

Climate Change: What's ahead for the Southwest?

Goal of talk:

review evidence for "global warming" and what's at stake

- what's the consensus among climate scientists
- what's new - focus on the Arctic and implications
- what's new - focus Southwest U.S. and....
the drought!.



Jonathan Overpeck
Professor of Geosciences
Professor of Atmospheric Sciences, and
Director, Institute for the Study of Planet Earth

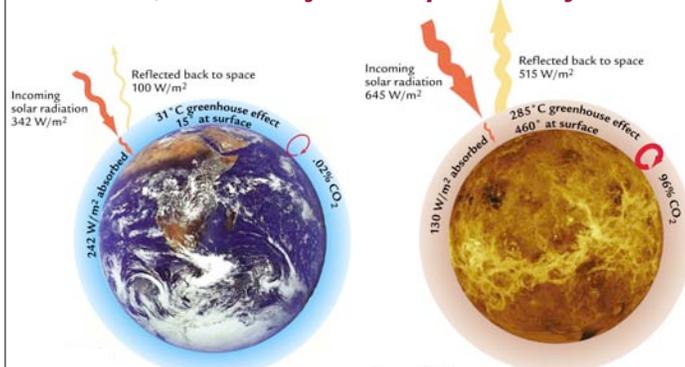
THE UNIVERSITY OF
ARIZONA
TUCSON ARIZONA

Pop-quiz!

For 10 points, answer the following question...

Is the "greenhouse effect" real, and how do we know?

The Greenhouse Effect... if you don't believe it, Venus is just the place for you...



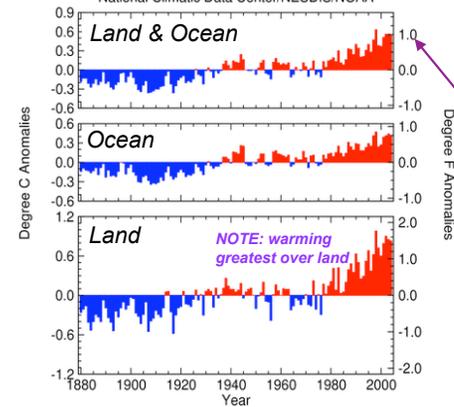
The Earth is 15°C on average
(would be frozen solid w/o CO₂)

Venus = 460°C on average

From: Ruddiman, 2001

"Global Warming" is real too...

Jan - Dec Global Surface Mean Temp Anomalies
National Climatic Data Center/NESDIS/NOAA



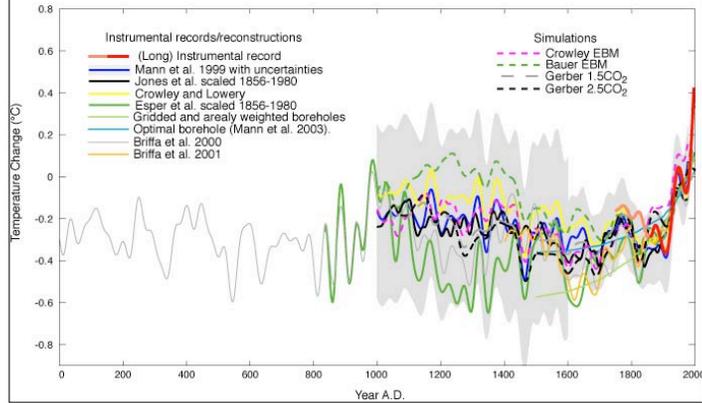
2004 = almost
2nd warmest
on record

8 of top 10
warmest years
have occurred in
the last decade!

Unprecedented?

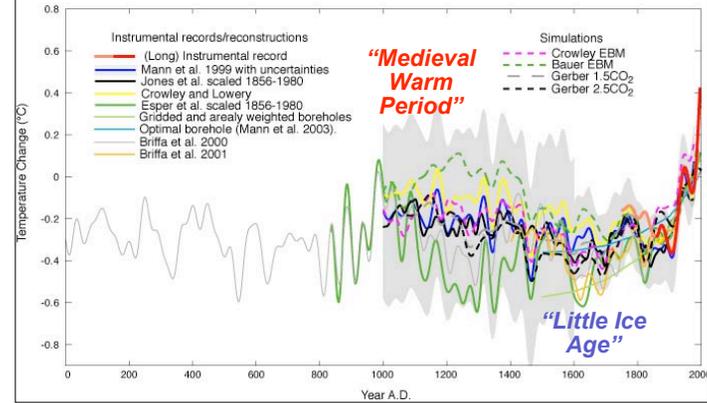
Latest view of last 2000 years of Northern Hemisphere Temperature Change

Mann, M.E., Ammann, C.M., Bradley, R.S., Briffa, K.R., Crowley, T.J., Jones, P.D., Oppenheimer, M., Osborn, T.J., Overpeck, J.T., Rutherford, S., Trenberth, K.E., Wigley, T.M.L. (EOS, 2003)



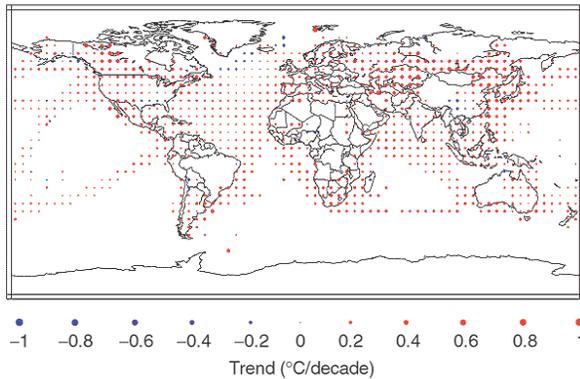
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Instrumental Observed Temperature Trends - ANNUAL

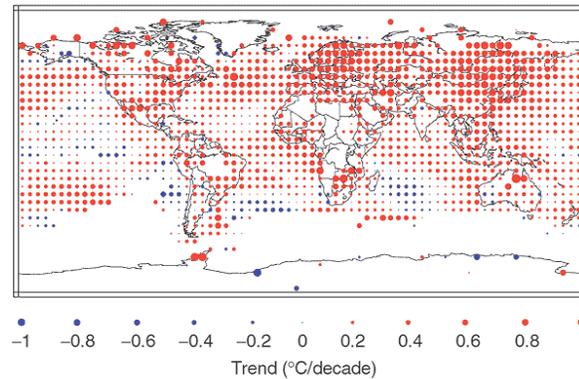
(a) Annual temperature trends, 1901 to 2000 **Note**



IPCC TAR (2001)

Instrumental Observed Temperature Trends - ANNUAL

(d) Annual temperature trends, 1976 to 2000 **Note**

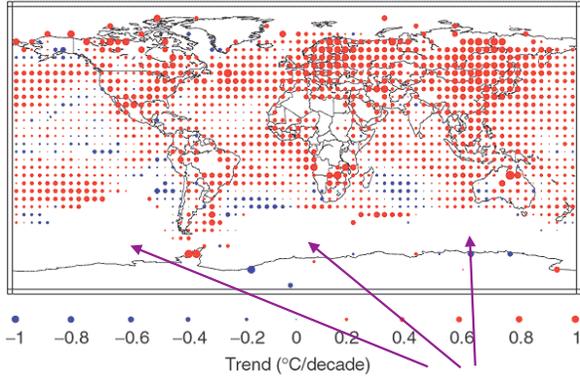


IPCC TAR (2001)

Instrumental Observed Temperature Trends - ANNUAL

(d) Annual temperature trends, 1976 to 2000

Note



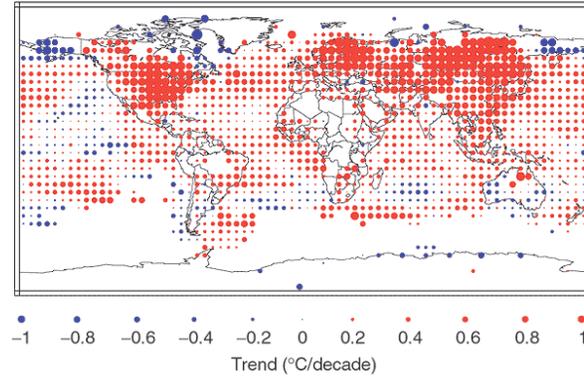
IPCC TAR (2001)

Large/deep ocean warming

Instrumental Observed Temperature Trends - Winter

(a) DJF temperature trends, 1976 to 2000

Note



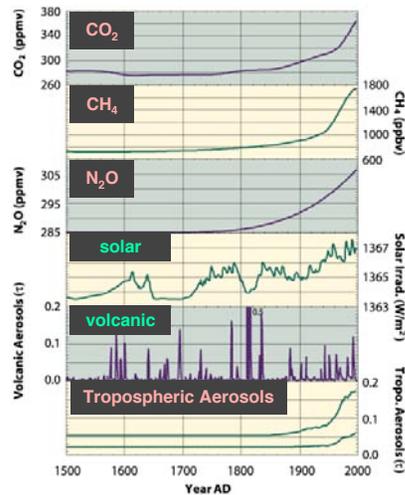
IPCC TAR (2001)

Hypothesized climate forcing time series for the last 500 years

Robertson et al.,
J. Geophys. Res. (2001)

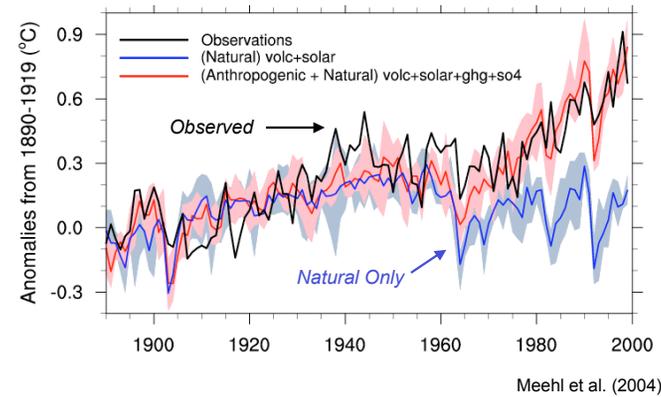


Greenland Summit



PCM - 20th Century Experiments

Forcings: Combined Natural-Anthropogenic and Natural only



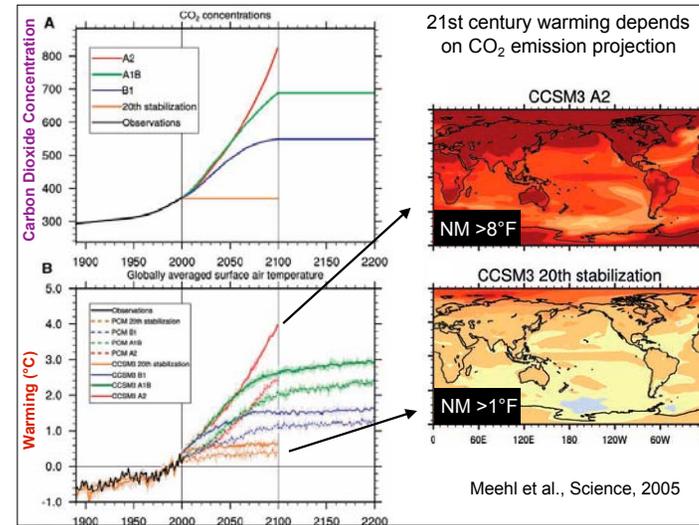
**The Intergovernmental Panel on Climate Change (IPCC)
Climate Change 2001:**

Hundreds of authors and hundreds of reviewers,
from most countries of the world



All climate scientists!

“globally averaged surface temperature
projected to increase by **1.4 to 5.8°C (2.5 to
10.4°F)** over the period 1990 to 2100”



So, what is ahead? Big change? Little Change?



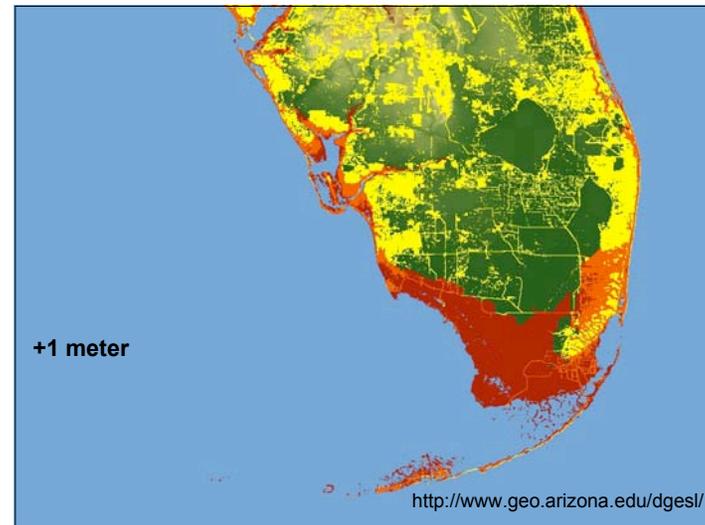
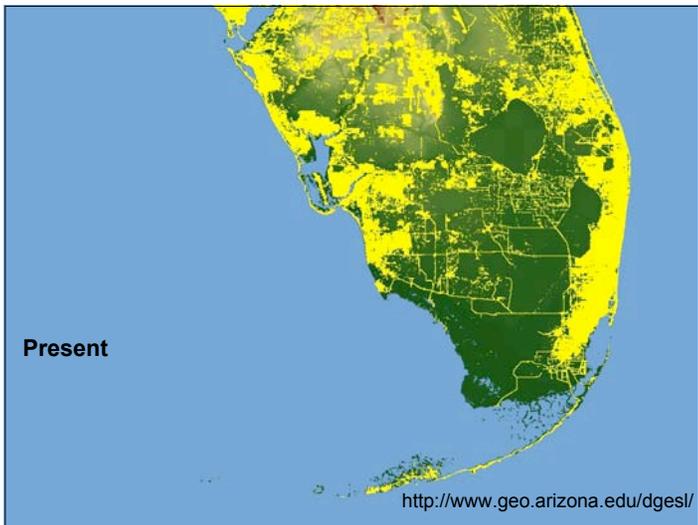
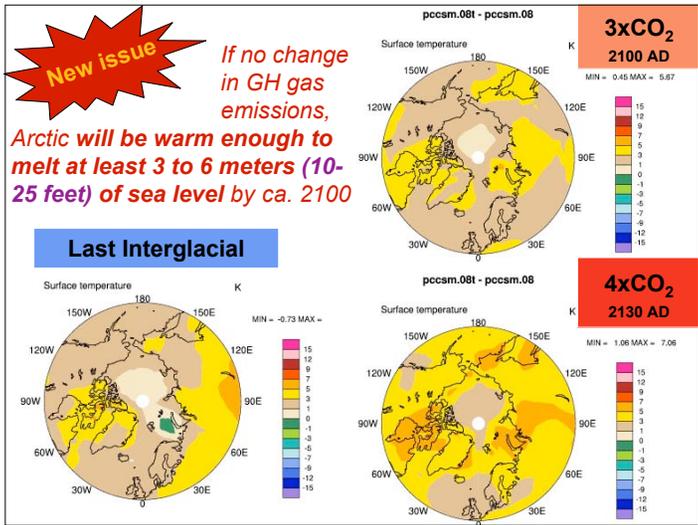
*Clues from
the Arctic...
A surprising
meltdown is
in progress*

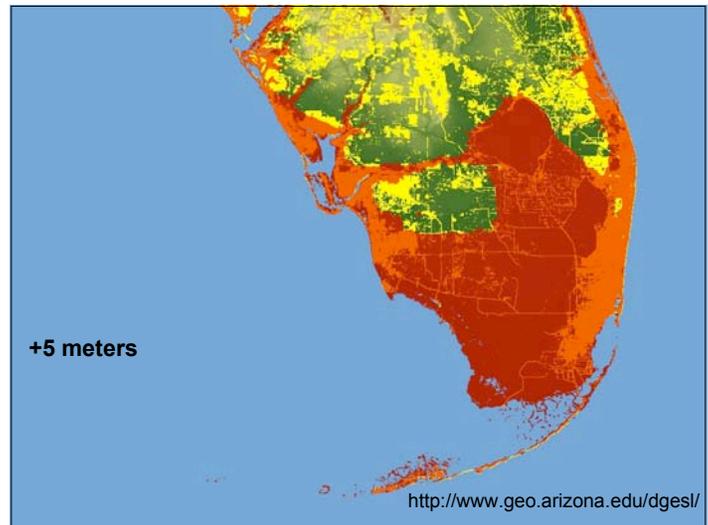
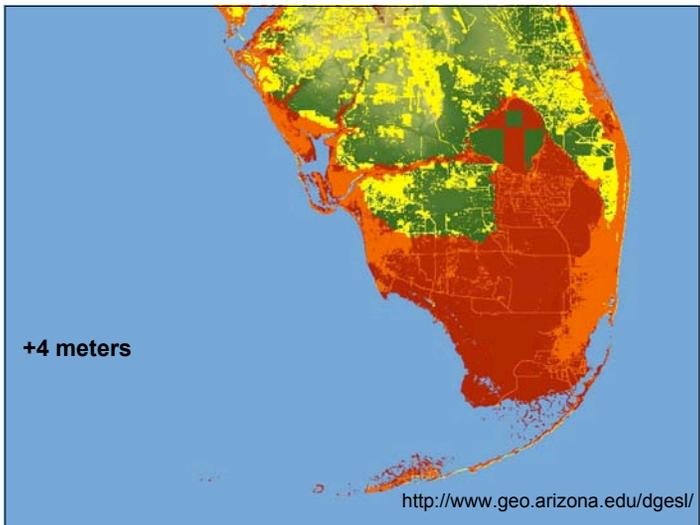
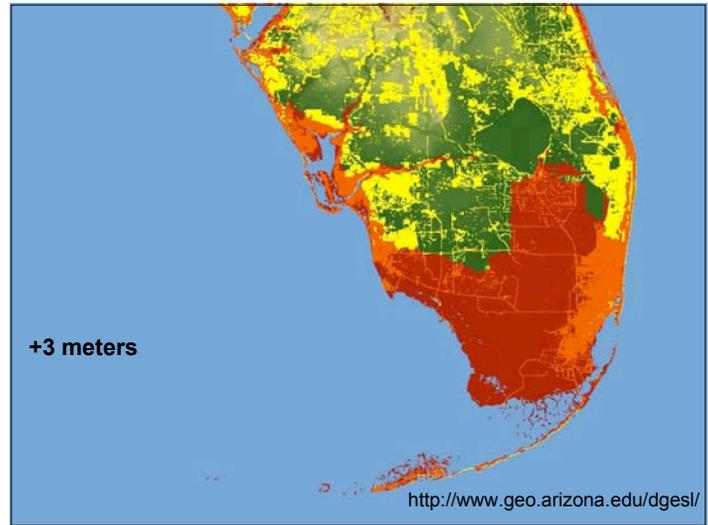
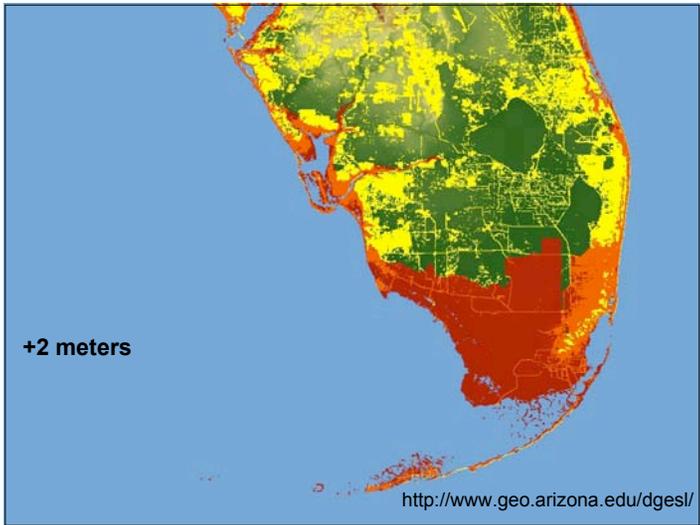
Climate Warming in the Arctic Significant and Accelerating

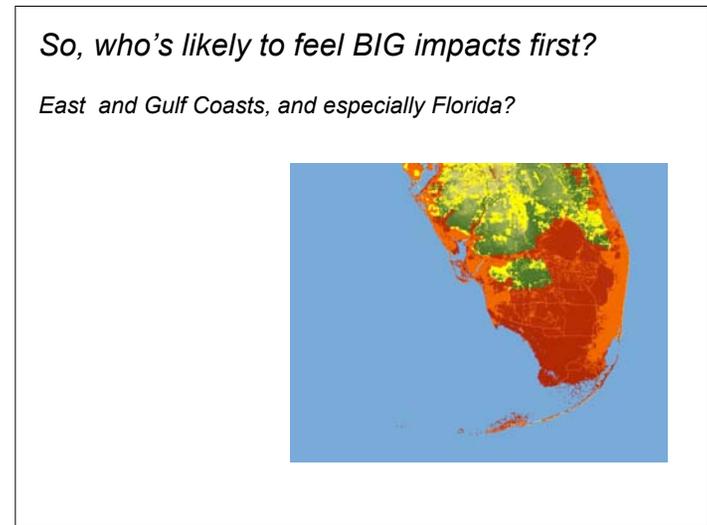
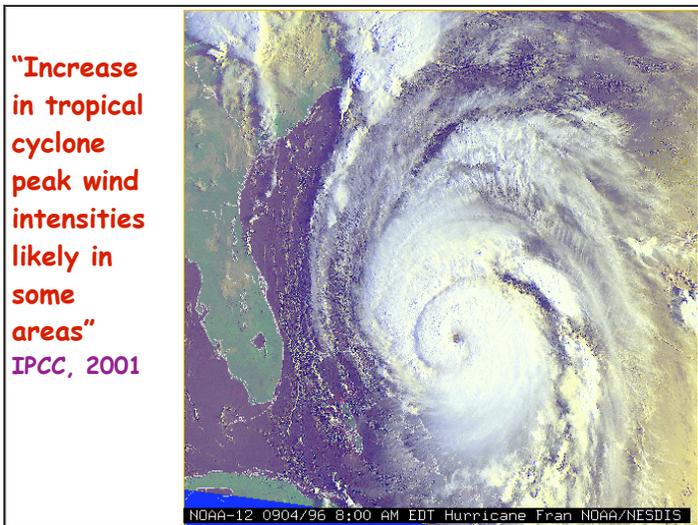
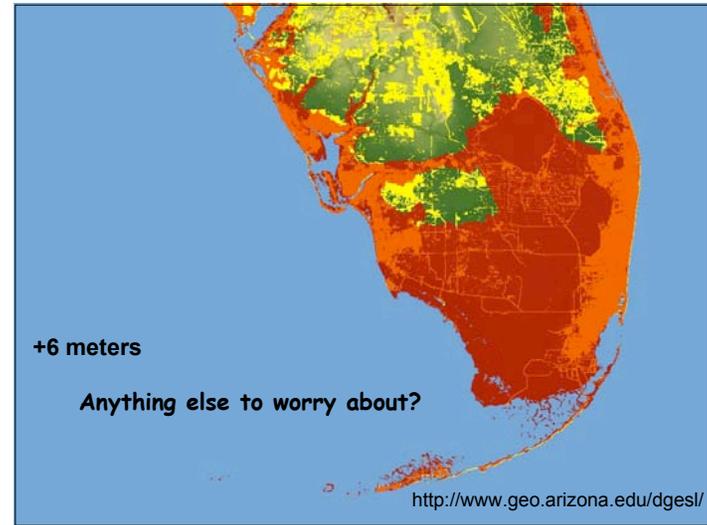
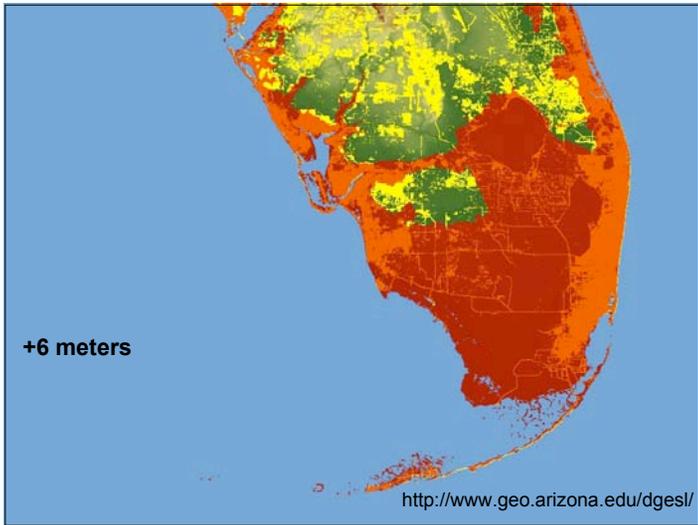
- **Warming greatest on planet**
- **Arctic Sea Ice Pack:** thinned by 40% in last 50 years
- **Summertime Arctic Sea Ice:** melting is accelerating
- **Greenland Ice Sheet:** ditto, 16% increase in melt area between 1979 and 2002



(Arctic Impacts of Arctic Warming, Cambridge Press, 2004).







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

East and Gulf Coasts, and especially Florida?

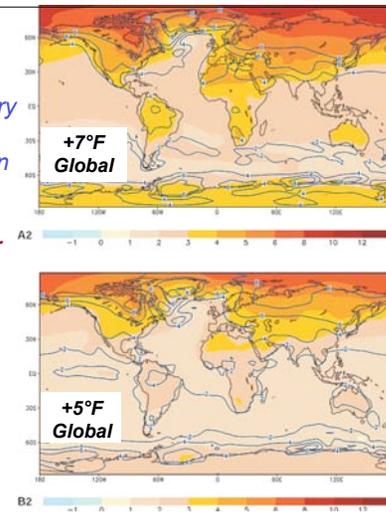
Maybe not...

Annual Mean Temperature Change:
Late 20th to Late 21st Century

Average of model simulation ensembles = shaded colors

Predicted **warming greater over land** and at higher latitudes - just as observed so far

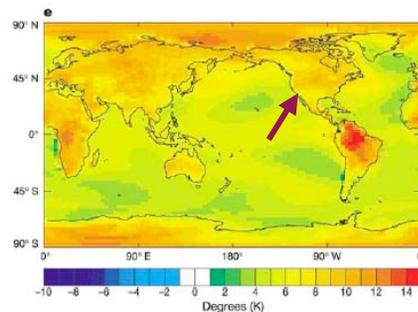
IPCC (2001)



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

temperature: up to 14°F (or even more!*) warming, more probably in winter than summer

*climateprediction.net - Stainforth et al., 2005
Nature



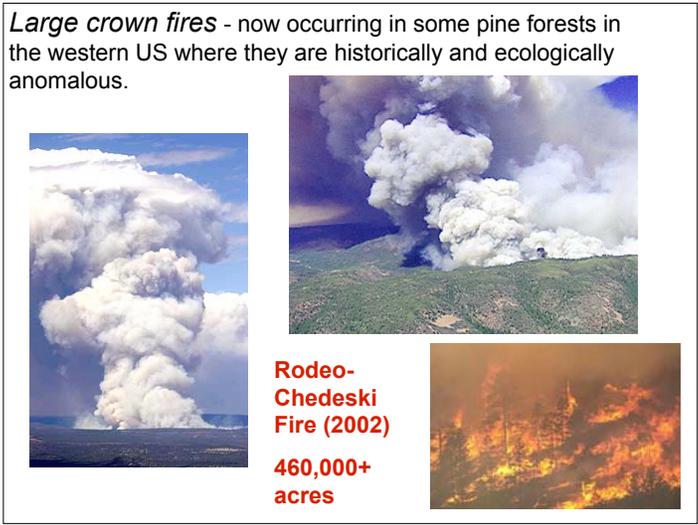
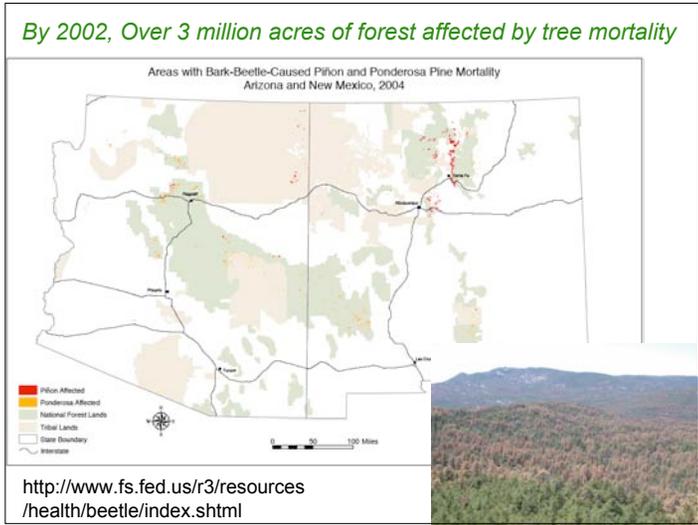
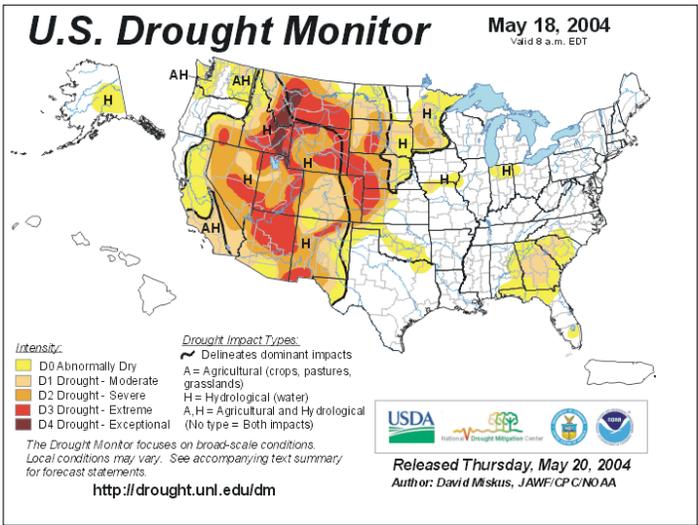
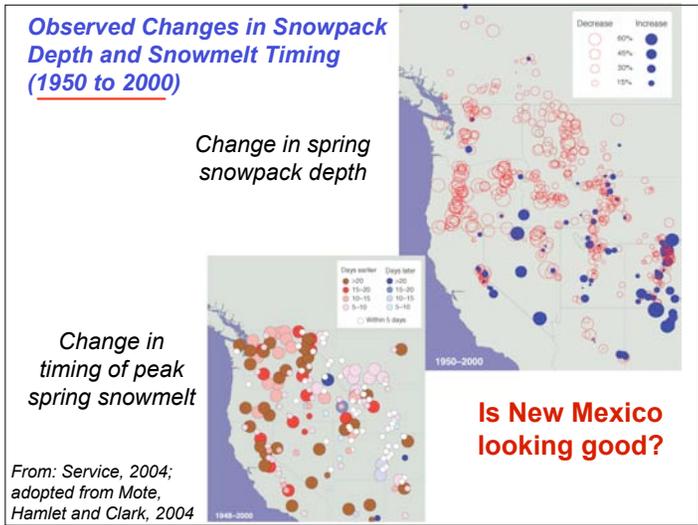
For **Southwest**? Best bet is that we'll see the following by the late 21st century:

Precipitation: flip a coin for changes in the mean, (winter increase more likely, at least in non-drought years) **plus:**

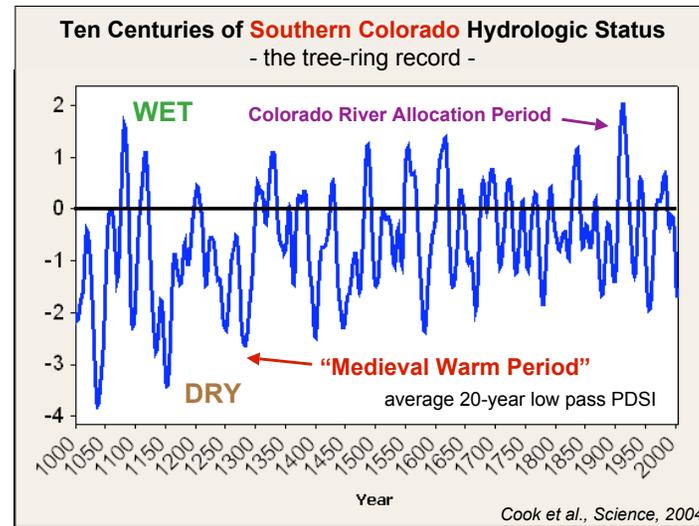
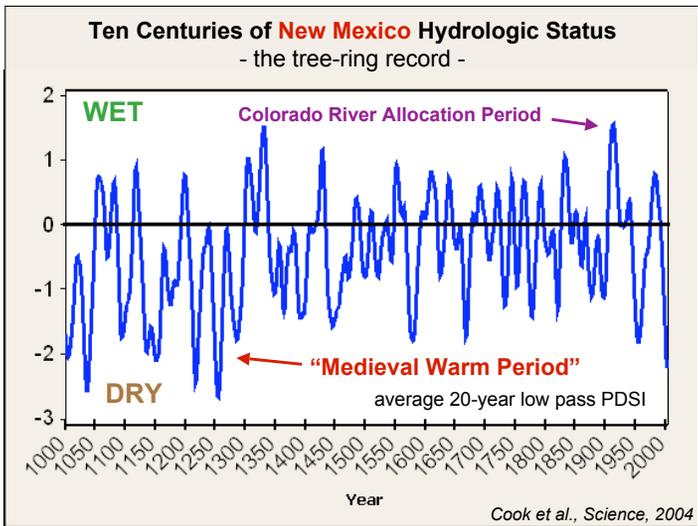
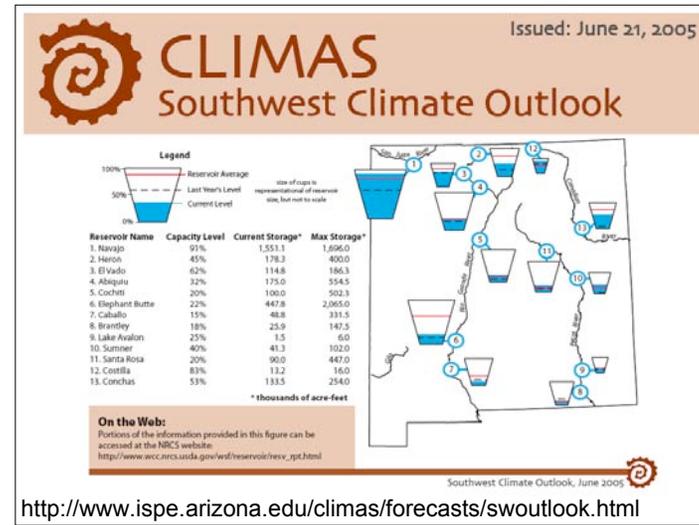
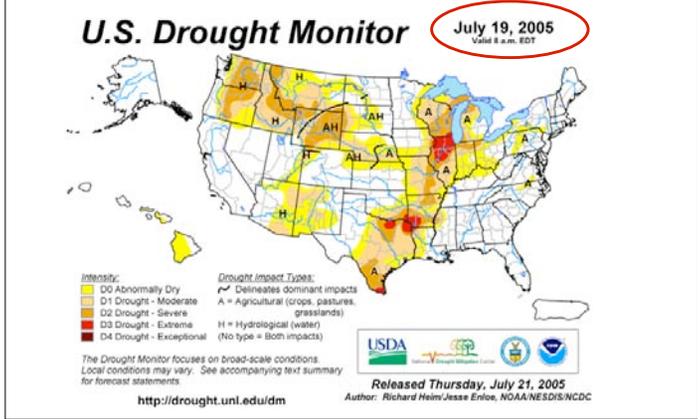
- **snow runoff** season will be significantly shorter
- **evaporation** will be significantly higher in all seasons
- **droughts** will be more likely
- **floods** will be more likely

Accelerated hydrologic cycle {

Note!



Note - Current drought began in 1996 - Lake Powell currently down to 52% capacity - it will take at least 10 years to fill if snow pack stays above normal (not likely)



New issue **The Perfect Ocean for Drought**
 Martin Hoerling^{1*} and Arun Kumar²

Science, (2003)

- Abrupt threshold passed in late 1990's?
- Interrupted by weak El Niño in Winter 2004-5?
- Will the dry winters come back?

Colorado River flow

Annual discharge

Legally allocated flow	16.5 maf
Measured flow, 1902-1932	15.8 maf
Estimates of past flow:	
Tree rings, upper basin, 1512-1961	13.5 maf
Isotopes, delta clams, 1500-1950	12.5 maf

(New UA Research
 - Prof. Karl Flessa and team)

Michael Collier photo, 1999

So, the new federal water warning seems on target...

Potential Water Supply Crises by 2025
 (Areas where existing supplies are not adequate to meet water demands for people, for farms, and for the environment)

Water Supply Issue Areas:
 Yellow: Conflict Potential - Moderate
 Orange: Conflict Potential - Substantial
 Red: Conflict Potential - Highly Likely

Southwest has the most at stake!

May 2003

Conservative estimates of climate change impact on the Colorado River System by the end of 21st century

- Annual runoff down by over 15%
- Basin storage down by 40%
- Power output decreased to 45-56% of historical average
- Central Arizona Project (CAP) hit hard

Christensen et al., Climatic Change (2004)

Conclusions - the science

- *decades-long drought possible even w/o anthropogenic climate change, especially during warmer periods*
- *given continued greenhouse gas emissions, future climate change will be substantial and persistent:*
 - substantial warming a sure bet
 - substantial increase in evaporation a sure bet
 - decreased snowpack and snow season likely
 - some increases in precipitation (esp. winter) possible, but best bet on less than in wet years of 20th century
 - likely increase in drought frequency and duration
 - current drought (hot and dry) should be considered a harbinger of things to come, unless we act soon



Conclusions - what to do?

- *ways to ensure best chance for continued economic growth, quality of life, and healthy ecosystems include:*
 - 1) ADAPT SMARTLY - *implement policy to reduce climate vulnerability (e.g., to high temperatures, water shortages and climatic extremes)*
 - 2) MITIGATE DANGEROUS CHANGE - *lead efforts to curb climate change - West will likely be the first part of the U.S. to suffer major impacts*

NOTE: both are "no regrets strategies" that have serious benefits beyond climate change (e.g., energy independence, improved air quality, and new economic growth engines)

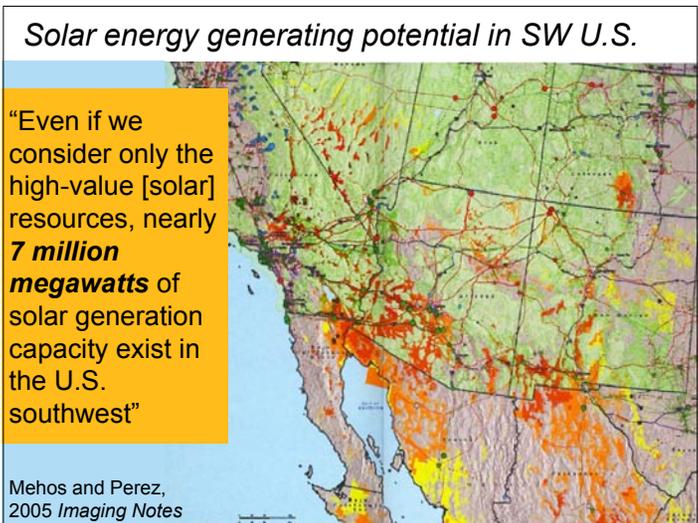
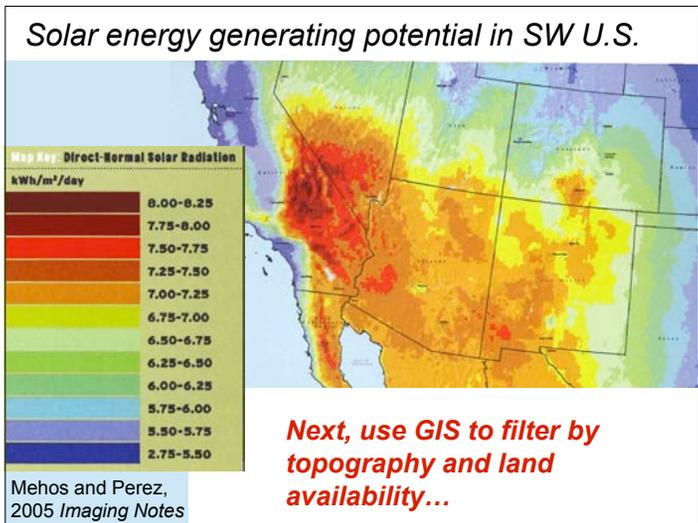
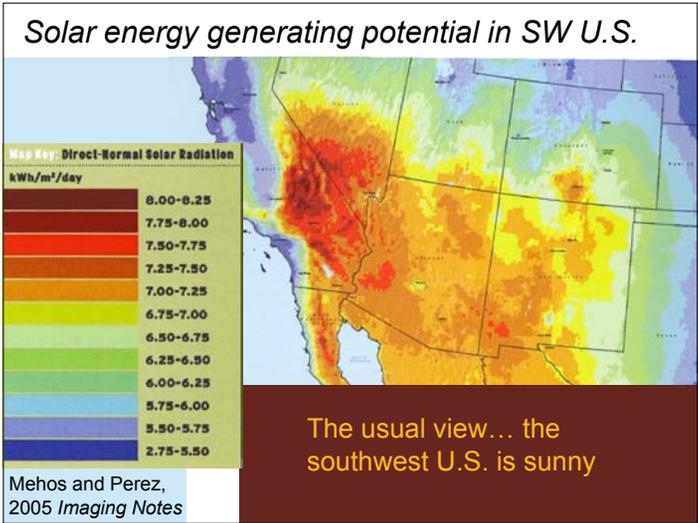
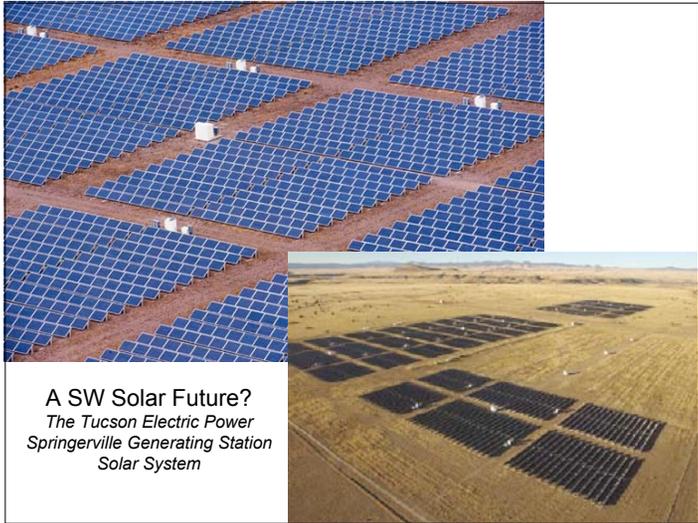
*"The end of the **stone age** did not end for lack of stone, and the **oil age** will end long before the world runs out Of Oil"* (Sheikh Yamani - former Oil Minister of Saudi Arabia)

What's needed:

- 1) *Increased focus on **no-regrets energy and water conservation measures***
- 2) *A **Manhattan Project**-like effort to develop the energy sources of the future*
- 3) *Need to **start soon** to avoid big impacts*



October 25-31 2003



Pop-quiz #2

For another 10 points, answer the following question...

What was the current TOTAL U.S. electricity generation capacity on January 1, 2004?

(according to the Department of Energy)

Solar energy generating potential in SW U.S.

Table 1. Results of satellite/GIS analysis showing area of land and associated power capacity for seven states in U.S. Southwest.

STATE	AVAILABLE AREA (MI ²)	CAPACITY (MW)*
Arizona	19,300	2,467,700
California	6,900	877,200
Colorado	2,100	271,900
Nevada	6,600	716,400
New Mexico	15,200	1,940,000
Texas	1,200	148,700
Utah	3,600	456,100
Total	59,900	6,877,000

*CSP power plants require about 5 acres of land area per megawatt of installed capacity. Solar generation can be estimated by assuming an average annual solar capacity factor of 25%-50%, depending on the degree of thermal storage used for a plant.

Mehos and Perez, 2005 *Imaging Notes*

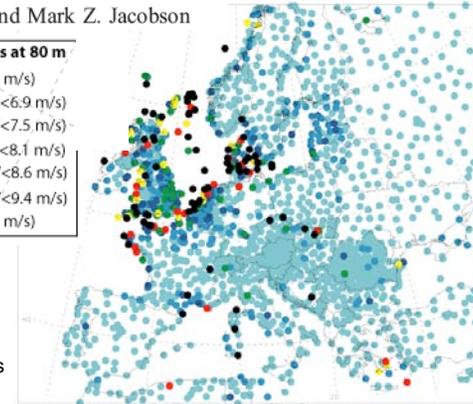


JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 110, D12110, doi:10.1029/2004JD005462, 2005

Evaluation of global wind power

Cristina L. Archer and Mark Z. Jacobson

- Wind classes at 80 m
- 1 (V < 5.9 m/s)
 - 2 (5.9 ≤ V < 6.9 m/s)
 - 3 (6.9 ≤ V < 7.5 m/s)
 - 4 (7.5 ≤ V < 8.1 m/s)
 - 5 (8.1 ≤ V < 8.6 m/s)
 - 6 (8.6 ≤ V < 9.4 m/s)
 - 7 (V ≥ 9.4 m/s)



Europe

(including Denmark, which already generates 20% of its electricity from wind)

Evaluation of global wind power

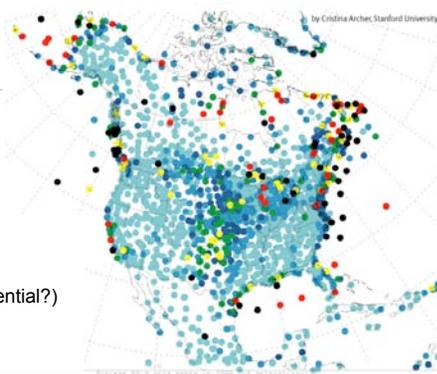
Cristina L. Archer and Mark Z. Jacobson

Wind classes at 80 m

- 1 ($V < 5.9$ m/s)
- 2 ($5.9 \leq V < 6.9$ m/s)
- 3 ($6.9 \leq V < 7.5$ m/s)
- 4 ($7.5 \leq V < 8.1$ m/s)
- 5 ($8.1 \leq V < 8.6$ m/s)
- 6 ($8.6 \leq V < 9.4$ m/s)
- 7 ($V \geq 9.4$ m/s)

North America

(greatest wind power potential?)



Sandia National Laboratory Sandia National Laboratory



The Southwest as the first major renewable energy exporter???

Wind turbines are cool

bp
BP Solar

Drawing by "Fergal" at
http://www.gepower.com/businesses/ge_wind_energy/en/kids_teachers/mhuire_realt.htm