The Effects of Precipitation Assimilation on the North American Regional Reanalysis Water Cycle

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Overview

1. Impacts Research at GISS
   - Bangladesh
   - RCM over Central America

2. North American Regional Reanalysis Water Cycle

3. Mean balance

4. Precipitation Assimilation

5. Normalized Covariance Approach

6. Annual Component Interactions

7. Diurnal Component Interactions
Integrated Climate Impacts Approach

**Climate Scenarios:**
Calculate climate changes relative to baseline
Downscale if necessary
Modify observations to produce scenarios

**Impacts Assessment Models:**
Pass each scenario all the way through process
Only produce ensemble at end
Crop, hydrologic, and coastal models for Bangladesh
% Change in Potential Rice Yield for Each Impact Component (Bangladesh)

<Preliminary Results>

(median displayed)

Dinajpur Irrigated Dry-Season Rice

Ishwardi Monsoon Rice

Khulna Monsoon Rice

Drought Region example

Flood Region example

Coastal Region example
• Large changes across short distances that could not be captured in the coarser CCSM.

• Mountains warm faster than surrounding lowlands.

• Project designed for impacts analysis
  - 2020-2050 A2 and B1 simulations
The NCEP North American Regional Reanalysis (NARR) covers 1979-2003 at 32-km and 3-hourly resolution.

- Driven by NCEP/DOE Reanalysis-2 forcing conditions
- Assimilates state variables every 3 hours
- Precipitation and radiance assimilation every hour

Elevation in NARR domain; From Mesinger et al., 2006, Bull. Amer. Meteor. Soc.
The Atmospheric Water Budget

Precipitable Water Tendency = Moisture Flux Convergence + Evaporation - Precipitation + residual

\[
\frac{\partial \{q\}}{\partial t} = -\nabla \cdot \{vq\} + E - P + r
\]

Mean balance:
\[
\overline{T} = \overline{C} + \overline{E} - \overline{P} + \overline{r}
\]

Transient balance:
\[
T' = C' + E' - P' + r'
\]
Note that the tendency term is negligible (<0.2mm/d) over the 20-year period.
### Sources of Assimilated Precipitation

<table>
<thead>
<tr>
<th>Region</th>
<th>Assimilation Source</th>
<th>Frequency of Source Measurements</th>
<th>Higher Frequency Filling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continental United States</td>
<td>1/8° rain gauge analysis with PRISM</td>
<td>Daily</td>
<td>2.5° hourly analysis</td>
</tr>
<tr>
<td>Canada</td>
<td>1° rain gauge analysis</td>
<td>Daily</td>
<td>~1.9° Reanalysis-2 hourly weights</td>
</tr>
<tr>
<td>Mexico</td>
<td>1° rain gauge analysis</td>
<td>Daily</td>
<td>~1.9° Reanalysis-2 hourly weights</td>
</tr>
<tr>
<td>Land South of Mexico</td>
<td>2.5° CMAP precipitation analysis</td>
<td>Pentad</td>
<td>~1.9° Reanalysis-2 hourly weights</td>
</tr>
<tr>
<td>Alaska</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Oceans, south of 27.5° latitude</td>
<td>2.5° CMAP precipitation analysis</td>
<td>Pentad</td>
<td>~1.9° Reanalysis-2 hourly weights</td>
</tr>
<tr>
<td>Oceans, 27.5°-42.5°</td>
<td>2.5° CMAP precipitation analysis to South blended with no assimilation to North</td>
<td>Pentad</td>
<td>~1.9° Reanalysis-2 hourly weights</td>
</tr>
<tr>
<td>Oceans, north of 42.5° latitude</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

CMAP = CPC Merged Analysis of Precipitation
Precipitation assimilation accomplished by comparing model-generated precipitation to observed precipitation analyses and adjusting using a moisture increment (hourly)

- If $\Delta > 0$: Revise convective parameters to drive appropriate amount of additional convection
- If $\Delta < 0$: Adjust latent heating profile to slow convection
- Liquid water and water vapor increments added to precipitable water column to reduce strain on convective parameterization
  - Add water into column if too dry
  - Remove water if too wet
  - No adjustment of evaporation or moisture flux convergence
- Useful to define model precipitation estimate ($M$)
1980-1999 Moisture Increment ($I$)

1980-1999 Model Precipitation Estimate ($M$)

1980-1999 NARR Precipitation ($P$)

Model Precipitation Estimate

$M \stackrel{\text{def}}{=} P - I$

More active hydrologic cycle suggested in underlying model
Normalized Covariance

Transient balance: $P' = C' + E' - T' + r'$

Isolated diurnal and annual variation using band-pass Fourier filtering

1) Take covariance of each side with $P'$
2) Divide by variance of $P'$
3) Multiply by 100%:

\[
\frac{\text{cov}(P', P')}{\text{var}(P')} \times 100\% = \frac{\text{cov}(C', P') + \text{cov}(E', P') + \text{cov}(-T', P') + \text{cov}(r', P')}{\text{var}(P')} \times 100\% = 100\%
\]

“Normalized covariance” of $Q'$ with $P' = \text{cov}(Q', P')/\text{var}(P')$
- sum of budget normalized covariances explain 100% of a variable’s variance
Visualization Example

Normalized Covariance of Evaporation with Precipitation in the Diurnal Band

\[
\frac{\text{cov}(E', P')}{\text{var}(P')} \times 100\%
\]

- \(<0\%\) = Normalized covariance indicates variance with opposite phase
- \(0\%\) = No covariant relationship
- \(100\%\) = Covariance explains all variance
- \(>100\%\) = Covariance exceeds variance

Insignificant areas omitted (excludes regions with low rainfall in this case)
Annual Water Cycle Interaction
Annual cycle has regional differences
- Wintertime over West
- Early summer over continental interior
- Low magnitude over SE USA

NARR closer to PERSIANN than CMORPH
Annual Precipitation Band

\[ \frac{\text{cov}(E', P')}{\text{var}(P')} \]

\[ \frac{\text{cov}(C', P')}{\text{var}(P')} \]

\[ \frac{\text{cov}(-T', P')}{\text{var}(P')} \]

\[ \frac{\text{cov}(r', P')}{\text{var}(P')} \]

Sum of all four = 100% for every grid point
Annual Budget Errors

\[ \frac{\text{cov}(E',P')}{\text{var}(P')} \quad \text{and} \quad \frac{\text{cov}(E',M')}{\text{var}(M')} \]

Covariances of Evaporation with Precipitation and Model Precipitation Estimate
Annual Budget Errors

\[
\frac{\text{cov}(C', P')}{\text{var}(P')}
\]

\[
\frac{\text{cov}(C', M')}{\text{var}(M')}
\]

Covariances of Moisture Flux Convergence with Precipitation and Model Precipitation Estimate
Diurnal Water Cycle Interaction
Diurnal cycle has large variation across North America
- Nocturnal maximum over Upper Midwest
- NARR does not match satellite-based High-Resolution Precipitation Products
Summertime Diurnal Band of Precipitation Assimilation

\[
cov(M', P')/\text{var}(P')
\]

\[
cov(V', P')/\text{var}(P')
\]

\[
cov(D', P')/\text{var}(P')
\]

Sum of all three = 100% for every grid point

\[
I' = V' + D'
\]

\[\Rightarrow P' = M' + V' + D'
\]

The precipitation assimilation Increment consists of both a Vapor and cloud condensate term which may be analyzed separately.
Diurnal Budget Errors

\[ \frac{\text{cov}(E', P')}{\text{var}(P')} \]

\[ \frac{\text{cov}(E', M')}{\text{var}(M')} \]

Covariances of Evaporation with Precipitation and Model Precipitation Estimate
Diurnal Budget Errors

\[
\frac{\text{cov}(C', P')}{\text{var}(P')}
\]

\[
\frac{\text{cov}(C', M')}{\text{var}(M')}
\]

Covariances of Moisture Flux Convergence with Precipitation and Model Precipitation Estimate
Precipitation assimilation requires new considerations in atmospheric water budget analysis
- Regional precipitation input may affect impact assessments

NARR output overestimates the role of other atmospheric water cycle components that are not directly adjusted by precipitation assimilation

Normalized covariance statistic reveals interesting regional balances and exchanges
- Nocturnal maximum over upper US Midwest: Precipitation assimilation reduces daily summer rainfall and adds a lesser amount during summer nights

Background and future publications
- Normalized covariances for Reanalysis-2 in Ruane and Roads, 2008a (J. Climate)
- Sensitivity comparisons in Ruane and Roads, 2008b (Earth Interactions)
- The NARR results presented here will be submitted as annual and diurnal companion papers (Ruane, 2009a,b, in preparation)
- Normalized covariance anomalies used to examine 1993 flood and 1988 drought (Ruane, 2009c, in preparation)
Thank You!

Contact me at aruane@giss.nasa.gov or come by room 304!