Climate Change:
What's in store for New Mexico

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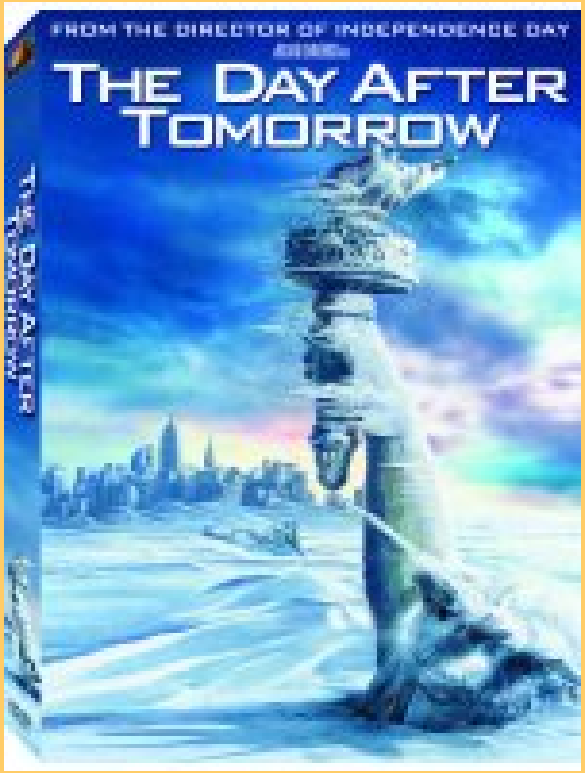
1. 20th Century climate change, globally and in NM
2. 20th Century climate trends in longer term context
3. Scenarios for the 21st Century
4. Closing remarks: Surprises? How important is this?

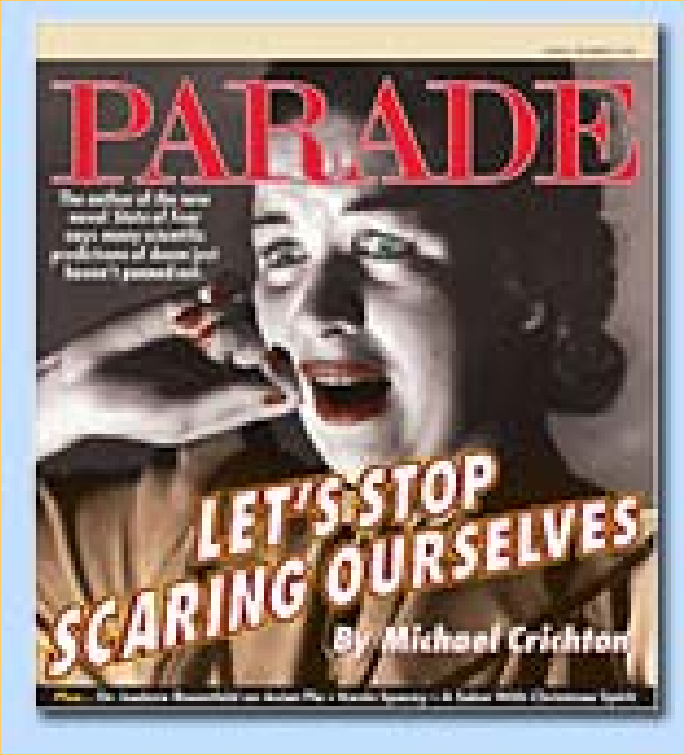
The University of New Mexico

NM Climate Change Initiative Discussion
October 19, 2005

Global Warming: What's New

U.S. popular culture

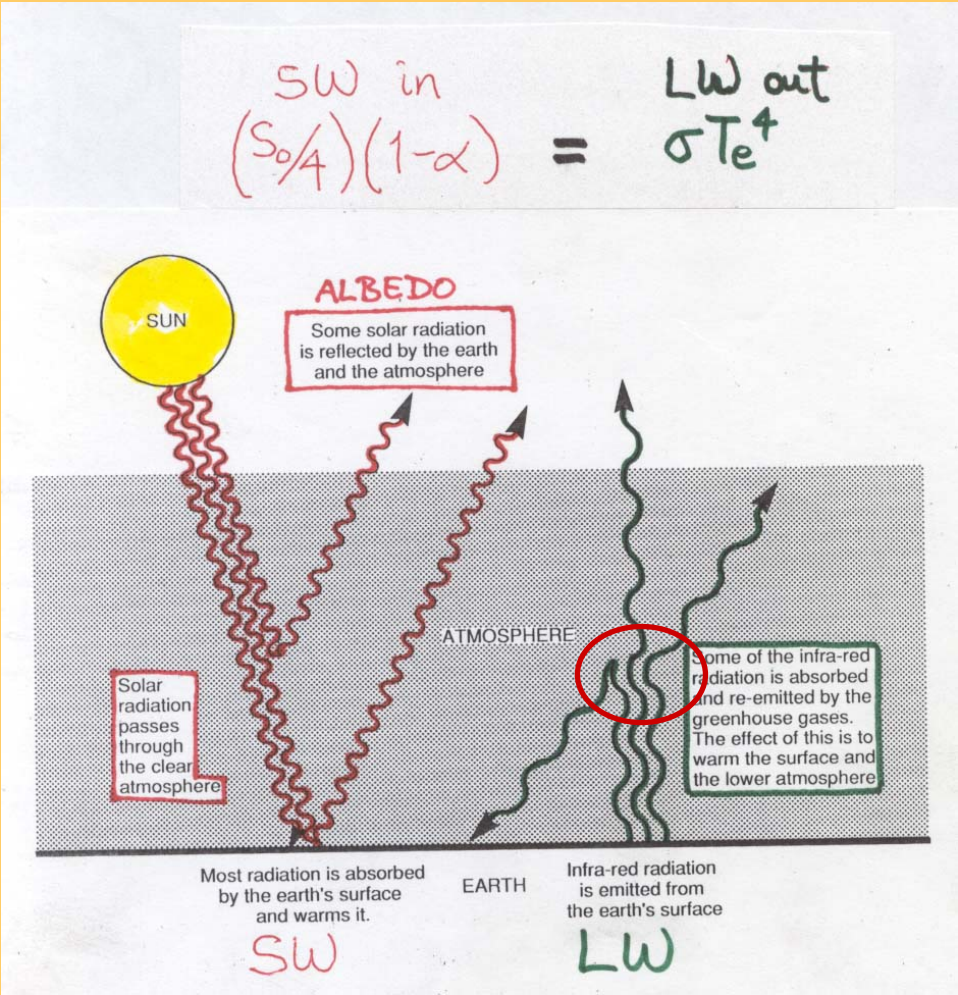




The movie:
LA, NYC obliterated!

The book:
Global warming is just a deadly hoax!

Earth's Greenhouse Effect: Not new



Global Energy Balance at top of atmosphere

T(sun) ~ 6000K

Te ≈ -18°C (below freezing)
(for current So, α)

Ts (Earth) ≈ 15°C & rising
... the Greenhouse Effect is a good thing!

Longwave radiation is absorbed and re-emitted by "Greenhouse Gases": H_2O, CO_2, CH_4, etc.

Greenhouse Gases

sampled concentrations since AD 1000

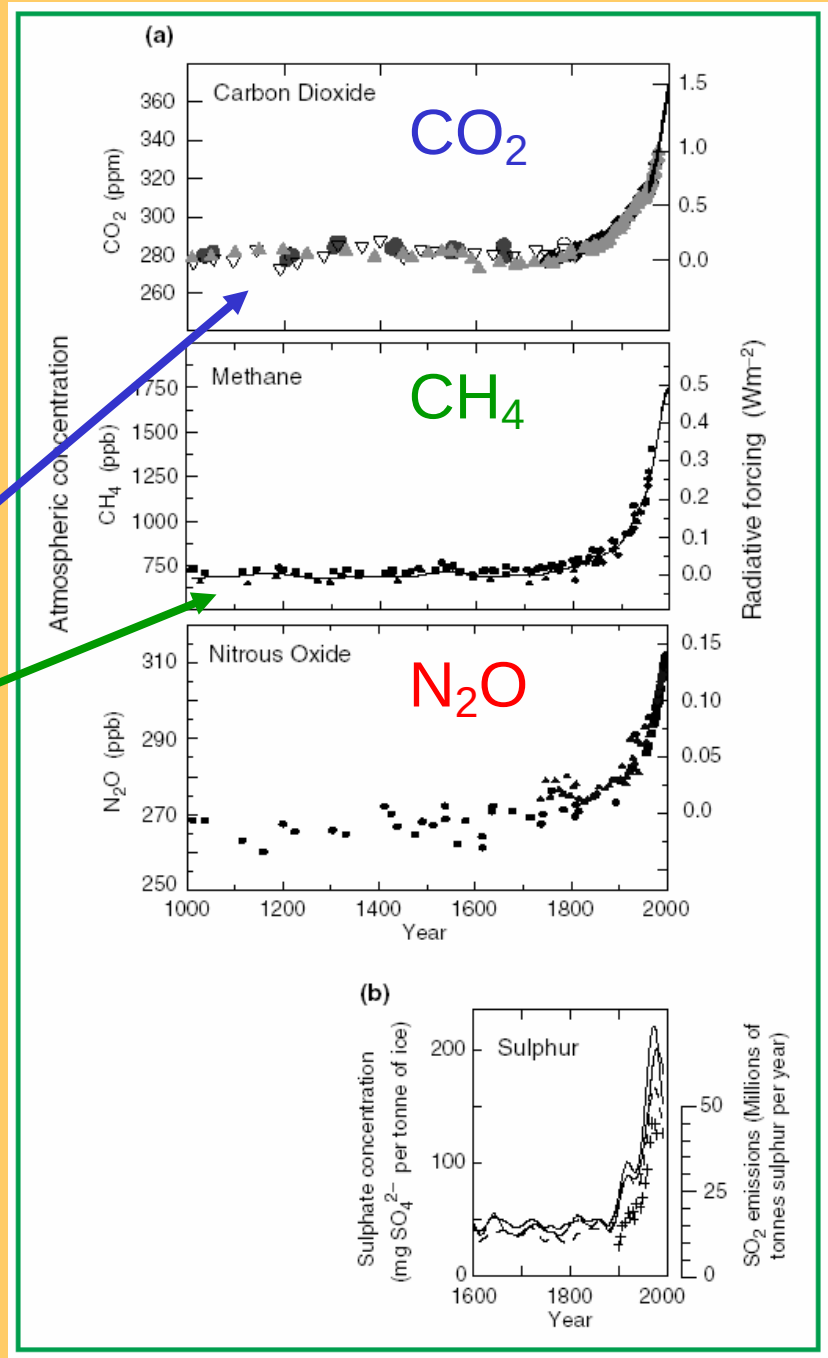
IPCC (2001)

"pre-industrial" values seem nearly constant prior to about 1750

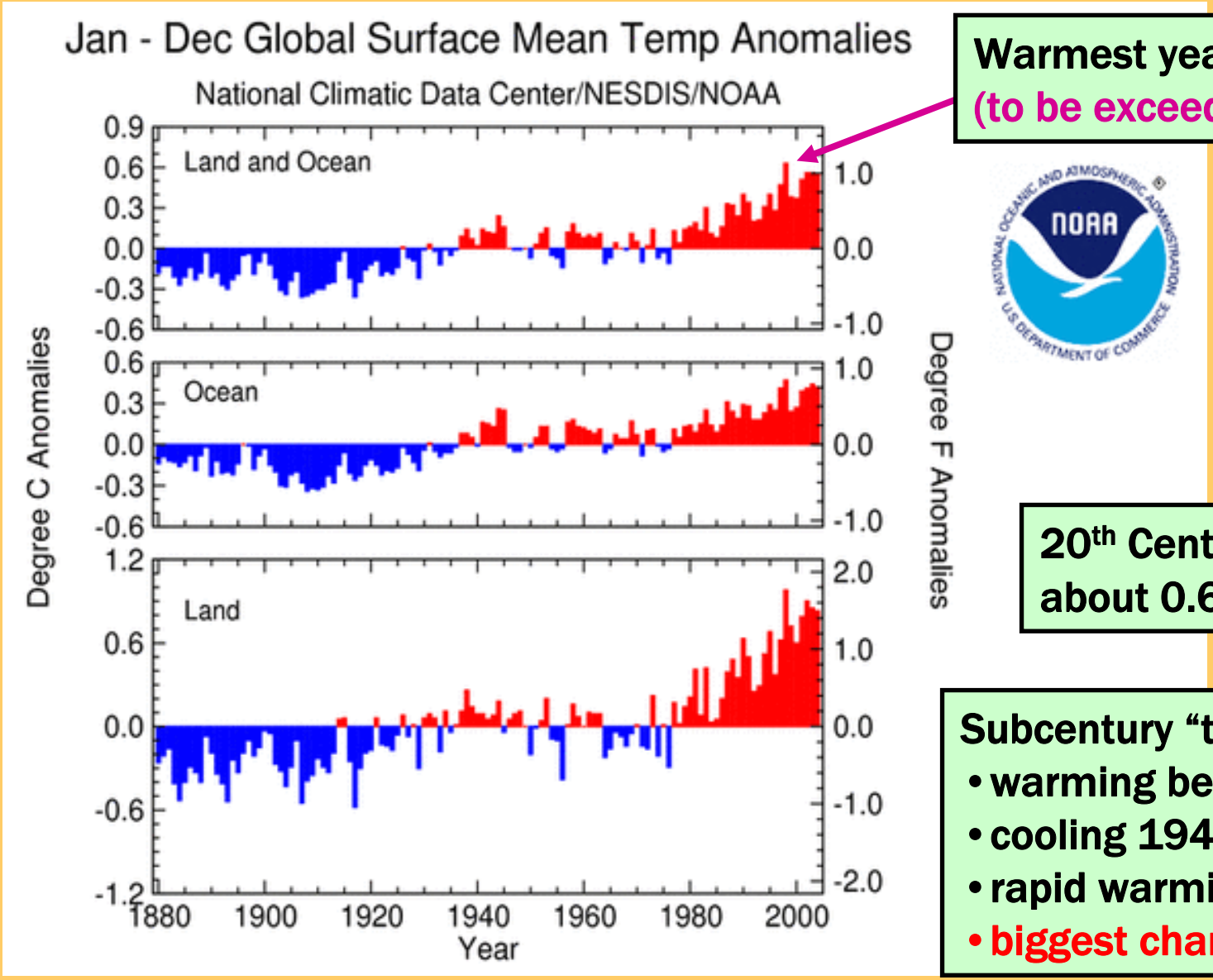
largest radiative forcing: CO_2

largest % increase: CH_4

These increases are unambiguously anthropogenic – <u>no controversy</u> about this



Global Warming in the 20th Century



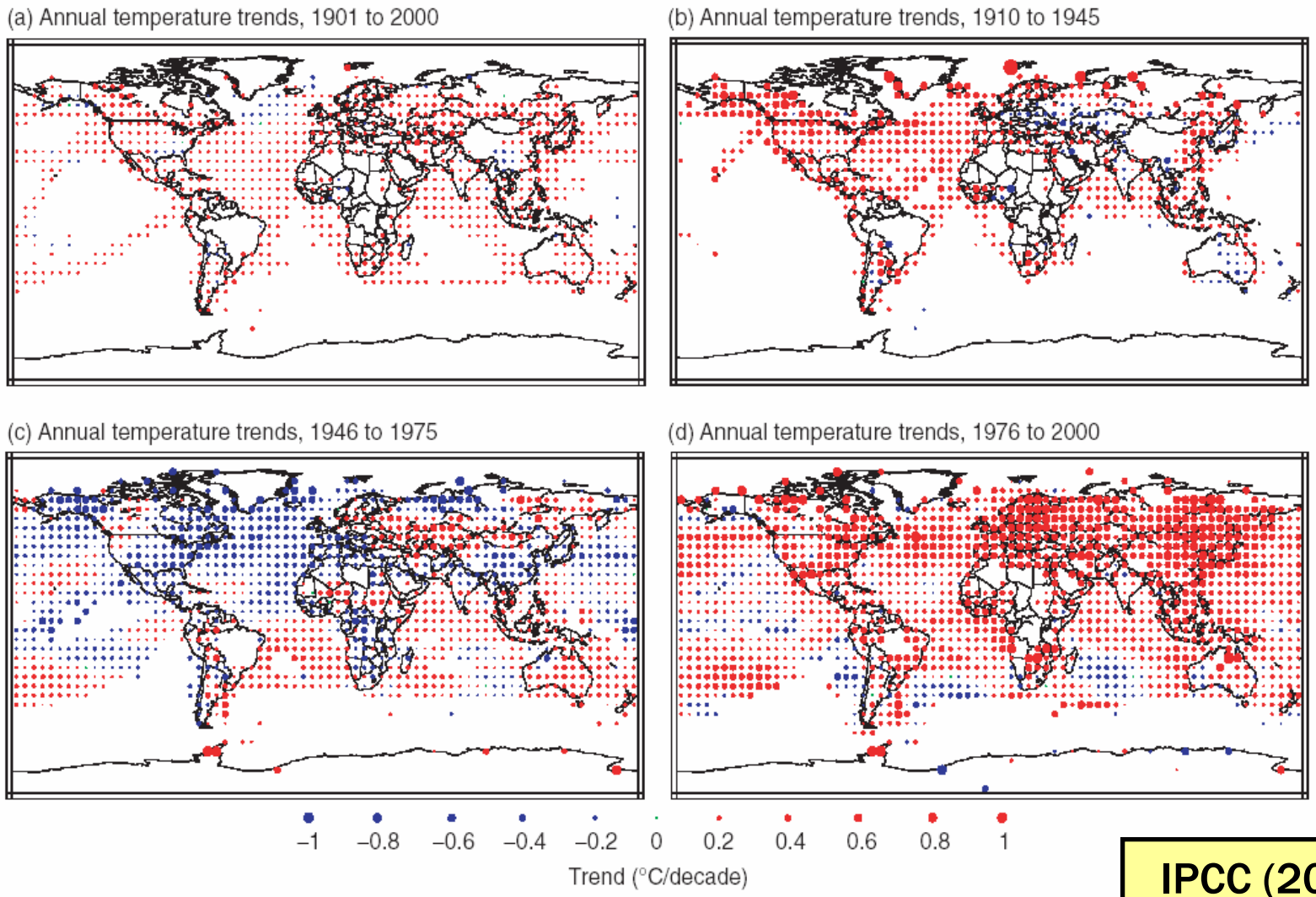
Warmest year = 1998
(to be exceeded in 2005?)

20th Century warming: about 0.6°F ± 0.2°F

Subcentury "trends":
- **warming before 1940**
- **cooling 1940-1975**
- **rapid warming since then**
- **biggest changes on Land**

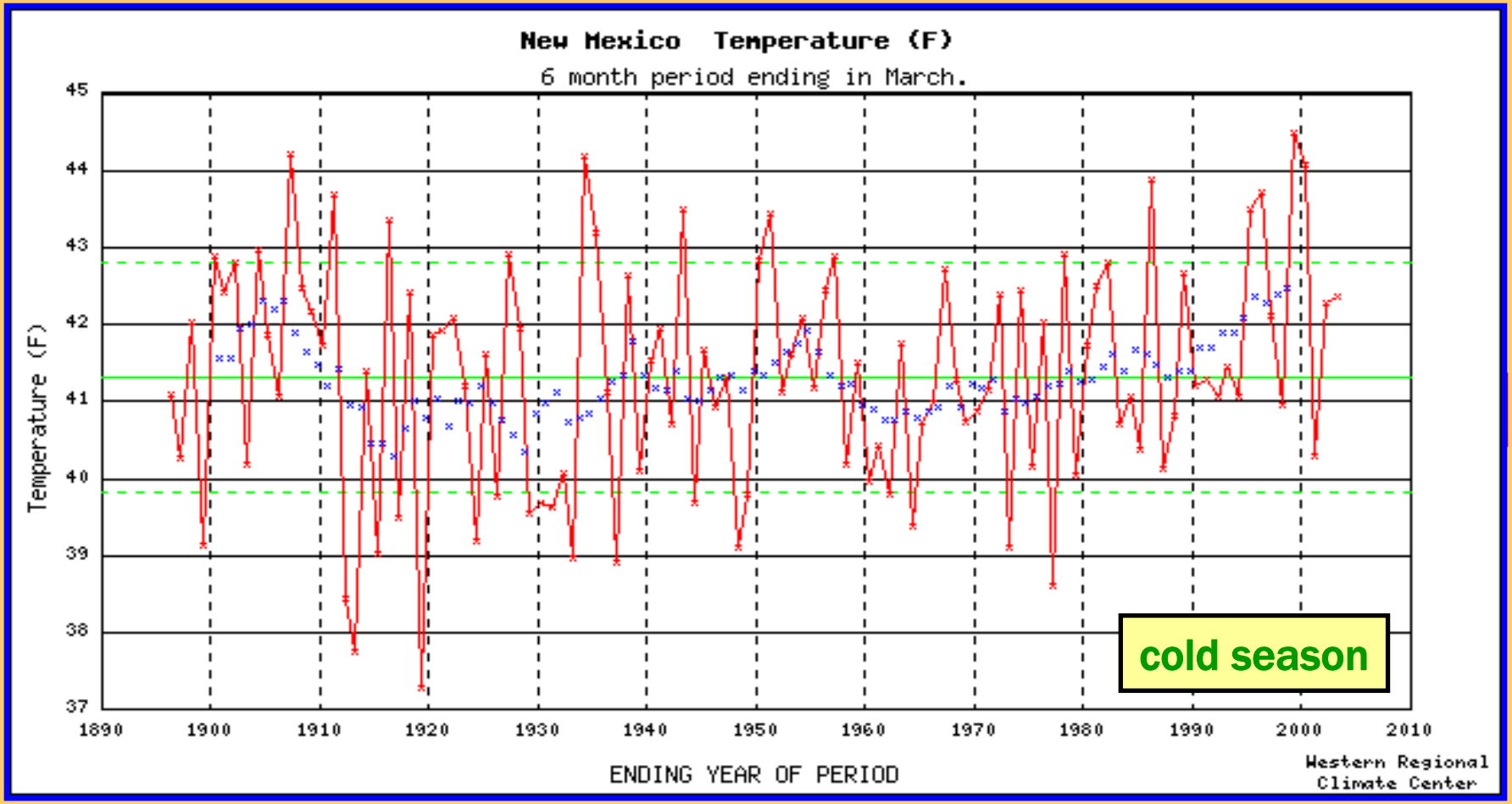
Global Warming in the 20th Century

"trends" during different periods



IPCC (2001)

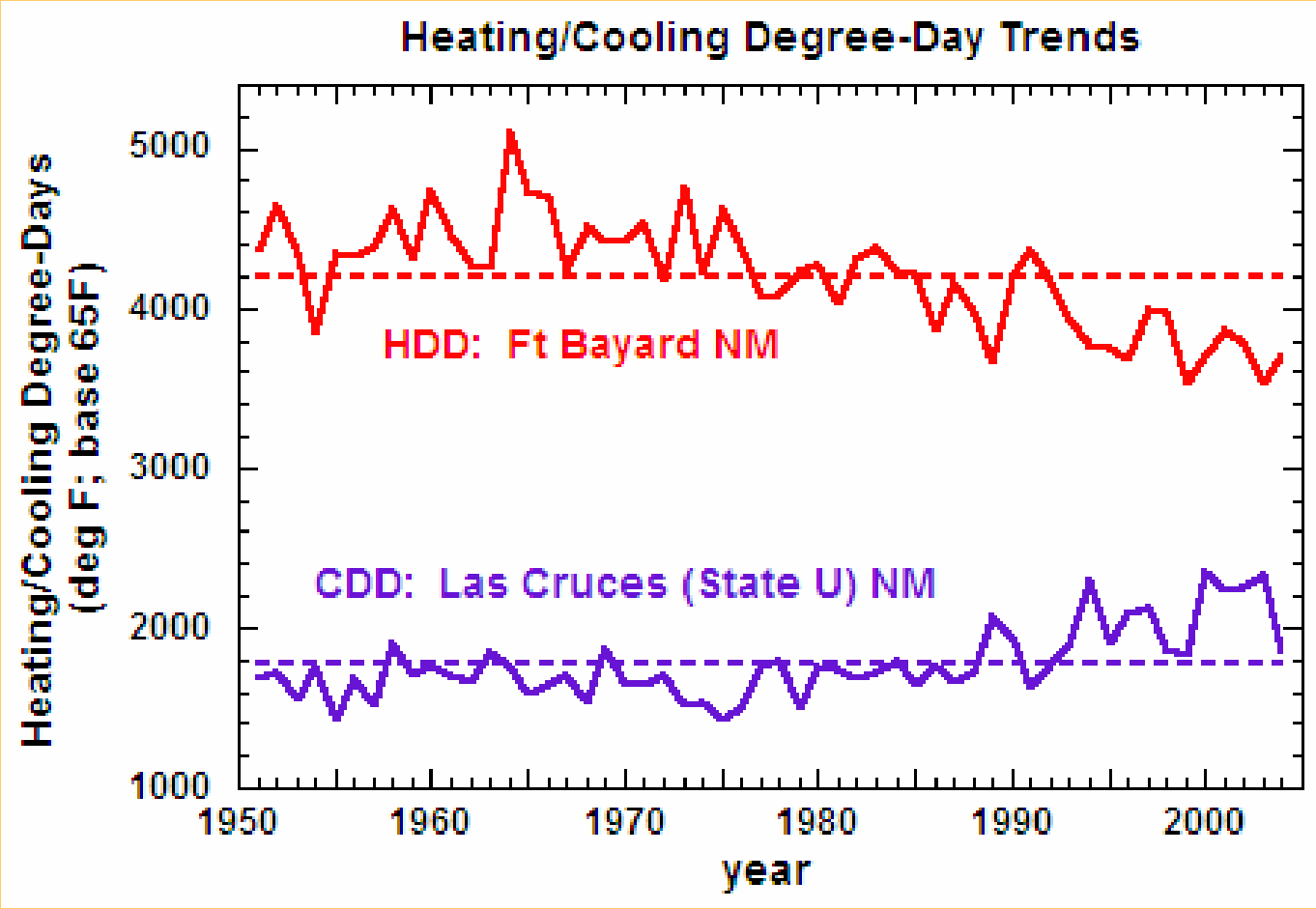
20th Century temperature variability
New Mexico statewide



Data from Western Regional Climate Center

Late 20th Century temperature trends in southern New Mexico

$$HDD_{daily} = \max\{0, 65°F-(T_{max}+T_{min})/2\}$$



Change from 1950s to the end of the 20th Century exceeds 15% for both HDD and CDD

NCDC data

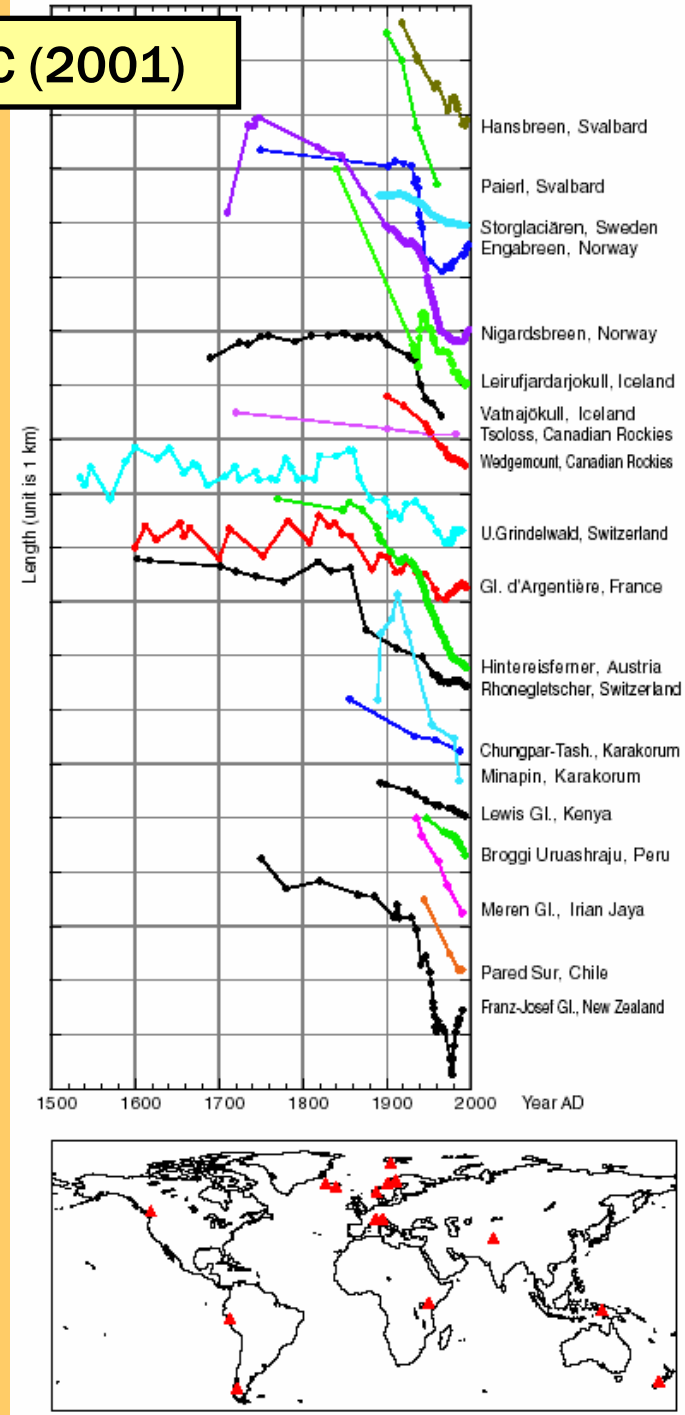
$$CDD_{daily} = \max\{0, (T_{max}+T_{min})/2-65°F\}$$

Snow and ice retreat in progress

Isolated glaciers and snowfields are melting away

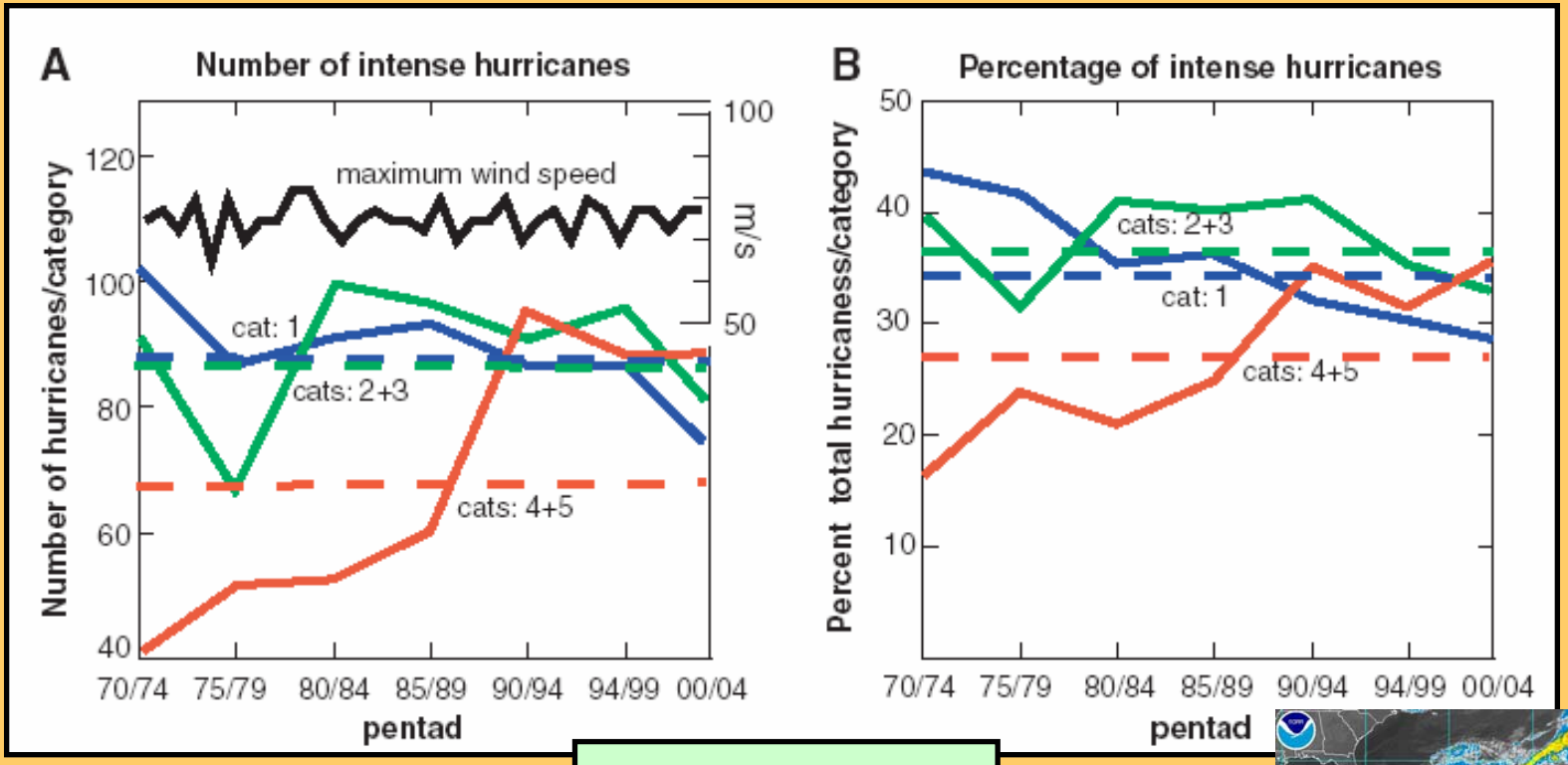
Gutzler (2000)
photo of Athabasca Glacier
courtesy P. Fawcett

IPCC (2001)



Recent trends in hurricane intensity?

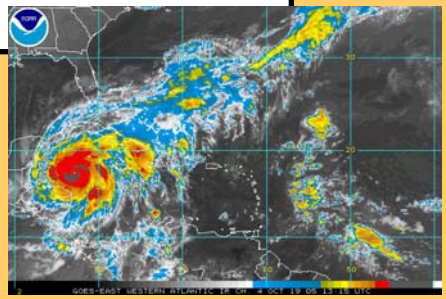
Webster et al. (2005)



(short data record)

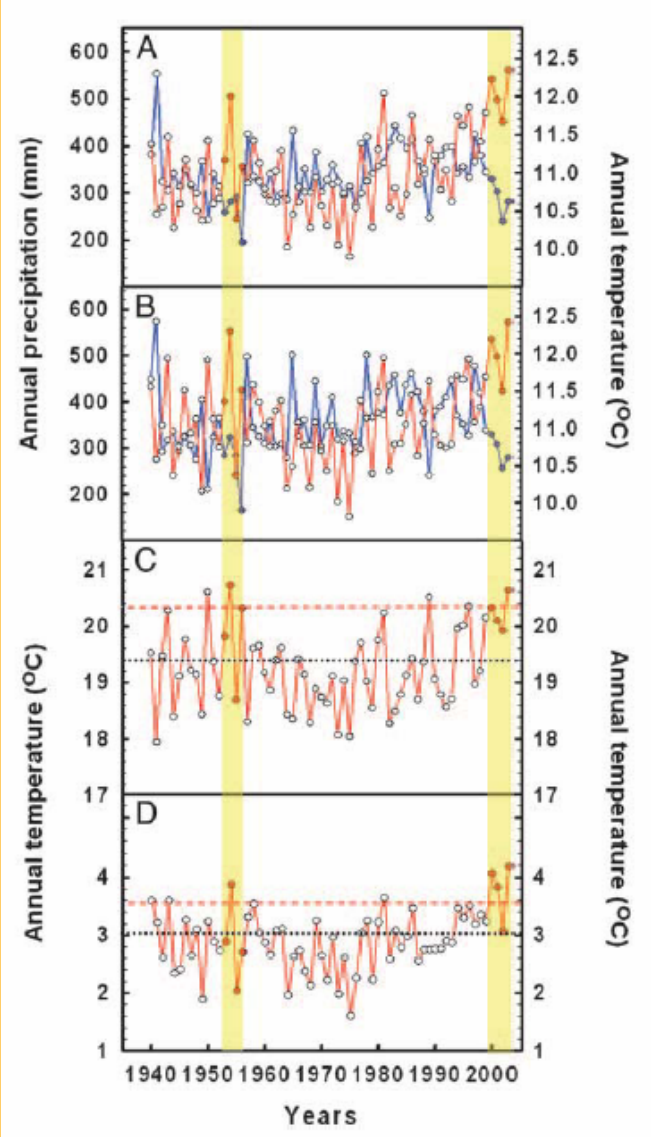
No significant trend in average max wind speed,
or in annual number of low-intensity hurricanes (cat 1-3)

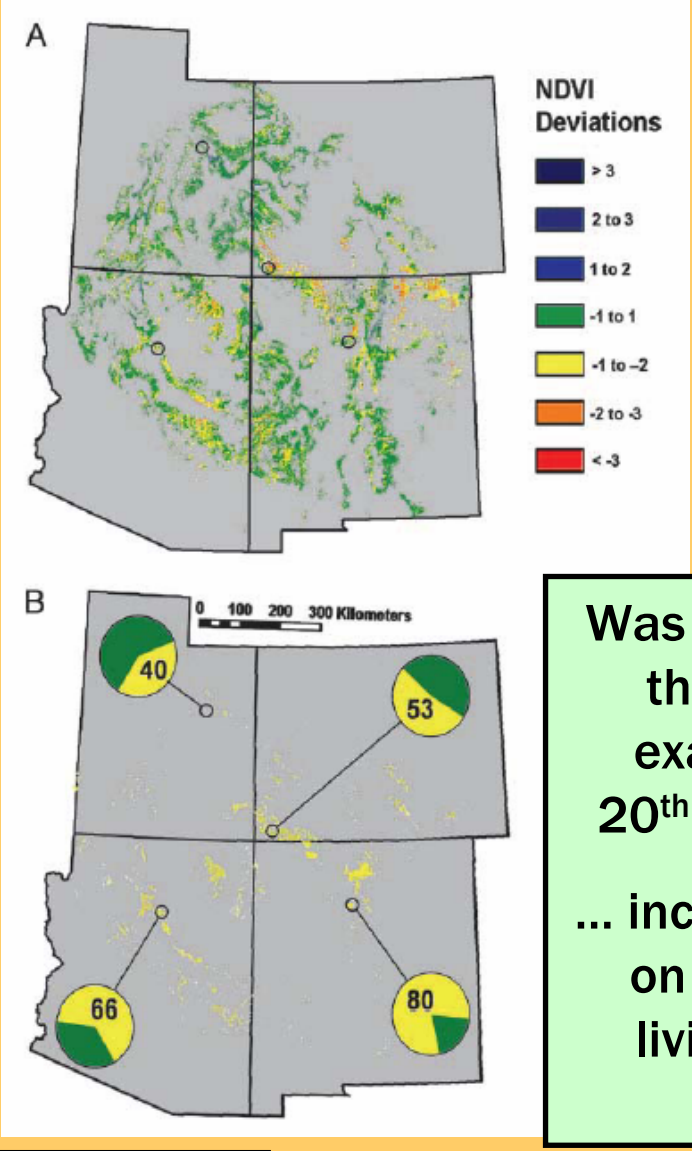
... but number of cat 4-5 hurricanes is up sharply since 1980s
(due to rise in SST, perhaps caused by increasing GH gases?)



Wilma
10/19/05

Piñon mortality across Southwest during recent drought



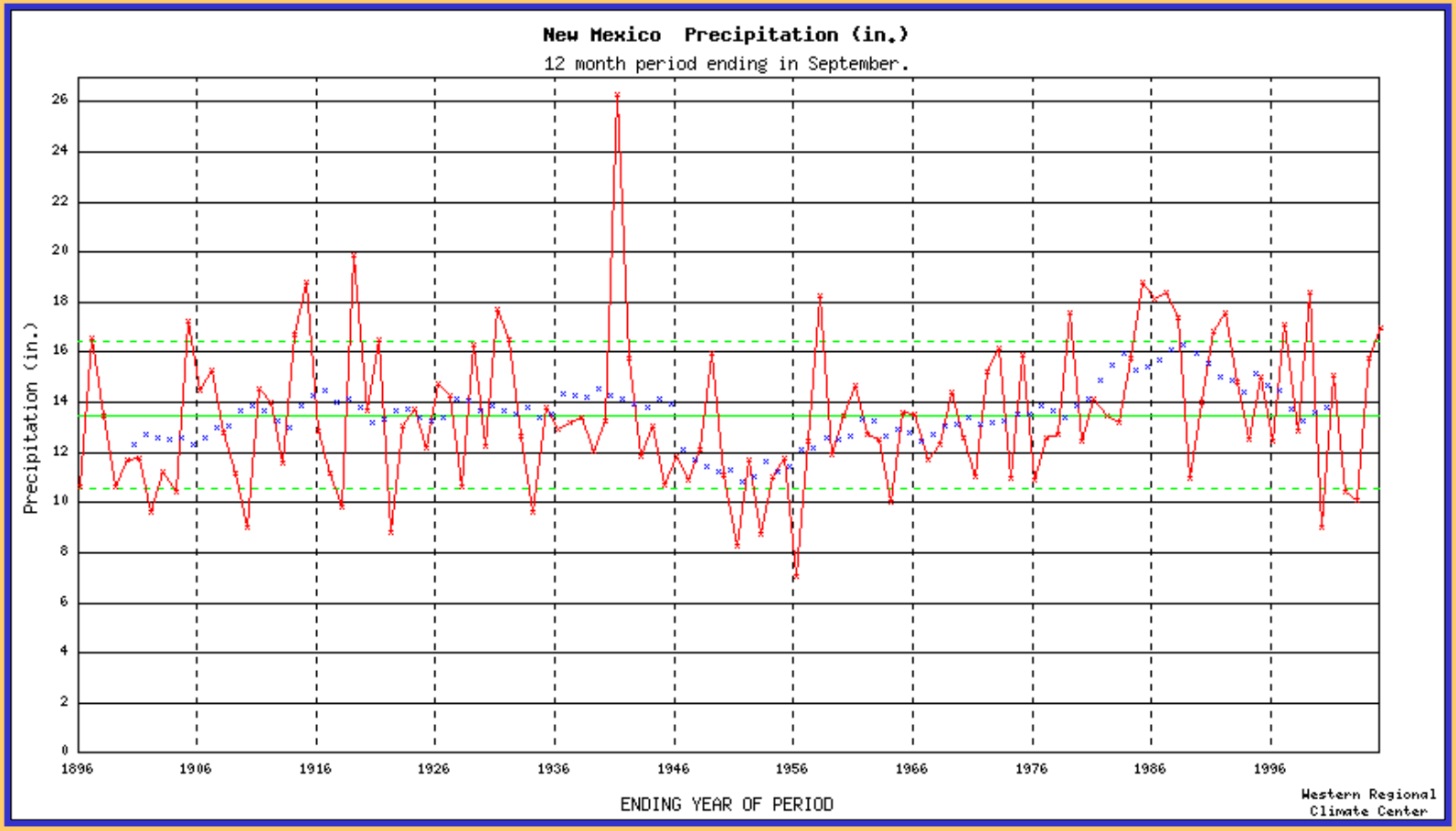


Was piñon dieoff during the recent drought exacerbated by late 20th Century warming?

... increased water stress on pines, and better living conditions for bark beetles

Breshears et al. (2005)

20th Century precipitation variability
New Mexico statewide, water year averages



Data from Western Regional Climate Center

Late 20th Century trends in western wintertime hydroclimatology

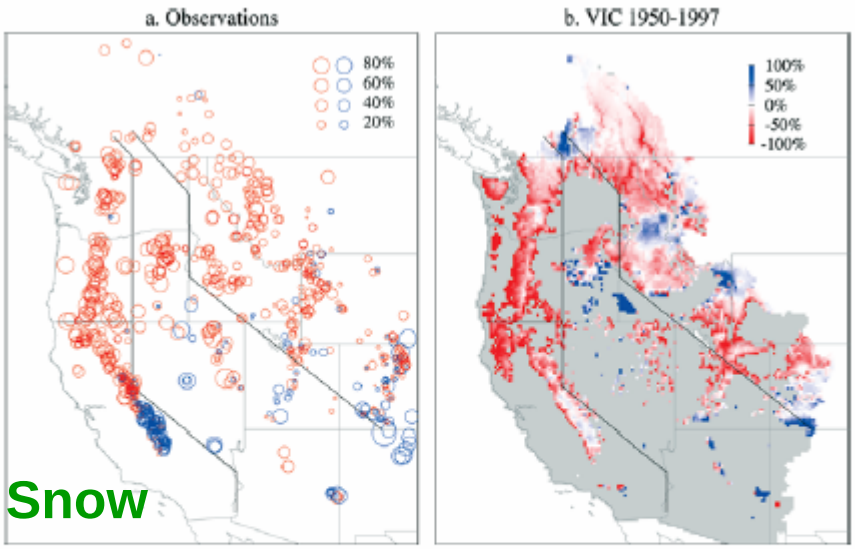


FIG. 1. Linear trends in 1 Apr SWE relative to the starting value for the linear fit (i.e., the 1950 value for the best-fit line): (a) at 824 snow course locations in the western United States and Canada for the period 1950–97, with negative trends shown by red circles and positive by blue circles; (b) from the simulation by the VIC hydrologic model (domain shown in gray) for the period 1950–97. Lines on the maps divide the West into four regions for analysis shown in subsequent figures.

Mote et al. (2005)

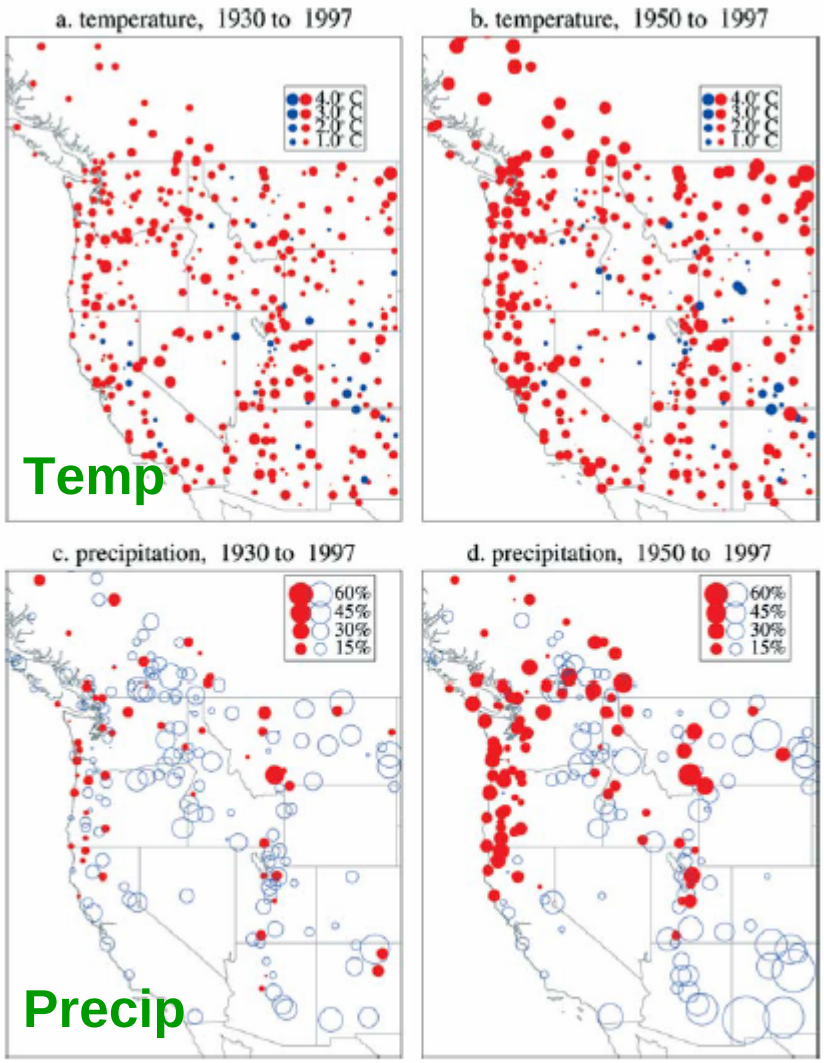
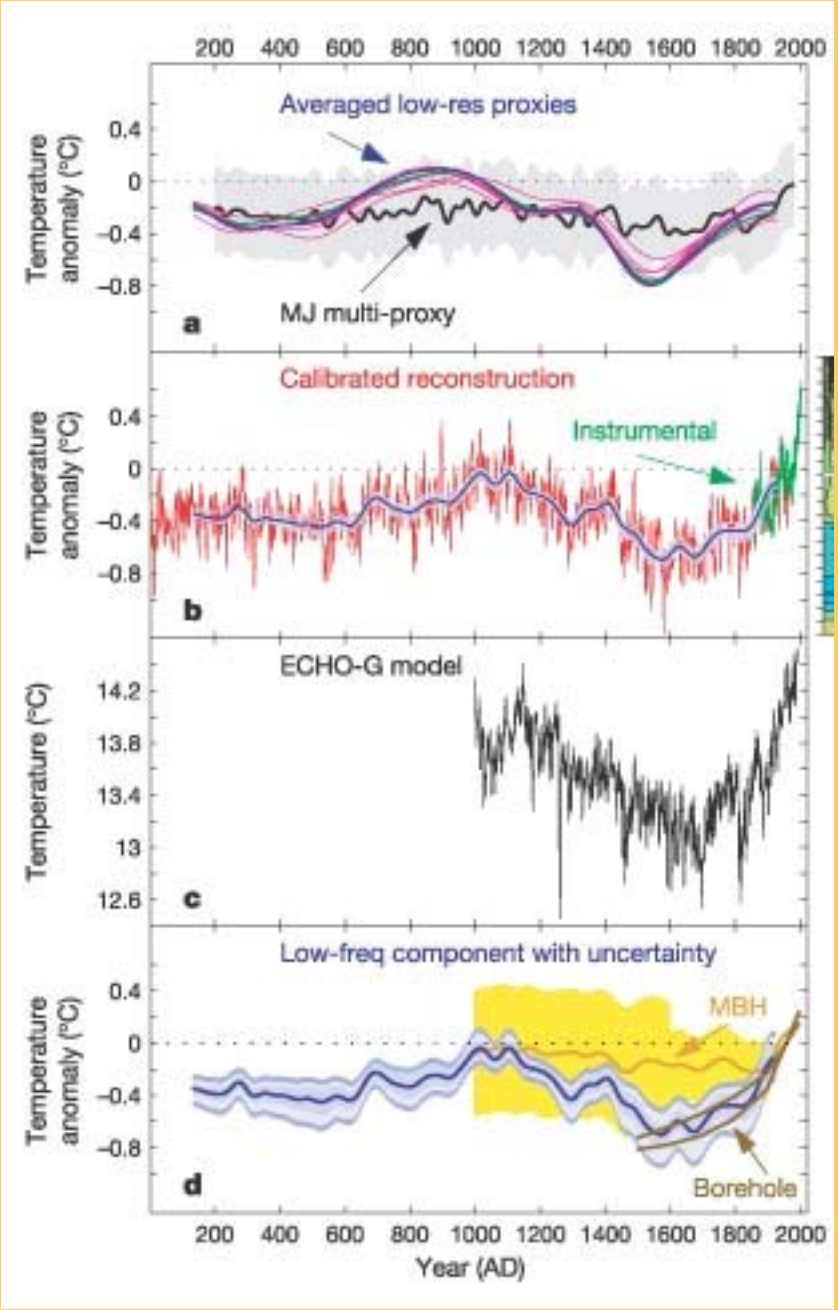


FIG. 6. Linear trends in Nov–Mar (a), (b) temperature and (c), (d) total precipitation over the period indicated. For temperature, negative trends are indicated by blue circles, and positive trends by red circles; values are given in degrees per century. For precipitation, trends are given as a percentage of the starting value (1930 or 1950), and positive trends are shown as blue circles.



Northern Hemisphere temperature reconstructions over the past two millennia (mostly tree ring-based)

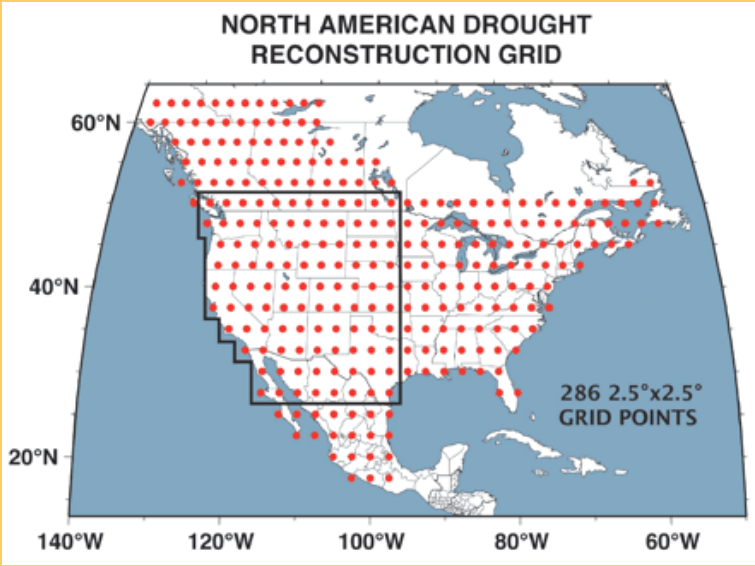
20th Century warming is large and rapid compared to past 2000 yr

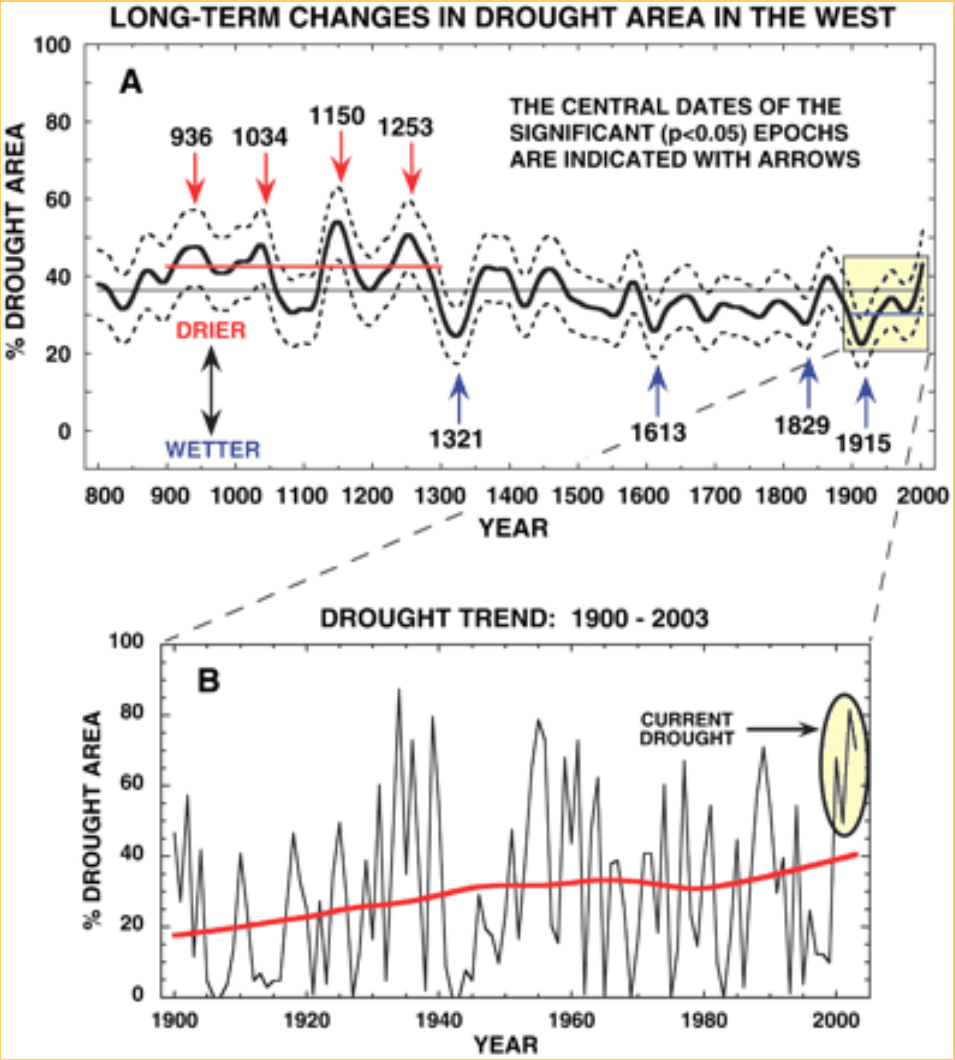
There's still plenty of debate over the degree of "stability" during the past millennium, but 20th Century warming stands out in every record

Note previous warm era around AD 1000

Moberg et al. (2005)

Drought History of the Western U.S.





Tree ring data suggest that the western U.S. was, overall, **drier with multiple big droughts** between 900-1300 AD ... **when climate was warm**

Does the 20th Century record imply that we are headed back to such a climatic regime?

Cook et al. (2004)

Central NM precipitation from tree ring data 622-1992

top: Drought Index reconstruction

middle: Low-pass filtered time series

bottom: Decadal changes in interannual variability

Evidence for sub-century drought periodicity? On average, major drought occurs every 50-80 years

Very high interannual variability in the 20th Century ... to be enhanced even more as climate warms?

Grissino-Mayer et al. (2002)

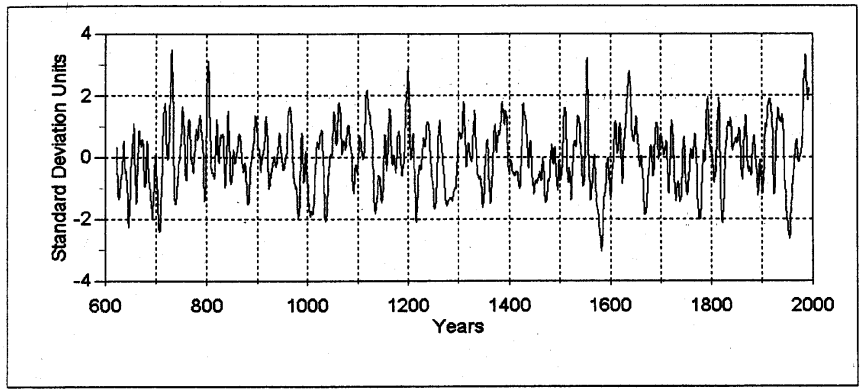


Figure 9. The reconstruction of June PDSI, AD 622 - 1992, in standard deviation units, filtered with a 10-year smoothing spline to accentuate interannual- to decadal-scale trends.

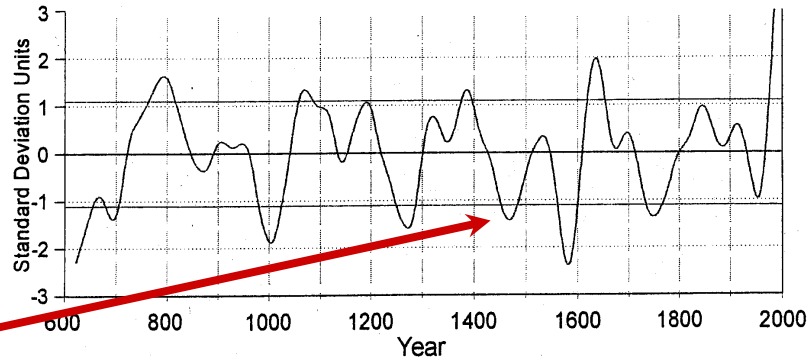


Figure 10. Major wet and dry periods between AD 622 - 1992 for the Middle Rio Grande Basin, filtered with a 100-year smoothing spline, expressed as standard deviation units. The ± 1.1 sd units are depicted as well. Any periods above or below these lines denote extreme wet and dry periods, respectively.

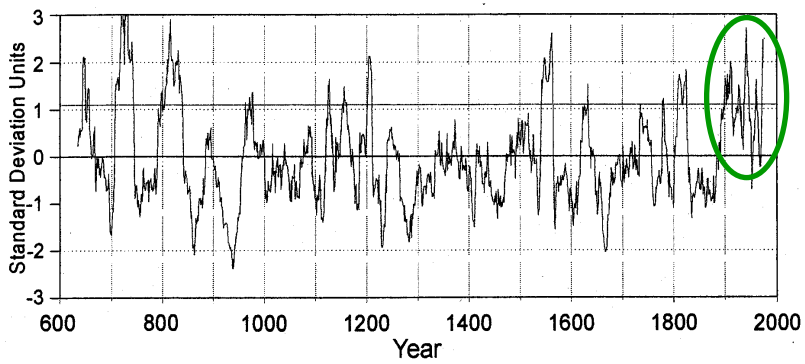
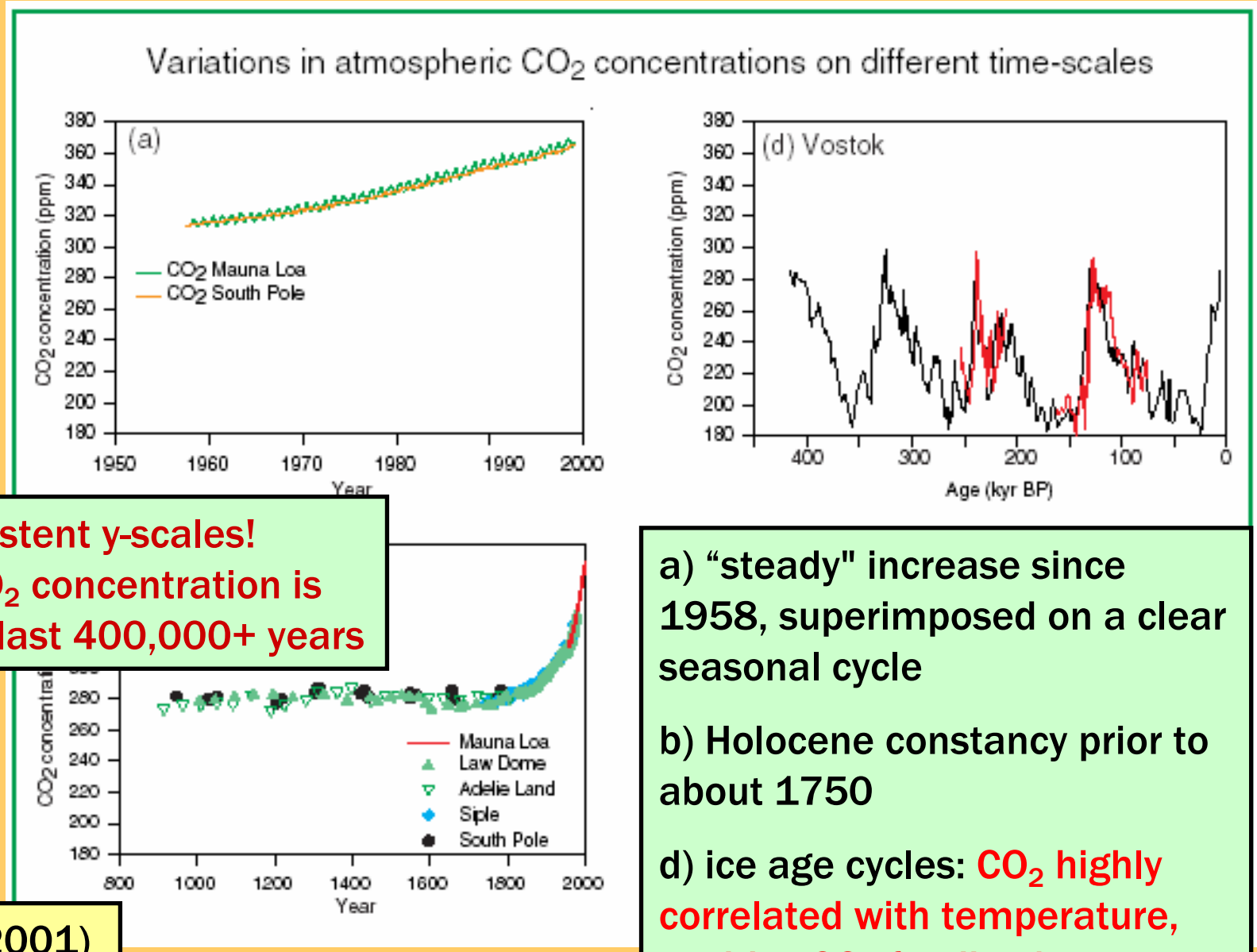


Figure 11. Running variance calculated for 25-year periods lagged by one year, then converted to standard deviation units to highlight periods of unusually high or low variability.

CO_2 variations in past half-million years



Note consistent y-scales!
Current CO_2 concentration is highest in last 400,000+ years

a) "steady" increase since 1958, superimposed on a clear seasonal cycle

b) Holocene constancy prior to about 1750

d) ice age cycles: CO_2 highly correlated with temperature, positive CO_2 feedback

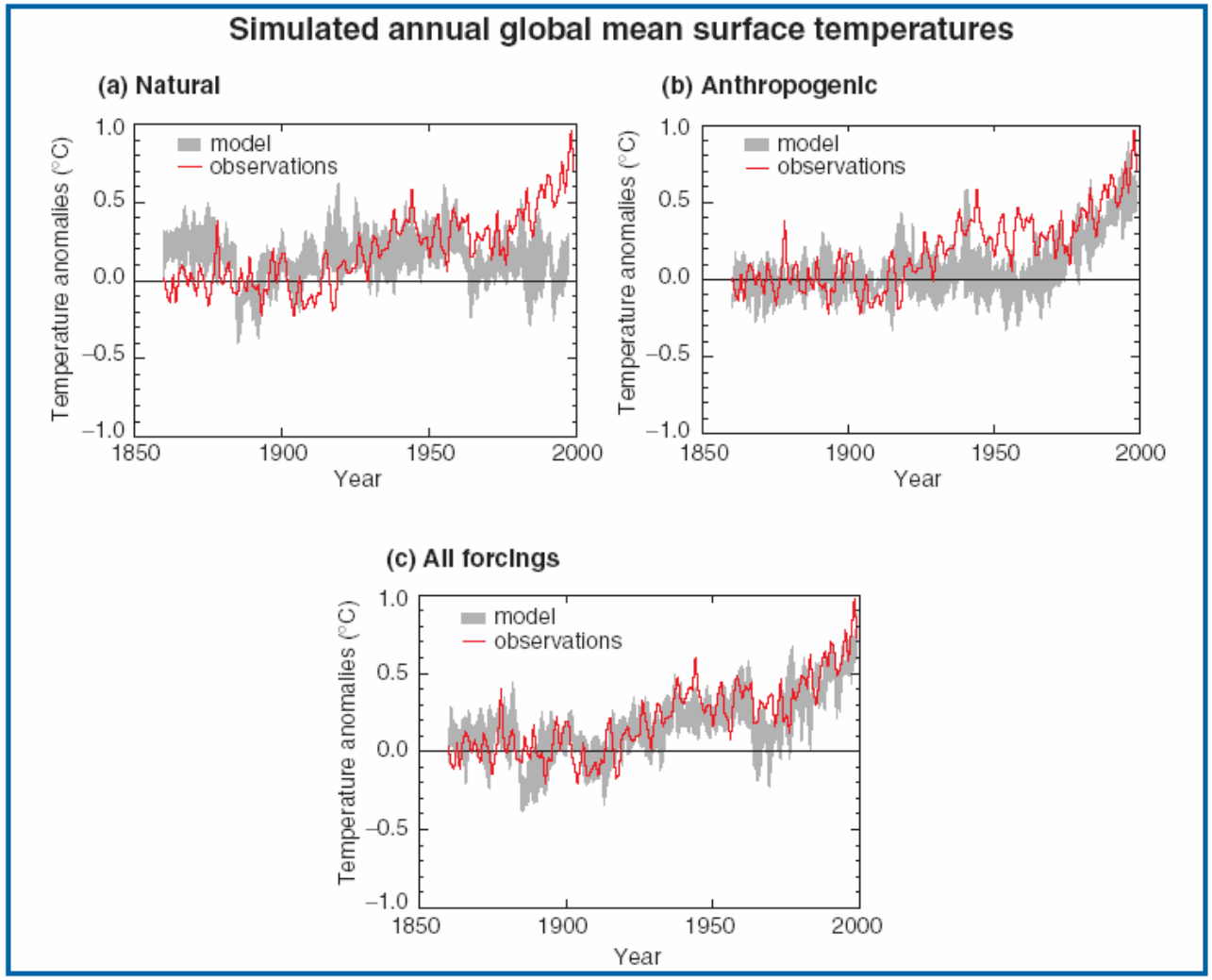
IPCC (2001)

From climate observations we <u>know</u> that:

* Atmospheric CO_2 concentration is increasing rapidly;
  the increase is definitely due to human activities
* Some other greenhouse gas concentrations (e.g. CH_4)
  have increased even more rapidly than CO_2
* Global temperatures increased in the 20th Century;
  the warming trend has accelerated in recent decades
* The greenhouse effect is well-understood:
  more CO_2, CH_4 $\Rightarrow$ increased longwave absorption
* CO_2 and temperature fluctuations are positively correlated
  in paleoclimate data

.... but making precise climate forecasts is still
extremely difficult; uncertainties are large

Simulations of 20th Century Climate Change



a) "Natural" forcing (solar brightness, volcanic activity) doesn't fit the data

b) "Anthropogenic" forcing does better

c) All forcings combined provide the best fit

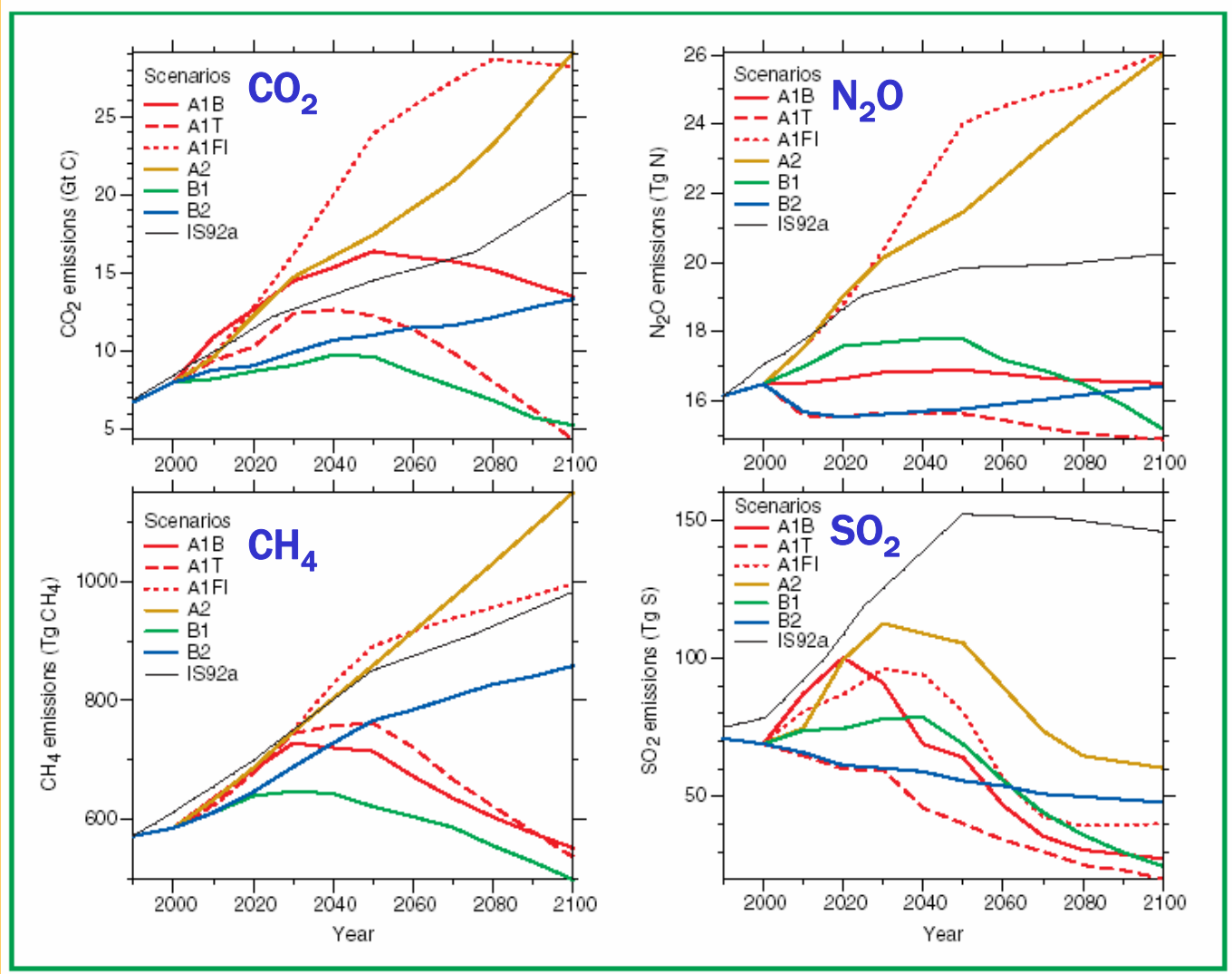
... hence a stronger case for attribution of 20th Cent change

IPCC (2001)

Emissions Scenarios

These are produced by economists and energy consultants; what choices will societies make, and how will the global economy evolve?

none of these scenarios assumes compliance with Kyoto Protocol, but some consider later emissions reductions



Scenarios cover a huge range of possibilities

IPCC (2001)

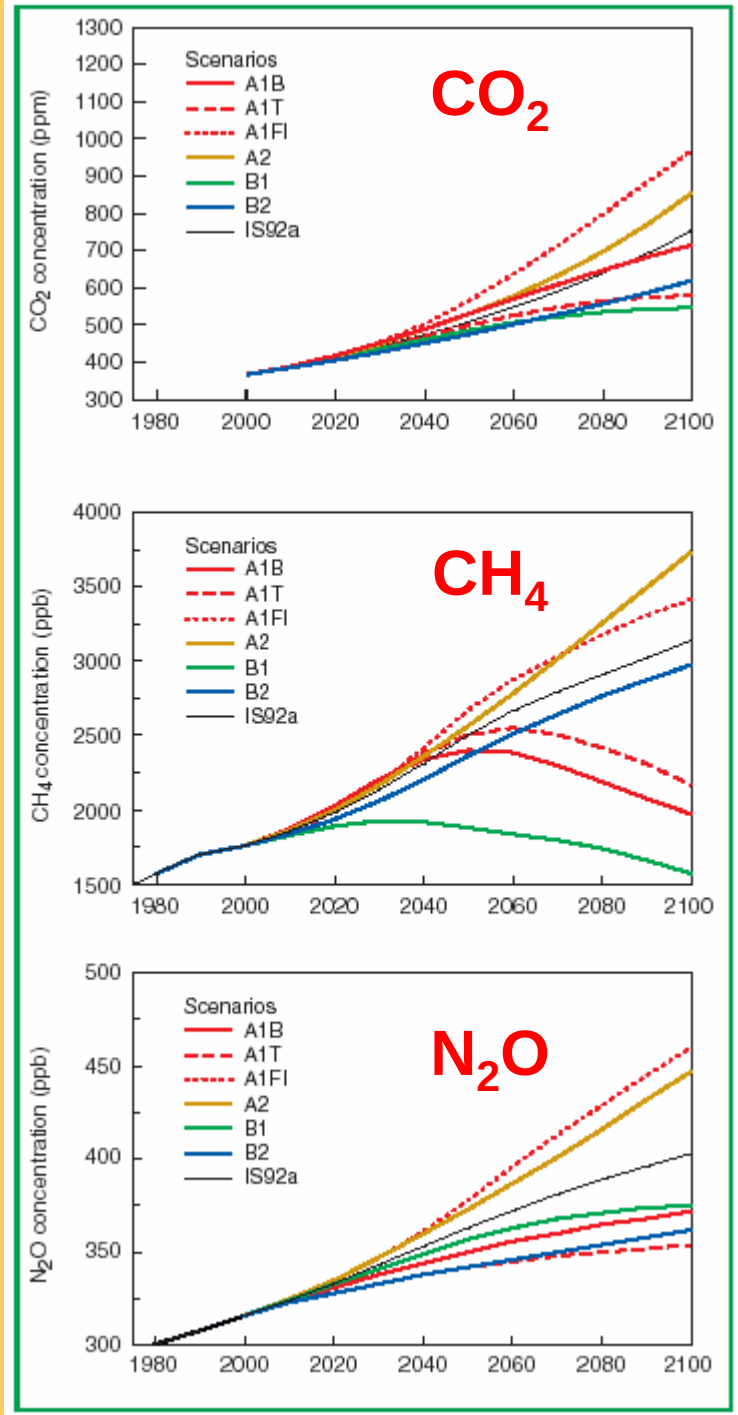
GHG Concentrations
from the 2001 Emissions Scenarios

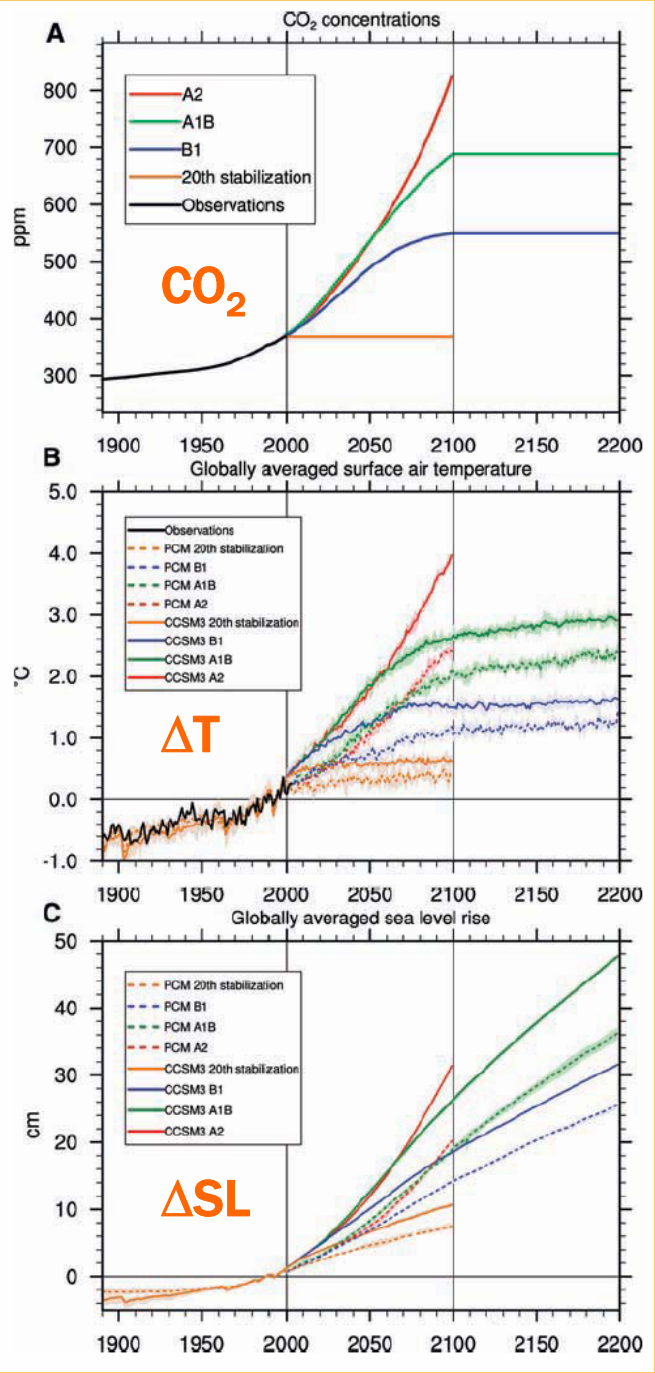
These are the output from carbon cycle models (and similar models for N_2O)

All scenarios call for significant increases in CO_2 and N_2O concentrations by 2100; CH_4 could go either way

uncertainties: terrestrial C uptake?
land use changes?
aerosol forcing?
(not shown here)

IPCC (2001)





Scenarios for 21st Century changes in global temperature and sea level

Four CO_2 concentration scenarios:

No emissions policy ("business as usual")
"Less ambitious" policy: 700 ppmv in 2100
"More ambitious" policy: 550 ppmv in 2100
"Current commitment": CO_2 remains at 2000 conc.

Some implications of the model predictions:

Big sea level rise is already committed. SL keeps rising for more than a century after stabilization!

Temp responds within decades to the ambitious emissions policy ; 1-2°C ΔT in 21st Cent. even so

Lag time for temperature response is longer for less ambitious emissions policy

Meehl et al. (2005)

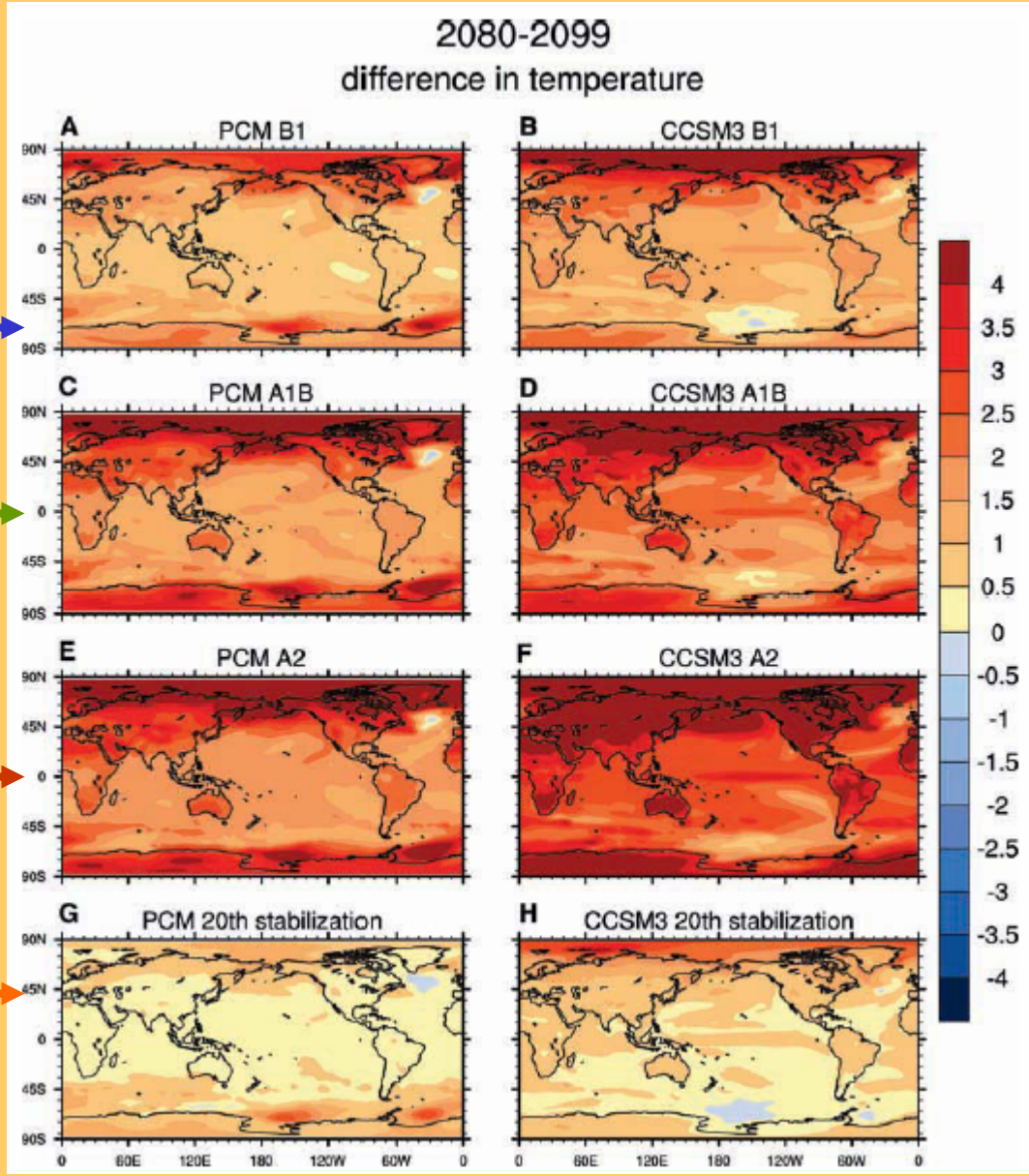
21st Century ΔT projections

B1: $2xCO_2$

A1B: 690 ppm

A2: exponential increase

"current commitment"



polar enhancement of warming in all simulations;
NM ΔT ranges from 2-6°C

Meehl et al. (2005)

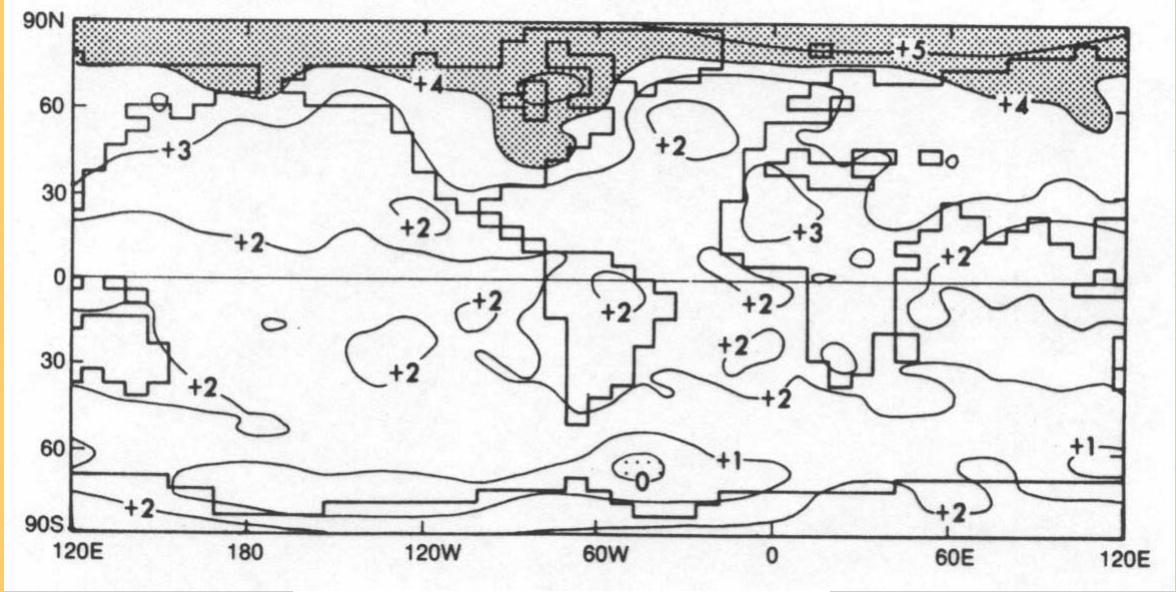
Longer-term ΔT projections

These simulations don't include aerosol forcing (would mitigate warming somewhat)

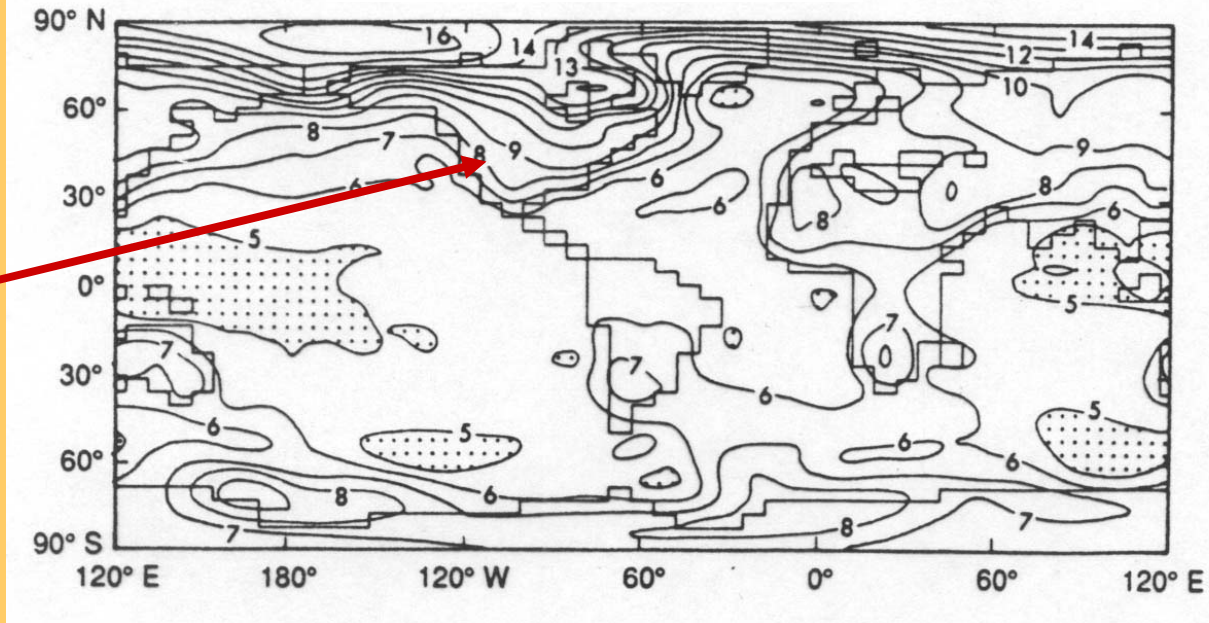
8-9°C warming in the vicinity of NM!

Manabe & Stouffer (1994)

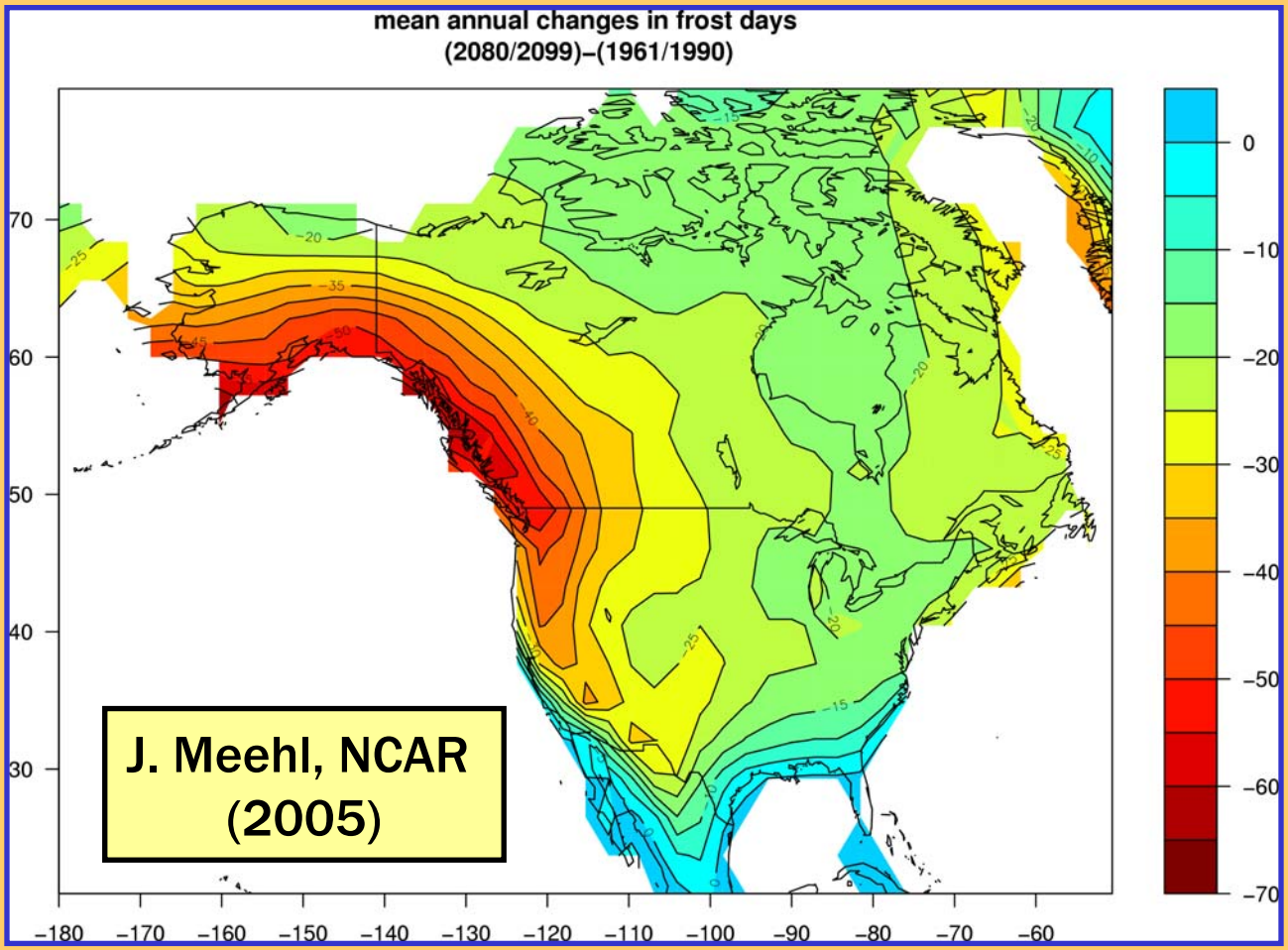
Equilibrium $2xCO_2$



Equilibrium $4xCO_2$



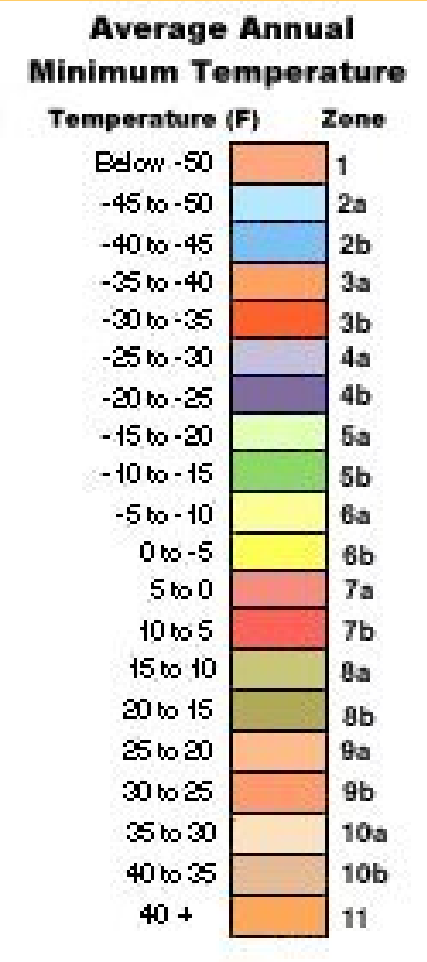
Modelled future changes in frost days
Late 21st century

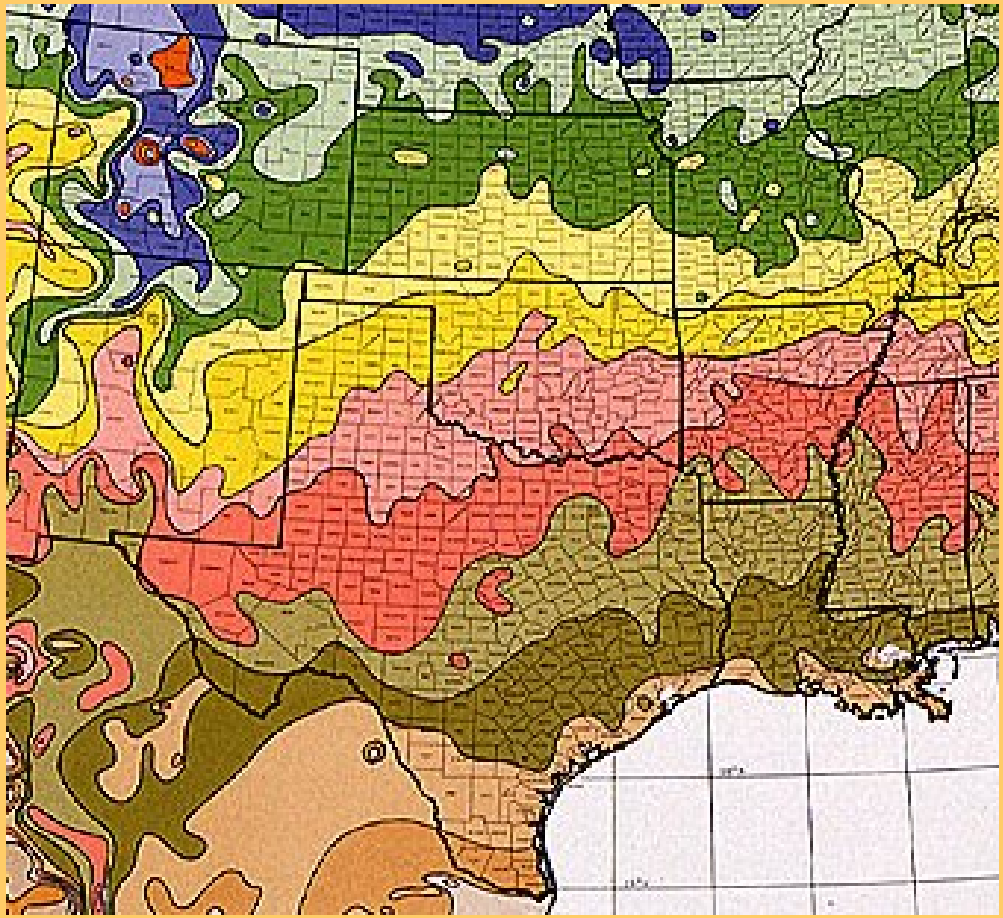


J. Meehl, NCAR (2005)

Using "less ambitious" scenario:
frost season about one month shorter in NM

USDA Plant Hardiness Zones





New Mexico features a huge range of these plant zones!

Each zone covers a range of 5°F

By mid 21st Century: change 1 zone warmer?

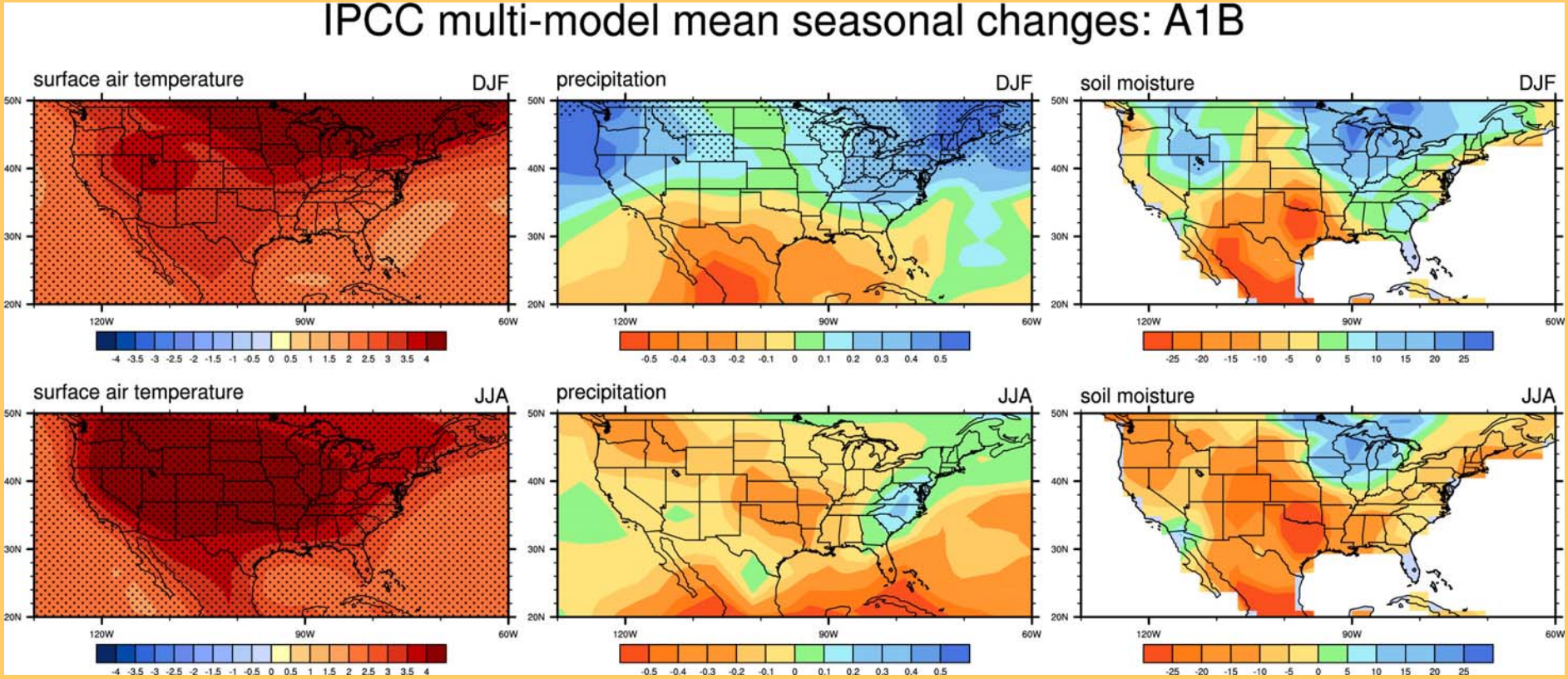
By end 21st Century: change 2 zones warmer?

US Dept Agriculture

Modelled future changes in the hydrologic cycle
Late 21st century

[J. Meehl, NCAR]

Temperature **Precipitation** **Soil moisture**



big temperature changes
uncertain precip changes

big decrease in
soil moisture

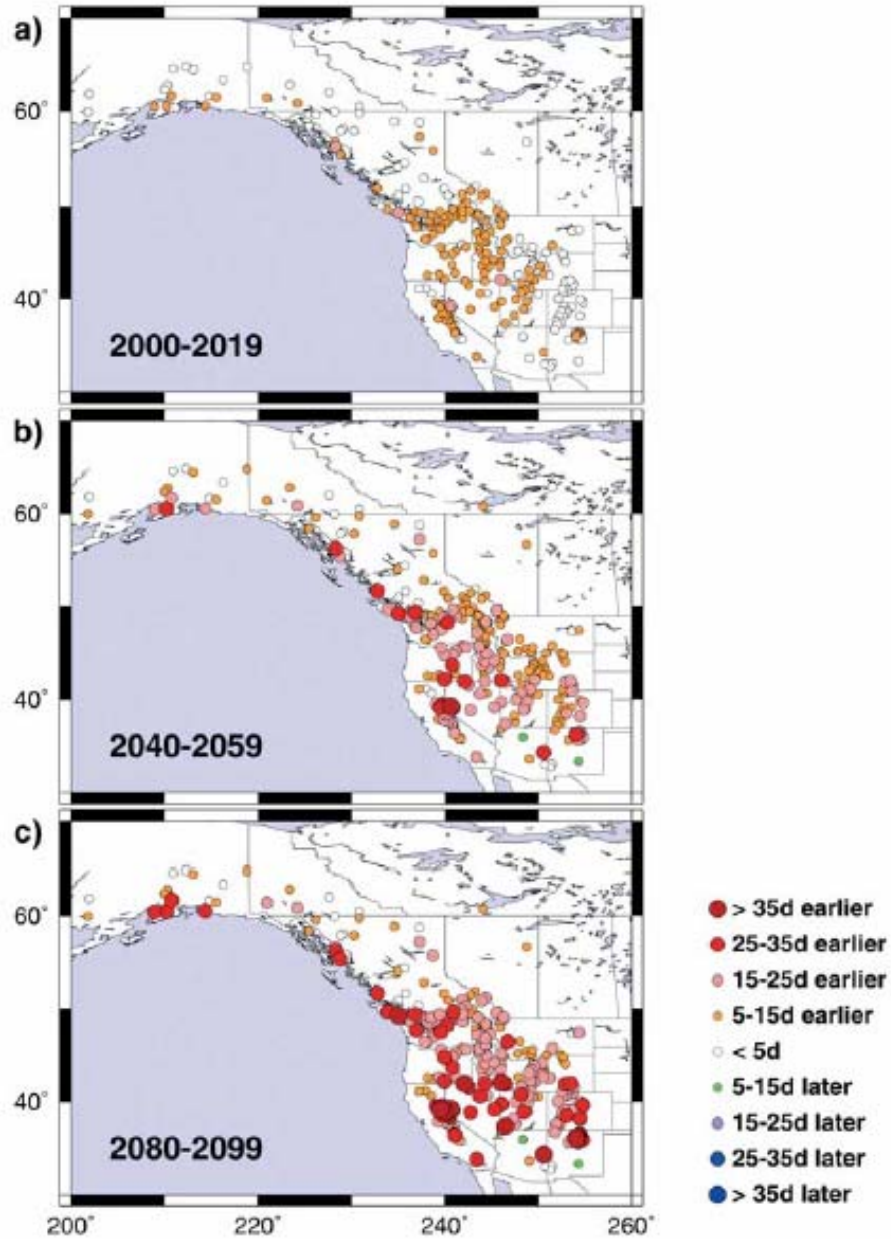
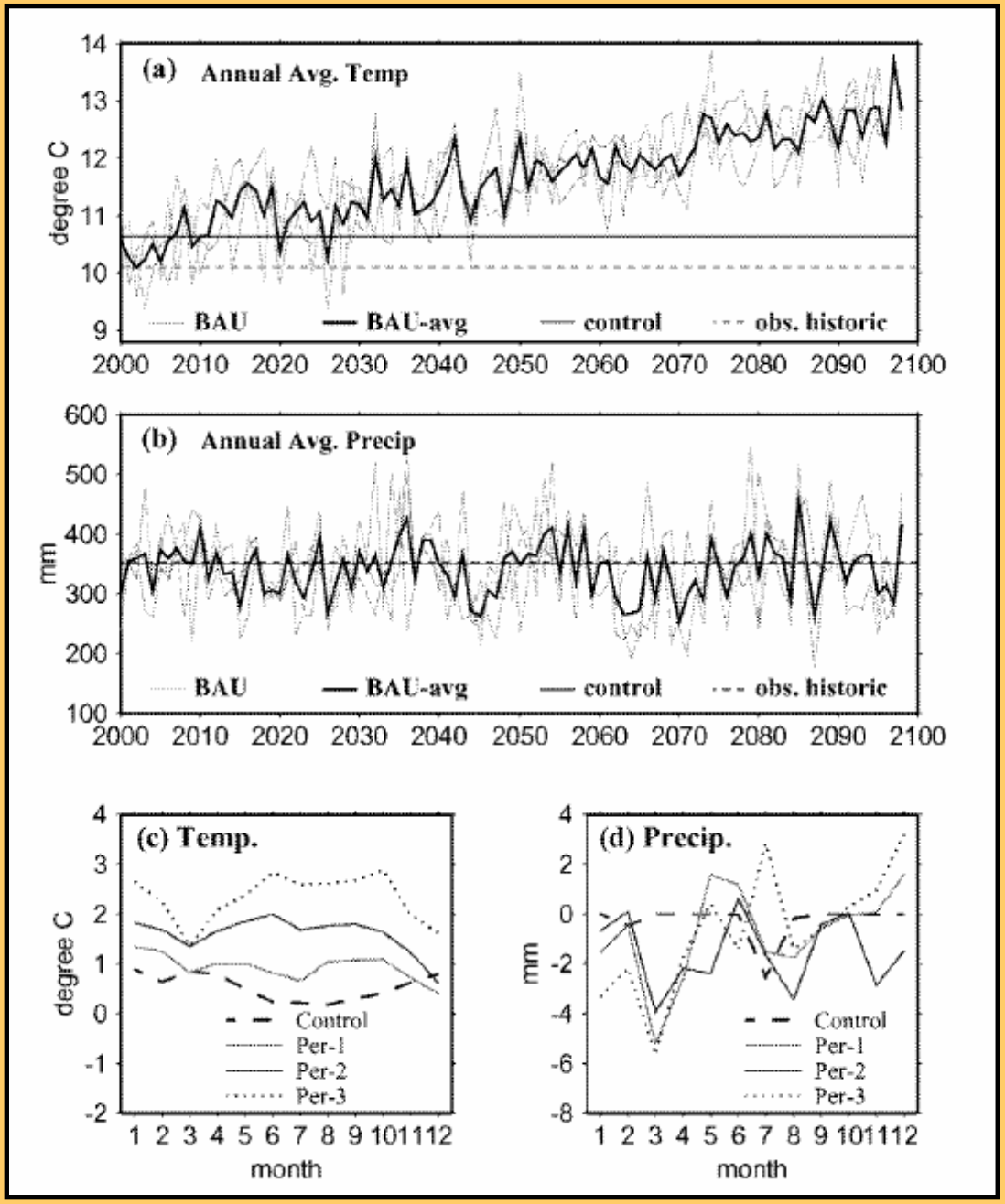


Figure 8. 20-year averages of projected changes in CT [days] as determined by regression with TI, and compared to the average CT using the 1951–1980 climatology. Projected CT is averaged over (a) 2000–2019, (b) 2040–2059, and (c) 2080–2099.

Projected change in snowmelt runoff timing

much earlier peak runoff date, driven by the warmer temps (less snow, warmer springtime temperatures)

Stewart et al. (2004)



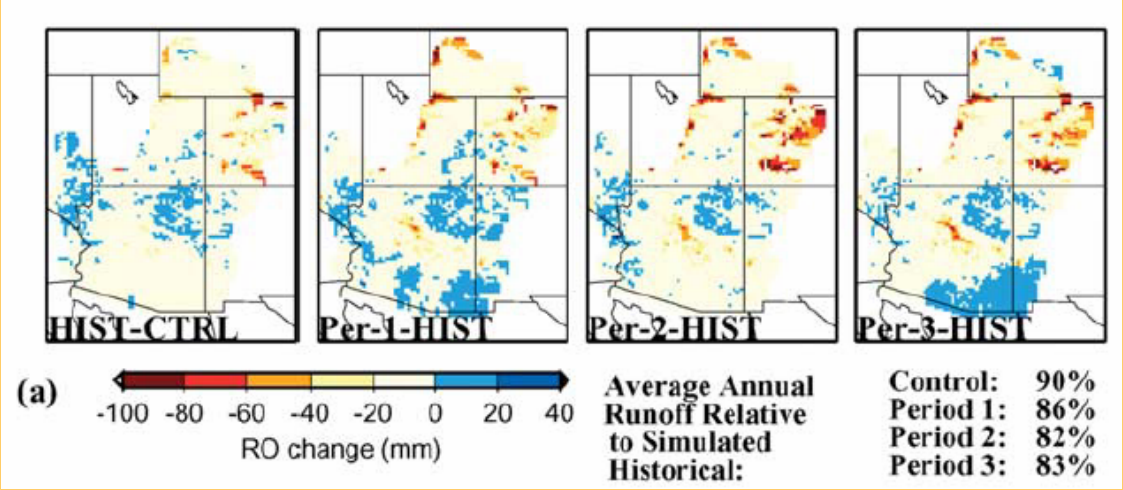
Colorado River basin temperature and precipitation change

Here again, the changes in modelled precip are modest but temperature exhibits pronounced increases

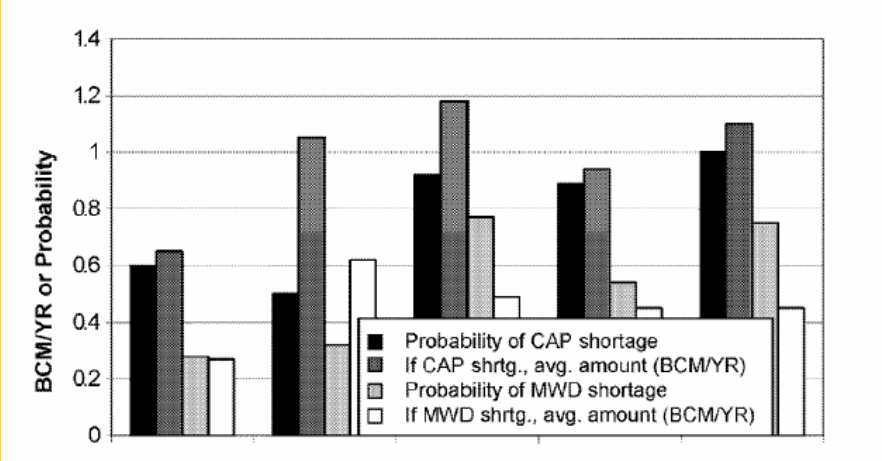
Christensen et al. (2004)

Colorado River streamflow variations

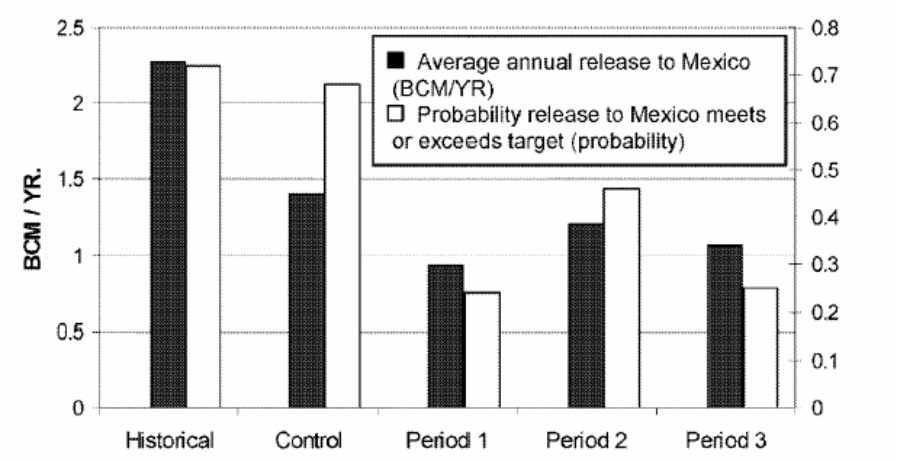
Christensen et al. (2004)



Combined effect of less snow, earlier runoff and high temperatures leads to severe water delivery shortfalls in the lower CO River basin

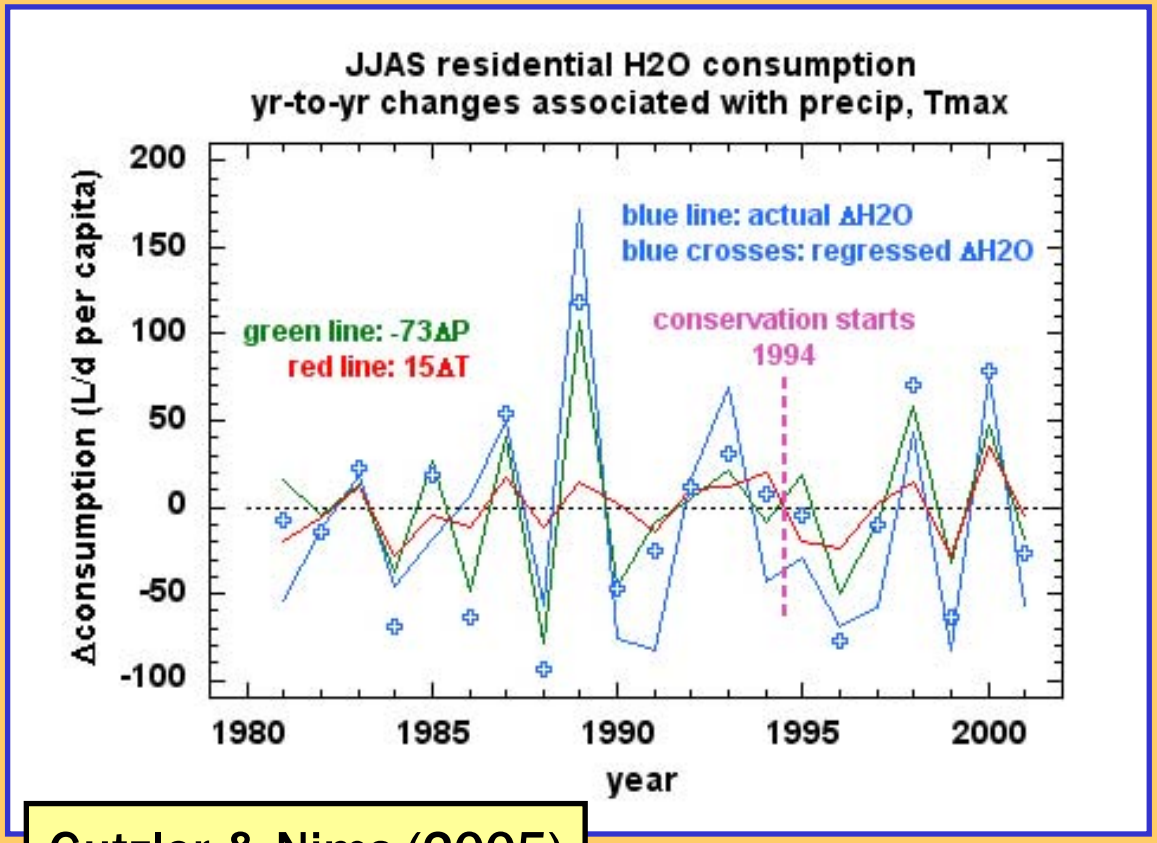


Shortages for CAP, MWD



Curtailed water deliveries to MX

Sensitivity of summer residential water demand in CABQ to precipitation and temperature fluctuations



Gutzler & Nims (2005)

Effects of CABQ conservation program

1) regression model for demand systematically overestimates post-1995 data by 21 L/d per capita

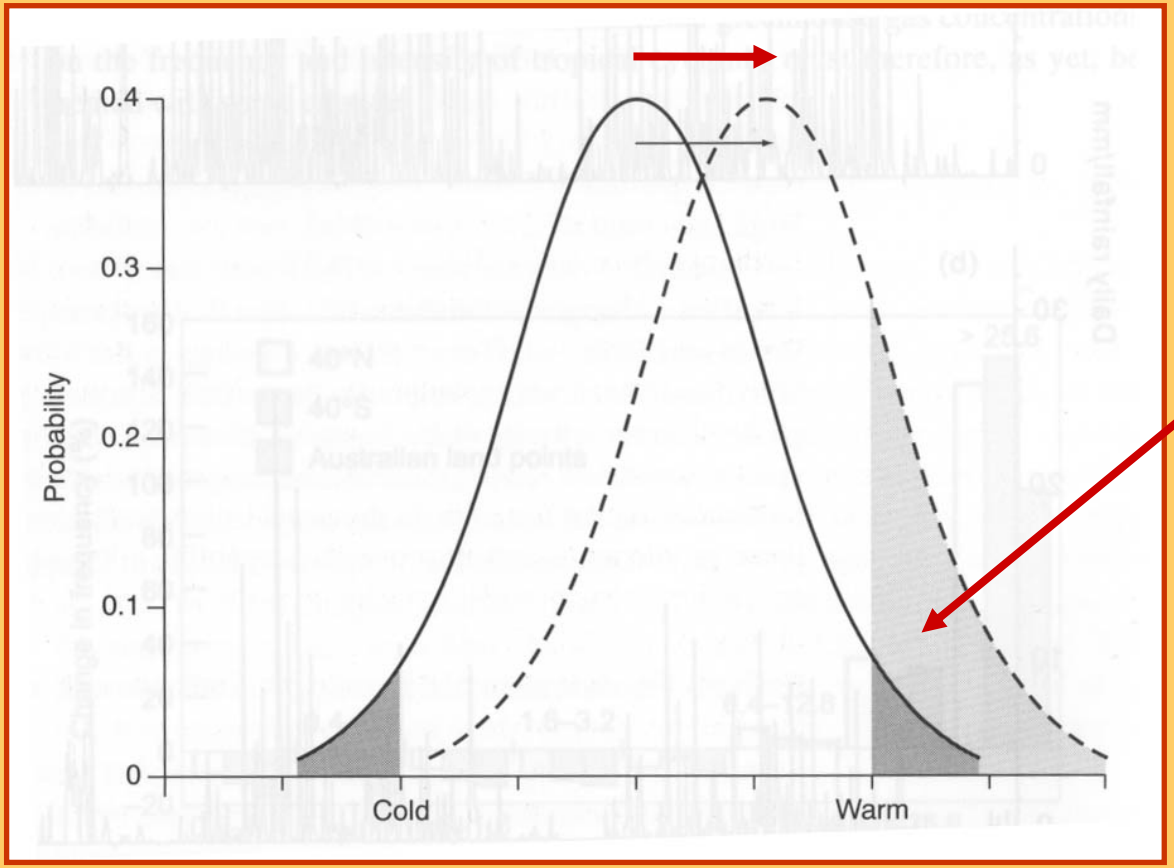
2) Improved fit to post-1995 data suggests that people may be adjusting their water use to climatic conditions more carefully

1 mm/d precip anomaly → 73 L/d consumption change

1 deg C Tmax change → 15 L/d consumption change

Modest annual average temperature changes can result in large increases in extreme temperatures

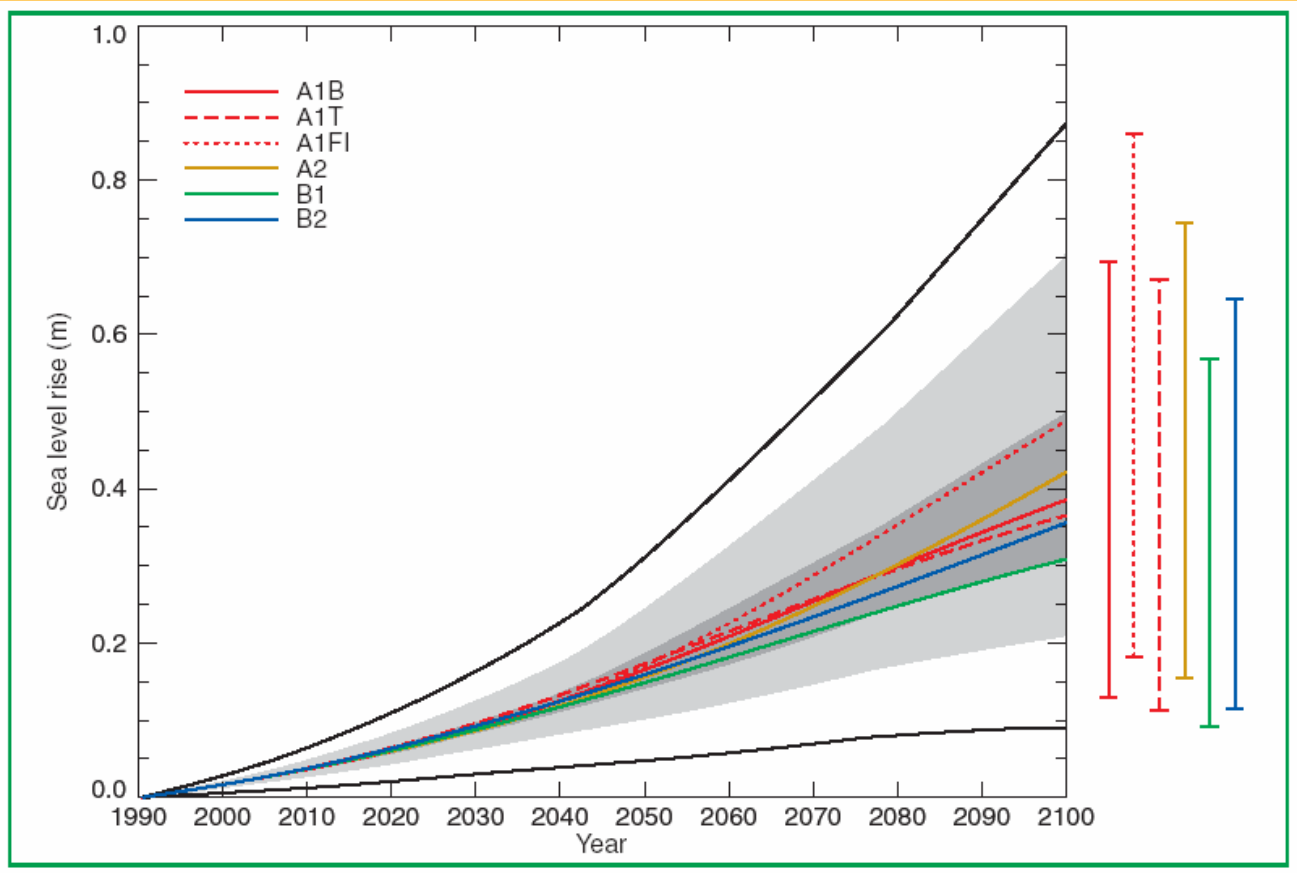
modest shift in
average temp ...



... can lead to huge change in number of extreme temp events (the hottest days at the tail of the temperature distribution)

(as seen in CDD and HDD plots for late 20th Century)

Sea level rise associated with emissions scenarios



Der Spiegel (2005)

range of projected changes produced by different models is large

very large projected increases in sea level relative to observed changes, because the ocean requires a long time for to absorb heat

... big future sea level changes are <u>already committed</u>

IPCC (2001)

What about "good news" from global warming?

The Annual Meeting of "Montanans for Global Warming"

Carbon dioxide in atmospheric concentrations is not toxic
Warmer temperatures are not, *per se,* a bad thing
Not every living creature is a loser in a warmer world

Many of our concerns pertain to loss of <u>climate stability</u>

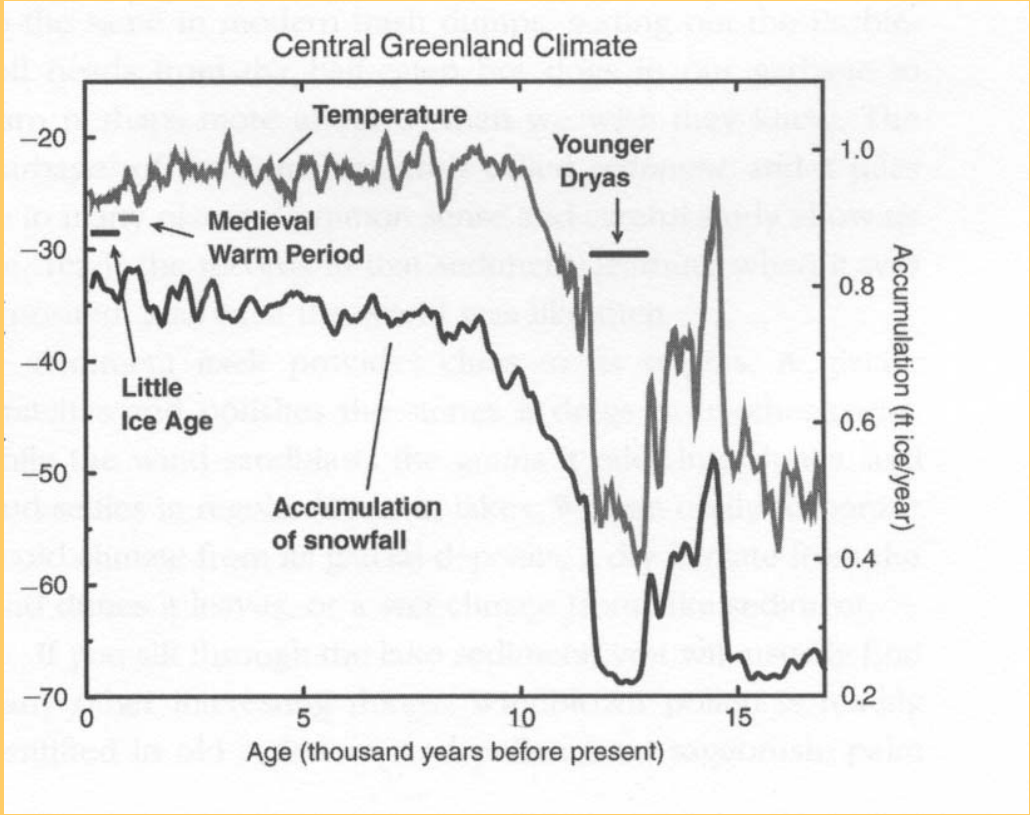
Nasty surprises?

Finally, a prediction I can deliver with confidence:

Climate change in the 21st Century will **not** be as smooth and steady as the model-generated scenarios of global warming

Here is an abrupt change that's happened at least once before ...

The hypothesized cause of this change could be triggered again by increased rainfall in the North Atlantic



Alley (2000)

How important is global warming?
Is it an urgent problem?

"I don't think that global warming is the most critical problem for the world right now. However I am concerned that we will *always* face short-term problems more immediately pressing than long-term climate change. I worry that the consequences of unabated global warming will ultimately be very grave, if not for my generation then for my children or grandchildren, who will look back in anger at us for saddling them with the consequences of our irresponsible environmental stewardship."

D. Gutzler (ABQ Tribune, 6/25/01)

"September 11 changed everything."

President G.W. Bush (and many others)

No, not everything has changed. Long term challenges don't go away simply because we choose to ignore or deny them.