From climate-change spaghetti to climate-change distributions

What are the models trying to tell us?
Under a business-as-usual emission scenario, climate models yield a fairly narrow range of warming scenarios for California...

They also suggest that major changes are not more than about 20 year away...
Still, the lessons we take from projections and reconstructions continue to be very uncertain…

### 21st Century Western US Climate - Conclusions

<table>
<thead>
<tr>
<th>Greenhouse Effect</th>
<th>Paleoclimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rising Temperatures</td>
<td>Continued Drought and Flood</td>
</tr>
<tr>
<td>Rising Sea Level</td>
<td>20th Century Warming</td>
</tr>
<tr>
<td>Less Snow &amp; Snowpack</td>
<td>Unprecedented</td>
</tr>
<tr>
<td>Early Runoff</td>
<td>Natural MegaFloods</td>
</tr>
<tr>
<td>More Flooding</td>
<td>MegaDroughts Possible</td>
</tr>
<tr>
<td>Drier Summers</td>
<td>20th Century Unusually</td>
</tr>
<tr>
<td>More or Less Precip?</td>
<td>Benign (wet)</td>
</tr>
<tr>
<td></td>
<td>Gradual /Abrupt Change?</td>
</tr>
</tbody>
</table>
However, by the middle of the 21st Century, even in the coolest of the models, earlier snowmelts & major reductions in snowpacks and water resources of the Sierra Nevada are projected...

Knowles & Cayan, GRL, 2002
So we are being whipsawed by projections of disruptive near-future climates that are highly uncertain.

At the same time, California is currently in engaged in making some major and long-term decisions balancing resource management & ecosystems restoration (e.g., CALFED & SWP Updates).

Climate-change issues are part of the discussion...

But what climate changes should we be preparing for?
What climate changes should we prepare for?

- Recent PIER-funded (& other) studies bookend possibilities by choosing HadCM (or CCC) warmest/wettest projections and PCM (or other) cooler/"drier" projections

- Recent DOE-funded studies “chose” a model with least climate changes

These approaches have led to public misconceptions re: what c-c projections (in general) are suggesting:

a relatively modest warming & wetter future for California?
A BROADER PERSPECTIVE GIVES A DIFFERENT VIEW:

For California, the influence of uncertainties about emission scenarios and scatter among models aren’t so different (among currently available projections).
Lets look at this ensemble of projections in more detail:

Let me separate the ensemble projections into independent components (by PCA) and then randomly shuffle those components to effectively increases the number of realizations.

This allows us to form a simple estimate of the projection distribution function (pdf).
HOW DOES THE ENSEMBLE EVOLVE?

The PCA-resampling procedure yields an estimate of time-varying joint projection distributions (pdfs) of temperature and precipitation change during the 21st Century, allowing us to better visualize what the projections are doing.
Time slices through these component-resampled pdfs emphasize:

- Important temperature (& snowmelt) changes within about 20 years
- Strong tendency toward little precipitation change, with a hint of slightly drier
- General spreading of possibilities (espec. temperatures) due to model and emissions uncertainties
WHAT JOINT BEHAVIORS OF TEMPERATURE & PRECIPITATION ARE INDICATED?

There is an interesting tendency for the warmer projections to be drier and for the cooler projections to be wetter... but we can’t explain it, so we can’t rely on it to be a general rule.
WHERE DO THESE UNCERTAINTIES COME FROM?

Forming a smaller ensemble from 6 models forced by just one set of emissions shows model differences contribute about 1/2 of the overall scatter. The other half mostly comes from differences between the emission scenarios.

Dashed: Responses to one emission
Solid: Full ensemble
Precipitation
Divergence in trend and magnitude

Air Temperature
Models agree that air temperature increases, but vary in the magnitude and rate of increase

(Source: D. Cayan, April 2003, ISAO Workshop)
Climate Change Predictions for Northern California Differ

Precipitation
Divergence in trend and magnitude

Air Temperature
Models agree that air temperature increases, but vary in the magnitude and rate of increase

(Source: D. Cayan, April 2003, ISAO Workshop)
WHAT IF SOME MODELS ARE BETTER THAN OTHERS?

Weighting the resampling by model climatological drift shows that choice of models may not be so crucial as long as a fairly complete ensemble is available.

Dashed: Model-types weighted differently
Solid: All models weighted equally
Ultimately, such climate changes and uncertainties imply corresponding changes in California streamflows...

Should we be starting to address the modes of these distributions?
WHAT IS THE ENSEMBLE TRYING TO SAY?

Northern California temperature projections are broadly in consensus (+3 to +6 or more °C), enough for earlier flows, more floods & drier summers

- Warming already underway and coming fast

Northern California precipitation projections are a bit more scattered, with MOST showing small (drier?) changes but with a couple of outliers much wetter

- These results hold even if we weight some models less than the others (without eliminating any completely).
To paraphrase Myles Allen (Nature 2003):

“It is time for climate modelers to start identifying changes that can be ruled out as unlikely rather than simply ruled in as possible.”

Or even more boldly...

Is it time for California analysts to address what is more likely rather than what is just possible?
The End