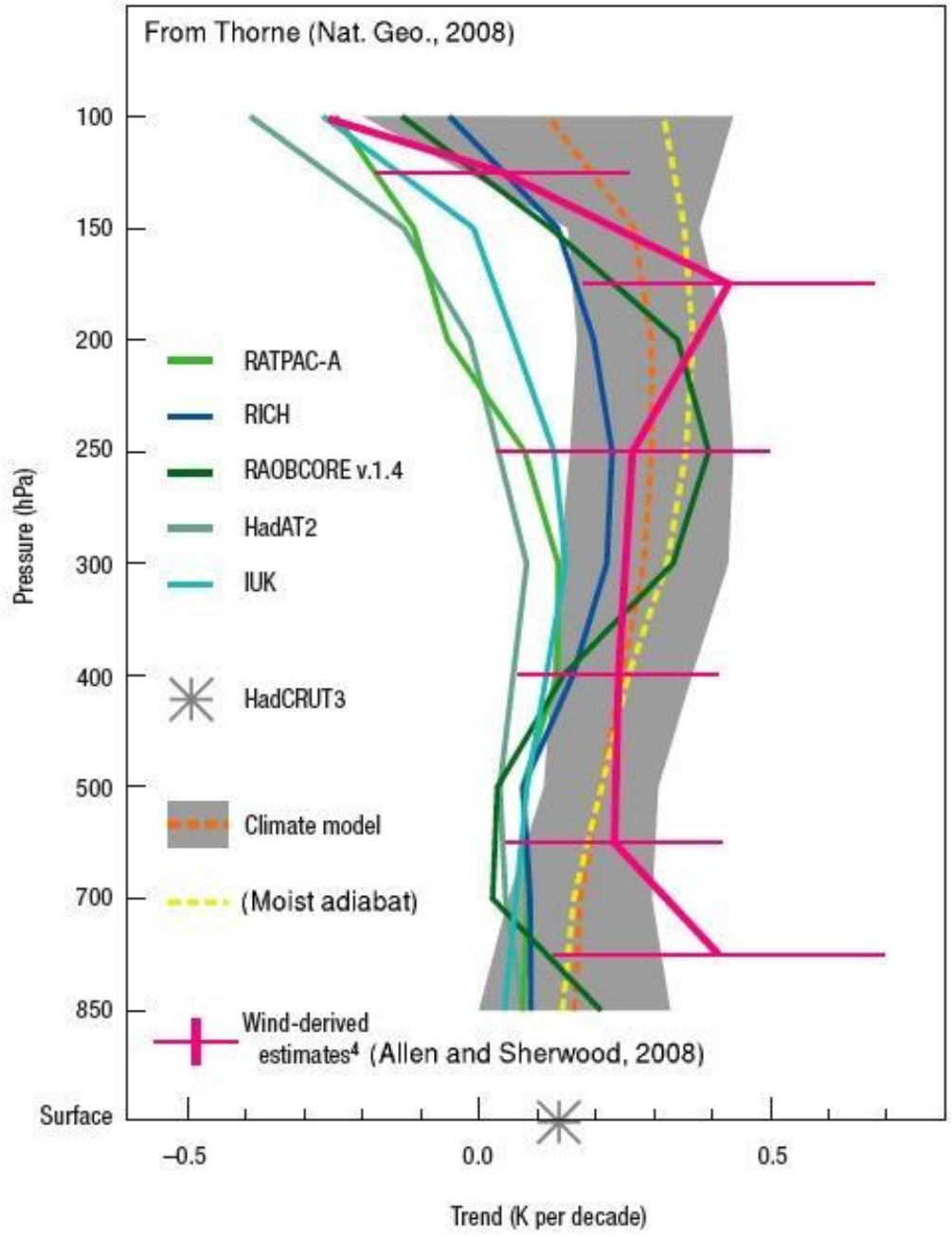
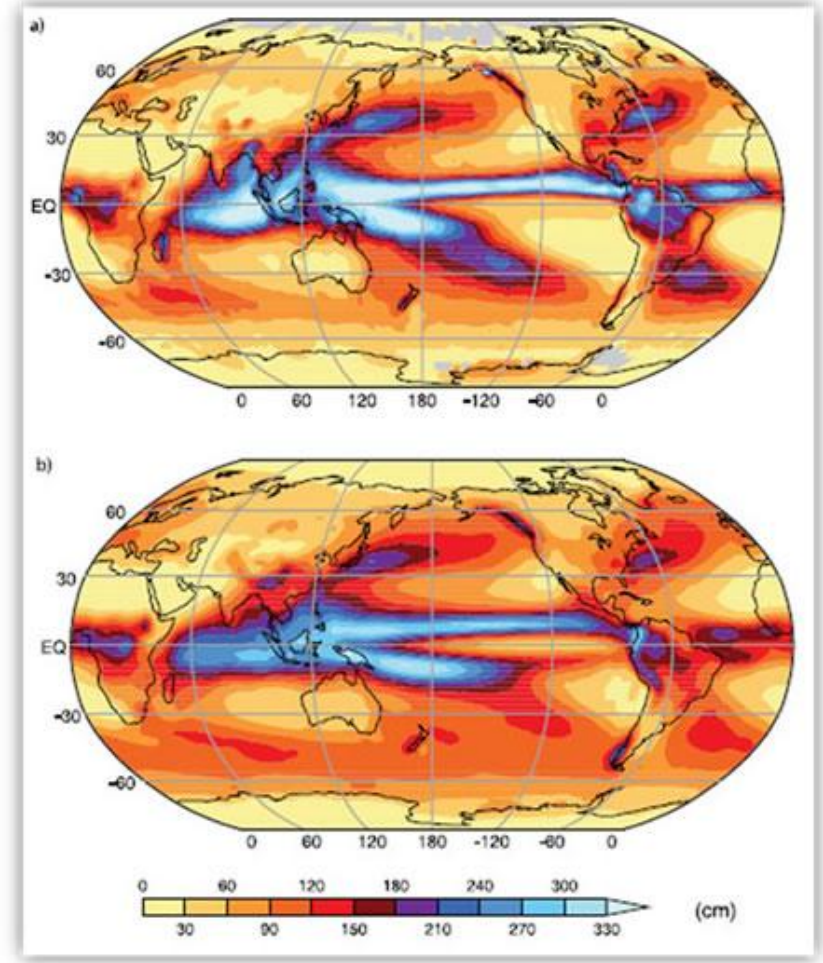
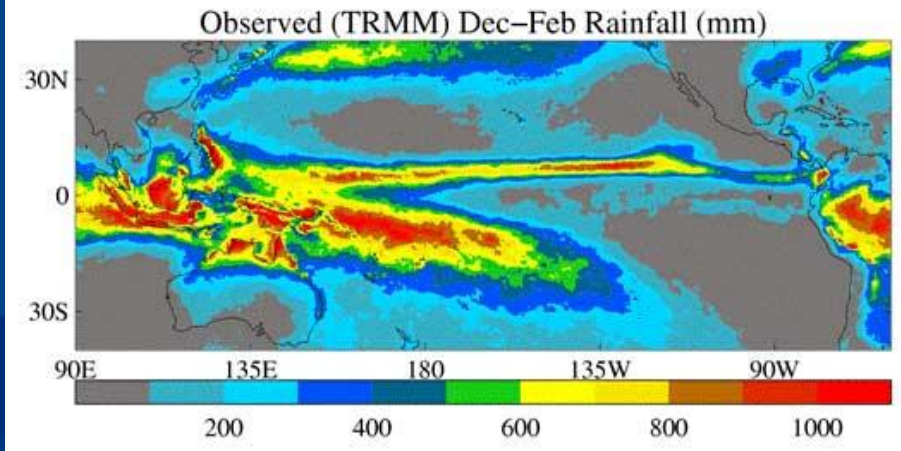
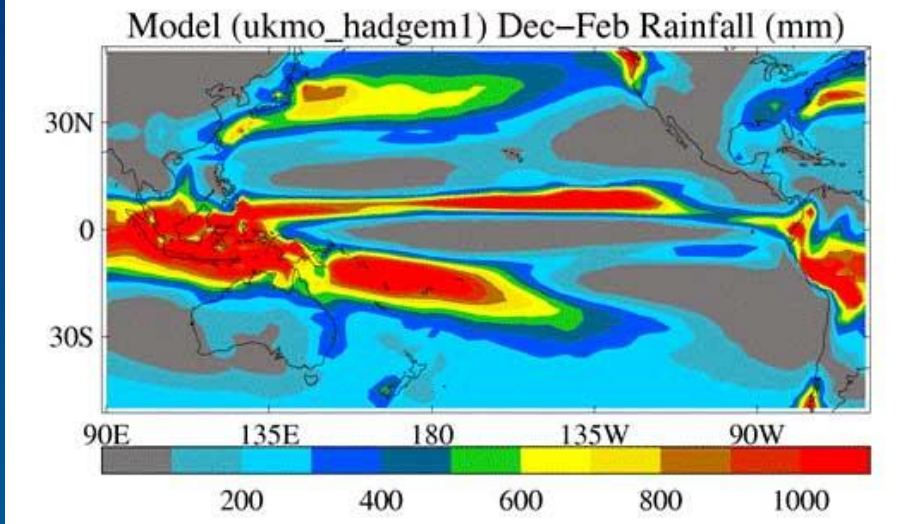




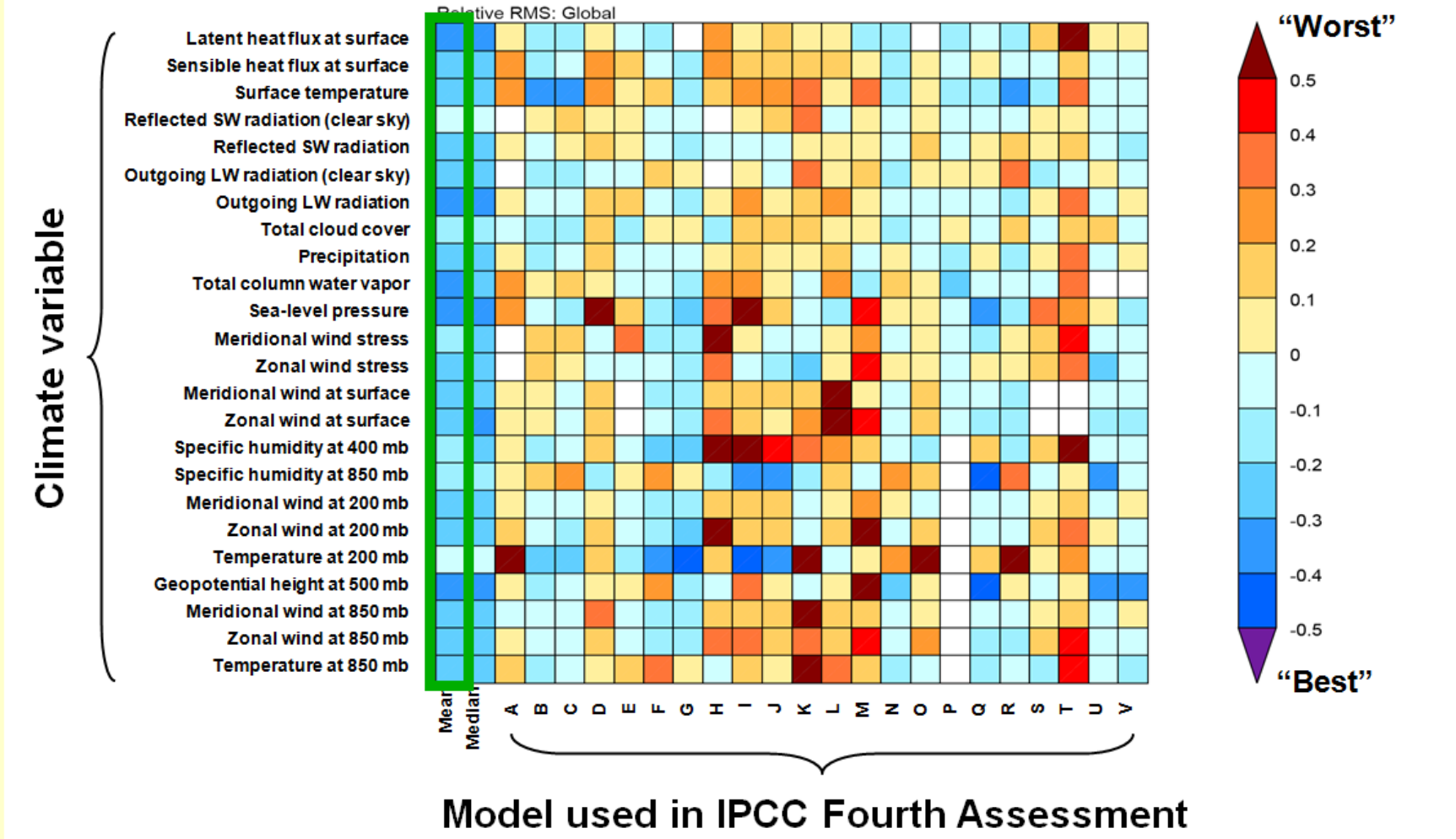



a)
60
30
EQ
-30
-60
0 60 120 180 -120 -60 0
b)
60
30
EQ
-30
-60
0 60 120 180 -120 -60 0
0 60 120 180 240 300
30 90 150 210 270 330
(cm)


Observed (TRMM) Dec–Feb Rainfall (mm)
30N
0
30S
90E 135E 180 135W 90W
200 400 600 800 1000


Model (ukmo_hadgem1) Dec–Feb Rainfall (mm)
30N
0
30S
90E 135E 180 135W 90W
200 400 600 800 1000

Evaluating how well computer models simulate seasonal changes in climate



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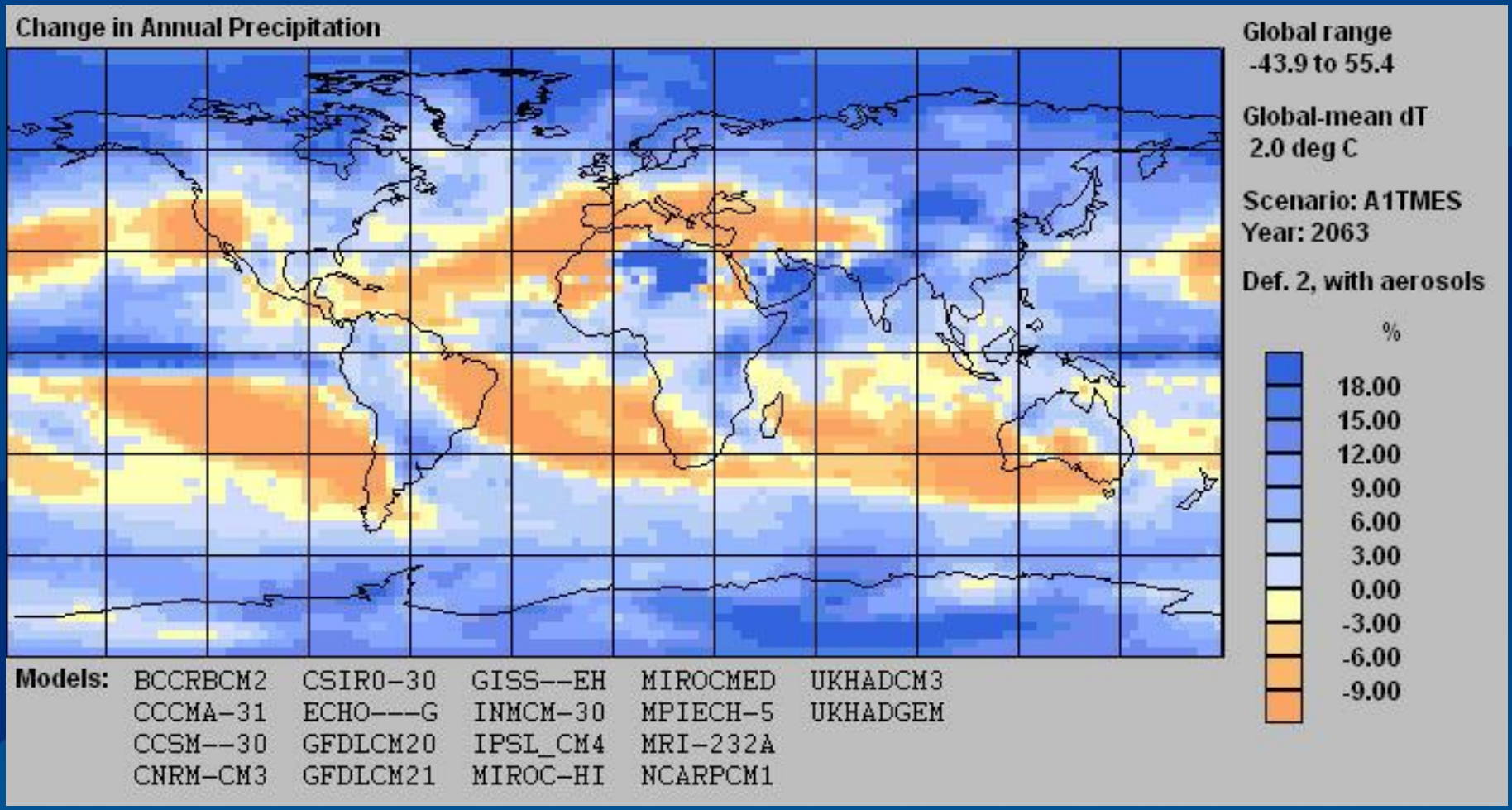
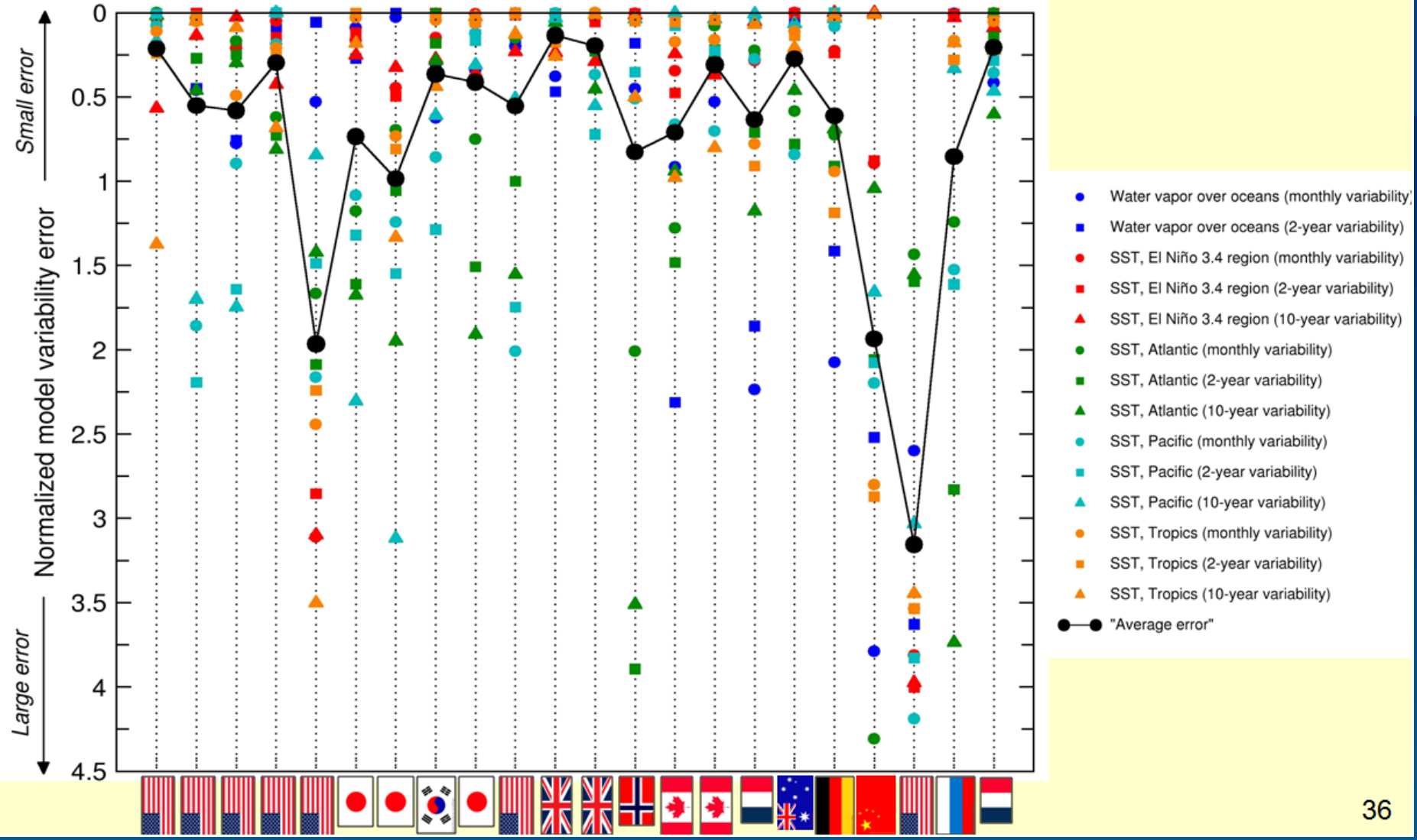


Model performance in simulating observed variability



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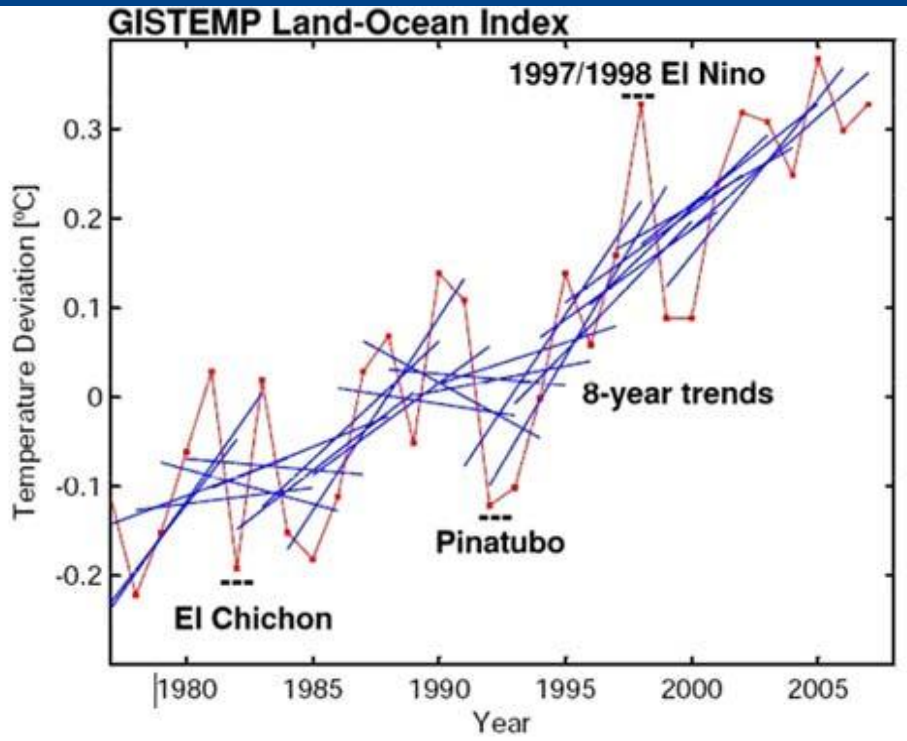
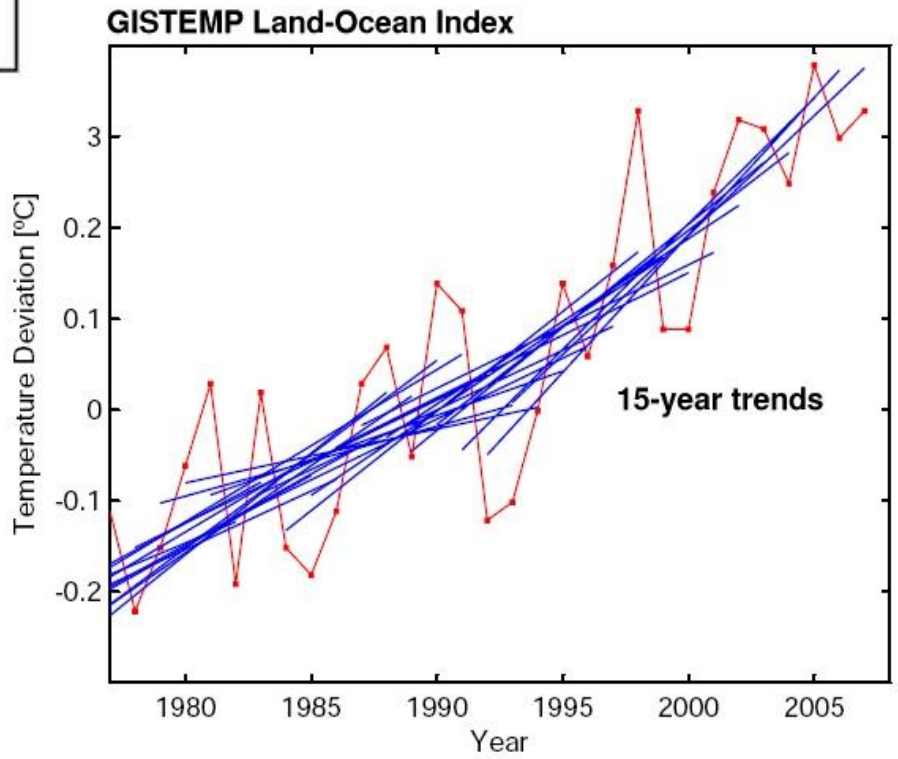
Recent flat temperatures disprove climate models


GISTEMP Land-Ocean Index
1997/1998 El Nino
8-year trends
Pinatubo
El Chichon
Temperature Deviation [°C]
Year
0.3
0.2
0.1
0
-0.1
-0.2
1980
1985
1990
1995
2000
2005


GISTEMP Land-Ocean Index
15-year trends
Temperature Deviation [°C]
Year
3
0.2
0.1
0
-0.1
-0.2
1980
1985
1990
1995
2000
2005

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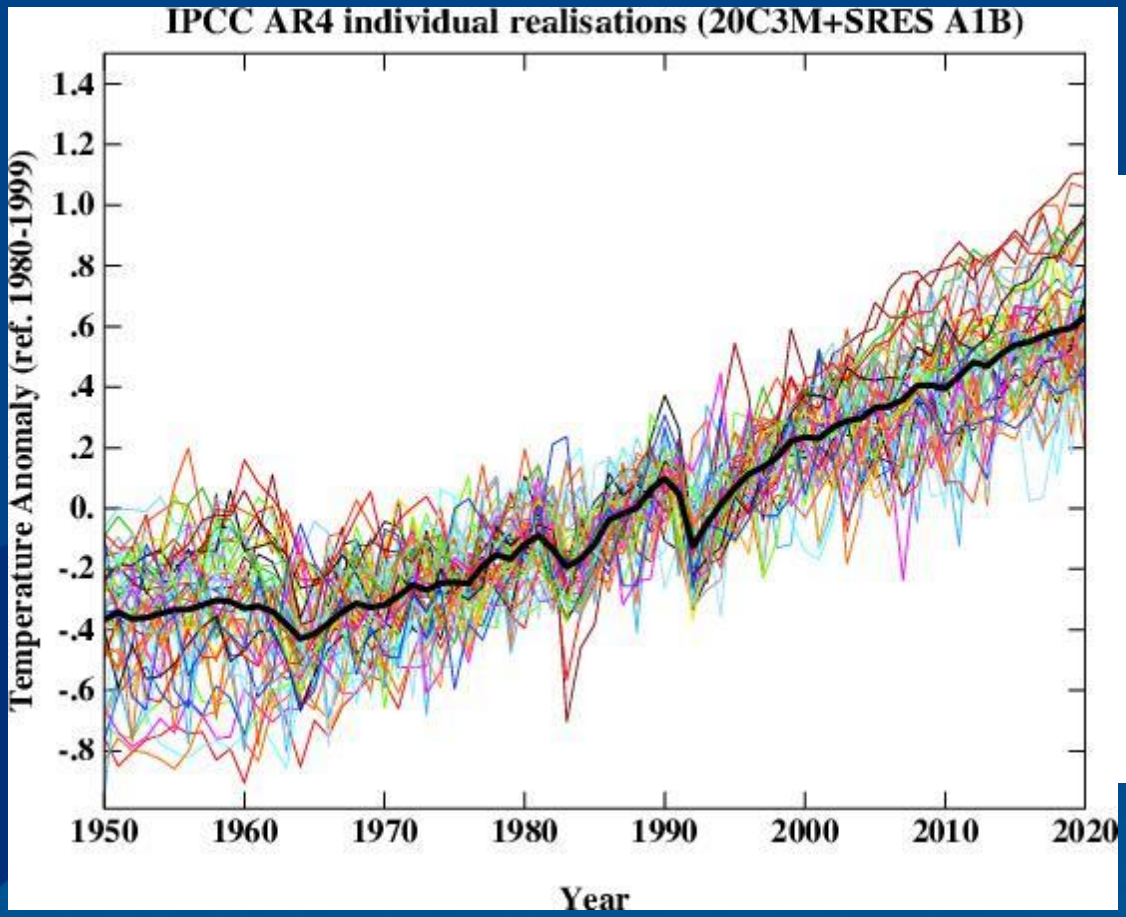

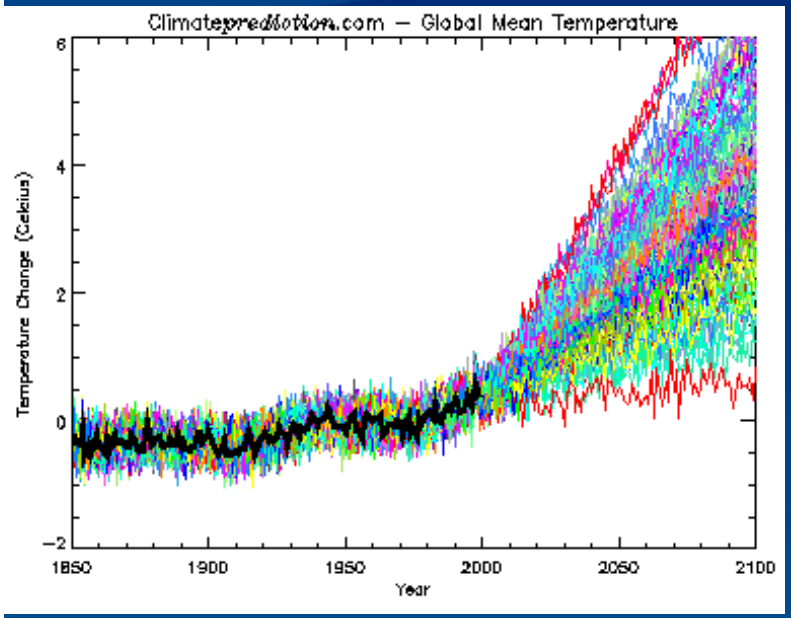

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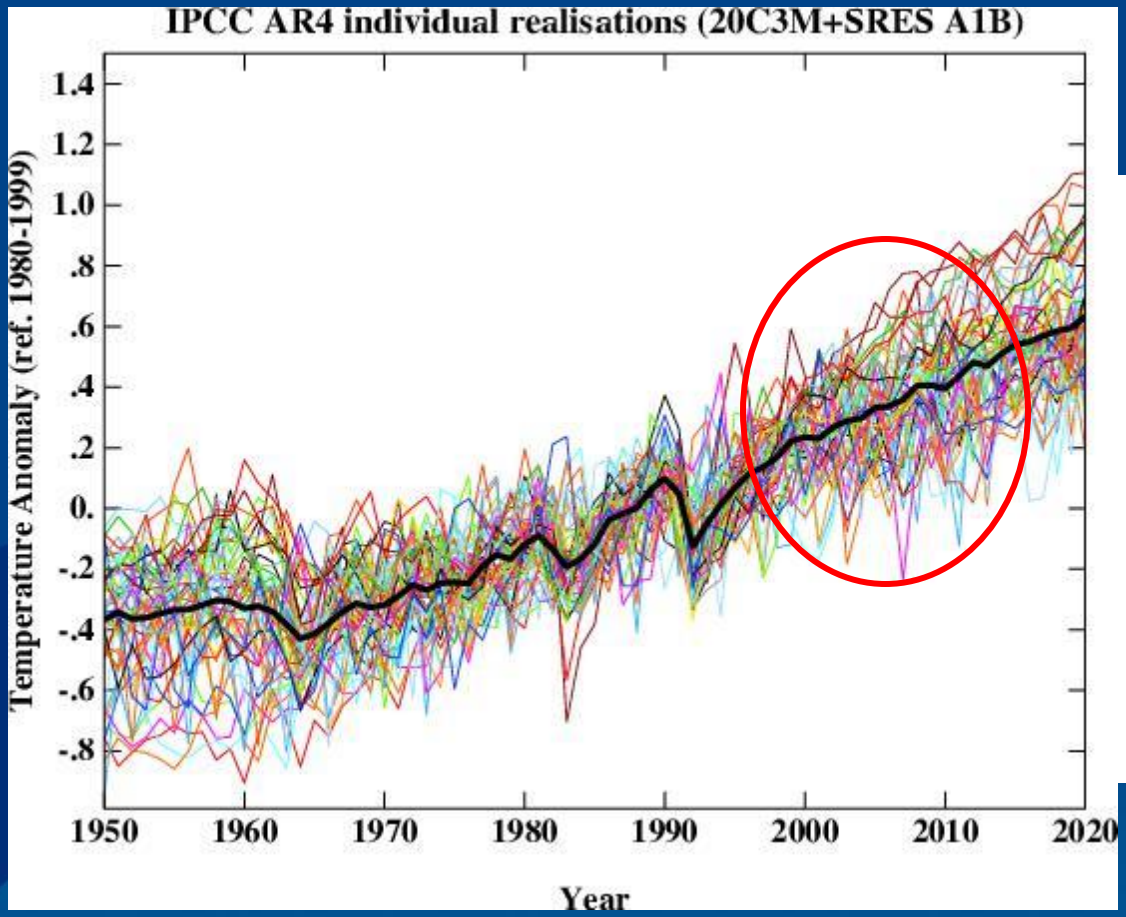
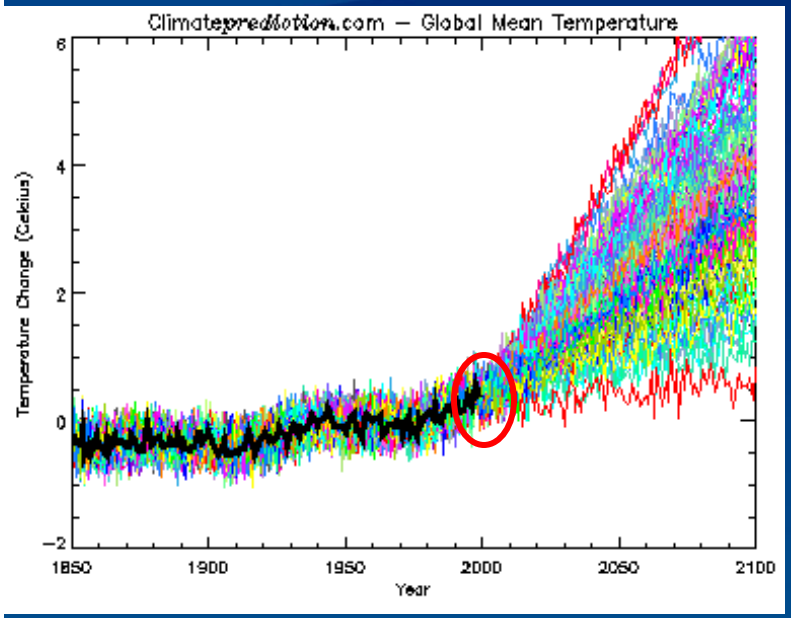
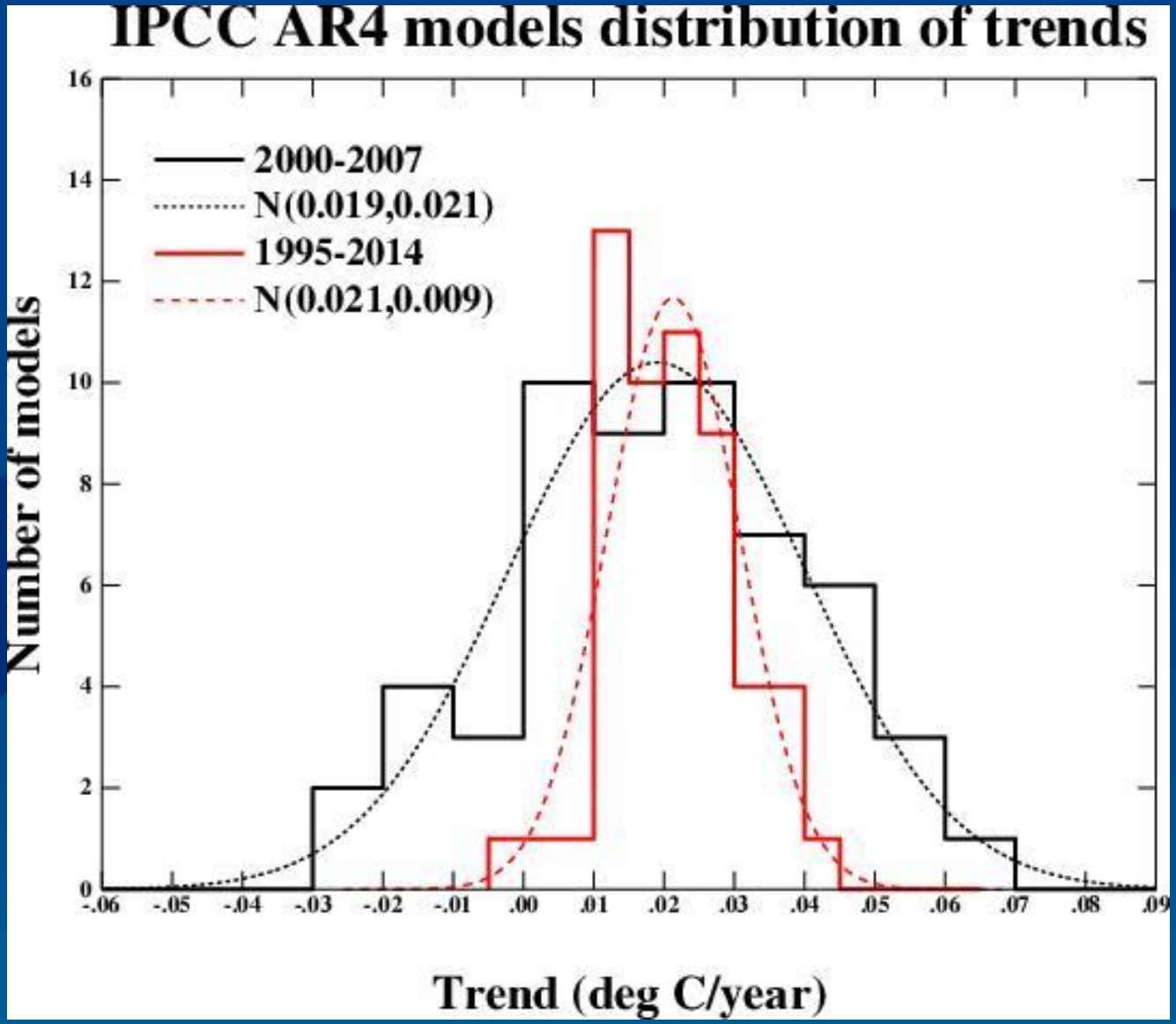
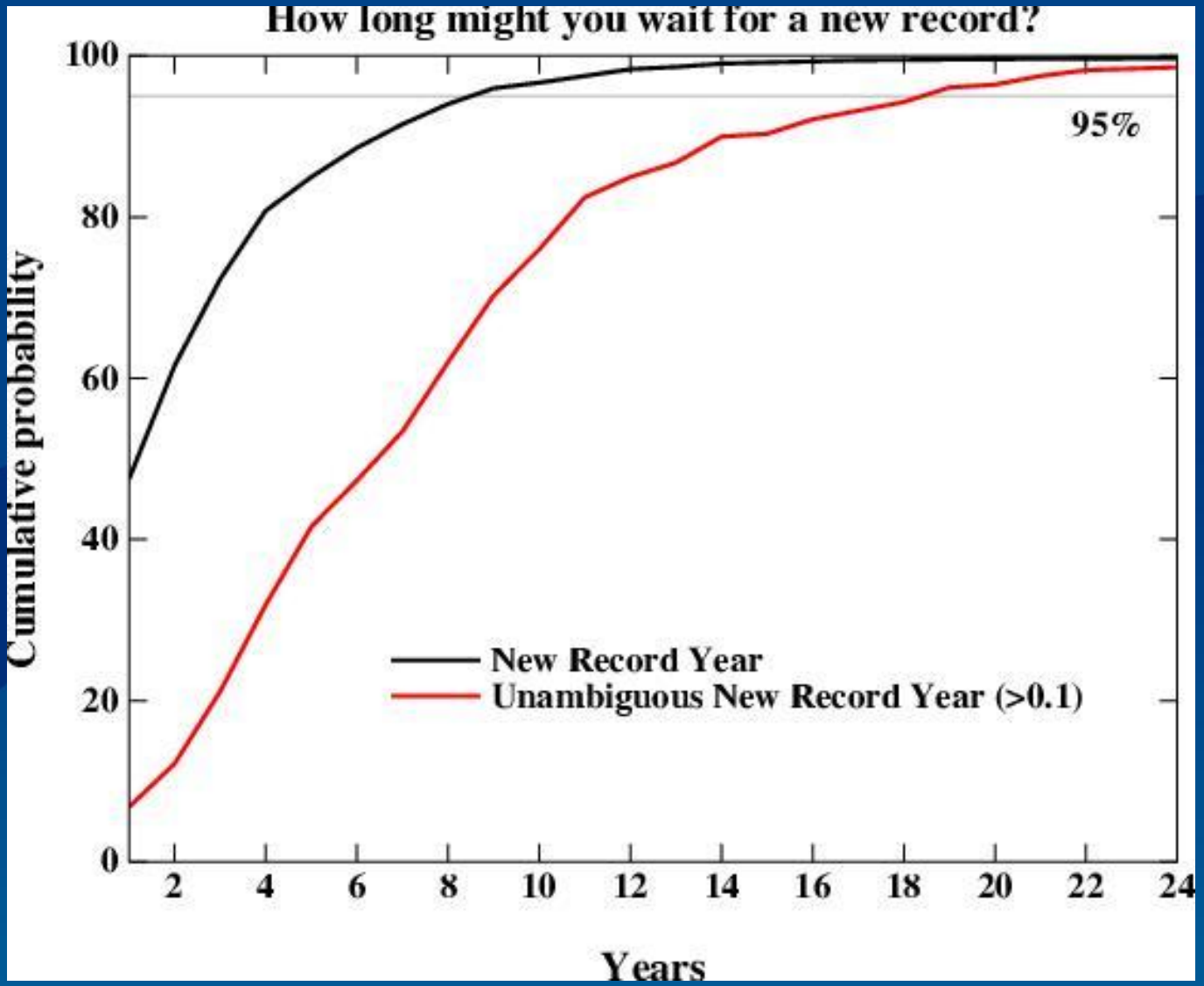





IPCC AR4 models distribution of trends
2000-2007
N(0.019,0.021)
1995-2014
N(0.021,0.009)
Number of models
0
2
4
6
8
10
12
14
16
-.06
-.05
-.04
-.03
-.02
-.01
.00
.01
.02
.03
.04
.05
.06
.07
.08
.09
Trend (deg C/year)


How long might you wait for a new record?
Cumulative probability
100
80
60
40
20
0
95%
New Record Year
Unambiguous New Record Year (>0.1)
2
4
6
8
10
12
14
16
18
20
22
24
Years

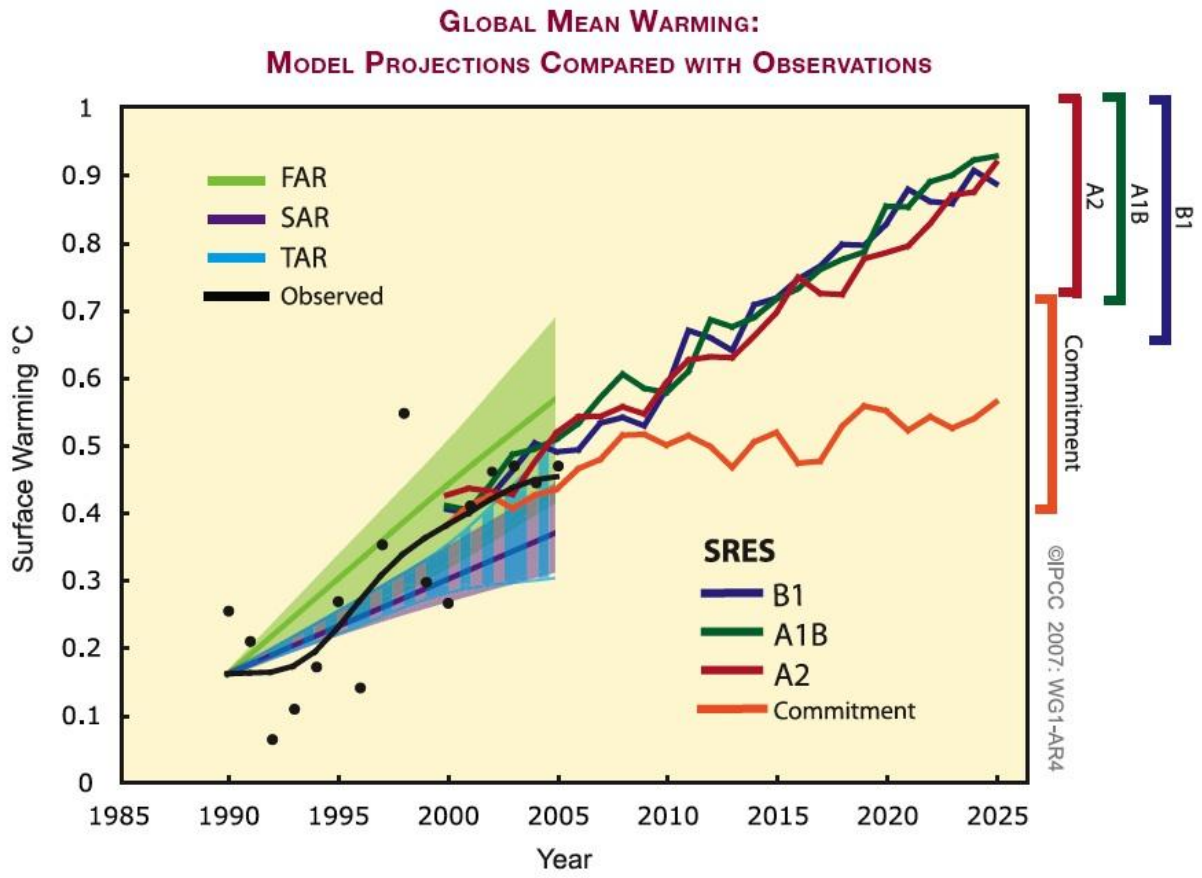
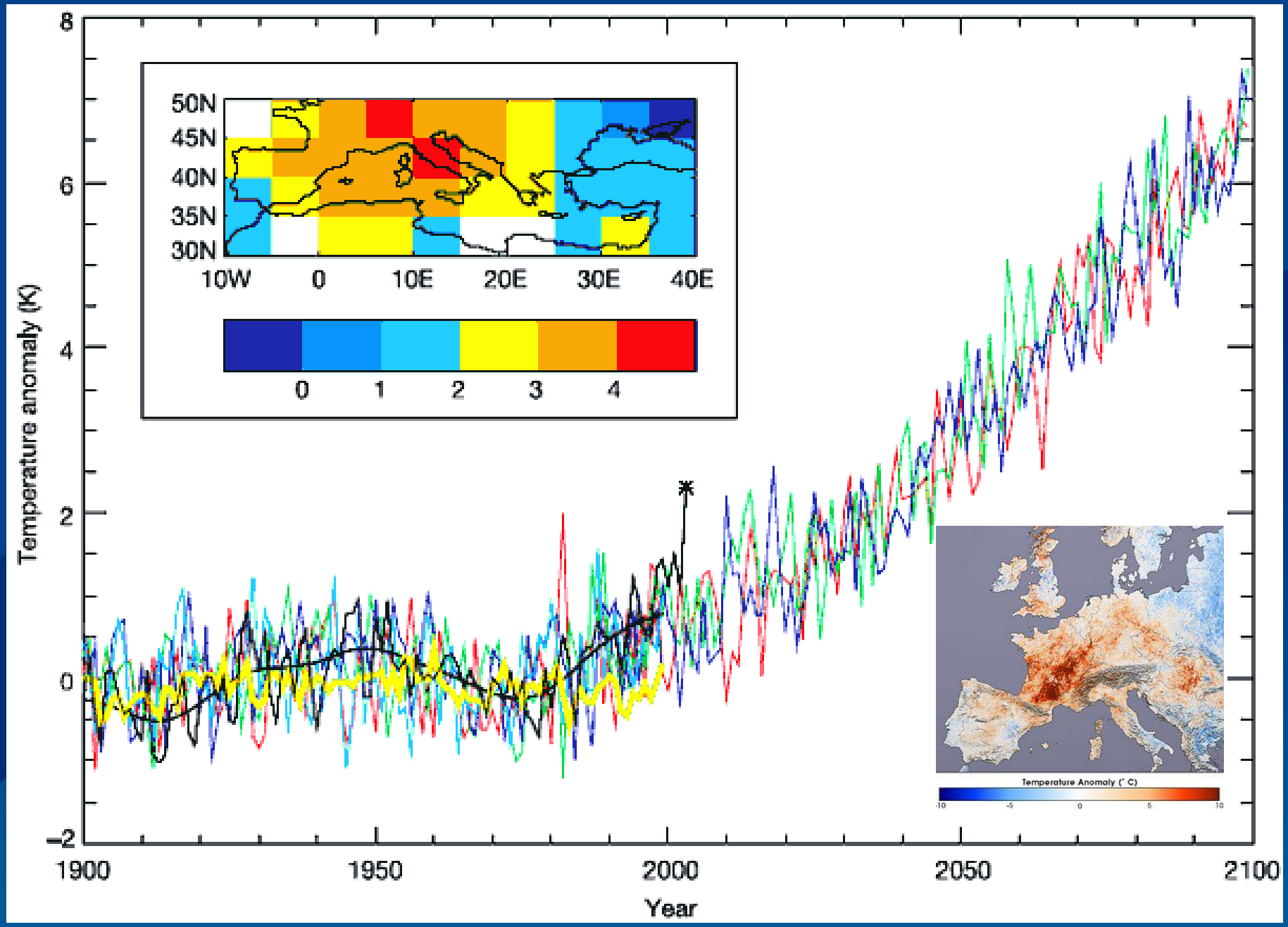


Figure TS.26. *Model projections of global mean warming compared to observed warming. Observed temperature anomalies, as in Figure TS.6, are shown as annual (black dots) and decadal average values (black line). Projected trends and their ranges from the IPCC First (FAR) and Second (SAR) Assessment Reports are shown as green and magenta solid lines and shaded areas, and the projected range from the TAR is shown by vertical blue bars. These projections were adjusted to start at the observed decadal average value in 1990. Multi-model mean projections from this report for the SRES B1, A1B and A2 scenarios, as in Figure TS.32, are shown for the period 2000 to 2025 as blue, green and red curves with uncertainty ranges indicated against the right-hand axis. The orange curve shows model projections of warming if greenhouse gas and aerosol concentrations were held constant from the year 2000 – that is, the committed warming. {Figures 1.1 and 10.4}*


Temperature anomaly (K)
8
6
4
2
0
−2
1900
1950
2000
2050
2100
Year
50N
45N
40N
35N
30N
10W
0
10E
20E
30E
40E
0
1
2
3
4
Temperature Anomaly (° C)
-10
-5
0
5
10

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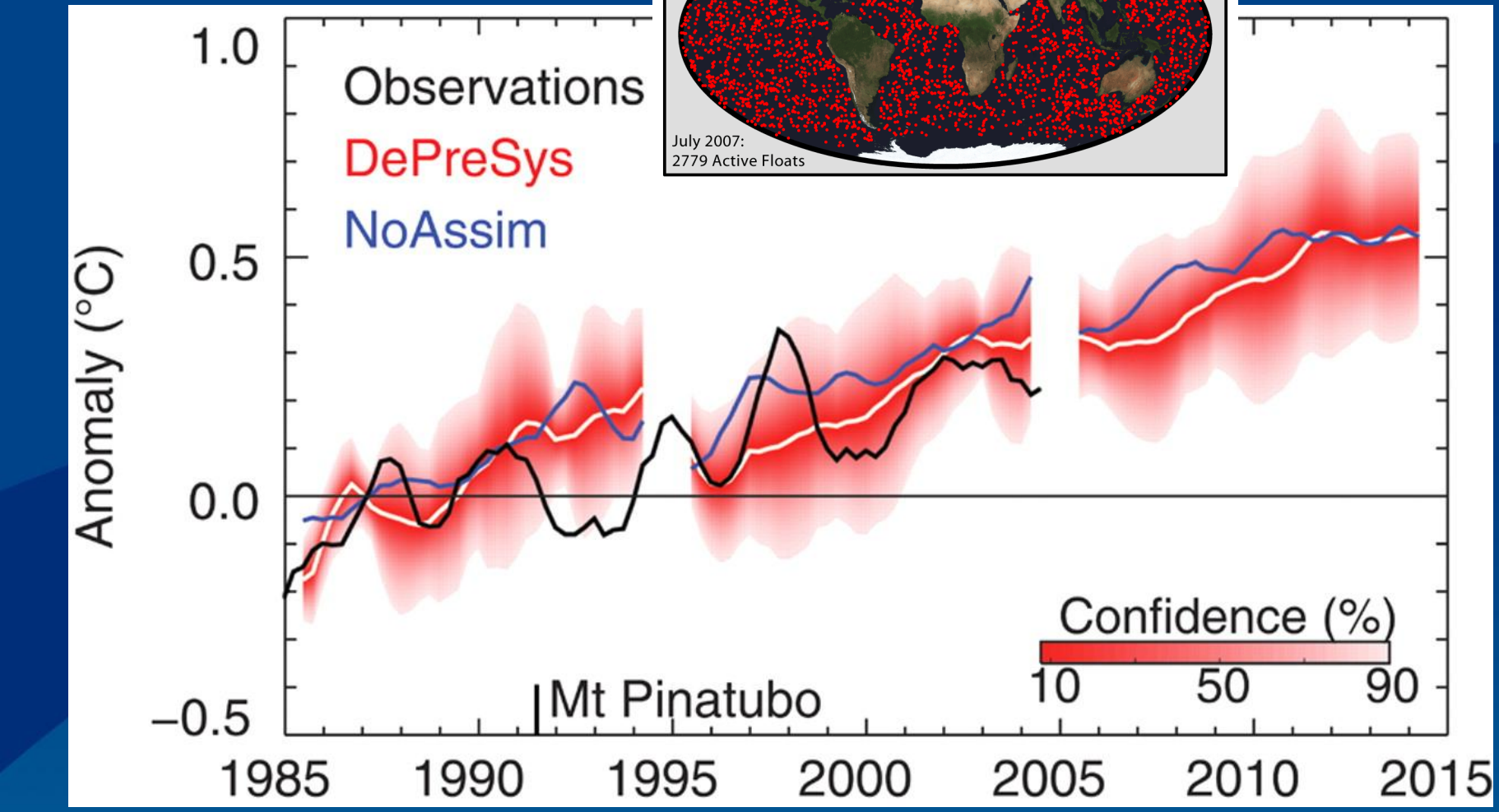

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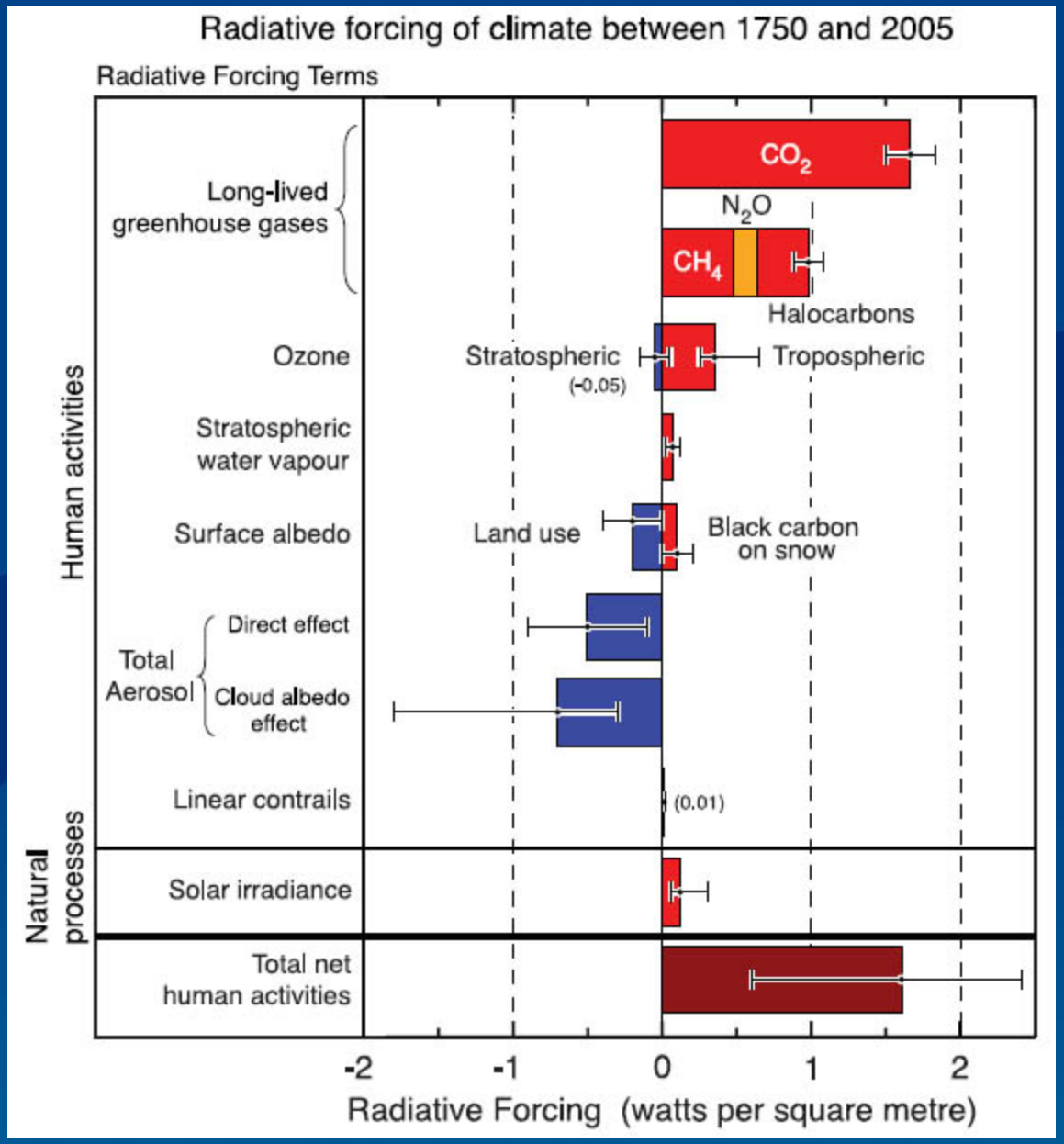
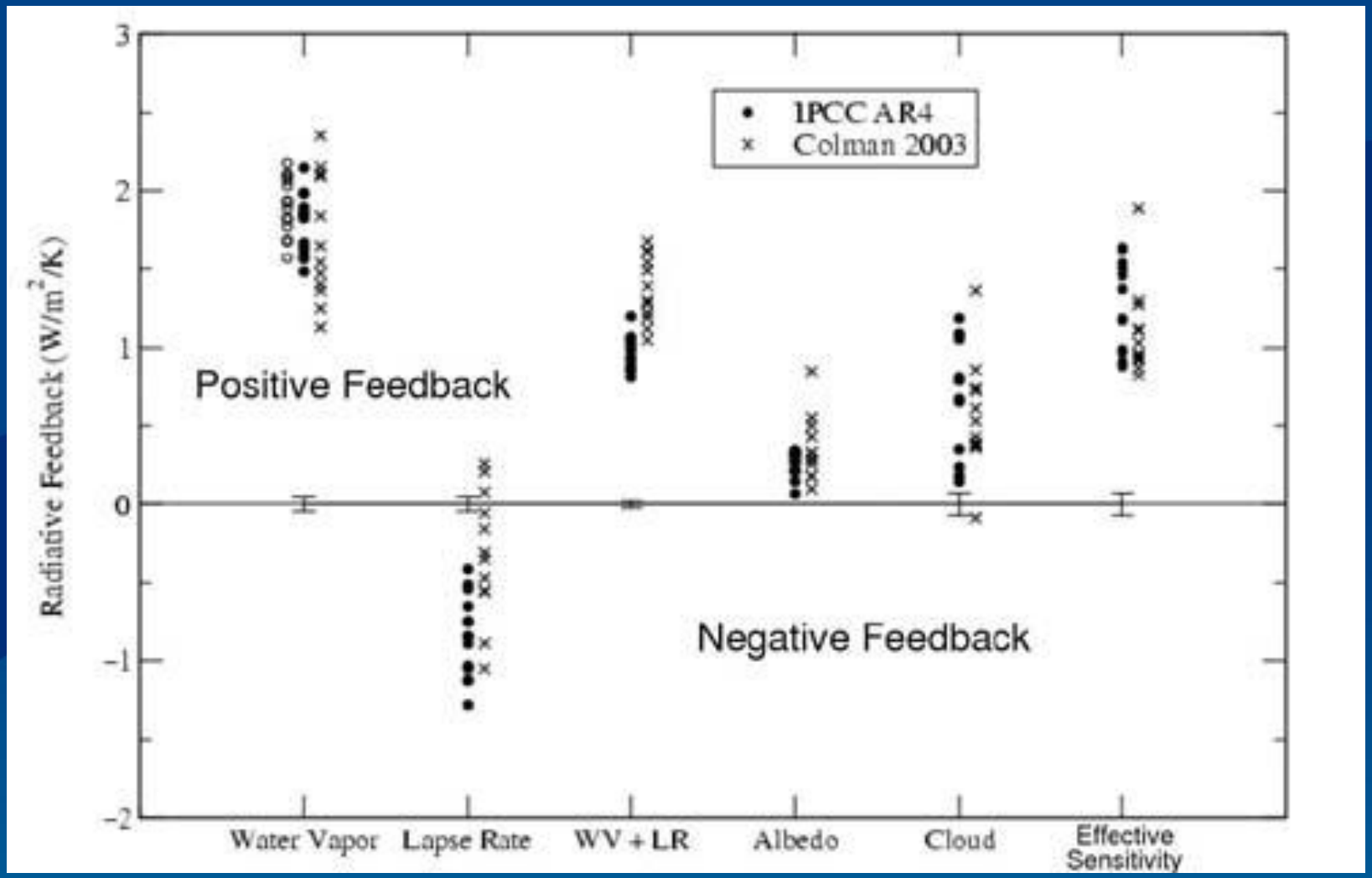
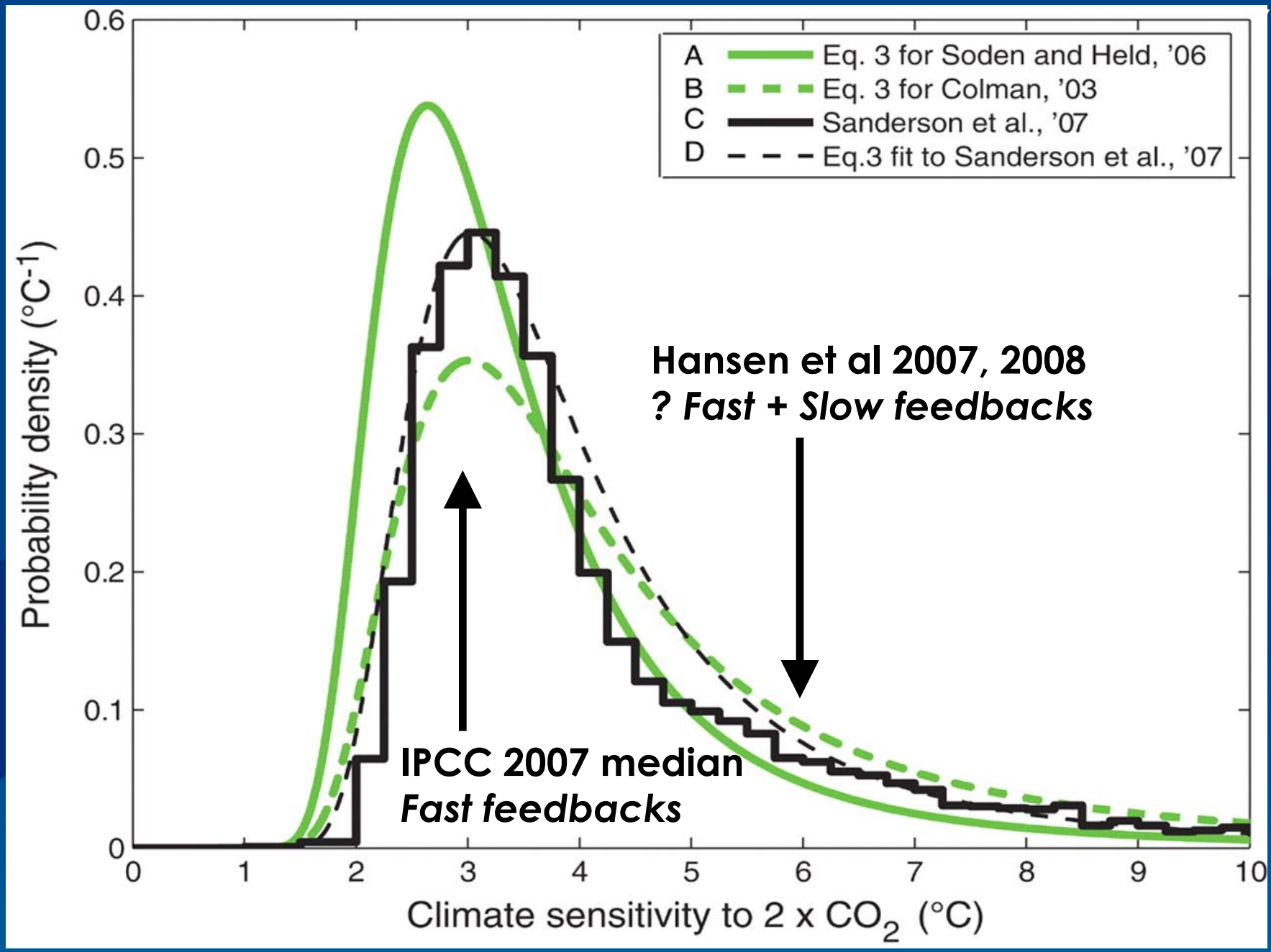
Climate sensitivity is low




IPCC AR4
Colman 2003
Positive Feedback
Negative Feedback
Radiative Feedback (W/m²/K)
3
2
1
0
−1
−2
Water Vapor
Lapse Rate
WV + LR
Albedo
Cloud
Effective Sensitivity


A Eq. 3 for Soden and Held, '06
B Eq. 3 for Colman, '03
C Sanderson et al., '07
D Eq.3 fit to Sanderson et al., '07
Hansen et al 2007, 2008
? Fast + Slow feedbacks
IPCC 2007 median
Fast feedbacks
Probability density (°C-1)
Climate sensitivity to 2 x CO2 (°C)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
1
2
3
4
5
6
7
8
9
10

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The IPCC scenarios are not realistic

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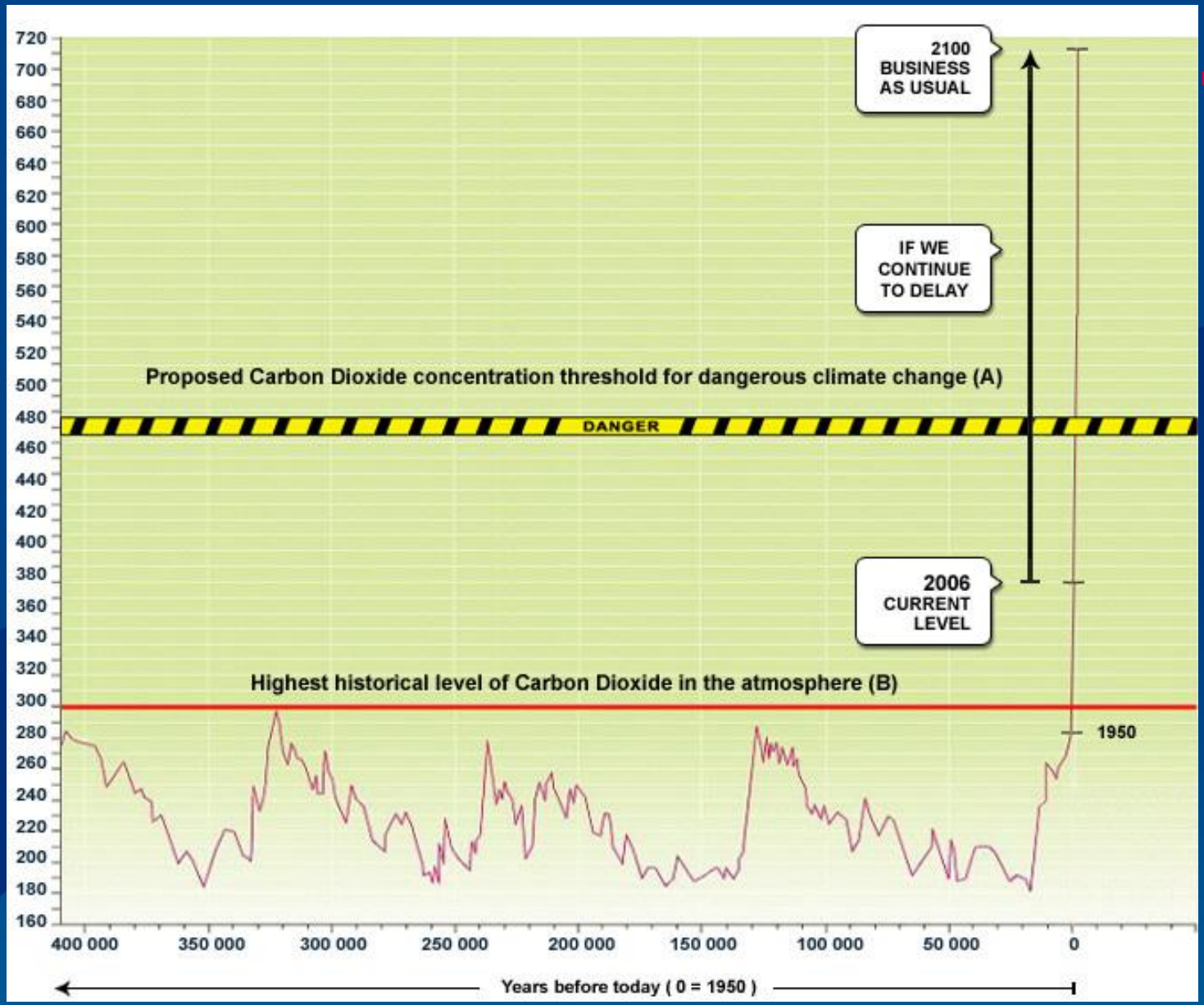
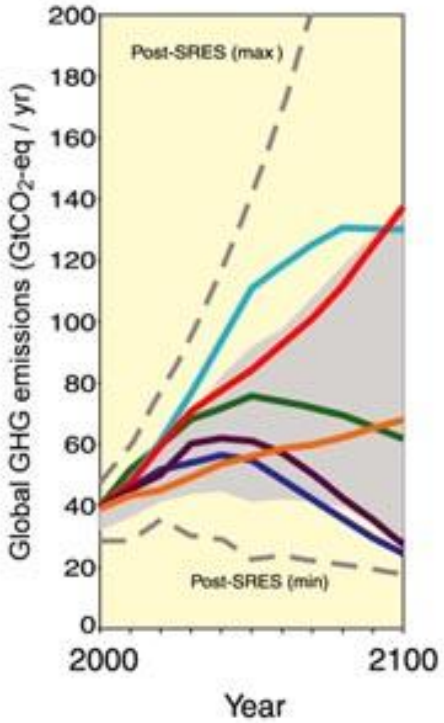
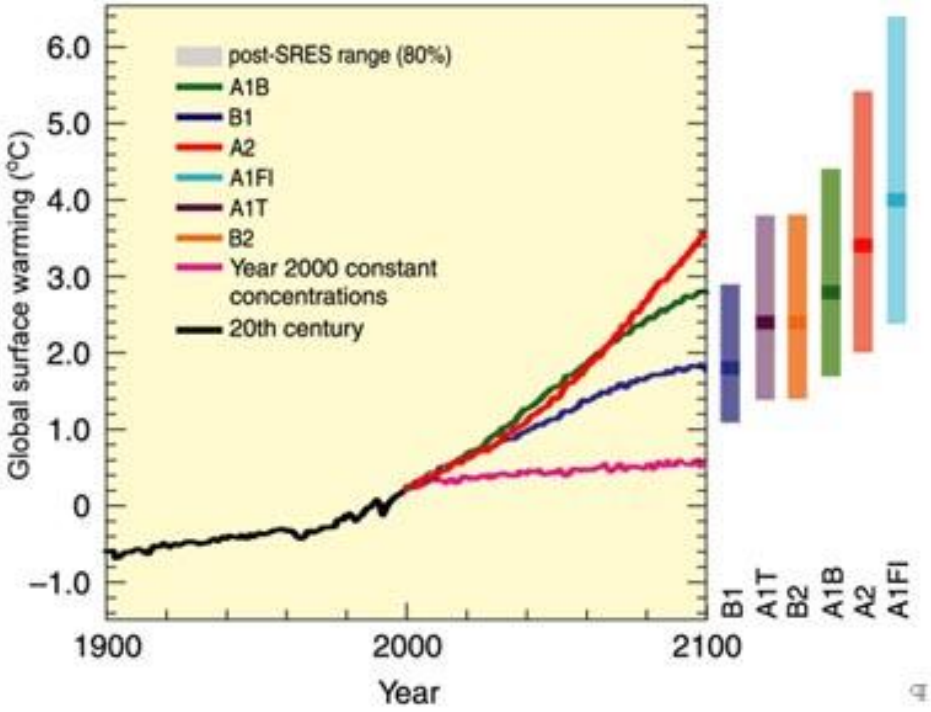


Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies) and projections of surface temperatures





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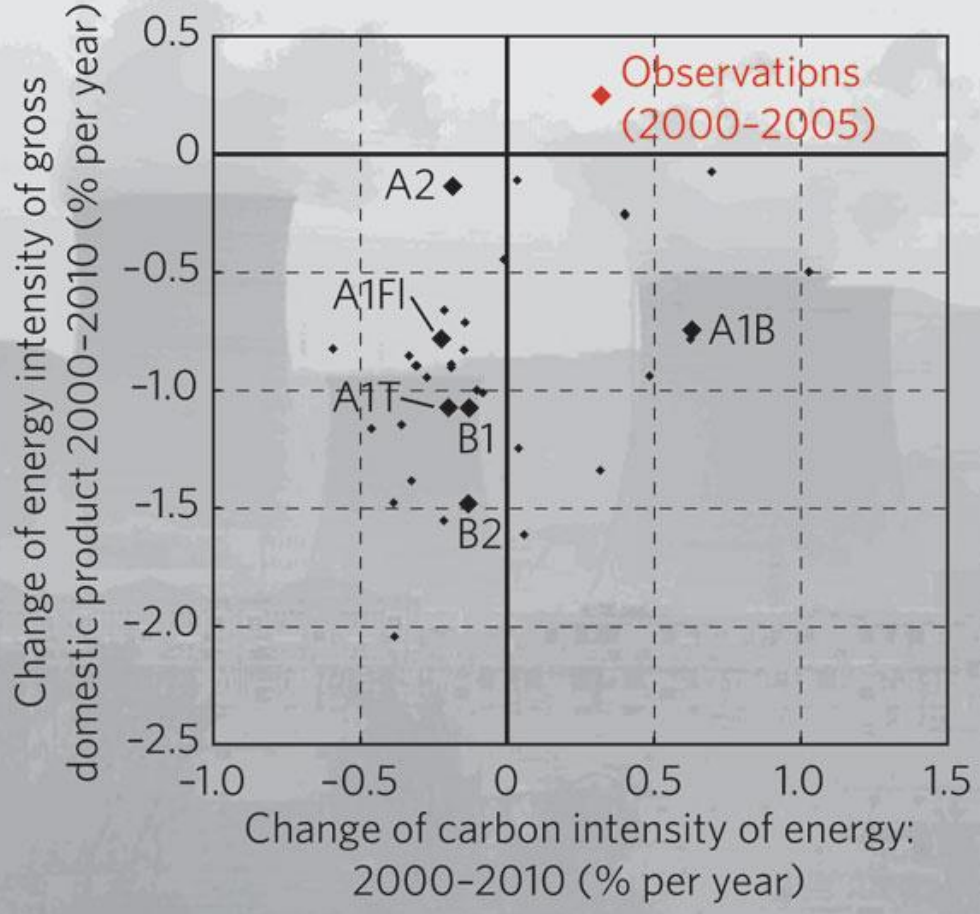
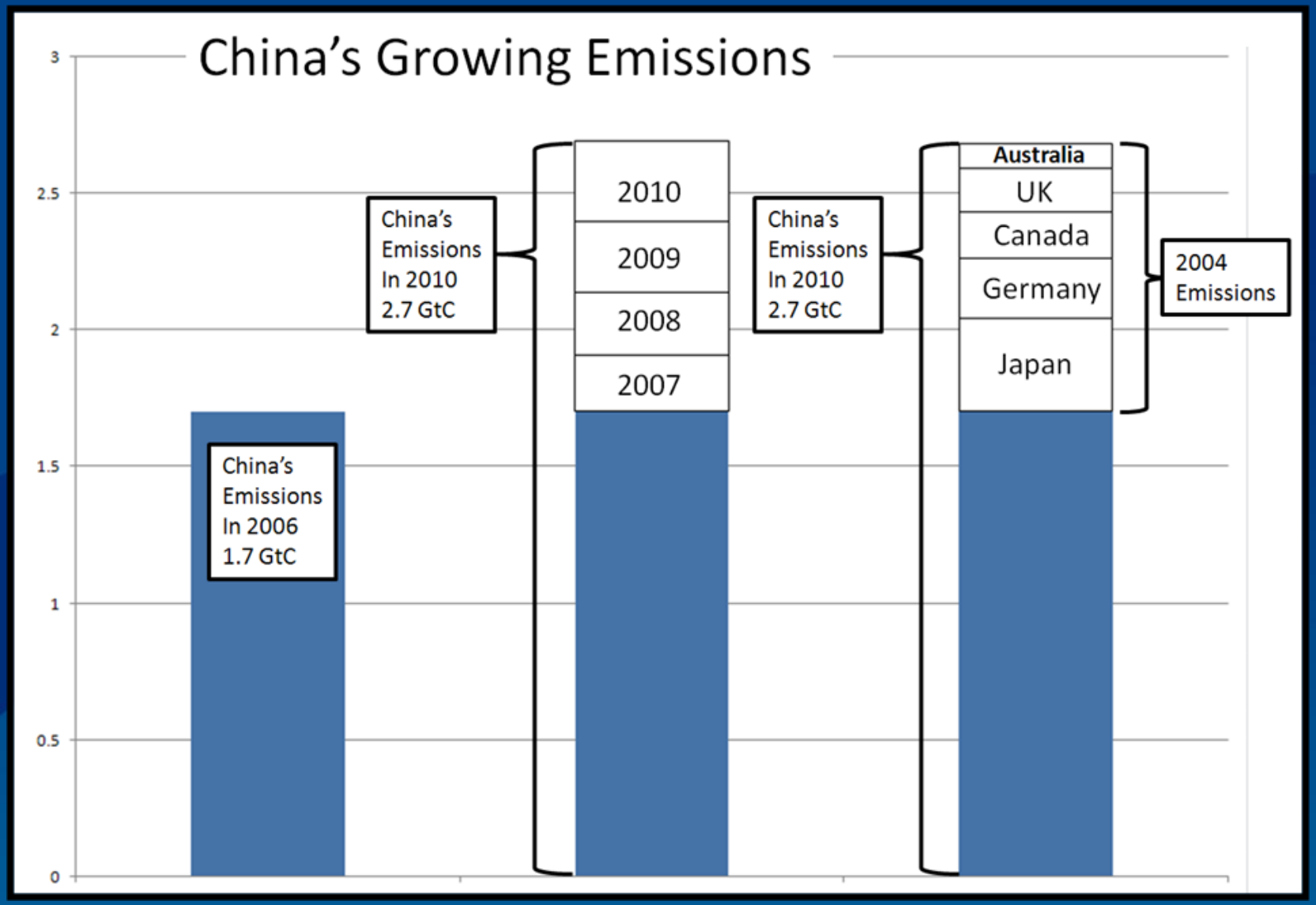
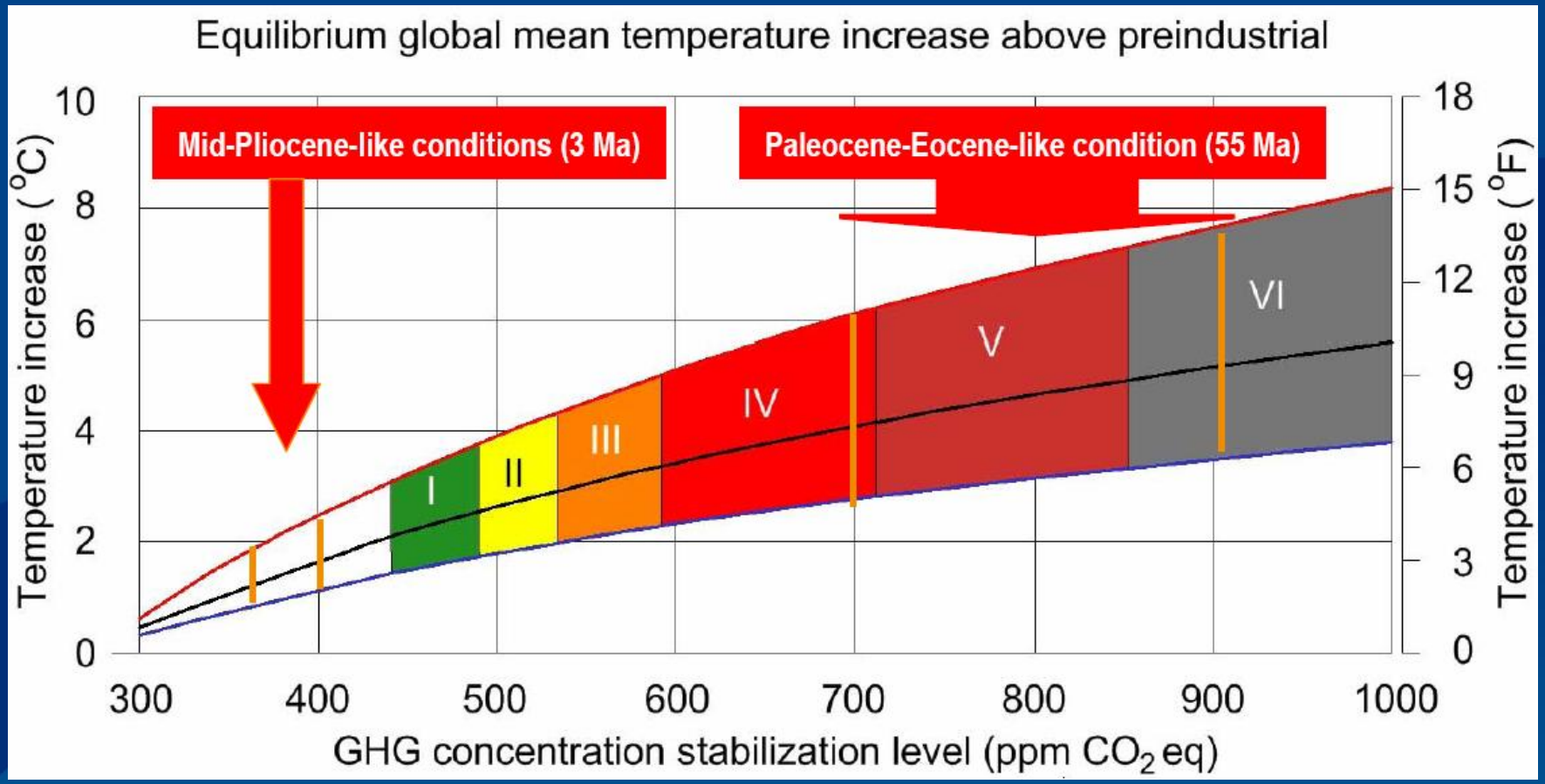
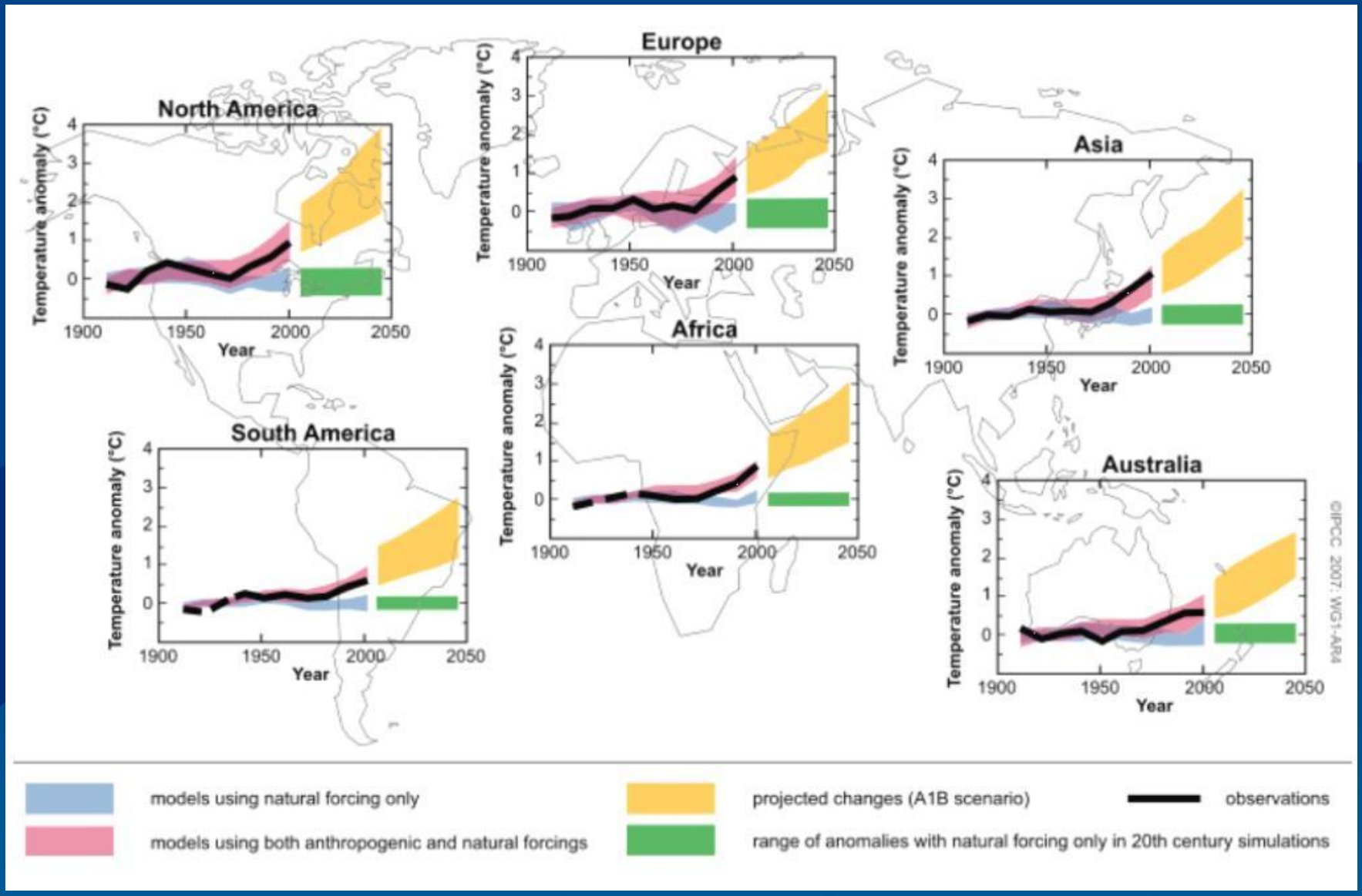
ASSUMED DECARBONIZATION IN THE 35 IPCC SCENARIOS FOR 2000–2010




China's Growing Emissions
3
2.5
2
1.5
1
0.5
0
China's Emissions In 2006 1.7 GtC
China's Emissions In 2010 2.7 GtC
2010
2009
2008
2007
China's Emissions In 2010 2.7 GtC
Australia
UK
Canada
Germany
Japan
2004 Emissions


Equilibrium global mean temperature increase above preindustrial
Mid-Pliocene-like conditions (3 Ma)
Paleocene-Eocene-like condition (55 Ma)
I
II
III
IV
V
VI
Temperature increase (°C)
Temperature increase (°F)
0
2
4
6
8
10
0
3
6
9
12
15
18
300
400
500
600
700
800
900
1000
GHG concentration stabilization level (ppm CO_2 eq)


North America
Europe
Asia
Africa
South America
Australia
Temperature anomaly (°C)
Year
1900
1950
2000
2050
models using natural forcing only
models using both anthropogenic and natural forcings
projected changes (A1B scenario)
range of anomalies with natural forcing only in 20th century simulations
observations
©IPCC 2007: WG1-AR4

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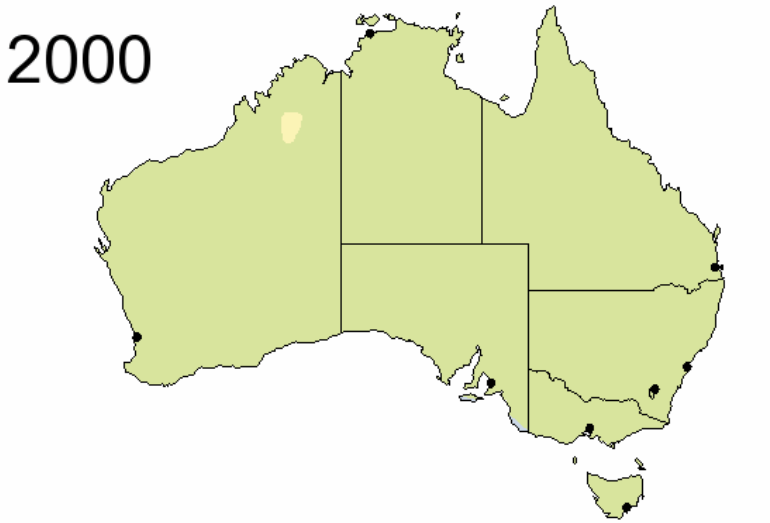
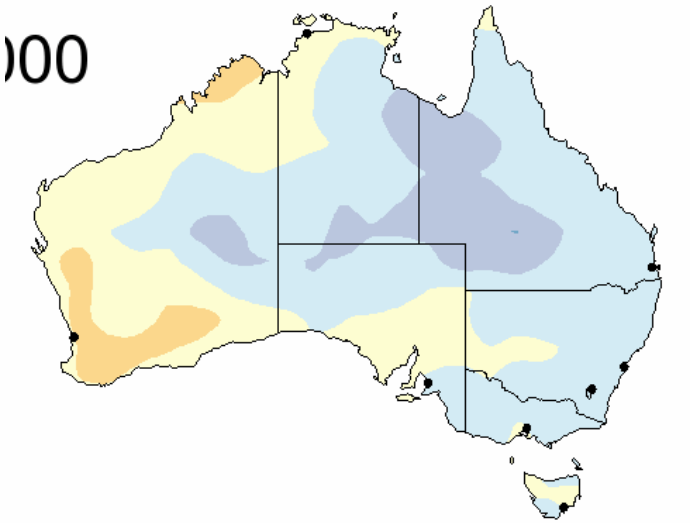


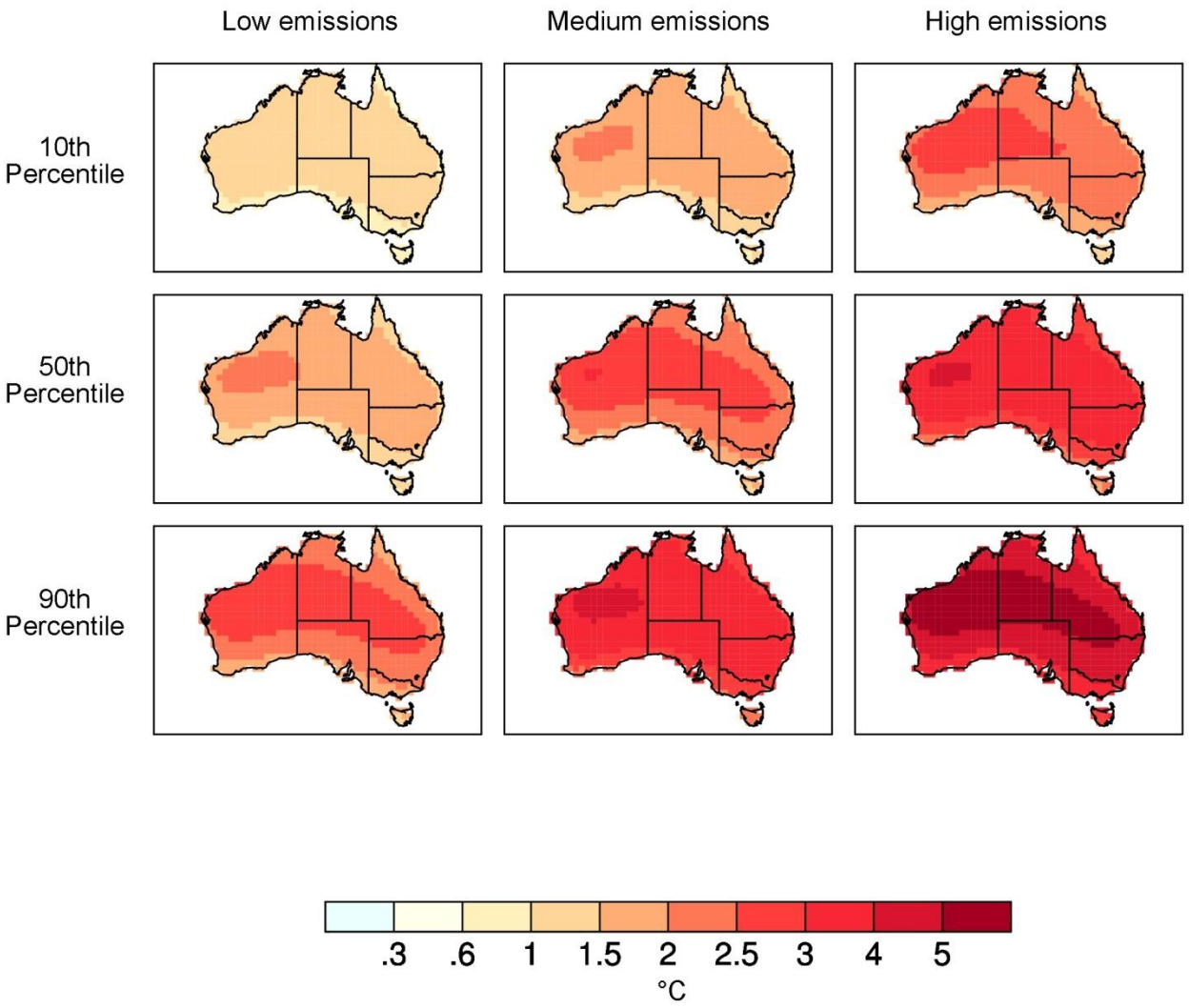


CSIRO Mark 3.5 climate model
IPCC SRES A1B emission scenario
Change relative to 1980-1999 average

CSIRO

ark 3.5 climate model
:S A1B emission scenario
lative to 1980-1999 average

CSIRO


Low emissions
Medium emissions
High emissions
10th Percentile
50th Percentile
90th Percentile
.3
.6
1
1.5
2
2.5
3
4
5
°C

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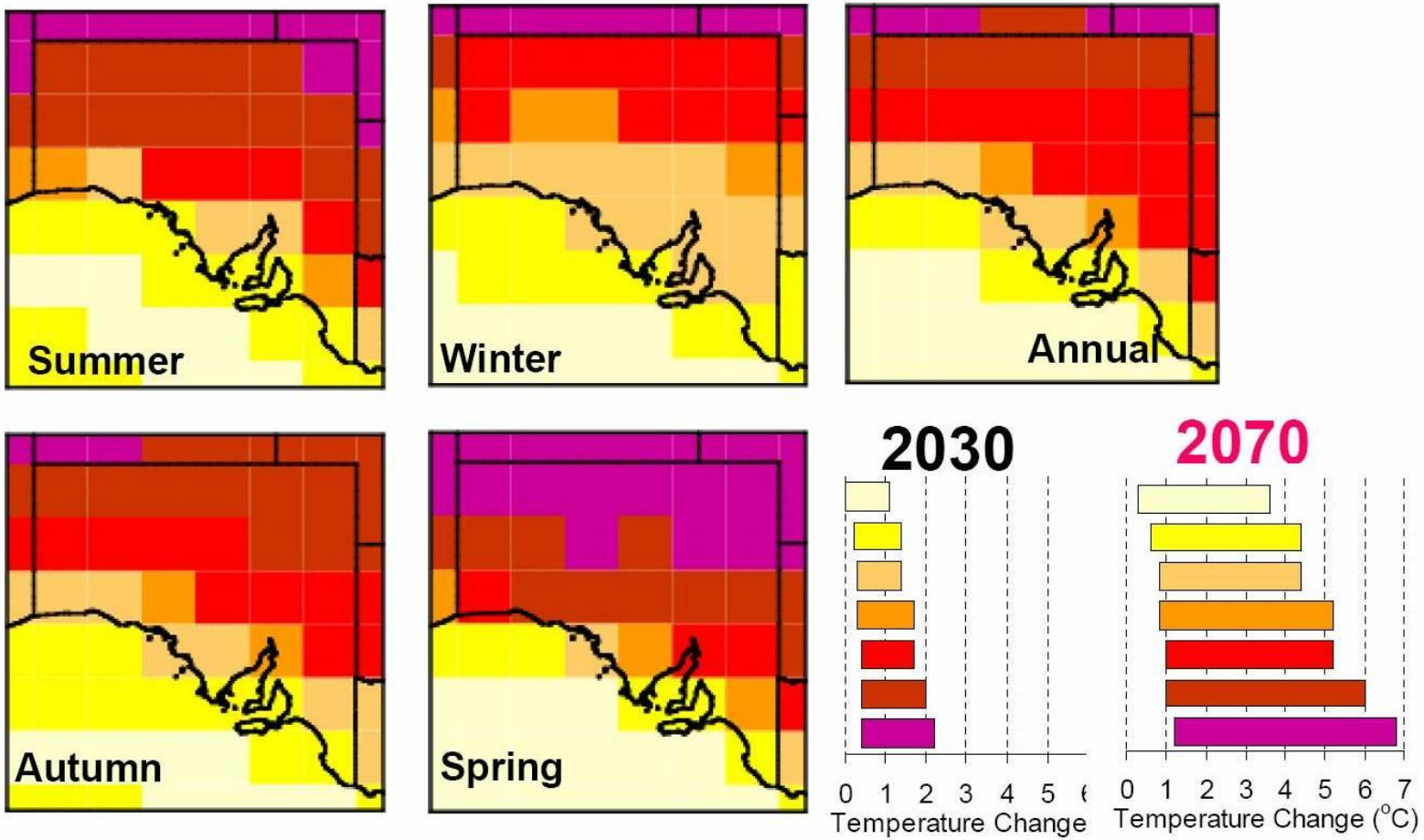
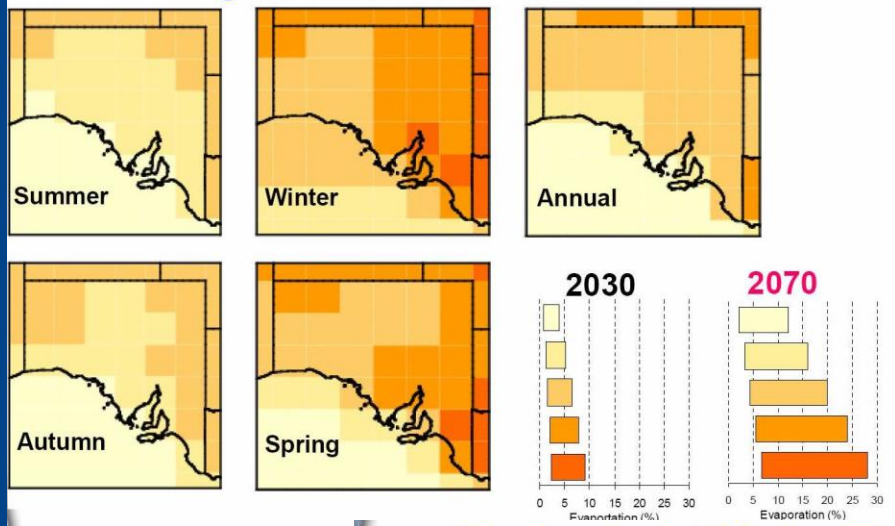
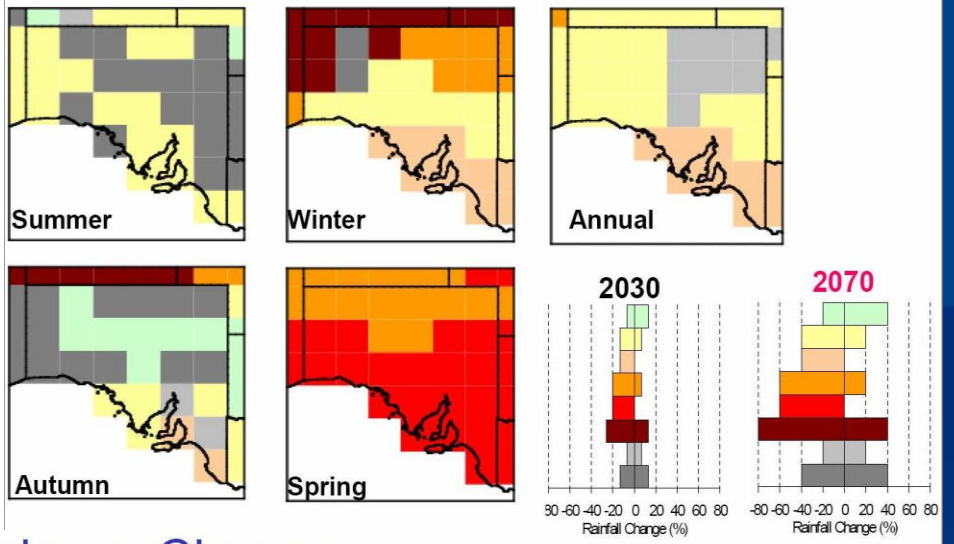
Projected Temperature Change



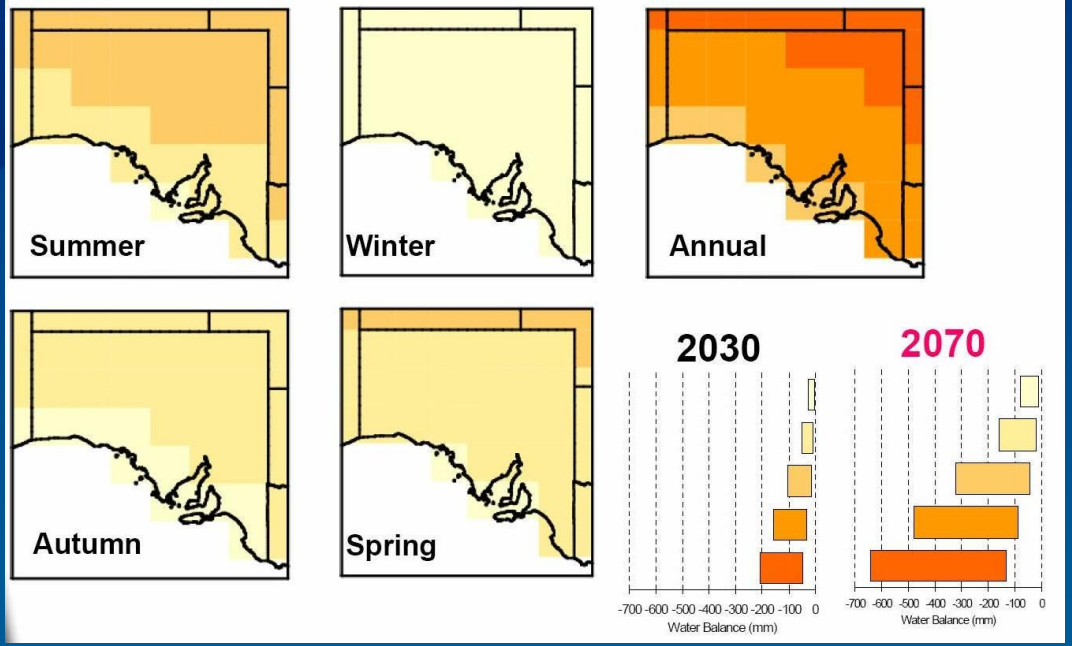
Projected Potential Evaporation Change

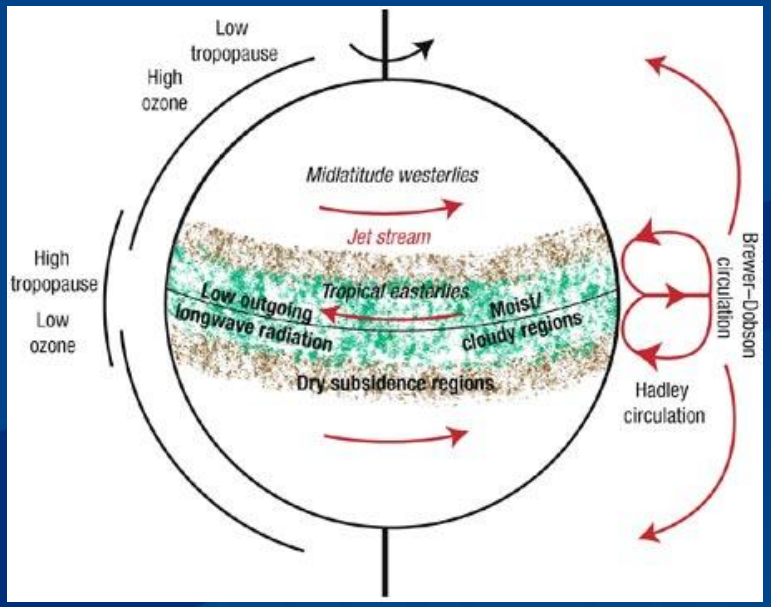


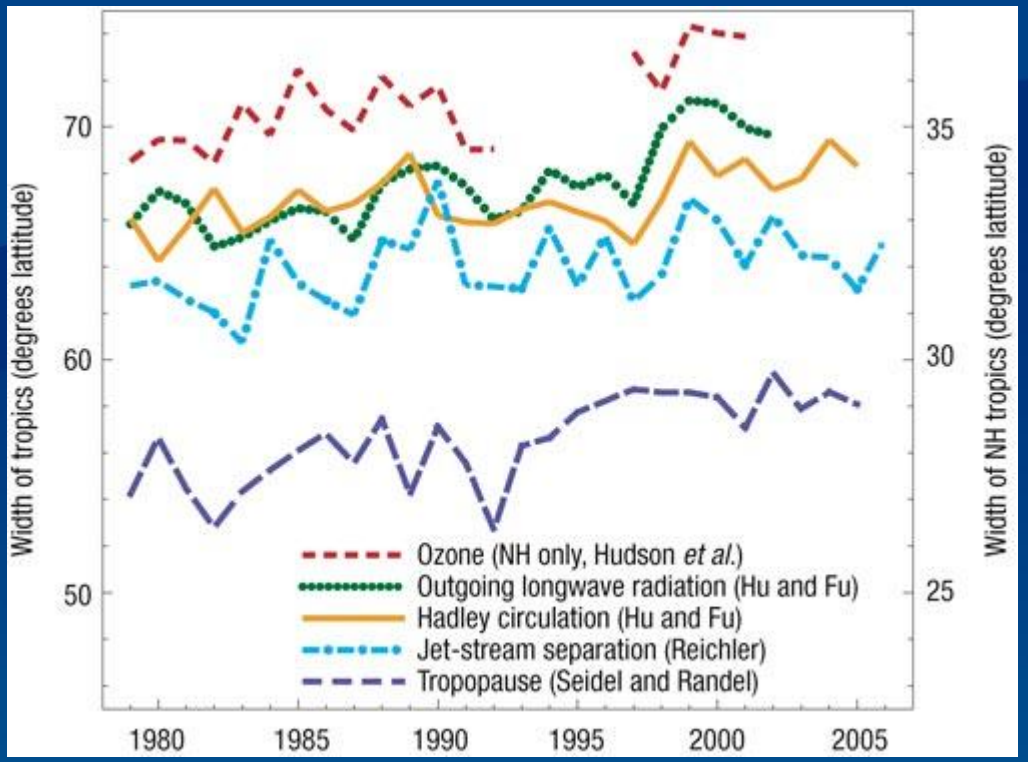
Projected Rainfall Change

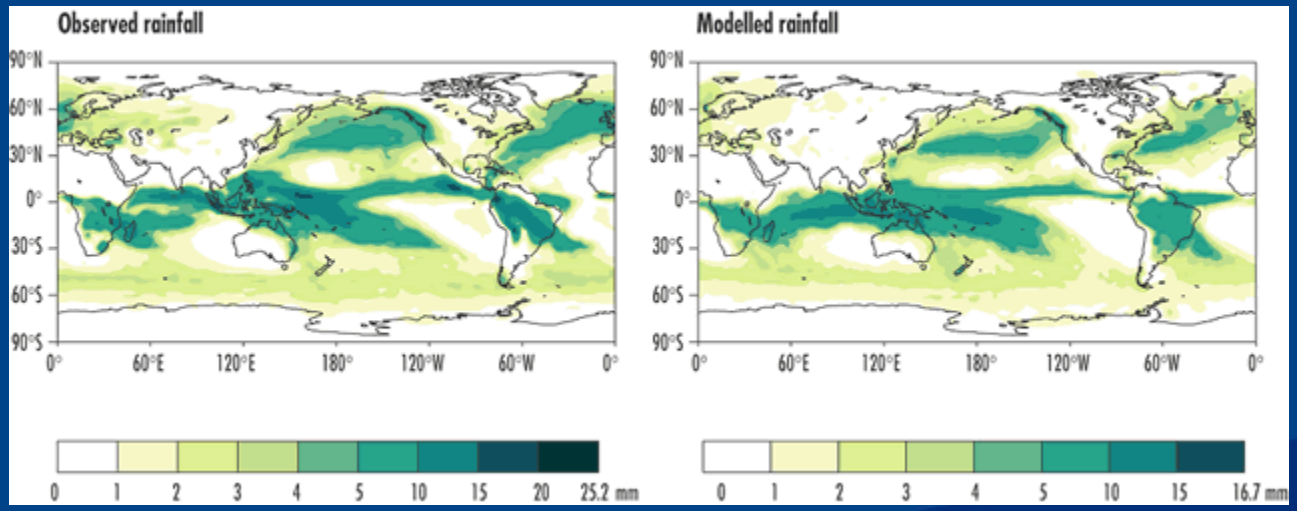


Projected Water Balance Change




Low tropopause
High ozone
Midlatitude westerlies
Jet stream
High tropopause
Low ozone
Tropical easterlies
Low outgoing longwave radiation
Moist/ cloudy regions
Dry subsidence regions
Brewer–Dobson circulation
Hadley circulation


Width of tropics (degrees lattitude)
Width of NH tropics (degrees lattitude)
70
60
50
35
30
25
1980
1985
1990
1995
2000
2005
Ozone (NH only, Hudson et al.)
Outgoing longwave radiation (Hu and Fu)
Hadley circulation (Hu and Fu)
Jet-stream separation (Reichler)
Tropopause (Seidel and Randel)



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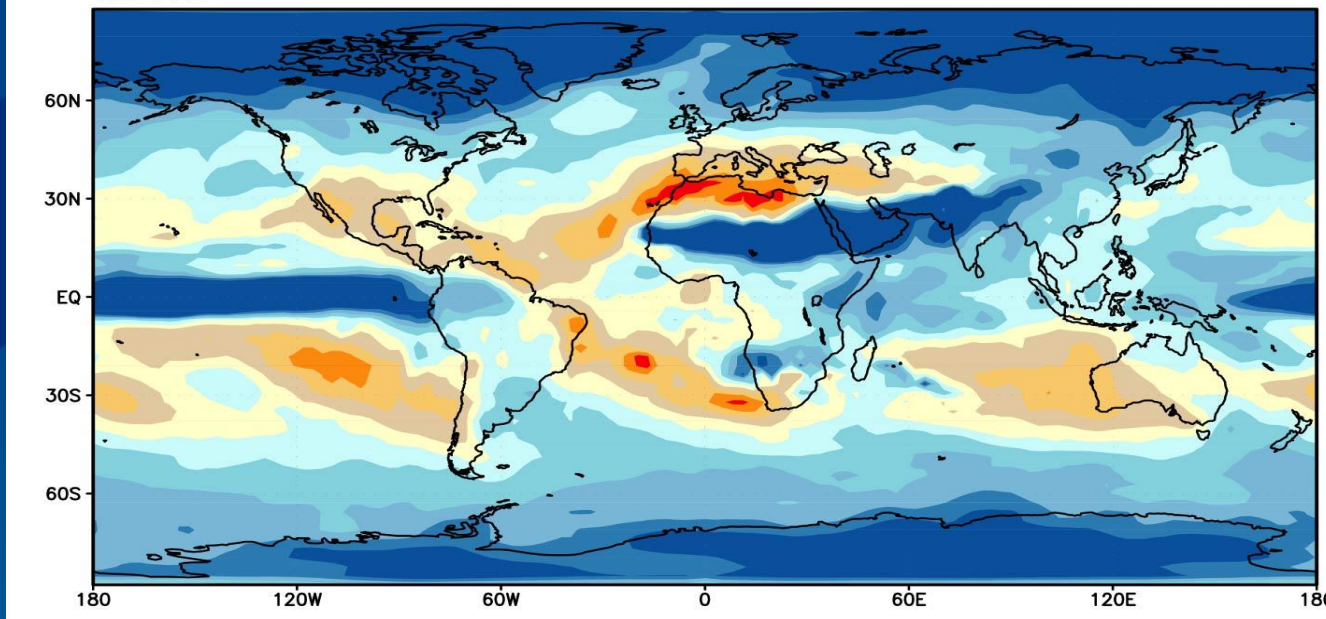
SUB CRUCE LUMEN



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Category	CO_2 concentration [a]	CO_2-equivalent concentration [a]	Peaking year for CO_2 emissions [b]	Change in global CO_2 emissions in 2050 (% of 2000 emissions) [b]	Global average temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity [c], [d]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only [e]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Lenton et al. (2008) *Proc Natl Acad Sci USA*, doi: 10.1073/pnas.0705414105

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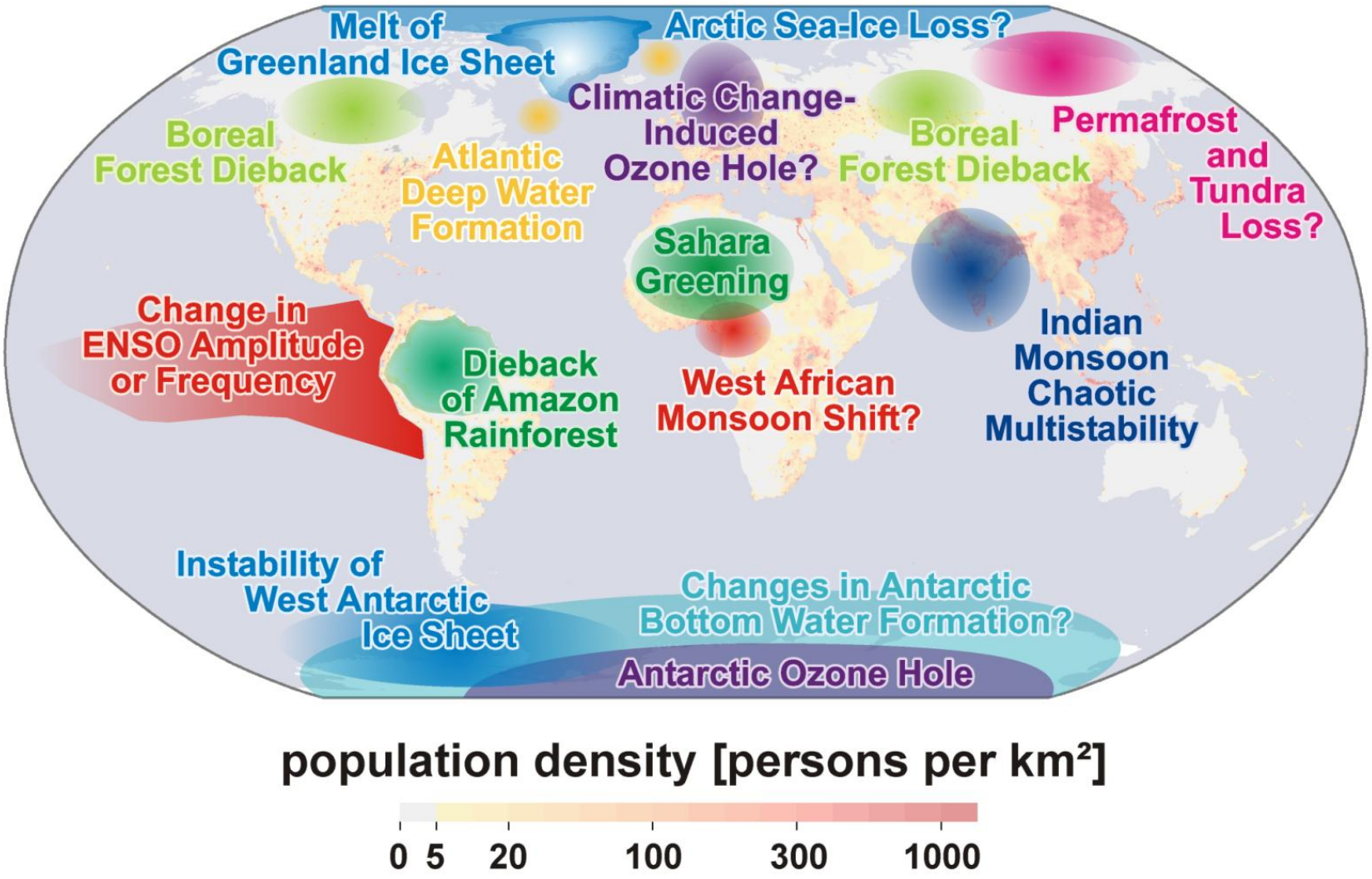
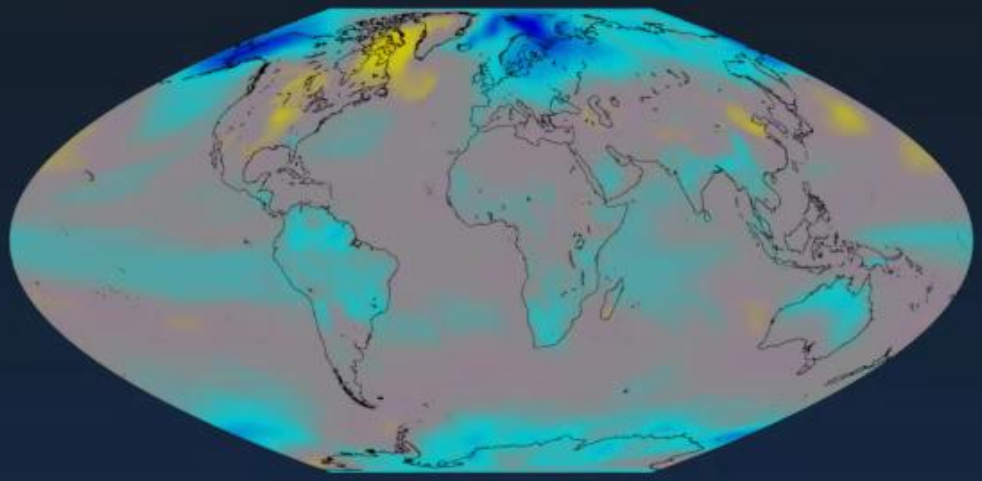
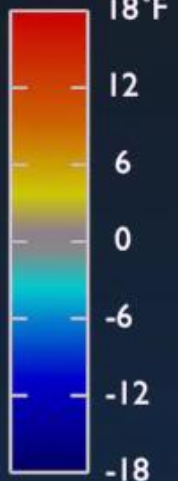
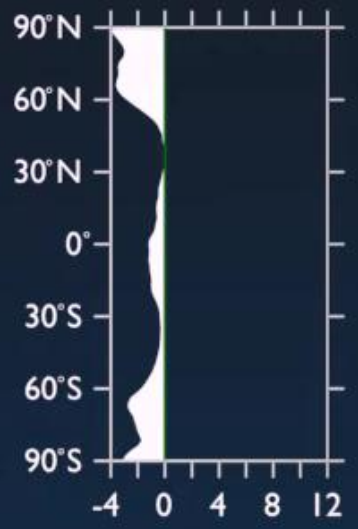


Surface Air Temperature Anomalies

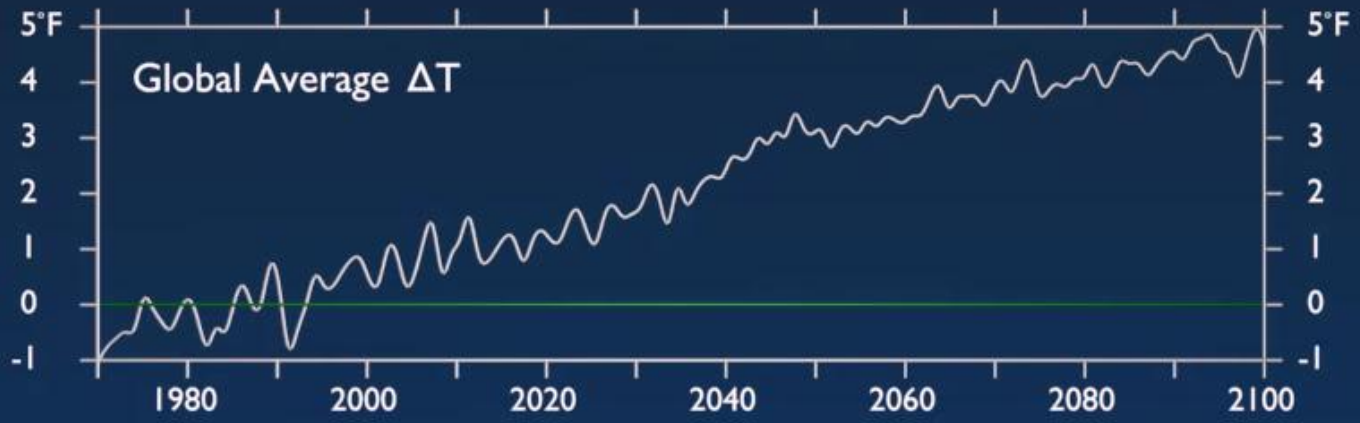




ΔT Anomalies Relative to 1971-2000 Mean

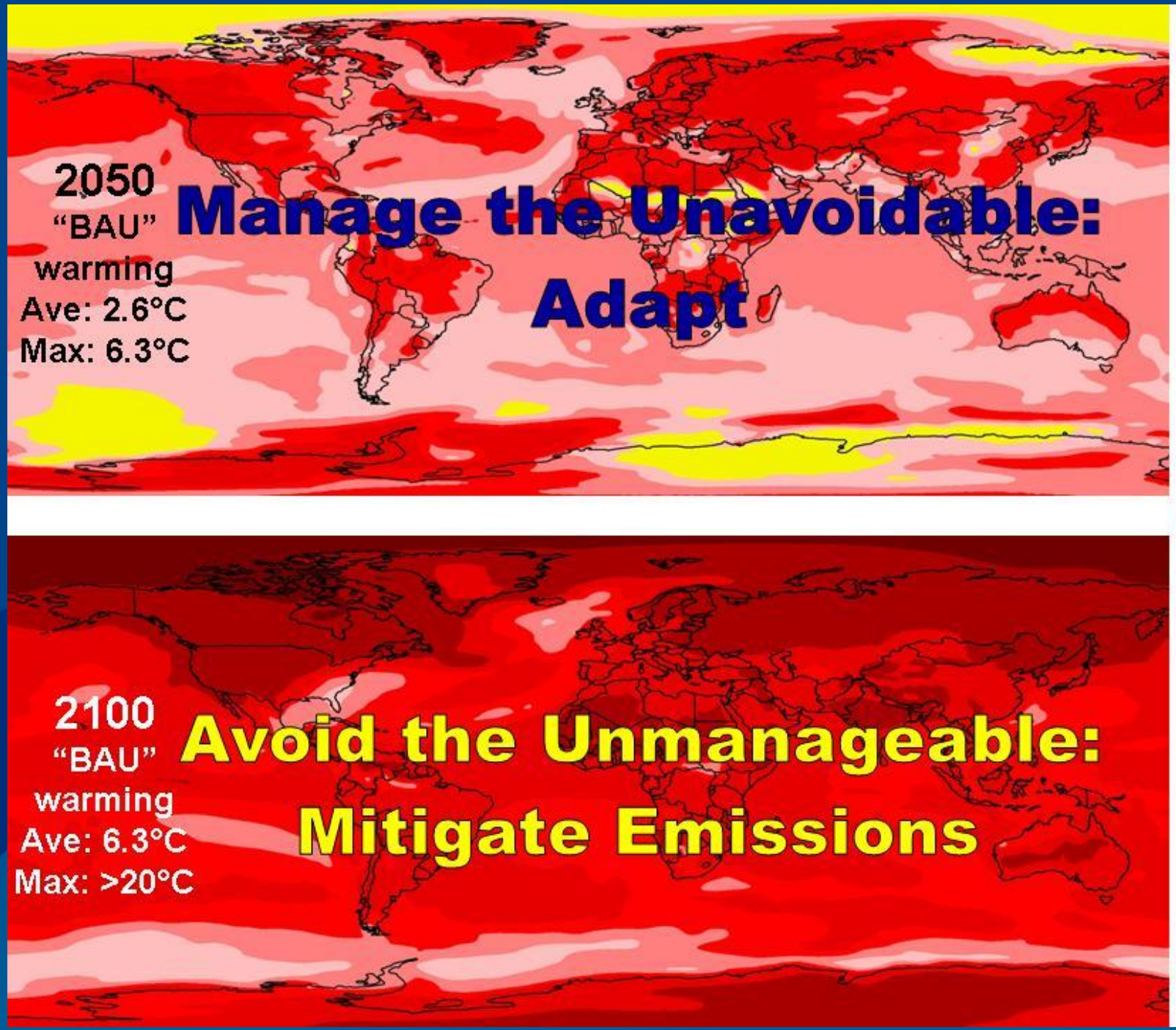


Zonal Average (°F)



1971
(Model Year)

GFDL CM 2.1
Climate Model



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More information and discussion:

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Climate Q&A slide sources include:

http://www.grist.org/news
http://n3xus6.blogspot.com
http://tamino.wordpress.com
http://www.realclimate.org
http://www.skepticalscience.com
http://www.aussmc.org
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