6-8-2005

SLIDES: Drought, Climate Change and Water Supply Vulnerability

Brad Udall

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Drought, Climate Change and Water Supply Vulnerability

Hard Times on the Colorado River: Drought, Growth and the Future of the Compact
June 8-10, 2005

Brad Udall
Director
CU-NOAA Western Water Assessment
Bradley.Udall@colorado.edu

Western Water Assessment
http://wwa.colorado.edu
Western Water Assessment one of 8 Similar Programs.

3 Programs in Colorado River Basin

* Recommended for funding
Why Western Water Assessment?

Help NOAA Consider and Implement Future “Climate Services”, an analog to the National Weather Service.

Climate is not weather!

It is the slowly varying aspects of the atmosphere – hydrosphere – land surface system. It is far more than just ‘average weather’.
Outline

1. A Brief Look at the Flows at the Time of the Compact and Now
2. 500-Year Drought or Not?
3. Future of Colorado River Hydrology
4. What’s a Water Manager to Do??
### 18 Gages in CRC Minutes
**Only 5 with More than 10 Years!**

<table>
<thead>
<tr>
<th>Name</th>
<th>Drainage Area</th>
<th>Number of Years</th>
<th>Average Annual Runoff, Acre-Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Colorado River at Holbrook, AZ</td>
<td>17,600</td>
<td>2</td>
<td>162,000</td>
</tr>
<tr>
<td>Uinta River at Fort Duchesne, UT</td>
<td>672</td>
<td>5</td>
<td>176,000</td>
</tr>
<tr>
<td>San Rafael River near Green River, UT</td>
<td>1,690</td>
<td>8</td>
<td>191,000</td>
</tr>
<tr>
<td>Virgin River at Virgin, UT</td>
<td>1,010</td>
<td>8</td>
<td>207,000</td>
</tr>
<tr>
<td>Gila River at Guthrie, AZ</td>
<td></td>
<td>6</td>
<td>301,000</td>
</tr>
<tr>
<td>San Francisco River at Clifton, AZ</td>
<td></td>
<td>3</td>
<td>357,000</td>
</tr>
<tr>
<td>Duchesne River at Myton, UT</td>
<td>2,750</td>
<td>12</td>
<td>556,000</td>
</tr>
<tr>
<td>Animas River at Farmington, NM</td>
<td></td>
<td>3</td>
<td>875,000</td>
</tr>
<tr>
<td>Yampa River Near Maybell, CO</td>
<td>3,670</td>
<td>8 periods</td>
<td>1,210,000</td>
</tr>
<tr>
<td>Green River at Green River, WY</td>
<td>7,670</td>
<td>13</td>
<td>1,510,000</td>
</tr>
<tr>
<td>Green River at Bridgeport, Utah</td>
<td>15,700</td>
<td>4</td>
<td>2,090,000</td>
</tr>
<tr>
<td>San Juan River at Farmington, NM</td>
<td></td>
<td>3</td>
<td>2,320,000</td>
</tr>
<tr>
<td>San Juan River near Bluff, UT</td>
<td>24,000</td>
<td>3</td>
<td>3,090,000</td>
</tr>
<tr>
<td>Green River at Green River and Little Valley, UT</td>
<td>41,000</td>
<td>18</td>
<td>5,690,000</td>
</tr>
<tr>
<td>Grand River near Fruita, CO</td>
<td>16,800</td>
<td>11</td>
<td>6,540,000</td>
</tr>
<tr>
<td>Grand River near Moab and Cisco, UT</td>
<td>23,800</td>
<td>4</td>
<td>7,540,000</td>
</tr>
<tr>
<td><strong>Colorado River near Topock, AZ</strong></td>
<td><strong>171,000</strong></td>
<td><strong>2</strong></td>
<td><strong>14,200,000</strong></td>
</tr>
<tr>
<td><strong>Colorado River at Yuma, AZ</strong></td>
<td><strong>242,000</strong></td>
<td><strong>18</strong></td>
<td><strong>17,300,000</strong></td>
</tr>
</tbody>
</table>
Known Flows at Laguna 1922
From USBR (A.P. Davis) SD 142 Report

<table>
<thead>
<tr>
<th>Year</th>
<th>MAF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1899</td>
<td>22</td>
</tr>
<tr>
<td>1900</td>
<td>18</td>
</tr>
<tr>
<td>1901</td>
<td>15</td>
</tr>
<tr>
<td>1902</td>
<td>20</td>
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<td>1903</td>
<td>17</td>
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<td>1904</td>
<td>14</td>
</tr>
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<td>1905</td>
<td>10</td>
</tr>
<tr>
<td>1906</td>
<td>25</td>
</tr>
<tr>
<td>1907</td>
<td>20</td>
</tr>
<tr>
<td>1908</td>
<td>15</td>
</tr>
<tr>
<td>1909</td>
<td>22</td>
</tr>
<tr>
<td>1910</td>
<td>18</td>
</tr>
<tr>
<td>1911</td>
<td>15</td>
</tr>
<tr>
<td>1912</td>
<td>12</td>
</tr>
<tr>
<td>1913</td>
<td>10</td>
</tr>
<tr>
<td>1914</td>
<td>17</td>
</tr>
<tr>
<td>1915</td>
<td>20</td>
</tr>
<tr>
<td>1916</td>
<td>15</td>
</tr>
<tr>
<td>1917</td>
<td>12</td>
</tr>
<tr>
<td>1918</td>
<td>10</td>
</tr>
<tr>
<td>1919</td>
<td>15</td>
</tr>
<tr>
<td>1920</td>
<td>20</td>
</tr>
</tbody>
</table>

3-Year 10 maf/yr drought
Long Time Average ~ 15maf
Natural Flow into Lake Powell

1906-1920 Avg was 17.3 maf
Odd and Unusual Material:
CRC Minutes
Stockton and Jacoby 1976
Tree-ring report
Nash and Gleick 1993
Climate Change and Colorado River Report
Other historical material being added.
2. 500-Year Drought?

Were trees chasing dogs?
A tale (tail) of Two Streamflow Reconstructions

A City That Bets on Water

By George F. Will

LAS VEGAS -- In this city of histrionic architecture, the building that matters most may be the bland, low-slung headquarters of the Southern Nevada Water Authority. The general manager since the authority was formed in 1991, the elegant, no-nonsense Pat Mulroy, 32*, is determined to prevent a water shortage from inhibiting the growth of this city, which is dedicated to the proposition that inhibitions are sinful.

* Age changed to protect the innocent, namely me.

Washington Post, February 27, 2005
“Similarly, the lowest 5-year average (Lake Powell inflow) using tree rings is 8.84 MAF* (A.D. 1590-1594), compared with 7.11 MAF+ from 1999 through 2003. These comparisons suggest that the current drought may be comparable to or more severe than the largest-known drought in 500 years.”

Climatic Fluctuations, Drought, and Flow in the Colorado River, June 2004
* From Stockton and Jacoby, 1976
+ Gaged, not Natural, flows
Facts - Colorado River Basin
2000-2004 Drought

- Worst drought in 100 years of recordkeeping
- Below average runoff every year, 2000-2004
  - 25% in 2002
- System is currently over half full
  - Was over 90% full in 1999

Source: Reclamation
# Mid-Term Droughts - Colorado River

(Average 100 year natural flow 15.1 maf)

<table>
<thead>
<tr>
<th>Years</th>
<th>Duration</th>
<th>Average Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1931-1935</td>
<td>5 years</td>
<td>11.4 maf</td>
</tr>
<tr>
<td>1953-1956</td>
<td>4 years</td>
<td>10.2 maf</td>
</tr>
<tr>
<td>1959-1964</td>
<td>6 years</td>
<td>11.4 maf</td>
</tr>
<tr>
<td>1988-1992</td>
<td>5 years</td>
<td>10.9 maf</td>
</tr>
<tr>
<td>2000-2004</td>
<td>5 years</td>
<td>9.9 maf *</td>
</tr>
</tbody>
</table>

* Estimated

Source: Reclamation
What can the trees tell us about drought?
The first Lees Ferry reconstruction was generated by Stockton and Jacoby in 1976

Source: Woodhouse
How is past streamflow reconstructed from tree rings?

Moisture-sensitive tree species growing on open, well drained sites reflect moisture variability in their ring widths and are targeted for collection.

Cores collected from about 20 trees are dated, measured, and averaged into site tree-ring chronologies.

Source: Woodhouse
Tree-ring data in the Upper Colorado and adjacent areas have recently been updated and expanded.

Stockton and Jacoby tree-ring sites

New network of tree-ring sites

Source: Woodhouse
Tree-ring data are calibrated with annual streamflow to generate a statistical model of reconstructed flow.

Blue River Annual Streamflow
Observed vs Reconstructed Flow, 1916-2002

Reconstruction Recipe
1 Part Tree-Rings
1 Part Native Flow Record
1 Part Statistics

63% of the variance in the gage record is explained by the reconstruction. The unexplained variance is often in the magnitude of the extremes.

Source: Woodhouse
Woodhouse, Meko, Gray have used the updated set of tree-ring chronologies to build a new reconstruction. Added 39 years of gage and calibration data to S&J.

**Comparison of Lees Ferry gage and reconstructed values 1906-1997**

- Explained variance = 80.6%
- Source: Woodhouse

*New Data 61-97*
Woodhouse, Meko, Gray New Reconstruction of Lees Ferry Streamflow, Each Year from 1536-1997

Source: Woodhouse
Woodhouse, Meko, Gray New Reconstruction of Lees Ferry Streamflow, 20-year moving average, 1536-1997

**Dry periods**

<table>
<thead>
<tr>
<th>Lowest 20-yr avg.</th>
<th>Lowest 25-yr avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1573-1592 (1)</td>
<td>1622-1646 (1)</td>
</tr>
<tr>
<td>1622-1641 (3)</td>
<td>1623-1647 (2)</td>
</tr>
<tr>
<td>1870-1889 (4)</td>
<td>1878-1902 (3)</td>
</tr>
</tbody>
</table>

**Pluvial (Wet) periods**

<table>
<thead>
<tr>
<th>Highest 20-yr avg.</th>
<th>Highest 25-yr avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1602-1621 (1)</td>
<td>1905-1929 (1)</td>
</tr>
<tr>
<td>1601-1620 (2)</td>
<td>1906-1930 (2)</td>
</tr>
<tr>
<td>1905-1924 (6)</td>
<td>1594-1618 (3)</td>
</tr>
</tbody>
</table>

Source: Woodhouse
There are other ways to examine features of the Lees Ferry streamflow reconstruction.

Extreme events are not evenly distributed over time.

Source: Woodhouse
Lees Ferry Reconstruction, 1536-1997
5-Year Running Mean

Assessing the 1999-2004 drought in a multi-century context

Source: Woodhouse

8 Periods may be worse than 2000-2004

Source: Woodhouse
Summary of New Reconstruction

• Added 40+ gage and tree-ring calibration years relative to Stockton and Jacoby
• 15.2 maf USBR Average Natural Flows
• 14.7 maf this reconstruction **
• 13.5 maf S&J 1975 reconstruction
• One 5-year period worse than 2000-2004, but eight other periods may have been as dry.**

** preliminary
Increasing Use of Paleodata in Modeling Studies

- Denver Water System Yield Studies
- USBR (Terry Fulp) / UA (Kathy Jacobs) / CSU (Salas – Stochastic) Effort
- SRP Studies
- Hydrosphere Monte Carlo Simulations using 6 different reconstructions
Monte Carlo Using Tree-rings

Total Expected Colorado River Storage Contents

500 traces each run 30 years, starting reservoir conditions set to late 2004

Source: Harding
2005 Tucson Tree-ring Workshop

- CA DWR, SRP, Denver Water, Wyoming Engineer’s Office, CAP, SNWA, NM State Engineer’s Office, USBR, UCRC Commission, many others
- 1 Day Meeting in April, 2005
- More NOAA-sponsored Paleoclimate and Future Climate Meetings Being Planned
Other Paleo: Center for the Study of Dead Clams

Preliminary Results ~ 10 maf at Delta from 1000 to 1500 AD
4. Future Hydrology of Colorado River

- Tales of Changing Snowpack
- IPCC Who?
- Underappreciated Theories and Facts
- Signs of Warming Everywhere…
- Lessons From Past Colorado River Climate Change Studies
- What’s a water manager to do?
A Profusion of Snow Related Journal Articles

- Trends and Variability in snowmelt runoff in the western United States – McCabe and Clark
- Changes in Snowmelt Runoff timing in Western North America Under a “Business as Usual’ Climate Change Scenario – Stewart, Cayan, Dettinger
- Seasonal Shifts in Hydroclimatology over the Western United States – Regonda, Rajagopalan, Clark, Pitlick
- Declining Mountain Snowpack in Western North America – Mote, Hamlet, Clark, Lettenmaier
Bulletin of American Meteorological Society, January 2005
Declining Snowpack

Source: Mote, et al.
A Warming West…

Source: Mote, et al.
Precipitation – Mixed Bag

Source: Mote, et al.
Declining Snowpack Summary

• Widespread Declines in SWE in West during 1925-2000, especially since 1950.
• Spatial Consistency, Elevational Dependence, Model Agreement point to climate as cause.
• Increases in temperature are consistent with rising ghg and will almost certainly continue.
• Likely that losses in snowpack will continue and even accelerate with highest losses in milder climates and slowest losses in high peaks of northern Rockies and Southern Sierra.

Source: Mote, et al.
The IPCC Alphabet

Intergovernmental Panel on Climate Change


3 Working Groups: (1) Science, (2) Impacts, Adaptation and Vulnerability, and (3) Mitigation.

~ 2000 Scientists working world-wide.

“Assessment Reports” from Each Group Every 5 Years or So.


Previous Reports 1991, 1995/6 and 2001 = “TAR”

Next Reports 2006-07 (“FAR”)

www.ipcc.ch
Anthropogenic causes are likely causing our climate to change; how much warming, where it will warm, and how fast it will warm are hotly debated.

Warming is not just summer maximums!

Warming will heat atmosphere, land, oceans, and melt ice.

CO2 residence time on the order of 100+ years.

Don’t Know where approximately HALF current Carbon is going – it is being emitted, but not ending up in the atmosphere.

Abrupt Change a reality. How hard do we want to push?

Feedbacks are key to the answer – clouds, water vapor is biggest ghg – and we don’t and won’t understand them for some time.

Don’t expect ‘eureka moments’ from Science in the near future.
Underappreciated Climate Change Theories and Facts - 2

- A last minute technological solution is quite unlikely.
- Different models show different precipitation changes in some parts of the world. Mid-continental US is one such location.
- Mid-continental areas are expected to warm more than average, and face more precipitation variability.
- Global mean temperature increase means nothing….no one lives in a ‘mean’ location.
- Northern Hemisphere will warm more than Southern Hemisphere.
- Models perform poorly in complex terrain such as the Rocky Mountain West.
- 9 IPCC Lead Authors in Colorado.
Pushing a climate system well beyond its norms.....

400,000 years of Temps, CO2 and CH4.

Warming goes where?

December 2004, American Geophysical Union Meeting New Study Released

Findings:

- Of 1000 Alaskan Glaciers, 985 receding, 15 growing
- Cause attributed to 3 degree F increase during 20th Century
- Change in snowfall not known, under study.

Warming goes where?

Arapahoe Glacier 1898

Arapahoe Glacier 2004

Source: Rocky Mountain News
Warming goes where?

Argo Floats

- 6-12 hours at surface to transmit data to satellite
- Total cycle time 10 days
- Descent to depth ~10 cm/s (~6 hours)
- 1000 db (1000m) Drift approx. 9 days
- Salinity & Temperature profile recorded during ascent ~10 cm/s (~6 hours)
- Float descends to begin profile from greater depth 2000 db (2000m)
Warming goes where?

Argo Float Distribution

Western Water Assessment

Colorado University of Colorado at Boulder
Earth’s Energy Imbalance, Confirmation and Implications
Hansen et. al Science 2005

• Landmark Paper
• Creative use of floating Argo ‘floats’ (buoys)
• Columbia, NASA, DOE Scientists
• Earth ‘Out of Energy Balance’ 1 watt/m2
• Additional 1ºF warming in pipeline if stop emissions today
• Thermal Inertia of ocean
  – Good – time to react
  – Bad – by time see changes, too late

• Article: http://pubs.giss.nasa.gov/authors/jhansen.html
• Argo Home Page: http://www.argo.ucsd.edu/index.html
Colorado River Climate Change Studies over the Years

- Revelle and Waggoner, 1983
- Gleick, 1988
- Nash and Gleick, 1991
- Nash and Gleick, 1993
- Christensen, 2004
Inputs - Nash and Gleick 1993

• Hypothetical Scenarios and GCM Output of Temp and Precipitation used to drive NWS hydrologic model** and CRSS

1. Hypothetical Scenarios
   • Temps increase 2°C and 4°C
   • Precipitation Increases -20%, -10%, +10%, + 20%

2. General Circulation Models (“GCM”)
   • GFDL (NOAA)
   • GISS (NASA)
   • UKMO (UK)
“The regional impacts of these (climate) changes will vary and cannot yet be predicted with much confidence; however, existing global climate models indicate that temperature increases in central North America will exceed the increase in the global mean, and will be accompanied by reduced summer precipitation and soil moisture. (IPCC, 1990)”

“Despite recent advances in modeling the atmosphere, large uncertainties remain about the details of regional hydrological changes. Until large –scale climate models improve both their spatial resolutions and their hydrologic parameterizations, information on the effects of global climatic changes on hydrologic sub-basins can best be produced using detailed, basin-specific hydrologic models.”

Nash and Gleick Page 1.
Results - Nash and Gleick 1993

• Hypothetical Scenario Results
  – 2ºC Increase with no precipitation change causes decrease of 4% to 12% in runoff
  – 4ºC increase with no precipitation change causes decrease of 9% to 21% in runoff
  – Increases and decreases in precipitation with no temperature change lead to proportional changes in runoff
  – 4ºC increase needs +15 to +20% precipitation to break even

• GCM Results
  – GFDL (large temp increase, no precipitation change) -10% to -24% runoff
  – UKMO, GISS (+30% and +20% precipitation), runoff 0 to 10% higher
Inputs
- NCAR Parallel Climate Model – 2 runs
  - “Business as Usual” (BAU) CO2 Increases Used
  - Control Run Fixed at 1995 CO2
  - Note: a model with moderate ‘climate sensitivity’.
- Also a Hydrology Model and a CRSS-like model

Climate Outputs
- Control Run warms additional 1°F
- BAU Run warms 2°F by 2040, 3°F by 2070 and 5°F by 2100
- Very little precipitation changes under Control Run or BAU Run

Water Outputs
- Powell Releases met 80% under Control Run
- Powell Releases met 59% to 75% under BAU Run

http://www.hydro.washington.edu/~niklas/
Population Growth: Colorado River Basin

CO, NV, NM, WY, UT and AZ

Includes California

3rd Wettest in 500 yr
4th (?) Wettest in 1000 yr

Gray, Betancourt, Woodhouse, Meko, Graumlich
What’s a water manager to do??

• How is Climate Science like Aer Lingus Customer Service?
• Hard to plan for something that will take time to appear and has significant unknowns including model inaccuracies
• Don’t Expect Miracles from Science – progress will be slow.
• But Consider:
  – Dam about to burst on political incorrectness of this topic
  – Irresponsible not to use Paleodata and likely climate change inputs into planning – why not in shortage criteria discussions?
  – Environmental uses may be first to get shorted, creating big problems
  – Possible Flood Control Issues – Redo Rule Curves?
  – Drought, Population Pressures as analog for climate change?
Talk Summary

- 500-Year Drought? Serious, but not unprecedented!
- Stockton and Jacoby 13.5 maf annual average flow, taken for so long as truth, needs a closer look.
- New reconstruction, despite higher average flows, has deep droughts and climate variability way beyond historic record.
- There are good lessons to learn from paleoclimatology, but just remember our new climate may be very different.
- Climate Change is a reality, don’t expect science to provide all the answers, be prepared to make decisions without complete information.
- Population pressures will keep us all busy, no matter what happens to the climate.
- ‘Dinner’s on me’
The End…

Science has the first word on everything, the last word on nothing. – Victor Hugo

Graphic: Scientific American, 2004
Bibliography - 0

Bibliography – 1


*The Satanic Gasses*, Pat Michaels. One of the main climate skeptics. He has a new book called “Meltdown” which I have not read.


Bibliography - 2


*Climate Science 2001: An Analysis of Key Questions*, National Academy of Sciences. 31-page report was done at the request of the Bush Administration to clarify status of science early in the Bush administration.

National Assessment

http://www.usgcrp.gov/usgcrp/nacc/default.htm

The water sector chapter and water report provide a good overview of the likely impacts of climate change on the nation’s water resources. The climate models used in the study are suspect, unfortunately.

“Global Warming, The Complete Briefing”. 3rd Edition. John Houghton. This is a very good summary of the IPCC Third Assessment Report by one of the principal authors. Expensive but worth it if you want a detailed look at the science without reading the whole IPCC reports.
Bibliography - 3

A 431-Yr Reconstruction of Western Colorado Snowpack from Tree Rings

Treeflow – a tree-ring website for Colorado.
http://www.ncdc.noaa.gov/paleo/streamflow/

2000 Years of Drought Variability in the Central United States, Connie A.
Woodhouse*,+ and Jonathan T. Overpeck, Bulletin of the American

Stewart, I.T., Cayan, D.R., and Dettinger, M.D., 2004, Changes in snowmelt
runoff timing in western North America under a ‘business as usual’ climate

Stockton, C.W.. and Jacoby, G.C., Jr., 1976, Long-term surface-water supply
and streamflow trends in the upper Colorado River basin based on tree-ring
Emissions Scenarios
One Key to The Answer
IPCC Precipitation Projections
IPCC Temperature Projections
A Scientific Status Report:

There is a natural greenhouse effect; it keeps the Earth warmer than it would be otherwise.

Points...

• In terms of basic physics:
  
  ① If an object is bathed in visible light...
  ② It warms up and...
  ③ It emits infrared light.

In terms of our planet Earth:

<table>
<thead>
<tr>
<th>Atmosphere</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>78%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>20%</td>
</tr>
<tr>
<td>Water vapor</td>
<td>2%</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>0.03%</td>
</tr>
</tbody>
</table>

Key Aspects

> Water vapor & carbon dioxide have been part of our atmosphere for millions of years.
> Their presence yields an average surface temperature of ~60°F.
> Without them, the average would be ~5°F.

Q: So... What's the problem?
Greenhouse gases are increasing in the atmosphere because of human activities, and they are increasingly trapping more heat.

**Points...**

- **Impeccable Scientific Measurements**
  
  ![Graph showing CO₂ abundance from 1000 to 2000 years with a notable increase after 1800.](image)
  
  - **Air Samples**
  - **Ice Cores**
  - **Carbon Dioxide**

- Other gases have increased too.
  - For example: **Methane** (1/3 the effect of CO₂)
  - **Sulfur** (a cooling tendency)

- The sources are human-caused.
  - CO₂ ~ All (Combustion)
  - Methane ~ Most

**Q: But, what are the consequences?**
There is a collective picture of a warming world, and human activities have likely contributed.

Points...

- **Global Temperatures:** Up 0.7 - 1.4°F over past 100 years

  ![Graph showing temperature change](image)

  - From thermometers
  - From tree rings, corals...
  - Consistent with the warming:
    - Glacial retreat
    - Snow-cover decrease
    - Freeze-free periods lengthened
    - Sea-level increased: 4 - 8 inches

- Most of the warming over the past 50 years is likely to be due to greenhouse-gas increases.

  **Reasons:** Comparisons of simulated vs. observed temperatures:
  - Simulations with natural and human factors match observations best.
  - Correspondences increase with time.
  - Probability is low that a “natural-only” Earth would have such correspondences.

Q: What could this mean for the future?

Source: Dan Albritton
A continued growth in greenhouse gases is projected to lead to very significant increases in global temperatures and sea level.

- **CO₂ abundance will likely double before 2100.**
  > Indeed... to stabilize at doubled → cuts in emissions.

- **Predicted climate responses**
  > For a range of future emission scenarios (non-intervention, economics, technology, population, etc.)
  - Global temperature rise: 2.5 - 10°F by 2100.
  - If so, this would exceed the natural changes over the past 10,000 years.
  - Corresponding sea level rise: 4 - 35 inches by 2100.

- **A greenhouse warming could be reversed only very slowly.**
  > Reason: the oceans are sluggish.

Q: Beyond “global averages”?
It is a complex planet and we have imperfect knowledge. So, prediction of further details suffers.

Points...

- What will happen in particular places? (Here? Or here?) Regional changes cannot yet be predicted reliably.

- But, some projections are likely robust...
  - Land areas warm more than oceans (N. North America: 40% increase in mid-continental soil drying. Above average)

- How about "extreme events"?
  - A warmer world → a more-vigorous "hydrological cycle" (heavier rains, with large variance from region to region)
  - Hurricanes: more/less frequent? Much tougher to call.

- Surprises?
  - Currently unknown geophysical processes activated?
  - Abrupt climate shifts?
    - Possible. Here's why:
      - We are entering a new regime of climate perturbation.
      - Climate is a non-linear system.
CONCLUDING COMMENTS

**Bottom Lines**

- **The vast majority scientific viewpoint:**
  - The issue is a real one.
  - The first signs of human-caused climate change have likely occurred.
  - Some degree of further changes appears inevitable.
  - Exactly where (regions), when (rate of change) is hard to predict,
    how much (magnitude).
  - Human-caused climate change would be slow to reverse.

**Basis of this information**

Inter governmental Panel on Climate Change: 3rd major assessment:

- IPCC Climate 2001
- IPCC Impacts 2001
- IPCC Economics 2001

- January
- February
- March

Key input to policy formulation

Source: Dan Albritton
### IPCC Projected Changes

#### Table 1: Estimates of confidence in observed and projected changes in extreme weather and climate events.

<table>
<thead>
<tr>
<th>Confidence in observed changes (latter half of the 20th century)</th>
<th>Changes in Phenomenon</th>
<th>Confidence in projected changes (during the 21st century)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Likely&lt;sup&gt;7&lt;/sup&gt;</td>
<td>Higher maximum temperatures and more hot days over nearly all land areas</td>
<td>Very likely&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>Very likely&lt;sup&gt;7&lt;/sup&gt;</td>
<td>Higher minimum temperatures, fewer cold days and frost days over nearly all land areas</td>
<td>Very likely&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>Very likely&lt;sup&gt;7&lt;/sup&gt;</td>
<td>Reduced diurnal temperature range over most land areas</td>
<td>Very likely&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>Likely&lt;sup&gt;7&lt;/sup&gt;, over many areas</td>
<td>Increase of heat index&lt;sup&gt;12&lt;/sup&gt; over land areas</td>
<td>Very likely&lt;sup&gt;7&lt;/sup&gt;, over most areas</td>
</tr>
<tr>
<td>Likely&lt;sup&gt;7&lt;/sup&gt;, over many Northern Hemisphere mid- to high latitude land areas</td>
<td>More intense precipitation events&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Very likely&lt;sup&gt;7&lt;/sup&gt;, over many areas</td>
</tr>
<tr>
<td>Likely&lt;sup&gt;7&lt;/sup&gt;, in a few areas</td>
<td>Increased summer continental drying and associated risk of drought</td>
<td>Likely&lt;sup&gt;7&lt;/sup&gt;, over most mid-latitude continental interiors. (Lack of consistent projections in other areas)</td>
</tr>
<tr>
<td>Not observed in the few analyses available</td>
<td>Increase in tropical cyclone peak wind intensities&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Likely&lt;sup&gt;7&lt;/sup&gt;, over some areas</td>
</tr>
<tr>
<td>Insufficient data for assessment</td>
<td>Increase in tropical cyclone mean and peak precipitation intensities&lt;sup&gt;7&lt;/sup&gt;</td>
<td>Likely&lt;sup&gt;7&lt;/sup&gt;, over some areas</td>
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