The NEWS Water and Energy Cycle Climatology Project

Matthew Rodell, Tristan L'Ecuyer, Hiroko Kato Beaudoin, and the NEWS Water and Energy Cycle Climatology Team
The State of the Global Water and Energy Cycles

Premise: In order to evaluate water and energy cycle consequences of climate change, we must establish the current "state of the global water/energy cycle".

Methods: Use modern, observation-integrating products and associated error-analyses to develop a monthly climatology of W&E cycle components for each continental/oceanic to global scale region.

Outcomes: (1) A benchmark for W&E cycle / climate change studies and model assessments. (2) Quantitative graphical depictions of the water and energy cycles.
Global Precipitation Climatology Project (GCPG)

A global data set project under WCRP/GEWEX
Adler, Huffman, Gu, Chiu, Xie, Ferraro, Schneider

Monthly Analysis of Global Precipitation Using Satellite and Gauge Information (1979-present)

GPCP data used in > 1200 journal articles

Huffman et al. (2009) GRL

Monthly 2.5° resolution; pentad and daily products also

Low-orbit microwave over ocean and land adjusting geo-IR and merged with gauges over land with sounder estimates at high latitudes

http://www.ncdc.noaa.gov/oa/wmo/wdcamet-ncdc.html
http://precip.gsfc.nasa.gov
Development and diagnostic analysis of a multi-decadal global evaporation product for NEWS

Eric F Wood

Panel a: Annual terrestrial ET using the ISCCP data and a Penman-Monteith RS model
Panel b: 1984-2007 terrestrial and global ET estimates using PM/ISCCP. Note comparison to VIC LSM and global P ~2.8 mm/day
Panel c: Comparing remote sensing to operational models being assessed by NEWS
SeaFlux Climatological Data Set Version 1.0
Carol Anne Clayson, project director

- Near-surface air temperature and humidity
  - Roberts et al. (2010) neural net technique
  - SSM/I only from CSU brightness temperatures (thus only covers 1997 - 2006)
  - Gap-filling uses MERRA variability – 3 hour
- Winds
  - Uses CCMP winds (cross-calibrated SSM/I, AMSR-E, TMI, QuikSCAT, SeaWinds)
  - Gap-filling uses MERRA variability – 3 hour
- SST
  - Pre-dawn based on Reynolds OISST
  - Diurnal curve from newly developed parameterization (Clayson and Bogdanoff, 2010)
- Uses neural net version of COARE 3.0 flux model to compute fluxes

1999 Latent Heat Flux

1999 Sensible Heat Flux
NASA’s Modern Era Retrospective-analysis for Research and Applications (MERRA)
Mike Bosilovich and Pete Robertson

- 1979-present (continuing as it is feasible)
- ½° horizontal resolution (72 model levels, sfc-strat)
- 1 hourly surface and 2D diagnostic data
  - Including complete budgets and extensive meteorology, lowest model level states
- 6 hourly 3-Dimensional atmospheric analysis
- 3 hourly 3-D model background diagnostics, coarse resolution
- >70 Tbs online storage, many portals (incl. subsetter) up to real time processing; 32 years of data
- NEW! Gridded observations and innovations from the data assimilation
Integration of Energy and Water Cycle Products in a Global Land Surface Modeling and Assimilation System

Matt Rodell and Hiroko Kato Beaudoing

**GOAL:** Integrate ground and satellite observations within sophisticated numerical models to produce physically consistent, high resolution fields of land surface states and fluxes

**Parameter Inputs**
- SW RADIATION
- PRECIPITATION
- SOIL TEXTURE
- LAND COVER
- SLOPE
- MODIS SNOW COVER

**Satellite Based Forcing**

**Assimilated Observations**

**Integrated Output**
- EVAPOTRANSPIRATION
- SOIL MOISTURE
- SNOW WATER EQ

**USES:** Weather and climate forecast initialization studies, water resources applications, hydrometeorological investigations

**AVAILABILITY:** Output from 1979-present simulations of Noah (1/4°; 1°), CLM (1°), and Mosaic (1°), and VIC (1°), at http://disc.gsfc.nasa.gov/hydrology/index.shtml

Matt Rodell
Hydrological Sciences Branch, NASA GSFC
Global Continental Runoff
Dennis Lettenmaier and Liz Clark

Following Dai et al. 2009:
- Runoff estimated from 920 streamflow gages.
- Gaps in record filled in based on regression with VIC modeled runoff
- Unmonitored areas filled in based on ratio of gaged flow and VIC modeled runoff.
Regional and global discharge estimation
Jay Famiglietti, Caroline DeLinage, MinHui Lo, Hyungjun Kim, JT Reager, and T. Hassan Syed

Terrestrial water balance
\[ \Delta S_{\text{LAND}} = P - E - R \]

Atmospheric water balance
\[ \Delta W = E - P - \text{divQ} \]

Coupled land-atmosphere water balance
\[ R = \Delta S_{\text{LAND}} - \Delta W - \text{divQ} \]

- Previously had to assume that \( \Delta S_{\text{LAND}} = 0 \) and apply at annual time scales
- Now we have \( \Delta S_{\text{LAND}} \) from GRACE so we can compute monthly time series
- \text{divQ} and \( \Delta W \) from atmospheric analyses
- Implicitly includes all surface and subsurface outflows, including water management

[Syed et al., 2005, 2007, 2009]
Atmospheric Vapor Flux
Kyle Hilburn and Frank Wentz; Tim Liu

• PMWC
  – “Passive Microwave Water Cycle” (Version-01b)
  – Resolution: 0.25-deg, monthly maps, global
  – Date Range: 1987-2009 (SSM/I)
  – Parameters: WVT spd, dir, div; evap, precip, vapor
  – Technique: adjust WVT to match E-P, uses CCMP winds (derived from RSS winds)
  – Note: update planned to PMWC using all new RSS Version-7 geophysical retrievals (from SSM/I, SSMIS, TMI, AMSR-E, and WindSat)

• Liu
  – Tim Liu (Version 3)
  – Resolution: 0.5-deg, daily maps, global (+/- 75 deg)
  – Date Range: 1999-2008 (QuikSCAT)
  – Parameters: WVT u,v, div
  – Technique: Support Vector Regression, uses 850 mb winds
GRACE Derived Terrestrial Water Storage Variations
Don Chambers, Jay Famiglietti, et al.

*GRACE Science Goal:* High resolution, mean and time variable gravity field mapping for Earth System Science applications

*Instruments:* Two identical satellites flying in tandem orbit, ~200 km apart, 500 km initial altitude

*Key Measurement:* Distance between two satellites tracked by K-band microwave ranging system

*Key Result:* Information on water stored at all depths on and within the land surface

GRACE measures changes in total terrestrial water storage, including groundwater, soil moisture, snow, and surface water. *(credit: Rodell/NASA)*

Animation of monthly GRACE terrestrial water storage anomaly fields. *(credit: Zaitchik/JHU)*
Atmospheric Total Water Vapor
Xiang Gao, Eric Fetzer, Adam Schlosser, and Van Dang

**Instruments:**
The Atmospheric Infrared Sounder (AIRS) and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) are two of six instruments on board the NASA Aqua satellite. AIRS’ spectral resolution is 100 times greater than previous infrared sounders and can create three-dimensional global distribution of water vapor. AMSR-E is a twelve channel, six frequency, passive microwave radiometer system to measure geophysical parameters, including total precipitable water vapor (TPWV) over ocean.

**Data/Processing:**
✧ 3-hourly Version 5 Level 2 (vector) total precipitable water vapor at 1-degree from AIRS and AMSR-E have been binned into 1x1 degree grids, and averaged to monthly for estimates of the annual amplitude of atmospheric moisture storage over various continents and ocean basins.
✧ Due to data gaps in the Level 2, 3-hourly AIRS/AMSR-E data, time series of the 5-day average centered on the first day of each month has been generated to estimate the monthly atmospheric moisture storage change.

**Accuracy/Error:**
✧ AIRS: Comparisons with radiosondes show AIRS TPWV uncertainties are <\$5\$ ± 10% globally.
✧ AMSR-E: AMSR-E TPWV uncertainties, also from radiosondes comparisons, are <\$5\$ ± 20%.
✧ Smaller RMS uncertainties are expected for the averaged data used in this analysis.
Global, Mean Annual Water Cycle

Global mean water fluxes (1,000 km³/yr) at the start of the 21st century.
Best guesses based on observational products and data integrating models with error estimates.
Achieving Water Balance

\[
ET_{\text{balanced}} = ET_{\text{best\_guess}} + (WBR \times \sigma_{ET} / (\sigma_P + \sigma_{ET} + \sigma_Q))
\]

\[WBR = \text{Water balance residual}\]
\[\sigma = \text{uncertainty/error (standard deviation of estimates)}\]
Global, Mean Annual Water Cycle

Global mean water fluxes (1,000 km³/yr) at the start of the 21st century. Best guesses based on observational products and data integrating models with error estimates.

Matt Rodell
NASA GSFC
Global mean water fluxes (1,000 km³/yr) at the start of the 21st century. Best guesses based on observational products and data integrating models with error estimates. When water balance is enforced, uncertainty decreases.
Global mean water fluxes (1,000 km³/yr) at the start of the 21st century.

Best guesses based on observational products and data integrating models with error estimates.

When water balance is enforced, uncertainty decreases

Trenberth et al. (2006) for comparison
## Continental, Mean Annual Water Fluxes

<table>
<thead>
<tr>
<th>Precipitation (downward arrows)</th>
<th>Evapotranspiration (upward arrows)</th>
<th>Runoff (outward arrows)</th>
<th>Annual Amplitude of Terrestrial Water Storage (white boxes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.2 ±0.9</td>
<td>9.9 ±1.3</td>
<td>39.3 ±2.3</td>
<td>22.7 ±4.8</td>
</tr>
<tr>
<td>5.5 ±1.1</td>
<td>29.7 ±1.4</td>
<td>10 ±2</td>
<td>10.7 ±1.7</td>
</tr>
<tr>
<td>18.4 ±0.8</td>
<td>18.1 ±4.2</td>
<td>7.7 ±0.3</td>
<td>4.5 ±1.0</td>
</tr>
<tr>
<td>3 ±0.4</td>
<td>0.9 ±0.6</td>
<td>0.5 ±0.2</td>
<td></td>
</tr>
<tr>
<td>2.5 ±0.5</td>
<td>2.2 ±1.4</td>
<td>3.4 ±0.5</td>
<td></td>
</tr>
<tr>
<td>9.6 ±1.1</td>
<td>3.4 ±0.5</td>
<td>9.6 ±1.1</td>
<td></td>
</tr>
</tbody>
</table>

Precipitation (downward arrows), evapotranspiration (upward arrows), runoff (outward arrows), and annual amplitude of terrestrial water storage (white boxes) in km$^3$/yr. Background shows GRACE-based amplitude of the annual cycle of terrestrial water storage (cm/yr). Antarctica: P=2.8 ±0.4  E=0.1 ±0.0  Q=2.7 ±0.6  AmpS=0.6 ±0.3

Matt Rodell
NASA GSFC
Mean Monthly Water Cycle for Continental Regions

Precipitation (black), evapotranspiration (red), runoff (blue), and anomaly of terrestrial water storage (green) in km$^3$.

Matt Rodell
NASA GSFC
Oceanic Mean Annual Water Fluxes

Precipitation (downward arrows) and evaporation (upward arrows) in km$^3$/yr.

Matt Rodell
NASA GSFC
Latent Heating
(Princeton/SRB + SeaFlux)

Global LH ~ 13 Wm$^{-2}$ smaller than Trenberth et al.
Sensible Heating (MERRA + SeaFlux)

Global SH ~ 9 Wm$^{-2}$ larger than Trenberth et al.
Downwelling longwave and shortwave radiation are \( \sim 10 \text{ Wm}^{-2} \)
and \( 6 \text{ Wm}^{-2} \) larger than Trenberth et al. (2009) estimates, respectively.
NEWS Surface Energy Balance

Relative to Trenberth et al:

- DLR \sim 10 \text{ Wm}^{-2} \text{ larger.}
- SSR \sim 6 \text{ Wm}^{-2} \text{ larger.}
- LH \sim 13 \text{ Wm}^{-2} \text{ smaller.}
- SH \sim 9 \text{ Wm}^{-2} \text{ larger.}

\Rightarrow \text{ Surface energy imbalance of } \sim 19 \text{ Wm}^{-2}
Other Combinations

SRB/PrISCCP/PrISCCP/MERRA/SeaFlux
- GLB : 22.15
- LND : 13.90
- SEA : 32.43

SRB/MERRA/SeaFlux/MERRA/SeaFlux
- GLB : 13.58
- LND : 1.252
- SEA : 28.49

SRB/PrSRB/PrSRB/MERRA/MERRA
- GLB : 24.89
- LND : 16.53
- SEA : 31.52

SRB/MERRA/MERRA/MERRA/MERRA
- GLB : 20.02
- LND : 1.252
- SEA : 30.74

ISCCP/PrISCCP/PrISCCP/MERRA/SeaFlux
- GLB : 26.49
- LND : 34.12
- SEA : 27.97

ISCCP/MERRA/SeaFlux/MERRA/SeaFlux
- GLB : 17.83
- LND : 21.47
- SEA : 24.03

ISCCP/PrSRB/PrSRB/MERRA/MERRA
- GLB : 27.20
- LND : 36.75
- SEA : 27.06

ISCCP/MERRA/MERRA/MERRA/MERRA
- GLB : 22.33
- LND : 21.47
- SEA : 26.28
The State of the Global Water and Energy Cycles

- The NEWS W&E Cycle Climatology Team is using modern, observation-integrating products and associated error-analyses to develop a monthly climatology of W&E cycle components for each continental/oceanic to global scale region, which will serve as a benchmark for W&E cycle / climate change studies and model assessments.

- Over most regions and time periods, the “best guess” (not balanced) water budget residual is within the uncertainty range expected based on individual error estimates.

- By forcing closure of the terrestrial, atmospheric, and oceanic water budgets, uncertainty in the flux estimates can be reduced.

- Near-future refinement of the results will include use of water and energy budgets to constrain each other using ET/LH.

- The energy budget is not forced to close because it may not be balanced.