Consistency of Estimated Global Water Cycle Variations Over the Satellite Era

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Focus of the present work is on the **VARIABILITY** of atmospheric P, ET and Transport processes

\[-\nabla \cdot \overline{qV} = P - ET + \frac{\partial q}{\partial t}\]
Questions...

- How consistent are signals in the variability of P-ET over global land, E-P over ocean, and the implied net transport during the satellite era (Interannual Variability, Decadal-scale Shift)?

- Can we point to priorities for improvements in these retrievals or reanalyses needed to detect climate variability signals?

Approach:

- Integrate a wide variety of satellite P, E retrievals, reanalysis vertically-integrated moisture flux divergence (over land), observationally-driven Land Surface Models.

\[-\nabla \cdot \overrightarrow{qV} = P - ET + \frac{\partial q}{\partial t}\]

- Focus on monthly anomalies around climatology.
- Domains are near-global land and ocean area averages (60 N/S).
- 13-mo filter applied for time series display only
<table>
<thead>
<tr>
<th>Data Set</th>
<th>Native Resolution</th>
<th>Physical Basis</th>
<th>Reference</th>
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<tr>
<td><strong>Remotely Sensed Precip</strong></td>
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<tr>
<td>GPCP</td>
<td>2.5 deg global 1979-present</td>
<td>Passive microwave emission calibrates IR</td>
<td>Adler et al, 2003; 2012</td>
<td>Tied to GPCC over land</td>
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<td>RSS V7</td>
<td>0.25 deg ocean only Jul1987- present</td>
<td>Unified passive mico</td>
<td>Hilburn and Wentz, 2008</td>
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<tr>
<td>GPROF 2010 V1a</td>
<td>0.25 deg global Jul1987- 2009</td>
<td>Bayesian passive microwave</td>
<td>Kummerow et al, 2001; 2010</td>
<td>Lookup table uses TRMM PR</td>
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<td><strong>Remotely Sensed Ocean evap</strong></td>
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<tr>
<td>OAFlux</td>
<td>1.0 deg 1959-present</td>
<td>Ol blend of reans, satellite w/ buoy constraints</td>
<td>Yu and Weller, 2007; 2008</td>
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<tr>
<td>GSSTF3</td>
<td>1.0 deg Jul1987- 2009</td>
<td>Passive microwave drives COARE 3.0 bulk aero model</td>
<td>Shie et al, 2009; 2012</td>
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<tr>
<td>SeaFlux</td>
<td>0.25 deg 1998-2007</td>
<td>Neural net retrievals drive COARE 3.0 bulk aero model</td>
<td>Roberts et al, 2010; Clayson et al, 2013</td>
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<tr>
<td><strong>Obs Driven Land Surface Models</strong></td>
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<td>GLDAS-2 Noah</td>
<td>0.5 deg 1948-present</td>
<td>Driven by Sheffield et al, 2006 “Princeton Forcing”</td>
<td>Rodell et al., 2004</td>
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<tr>
<td>GLDAS VIC</td>
<td>1.0 deg 1948-2006</td>
<td>Driven by earlier version of “Princeton Forcing”</td>
<td>Sheffield et al. (2006) and Sheffield and Wood (2007)</td>
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<td>MPI-BGC</td>
<td>0.5 deg 1982-2011</td>
<td>Scaling-up of FLUXNET via machine learning algorithm</td>
<td>Jung et al., 2009; 2010</td>
<td>GPCC precip used</td>
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<tr>
<td>GPCC</td>
<td>0.5 deg</td>
<td>67,200 gauges world-wide</td>
<td>Schneider et al (2011; 2013)</td>
<td>Gauge only</td>
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<td>MERRA-Land</td>
<td>0.625 lon; 0.5 lat</td>
<td>Offline version of MERRA Catchment LSM</td>
<td>Reichle et al, 2011; 2013</td>
<td>CPCU precip</td>
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<td><strong>Reanalyses (Land Only)</strong></td>
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<tr>
<td>MERRA</td>
<td>0.625 lon; 0.5 lat</td>
<td>GEOS 5 Model; Incremental Analysis Update</td>
<td>Rienecker et al, 2011</td>
<td>Vert.-integ moisture flux diverg as corrected by NCAR/CAS (Trenberth et al., 2011)</td>
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<td>ERA-Interim</td>
<td>1.0 deg 1979-2010</td>
<td>ECMWF Integrated Forecast Model (IFS Cy31r2)</td>
<td>Dee et al, 2011</td>
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<td>CFSR</td>
<td>1.0 deg 1979-2010</td>
<td>Weak ocean / atm coupling</td>
<td>Saha et al, 2010</td>
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Ocean Area Average E, P Anomalies (mm d⁻¹)

**Correlation 1992 / 2009**
- (gpcp, rss) = .72
- (gpcp, gprof) = .66
- (gprof, rss) = .80

**Correlation 1998 / 2007**
- (seaflux, oaflux) = .05
- (gsstf3, oaflux) = .18
- (seaflux, gsstf3) = .89

**1988/2008**
- (gsstf3, oaflux) = .61
Wind Speed and Saturation Deficit Controls On Ocean Evaporation

**Bulk Formula:**

\[ E = C_E \rho_a U (q_s (SST) - q_a (T_a)) \]

**Taylor Series Expansion:**

\[ \delta E = \frac{\partial E}{\partial q} \delta q + \frac{\partial E}{\partial U} \delta U + \frac{\partial E}{\partial C_E} \delta C_E \]

**Sensitivities:**

- Wind
  \[ \partial E/\partial U = \rho_a C_E (q_s (SST) - q_a (T_a)) \]
- Moisture Deficit
  \[ \partial E/\partial q = \rho_a U (q_s (SST) - q_a (T_a)) \]
- Exch Coefficient
  \[ \partial E/\partial \Delta q = C_E \rho_a U \]
Differences Among 10m Ocean Wind Speed Products

RSS V7 SSMI winds account for spacecraft Earth Incidence Angle variations (pitch/yaw/roll) and result in substantially less upward trend in speed than in earlier versions.
E-P Estimates (mm/d) from Combined Satellite Products
Ocean Area-Average 60 N/S
Reanalysis Vertically-Integrated Moisture Flux Convergence Anomalies (mm/d) 60 N/S

**Correlation 1979 / 2011:**
- (erai, cfsr) = 0.85
- (erai, merra) = 0.83
- (cfsr, merra) = 0.88
60 N/S De-seasonalized (anomaly + mean)
Land P (solid) and ET (dotted) mm/d
Std Dev of Monthly P-ET Anomalies (mm/d) 1979 to Present

- LSM is mean of GLDAS-2 Noah, MERRA-Land and MPI-BGC ET w/GPCC precip.
- Reanalyses are vertically-integrated moisture flux convergence (-∇·qV).

*Significant differences between LSMs and reanalyses are apparent over central Africa*
Leading $-\nabla \cdot \mathbf{qV}$ Artifacts in Reanalyses

ERA-I and JRA 55 units (mm/)    MERRA PC1 is non-dimensional
Conclusions

1. Ocean LHF uncertainties from satellite-derived component qs-qa and wind speeds combine with remaining problems in P retrievals to prevent P-E estimates with sufficient accuracy to monitor decadal changes in land/ocean moisture transport variations. However, prospects for improved retrievals by accounting for spacecraft EIA variations are very good.

2. Reanalysis VMFC have systematic errors arising from input data inconsistencies that induce erroneous trends. To first order these can be identified and removed. Resulting VMFC variations over global land show substantial agreement with largely independent, observationally-forced LSMs.

3. Using monthly data the largest signals in the land → ocean moisture transport (P-ET) are those of ENSO with net transport decreasing (increasing) during warm (cold) events. Transport variations are consistent with both IA as well as lower frequency ENSO signals.

4. Further work on the fidelity of important regional pattern variations and trends is underway.