Global Observations of the Water Cycle


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Outline

1. Objectives
2. Recent knowledge of CC-influence on the water cycle
3. Data availability
4. Observed state of the water cycle
5. Discussion and next steps
**BOX 1: Closing the global water cycle**

<table>
<thead>
<tr>
<th>Targets</th>
<th>Close water cycle globally within 5% on annual timescales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who</td>
<td>Operators of GCOS-related systems, including data centres</td>
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<tr>
<td>Time frame</td>
<td>Ongoing</td>
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<tr>
<td>Performance indicator</td>
<td>Regular assessment of the uncertainties in estimated turbulent flux of latent heat</td>
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</table>

Simultaneous closing of the energy and water budget via the equivalence of both ET and latent heat fluxes.
Why does it matter?
Impact of climate change:

General global risks

- The increase in greenhouse gases significantly **increases** the risks to water resources.

- Per degree of warming,
  - the renewable water resource is reduced by 20%,
  - with a simultaneous population growth of 7%.

1°C = 20%↓ population growth of 7%.
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The global water cycle

Key Processes
- Evaporation, transpiration and water vapor generation
- Atmospheric transport of water vapor
- Precipitation
- Storage and release by the cryosphere, lakes and reservoirs, soil moisture, and groundwater
- Water flow on the surface
- River discharges to the ocean
- Groundwater discharges to the oceans
Expected Changes in the Water Cycle

Hydrological Sensitivity: +1K $\rightarrow$ 2-3% increase in precip.

Hegerl et al., 2015/BAMS
Expected Changes in the Water Cycle

A lot of uncertainty are covered by the observations

Hegerl et al., 2015/BAMS
observed temperature increases during the 20th century may have resulted in increasing ET where moisture is not limiting.

Huntington, 2006/JHydrol
Impact of climate change

Intensification of the water cycle

– 1 °C more temperature accelerates the cycle of evaporation and precipitation by 2-3% (likely safety).

This leads to changes P-E patterns and intensification of inequalities in the global water supply.

But:

– Estimates extremely difficult due to lack of measurement data, especially over the oceans.

– Small S/N ratio makes it difficult to detect/attribute changes of the water cycle.

– Also missing: uncertainty estimations on long-term trends

  • Difficult to provide
  • Account for natural (multi)decadal variability
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The existing operational global water data centers (mostly in situ)
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**Network** of the global water data centres

**Joint project** of GCOS and WMO;

implemented in 2001
GCOS specifies 54 Essential Climate Variables (ECV) that are key for sustainable climate observations.

GTN-H: Synergies at development of requirements for hydrological ECV
Global Precipitation Climatology Centre (GPCC)

The Global Precipitation Climatology (over land) is the background for all other GPCC precipitation analysis products and is based over 75,100 stations with climatological normal. Overall, the GPCC data base consists of over 110,000 stations.
Timeliness issue
High-latitude (55°–90°N) annual-mean precipitation trends (mm decade–1) from 1951 to 2005
Temporal coverage of SMMR, SSM/I and SSMIS instrument aboard Nimbus-7 and DMSP satellite platforms.
Global Runoff Data Centre (GRDC)

- International archive of river discharge times series supporting global change research
- Operated by the German Federal Institute of Hydrology (BfG) under the auspices of the WMO.
Annual Freshwater discharge from all continents

Average annual river runoff: 41,900 km³/yr

Rain – discharge relation:

Application of WaterGAP (no glacier/ice sheet dynamics)

Future SWOT mission
Relevant open tasks

- data limitations (in time and/or space),
- the spatial representativeness of point-based measurements,
- scaling issues between observations (in situ and remotely sensed) and models,
- uncertainties in variable estimates from satellite retrievals and numerical modelling,
- differences in how extremes are defined.
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The global water cycle (in-situ focus)

On global average: Water exchange by precipitation / evapotranspiration = 503,600 km³/a (equivalent to 987 mm/a)

- Transport of water vapour: 45,800 km³/a
- Precipitation: 117,600 km³/a
- Evapotranspiration: 71,800 km³/a
- Evaporation: 431,800 km³/a
- Precipitation: 386,000 km³/a
- River runoff: ca. 44,800 km³/a
- Groundwater flow: ca. 1,000 km³/a
- Total runoff (Rivers, groundwater) into the oceans: 45,800 km³/a

Schneider et al., 2017
### TABLE 1. Sources of data used in this study.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dataset name</th>
<th>Contributing remote sensing instruments</th>
<th>Key references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>GPCP v2.2</td>
<td>SSM/I, SSMIS, GOES-IR, TOVS, and AIRS</td>
<td>Adler et al. (2003) and Huffman et al. (2009)</td>
</tr>
<tr>
<td>Ocean evaporation</td>
<td>SeaFlux v1.0</td>
<td>SSM/I, AVHRR, AMSR-E, TMI, and WindSat</td>
<td>Clayson et al. (2015, manuscript submitted to <em>Int. J. Climatol.</em>)</td>
</tr>
<tr>
<td>Terrestrial evapotranspiration</td>
<td>Princeton ET</td>
<td>AIRS, CERES, MODIS, and AVHRR</td>
<td>Vinukollu et al. (2011)</td>
</tr>
<tr>
<td></td>
<td>MERRA and MERRA-Land</td>
<td>MSU, HIRS, SSU, AMSU, AIRS, SSM/I, ERS-1/-2, QuikSCAT, MODIS, GOES</td>
<td>Rienecker et al. (2011), Bosilovich et al. (2011), and Reichle (2012)</td>
</tr>
<tr>
<td></td>
<td>GLDAS</td>
<td>SSM/I, SSMIS, GOES-IR, TOVS, AIRS, TRMM, MODIS, and AVHRR</td>
<td>Rodell et al. (2004b)</td>
</tr>
<tr>
<td>River runoff</td>
<td>University of Washington runoff</td>
<td>TRMM, GOES-IR, TOVS, SSM/I, ERS, and ATOVS</td>
<td>Clark et al. (2015)</td>
</tr>
<tr>
<td>Atmospheric convergence</td>
<td>MERRA</td>
<td>See MERRA above</td>
<td>See MERRA above</td>
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<tr>
<td></td>
<td>QuikSCAT water balance</td>
<td>QuikSCAT, TRMM, and GRACE</td>
<td>Liu et al. (2006)</td>
</tr>
<tr>
<td></td>
<td>PMWC v2.0</td>
<td>SSM/I, AMSR-E, TMI, and WindSat</td>
<td>Hilburn (2009)</td>
</tr>
<tr>
<td>Precipitable water vapor</td>
<td>AIRS and AMSR-E precipitable water</td>
<td>AIRS and AMSR-E</td>
<td>Fetzer et al. (2006)</td>
</tr>
</tbody>
</table>
Satellites + data-integrating models

Total continental runoff = 47.1
= 41.9 + 2.3 + 2.9
= \( Q_{\text{River}} + Q_{\text{submar. GW}} + Q_{\text{ice sheet}} \)

Mean annual fluxes (2001-2010)

Obs records + models (white)

Optimized estimates by forcing water and energy budget closure (blue)

Rodell et al., 2015/JClim

Annual total water exchange: \( 520.1 \pm 27.2 \times 10^3 \text{km}^3\text{yr}^{-1} \)
Satellites + data-integrating models

Optimized annual-mean fluxes ($10^3$km$^3$/yr) for 2001-2010. Precip., ET, runoff, annual amplitude of terrestrial water storage (yellow) GRACE-based amplitude of terrestrial water storage (gray)

Rodell et al., 2015/JClim
## Residuals

<table>
<thead>
<tr>
<th></th>
<th>Observed residual</th>
<th>Predicted closure error</th>
<th>Optimized uncertainty*</th>
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<tbody>
<tr>
<td><strong>Global water budget</strong></td>
<td>3.9%</td>
<td>12.5%</td>
<td>7.4%</td>
</tr>
<tr>
<td>• Land</td>
<td>4.3%</td>
<td>10.1%</td>
<td>7.2%</td>
</tr>
<tr>
<td>• Ocean</td>
<td>6.6%</td>
<td>13.8%</td>
<td>7.8%</td>
</tr>
<tr>
<td>• Atmosphere</td>
<td>4.7%</td>
<td>13.6%</td>
<td>7.5%</td>
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</tbody>
</table>

* Residual being forced towards zero

- Changes are indicated as % relative to $P_{L/Oc/Atm}$
- Expected errors of optimized water budgets: <10%
- Observed residuals < expected errors

**Rodell et al., 2015/JClim**
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Necessary steps

1. Significant enhancement in the ability to sustainably measure key spatial components of water cycle

2. Strengthening the observing system to provide better understanding of the physical mechanisms and interactive processes that control variability in the water cycle

3. Developing improved physical models and use of data assimilation methods that are critical to:
   - distinguish natural variability in the water cycle from human-induced variability
   - deliver better hydrological prediction
   - obtain new insight on coupling of water, carbon, and energy cycles
Priority List

Improved and sustained observations of

- **precipitation** (both over ocean and land) to quantify global and regional trends in the water cycle;

- **snow water equivalent, soil moisture, and land cover change**
  - assimilation into dedicated high spatial resolution hydrological land surface models to better quantify stream flow, soil moisture and evapotranspiration and the carbon cycle

- **ground water monitoring** from satellite gravity observations

- quantitative observation of **river discharges**

- **snow- and ice inventories** as important water storage and frozen soil/permafrost monitoring
  - the surface albedo (e.g. from changes in snow cover and composition, sea ice extent, glacier and ice sheet extent) and its influence on evaporation, cloud formation and precipitation.

- **sea surface salinity** regarding the oceanic branch of the hydrological cycle

- socio-economic trends of **water use** (e.g., agricultural water demands, water quality demands)
Need for increased international collaboration and the use of observations from
• many satellites and/or satellite constellations
• together with dedicated in-situ observation networks
• From both, research as well as operational observational networks
“Interoperability seems to be about the integration of information. What it’s really about is the coordination of organizational behavior.”

David Schelle, Founder and Chairman of the OGC
Improvement of interoperability

Do you follow an international standard for metadata description?

Satellites

Data assimilation

In-situ models

Building a discoverability service

GTN-H Questionnaire 2018
Questions?

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimated Water Fluxes</th>
<th>References and Data Sources</th>
<th>Significant ECVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td></td>
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<tr>
<td>Water storage in ice and snow</td>
<td></td>
<td>Global ice volume (glaciers and ice caps) of 158,000 cubic kilometres (uncertainty of 25%)</td>
<td></td>
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<td>Study by Farinotti et al. 2019, Nature Geoscience.</td>
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<td>About 1 mm/a SLE (sea level elevation) from glacier melt (glaciers and ice caps), glaciers</td>
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<td></td>
<td></td>
<td>contribute 30% of the observed SLE (Zemp et al. in press, Nature Geoscience).</td>
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<tr>
<td>Lakes</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>River discharge</td>
<td>41,867</td>
<td>GRDC (2014) Global freshwater fluxes into the World Oceans</td>
<td></td>
</tr>
<tr>
<td>Water vapour</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Soil moisture</td>
<td>12,393</td>
<td>Likewise Jones 1997, Global hydrology</td>
<td></td>
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<tr>
<td>Groundwater</td>
<td>13,000 - 15,000</td>
<td>Taylor et al. 2012</td>
<td></td>
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<tr>
<td>Sea-level</td>
<td></td>
<td></td>
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<tr>
<td>Evapotranspiration</td>
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<td>Budget imbalance</td>
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<tr>
<td>Not included</td>
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<td></td>
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<tr>
<td>Total water storage</td>
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<td>Salinity</td>
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www.gtn-h.info
Thank you!

International Centre for Water Resources and Global Change
Koblenz