A Satellite View of the Global Water and Energy Cycle

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Water Cycle Research Making a Difference

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.**
The availability of new observations strongly motivates advances in understanding, prediction, and application.

Transport + Evaporation - Precipitation – Runoff

\[ P = \Delta \text{Land Storage} + \Delta \text{Water Vapor} \]

We must define and develop an integrated user-focused water observation system that can not only detect climate trends but also local variation of extremes.

We must preserve critical in-situ benchmark observations that enable us to detect trends & extremes.
### 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>Precipitation</td>
<td>TMPA</td>
<td>60S ~ 60N; 180W ~ 180E (0.25°)</td>
<td>12Z29Jan2002 ~ present (3hr)</td>
<td>trmmopen.gsfc.nasa.gov (George J. Huffman)</td>
</tr>
<tr>
<td></td>
<td>CMORPH</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>PERSIANN</td>
<td>50S ~ 50N; 180W ~ 180E (0.25°)</td>
<td>00Z01Mar2000 ~ present (6hr)</td>
<td>hydis8.eng.uci.edu (Kuolint Hsu &amp; Dan Braithwaite)</td>
</tr>
<tr>
<td>Evaporation</td>
<td>GLDAS (Land)</td>
<td>60S ~ 90N; 180W ~ 180E (1°)</td>
<td>Jan1979 ~ Aug2006 (Monthly)</td>
<td>hsbserv.gsfc.nasa.gov (Matthew Rodell)</td>
</tr>
<tr>
<td></td>
<td>HOAPS (Ocean)</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>Storage</td>
<td>AIRS-AMSRE</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>(Atmosphere)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Terrestrial)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture Transport</td>
<td>MOIS_TRANS</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>
</tbody>
</table>

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

**Terrestrial Budget:** \[ \frac{dS}{dt} = P - E - R \]
• 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 monotic trend to verify GCMs (for low-risk detection).

<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>

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.
“Global” (50S-50N) Annual Timeseries of Legacy and Next-Generation Precipitation

Not much consistency seen between legacy and next-generation estimates at the global scale... for now.
Atmospheric Water Storage (AIRS, AMSR-E)

Annual mean storage (mm)

mean annual cycle of storage change (mm/mon)
Terrestrial Water Storage Change

**A: GRACE**

\[ d = \text{anomaly of monthly mean equivalent water thickness} \]

\[ \Delta S = d_{mn} - d_{mc} \]

**B: GLDAS_der**

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

\[ = \frac{1}{N} \sum_{i=1}^{N} \sum_{j=i}^{N} (P_{j} - E_{j} - R_{j}) \]

**C: GLDAS_dW**

\[ W = \text{monthly mean of sum of soil moisture in all soil layers, accumulated snow water equivalent, and plant canopy surface water}. \]

\[ \Delta \bar{S} = \bar{W}_{mn} - \bar{W}_{mc} \]

**D: GLDAS_dW01**

\[ W = \text{Sum of soil moisture in all soil layers, accumulated snow water equivalent, and plant canopy surface water at 1^{st} day of each month}. \]

\[ \Delta \bar{S} = W_{mn\ 01} - W_{mc\ 01} \]
terrestrial water storage change (mm/mon)
Atmospheric heat budget

- Radiation:
  TOA & sfc -- SRB, CERES, ISCCP-FD
  bias errors: ~ 10 W/m$^2$

- Sea surface turbulent fluxes:
  GSSTF, HOAPS
  bias errors: ~ 7 W/m$^2$

- Precipitation: GPCP
  atmospheric latent heat balance
  annual mean errors: 5%
oceanic heat transport

Zhang et al., JGR, 20
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

Δ(P-E) mm/day

Held and Soden (2006)

Vecchi and Soden (2007)
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.
Future Work

• More observational data becoming available

• Obtain error /uncertainty estimates of all water-cycle variables for more accurate quantification of the closure of global water budget and consistency.

• Compare the budget and residual estimates to other “independent” data, such as coupled GCM simulations from the IPCC AR4 archive and reanalysis products from NCEP-NCAR and ECMWF.
  – highlight consistencies and discrepancies between model estimates and satellite observations
  – provide insights on the regions where the continued evaluation, future model improvement, in-situ networks, field campaigns, and (potential) experimental satellite missions should emphasize.