Representation of irrigation water withdrawal in SiBUC

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Land Surface Model

SiBUC

Simple Biosphere model including Urban Canopy

Tanaka (2004)
Kotsuki and Tanaka (2012)
Hydrological simulation considering water withdrawal and dam operation

- Land surface model SiBUC
  - Land use
  - Configuration of the ground
  - Weather forcing data

- Base flow
- Surface flow
- Irrigation water demand
  - Industrial water
  - Domestic water

Water-intake

- 20%
- 80%

River routing model
Kinematic wave

- Inflow
- Outflow
- Reservoir operation

Groundwater withdrawal

Groundwater
Land surface model (SiBUC)

Grid box is divided into three landuse categories:
1. Green Area
   - Broadleaf-evergreen trees
   - Broadleaf-deciduous trees
   - Broadleaf and needle leaf trees
   - Needle leaf-evergreen trees
   - Needle leaf-deciduous trees
   - Short vegetation/C4 grassland
   - Broadleaf shrubs with bare soil
   - Dwarf trees and shrubs
   - Farmland (non-irrigated)
   - Paddy field (non-irrigated)
   - Paddy field (irrigated)
   - Spring wheat (irrigated)
   - Winter wheat (irrigated)
   - Corn (irrigated)
   - Other crops (irrigated)
2. Urban Area
3. Water Body
Green area model (SiB)

- **Prognostic variables**
  - temperature (canopy, ground, deep soil)
  - interception water (canopy, ground)
  - soil wetness (surface, root zone, recharge)

- **Time invariant parameter**
  - geometrical parameter
  - optical parameter
  - physiological parameter
  - soil physical properties

- **Time varying parameter** (LAI etc.)
  - estimate from satellite data

- **Physical processes**
  - radiative transfer
  - interception loss
  - soil hydrology
  - canopy resistance
  - transpiration
  - turbulent transfer,
  - snow, freezing/melting,… etc.
Irrigation

Basic concept is to maintain soil moisture/water depth within appropriate ranges for optimal crop growth. Application to wheat, corn, soy bean, cotton etc… Water layer is added to treat paddy field more accurately.
Paddy field model

- Water depth and water temperature are added

\[
\begin{align*}
C_c \frac{\partial T_c}{\partial t} &= Rn_c - H_c - lE_c \\
C_w D_w \frac{\partial T_w}{\partial t} &= Rn_w - H_w - lE_w - k_w \frac{T_w - T_g}{D_w} \\
C_g \frac{\partial T_g}{\partial t} &= k_w \frac{T_w - T_g}{D_w} - \omega C_g (T_g - T_d) \\
C_d \frac{\partial T_d}{\partial t} &= \omega C_d (T_g - T_d)
\end{align*}
\]
In-situ Flux station (Lake Biwa Project)

- Three sites from the Lake Biwa Project
  Fluxes of radiation budget and heat budget component and related meteorological and hydrological variables can be used from these datasets.
- Two sites from the snow depth observation station
Grid P (paddy field)

Heat budget (10day)

albedo (1day)

Water depth (1day)

Water depth (1hr)
Grid L (lake surface)

Heat budget (10day)

Albedo (10day)

Heat Budget (1hr)

Albedo (1hr)
<table>
<thead>
<tr>
<th>Crop type</th>
<th>Growing stage</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring wheat</td>
<td>Periods(%)</td>
<td>23</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Soil wetness</td>
<td>0.70</td>
<td>0.60</td>
<td>0.80</td>
<td>0.80</td>
<td>0.55</td>
</tr>
<tr>
<td>Winter wheat</td>
<td>Periods(%)</td>
<td>25</td>
<td>20</td>
<td>22</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Soil wetness</td>
<td>0.70</td>
<td>0.70</td>
<td>0.80</td>
<td>0.80</td>
<td>0.55</td>
</tr>
<tr>
<td>Corn</td>
<td>Periods(%)</td>
<td>8</td>
<td>48</td>
<td>6</td>
<td>14</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Soil wetness</td>
<td>0.75</td>
<td>0.65</td>
<td>0.70</td>
<td>0.75</td>
<td>0.65</td>
</tr>
<tr>
<td>Rice</td>
<td>Periods(%)</td>
<td>25</td>
<td>13</td>
<td>33</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Water depth (mm)</td>
<td>20-50</td>
<td>none</td>
<td>20-60</td>
<td>moistening</td>
<td>intermittent</td>
</tr>
<tr>
<td>soy bean</td>
<td>Periods(%)</td>
<td>3</td>
<td>26</td>
<td>16</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Soil wetness</td>
<td>0.75</td>
<td>0.65</td>
<td>0.65</td>
<td>0.70</td>
<td>0.65</td>
</tr>
<tr>
<td>cotton</td>
<td>Periods(%)</td>
<td>4</td>
<td>21</td>
<td>13</td>
<td>26</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Soil wetness</td>
<td>none</td>
<td>0.5</td>
<td>0.55</td>
<td>0.55</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Chart by required water for cultivation in China
Satellite-derived crop calendar (SACRA)

SACRA - a method for the estimation of global high-resolution crop calendars from a satellite-sensed NDVI. Hydrology and Earth System Sciences, 19, 4441-4461.

Comparison with other products

SOWING DATE: SELECTED CROPS

(a-1) SACRA

(b-1) MIRCA

(c-1) Waha

Satellite-based
Census-based
Model-based
Cropping Intensity

SPOT VEGETATION (04–06)
SACRA: Harvesting Date [DOY]  First (frm Jan.)
Annual IWR (Irrigation Water Requirement) [mm/yr]

Annual IWR for each grids are aggregated into country, then compared with AQUASTAT

※ Using irrigation efficiency (Doll et al., 2002)
**Efficient Irrigation (Drip Irrigation)**

- Water is directly supplied to the root zone.
- Small amount of water is frequently supplied.

\[
\text{\( \Delta SM_1 = \text{waterin} \times \frac{d_1}{d_1 + d_2} \)}
\]

\[
\text{\( \Delta SM_2 = \text{waterin} \times \frac{d_2}{d_1 + d_2} \)}
\]

**Traditional Irrigation (Furrow Irrigation)**

- Water is supplied on the ground.
- Huge amount of water is supplied around once a week.

\[
\text{\( p_0 = \text{waterin} \)}
\]
WATER BALANCE IN IRRIGATED FARM

Drip irrigation

Evapotranspiration

Evaporation/ Evapotranspiration

Infiltration to deeper layer

Soil moisture

Furrow irrigation

Evapotranspiration

Evaporation/ Evapotranspiration

Infiltration to deeper layer

Soil moisture
OBSERVATION SYSTEM IN UZBEKISTAN

New equipment in Sorghum farm

Cotton

Precipitation gauge
About Model

**About Water Circulation Model**

Aral Sea shrinking is dynamically analyzed in the model.

Model can be applied for global scale,
But **Basin scale water balance** is analyzed considering regional features.
Calculation of Water Balance

Water balance of each mesh

\[ \text{Runoff} = \text{prec} - \text{evap} - \Delta \text{swe} - \Delta \text{soilm} \]

Water balance of the catchment

\[ \text{Qin} = \sum \text{Runoff} - \sum \frac{\text{Win}}{\gamma} + \sum \text{Wout} - \alpha \]

Water balance of the Aral Sea

\[ \Delta S = \text{Qin} + (P - E)_{\text{aral}} \]

<table>
<thead>
<tr>
<th>Runoff</th>
<th>Water resource</th>
<th>Gt</th>
</tr>
</thead>
<tbody>
<tr>
<td>prec</td>
<td>Precipitation</td>
<td>Gt</td>
</tr>
<tr>
<td>evap</td>
<td>Evapotranspiration</td>
<td>Gt</td>
</tr>
<tr>
<td>Win</td>
<td>Irrigation water requirement</td>
<td>Gt</td>
</tr>
<tr>
<td>Wout</td>
<td>Drainage water</td>
<td>Gt</td>
</tr>
</tbody>
</table>

\( \gamma \): Water conveyance efficiency (=0.4)

<table>
<thead>
<tr>
<th>Qin</th>
<th>Inflow to the Aral</th>
<th>Gt</th>
</tr>
</thead>
<tbody>
<tr>
<td>soilm</td>
<td>Soil moisture</td>
<td>Gt</td>
</tr>
<tr>
<td>swe</td>
<td>Snow water equivalent</td>
<td>Gt</td>
</tr>
</tbody>
</table>

\( \alpha \): Water requirement outside of the basin
Annual water balance of the Aral Sea

Prec  Evap

Storage volume of Aral sea is calculated from annual water balance. From the relationship between storage volume and surface area, land use fraction is updated for the next year’s analysis.

\[
S(t+1) = S(t) + Qin + (\text{Prec-Evap})
\]

\[
A(t) = f(S(t))
\]

\[
A(t+1) = f(S(t+1))
\]
**WATER BALANCE OF THE BASIN**

### Historical change of water balance

**Comparing with reported value**

**Average of water resource**
- Analysis 137Gt  Report 133Gt

**Irrigation water demand**
- 1990 Analysis 124Gt  Report 126Gt
- 1995 Analysis 106Gt  Report 111Gt

(Report: Micklin, 2000)

**Historical water balance is clearly analyzed.**

<table>
<thead>
<tr>
<th>Qin</th>
<th>Water inflow into the Aral Sea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrig</td>
<td>Irrigation water requirement</td>
</tr>
<tr>
<td>Runoff</td>
<td>Water resource</td>
</tr>
<tr>
<td>P-E</td>
<td>Precipitation - Evaporation in the Aral Sea</td>
</tr>
<tr>
<td>∆Sanal</td>
<td>Analyzed storage change</td>
</tr>
<tr>
<td>∆Srep</td>
<td>Reported storage change</td>
</tr>
</tbody>
</table>
REPRODUCING OF THE ARAL SEA SHRINKING

Annual water balance in the basin (Inflow to the Aral Sea) → The Aral Sea area

Historical change of the Aral Sea area

Aral Sea shrinking is clearly analyzed.
Urban Canopy model

- Urban canyon concept
  - Sky-view factor (road: skyg, wall: skyw)
- Prognostic variables
  - Temperature (roof, wall, road, deep soil)
  - Interception water (roof, wall, road)
- Roughness elements
  - (same width but different roof height)
- Spatial distribution of roof height and anthropogenic heat
Building floor number distribution

Example for $r(1)=0.6$, $r(2)=0.3$, $r(3)=0.1$
How to estimate urban parameter where GIS information is not available?

Digital Surface Model from satellite (ALOS PRISM)
Building Floor number distribution

Ikebukuro

Comparison of floor number (Ikebukuro)

Shinjuku

Comparison of floor number (Shinjuku)

Shibuya

Comparison of floor number (Shibuya)

Tokyo

Comparison of floor number (Tokyo)

Rinkai

Comparison of floor number (Rinkai)

Wide Area

Comparison of floor number (Wide Area)

New building? MAPCUBEで要検証
1231 dams (more than one million m$^3$)
- Flood protection dam (f)
- Water utilization dam (u)
- Multi purpose dam (m)

1. Flood protection operation

\[ Q_{\text{base}} = \begin{cases} Q_{\text{flood}} & \text{when } Q_{\text{inf}} > Q_{\text{flood}} \\ Q_{\text{norm}} & \text{when } Q_{\text{inf}} \leq Q_{\text{flood}} \end{cases} \]

2. Water utilization operation

\[ Q_{\text{ouf}} = \max \left\{ Q_{\text{base}} , \beta \cdot Q_{\text{req}} \right\} \]

- \( Q_{\text{req}} \): water demand
- \( Q_{\text{dry}} \): \( \frac{S_t}{\text{dry period}} \)
- \( S_t \): storage
- \( V_u \): water use capacity

Catchesment area of all dams more than one million m$^3$
Based on the historical data, model parameters can be optimized.

Now we are trying to find out the relationship between optimized parameters and dam specification to estimate the parameter of the dam where no historical data are available.
## Data source for future water demand estimation

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Unit</th>
<th>Year</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic water</td>
<td>country</td>
<td>1960-2010 (every 5 year)</td>
<td>Determination of parameter and variable</td>
</tr>
<tr>
<td>Industrial water</td>
<td>country</td>
<td>1960-2010 (every 5 year)</td>
<td>Determination of parameter and variable</td>
</tr>
<tr>
<td>Population (nation)</td>
<td>country</td>
<td>1950-2100 (every year)</td>
<td>Future projection of domestic water</td>
</tr>
<tr>
<td>Power generation</td>
<td>region</td>
<td>Historical data (every year)</td>
<td>Future projection of industrial water</td>
</tr>
<tr>
<td>GDP</td>
<td>country</td>
<td>2050, 2100 (each SSP)</td>
<td>Power generation (region -&gt; country)</td>
</tr>
<tr>
<td>Population (gridded)</td>
<td>2.5 min mesh</td>
<td>2010</td>
<td>Country -&gt; 2.5min Grid</td>
</tr>
</tbody>
</table>
Prognostic equation for domestic and industrial water demand

\[ D = \text{POP} \times \left( \text{idom},t_0 + s_{\text{dom}} \times (t-t_0) \right) \times 0.365 \]

\[ I = \text{ELC} \times \left( \text{ind},t_0 + s_{\text{ind}} \times (t-t_0) \right) \]

Disaggregate the regional future estimation by AIM using power generation \( \propto \) GDP

- **D** \([m^3\text{year}^{-1}]\): domestic water demand
- **POP** [person]: population
- **I** \([m^3\text{year}^{-1}]\): industrial water demand
- **ELC** [MWh]: power generation
- **idom, to** [L day\(^{-1}\)person\(^{-1}\)]: domestic water per capita at \(t_0\)
- **ind, to** [m\(^3\) yr\(^{-1}\)MWh\(^{-1}\)]: industrial water per power generation at \(t_0\)
- \(t_0\) [yr]: reference year
- \(t\) [yr]: target year
- **S_{\text{dom}}** [L day\(^{-1}\)person\(^{-1}\)yr\(^{-1}\)]: change rate of domestic water per capita
- **S_{\text{ind}}** [m\(^3\) \(-\)1 person\(^{-1}\)yr\(^{-2}\)]: change rate of industrial water per power generation
Domestic water demand reproduction

Industrial water demand reproduction
Disaggregation to each grid

Water demand for each mesh = Water demand for each country × Population for each mesh

Population for country

GPW (Gridded Population of the World)
Virtual water balance in each scenario is **quantitatively** estimated by **physical** approach.

### Scenario

<table>
<thead>
<tr>
<th>Irrigation type</th>
<th>Drip irrigation</th>
<th>Furrow irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water conveyance efficiency</td>
<td>40%</td>
<td>45%</td>
</tr>
<tr>
<td>Irrigated area</td>
<td>0%</td>
<td>25%</td>
</tr>
</tbody>
</table>
**Scenario Analysis**

**Irrigation type**

- **Drip irrigation scenario**
  - 0% → 16Gt can be annually saved
  - Aral Sea would be 1976’s level.

**Irrigated area**

- 0% → 23Gt water can be annually saved
  - Aral Sea would be 1960’s level.
- 25% → 17Gt water can be annually saved
  - Aral Sea would be 1974’s level.
- 50% → 10Gt water can be annually saved
  - Aral Sea would be 1982’s level.
- 75% → 4Gt water can be annually saved
  - Aral Sea would be 1991’s level.
SCENARIO ANALYSIS

Quantitative scenario analysis was enabled by physical model.

To Make a plan for sustainable development, these information will be important.

Water conveyance efficiency

- 0.45 (5% improvement)  
  ⇒ 6Gt water can be annually saved  
  Aral Sea would be 1986’s level.

- 0.50 (10% improvement)  
  ⇒ 12Gt water can be annually saved  
  Aral Sea would be 1980’s level.

- 0.55 (15% improvement)  
  ⇒ 18Gt water can be annually saved.  
  Aral Sea would be 1974’s level.

- 0.60 (20% improvement)  
  ⇒ 22Gt water can be annually saved  
  Aral Sea would be 1967’s level.