Verifying the water vapor feedback using ENSO

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How can we measure this?

forcing e.g., CO$_2$ increase

$T_s$ increase

Atmospheric humidity increases

feedback
<table>
<thead>
<tr>
<th>Volcano</th>
<th>Constant Relative Humidity</th>
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<tbody>
<tr>
<td>ENSO+interannual</td>
<td>Partial Radiative Perturbation</td>
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<tr>
<td>seasonal cycle</td>
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<td>decade-scale warming</td>
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</table>
### Observational tests of the water vapor feedback

<table>
<thead>
<tr>
<th>Phenomenon</th>
<th>References</th>
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<tbody>
<tr>
<td>Volcano</td>
<td>Soden et al., 2002; Forster and Collins, 2004</td>
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<tr>
<td>ENSO+interannual</td>
<td>Soden, 1997; Dessler et al., 2008; Minschwaner and Dessler, 2004; Gettelman and Fu, 2008;</td>
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<td>Seasonal cycle</td>
<td>Inamdar and Ramanathan, 1998; Wu et al., 2008</td>
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<td>Decade-scale warming</td>
<td>Hall and Manabe, 1999; Soden et al., 2005</td>
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</tbody>
</table>
Partial Radiative Perturbation

\[ T_{s-a} \quad q_a \quad T_{atm-a} \quad ice_a \quad T_{s-b} \quad q_b \quad T_{atm-b} \quad ice_b \]

Wetherald and Manabe, 1988
Colman, 2003; Forster and Collins, 2004;
Soden and Held, 2006
Wetherald and Manabe, 1988?
Colman, 2003; Forster and Collins, 2004;
Soden and Held, 2006
\[ \Delta R = \text{change in global average TOA flux due to } \Delta q \]
\[ \Delta T_s = \text{change in global avg. surface temperature change (} T_{s-b} - T_{s-a} \) associated with } \Delta q \]

\[ T_{s-a} \]
\[ q_a \]
\[ T_{atm-a} \]
\[ \text{ice}_a \]

\[ T_{s-b} \]
\[ q_b \]
\[ T_{atm-b} \]
\[ \text{ice}_b \]

Wetherald and Manabe, 1988?
Colman, 2003; Forster and Collins, 2004;
Soden and Held, 2006
the water vapor feedback

\[ \lambda = \frac{\Delta R}{\Delta T_s} \]

\[ T_s = \frac{-G}{\lambda_o + \lambda_1 + \lambda_2 + \cdots} \]

\( \Delta R = \text{change in global average TOA flux due to } \Delta q \text{ between two climate states} \)

\( \Delta T_s = \text{change in global avg. surface temperature change (} T_{s-b} - T_{s-a} \text{) associated with } \Delta q \)

Wetherald and Manabe, 1988?
Colman, 2003; Forster and Collins, 2004;
Soden and Held, 2006
Method

- AMIP models from the PCMDI archive
- Reanalysis: ERA40 & MERRA
- For each strong DJF ENSO month (e.g., Jan. 1983), calculate $\Delta R$ and $\Delta T_s$ between that month and the long-term average for all Januaries in the model run
- Obtain one estimate of $\Delta R$ and $\Delta T_s$ for every strong ENSO month
Each point is a strong ENSO DJF
\[ \lambda = \frac{\Delta R}{\Delta T_S} \]

<table>
<thead>
<tr>
<th>Model</th>
<th>ERA40</th>
<th>MERRA</th>
<th>Dessler 2008</th>
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AMIP models

Soden and Held estimate of long-term feedback
Conclusions 1

• Models, reanalysis, and pure obs. agree that the feedback is positive and strong

• Reanalysis is larger than the models
  – if reanalysis is correct, then models are *underestimating* the feedback
  – uncertainties generally overlap

• ENSO WV feedback larger than in response to long-term warming (e.g., Colman, Soden and Held)
Questions for the rest of the talk

• What is the source of disagreements among the models and between the models and reanalyses?

• Speculation: Why is the ENSO feedback larger than the feedback in response to long-term warming?
Water vapor feedback is primarily a “tropical” phenomenon

* ΔR determined by tropical UT Δq
* tropical q controlled by tropical surface temperatures
  e.g., Minschwaner and Dessler, 2004
* ΔR (and the WV feedback) is controlled by tropical surface T

Change in R per unit change in q(x,y,z): ΔR/Δq(x,y,z)

Fig. 2 of Soden et al., 2008
Regress $\Delta R$ vs. *global* surface temperature
Regress $\Delta R$ vs. *tropical* surface temperature
What does this mean?

• A consistent relationship exists between tropical surface $\Delta T_T$ and the radiative response to water vapor $\Delta R$
  – GCMs
  – reanalyses
  – pure obs.
\[ \lambda = \frac{\Delta R}{\Delta T_S} \]

\(\Delta R\) for these two worlds is the same.
\(\Delta T_S\) is different.
\[ \lambda = \frac{\Delta R(\Delta q(\Delta T_T))}{\Delta T_G} \]
Summary

• In response to ENSO climate change, models, reanalysis, and pure obs. show a strong and positive water vapor feedback.
• Models, reanalysis, and pure obs. show that the radiative response to WV between two climate states is determined by change in the tropical surface T.
  • WV feedback determined by tropical UT water.
  • Tropical UT water is controlled by surface T described by Minschwaner and Dessler [2004] (see me for reprints).
• Differences among models and between models and reanalyses are due to differing estimates of extratropical surface T changes --- they are NOT due to the radiative response of WV.
• This work is in press at *J. Climate*. See me for preprints.