"A Paleoclimatic Perspective on Abrupt Climate System Change"

Jonathan Overpeck
University of Arizona

With significant input from others, especially **Bette Otto-Bliesner** (co-lead of recent *Science* papers) and **Julie Cole** (co-author of abrupt climate change review in *Annual Review of Environment and Resources* (in press).

Overview: Quick intro/definition
Quick "cold climate" review
Warm-climate surprises?
Atlantic, sea level, drought,
US-centric due to time limits
Hypotheses in need of testing

http://www.imdb.com/title/tt0319262/

The objective of this presentation is to highlight:

That "abrupt climate change" is NOT only about *low probability, high impact events*…

… instead, it is also about:

1) the way the climate system normally works

2) large impact events that could really happen, particularly in response to anthropogenic climate forcing

3) what we don't know about climate dynamics

4) what we need to do about the issue, i.e., build a better modeling framework for abrupt climate change

But first… a definition of abrupt change…*

Abrupt change:

1) can be *forced* or *unforced*.

2) involves crossing a threshold to a new climate regime (e.g., new mean state or character of variability) , where the transition time to the new regime is short relative to duration of the regime.

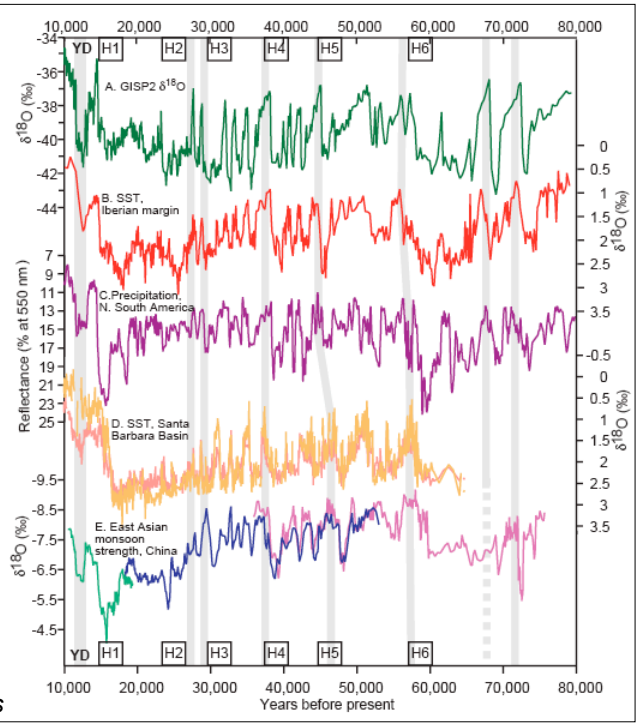
*see Overpeck and Cole for review of related definitions

Classic "cold climate" or glacial period abrupt change

Includes > 10°C warming in less than a decade

Key questions:

- *ultimate causes*
- *mechanisms behind globalization of regional change*



Overpeck and Cole, in press

Abrupt climate change of the first kind….

Shutdown (or slowdown) of the “great ocean conveyor”

Courtesy of William Curry, Woods Hole Oceanographic Institution

The 8k event: cause and consequences of a major Holocene abrupt climate change

Richard B. Alley[a,*], Anna Maria Ágústsdóttir[a,b]

In Greenland, up to 8°C cooling in less than 5 years

Quaternary Science Reviews (2005)

Other key recent "8.2 event" papers…

How widespread were climate anomalies 8200 years ago?

Carrie Morrill[1] and Robert M. Jacobsen[2]

Geophysical Research Letters, 2005

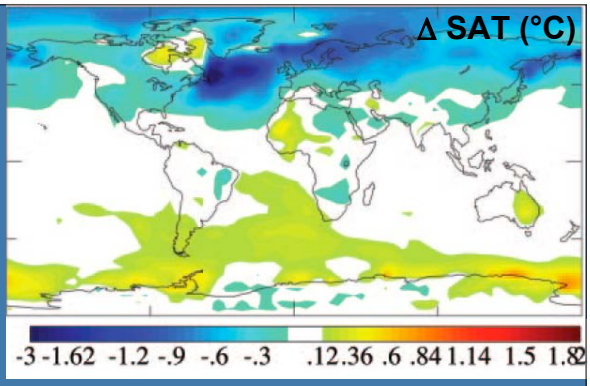
Consistent simulations of multiple proxy responses to an abrupt climate change event

A. N. LeGrande*†, G. A. Schmidt*, D. T. Shindell*, C. V. Field*, R. L. Miller*, D. M. Koch*, G. Faluvegi*, and G. Hoffmann‡

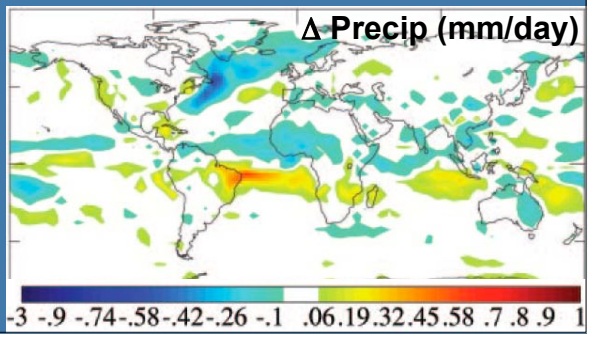
PNAS, 2006

Simulating the response of Holocene interglacial to freshwater forcing

LeGrande et al., 2006



40% reduction in Atlantic overturning circulation

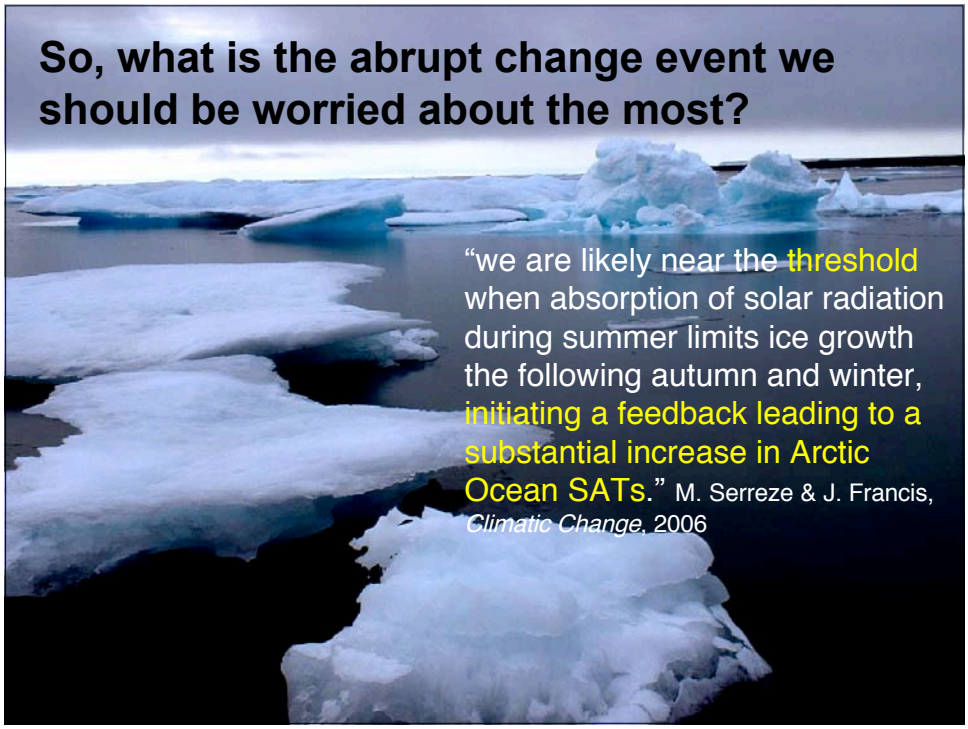


Abrupt climate change of the first kind….

Shutdown (or slowdown) of the Atlantic MOC

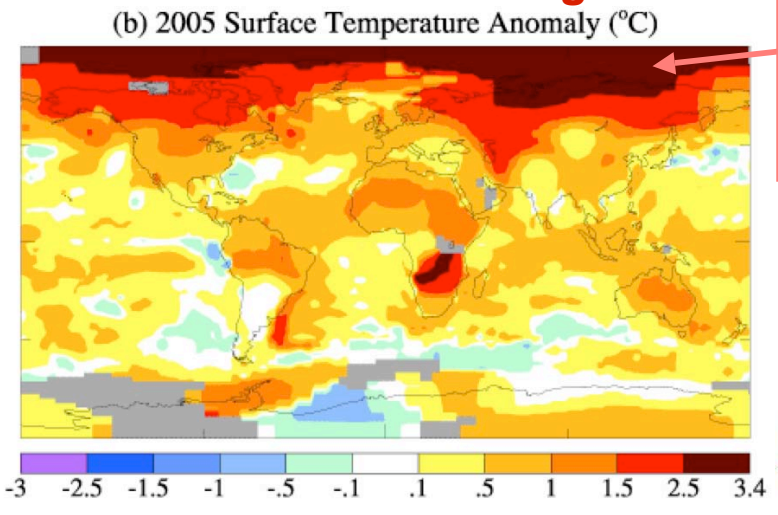
- it has happened before, and could happen again
- in the past, most likely a response to large-scale meltwater discharge
- in the future, could be driven by P-E *and* meltwater anomalies
- do we really know the sensitivity off the Atlantic MOC to freshwater forcing? Not really.
- should we be worried about recent large change in the Arctic and North Atlantic? Might be wise…

So, what is the abrupt change event we should be worried about the most?



"we are likely near the threshold when absorption of solar radiation during summer limits ice growth the following autumn and winter, initiating a feedback leading to a substantial increase in Arctic Ocean SATs." M. Serreze & J. Francis, *Climatic Change*, 2006

The NASA View: ***2005 - the warmest on record for the globe***



More than 2°C!

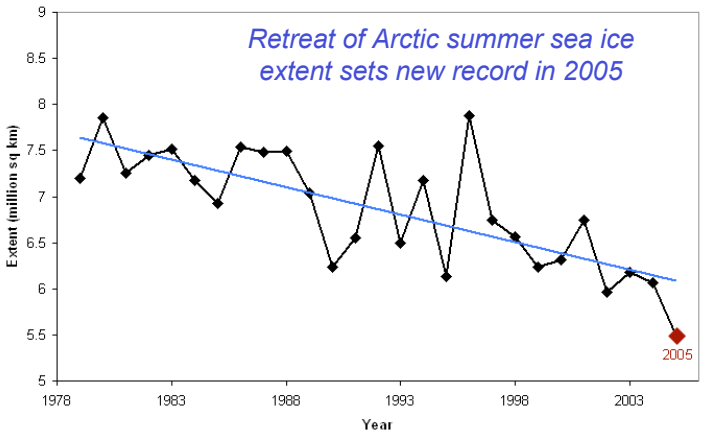
(pushing 4°F)

(Relative to 1951 to 1980 mean)

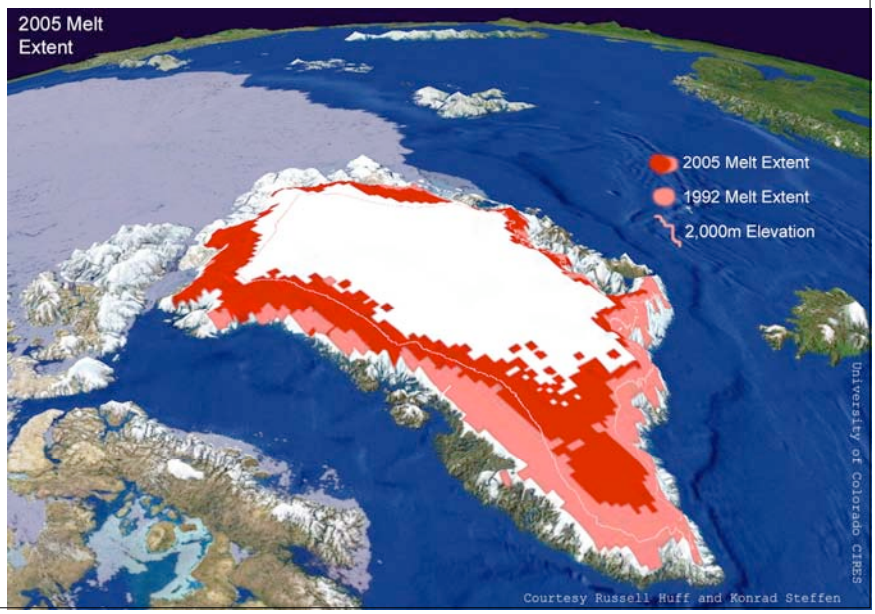
(Source: NASA GISS)

Arctic climate change significant and accelerating

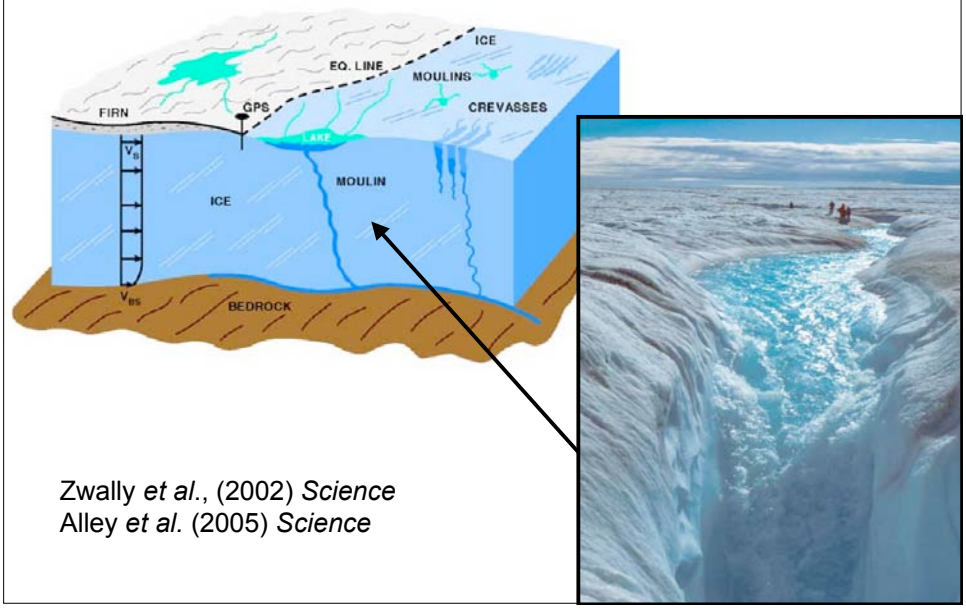
- **Warming greatest on planet**
- **Arctic Sea Ice Pack:** *thinned by 40% in last 50 years*
- **Summertime Arctic Sea Ice:** *retreat accelerating?*



- **Greenland Ice Sheet:** *16% increase in melt area between 1979 and 2002 - still increasing, with new record in 2005*

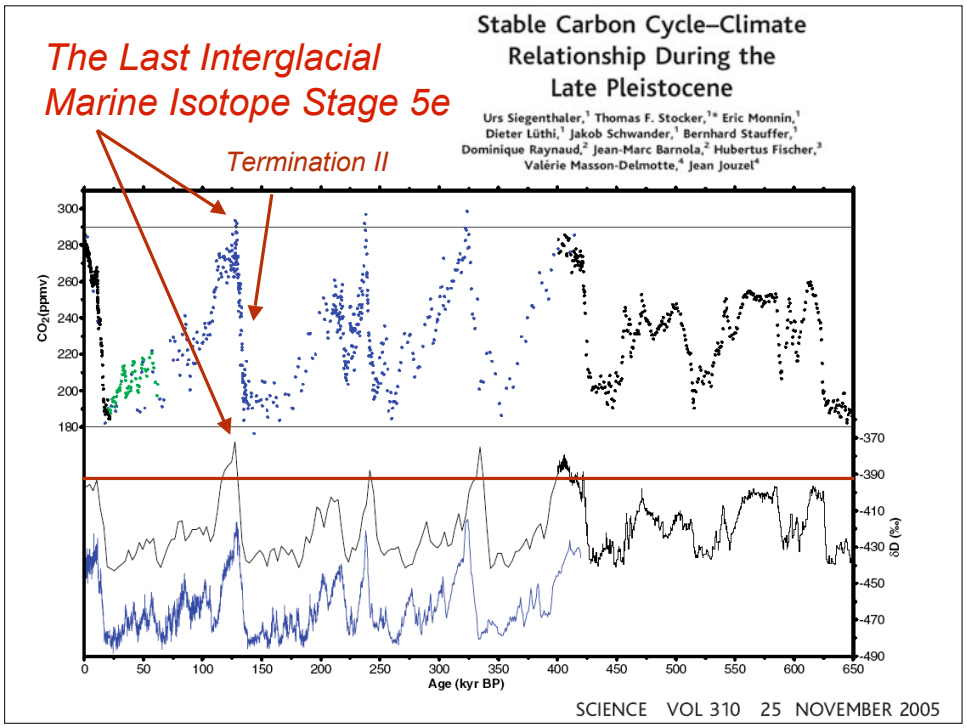


Multiple new dynamic mechanisms for increased ice sheet sensitivity to surface warming have been discovered



Zwally *et al*., (2002) *Science*
Alley *et al.* (2005) *Science*

What about the last time the Arctic was warmer than present?



*Investigation of **climate**, **ice sheet**, and **sea level change** of the Last Interglacial Period, and implications for the future*

Jonathan T. Overpeck
Bette L. Otto-Bliesner
Gifford H. Miller
Daniel R. Muhs
Richard Alley
Jeffrey T. Kiehl

B. L. Otto-Bliesner
S. J. Marshall
J. T. Overpeck
G. H. Miller
A. Hu
and
CAPE Last Interglacial Project Members

Two teams, two papers

Key Largo, Florida

129ka, sea level > 4-6 m above present

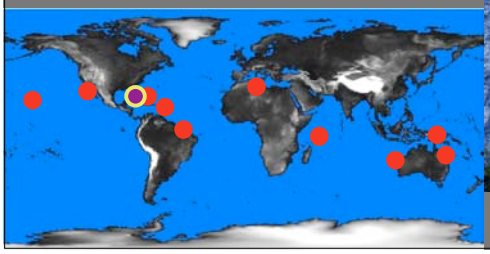
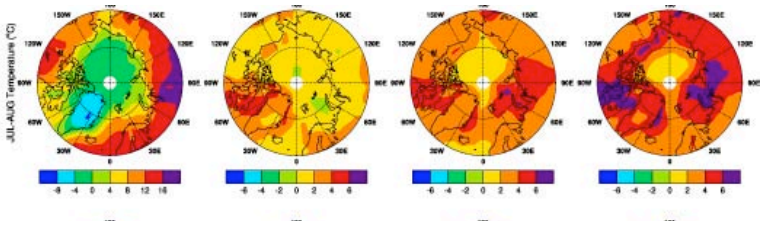


Photo: Dan Muhs

Simulated summer temperature (modern) and temperature anomalies (paleo & future)

Using the NCAR CCSM2 Coupled Ocean-atmosphere general circulation model

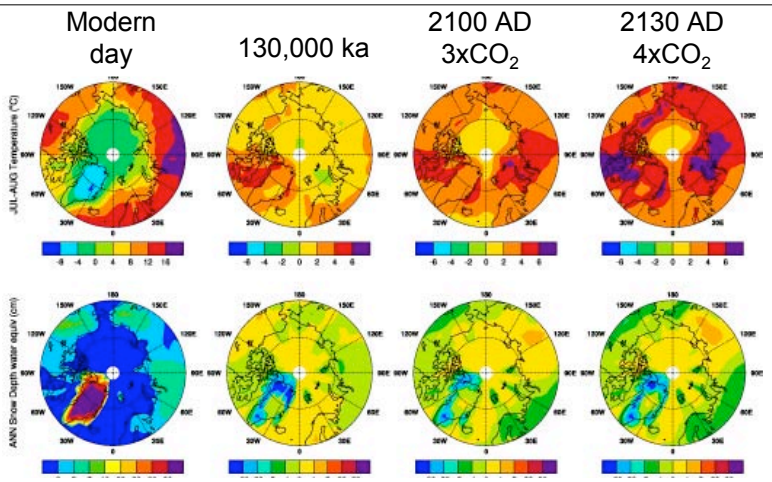
Modern day | 130,000 ka | 2100 AD $3xCO_2$ | 2130 AD $4xCO_2$



Note: results (not shown) also confirm that simulated 130 ka Arctic warming matches observed warming - driven by changes in the Earth's orbit

Simulated summer temperature (modern) and temperature anomalies (paleo & future)

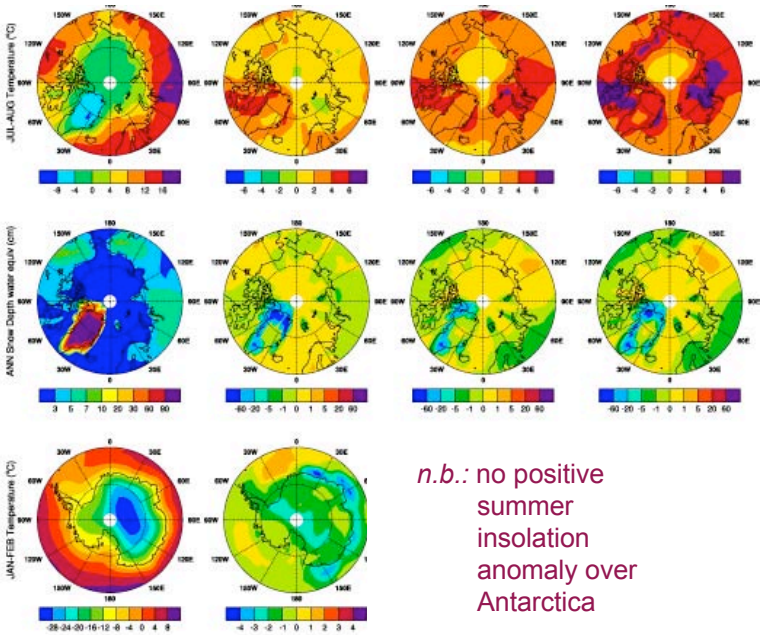
Using the NCAR CCSM2 Coupled Ocean-atmosphere general circulation model



Simulated annual snow and snow anomalies

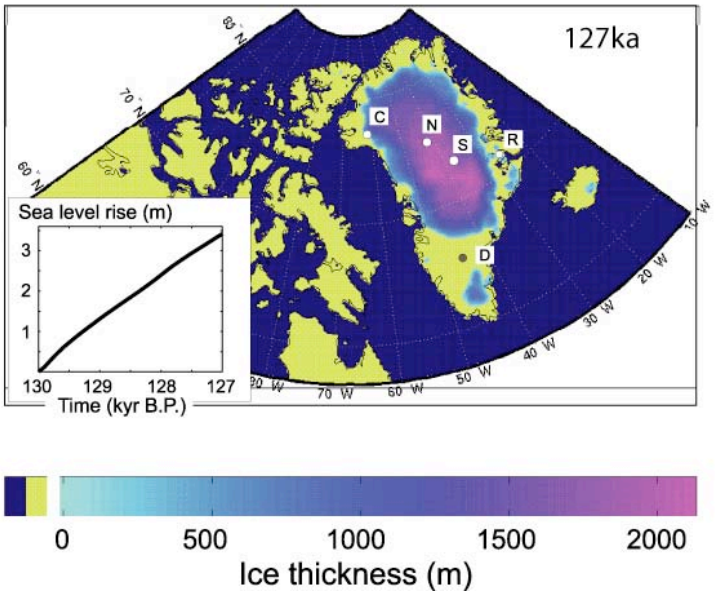
Simulated summer temperature (modern) and temperature anomalies (paleo & future)

Using the NCAR CCSM Coupled Ocean-atmosphere general circulation model



n.b.: no positive summer insolation anomaly over Antarctica

Arctic ice sheets and caps were good for between 2.2 and 3.5 m of sea level rise



Otto-Bliesner, Marshall, et al., 2006

So, where did the other 2-3m+ of sea level come from?

West Antarctic Ice Sheet (WAIS)

Grounded below sea level and buttressed by ice shelves

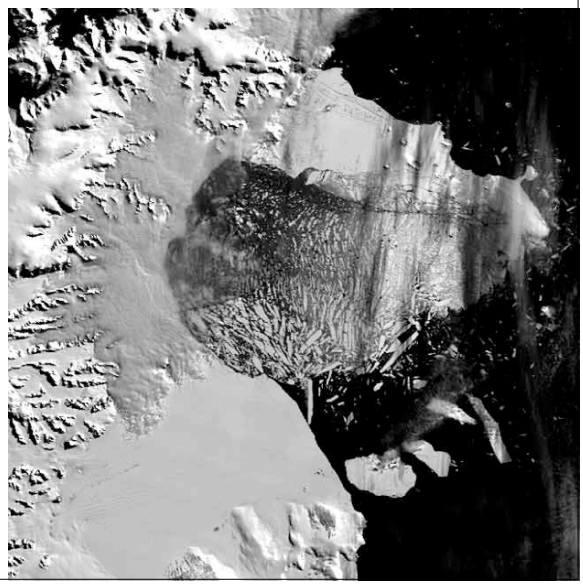
In 2002, the Larsen B Ice Shelf collapsed…

3250 km² ice shelf*, 200m thick…

"500 billion tonnes of ice sheet has disintegrated in less than a month" *(David Vaughan, British Antarctic Survey)*

Image from NSIDC

** 1.2X Rhode Island*

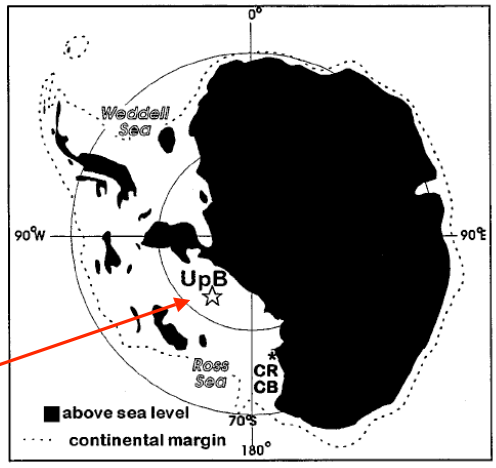


A "controversial" paper?

Pleistocene Collapse of the West Antarctic Ice Sheet

Reed P. Scherer,* Ala Aldahan, Slawek Tulaczyk, Göran Possnert, Hermann Engelhardt, Barclay Kamb

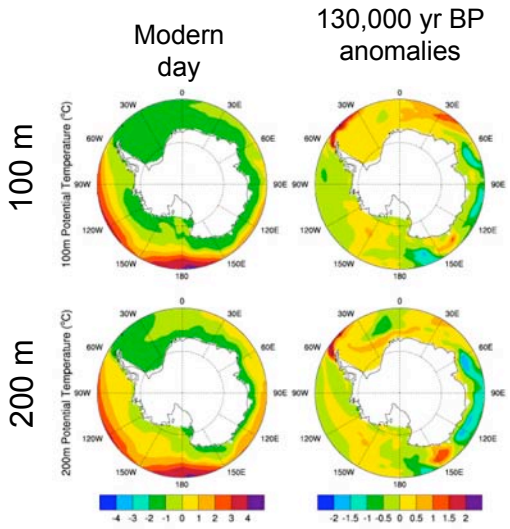
Fig. 1. Approximate configuration of West Antarctic seaways after the complete collapse of the WAIS. The setting would include some combination of open water, sea ice, fringing ice shelves, coastal tidewater glaciation, and ice tongues. Transantarctic surface water circulation would be limited by crustal geometry and ice distribution. The locations of UpB, Cape Roberts (CR), and Cape Barne (CB) are indicated.



Star marks to spot where late Quaternary diatoms and anomalously high ^{10}Be were found in sediments under the WAIS

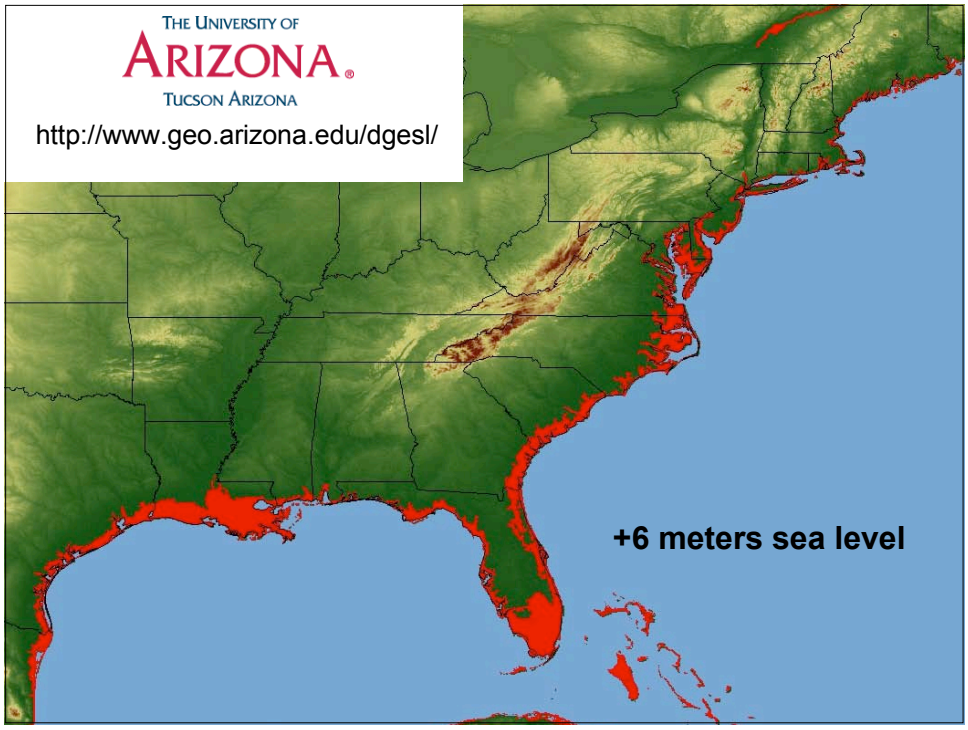
3 JULY 1998 VOL 281 SCIENCE

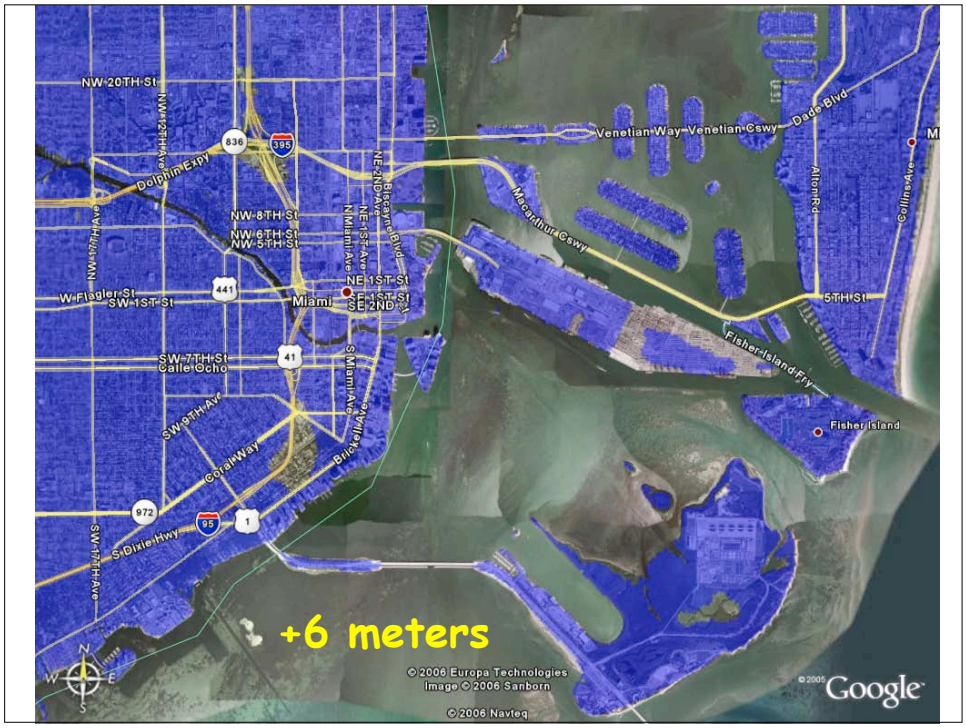
Simulated ocean temperatures at depths intersecting ice shelves



Climate model results also suggest that *climate change may have warmed ice shelves from below* at same time they were being floated by Greenland-driven sea level rise

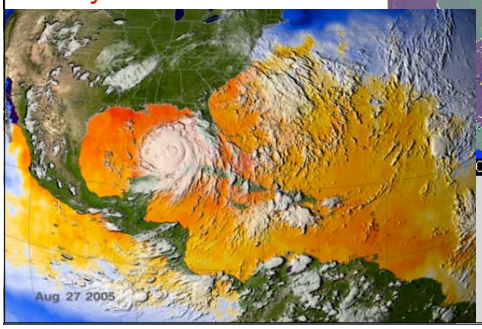
Note positive CO_2 and sea level feedbacks

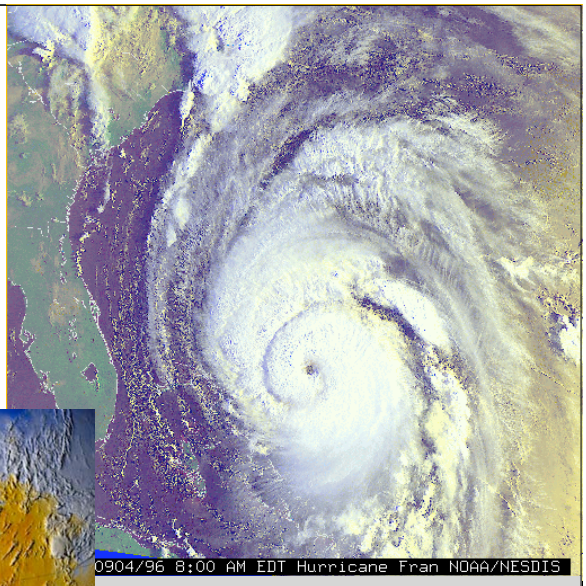




IPCC, 2001:
"Increase in tropical cyclone peak **wind intensities** likely"

New - increased **rainfall intensity** likely also





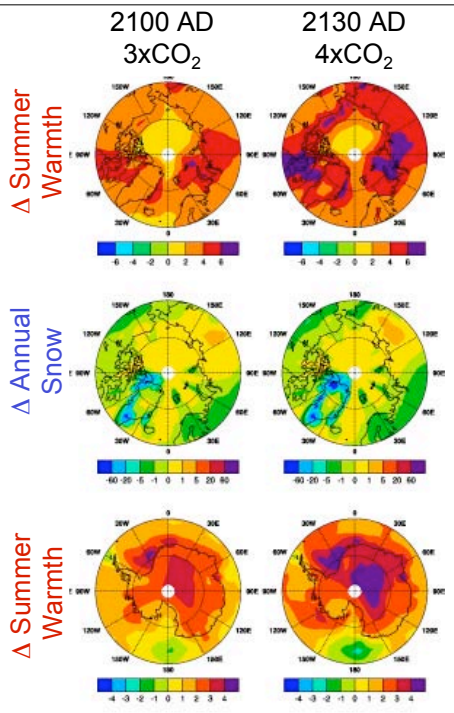
"July 2005 was a record-setting month in the world of Atlantic Ocean hurricanes."
(Five named storms)

Abrupt Sea Level Conclusions

- ***global warmth in this this century could exceed that of 130 ka***
- ***in the Northern Hemisphere, this will be at least enough to initiate 4-6+m of sea level rise***
- ***Greenland melting could trigger collapse of the West Antarctic Ice Sheet***
- ***unlike 130ka, future sea level will also respond to:***

  - large-scale Antarctic warming
  - polluted ice sheets = darker and easier to melt
  - significant thermal expansion of ocean (ca. 0.5m sea level rise)

- ***Mercer may have had it right - WAIS collapse could mean >>1m/100 year sea level rise***

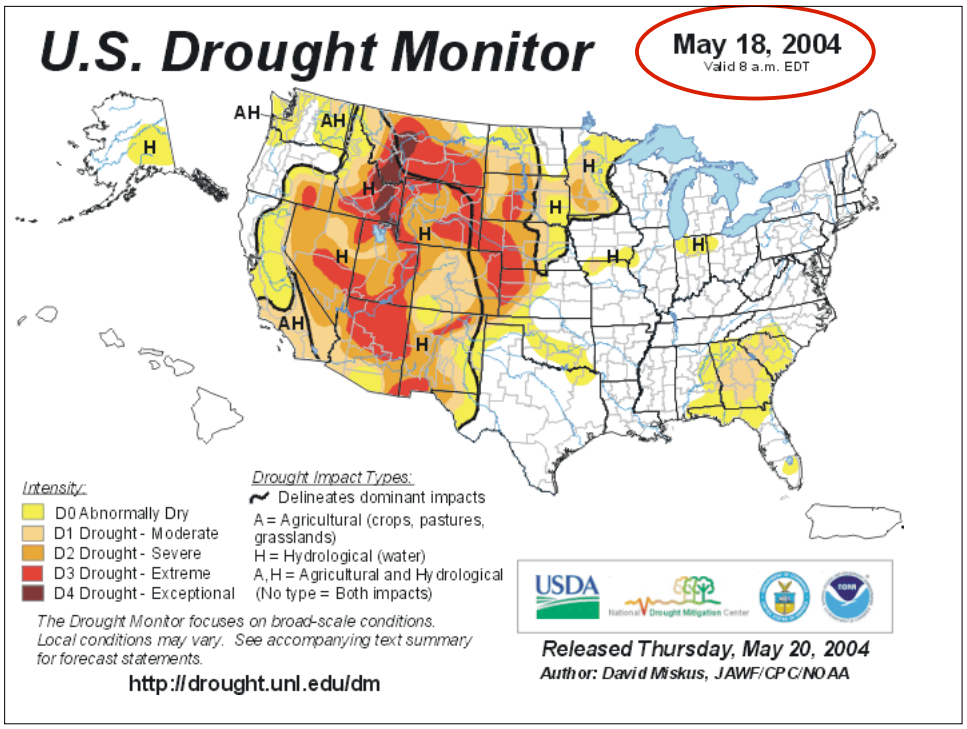


So, who's likely to feel BIG global warming impacts first?

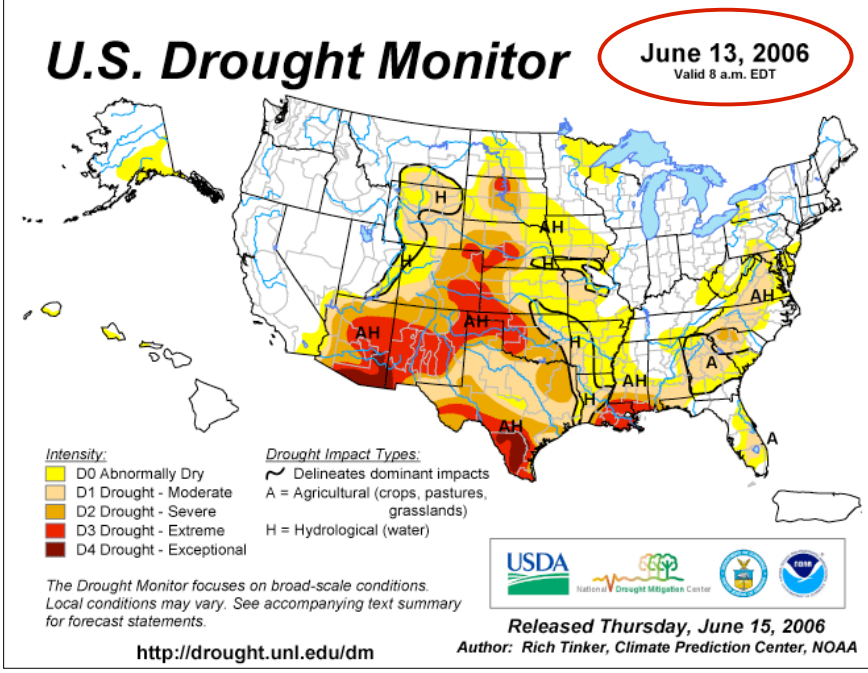
East and Gulf Coasts, and especially New Orleans and Florida?

http://www.geo.arizona.edu/dgesl/

Drought… the real wildcard



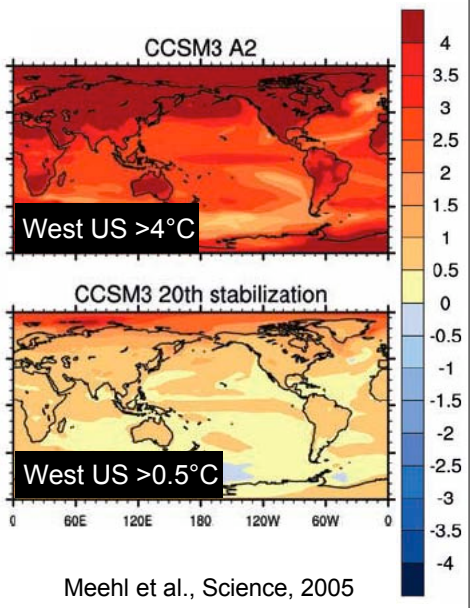
As we enter the summer of 2006, the drought still persists…



*For **the West**? Best bet is that we'll see the following by the late 21st century:*

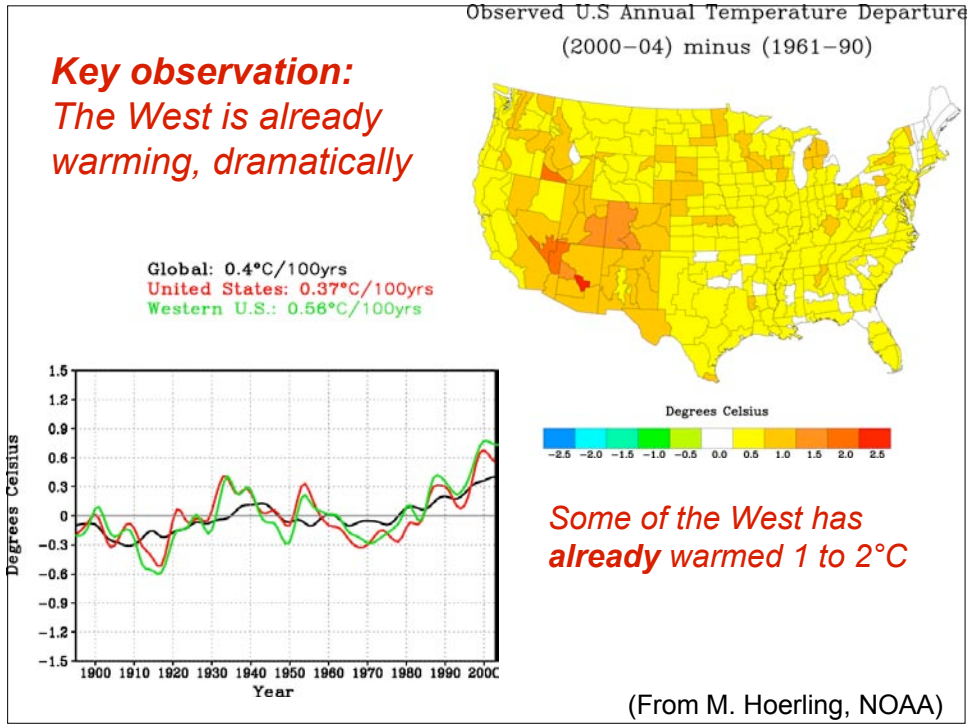
temperature: it's gunna get hot, folks…

…least 4°C likely, more in winter than in summer



Meehl et al., Science, 2005

Key observation:
The West is already warming, dramatically



*Some of the West has **already** warmed 1 to 2°C*

(From M. Hoerling, NOAA)

*For **the West**? Best bet is that we'll see the following by the late 21st century:*

Precipitation: most recent ***modeling suggests mean decrease south, and increase north*** **plus**:

- ***snow runoff*** season will be significantly shorter*
- ***evaporation and evapotranspiration*** will be likely significantly higher in all seasons*
- ***streamflow*** will be significantly lower, especially in late spring and summer*

* denotes change already seems to be happening

*For **the West**? Best bet is that we'll see the following by the late 21st century:*

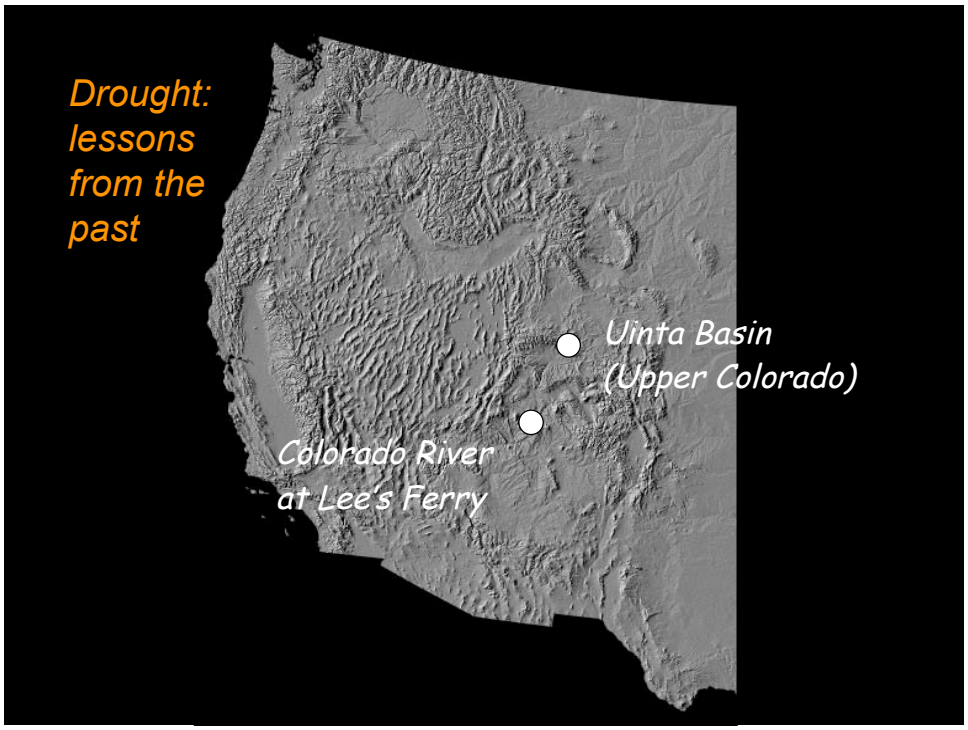
Precipitation: flip a coin for changes in the mean, *(**many models show decrease south, and increase north**)* **plus**:

- ***snow runoff*** season will be significantly shorter
- ***evaporation*** will be significantly higher in all seasons
- ***streamflow*** will be significantly lower, especially in late spring and summer

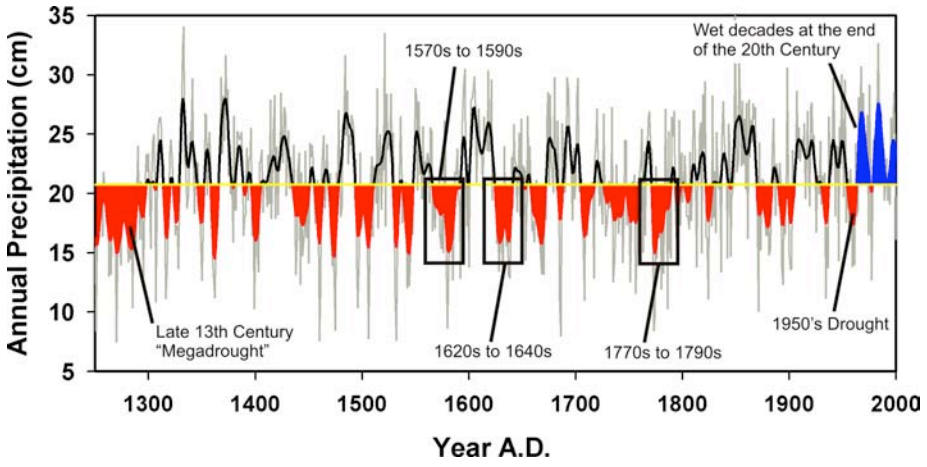
Accelerated hydrologic cycle {

- ***droughts*** will be more likely
- ***floods*** will be more likely

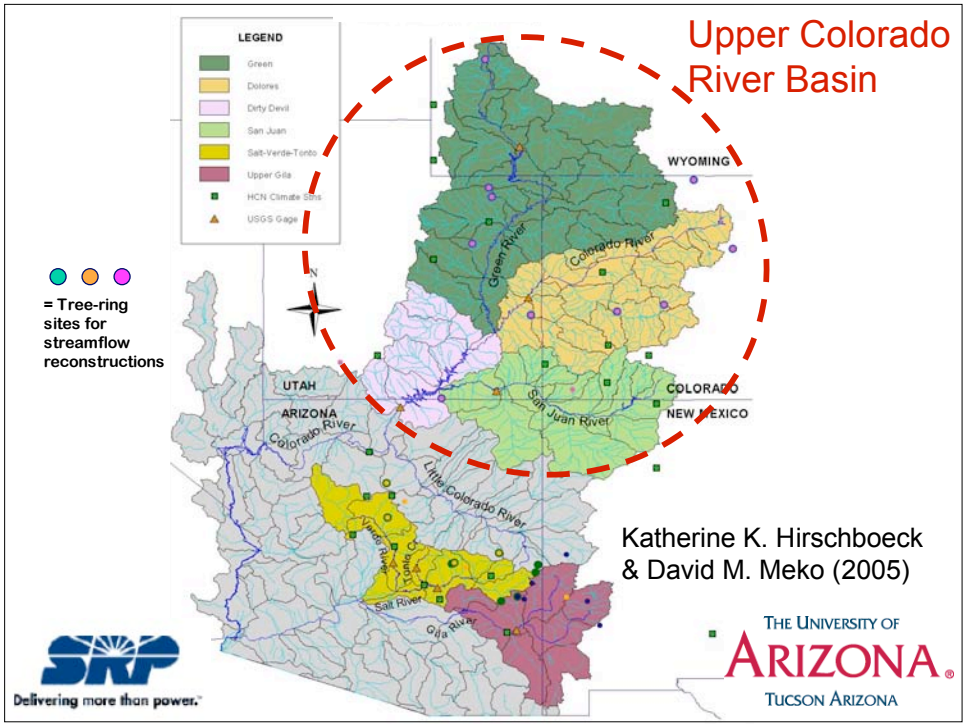
Note!



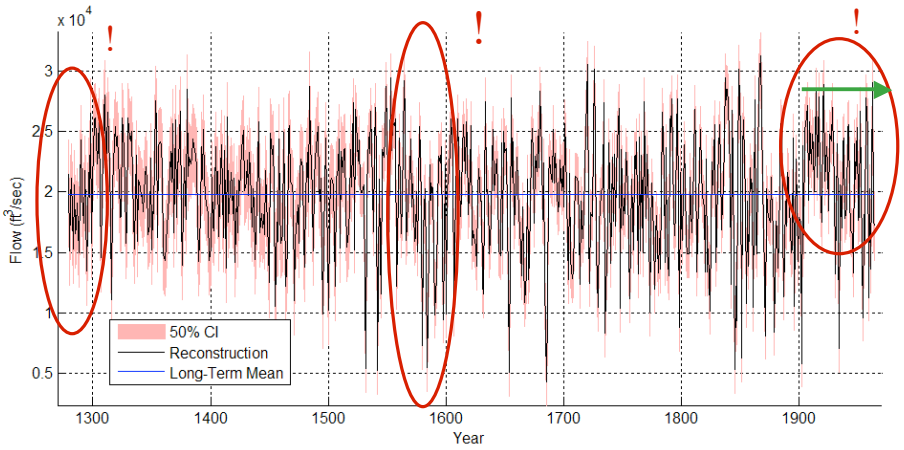
Precipitation reconstruction for the Uinta Basin, NE Utah
(Upper Colorado River)



Gray, Jackson & Betancourt 2004. *J. Am. Water Resources Assoc.*



Tree-ring reconstructed annual flows, Colorado River at Lees Ferry
Katherine K. Hirschboeck & David M. Meko, 2005



CI = Confidence interval measured by root-mean-square error of cross-validation.

THE UNIVERSITY OF ARIZONA
TUCSON ARIZONA

*What happens when you **couple chronic warming with drought**? (an eye-opener for the future)*

Regional vegetation die-off in response to global-change-type drought

David D. Breshears[a,b], Neil S. Cobb[c], Paul M. Rich[d], Kevin P. Price[e,f], Craig D. Allen[g], Randy G. Balice[h], William H. Romme[i], Jude H. Kastens[f,j], M. Lisa Floyd[k], Jayne Belnap[l,m], Jesse J. Anderson[c], Orrin B. Myers[n], and Clifton W. Meyer[d]

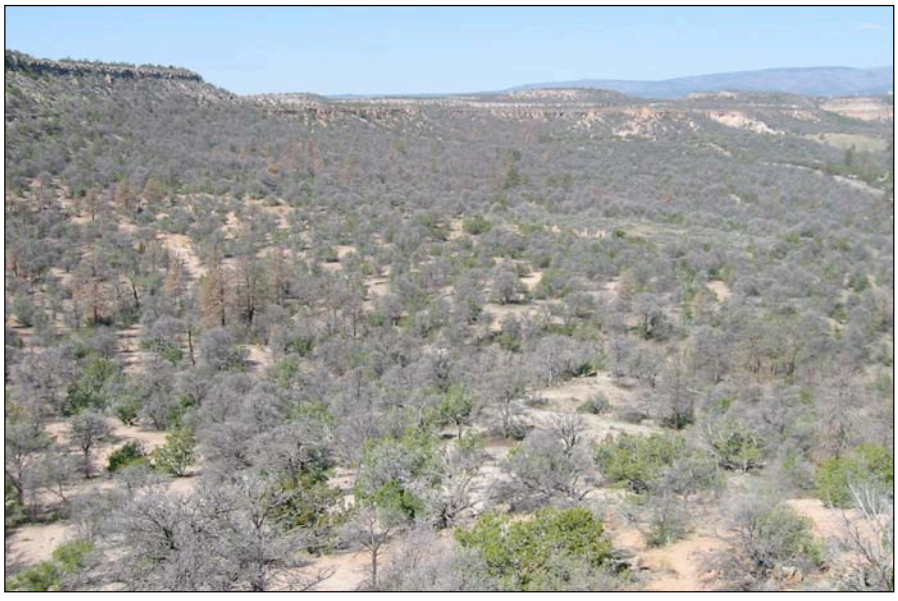
[a]School of Natural Resources, Institute for the Study of Planet Earth, and Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, AZ 85721-0043; [c]Merriam Powell Center for Environmental Research and Department of Biological Sciences, Northern Arizona University, Flagstaff, AZ 86011; [g]Earth and Environmental Sciences Division, and [h]Environmental Stewardship Division, University of California–Los Alamos National Laboratory, Los Alamos, NM 87545; Departments of [e]Geography and [f]Mathematics, University of Kansas, Lawrence, KS 66045; [f]Kansas Applied Remote Sensing Program, 2101 Constant Avenue, Lawrence, KS 66047-3759; [g]Fort Collins Science Center, U.S. Geological Survey, Jemez Mountains Field Station, Los Alamos, NM 87544; [i]Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO 80523; [k]Environmental Studies Program,Prescott College, 220 Grove Avenue, Prescott, AZ 86301; [l]Southwest Biological Science Center, U.S. Geological Survey, Moab, UT 84532; [m]Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523-1499; and [n]Division of Epidemiology and Biostatistics, University of New Mexico, Albuquerque, NM 87131

Edited by Harold A. Mooney, Stanford University, Stanford, CA, and approved September 7, 2005 (received for review July 8, 2005)

Proceedings of the National Academy of Sciences (PNAS), October, 2005…

October 2002

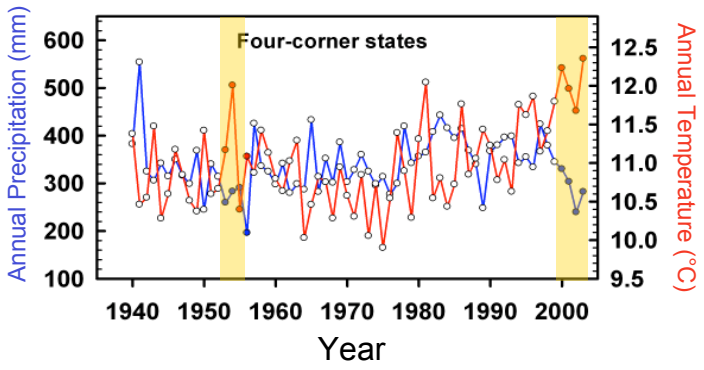
Photo: C. D. Allen



May 2004

Photo: C. D. Allen

2000s versus 1950s Drought



Significant mortality in a region over 12,000 km^2 in size
(and that's only in Pinyon Pine [*Pinus edulis*] dominated landscapes…)

Breshears et al. (2005) Proc. Natl. Acad. Sci.

Now consider a *decades-long mega-drought* super-imposed on unprecedented hot/dry mean climate

(many western water managers won't)

Large crown fires are already occurring in some forests in the western US where they are historically and ecologically anomalous.

Conclusions - key abrupt change hypotheses include*:

1) *Abrupt change is not exceptional*, but rather is a normal way in which the climate system responds to changes in forcing.

2) *Regional forcing can trigger widespread changes* (global and far-field remote).

3) Abrupt climate change occurs naturally in aspects of climate that are highly relevant to society (e.g., droughts, floods, tropical storms and sea level change), and many of these aspects are changing now in ways consistent with projected responses to anthropogenic forcing. Thus, the *potential for abrupt change in important components of the climate system is very real, and potentially immediate*.

*From Overpeck & Cole, in press - also, these need rigorous data/model testing

Conclusions - key abrupt change hypotheses include*:

4) We should expect the climate system to respond abruptly to current and future climate forcing, *but in ways whose specifics are difficult to predict with geographic and temporal specificity.*

5) *Anthropogenic climate change likely increases the threat of major abrupt climate change, and will also likely increase the severity of some abrupt change impacts*. (e.g., future droughts will be hotter and thus more stressful on human and natural systems. Also, increased chances of abrupt sea level rise coincident with more powerful tropical storms is likely to result in significantly greater "multiple stress" impacts in coastal regions).

*From Overpeck & Cole, in press - also, these need rigorous data/model testing

Conclusions - key abrupt change hypotheses include*:

6) Some abrupt climate change threats are plausible in coming years to decades (e.g., drought- and perhaps tropical storm-related), *however "next-generational" abrupt climate change threats (e.g., major sea level rise and large-scale clathrate methane release) could be the most costly* in terms of economics and human-suffering.

*From Overpeck & Cole, in press - also, these need rigorous data/model testing

Photo: R. Alley