Prediction of Hydrologic Impact of Climate Change on Forested Watersheds in Korea

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1. Land and Water in Korea

- About 70% of land is occupied by forests
- About 74% of annual precipitation in forested land
  - Forests play the key roles in controlling the quantity and quality of downstream watersheds

Annual precipitation = \(1,276 \times 10^8\) ton / yr
(1971 to 2000)
2. Potential Effects of Climate Change

- The increasing trend of precipitation will be continuing in the 21st century
- Climate is a major driver of forest species distribution, the growth rate and structure
- The physiological effect of increasing CO₂ conc. on plant transpiration is another driver for global mean runoff increases
3. Structure of Impact Assessment

- Define and develop geographic and ecological scope of Korean ecosystem and watersheds
- Development and evaluation of climate change scenarios (5km resolution)
- Stochastic weather generation with monthly climate

- Atmospheric CO2 concentration
- Threats to habitat and biodiversity
- Threats to hydrological function

- Land use management and conservation strategy
- Future Land and Vegetation Cover Database
- A GIS-based Hydrological Model

- Change in biodiversity and conservation status
  - Changes in potential vegetation
  - Extents, continuity and fragmentation of remaining forest cover
  - Changes in land use allocation

- Define Ecological and Hydrological Hot-spots for implementing adaptation strategies
- Change in hydrological response in watersheds
  - Changes in water availability
  - Changes in flood events and intensity
  - Changes in drought events and intensity

- Model parameterization and calibration
3.1 Hydrological Model

- A deterministic, process-oriented, distributed parameter hydrologic model based on 1D-SVAT BROOK90 model.
- Day-night simulation generates daily water balance and streamflow in each unit basin.
3.2 Delineating Watersheds and Hydro-Net

- The 3 arc second (about 90m) Digital Elevation Models (DEMs) from the NASA shuttle radar topographic mission (SRTM, http://srtm.csi.cgiar.org/) assigned by the Pfafstetter watershed coding system (Pfafstetter, 1989) to identify the upstream and downstream watersheds.

- Validated with 174 river gauging stations

![Maps](image)
3.3 Climate and Weather Generator

- Spatial interpolation of observed daily metrological data from 111 GTS-weather stations (ROK-84, DPK-27) during 1971 – 2000
- Extract stochastic characteristics for estimating daily weather generator, WXGEN parameters

Annual mean temperature (°C)
Annual mean precipitation (mm/year)

Generated daily precipitation at Mt. Junbong flux tower
3.4 Initial Surface Parameters

<table>
<thead>
<tr>
<th>Important Surface parameters</th>
<th>Conifer (cf)</th>
<th>Deciduous (df)</th>
<th>Mixed (mf)</th>
<th>Cropland (cu)</th>
<th>Grassland (gr)</th>
<th>Barren (br)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Max. leaf conductance</strong> $^{1)}$, $g_{\text{max}}$ (cm s$^{-1}$)</td>
<td>0.55</td>
<td>0.59</td>
<td>0.46</td>
<td>1.1(0.84)$^{2)}$</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Max. leaf area index</strong>, $L_{\text{pmax}}$ (m$^2$ m$^{-2}$)</td>
<td>5</td>
<td>6</td>
<td>5.5</td>
<td>2.5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Min. leaf area index</strong>, $L_{\text{pmin}}$ (m$^2$ m$^{-2}$)</td>
<td>1.2</td>
<td>0.6</td>
<td>1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Canopy height</strong>, $h$ (m)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>0.7</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Leaf width</strong>, $l$ (m)</td>
<td>0.004</td>
<td>0.1</td>
<td>0.1</td>
<td>0.03</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Ground surface roughness</strong>, $z_{0g}$ (m)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.005</td>
<td>0.01</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Albedo</strong>, $a$ (-)</td>
<td>0.14</td>
<td>0.18</td>
<td>0.15</td>
<td>0.22</td>
<td>0.24</td>
<td>0.26</td>
</tr>
<tr>
<td><strong>Radiation extinction coefficient</strong>, $C_R$ (-)</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Root length</strong> (m m$^{-2}$)</td>
<td>3100</td>
<td>3000</td>
<td>3050</td>
<td>110</td>
<td>1000</td>
<td>280</td>
</tr>
<tr>
<td><strong>99% root mass depth</strong> $^{1)}$, $D_{r99}$ (m)</td>
<td>1.86</td>
<td>1.33</td>
<td>1.6</td>
<td>1.13</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>95% root mass depth</strong> $^{1)}$, $D_{r95}$ (m)</td>
<td>1.21</td>
<td>0.86</td>
<td>1.04</td>
<td>0.73</td>
<td>0.52</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Source: Federer et al (1996, 2003); 1) Table 1 and Appendix table 2 in Schulz et al. (1994); 2) Maximum leaf conductance for rice paddy; 3) Root length for type from Jackson et al. (1996)
4. Model Validation

- Daily simulation: Mean bias error and efficiency at each watersheds
- Comparison between simulated long-term (more than 6-7 years) average annual runoff with the results from governmental estimate (1969-1998), Water Vision 2020
4.1 Daily Input Validation Result

- Annual mean bias error: -7~10%
- Monthly flow $r^2$: 0.799~0.955
- Daily flow efficiency: 0.513~0.865
4.2 Generated Daily Input Validation Result

- Monthly flow and model efficiency using generated daily climate:
  - Monthly mean bias error: 0.03 km³/month ($r^2=0.9989$)

  - 30yr(1971-2000) mean annual runoff difference: -4.3%
5. Ecosystem Contribution to Runoff Change

Climate change scenario: MRI-RCM(2081-2100)

<table>
<thead>
<tr>
<th>Variables</th>
<th>SY</th>
<th>HW</th>
<th>CJ</th>
<th>NG</th>
<th>HC</th>
<th>AD</th>
<th>DC</th>
<th>SJ</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta T (^\circ C)$</td>
<td>3.0</td>
<td>2.8</td>
<td>2.9</td>
<td>2.8</td>
<td>2.8</td>
<td>2.9</td>
<td>2.7</td>
<td>2.6</td>
<td>2.8</td>
</tr>
<tr>
<td>$\Delta P (%)$</td>
<td>11.4%</td>
<td>14.6%</td>
<td>16.3%</td>
<td>7.1%</td>
<td>6.7%</td>
<td>22.1%</td>
<td>13.7%</td>
<td>13.2%</td>
<td>13.1%</td>
</tr>
<tr>
<td>$\Delta Wind (%)$</td>
<td>0.2%</td>
<td>-0.1%</td>
<td>0.1%</td>
<td>-0.3%</td>
<td>-0.1%</td>
<td>0.5%</td>
<td>-0.7%</td>
<td>-1.6%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>$\Delta Humidity (%)$</td>
<td>18.7%</td>
<td>17.7%</td>
<td>18.0%</td>
<td>17.6%</td>
<td>17.7%</td>
<td>17.8%</td>
<td>16.8%</td>
<td>16.7%</td>
<td>17.6%</td>
</tr>
<tr>
<td>$\Delta Radiation (%)$</td>
<td>1.0%</td>
<td>0.5%</td>
<td>1.8%</td>
<td>-0.3%</td>
<td>0.1%</td>
<td>0.7%</td>
<td>0.8%</td>
<td>0.4%</td>
<td>0.6%</td>
</tr>
</tbody>
</table>

Three novel approaches

- **Case C**: Climate change only
- **Case CP**: $C +$ Physiological forcing, P
  
  (Atmospheric $CO_2$ conc., $=700$ ppmv.)
- **Case CPV**: $CP +$ Vegetation distribution change, V
  
  (35% increases in the deciduous forest fraction)
5. Ecosystem Contribution to Runoff Change

- Climate change alone: 12% (2~17%) increase in runoff
  - CP change: 16% (5~32%) increase in runoff
  - CPV change: 17% (8~28%) increase in runoff
- Increased CO₂ effect on runoff: 3.3% (1.1~7.7%)
- Increased CO₂ and deciduous forests effects: 5.0% (2.5~10.8%)
6. Potential Impact on the Korean Watersheds

- **Target Periods**: 2081-2100
- **Future scenarios**: MRI-RCM SRES A2, MIROC high res. A1B GCM, and CSIRO GCM A1, A2, B1, B2
- **Output**: % changes in runoff, floods and droughts
  - **Flood risk flow** is defined as **the daily Q5 flow** of the BASE period (1981-2000);
  - **Drought risk flow** is **the monthly Q95 flow** of the BASE period; and
  - **Average water availability** is **the monthly Q50 flow (median)** of the BASE period

- **Q5 flow (high flow)** is the flow exceeded 5% of the time (or the 95th percentile of a probability density function), and
- **Q95 flow (low flow)** is the flow exceeded 95% of the time
6.1 Base Scenario

- **Annual mean precipitation during a 30-year (1971-2000):**
  - **1058 mm** (South: 1280 mm, North: 877 mm)

- **Annual runoff:**
  - **570 mm** (54% of Precipitation) (South Korea: 706 mm (55%), North Korea: 459 mm (52%))

- Wet season (June-September) runoff: 68% of annual runoff
6.2 Changes in Runoff

- **Annual runoff change during 2081-2100:**
  - MRI-RCM A2: South Korea 9.4%, North Korea: 8.4%
  - **MIROC A1B:** South Korea 32.1%, North Korea: 41%

- **Wet season (June-September) runoff change:**
  - MRI-RCM A2: South Korea 23.7%, North Korea: 17.7%
  - **MIROC A1B:** South Korea 35.2%, North Korea: 44.9%
6.2 Changes in Runoff (MRI-RCM-A2)
6.2 Changes in Runoff (MIROC-A1B)
6.3 Changes in Extreme Flow

Changes in flood risk flow (2081-2100):
- MRI-RCM A2: South Korea: 11.4~44.1%, North 7.7%~38.1%
- MIROC A1B: South Korea: 24.8~40.3%, North 37.1%~58.8%

Changes in drought risk flow (2081-2100):
- MRI-RCM A2: South Korea: -5.4~-14.7%, North Korea: -12.3%,
- MIROC A1B: None
6.4 Potential Risk Area

- Extreme event risk area affected by floods and drought, simultaneously (MRI-RCM): South Korea: about 53%, North Korea: 24% of inland area
6.5 Conclusions

- **Runoff tends to be increased in western coastal region** of the peninsula and upper interior region of the Han River Basin around the Gwangwon province.

- **Extreme flows tend to be increased in maritime parts of the peninsula.** Floods may be increased over the whole peninsula, especially western coastal region and North Korea, because of increases of the heavy rainfall in summer season.

- **Low flow also tends to be increased** however the western coastal region of the peninsula and the middle parts of the Han River basin are showing reduced low flow by 2090s in MRIRCM scenario.

- Changes in **forest ecosystem has an additional contribution to future runoff increases**. Increases in atmospheric CO₂ concentration and deciduous forest species fraction produce about 5% of more runoff ranging from 2.5% to 10.8% in the forested watersheds.
# Model Validation Results

<table>
<thead>
<tr>
<th>Name</th>
<th>Annual water balance (1981 – 2000, mm/yr)</th>
<th>Daily mean flow (m³/s) Calibration</th>
<th>Daily mean flow (m³/s) Validation</th>
<th>Daily Q5 flow (m³/s) Calibration</th>
<th>Daily Q5 flow (m³/s) Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Simulated</td>
<td>%Bias</td>
<td>%Bias</td>
<td>Efficiency</td>
</tr>
<tr>
<td>Soyanggang</td>
<td>836</td>
<td>836</td>
<td>0</td>
<td>4.8</td>
<td>0.842</td>
</tr>
<tr>
<td>Hwacheon</td>
<td>717</td>
<td>717</td>
<td>-0.1</td>
<td>3</td>
<td>0.771</td>
</tr>
<tr>
<td>Chungju</td>
<td>781</td>
<td>717</td>
<td>-0.4</td>
<td>3</td>
<td>0.533</td>
</tr>
<tr>
<td>Namgang</td>
<td>857</td>
<td>871</td>
<td>0.5</td>
<td>-8.8</td>
<td>0.799</td>
</tr>
<tr>
<td>Hapcheon</td>
<td>641</td>
<td>690</td>
<td>-0.1</td>
<td>0.1</td>
<td>0.822</td>
</tr>
<tr>
<td>Andong</td>
<td>596</td>
<td>605</td>
<td>-0.2</td>
<td>3.5</td>
<td>0.687</td>
</tr>
<tr>
<td>Deacheong</td>
<td>663</td>
<td>656</td>
<td>0</td>
<td>1.7</td>
<td>0.672</td>
</tr>
<tr>
<td>Seomjingang</td>
<td>718</td>
<td>711</td>
<td>0.1</td>
<td>-1.3</td>
<td>0.695</td>
</tr>
</tbody>
</table>