Human-induced changes in the hydrological cycle of the western United States

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The Problem

The hydrological cycle is changing over the western United States

WHY?

Natural variability or man made?
WHY? Detection and Attribution (D&A)

• Detection: are the changes *inconsistent* with natural variability?

• Attribution: are the changes *consistent* with anthropogenic (or other) forcing?

• Generate a “fingerprint” that encapsulates changes expected (from model runs)

• Match fingerprint in obs and forced models
Detection & Attribution: Overall scheme

1. Start with global GCMs: control and anthropogenically forced runs


3. Run VIC hydrological model w/ downscaled data

4. D&A on 3 variables:
   - SWE/P (1 April Snow Water Equv. / Oct-Mar precip)
   - Temperature (examined JFM daily minimum temperature)
   - River flow (examined JFM fraction and CT, center of timing)
Multivariate fingerprint: PCM vs. MIROC
Ensemble signal strength & significance

Fingerprint

Signal Strength

Significance
D&A summary

- Natural variability cannot explain obs.
- Solar/volcanic forcing cannot explain obs.
- Changes in precipitation cannot explain obs.

- ANTHROPOGENIC warming CAN explain obs. changes very well

Q: WHY? ANS: It is ‘US’!
How good are estimates of Natural Variability?

Spectra reconstructed Colorado River flow last 1000+ years
Detection and Attribution of Human-induced changes in the western water supply

Signal to noise ratio

Significance of observed trends over time

High significance (< 1%)

Medium significance (< 5%)

Low significance (> 10%)

Changes detectable by mid 1980s

Barnett et al., Science, 2008
Conclusions

- The changes in western hydrology over 1950-99 are largely due to human-induced warming; PCM captures 74% of low frequency signal.

- The PCM, run in forecast mode, shows a grim view of western U.S. water supplies within the next 30 years (ACPI). If PCM worked so well over the last 50 years, we have good reason to believe these predictions.
Colorado River drainage

Water supply for:
- 27 million people
- 3.5 million acres of farmland

Users in:
- 7 states
- 2 countries
- Several Native American tribes

Current deliveries:
- ~13.5 maf/yr, increase to ~14.4 maf/yr by 2060
“Modeling assumptions…allowed a maximum shortage of 3.3 maf, resulting in the inability to absolutely protect Lake Mead elevation 1,000 feet msl.” (pg. N-18)
Changes in Runoff by midcentury
(Numbers show model agreement; colors show change)

Climate change assumptions

• Two areas of inquiry

1. How will the river runoff change?

2. How will the change affect deliveries?

<table>
<thead>
<tr>
<th>Source</th>
<th>Runoff reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nash and Gleick (1991)</td>
<td>12-31% (depends on scenario)</td>
</tr>
<tr>
<td>Nash and Gleick (1993)</td>
<td>8-20%</td>
</tr>
<tr>
<td>Christensen et al. (2004)</td>
<td>18%</td>
</tr>
<tr>
<td>Milly et al. (2005)</td>
<td>10-25%</td>
</tr>
<tr>
<td>Seager et al. (2007)</td>
<td>15-20%</td>
</tr>
<tr>
<td>Christensen &amp; Lettenmaier (2007)</td>
<td>6-7%</td>
</tr>
<tr>
<td>Hoerling and Eischeid (2007)</td>
<td>45% (under revision)</td>
</tr>
<tr>
<td>McCabe and Wolock (2007)</td>
<td>8-17%</td>
</tr>
</tbody>
</table>
How much water can the river supply?

Assuming 20th century flows:
- 10% runoff: ~13.7 maf/yr
- 20% runoff: ~12.5 maf/yr
a) 20th cen, no climate change

"R": Requested
"D": Delivered (mean)
"B10%": Delivered (bottom 10%)

b) 20th cen, -10% runoff

c) 20th cen, -20% runoff

d) Paleo mean, no climate change

e) Paleo mean, -10% runoff

f) Paleo mean, -20% runoff
Do we have time to change directions??

We are headed for a water ‘crisis’ in the Western U.S. (and it has already started)
Lake Mead, Oct 2007(&Feb,2010)

Lake Mead's elevation is 15 feet lower than last year at this time!
Lake Mead is 118 feet below maximum elevation!
Lake Mead has fallen to 46% of capacity!

From K. Dewey, HPRCC