Toward AR5: Activity of global water resources model H08

Naota Hanasaki
NIES
Outline

• Global water resources model: H08
• Activities toward IPCC/AR5
  1. Global water scarcity assessment
  2. Impact/adaptation study of Thailand
  3. Global integrated assessment
  4. Multi-model simulation of CC impact on global hydrological cycle
• Other activity
  – Global virtual water assessment
Application 1:
Global water scarcity assessment


Water scarcity assessment

• Several indices have been proposed to quantify regional water scarcity.

Water scarcity index = \frac{\text{Mean annual water withdrawal (water use)}}{\text{Mean annual runoff (water availability)}}

Oki and Kanae, 2006, Science
Projection of water scarcity in future

Use of statistical (regression) models
- Population scenario
- Economic scenario

Mean annual water withdrawal
Mean annual runoff

Population under high water stress (billion)

Milly et al., 2005, Nature
Oki and Kanae, 2006, Science
Impact of climate change on water cycle

- IPCC AR4/WG2/Ch3
  - Change in annual precipitation/runoff
  - Change in precipitation intensity (強度)/frequency (頻度)
  - Decrease of snowfall, shift of snowmelt season

Projected number of days with heavy rain (Japan)

Projected change in annual runoff by 2041-60 relative to 1900-70

Milly et al., 2005, Nature

Mean annual water withdrawal
Mean annual runoff
Water stress decreases??

Sub-annual-basis assessment is needed
Global water resources model H08

• Requirements
  1. Simulate both water availability (streamflow) and water use at daily-basis
  2. Deal with interaction between natural hydrological cycle and anthropogenic activities
  3. Applicable for future climate change simulation

Hanasaki et al., 2006, J. of Hydrol.
Hanasaki et al., 2008a,b, Hydrol. Earth Sys. Sci.
Input and Output

**Input (1°×1°, 3-hourly, 1986-1995)**
- Air temperature
- Specific humidity
- Air pressure
- Wind speed
- Shortwave radiation
- Longwave radiation
- Precipitation

**Meteorological (1°×1°, 3-hourly, 1986-1995)**

<table>
<thead>
<tr>
<th>Input</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>Revised GSWP2 (Hanasaki et al., 2008a)</td>
</tr>
<tr>
<td>Specific humidity</td>
<td></td>
</tr>
<tr>
<td>Air pressure</td>
<td></td>
</tr>
<tr>
<td>Wind speed</td>
<td></td>
</tr>
<tr>
<td>Shortwave radiation</td>
<td></td>
</tr>
<tr>
<td>Longwave radiation</td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
</tr>
</tbody>
</table>

**Geographical/other (1°×1°, circa 1990)**

<table>
<thead>
<tr>
<th>Input</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland area</td>
<td>Ramankutty et al. 1998</td>
</tr>
<tr>
<td>Irrigated area</td>
<td>Döll and Siebert, 2000</td>
</tr>
<tr>
<td>Crop intensity</td>
<td>Döll and Siebert, 2002</td>
</tr>
<tr>
<td>Crop type</td>
<td>Leff et al., 2004</td>
</tr>
<tr>
<td>River map</td>
<td>Oki and Sud, 1998</td>
</tr>
<tr>
<td>Reservoir map</td>
<td>Hanasaki et al. 2006</td>
</tr>
<tr>
<td>Industrial water dem.</td>
<td>FAO, 2007</td>
</tr>
<tr>
<td>Domestic water dem.</td>
<td>FAO, 2007</td>
</tr>
</tbody>
</table>

No feedback to atmosphere

**Output (1°×1°, daily, 1986-1995)**

<table>
<thead>
<tr>
<th>Output</th>
<th>Sub-model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land</td>
<td>Evapotranspiration</td>
</tr>
<tr>
<td></td>
<td>Runoff</td>
</tr>
<tr>
<td></td>
<td>Soil moisture</td>
</tr>
<tr>
<td></td>
<td>Snow water equivalent</td>
</tr>
<tr>
<td></td>
<td>Energy term</td>
</tr>
<tr>
<td>River</td>
<td>Streamflow</td>
</tr>
<tr>
<td></td>
<td>River channel storage</td>
</tr>
<tr>
<td>Crop growth</td>
<td>Planting date</td>
</tr>
<tr>
<td></td>
<td>Harvesting date</td>
</tr>
<tr>
<td>Reservoir</td>
<td>Agricultural water dem.</td>
</tr>
<tr>
<td></td>
<td>Crop yield (not used)</td>
</tr>
<tr>
<td>Reservoir</td>
<td>Reservoir storage</td>
</tr>
<tr>
<td></td>
<td>Reservoir outflow</td>
</tr>
<tr>
<td>Environmental flow</td>
<td>Agri. water withdrawal</td>
</tr>
<tr>
<td></td>
<td>Ind. water withdrawal</td>
</tr>
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<td></td>
<td>Dom. water withdrawal</td>
</tr>
<tr>
<td></td>
<td>Env. flow requirement</td>
</tr>
</tbody>
</table>

**Output (1°×1°, daily, 1986-1995)**

- Land sub-model
- River sub-model
- Crop growth sub-model
- Reservoir sub-model
- Environmental flow
Water resources assessment

Index = \[ \frac{\sum \text{Daily withdrawal (simulated)}}{\sum \text{Daily demand (simulated)}} \]

<table>
<thead>
<tr>
<th>Stress Level</th>
<th>Index Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>High stress</td>
<td>Index &lt; 0.5</td>
</tr>
<tr>
<td>Medium stress</td>
<td>0.5 \leq \text{Index} &lt; 0.8</td>
</tr>
<tr>
<td>Low stress</td>
<td>\text{Index} \geq 0.8</td>
</tr>
</tbody>
</table>

Hanasaki et al., 2006, J. of Hydrol.
Hanasaki et al., 2008a,b, Hydrol. Earth Sys. Sci.
For future projection

<table>
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<th>Meteorological (1°×1°, daily?, 2001-2100)</th>
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<td>Air temperature</td>
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<td>Specific humidity</td>
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</table>

→ An European group developed a new dataset
→ Some Japanese groups are also working hard.

→ Land use & Agriculture model needed?

→ New project launched in NIES
Application 2: Estimation of global virtual water flows and sources of water

Introduction

- Global water resources assessments
  - high water stressed regions are sometimes densely populated

- Virtual water (Allan, 1996)
  - Regional water scarcity can be alleviated by importing commodities, especially foods
  - Production of agricultural/livestock products consumes a large volume of water

- Virtual water complements water resource analyses of local water availability and use
Virtual water export

volume of water that an exporting nation consumes to produce the commodities that it trades abroad
（輸出製品を作るために海外の国が消費した水の量）

Importing country (Japan)  Exporting country (USA)

<table>
<thead>
<tr>
<th>Wheat</th>
<th>1t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Export of wheat</td>
<td>1t</td>
</tr>
<tr>
<td>Virtual water export</td>
<td>1,000t</td>
</tr>
</tbody>
</table>
Sources of virtual water

- Evapotranspiration (蒸発散) of cropland originates from
  - Precipitation
  - Irrigation
    - River
    - Reservoirs
    - Aquifers, aqueduct, glacier

- Separating the source of virtual water
Objective & Methodology

• Objective
  – Estimate global virtual water flows and their sources

• Research focus
  – International food trade in 2000
  – Five major crop products: barley, maize, rice, soy, wheat
  – Three major livestock products: beef, pork, chicken

• Methodology
  – Virtual water export = \frac{\text{National average Evapotranspiration from cropland (sim)}}{\text{National crop yield (statistics)}} \times \text{Trade matrix (statistics)}
Water consumption from cropland

Rainfed: Ramankutty et al. (2008)
Irrigated: Siebert et al. (2005)
Crop type: Monfreda et al. (2008)

Where
Crop growth submodel estimates planting/harvesting date.

When
Land surface hydrology submodel estimates ET from planting date to harvesting date.

How much
Globally 0.5° × 0.5°, daily-based calculation
Sources of water

- **River**
- **ET**
- **Withdrawal**

**Withdrawal ①** (River)
**Withdrawal ②** (Medium)
**Withdrawal ③** (NNBW = Nonrenewalbe and Nonlocal Blue Water)

**Land**
- **Runoff**
- **Rainfed Irrigated**
- **Medium-size reservoirs** (< 1km³, 25000, 3280km³)

**Large reservoirs**
- 1km³ < 452 km³
- 4140km³

**Excess water**

**Precip (P)**
- **ET (Evapotranspiration)**

**Diagram Description**
- Arrows indicate movement of water sources and withdrawals.
Sources of evapotranspiration from irrigated cropland

- Irrigation/Total evaporation
- River/Total Irrigation
- Medium-size reservoirs/Total irrigation
- NNBW/Total Irrigation

NNBW = Nonrenewable and Nonlocal Blue Water
NNBW/Total Irrigation

- Reported regions of aquifer overexploitation (Postel, 1999)

NNBW=Nonrenewable and Nonlocal Blue Water
Global flows of virtual water export

Virtual water export (total)

Total 545 km$^3$ yr$^{-1}$

Virtual water export (irrigation)

Total 61 km$^3$ yr$^{-1}$

Virtual water export (Nonlocal/Nonrenewable Blue Water)

Total 26 km$^3$ yr$^{-1}$

Total water withdrawal: 3,800 km$^3$ yr$^{-1}$

- Industrial: 770
- Domestic: 380
- Agricultural: 2,660

Shiklomanov, 2000
Summary

• Global water scarcity assessment
  – Daily basis assessment

• Global virtual water assessment
  – The virtual water export of the world was estimated at 545km$^3$yr$^{-1}$.
  – Of total, 61km$^3$yr$^{-1}$ (11%) is irrigation water, and 26km$^3$yr$^{-1}$ (5%) is NNBW.
References

  http://www.springerlink.com/content/k4223u6px5677467/?p=1460a4ebf9054aa8ac8ca8befdca0e76&pi=15


See: http://hydro.iis.u-tokyo.ac.jp/~hanasaki/pmwiki/index.php?n=CV.English