An updated view of global water cycling

P. Houser (EWG & GMU),
C. Schlosser (MIT), X. Gao (MIT),
B. Lin (LaRC), J. Lehr (EWG), J. Entin (NASA),
NASA-NEWS Team

http://crew.iges.org
Why study the water & Energy cycle?

1. Water exists in all three phases in the climate system and the phase transitions are a significant factor in the regulation of the global and regional energy balances.

2. Water vapor in the atmosphere is the principal greenhouse gas and clouds at various levels and composition in the atmosphere represent both positive and negative feedback in climate system response.

3. Water is the ultimate solvent and global biogeochemical and element cycles are mediated by the dynamics of the water cycle.

4. Water is the element of the Earth system that most directly impacts and constraint human society and its well-being.
Multi-model ensemble mean change from IPCC GCMs

Change in (P-E) for 2100 minus 2000

"Dry regions get drier, wet regions get wetter"

Held and Soden (2006)

"Thermodynamic" component

Held and Soden (2006)

"Dry regions get drier, wet regions get wetter"

Vecchi and Soden (2007)
**Objective**

**Summary:** Integrate legacy global water and energy (W&E) cycle data sets and construct/splice the state-of-the-art W&E climatology; understand the global W&E variations at annual and longer time scales.

**Hypothesis:** Observationally-based estimates water and energy fluxes can be balanced and provide useful characterizations and evaluation data for climate studies and modeling.

**Science Questions:**
- Do observations provide a consistent depiction of global energy and water cycling?
- What are the observational uncertainties, and are they “useful” for evaluation?
- What basic processes can be resolved and characterized by the integrated data sets?
- How do we test weather/climate models using these integrated W&E observations?
- Why do the water and energy budget terms not balance? Are there algorithms and/or assumptions at play?
## Data and Methods

### Extended Analyses (of Schlosser and Houser, J. Climate, 2007)

<table>
<thead>
<tr>
<th>Fluxes</th>
<th>Product</th>
<th>Spatial</th>
<th>Temporal</th>
<th>Source &amp; Primary Contact(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>60S ~ 60N; 180W ~ 180E (0.25°)</td>
<td>12Z29Jan2002 ~ present (3hr)</td>
<td>trmmopn.gsfc.nasa.gov (George J. Huffman)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>TMPA</td>
<td>60S ~ 60N; 180W ~ 180E (0.25°)</td>
<td>00Z07Dec2002 ~ present (3hr)</td>
<td>ftp.cpc.ncep.noaa.gov (Robert Joyce &amp; John Janowiak)</td>
</tr>
<tr>
<td></td>
<td>CMORPH</td>
<td>50S ~ 50N; 180W ~ 180E (0.25°)</td>
<td>00Z01Mar2000 ~ present (6hr)</td>
<td>hydis8.eng.uci.edu (Kuolin Hsu &amp; Dan Braithwaite)</td>
</tr>
<tr>
<td></td>
<td>PERSIANN</td>
<td>60S ~ 90N; 180W ~ 180E (1°)</td>
<td>Jan1979 ~ Aug2006 (Monthly)</td>
<td>hsbserv.gsfc.nasa.gov (Matthew Rodell)</td>
</tr>
<tr>
<td>Evaporation</td>
<td>GLDAS (Land)</td>
<td>80S ~ 80N; 180W ~ 180E (1°)</td>
<td>00Z01Jan1987 ~ 12Z31Dec2005 (12hr)</td>
<td><a href="http://www.hoaps.zmaw.de">www.hoaps.zmaw.de</a> (Axel Andersson)</td>
</tr>
<tr>
<td></td>
<td>HOAPS (Ocean)</td>
<td>90S ~ 90N; 180W ~ 180E (1°)</td>
<td>00Z01Jan2005 ~ 21Z31Dec2005 (3hr)</td>
<td>JPL (Eric Fetzer and Van Dang)</td>
</tr>
<tr>
<td></td>
<td>GRACE (Terrestrial)</td>
<td>30S-30N; 180W-180E (0.5°)</td>
<td>07Jul1999 ~ 31Dec2005 (daily)</td>
<td>airsea.jpl.nasa.gov (Timothy Liu &amp; Xiaosu Xie)</td>
</tr>
<tr>
<td>Moisture Transport</td>
<td>MOIS_TRANS</td>
<td>30S-30N; 180W-180E (0.5°)</td>
<td>00Z01Jan2005 ~ 31Z31Dec2005 (12hr)</td>
<td>JPL (Eric Fetzer and Van Dang)</td>
</tr>
</tbody>
</table>

**Atmospheric Budget:** \[ \frac{dQ}{dt} = E - P - \text{div}(Q_t) \]

**Terrestrial Budget:** \[ \frac{dS}{dt} = P - E - R \]
Global Results: 1988-2001

- HOAPS (still) shows trend and Pinatubo plunge.
- GPCP/CMAP(r): The good, the bad, and the "split"
- Latter half of period, fluxes converging, really?
- Trend detection - need long monotonic trend to verify GCMs (for low-risk detection).

### Table 1. Global annual mean results of water budget terms for the period 1988-2001.
Values are given in units of $10^{17}$ kg/yr.

<table>
<thead>
<tr>
<th></th>
<th>GPCP</th>
<th>CMAP</th>
<th>CMAPr</th>
<th>HOAPS &amp; GOLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land</td>
<td>1.07 ± 0.02</td>
<td>9.98 ± 0.01</td>
<td>1.00 ± 0.01</td>
<td>0.684</td>
</tr>
<tr>
<td>Ocean</td>
<td>3.79 ± 0.06</td>
<td>3.74 ± 0.04</td>
<td>3.94 ± 0.04</td>
<td>3.95</td>
</tr>
<tr>
<td>Global</td>
<td>4.86 ± 0.06</td>
<td>4.75 ± 0.04</td>
<td>4.94 ± 0.04</td>
<td>4.63</td>
</tr>
</tbody>
</table>
Most regions - land evaporation peaks in summer, ocean evaporation in winter.

Annual cycle of global water vapor storage reflects the Northern Hemisphere signal.
Not much consistency seen between legacy and next-generation estimates at the global scale... for now.
Most land regions - evaporation positively correlated with atmospheric vapor.

Most ocean regions - correlation is largely negative. Due to bulk evaporation formula driven by winds, which are high in winter.

These characterizations, although weakened somewhat, also hold if “annual cycle” of period removed.
Consistency between Atmospheric Storage and Surface (Land+Ocean) Storage?

\[ \Delta Q_{\text{LAND}} + \Delta Q_{\text{OCEAN}} + \Delta Q_{\text{ATMOS}} = 0 \]
Terrestrial Water Storage Change

A: GRACE
\[ \Delta \bar{S} = d_{mn} - d_{mc} \]
\[ \Delta \bar{S} = \bar{S}_{mn} - \bar{S}_{mc} = \frac{1}{N} \sum_{i=1}^{N} (S_{mn,i} - S_{mc,i}) \]

B: GLDAS_der
\[ \Delta \bar{S} = \frac{1}{N} \sum_{i=1}^{N} \sum_{j=i}^{N+i-1} (P_j - E_j - R_j) \]

C: GLDAS_dW
\[ \Delta \bar{S} = \bar{W}_{mn} - \bar{W}_{mc} \]
\[ W = \text{monthly mean of sum of soil moisture in all soil layers, accumulated snow water equivalent, and plant canopy surface water.} \]

D: GLDAS_dW01
\[ \Delta \bar{S} = W_{mn\ 01} - W_{mc\ 01} \]
\[ W = \text{Sum of soil moisture in all soil layers, accumulated snow water equivalent, and plant canopy surface water at 1st day of each month.} \]
terrestrial water storage change (mm/mon)

GLDAS_der

NOAH

MOS

CLM

GLDAS_dW01
GLDAS-based continental water balance

Annual mean precipitation (GPCP/CMA), evapotranspiration, runoff, and terrestrial water storage amplitude (range/2) by continent, as equivalent heights of water (cm = 10 kg/m²) based on 1979-2007 output from four GLDAS-driven models: Noah, VIC, CLM2, and Mosaic. Map shows terrestrial water storage amplitude (cm).

Rodell et al., 2008
Summary

• Annual global precipitation and evaporation are close to balance - with uncertainty.
• Ocean evaporation estimates still show unconfirmed trend.
• Next generation, high resolution precipitation data need work.
• The derived water vapor convergence from AIRS and AMSR-E demonstrates strong spatiotemporal consistency with each other.
• The terrestrial water storage change derived from GLDAS compares quite well with GRACE observations in terms of spatial pattern and seasonal variations, but their magnitudes show notable differences.
• Energy balance estimates are mature, and need integration with water balance analysis.