Environmental Impact of Climate Change on Kansas

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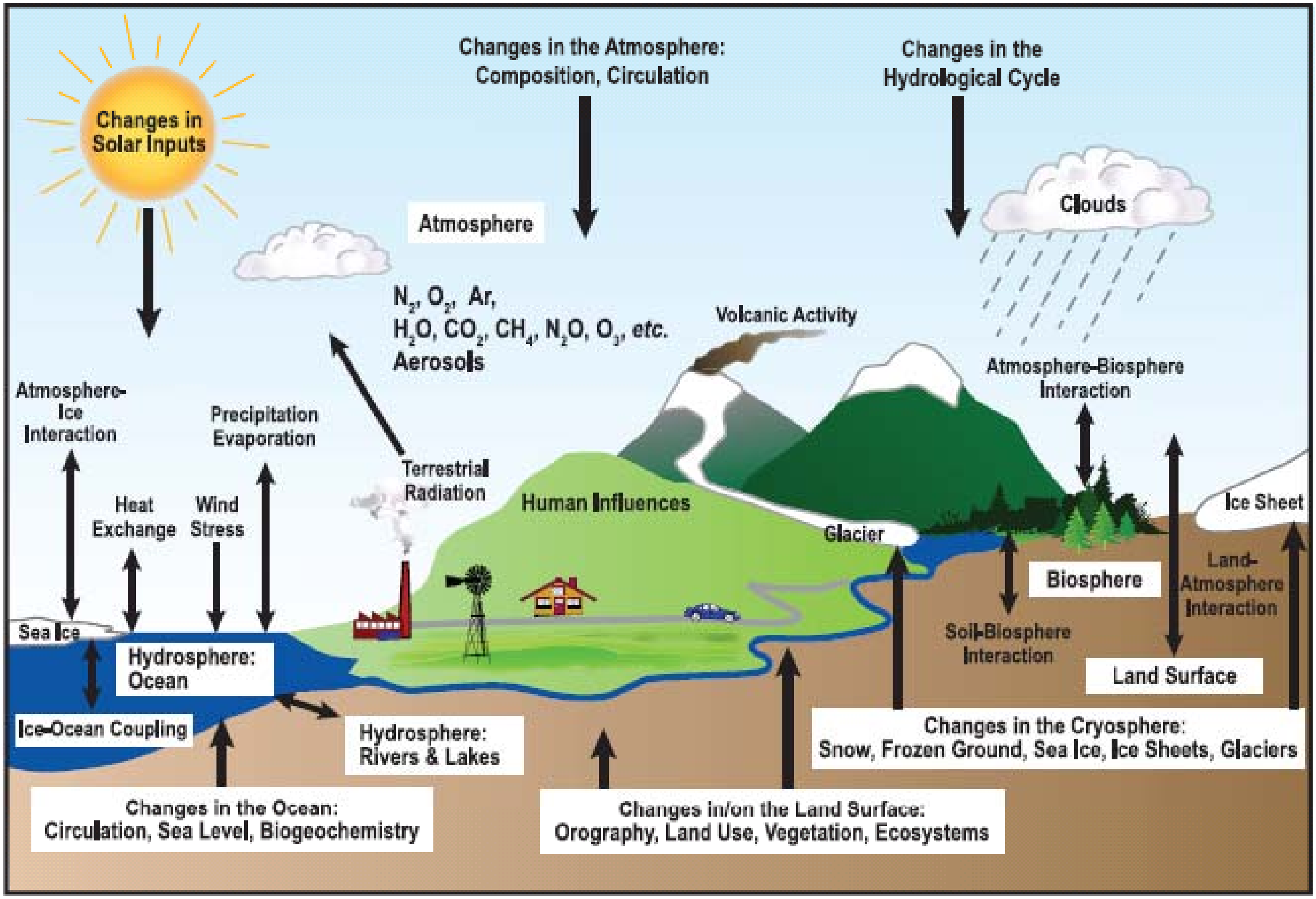
Outline

Kansas and Climate Change

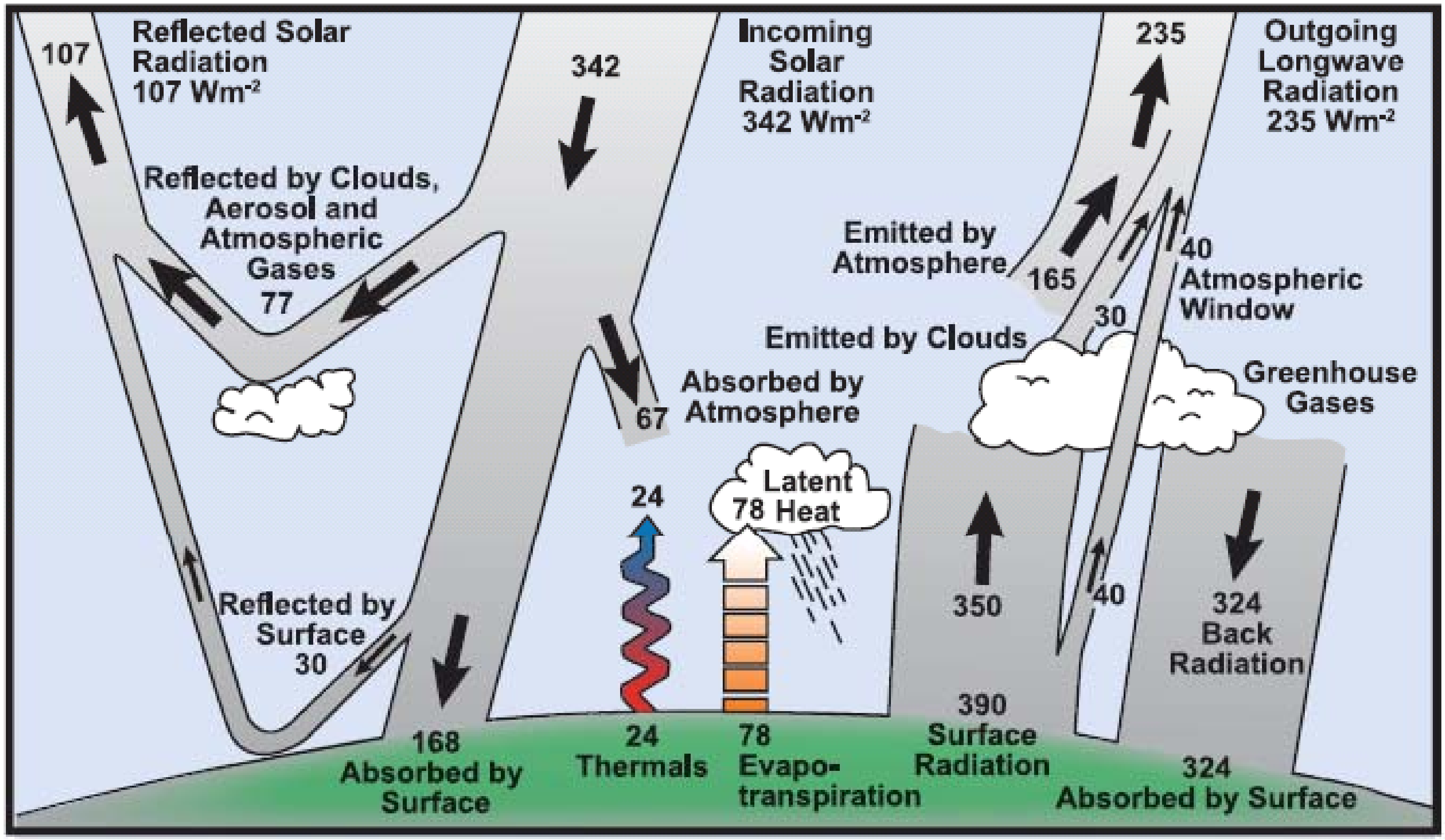
- Background on climate and on human impacts on climate
- Global climate over the last century
- If we can’t trust the weatherman what about climate projections – How reliable are climate models
- Climate projections
- Climate impacts
- Background on Kansas climate
- Kansas climate over the last century
- Potential Kansas climate impacts

Background: The Climate System



FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

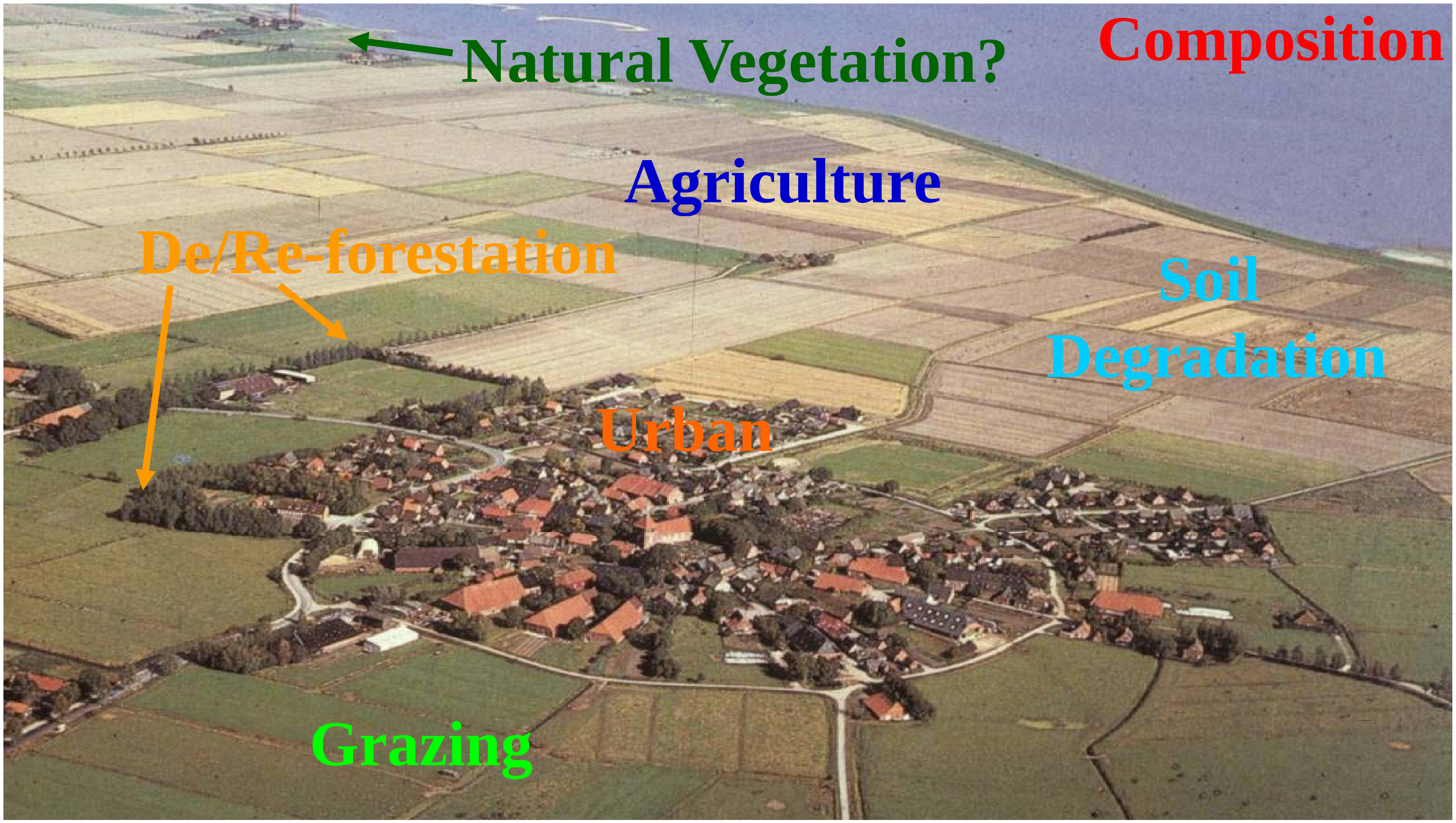
Background: The Climate System



FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*

Background: Human Climate Interactions

Human impacts on the climate system



Global Climate over the last century

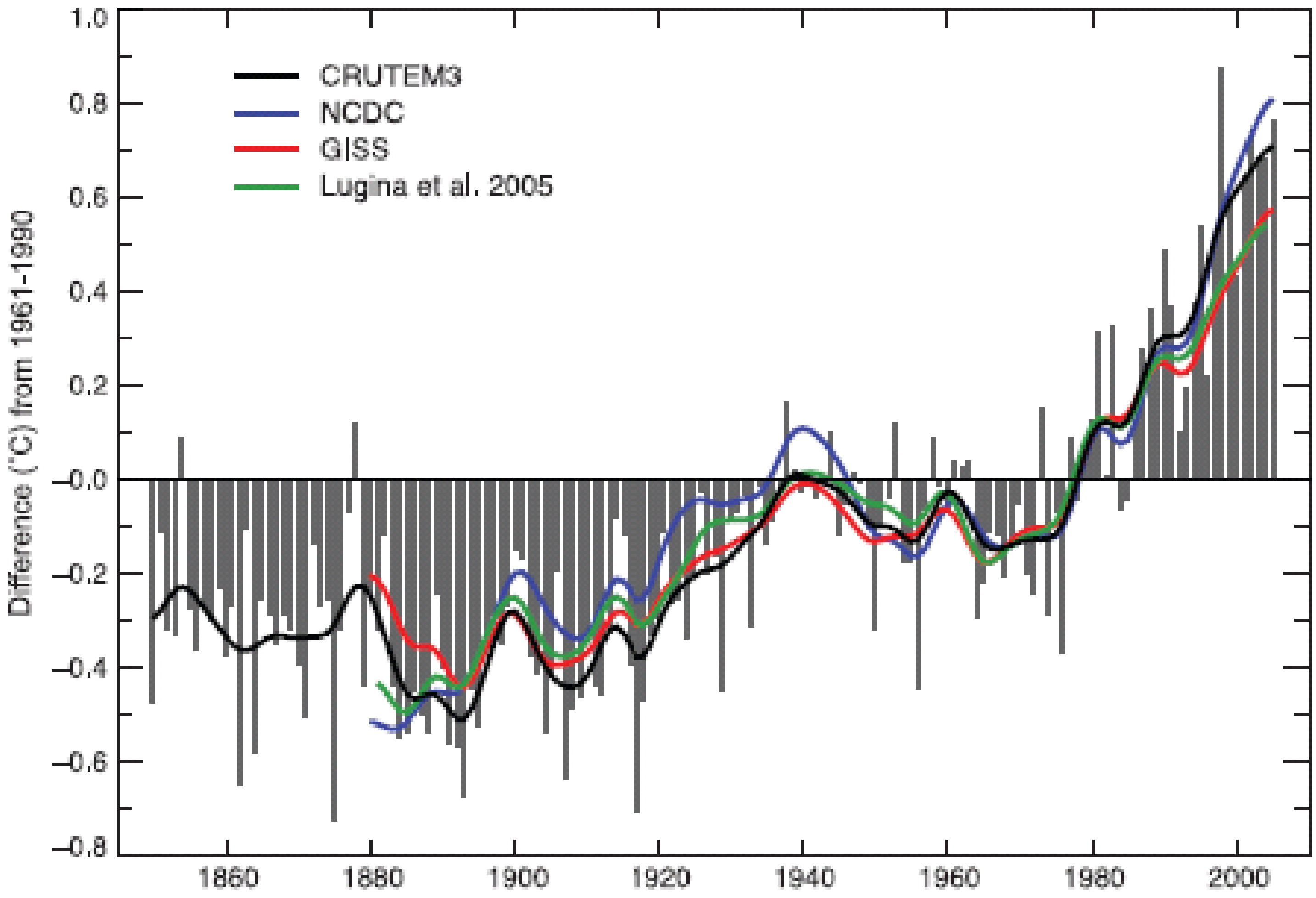


Figure 3.1. *Annual anomalies of global land-surface air temperature (°C), 1850 to 2005, relative to the 1961 to 1990 mean for CRUTEM3 updated from Brohan et al. (2006). The smooth curves show decadal variations (see Appendix 3.A). The black curve from CRUTEM3 is compared with those from NCDC (Smith and Reynolds, 2005; blue), GISS (Hansen et al., 2001; red) and Lugina et al. (2005; green).*

Global Climate over the last century

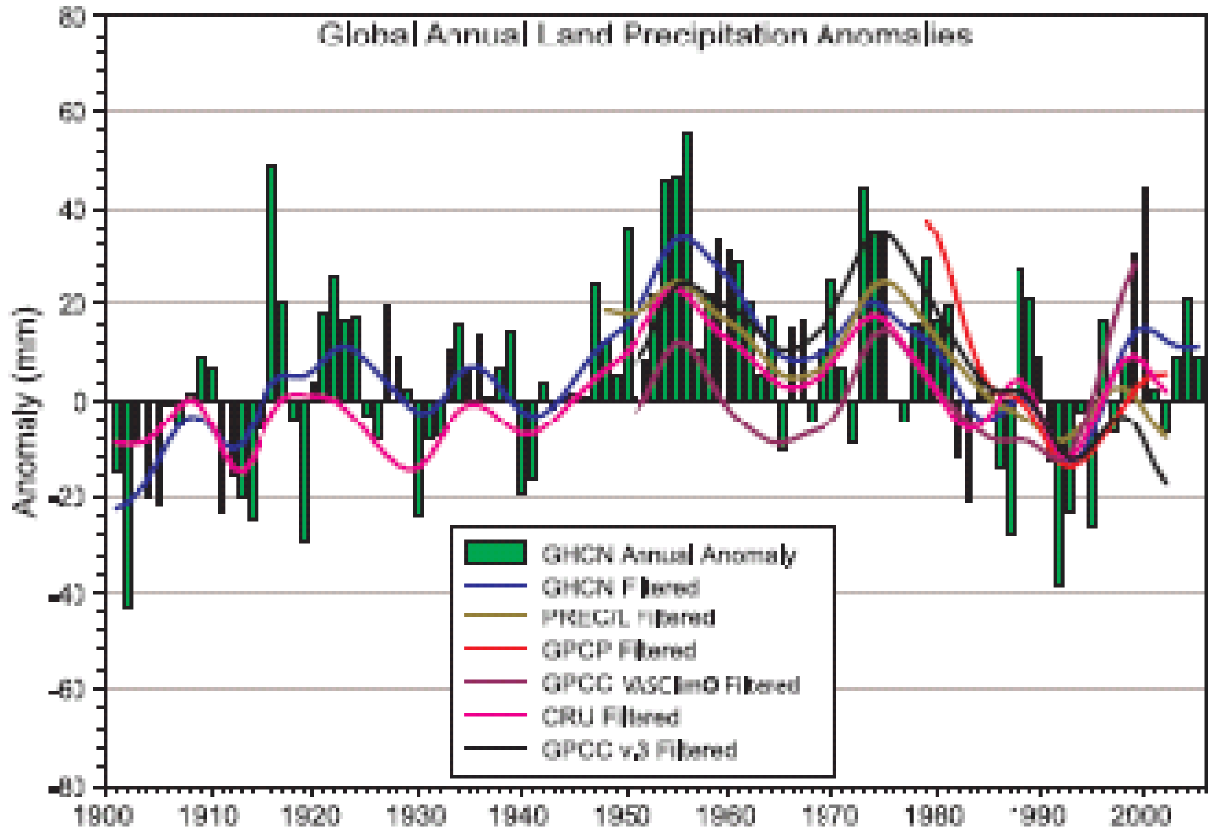


Figure 3.12. *Time series for 1900 to 2005 of annual global land precipitation anomalies (mm) from GHCN with respect to the 1981 to 2000 base period. The smooth curves show decadal variations (see Appendix 3.A) for the GHCN (Peterson and Vose, 1997), PREC/L (Chen et al., 2002) GPCP (Adler et al., 2003), GPCC (Rudolf et al., 1994) and CRU (Mitchell and Jones, 2005) data sets.*

Global Climate over the last century

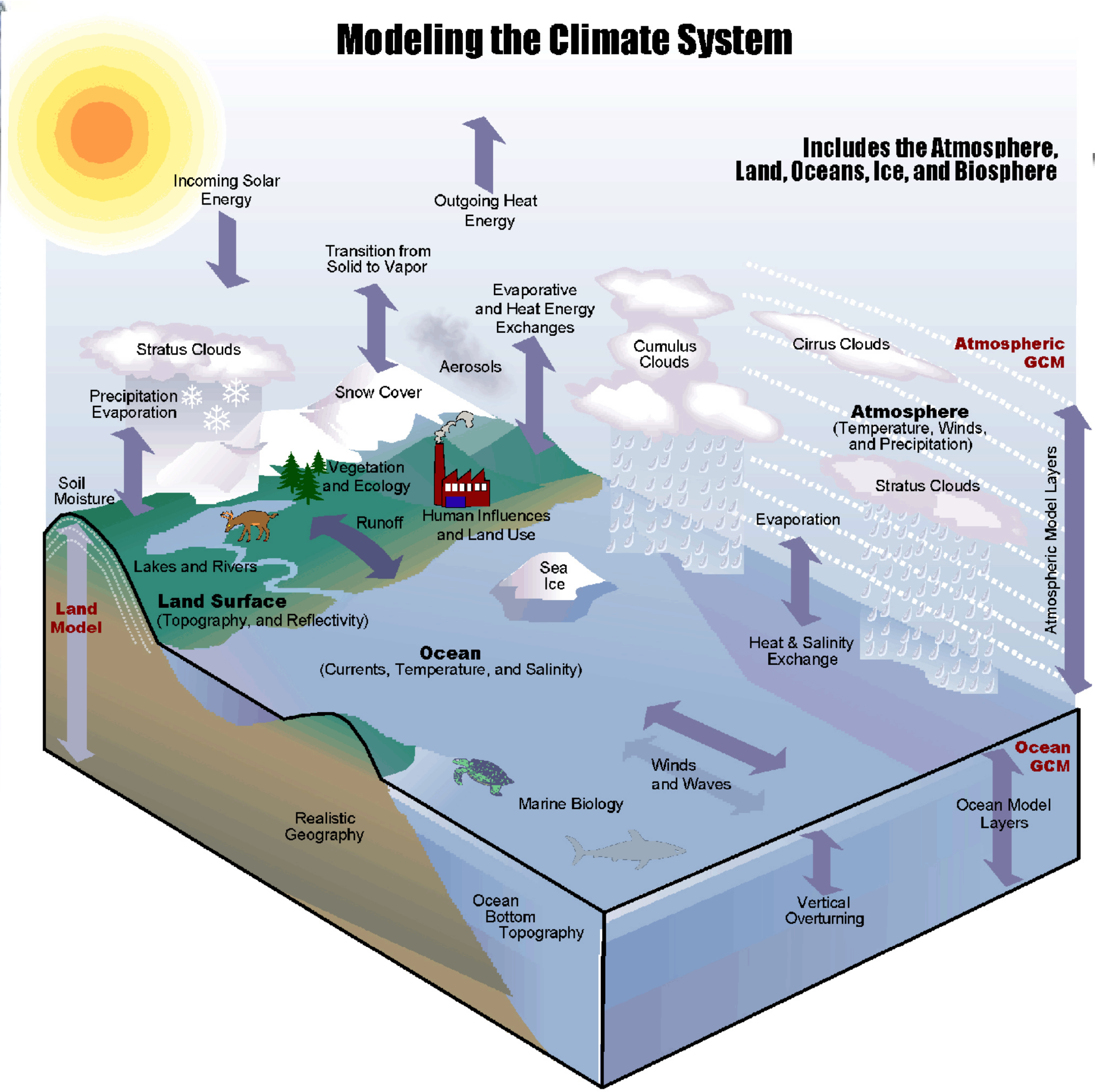
What is the cause of these changes?

How do we separate out different forcings?

Models

- **Explain our theoretical knowledge**
- **Isolate components for more detailed study**
- **Simulate potential future processes**

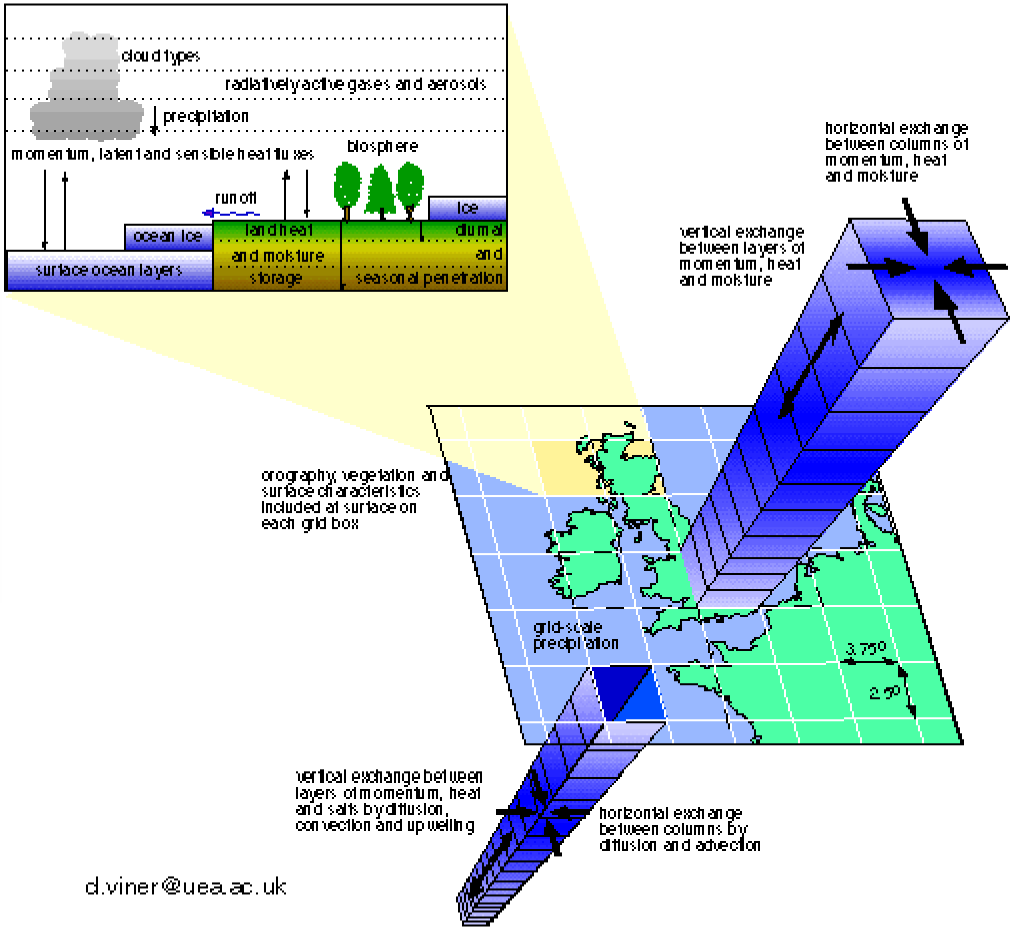
Modeling the Climate System



Timeline of Climate Model Development

Mid-1960s	Mid 1970s-1980s	1990s	Present Day	2000-2010
Atmosphere/ Land Surface	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation
Ocean	Ocean	Ocean	Ocean	Ocean
	Sea Ice	Sea Ice	Sea Ice	Sea Ice
	Coupled Climate Model	Coupled Climate Model	Coupled Climate Model	Coupled Climate Model
		Sulfate Aerosol	Sulfate Aerosol	Sulfate Aerosol
		Carbon Cycle	Carbon Cycle	Carbon Cycle
			Dust/Sea Spray/Carbon Aerosols	Dust/Sea Spray/Carbon Aerosols
			Interactive Vegetation	Interactive Vegetation
			Biogeochemical Cycles	Biogeochemical Cycles
				Ice Sheet

Climate Models



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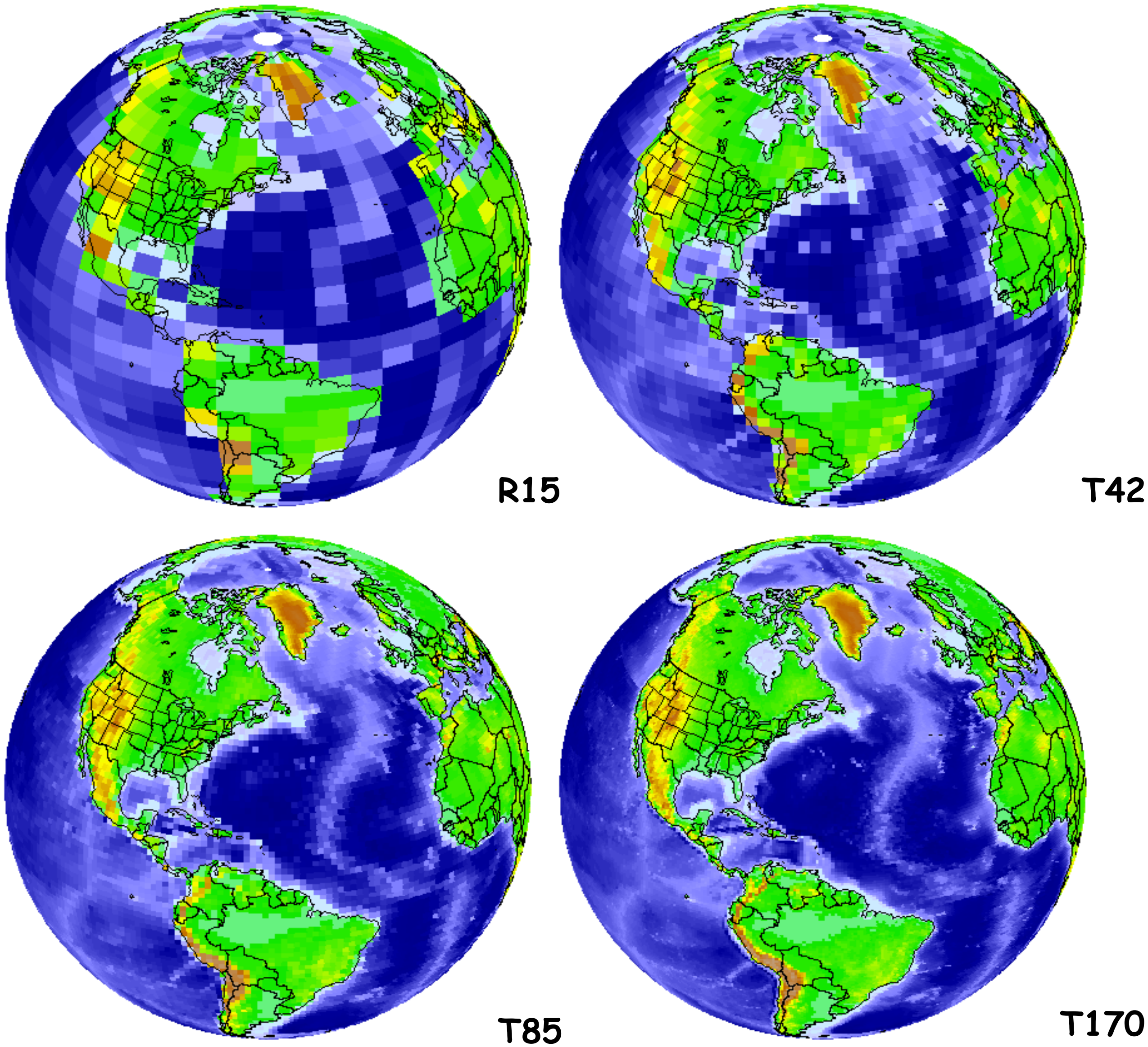
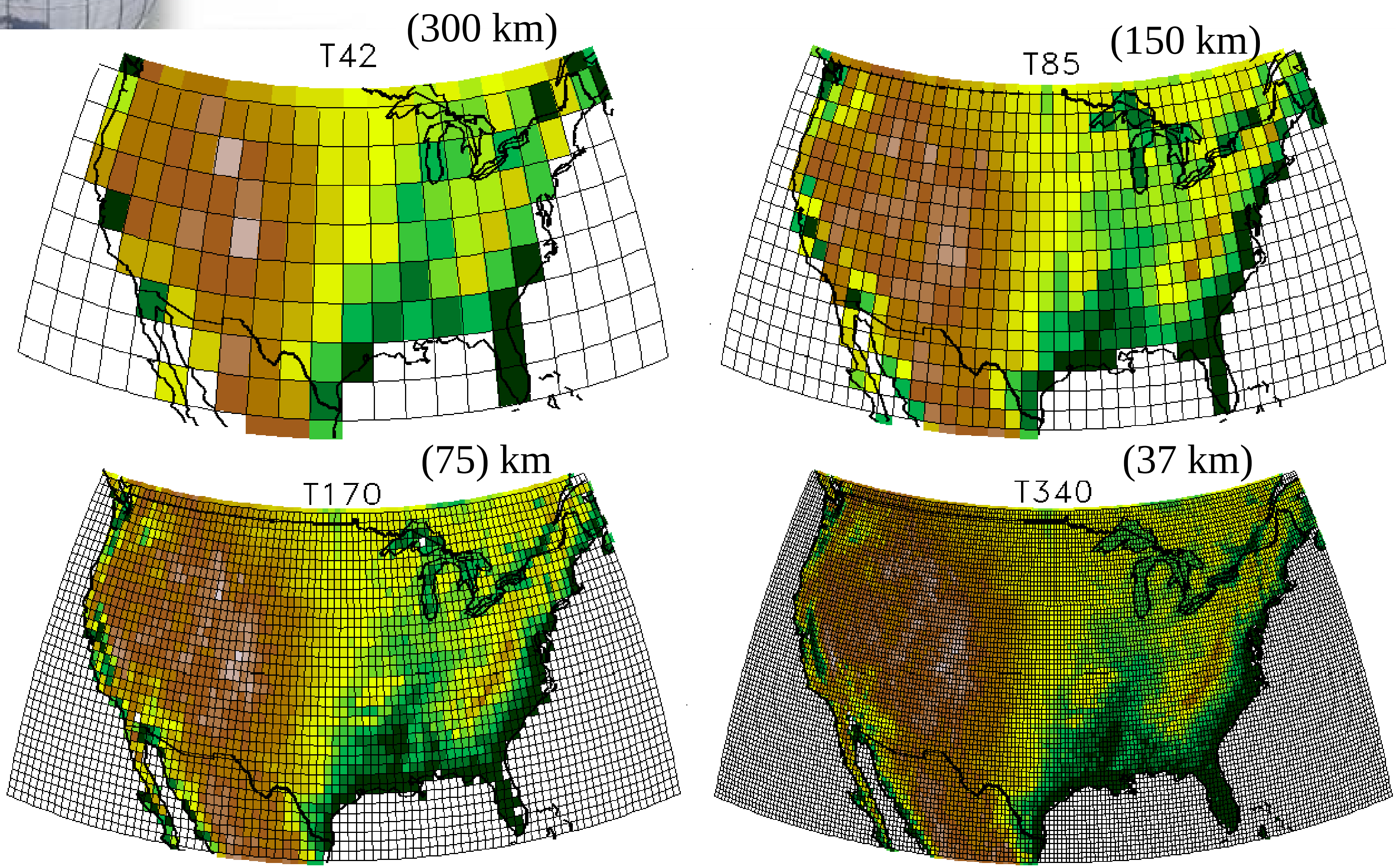
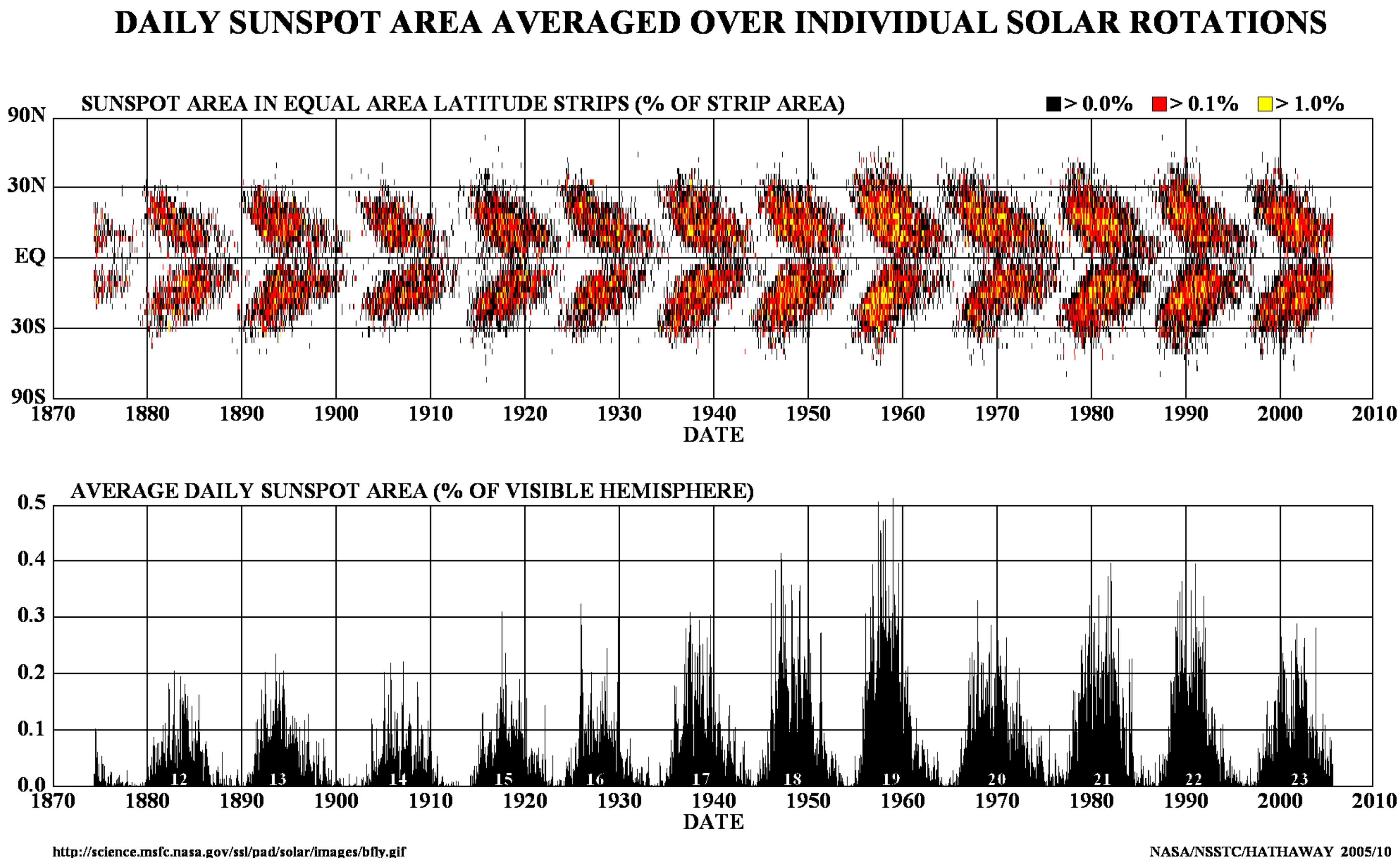
Climate Models



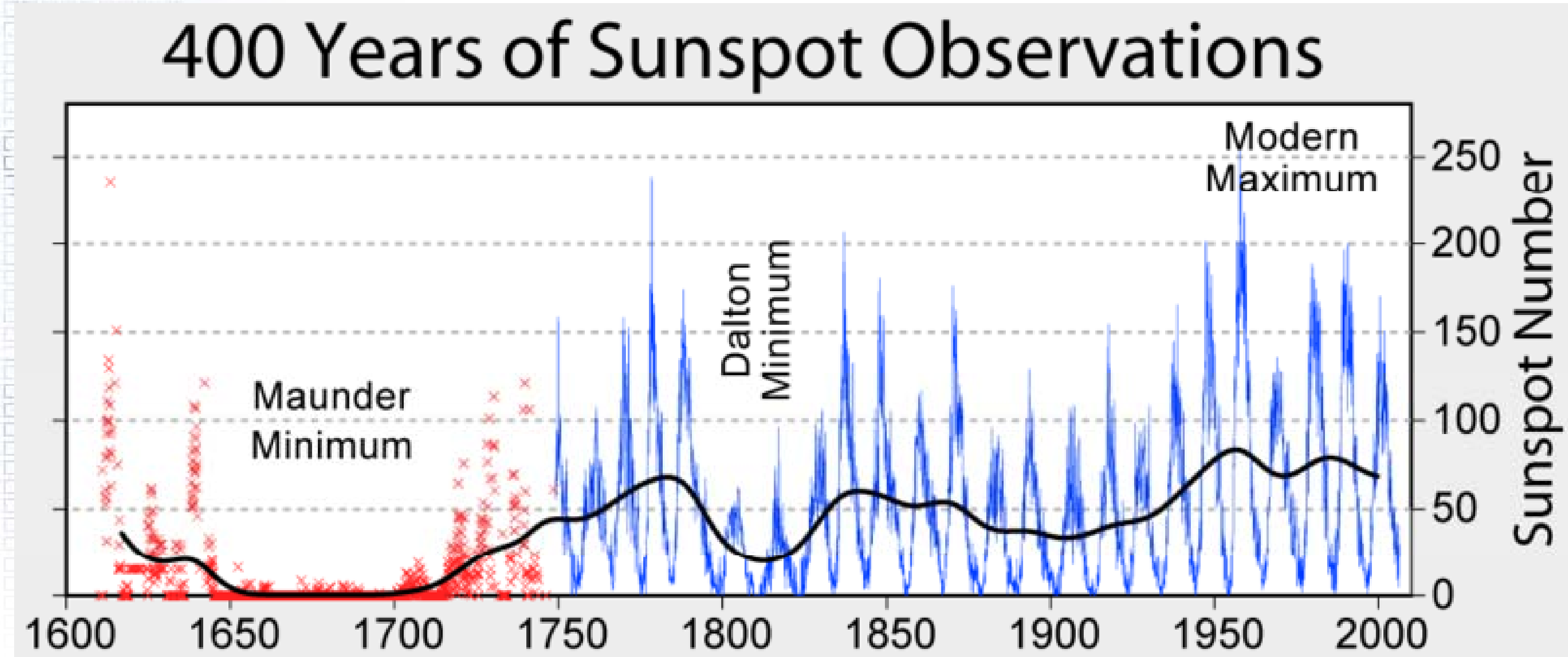
Climate Models



Climate Forcing (Natural)



Natural Forcing over the last century



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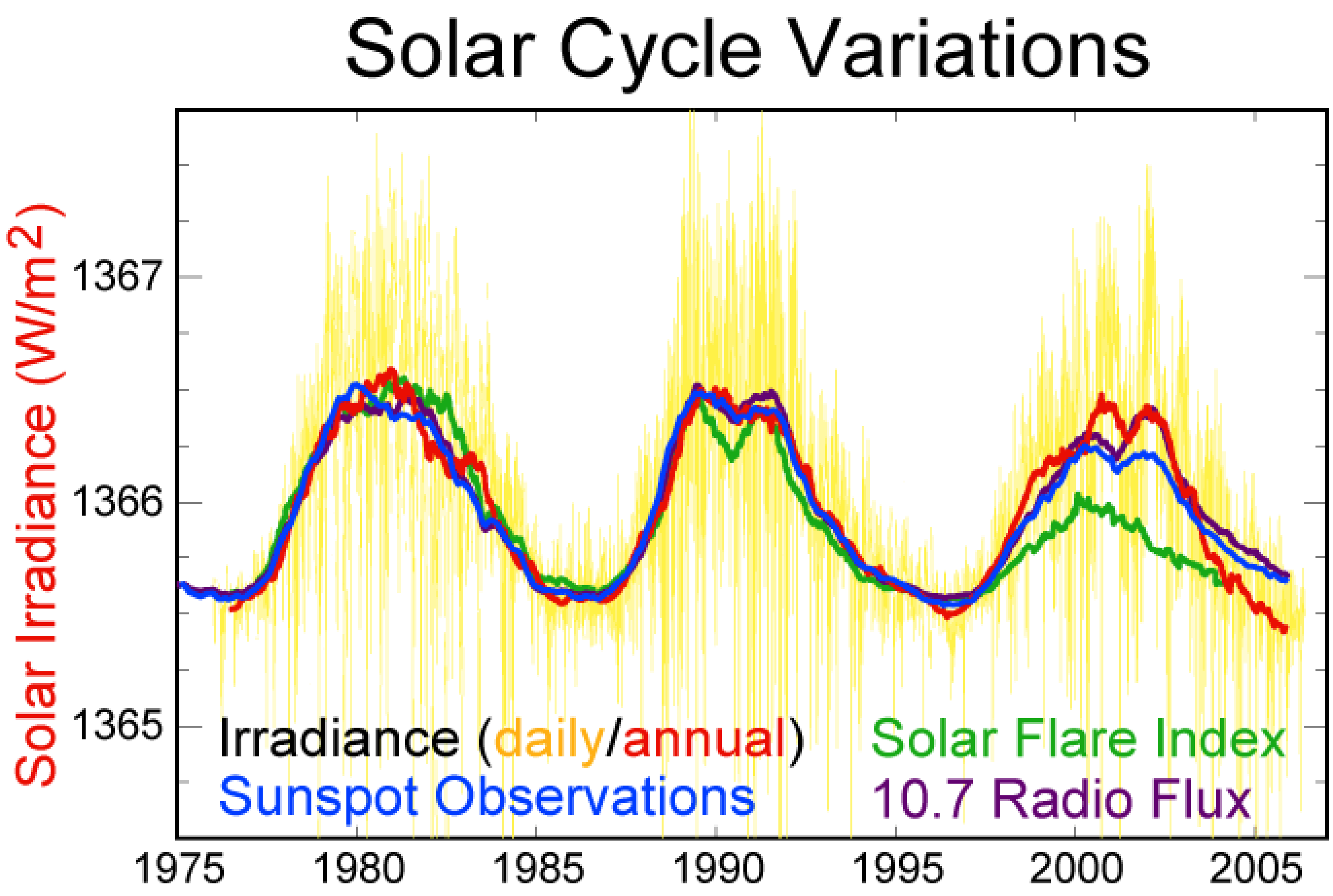
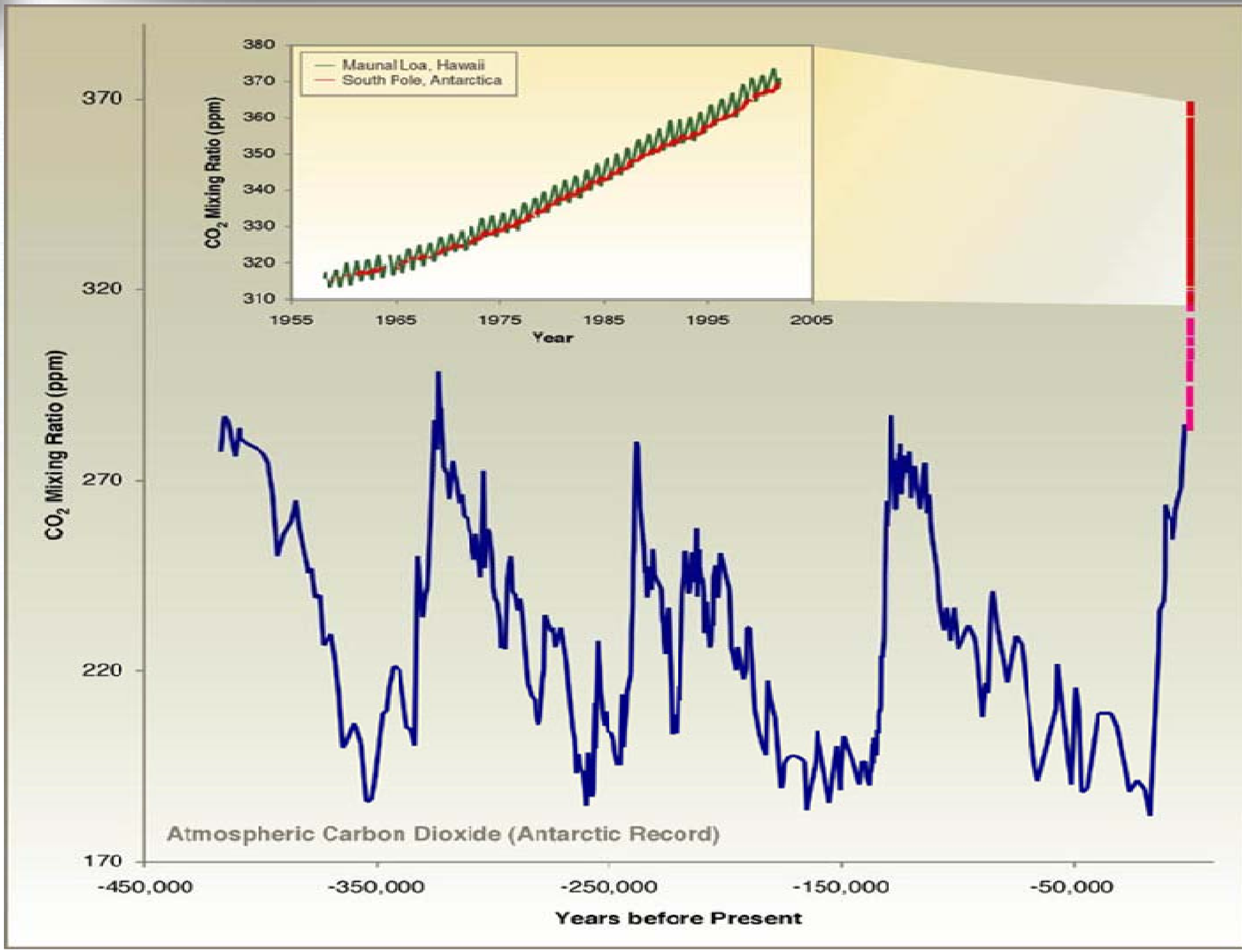


Climate Forcing (Anthropogenic)

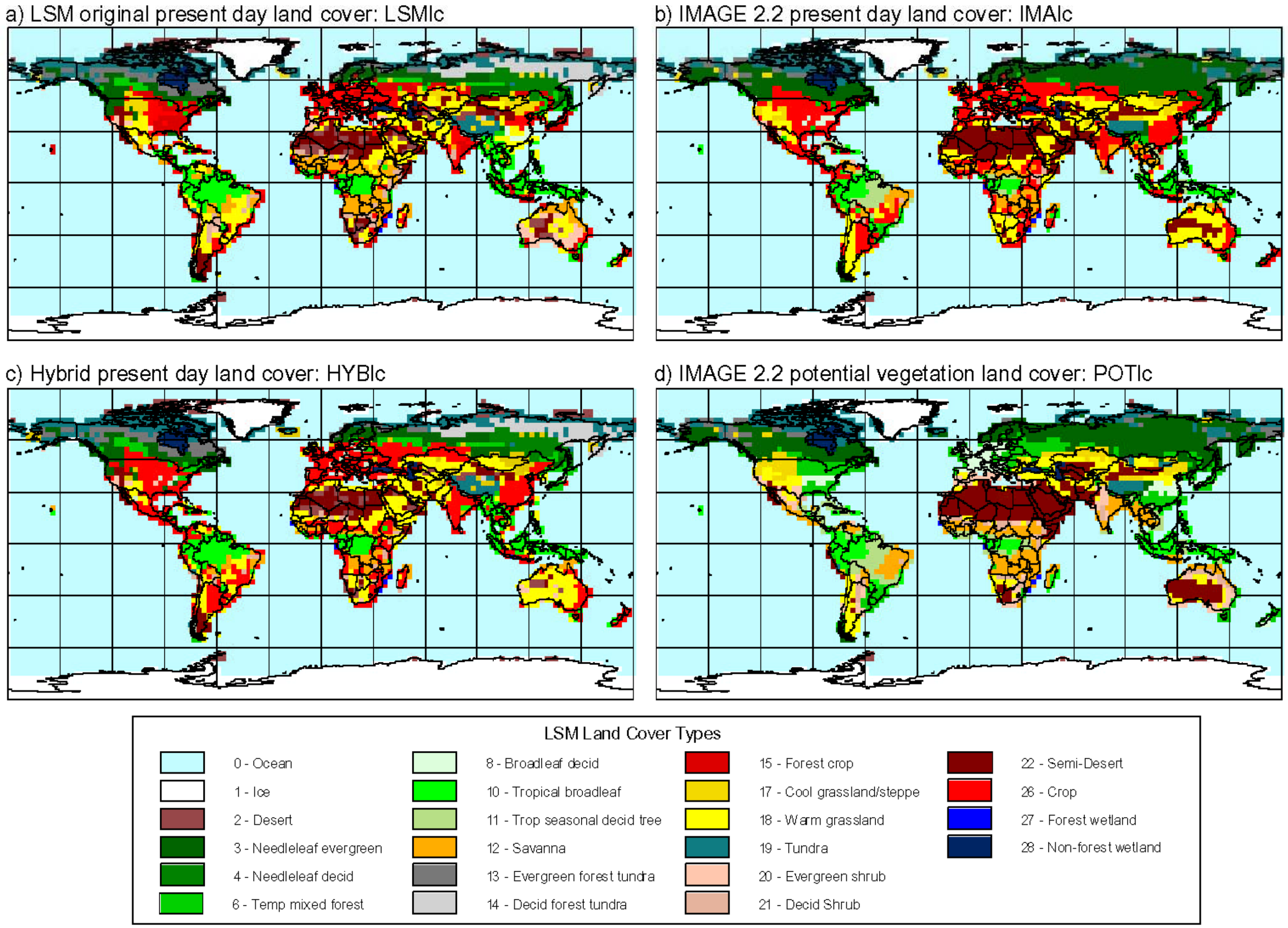
Source: World Resources 2000-2001 Time Magazine – 9 April 2001

Climate Forcing (Anthropogenic)



Climate Forcing (Anthropogenic)

PCM Uncertainty/Historical Equilibrium Land Cover Simulations



Climate Forcing (Anthropogenic)

PCM Uncertainty/Historical Equilibrium Land Cover Simulations

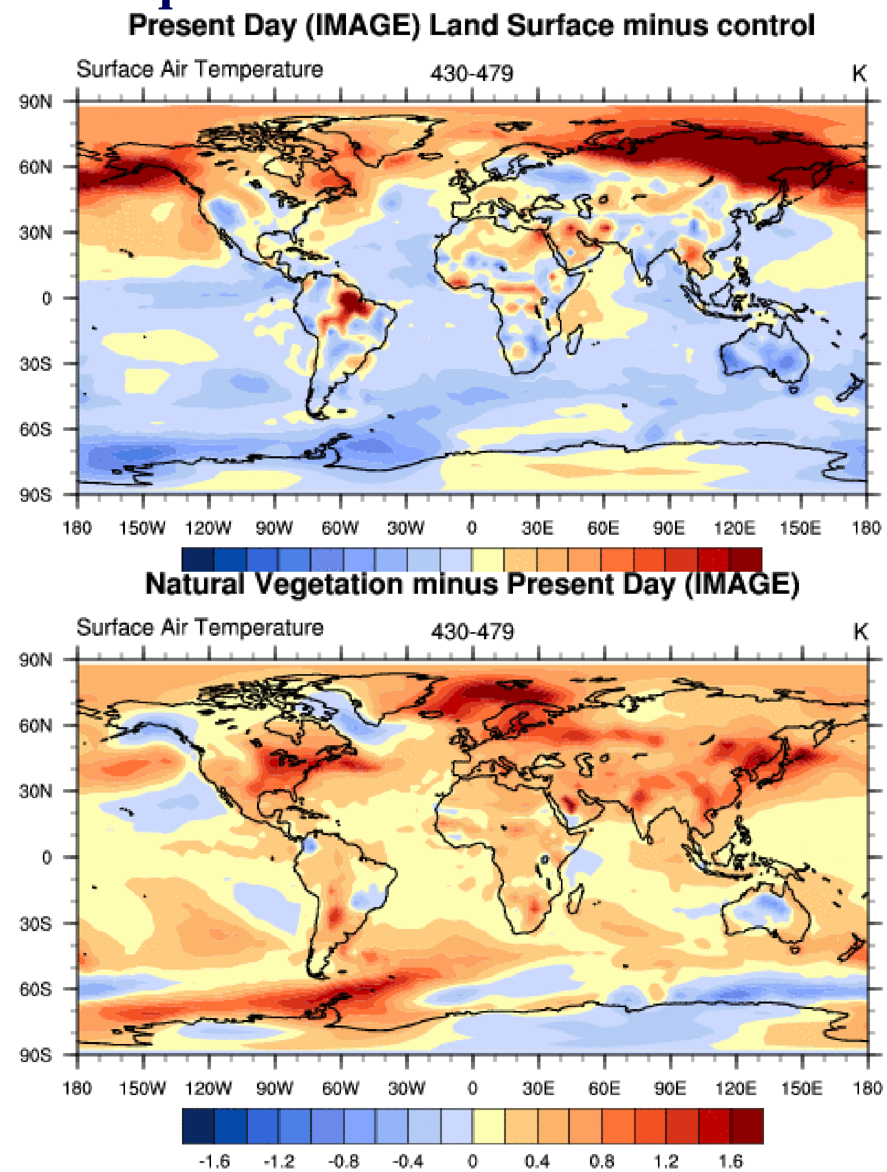
PRESENT DAY UNCERTAINTY

- Arctic – albedo
- Amazon – latent heat flux
- Australia – albedo

HISTORICAL CHANGE

Climate difference from land cover classification is as large as the climate difference from land cover change

- Primarily shift to agriculture

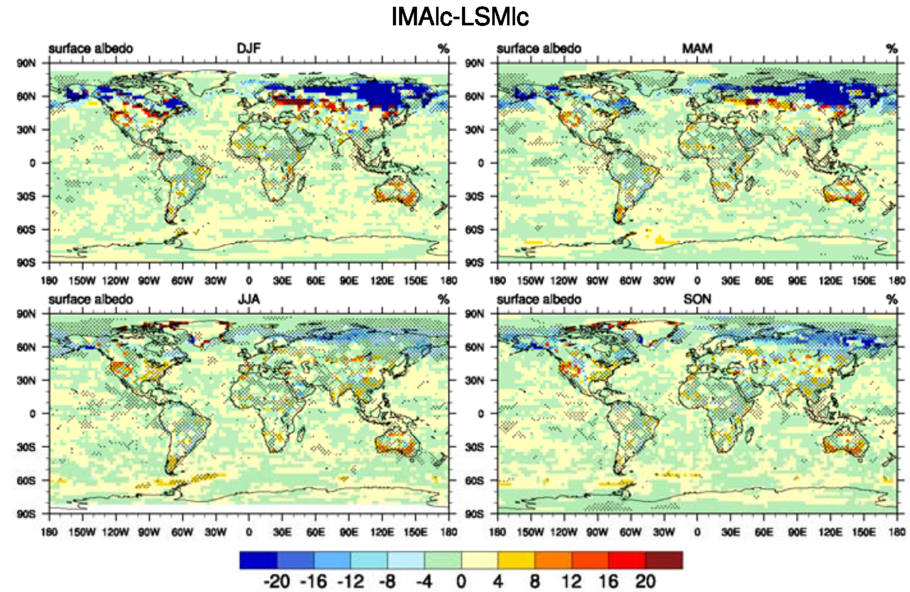


Climate Forcing (Anthropogenic)

PCM Present Day Comparison

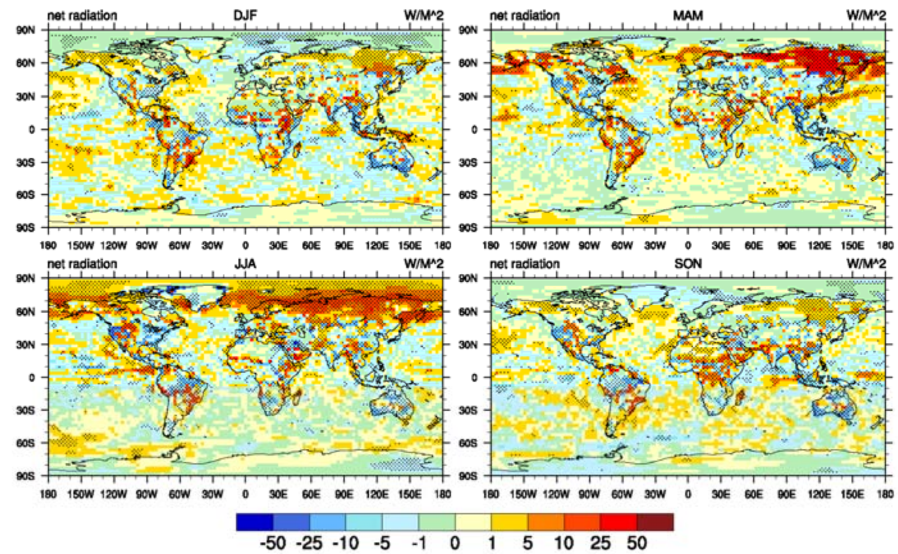
Image - LSM

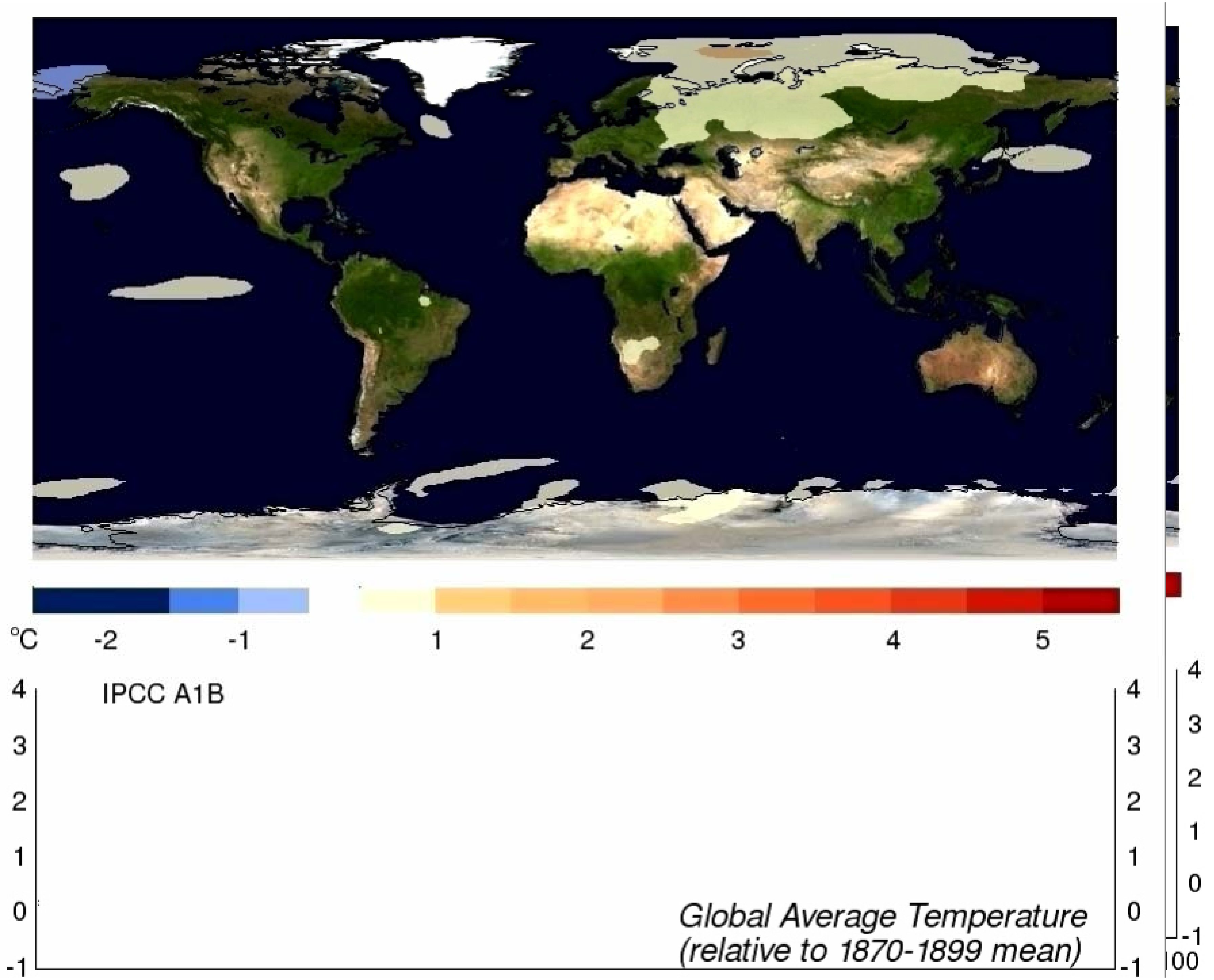
Seasonal Change in Albedo



Strong winter/spring albedo change in the Northern Hemisphere translates to spring/summer net radiation change due to solar seasonality

Seasonal Change in Net Radiation



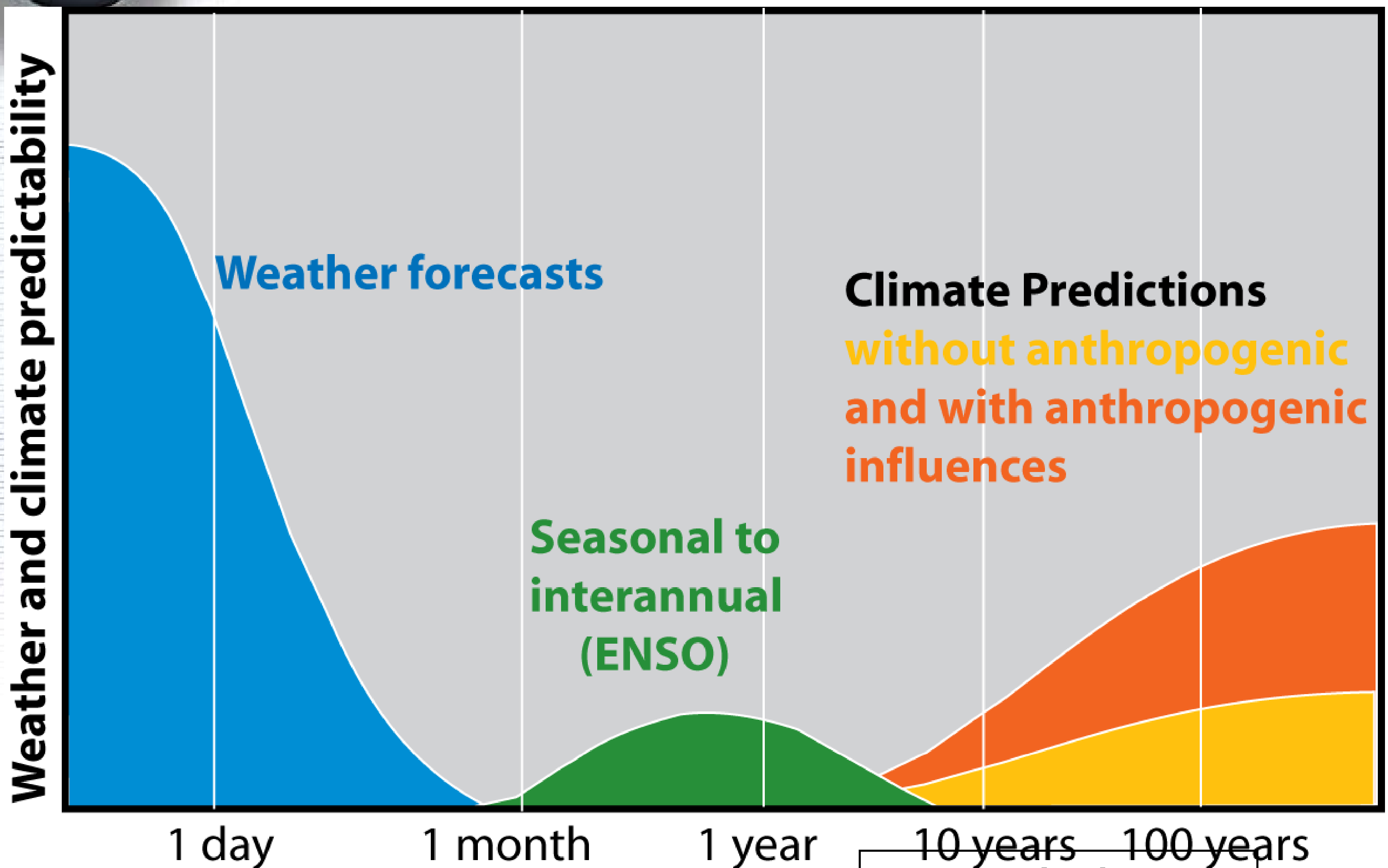

°C -2 -1 1 2 3 4 5
IPCC A1B
4
3
2
1
0
-1
Global Average Temperature
(relative to 1870-1899 mean)

Global Climate over the last century

What will the future bring?

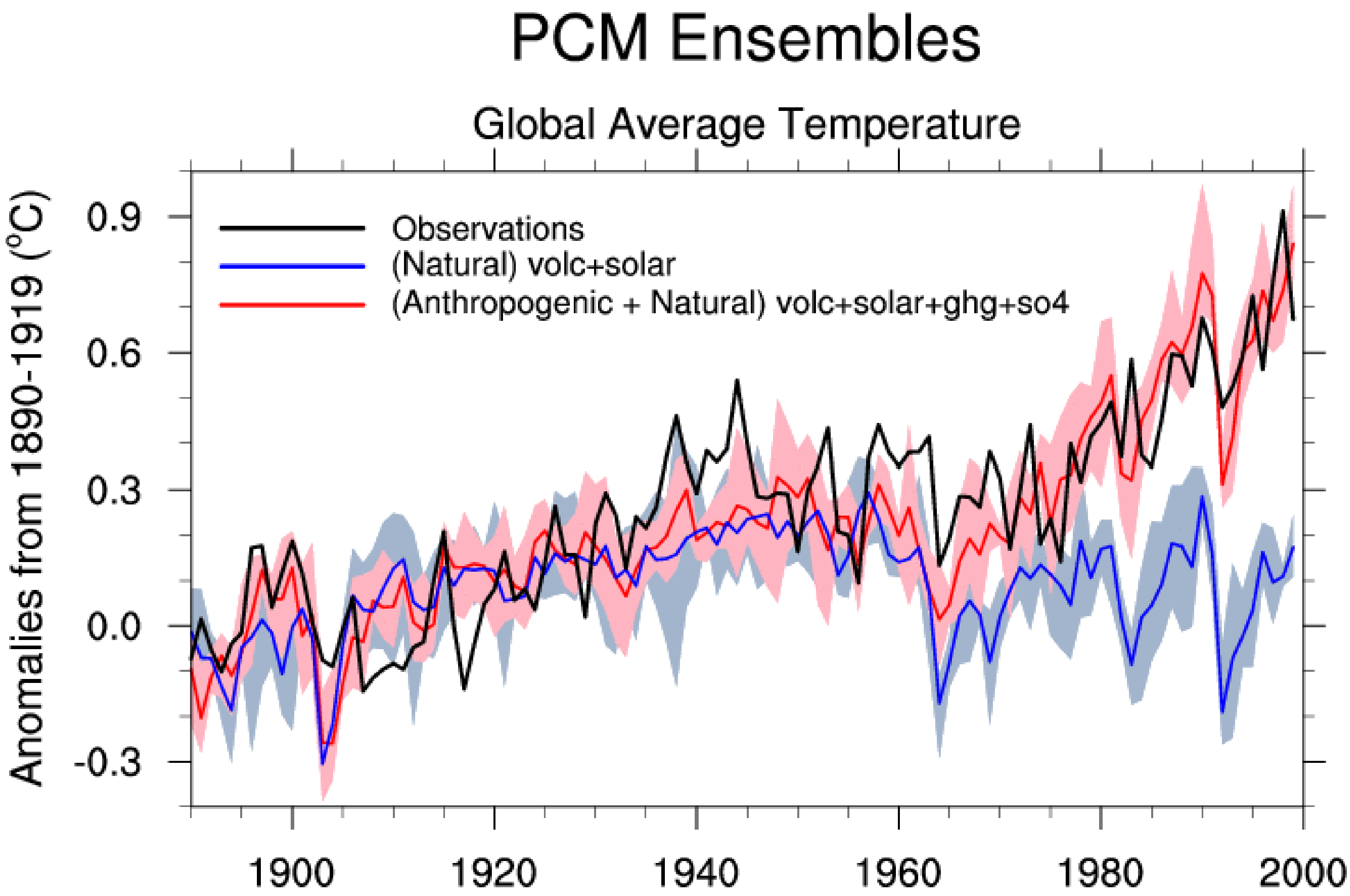
Using Models to simulate possible scenarios?

How reliable are climate models



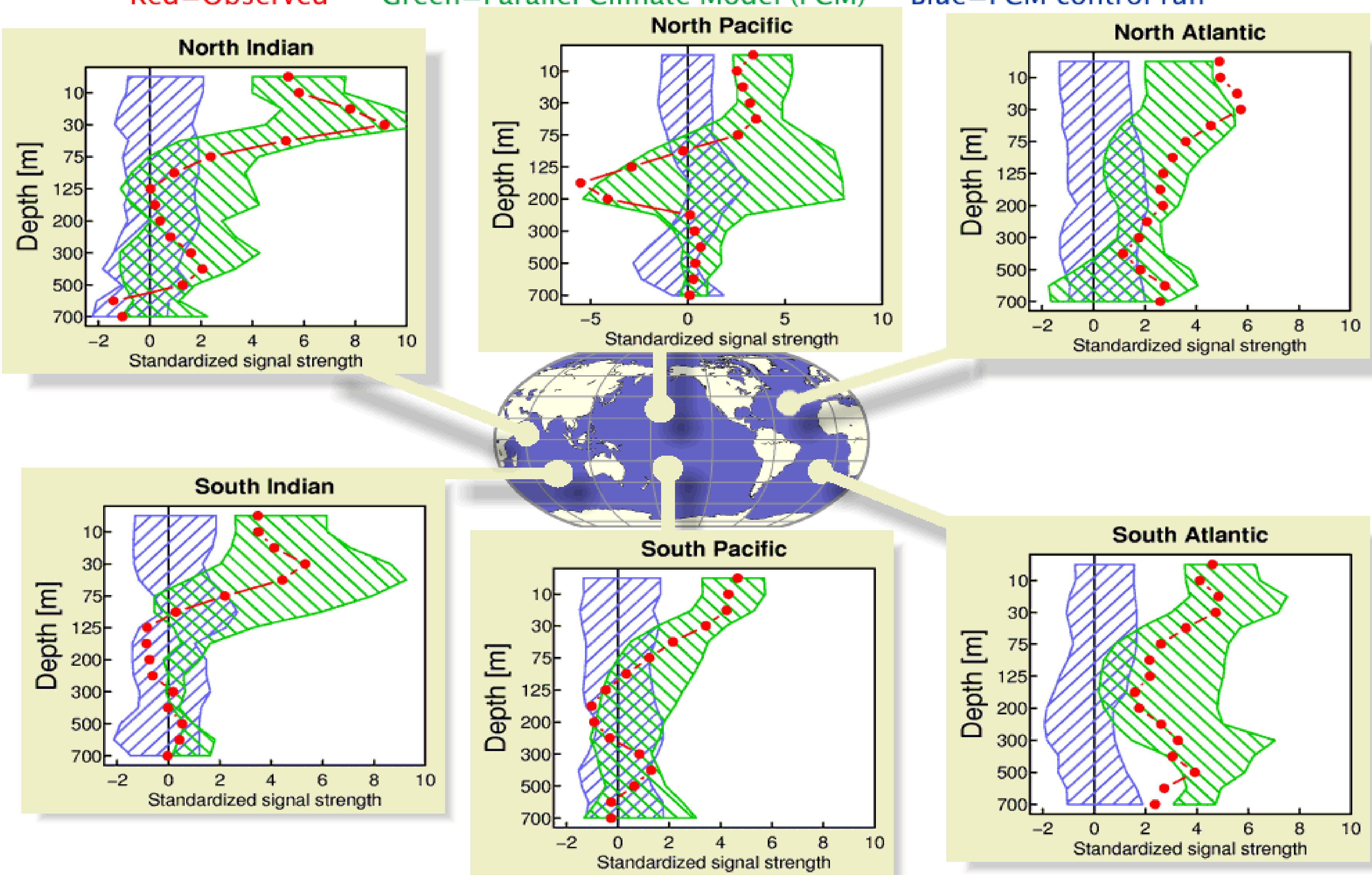
Keven Trenberth, NCAR

How reliable are climate models



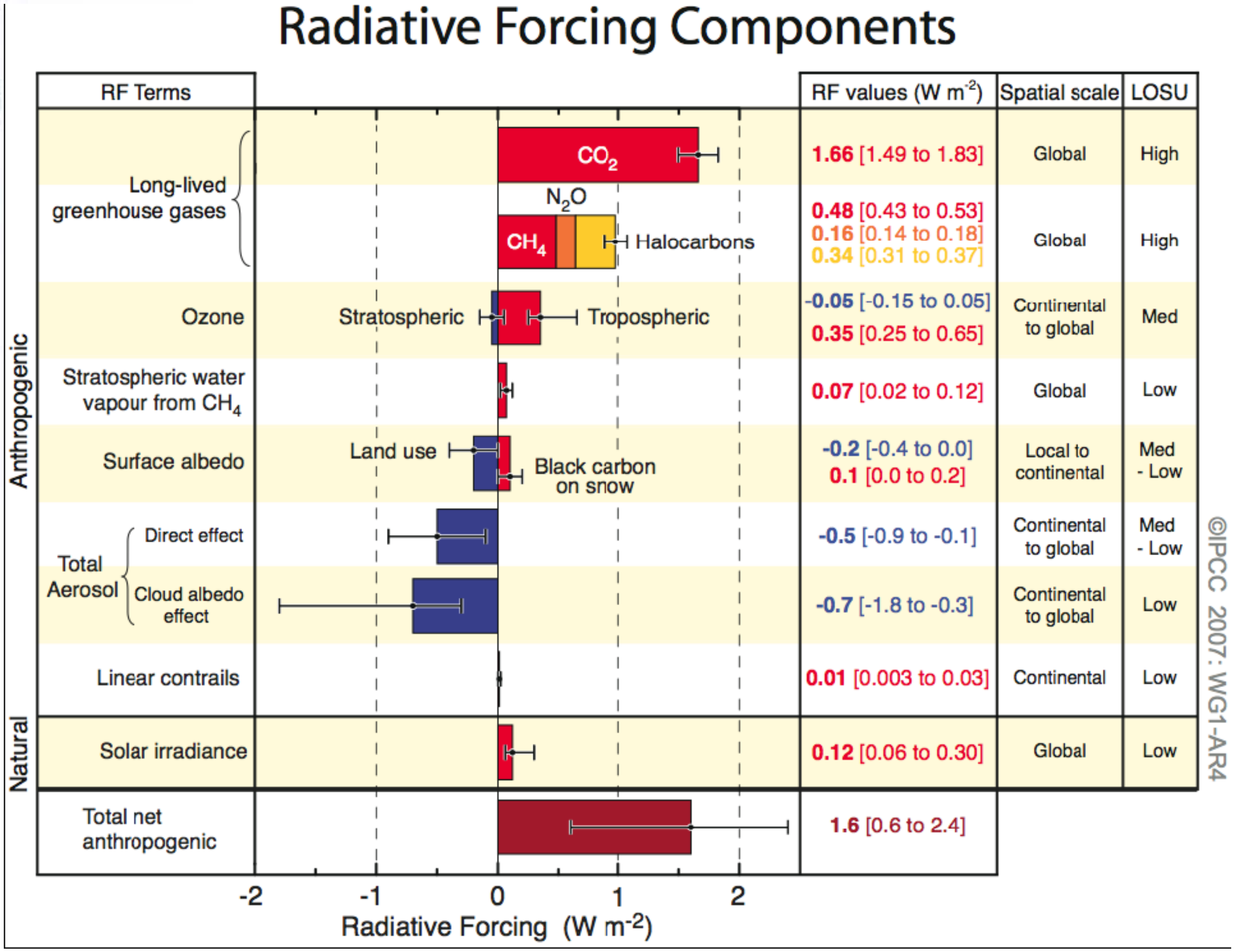
Penetration of Ocean Warming Signal (1955–1999)

Red=Observed Green=Parallel Climate Model (PCM) Blue=PCM control run

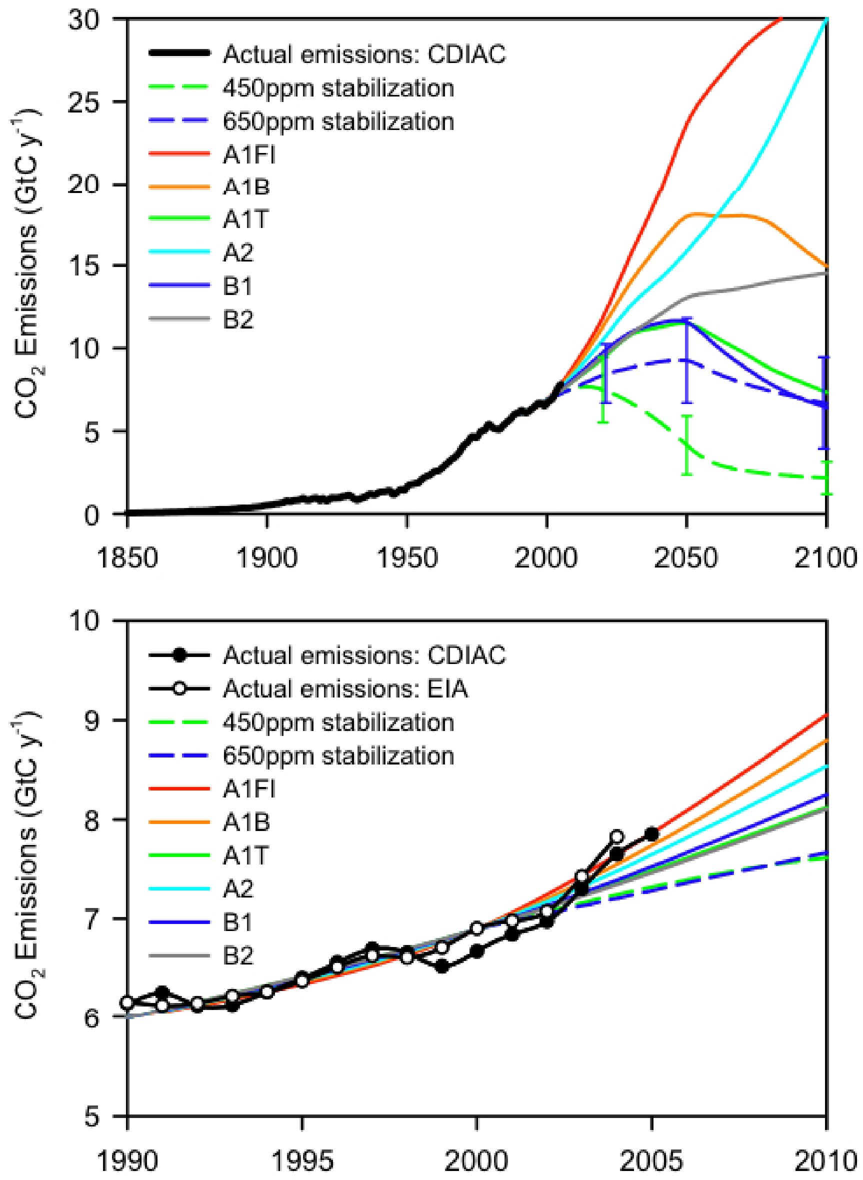


T. Barnett and D. Pierce of SIO

IPCC Report on Anthropogenic Climate Impacts



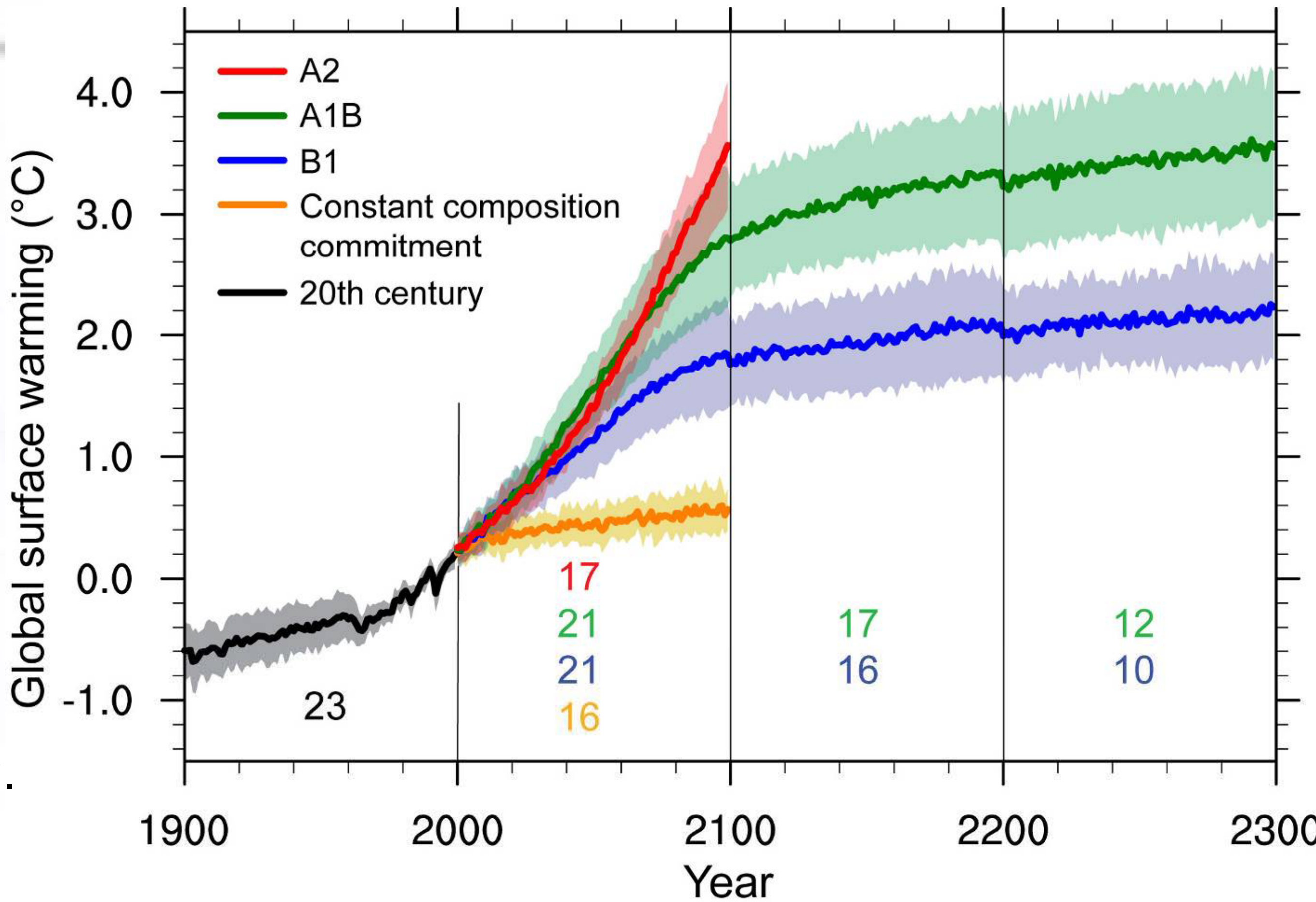
Climate projections



Raupach et al., PNAS, 2007

Climate projections: GHG

Anomalies relative to 1980-99



IPCC Ch. 10, Fig. 10.4, TS-32

Climate change experiments from 16 groups (11 countries) and 23 models collected at PCMDI (over 31 terabytes of model data)

Committed warming averages 0.1°C per decade for the first two decades of the 21st century; across all scenarios, the average warming is 0.2°C per decade for that time period (recent observed trend 0.2°C per decade)

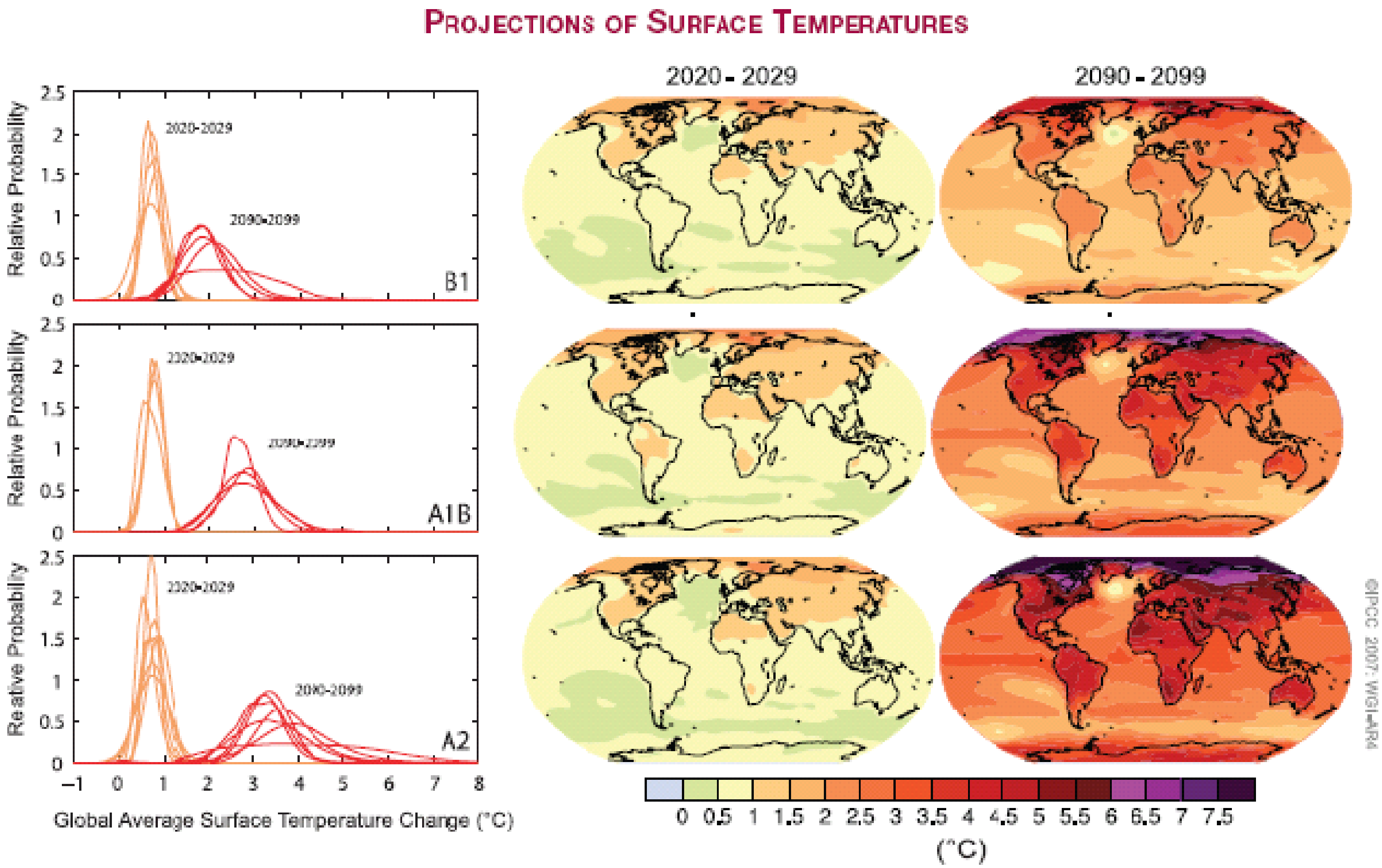
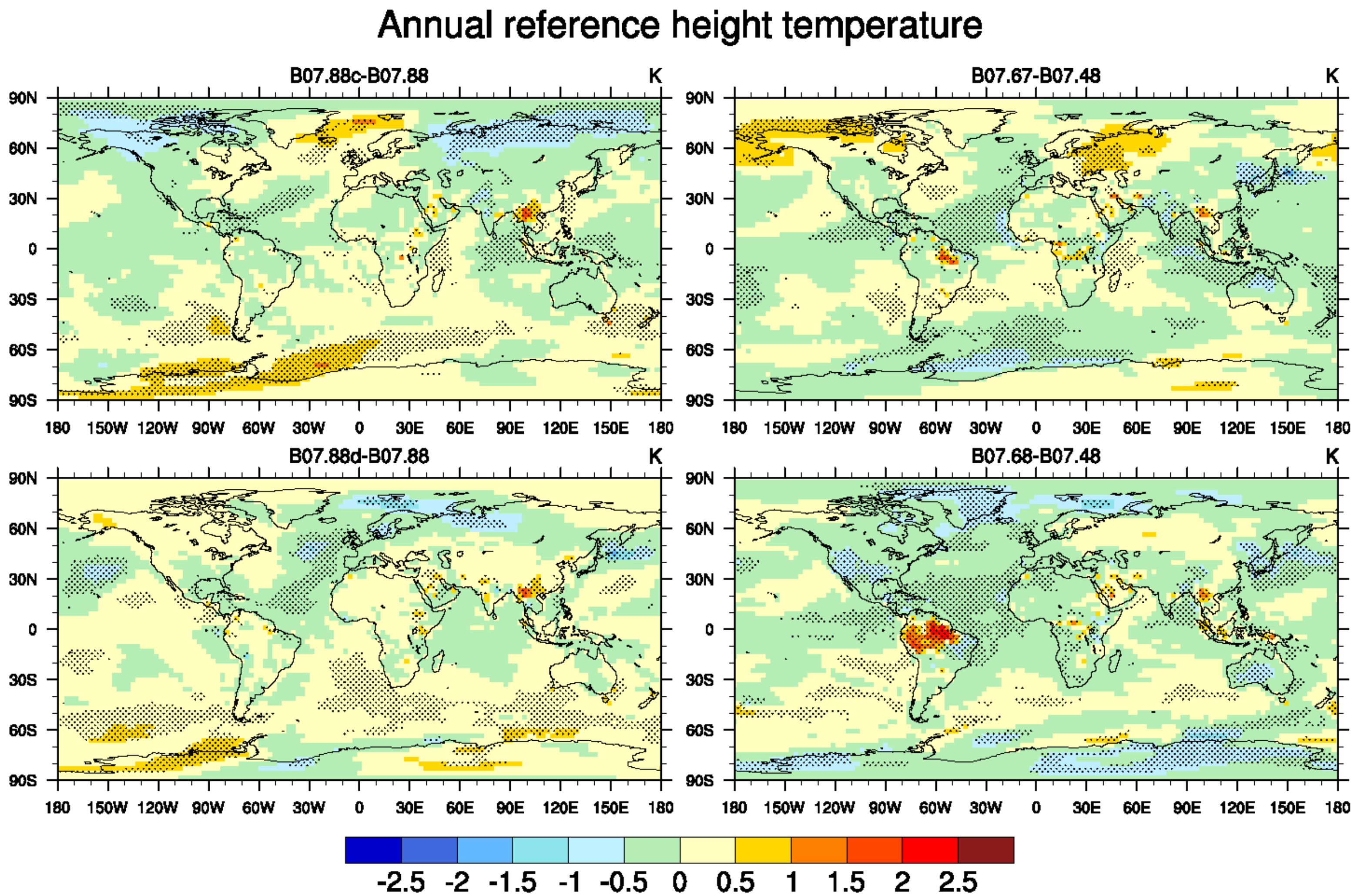
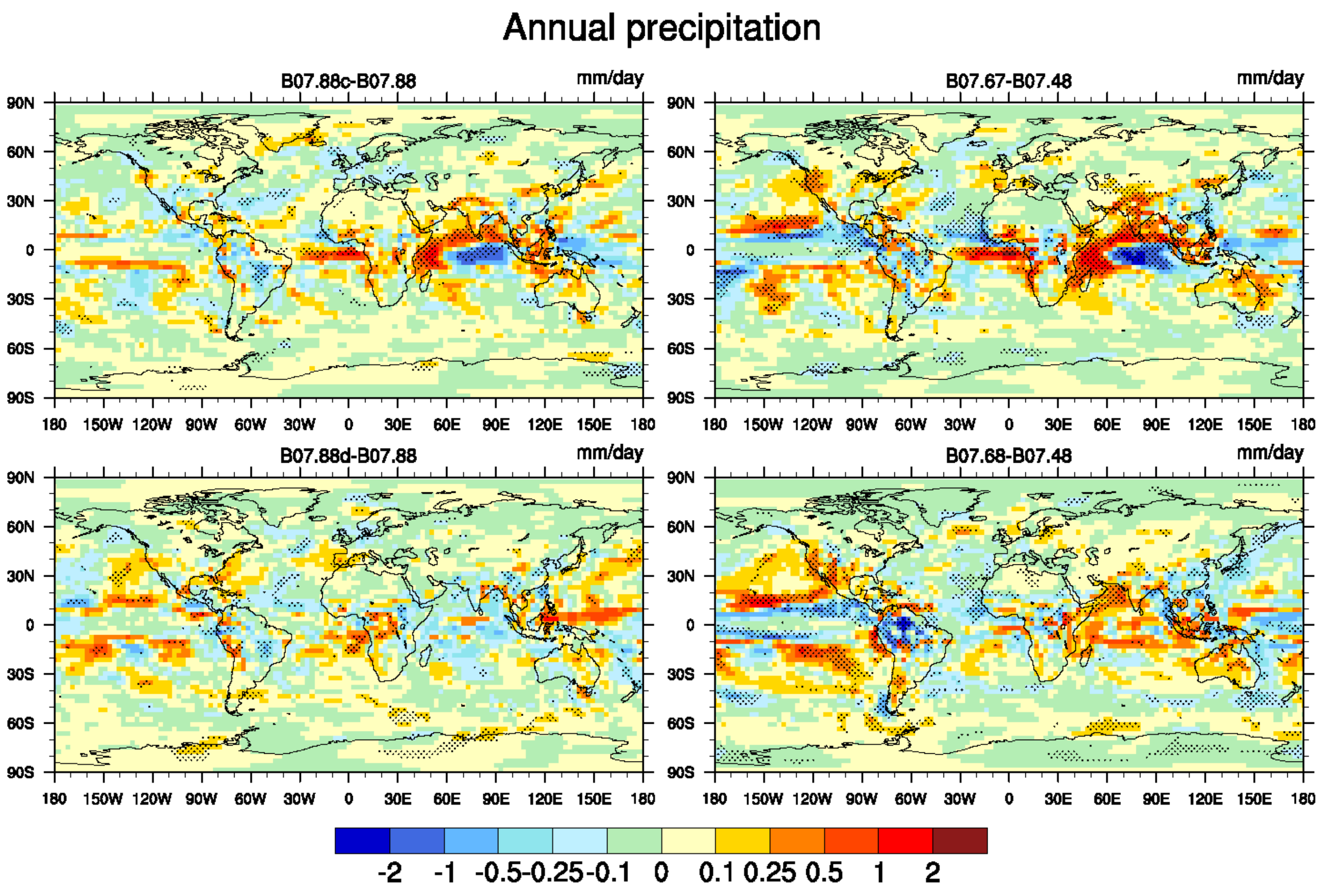


Figure TS.28. *Projected surface temperature changes for the early and late 21st century relative to the period 1980 to 1999. The central and right panels show the AOGCM multi-model average projections (°C) for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over the decades 2020 to 2029 (centre) and 2090 to 2099 (right). The left panel shows corresponding uncertainties as the relative probabilities of estimated global average warming from several different AOGCM and EMIC studies for the same periods. Some studies present results only for a subset of the SRES scenarios, or for various model versions. Therefore the difference in the number of curves, shown in the left-hand panels, is due only to differences in the availability of results. {Adapted from Figures 10.8 and 10.28}*

Climate projections: Land Cover



Climate projections: Land Cover

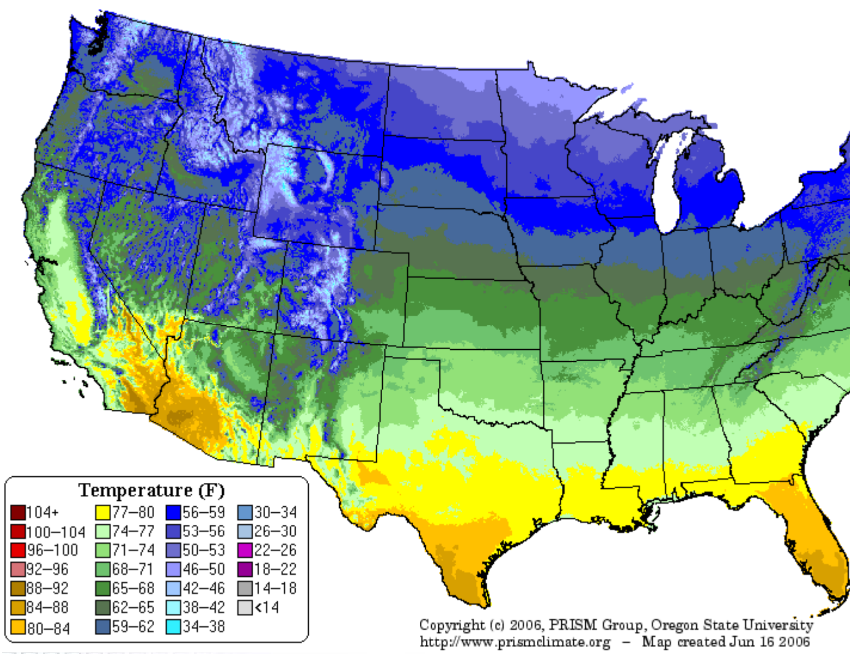


Global Climate over the last century

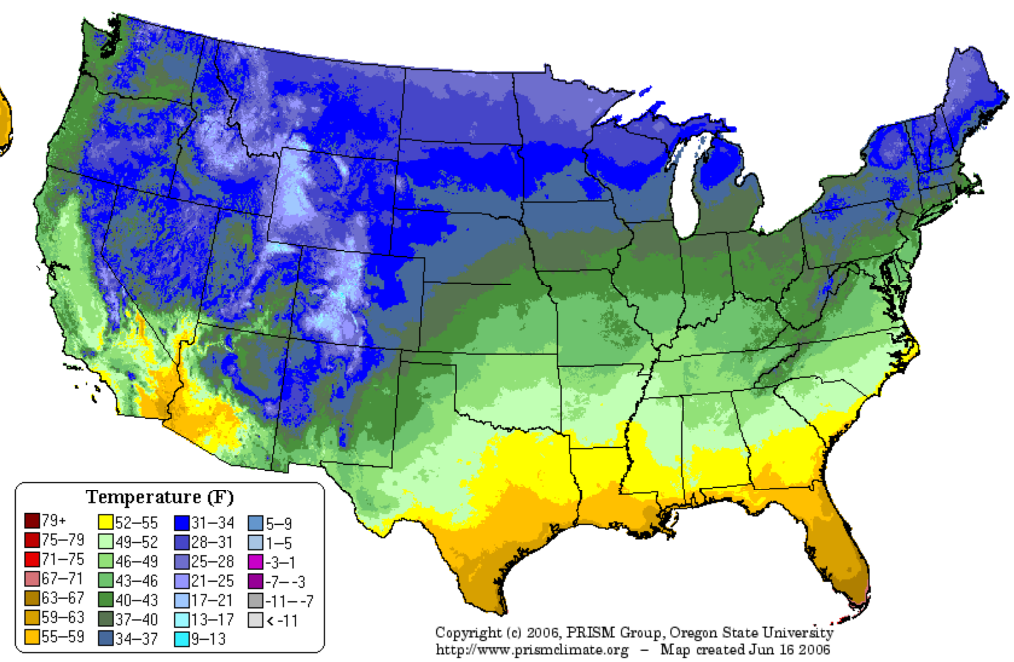
What about Kansas?

Background on Kansas Climate

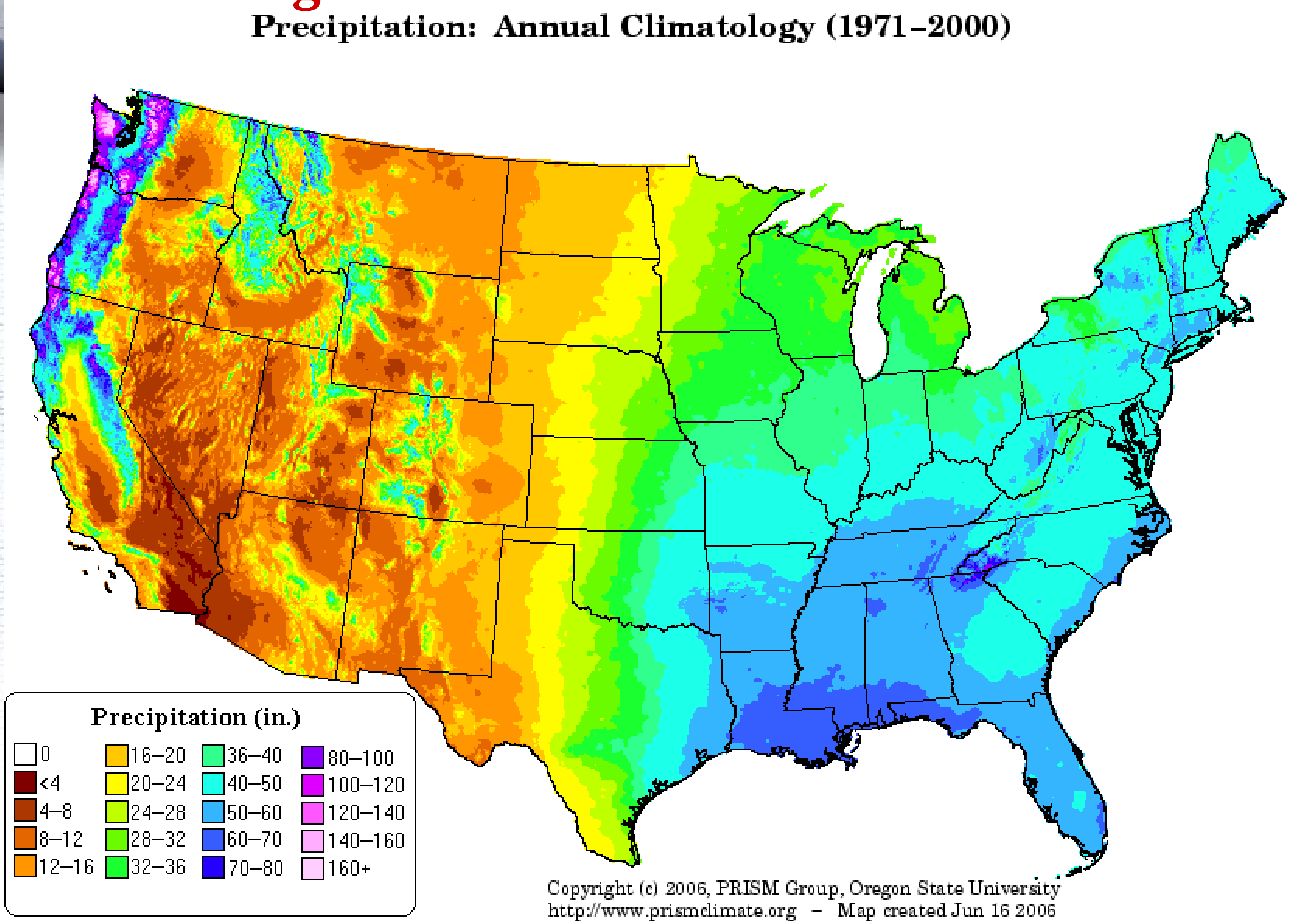
Maximum Temperature: Annual Climatology (1971–2000)



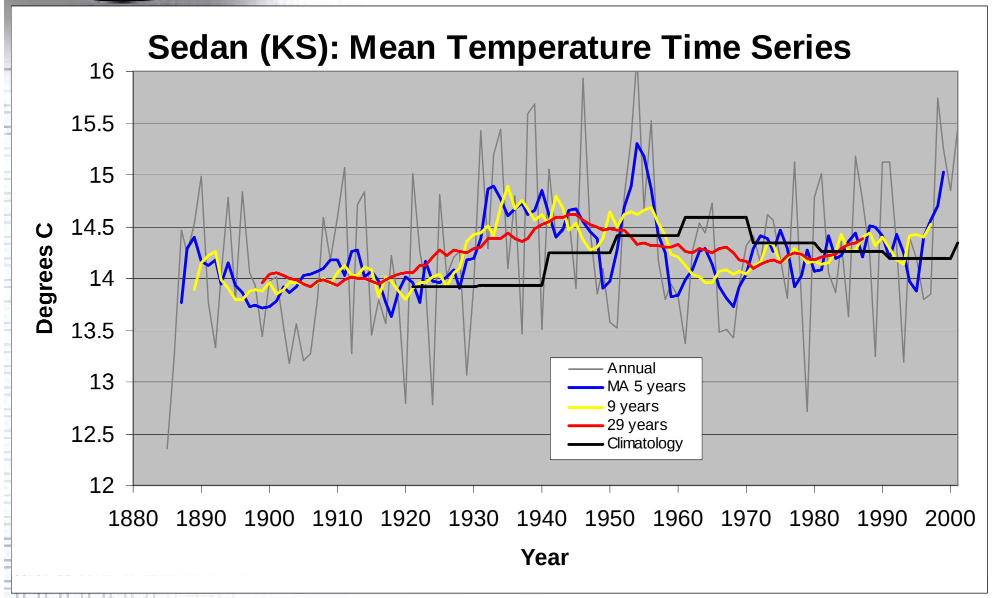
Minimum Temperature: Annual Climatology (1971–2000)

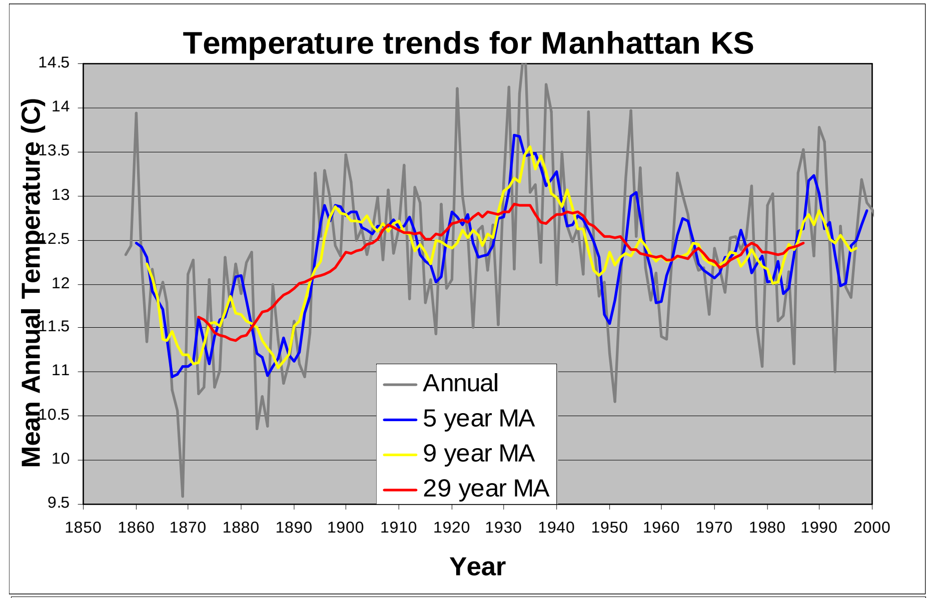


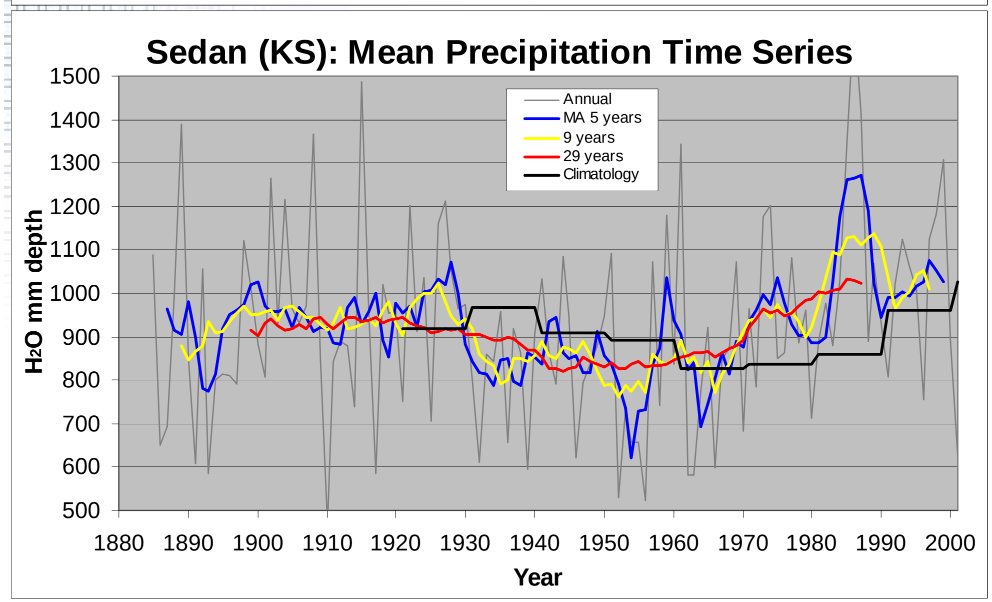
Background on Kansas Climate

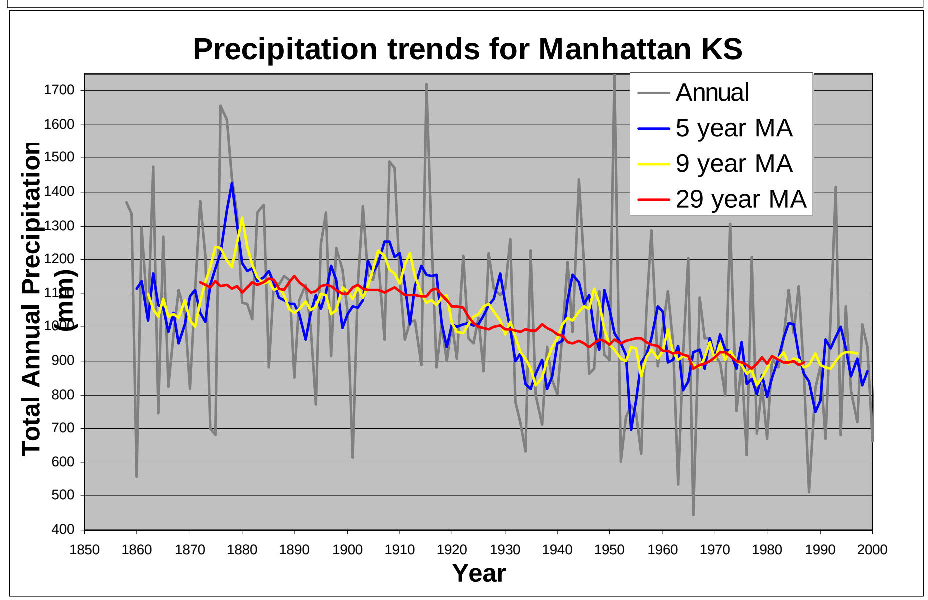


Kansas Climate over the last century

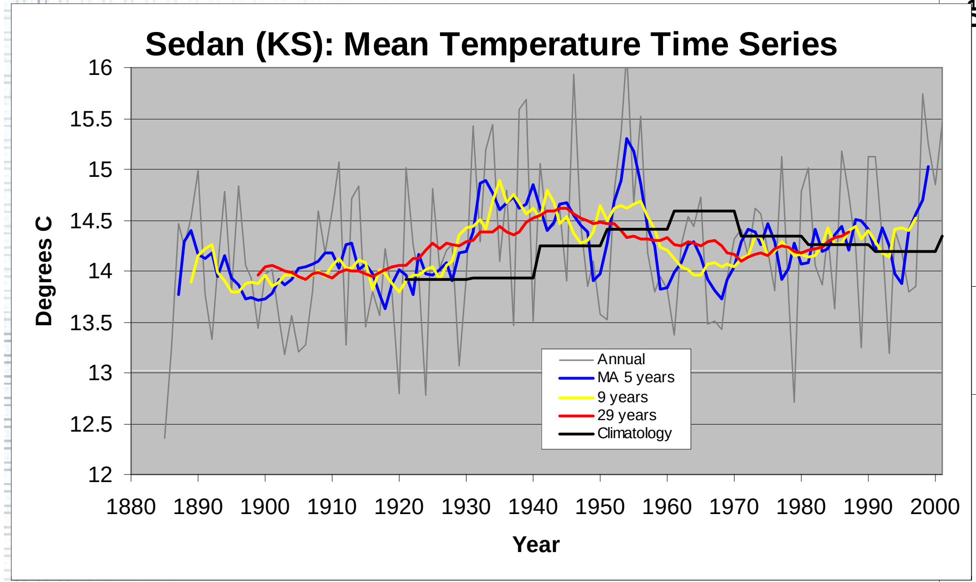


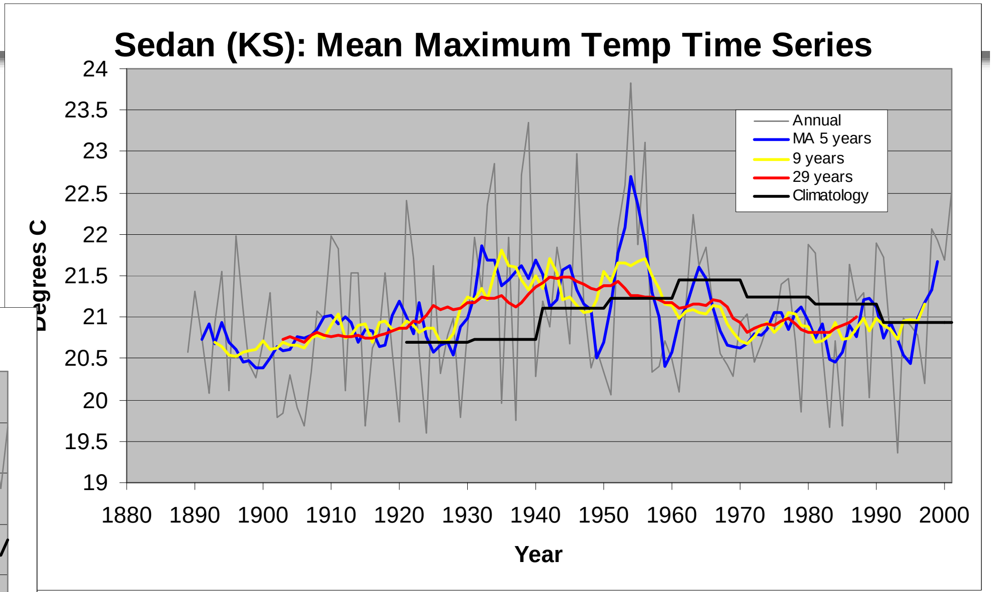


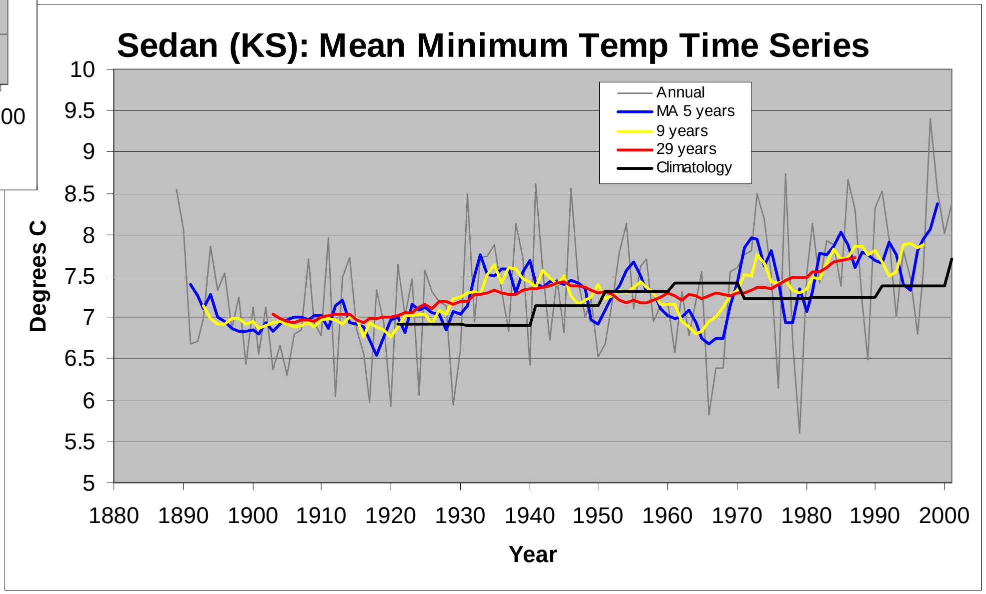




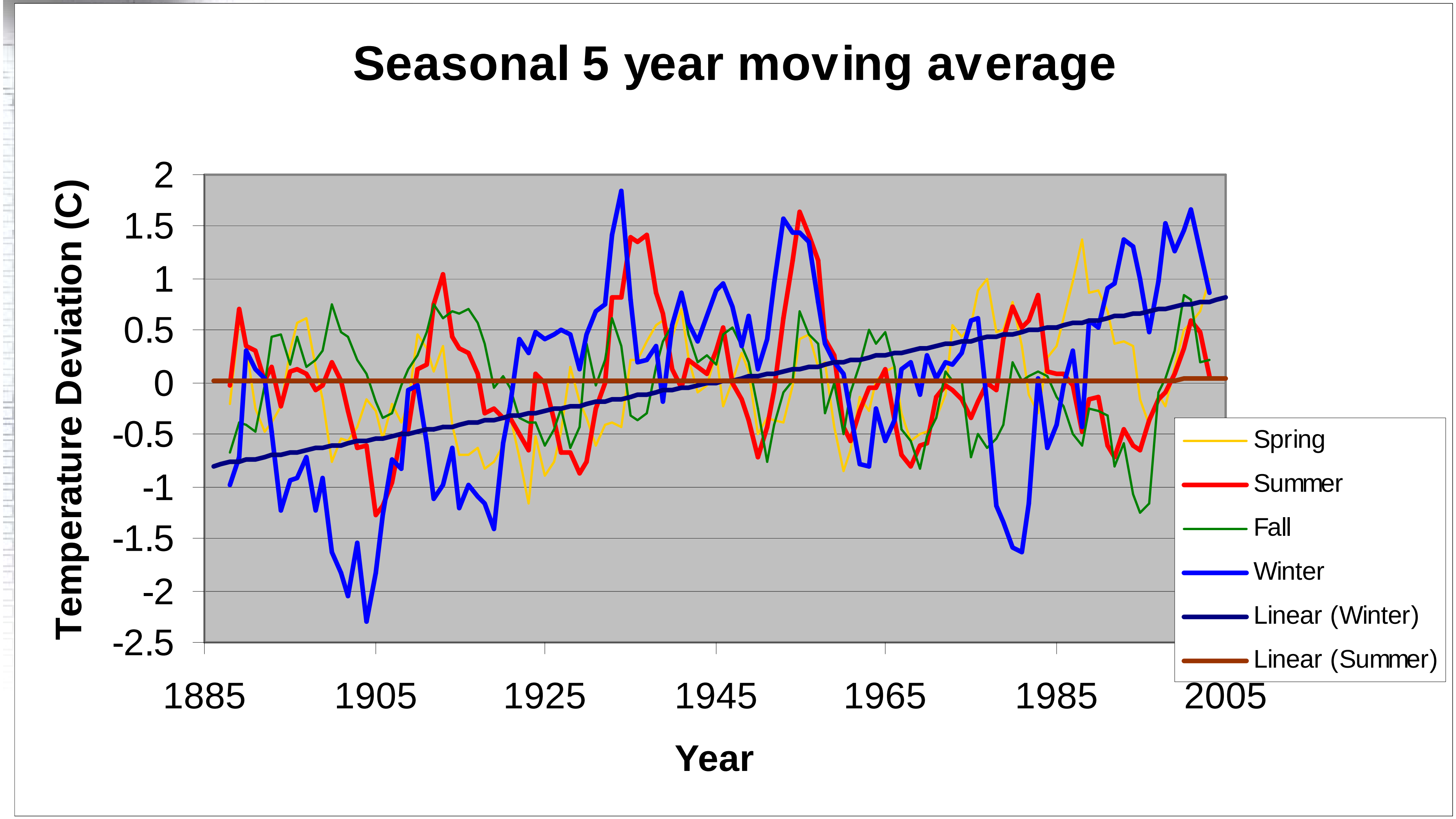
Kansas Climate over the last century





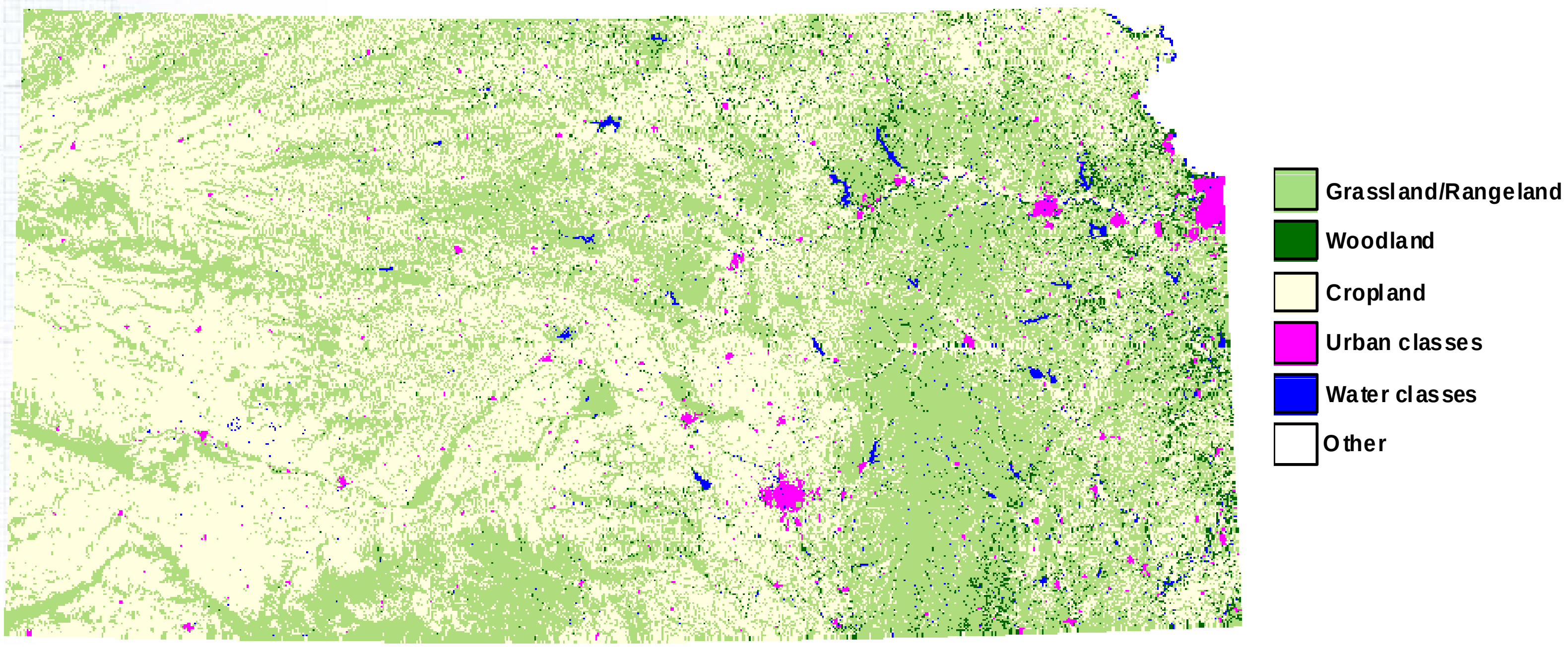


Sedan Temperature: Seasonal Details



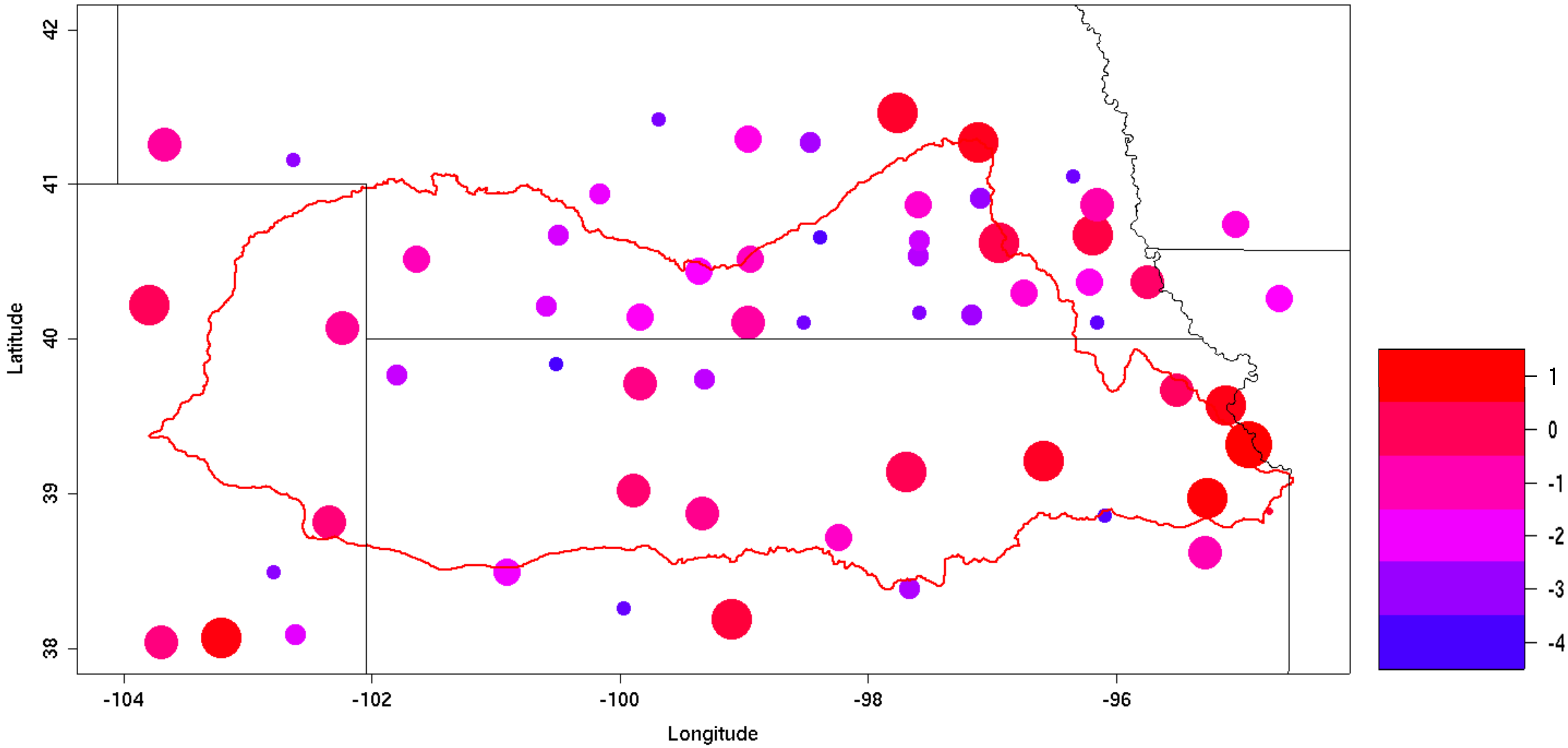
Kansas Climate over the last century

Kansas Land Cover Patterns

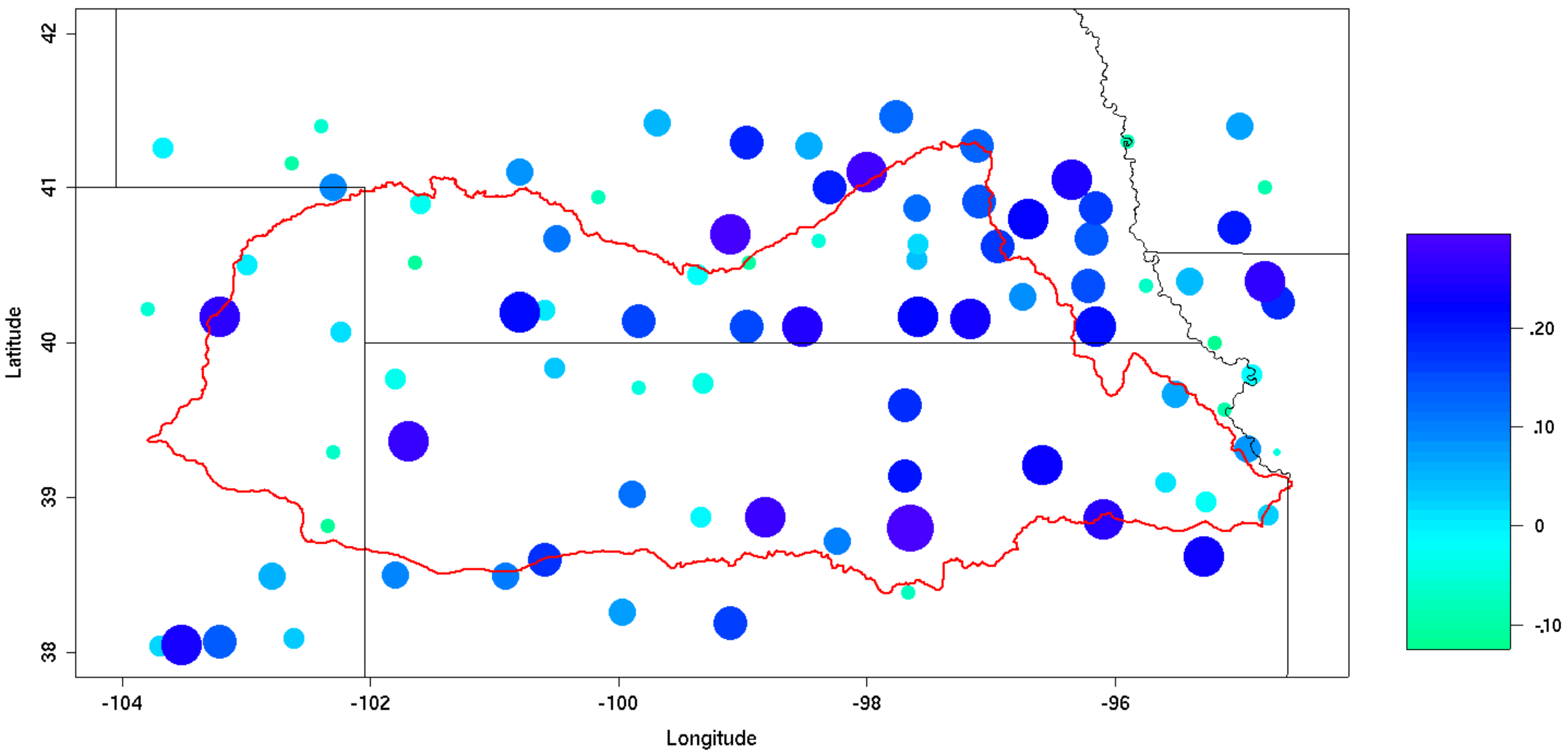


- 91 % overall accuracy

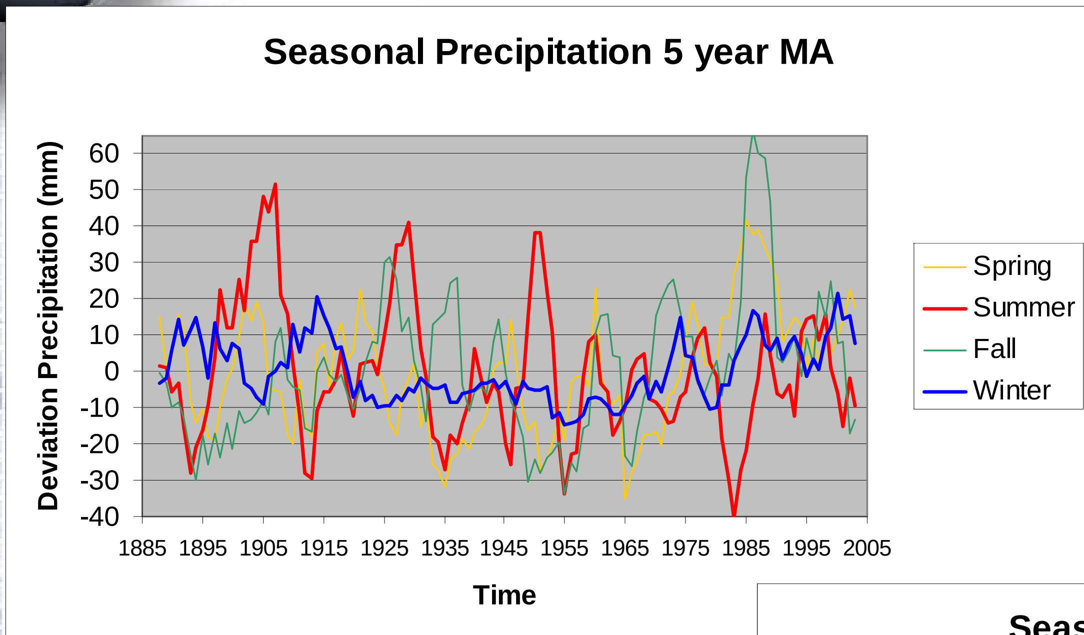
Kansas Climate over the last century

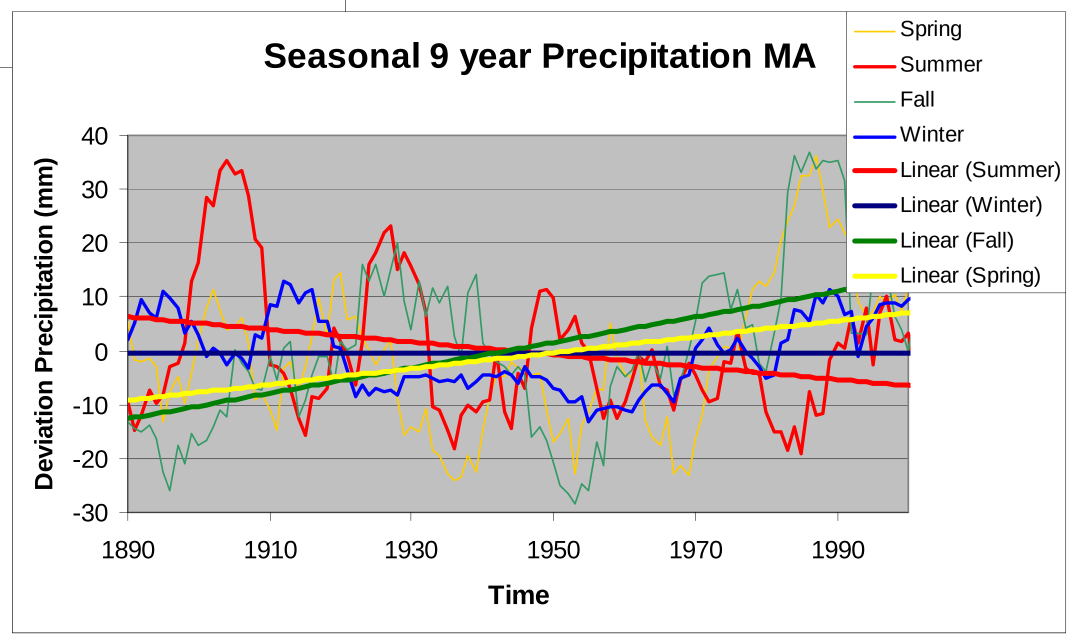


Kansas Climate over the last century

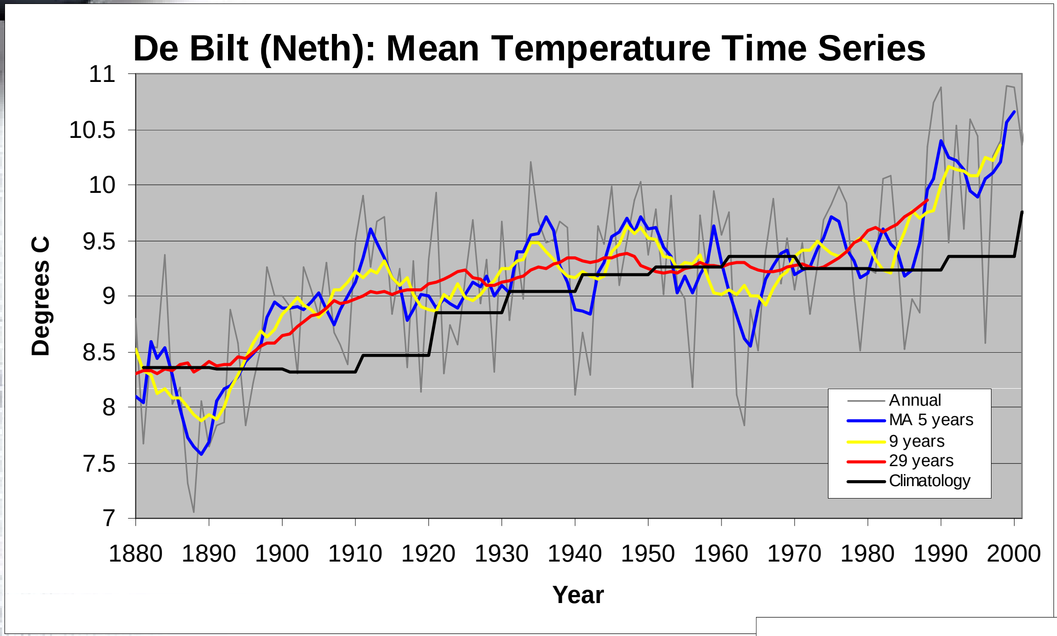


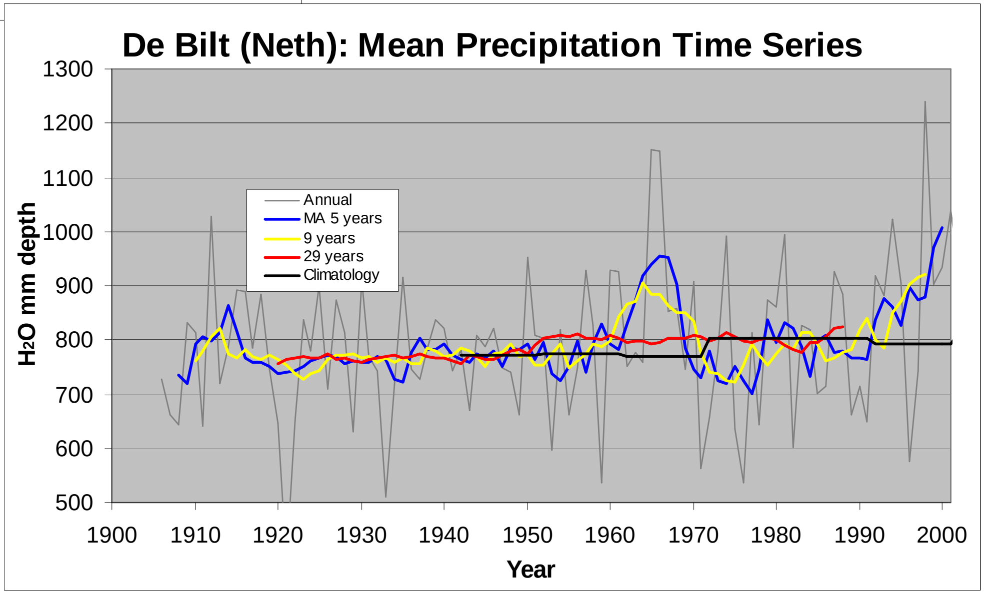
Sedan Precipitation: Seasonal Details



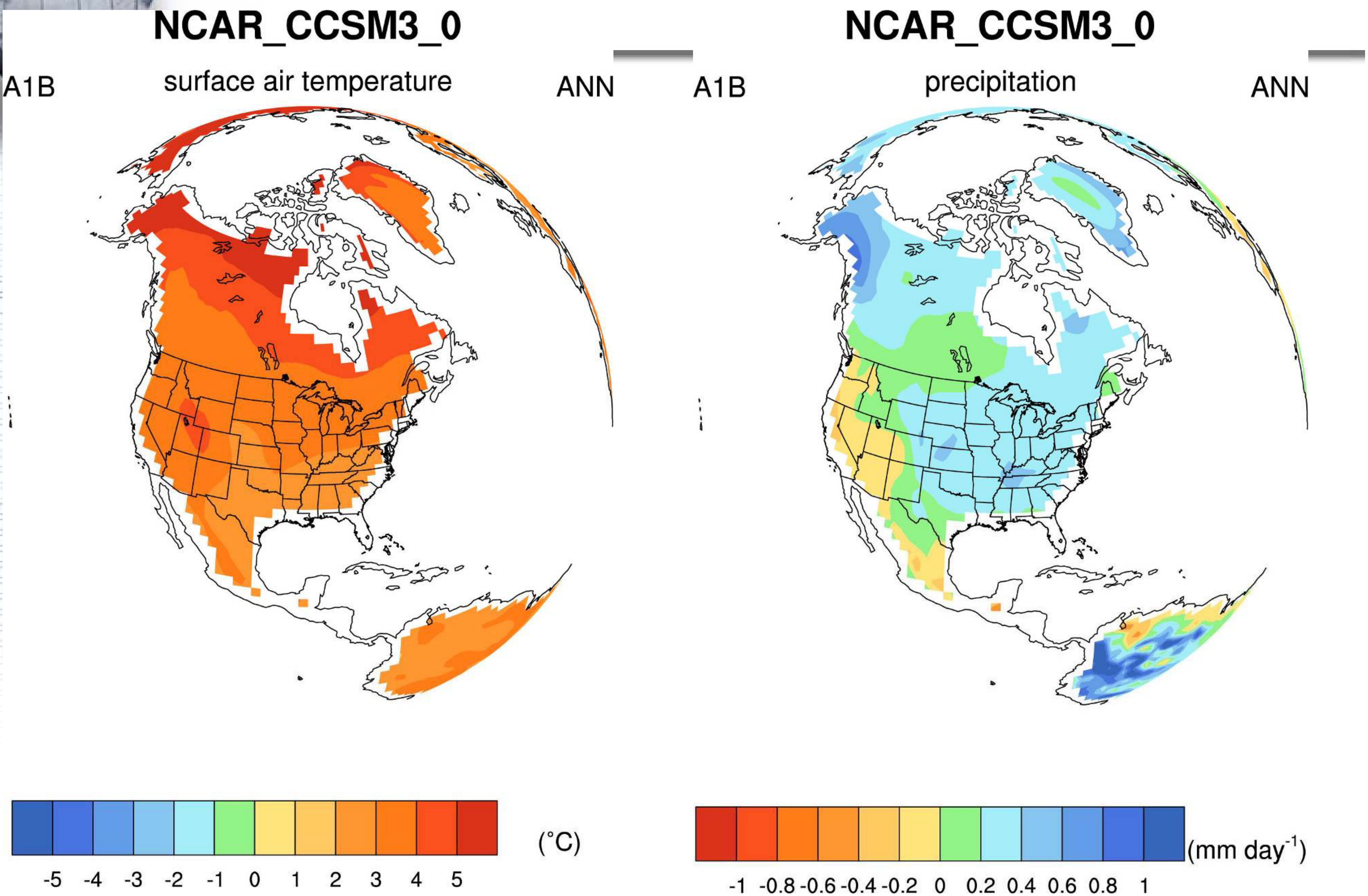


Global Climate over the last century



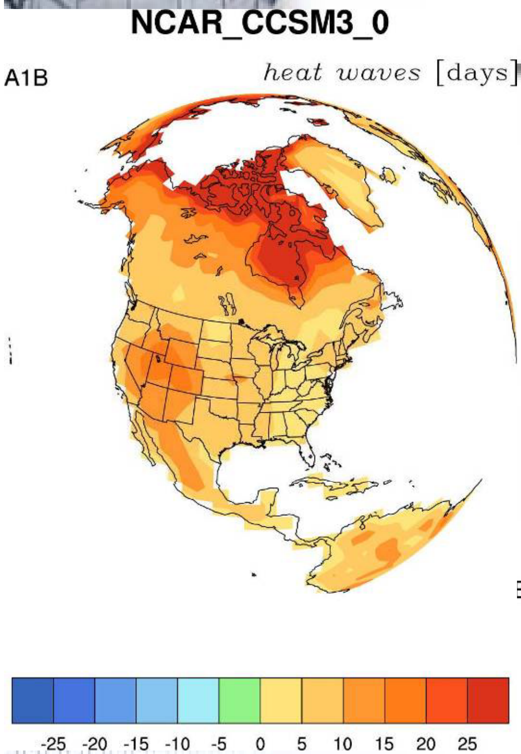


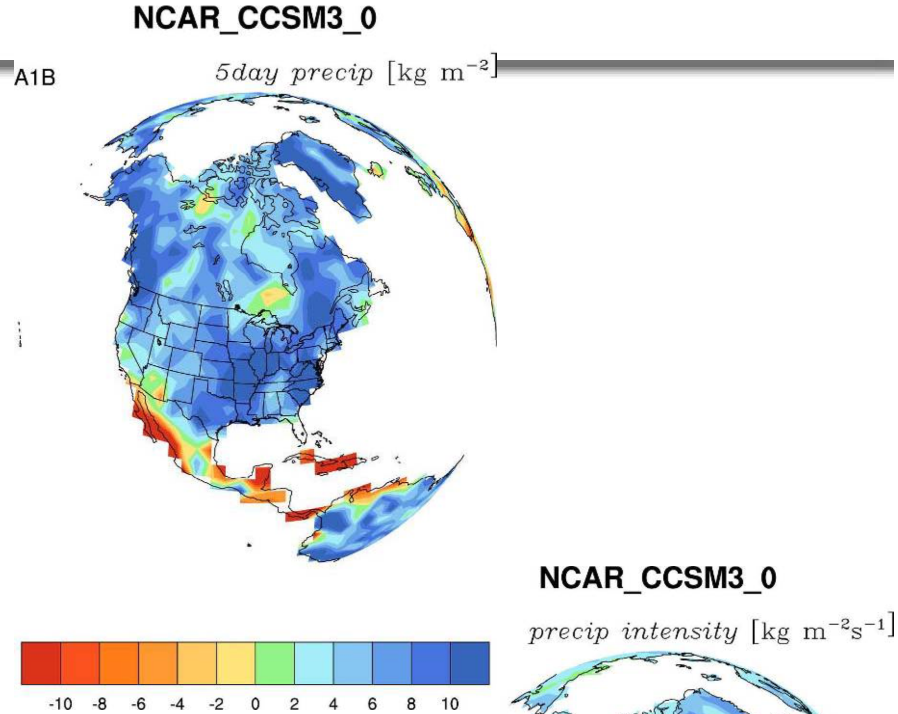
Climate projections

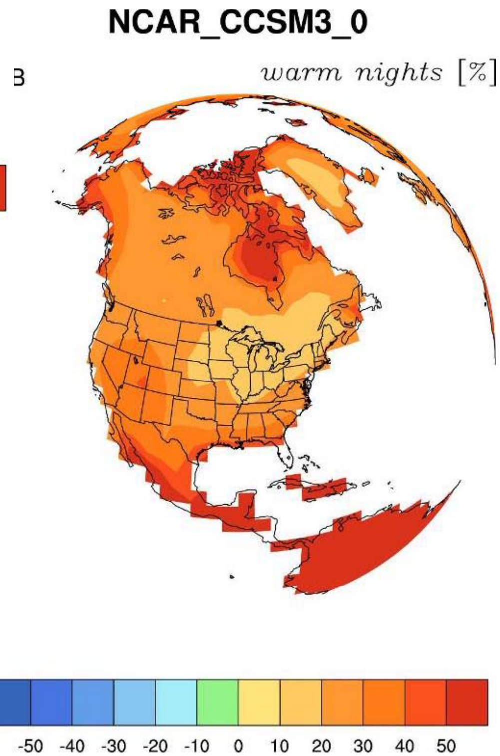


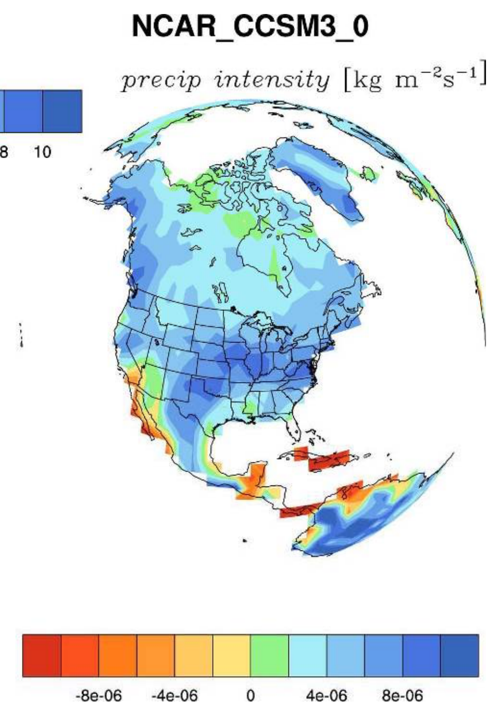
Figures based on Tebaldi et al. 2006: *Climatic Change*, Going to the extremes; An intercomparison of model-simulated historical and future changes in extreme events, http://www.cgd.ucar.edu/ccr/publications/tebaldi-extremes.html

Climate projections









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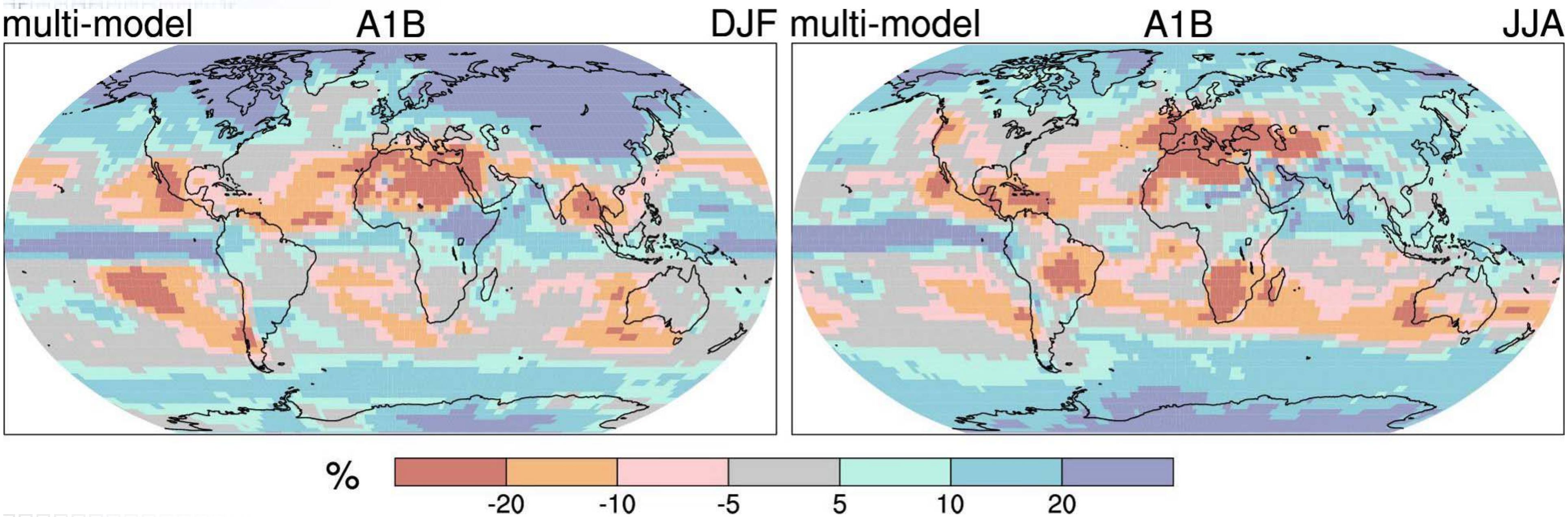
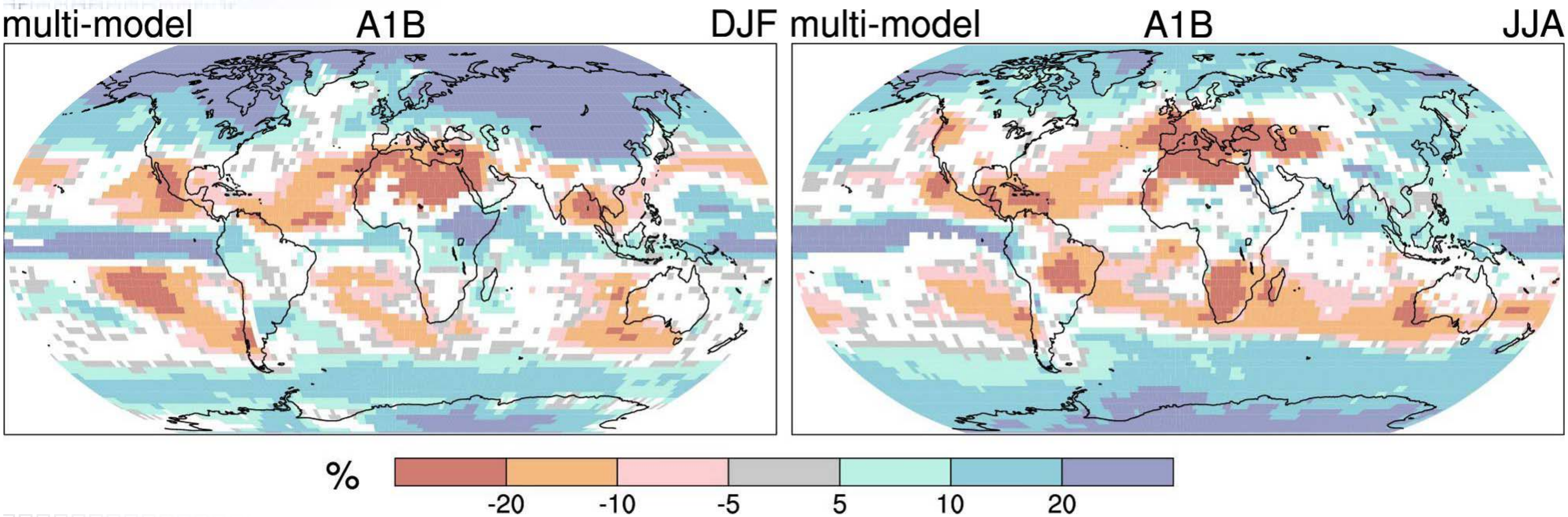
Climate projections



Multi-model average precipitation % change, medium scenario (A1B), representing seasonal precipitation regimes, total differences 2090-99 minus 1980-99

Climate projections



White areas are where less than two thirds of the models agree in the sign of the change

Climate projections

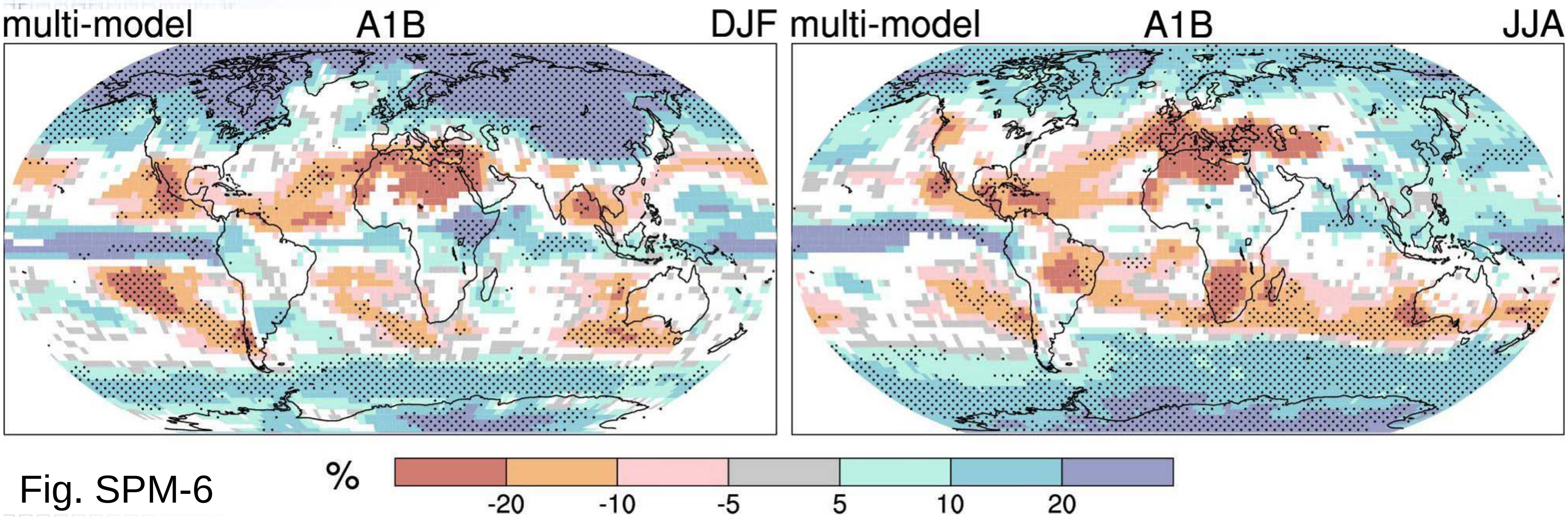


Fig. SPM-6

Stippled areas are where more than 90% of the models agree in the sign of the change

Precipitation increases very likely in high latitudes

Decreases likely in most subtropical land regions

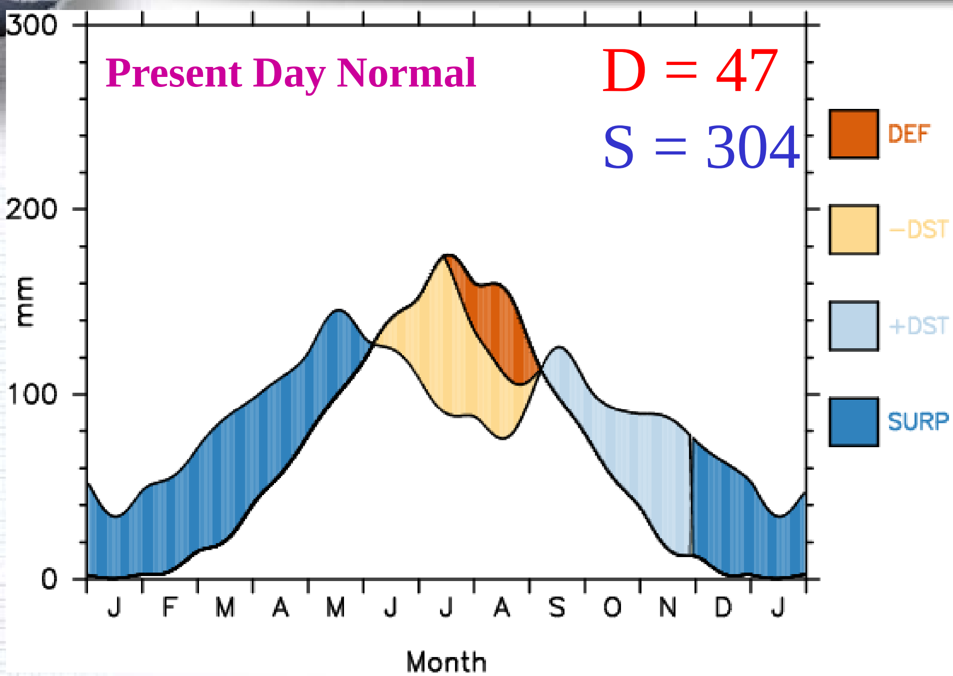
This continues the observed patterns in recent trends

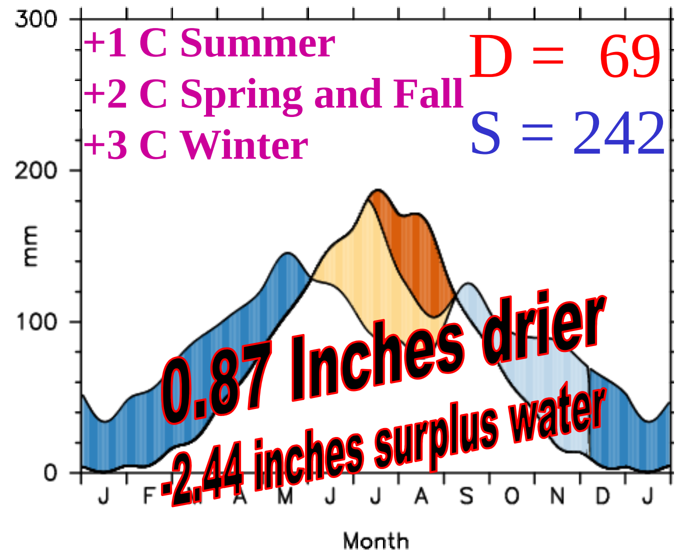
Climate projections

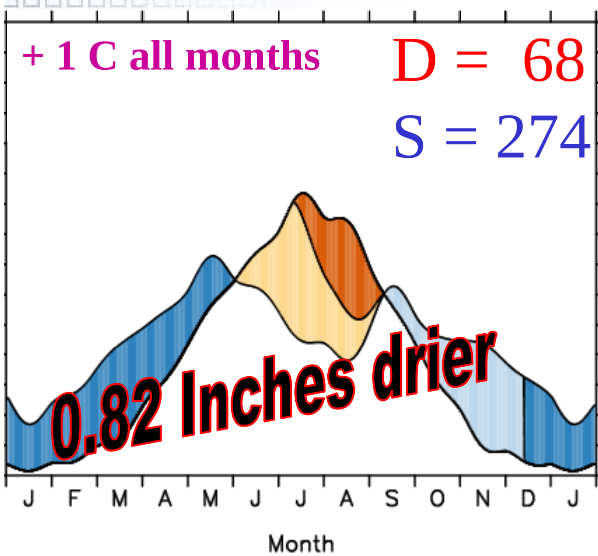
Eastern Kansas (37N, 95W)

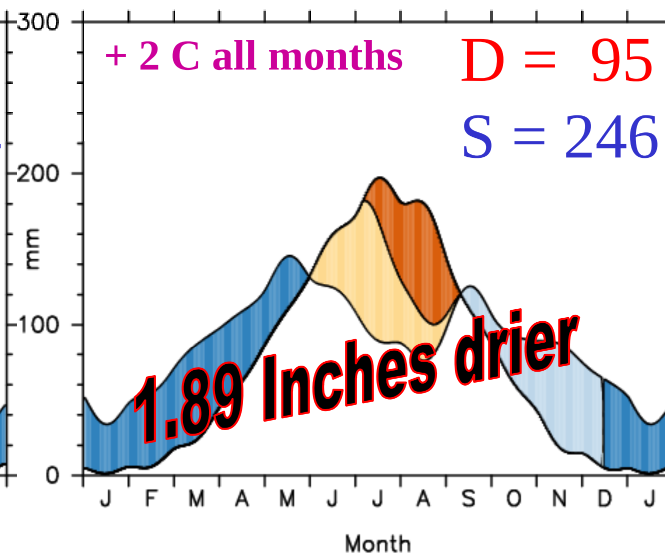
D = Annual Deficit (mm)

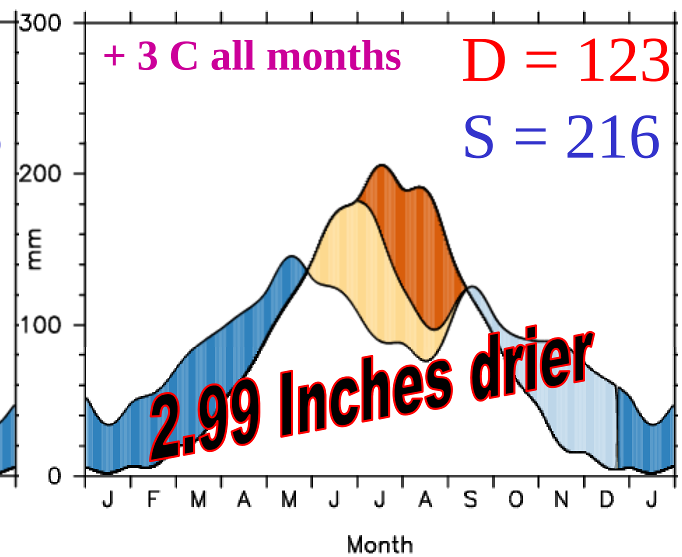
S = Annual Surplus (mm)







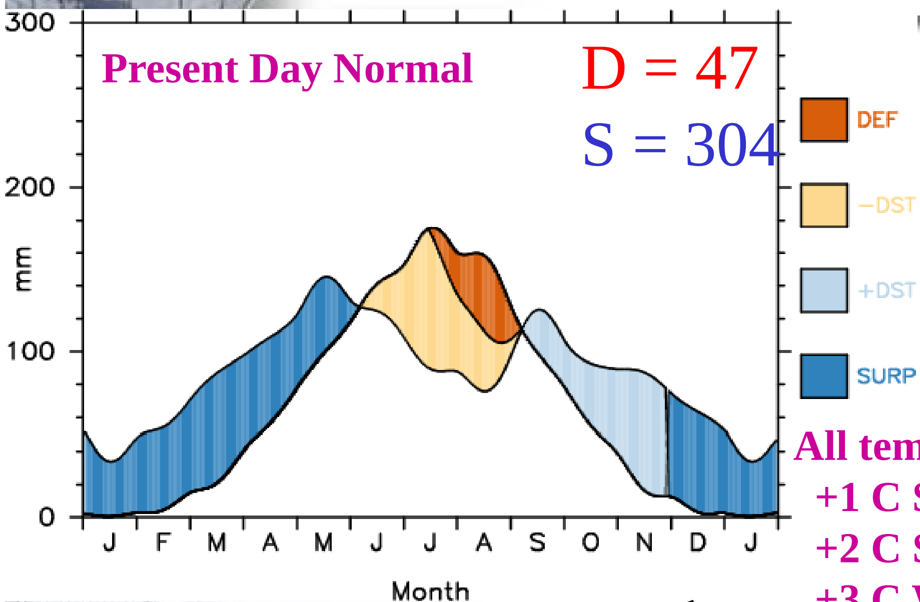




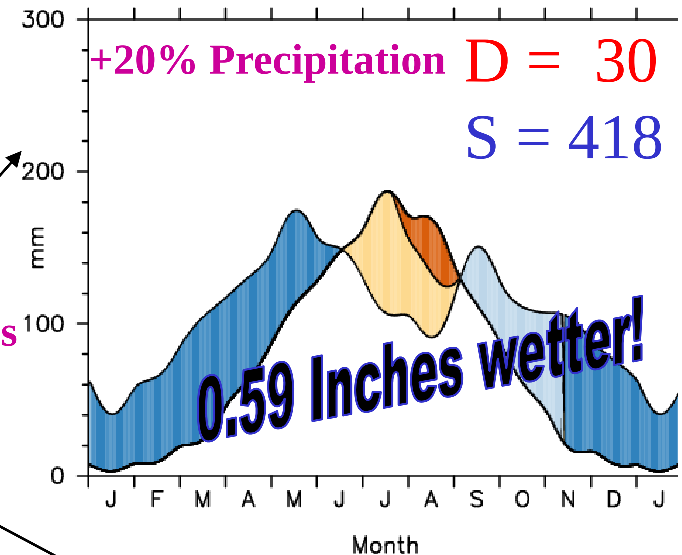
Climate projections

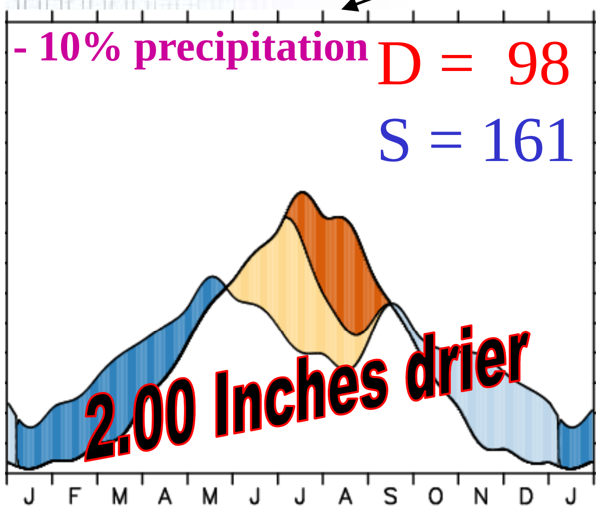
Eastern Kansas (37N, 95W)

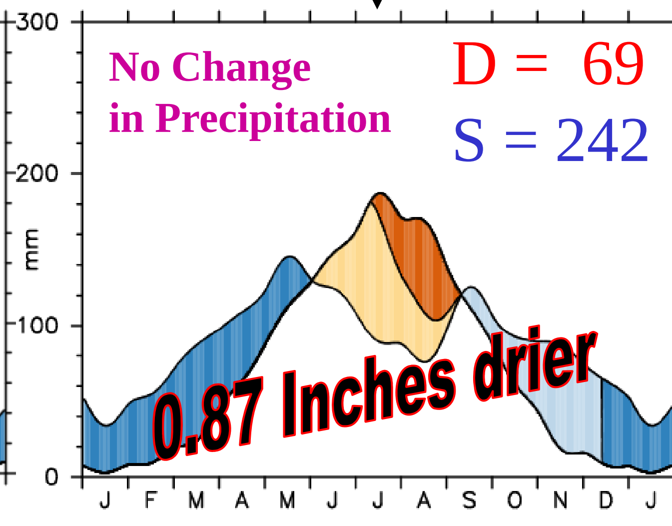
D = Annual Deficit (mm)
S = Annual Surplus (mm)

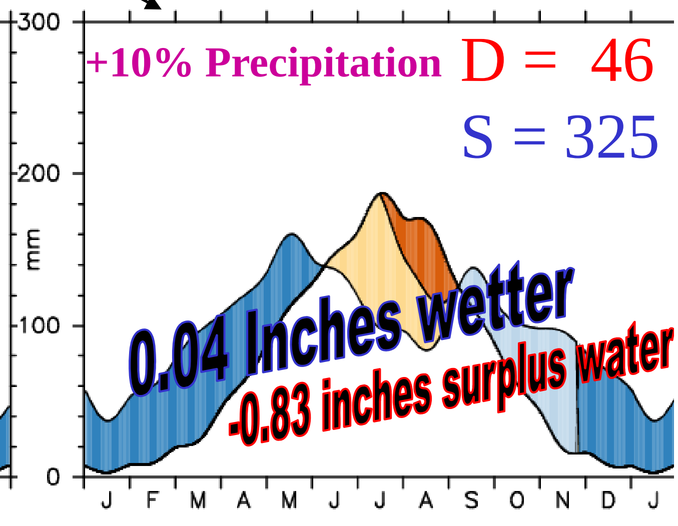


All temperature scenarios
+1 C Summer
+2 C Spring and Fall
+3 C Winter







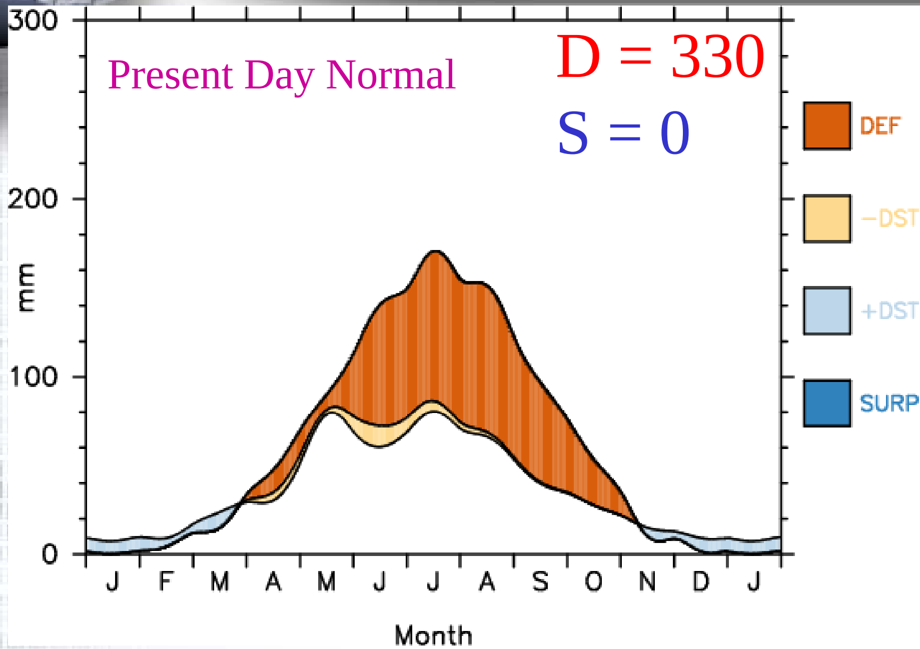


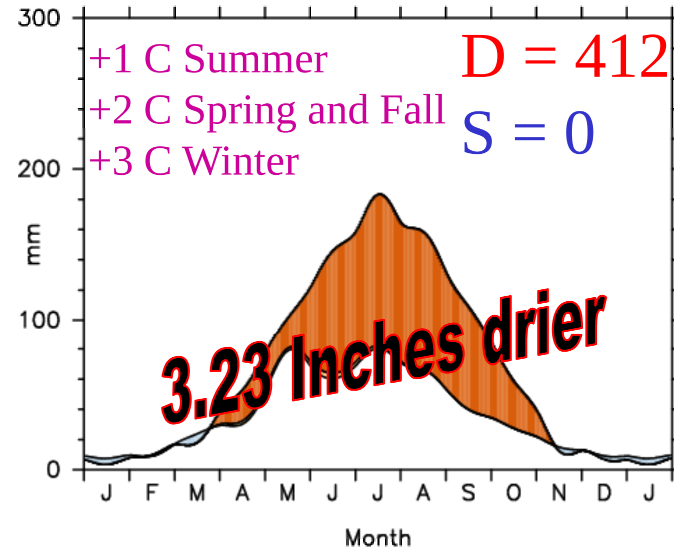
Climate projections

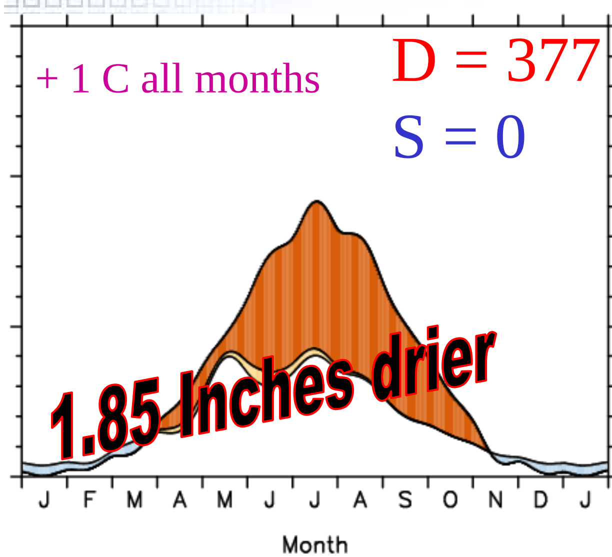
Western Kansas (37N, 102W)

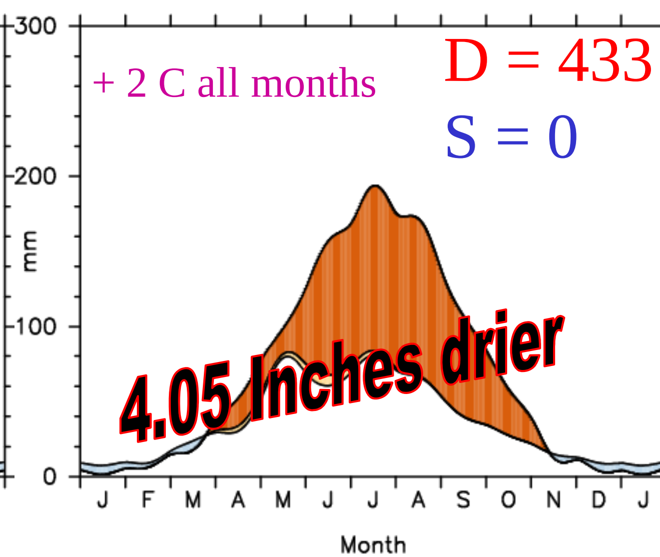
D = Annual Deficit (mm)

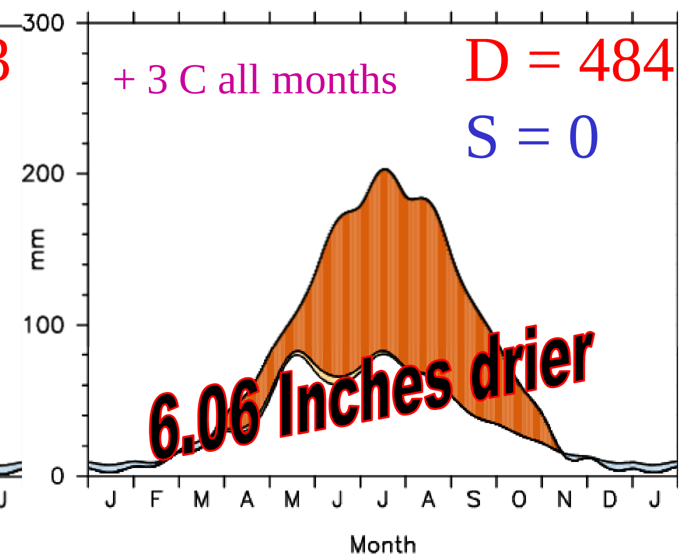
S = Annual Surplus (mm)









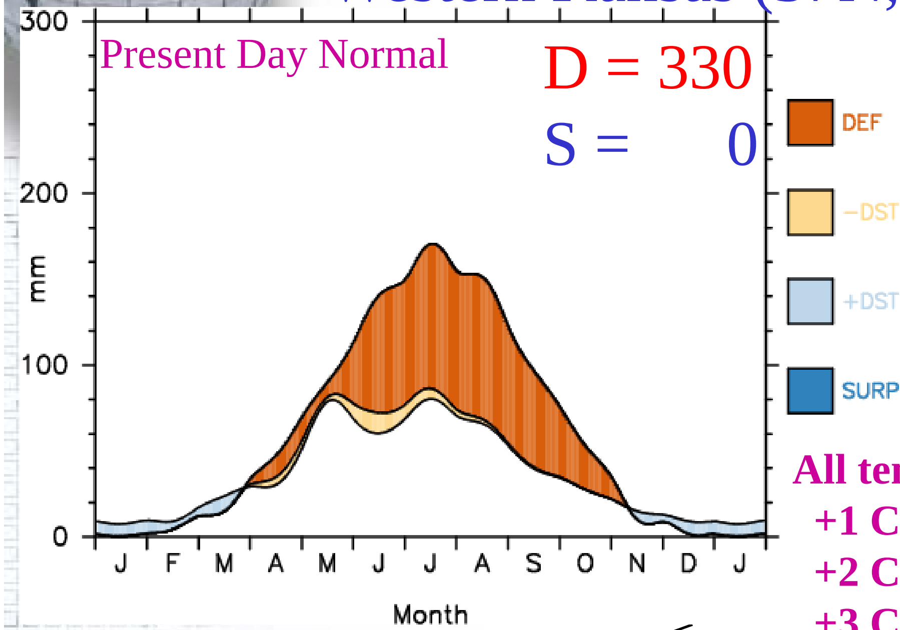


Climate projections

Western Kansas (37N, 102W)

D = Annual Deficit (mm)

S = Annual Surplus (mm)

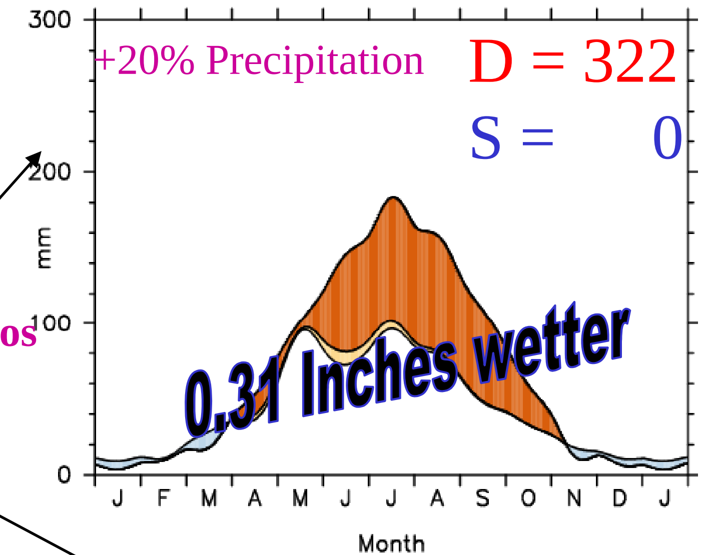


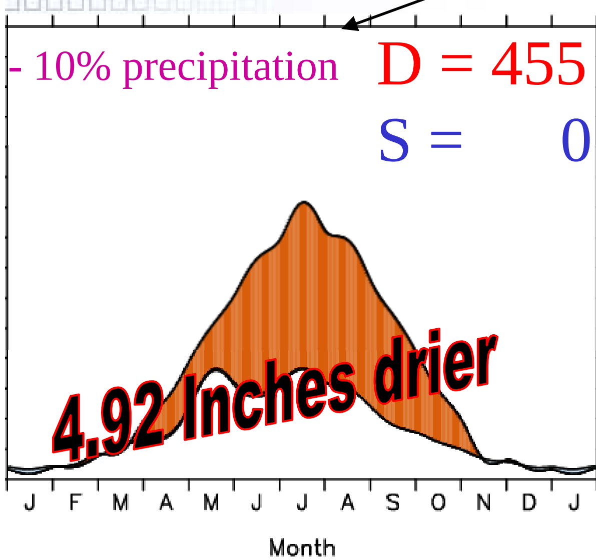
All temperature scenarios

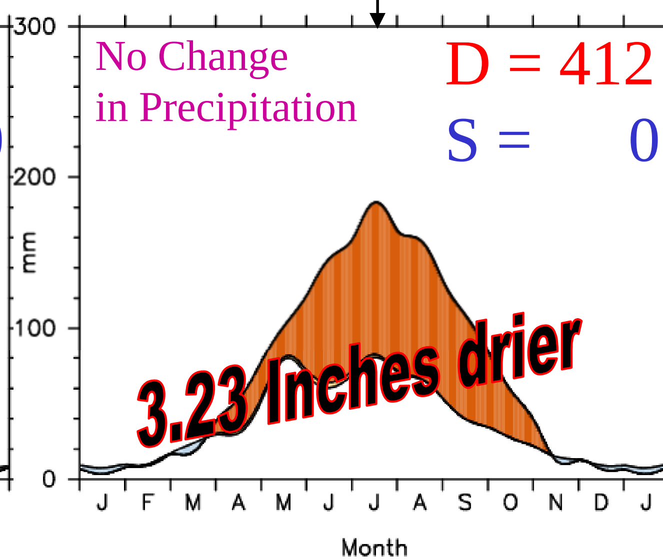
+1 C Summer

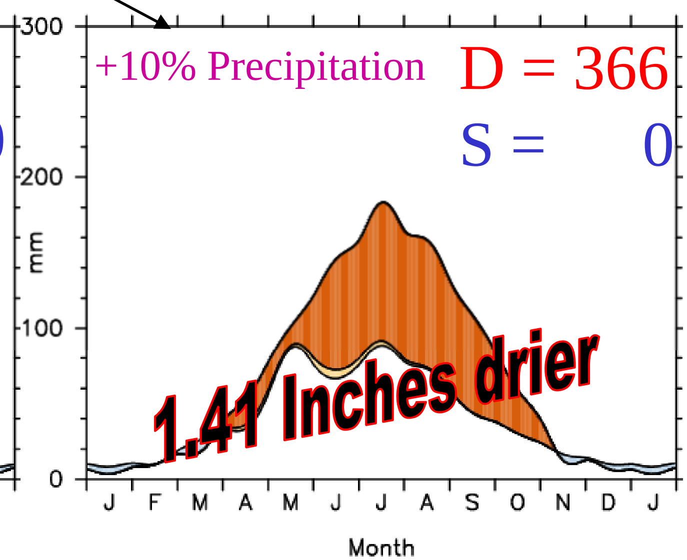
+2 C Spring and Fall

+3 C Winter









The End


Positive proof of global warming.
18th Century
1900
1950
1970
1980
1990
2006

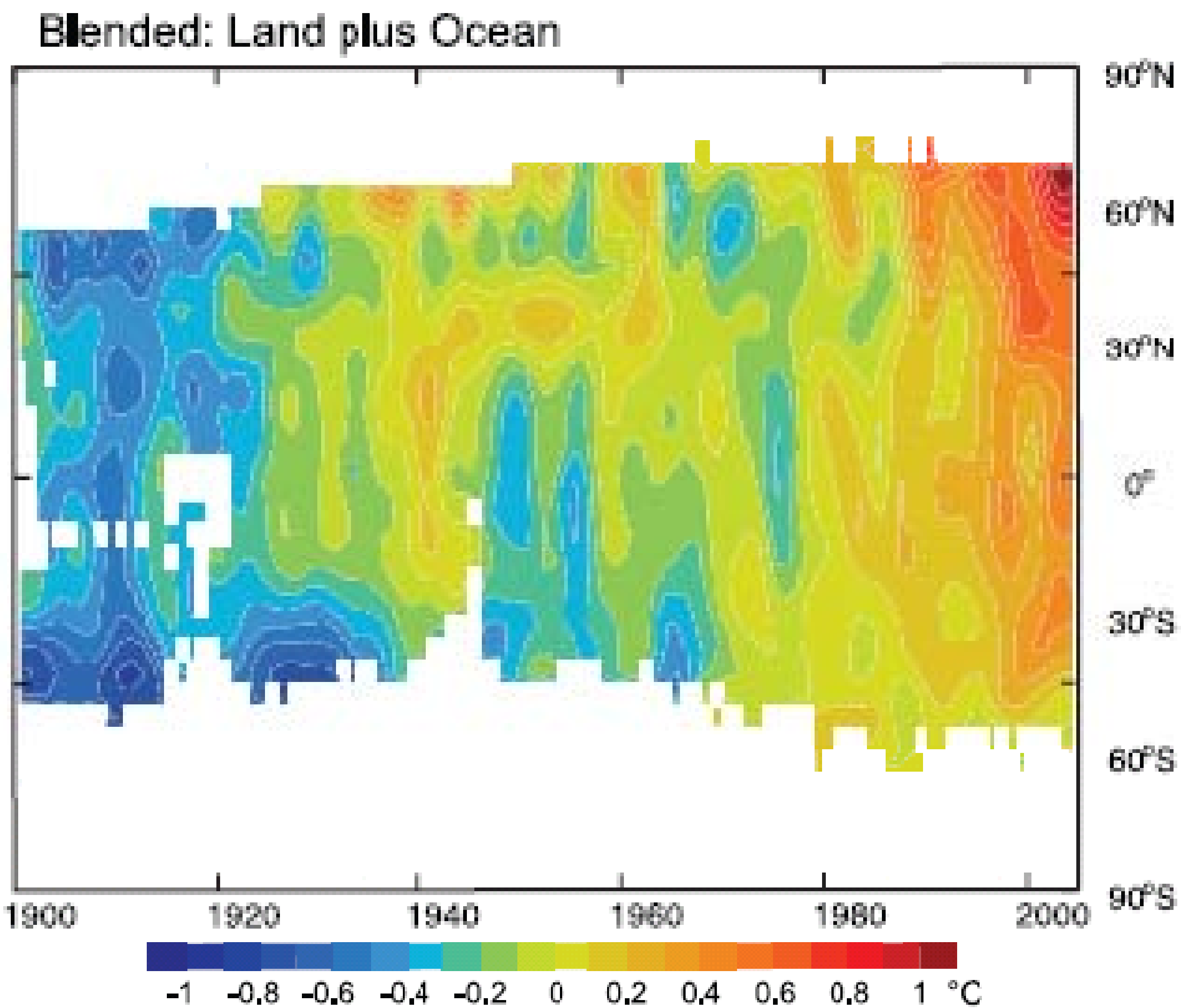
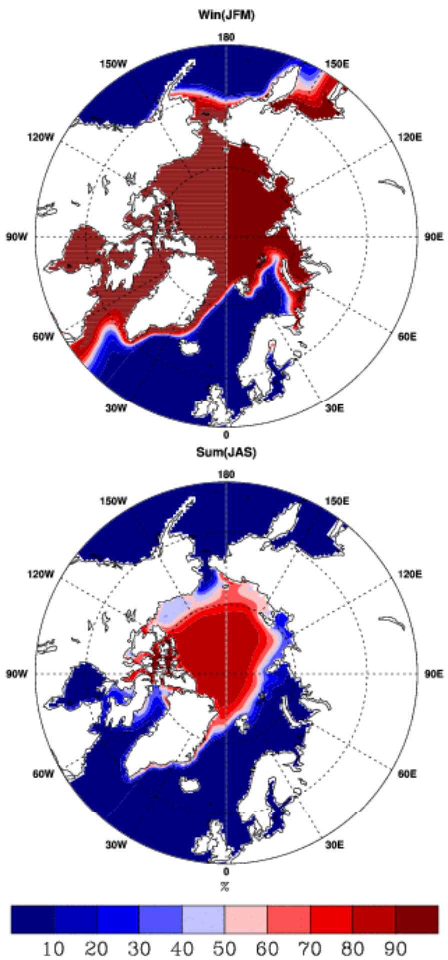


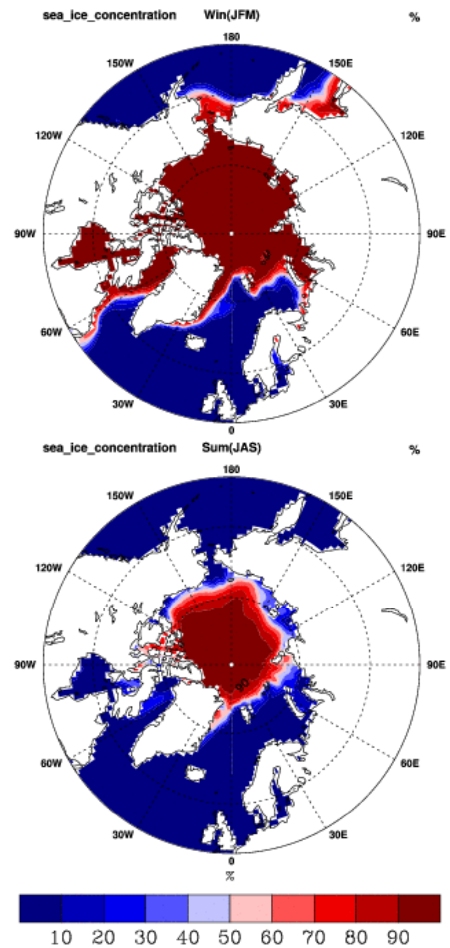
Figure 3.5. *Latitude-time sections of zonal mean temperature anomalies (°C) from 1900 to 2005, relative to the 1961 to 1990 mean. Left panels: SST annual anomalies across each ocean from HadSST2 (Rayner et al., 2006). Right panels: Surface temperature annual anomalies for land (top, CRUTEM3) and land plus ocean (bottom, HadCRUT3). Values are smoothed with the 5-point filter to remove fluctuations of less than about six years (see Appendix 3.A); and white areas indicate missing data.*

Sea-ice Concentration: Climatology (1979-1999)…
Mixture of Improved Physics and Resolution

1979−1999 b30.030a−d aice climatology



1979−1999 Obs aice climatology



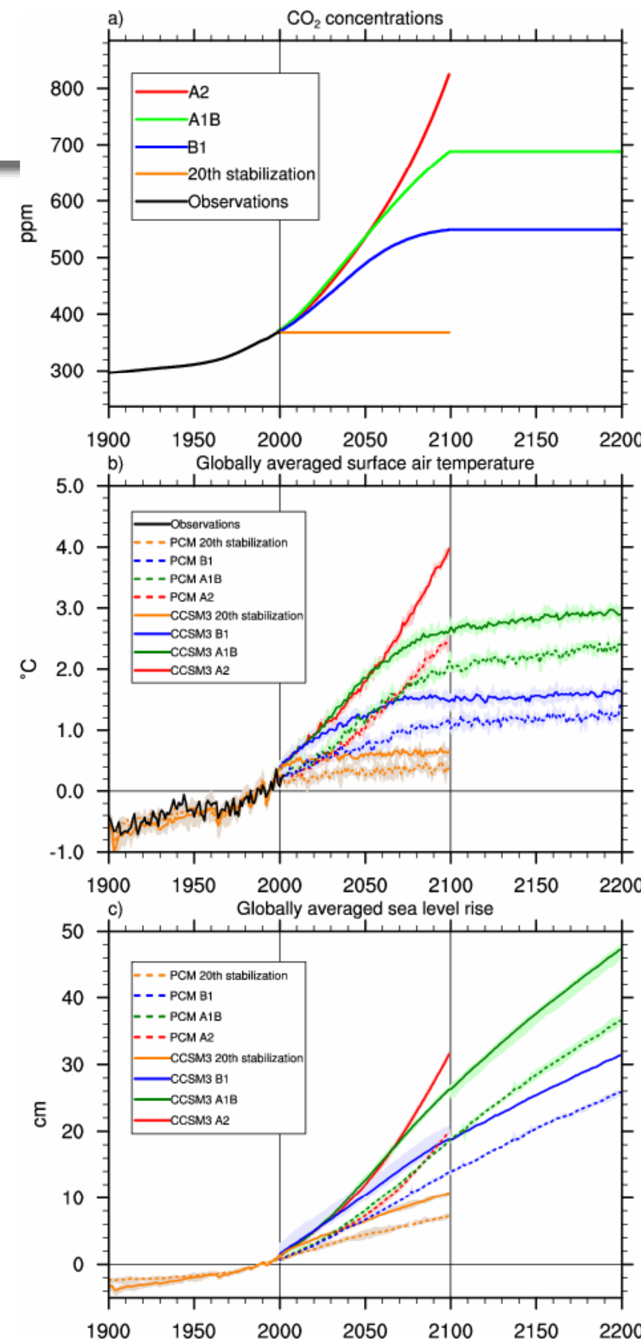
Climate Change Scenarios:

At any point in time, we are committed to additional warming and sea level rise from the radiative forcing already in the system.

Warming stabilizes after several decades, but sea level from thermal expansion continues to rise for centuries.

Each emission scenario has a warming impact.

(Meehl et al., 2005: How much more warming and sea level rise? *Science*, **307**, 1769-1772)



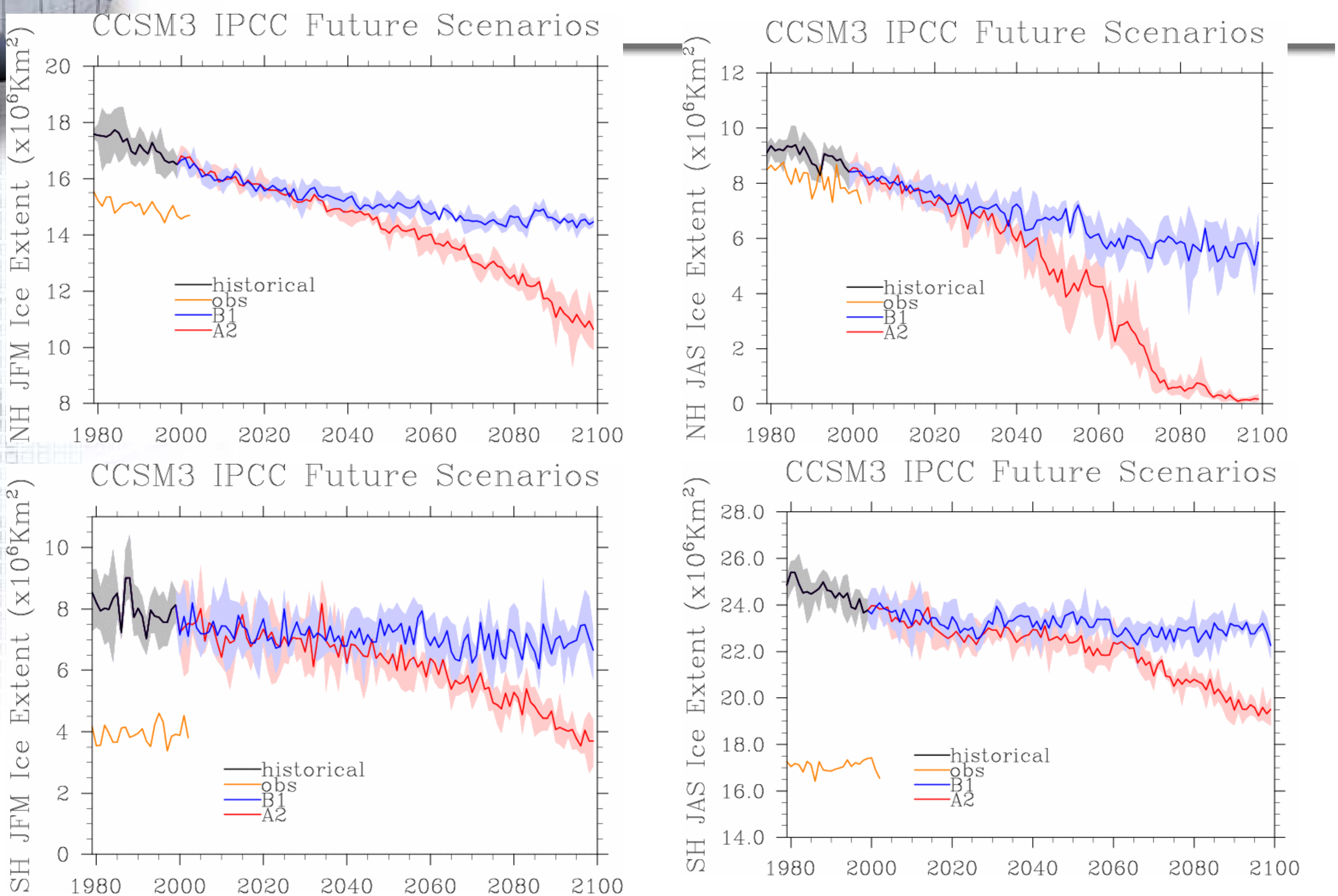
Media Attention to Global Warming…Not Sufficient to Change Policies!

What is the role of skeptics?

What will the new Congress do?

What will Kansas Do?

Sea-ice Extent in Both NH and SH

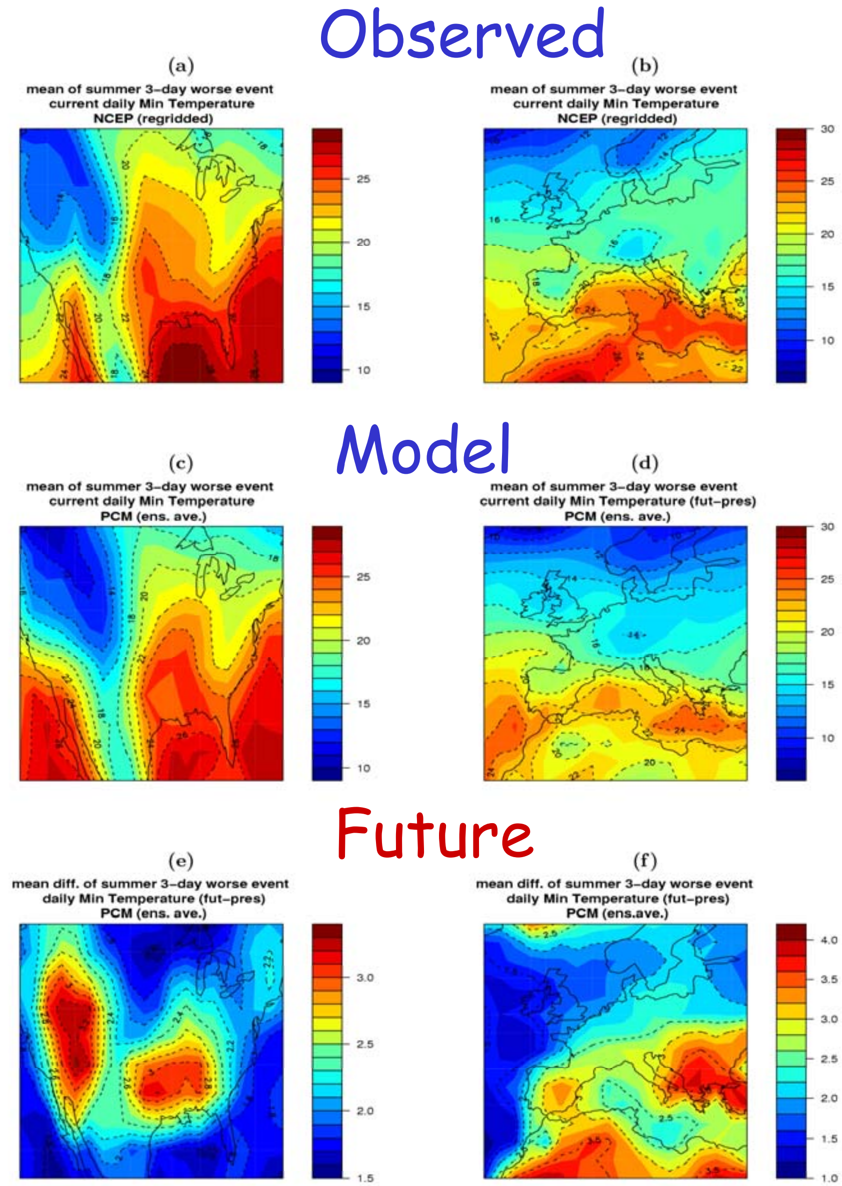


Climate models can be used to provide information on changes in extreme events such as heat waves

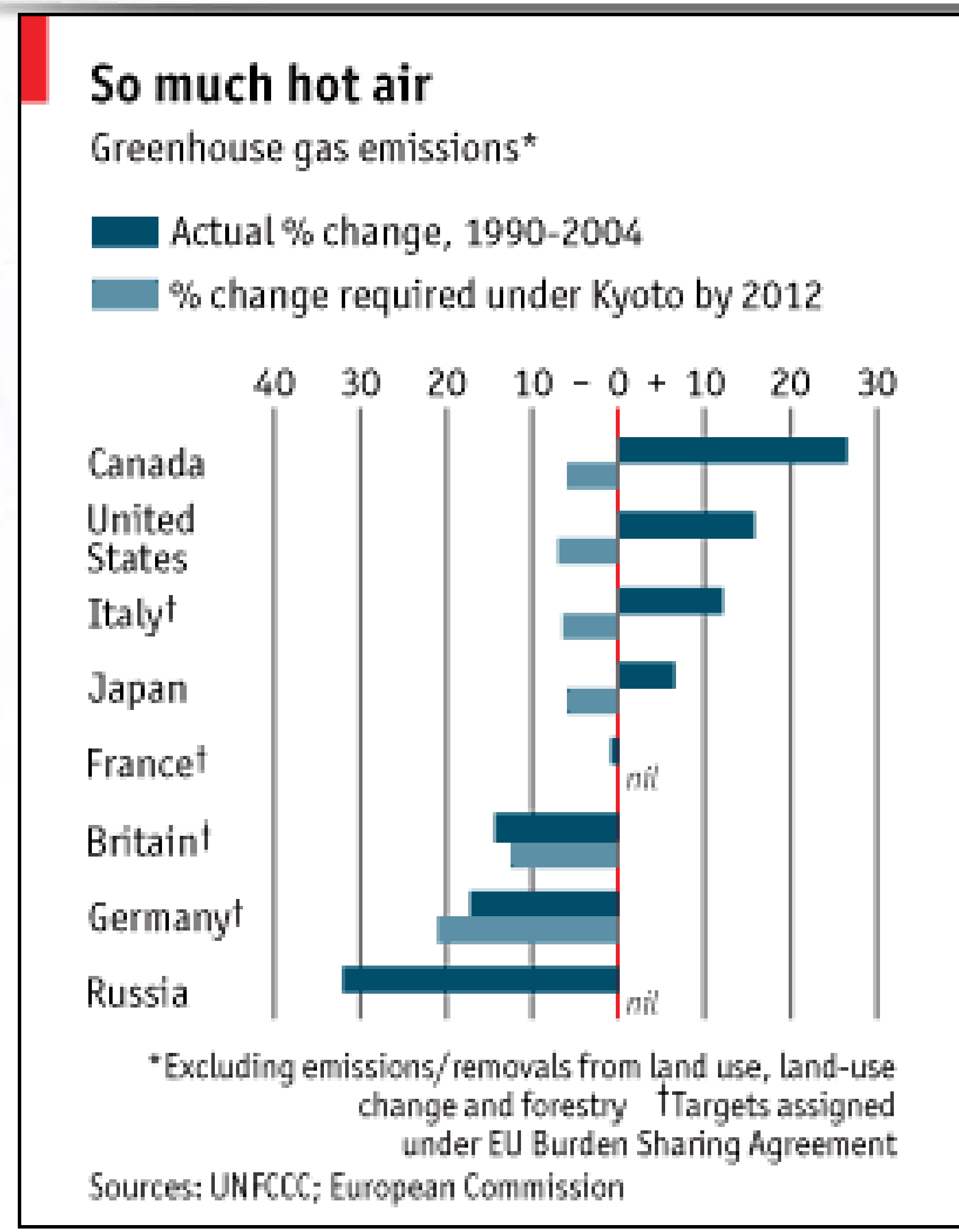
Heat wave severity defined as the mean annual 3-day warmest nighttime minima event

Model compares favorably with present-day heat wave severity

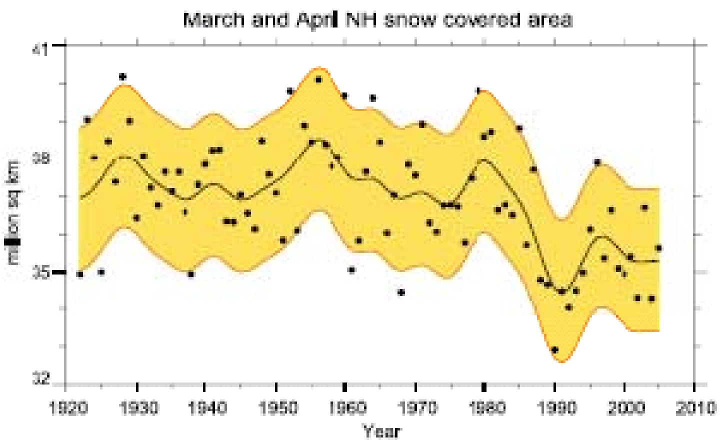
In a future warmer climate, heat waves become more severe in southern and western North America, and in the western European and Mediterranean region



From Meehl and Tebaldi 2005


So much hot air
Greenhouse gas emissions*
Actual % change, 1990-2004
% change required under Kyoto by 2012
40 30 20 10 – 0 + 10 20 30
Canada
United States
Italy†
Japan
France†
nil
Britain†
Germany†
Russia
nil
*Excluding emissions/removals from land use, land-use change and forestry †Targets assigned under EU Burden Sharing Agreement
Sources: UNFCCC; European Commission

Changes in Snow Cover



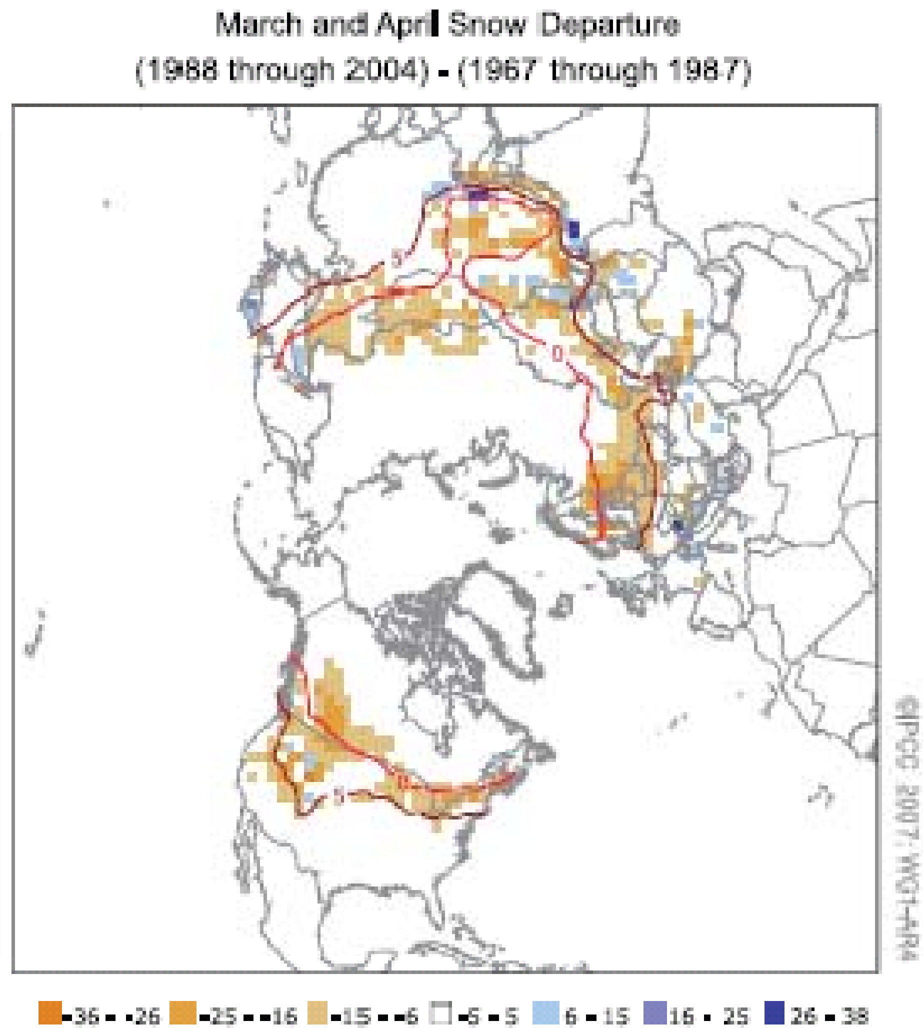


Figure TS.12. *(Top) Northern Hemisphere March-April snow-covered area from a station-derived snow cover index (prior to 1972) and from satellite data (during and after 1972). The smooth curve shows decadal variations (see Appendix 3.A) with the 5 to 95% data range shaded in yellow. (Bottom) Differences in the distribution of March-April snow cover between earlier (1967–1987) and later (1988–2004) portions of the satellite era (expressed in percent coverage). Tan colours show areas where snow cover has declined. Red curves show the 0°C and 5°C isotherms averaged for March-April 1967 to 2004, from the Climatic Research Unit (CRU) gridded land surface temperature version 2 (CRUTEM2v) data. The greatest decline generally tracks the 0°C and 5°C isotherms, reflecting the strong feedback between snow and temperature. {Figures 4.2, 4.3}*

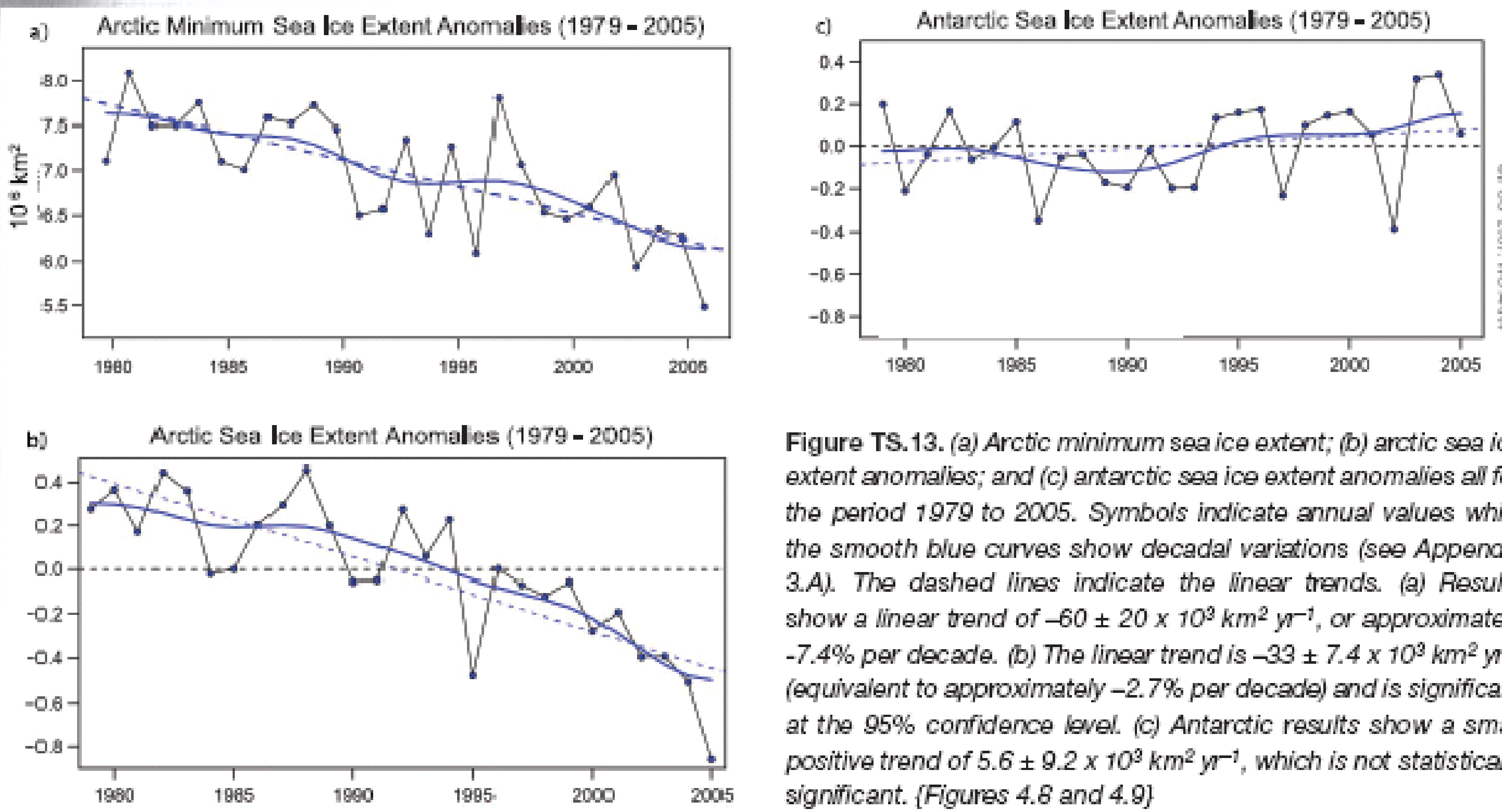


Figure TS.13. *(a) Arctic minimum sea ice extent; (b) arctic sea ice extent anomalies; and (c) antarctic sea ice extent anomalies all for the period 1979 to 2005. Symbols indicate annual values while the smooth blue curves show decadal variations (see Appendix 3.A). The dashed lines indicate the linear trends. (a) Results show a linear trend of $-60 \pm 20 \times 10^3$ km^2 yr^{-1}, or approximately -7.4% per decade. (b) The linear trend is $-33 \pm 7.4 \times 10^3$ km^2 yr^{-1} (equivalent to approximately –2.7% per decade) and is significant at the 95% confidence level. (c) Antarctic results show a small positive trend of $5.6 \pm 9.2 \times 10^3$ km^2 yr^{-1}, which is not statistically significant. {Figures 4.8 and 4.9}*

Rates of Observed Surface Elevation Change

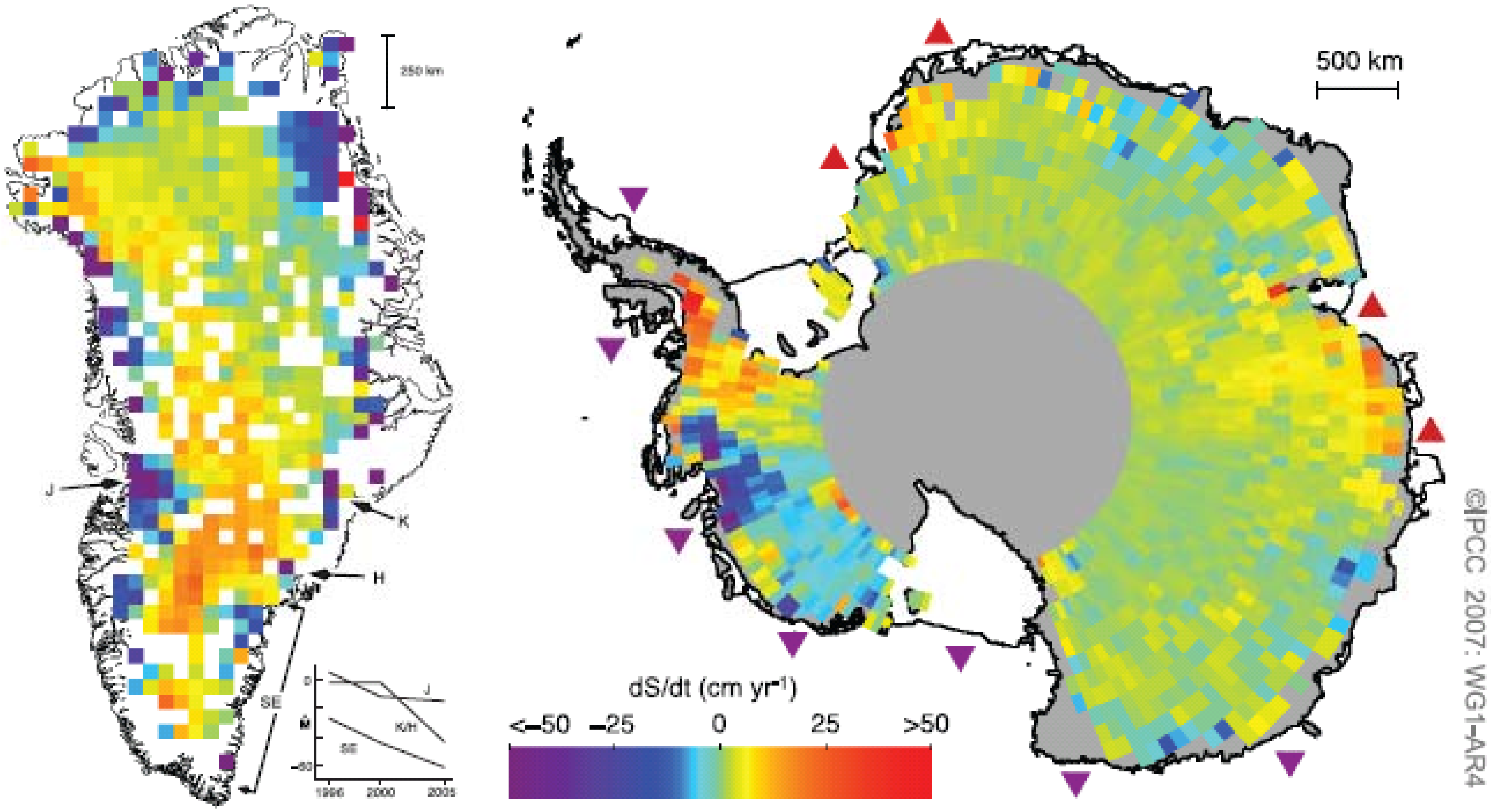


Figure TS.14. *Rates of observed recent surface elevation change for Greenland (left; 1989–2005) and Antarctica (right; 1992–2005). Red hues indicate a rising surface and blue hues a falling surface, which typically indicate an increase or loss in ice mass at a site, although changes over time in bedrock elevation and in near-surface density can be important. For Greenland, the rapidly thinning outlet glaciers Jakobshavn (J), Kangerdlugssuaq (K), Helheim (H) and areas along the southeast coast (SE) are shown, together with their estimated mass balance vs. time (with K and H combined, in Gt yr^{-1}, with negative values indicating loss of mass from the ice sheet to the ocean). For Antarctica, ice shelves estimated to be thickening or thinning by more than 30 cm yr^{-1} are shown by point-down purple triangles (thinning) and point-up red triangles (thickening) plotted just seaward of the relevant ice shelves. {Figures 4.17 and 4.19}*

GLOBAL MEAN SEA LEVEL

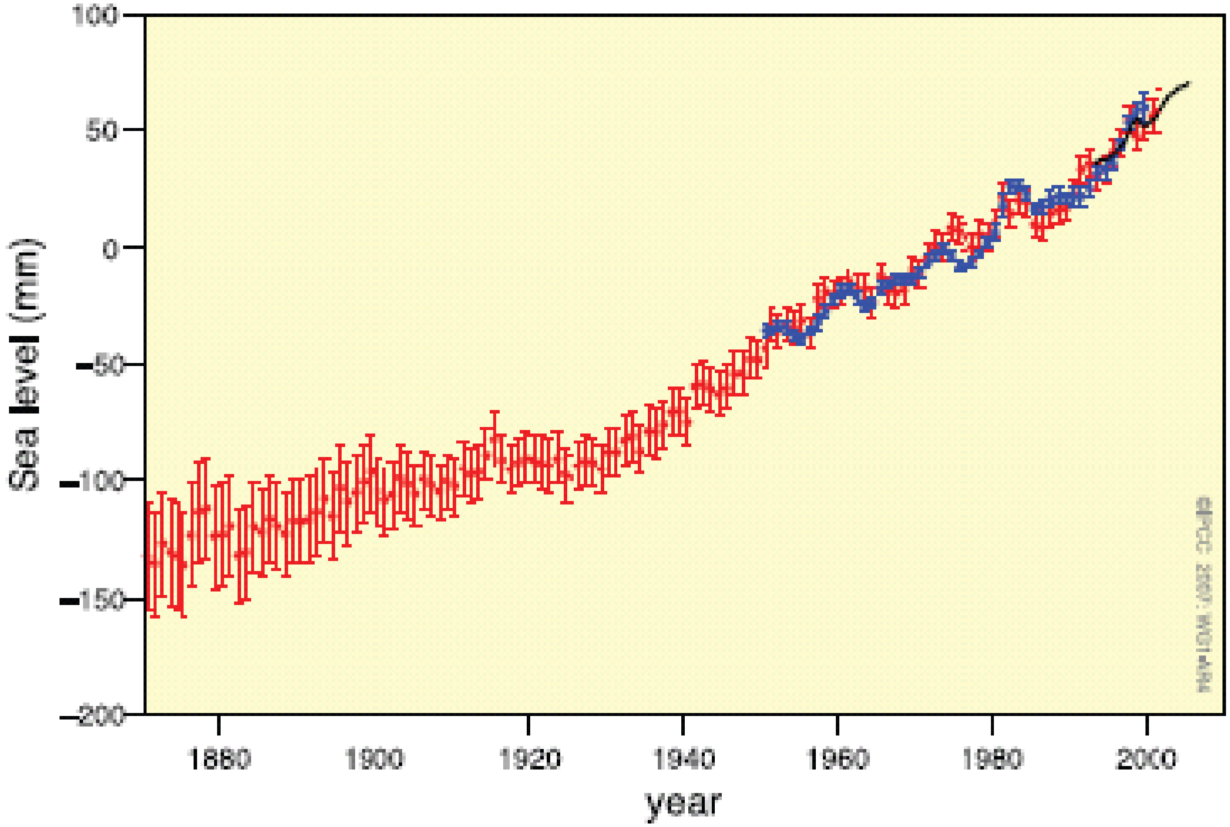


Figure TS.18. *Annual averages of the global mean sea level based on reconstructed sea level fields since 1870 (red), tide gauge measurements since 1950 (blue) and satellite altimetry since 1992 (black). Units are in mm relative to the average for 1961 to 1990. Error bars are 90% confidence intervals. {Figure 5.13}*

Global and Continental Temperature Change

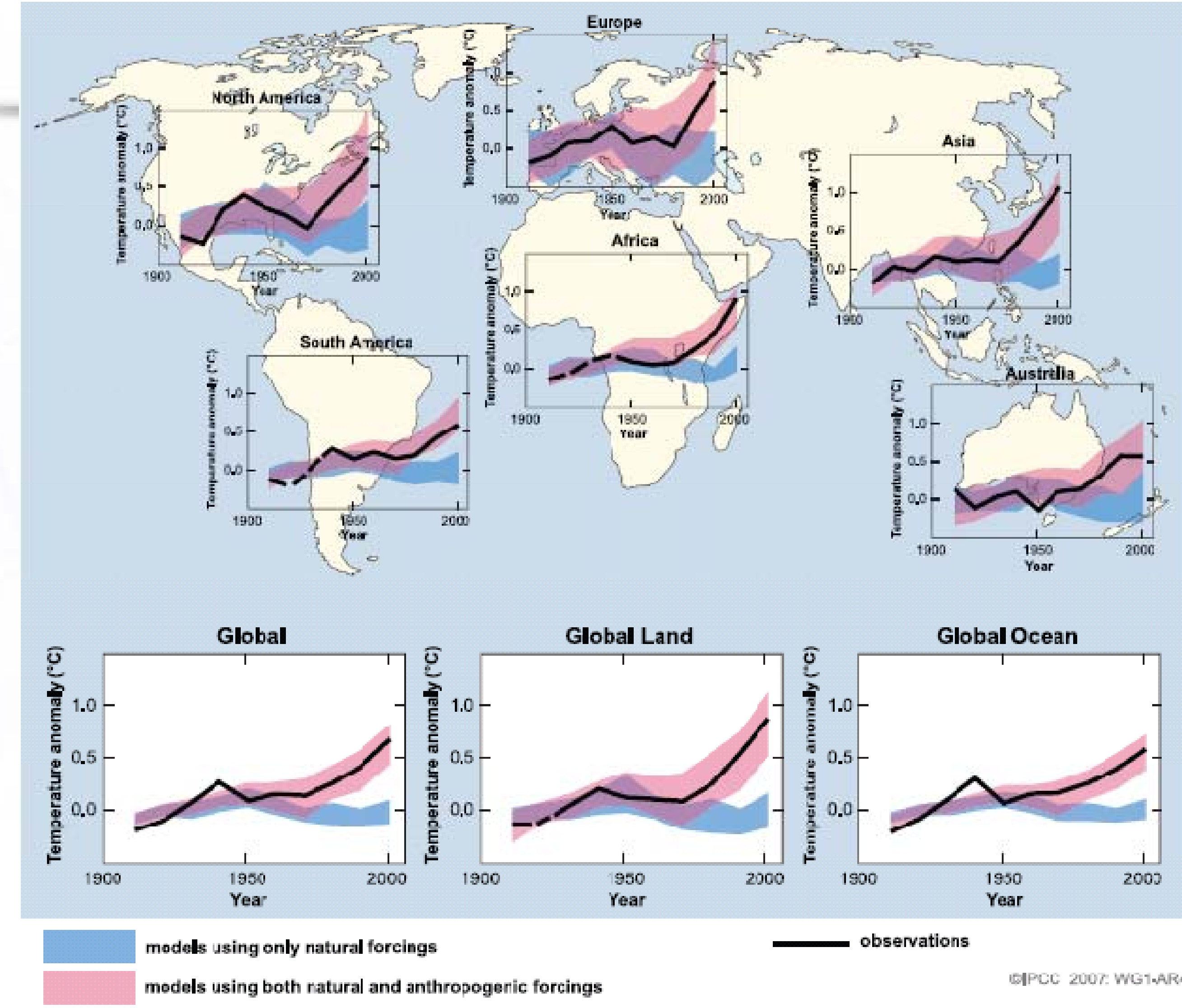


Figure TS.22. *Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906 to 2005 (black line) plotted against the centre of the decade and relative to the corresponding average for 1901 to 1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5% to 95% range for 19 simulations from 5 climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5% to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. Data sources and models used are described in Section 9.4, FAQ 9.2, Table 8.1 and the supplementary information for Chapter 9. {FAQ 9.2, Figure 1}*

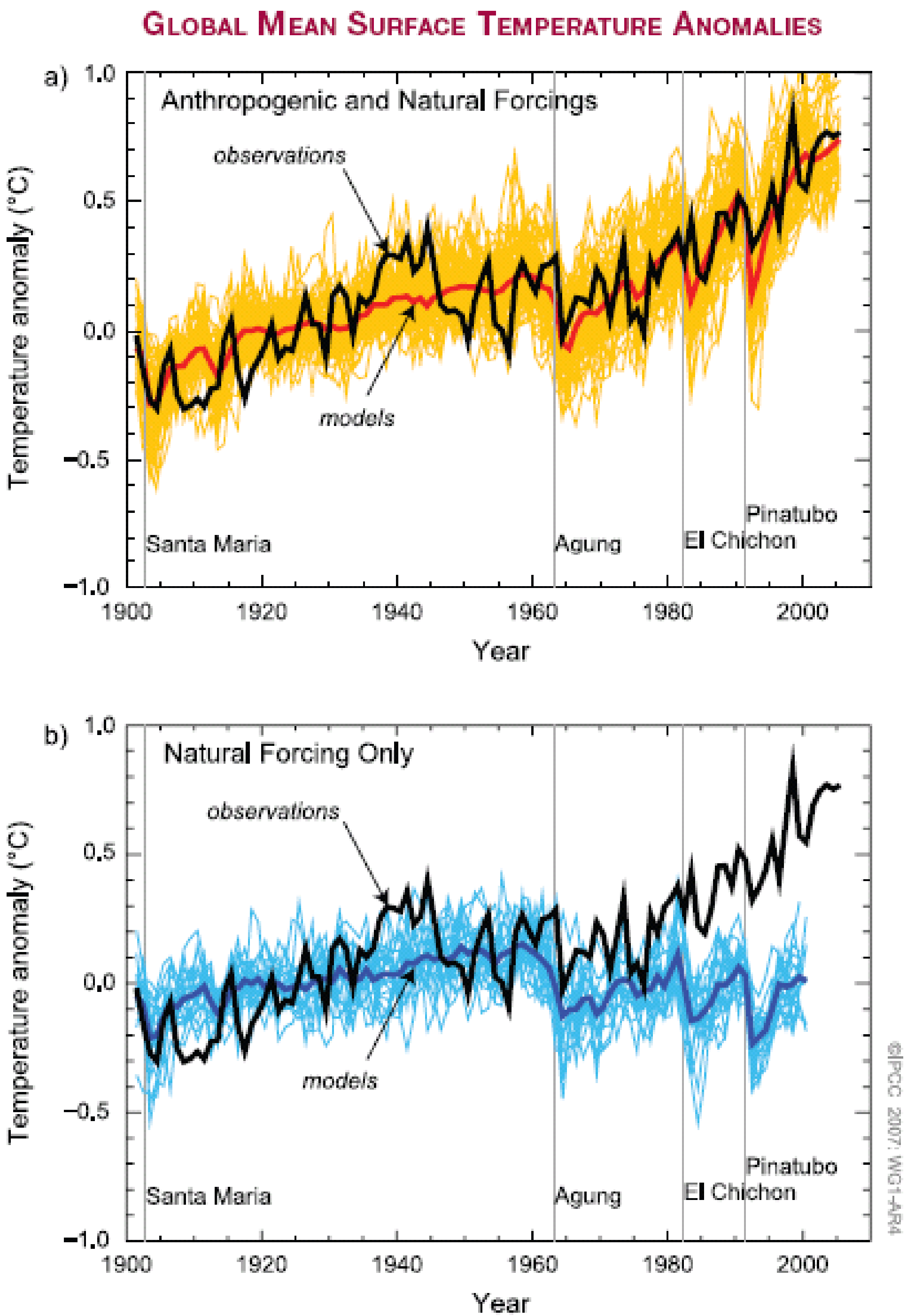


Figure TS.23. *(a) Global mean surface temperature anomalies relative to the period 1901 to 1950, as observed (black line) and as obtained from simulations with both anthropogenic and natural forcings. The thick red curve shows the multi-model ensemble mean and the thin lighter red curves show the individual simulations. Vertical grey lines indicate the timing of major volcanic events. (b) As in (a), except that the simulated global mean temperature anomalies are for natural forcings only. The thick blue curve shows the multi-model ensemble mean and the thin lighter blue curves show individual simulations. Each simulation was sampled so that coverage corresponds to that of the observations. {Figure 9.5}*

PROJECTIONS OF SURFACE TEMPERATURES

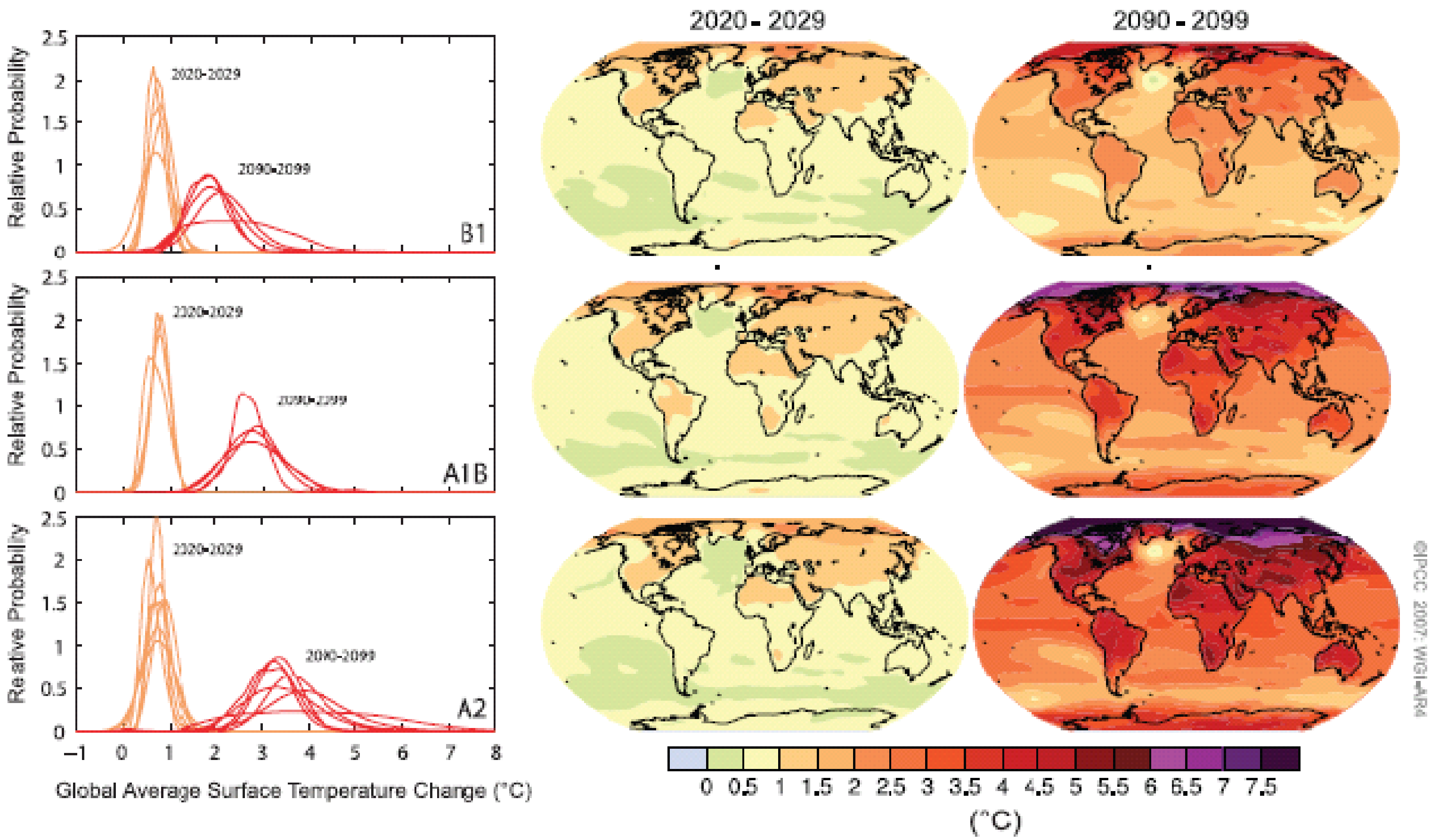


Figure TS.28. *Projected surface temperature changes for the early and late 21st century relative to the period 1980 to 1999. The central and right panels show the AOGCM multi-model average projections (°C) for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over the decades 2020 to 2029 (centre) and 2090 to 2099 (right). The left panel shows corresponding uncertainties as the relative probabilities of estimated global average warming from several different AOGCM and EMIC studies for the same periods. Some studies present results only for a subset of the SRES scenarios, or for various model versions. Therefore the difference in the number of curves, shown in the left-hand panels, is due only to differences in the availability of results. {Adapted from Figures 10.8 and 10.28}*

SRES Mean Surface Warming Projections

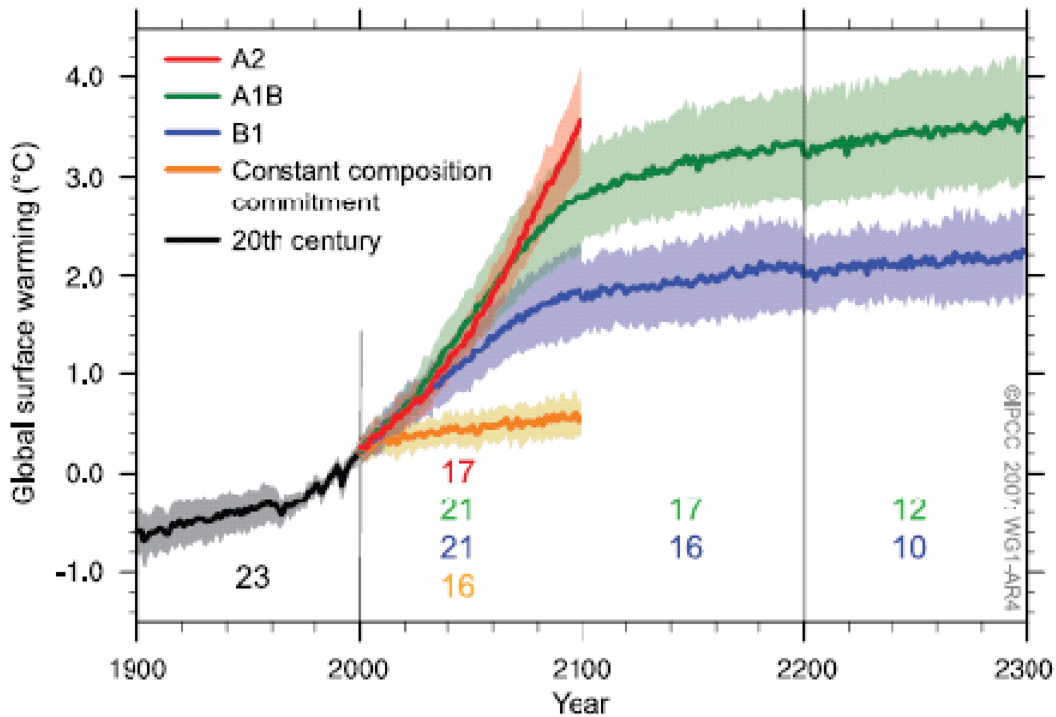
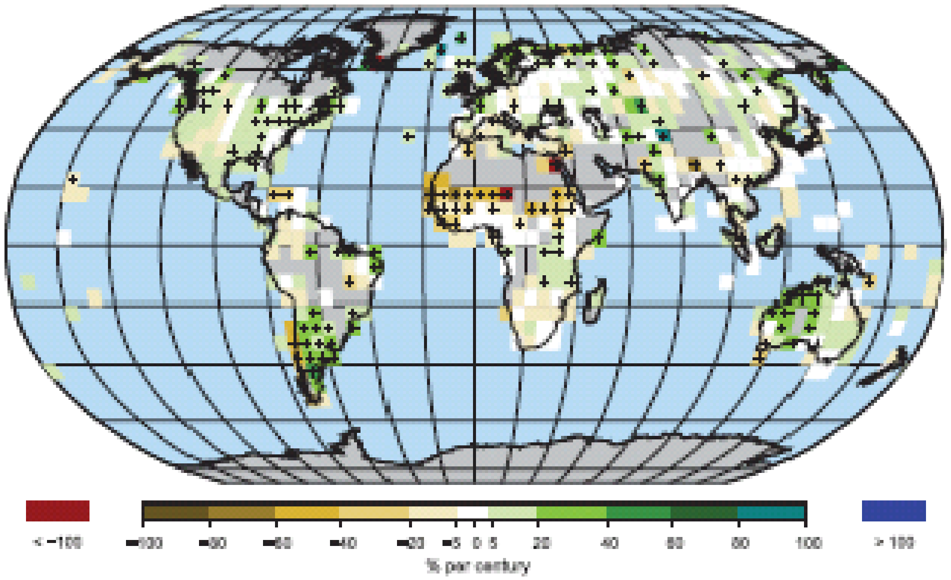
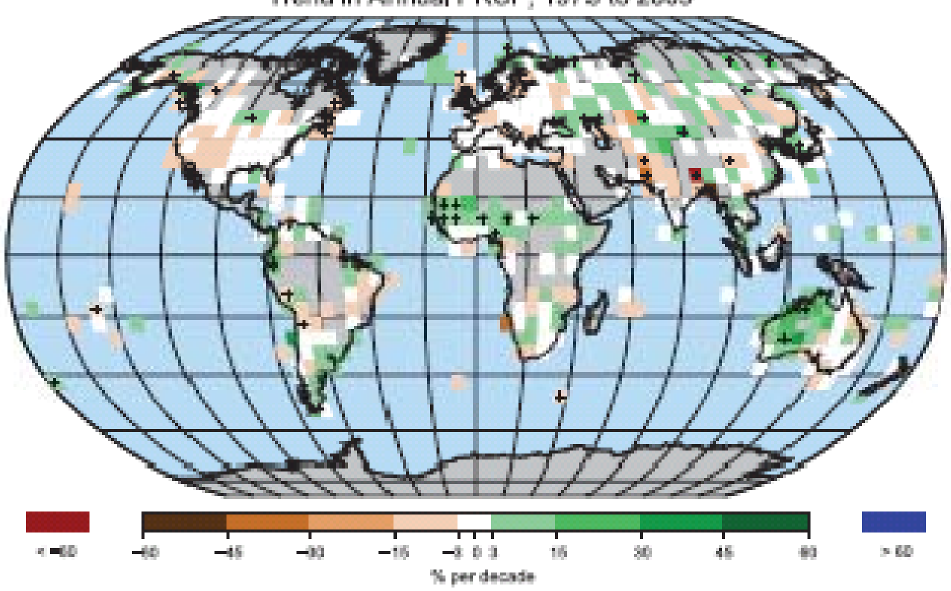


Figure TS.32. *Multi-model means of surface warming (compared to the 1980–1999 base period) for the SRES scenarios A2 (red), A1B (green) and B1 (blue), shown as continuations of the 20th-century simulation. The latter two scenarios are continued beyond the year 2100 with forcing kept constant (committed climate change as it is defined in Box TS.9). An additional experiment, in which the forcing is kept at the year 2000 level is also shown (orange). 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. 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 (numbers indicated in figure). For the same reason, uncertainty across scenarios should not be interpreted from this figure (see Section 10.5 for uncertainty estimates). {Figure 10.4}*

Trend in Annual PRCP, 1901 to 2005



Trend in Annual PRCP, 1979 to 2005



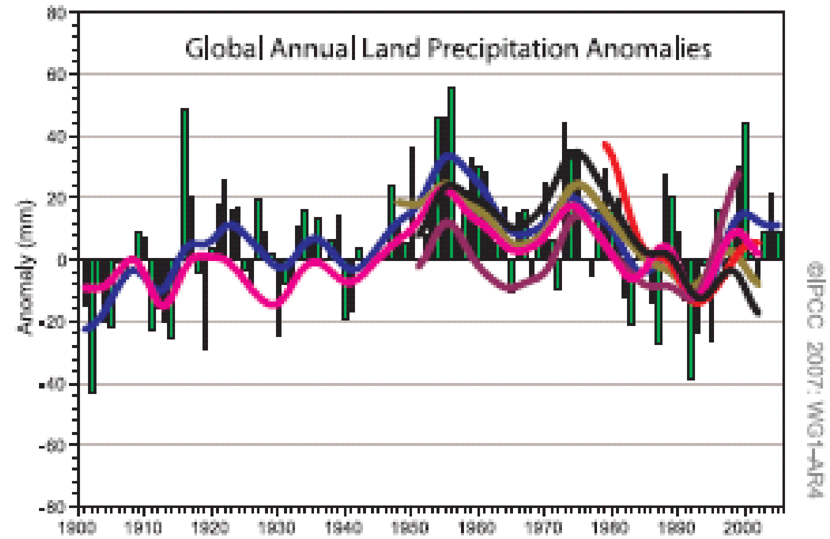


Figure TS.9. *(Top) Distribution of linear trends of annual land precipitation amounts over the period 1901 to 2005 (% per century) and (middle) 1979 to 2005 (% per decade). Areas in grey have insufficient data to produce reliable trends. The percentage is based on the 1961 to 1990 period. (Bottom) Time series of annual global land precipitation anomalies with respect to the 1961 to 1990 base period for 1900 to 2005. The smooth curves show decadal variations (see Appendix 3.A) for different data sets. {3.3, Figures 3.12 and 3.13}*