Climate Change Impact on River Flow of the Tone River Basin, Japan

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Introduction

- Climate change is now an unequivocal truth, and it is expected to strongly affect the hydrologic cycle in the coming decades.

Arctic Sea Ice (source: earth observatory, NASA)

The Kyetrak Glacier, Tibet
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• Water supply condition in Japan is not stable even now due to its severe seasonal variation and high population density.

• So far, this water related problems have been skillfully handled with many types of reservoir and multi-purpose dam.
Introduction

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- Water supply condition in Japan is not stable even now due to its severe seasonal variation and high population density.

- So far, this water related problems have been skillfully handled with many types of reservoir and multi-purpose dam.

- **However, this current dam operation rules may not work properly for the changed hydrologic cycle in the future.**

- Future hydrologic impact analysis should be carried out with consideration for the sophisticated water control and usage.
Objectives

• Future river flow changes in the Tone River basin, Japan, were investigated using a distributed hydrologic model considering multiple dam reservoir operations and current water usage condition.

Contents

• General Circulation Model Output

• Distributed Hydrologic Model

• Reservoir Operation Model

• Future Water Resources Analysis
  – Flow Duration Curves
  – Mean Flow and Minimum Flow
  – Flood Peaks in Hourly and Daily
MRI-AGCM20km

- Rapid evolution of GCMs in the last three decades allows us to expect reasonable hydrologic dataset from the model output.

Source: IPCC AR4 (WG1)

Figure 1.4. Geographic resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (IPCC, 1990), SAR (IPCC, 1996), TAR (IPCC, 2001a), and AR4 (2007). The figures above show how successive generations of these global models increasingly resolved northern Europe. These illustrations are representative of the most detailed horizontal resolution used for short-term climate simulations. The century-long simulations cited in IPCC Assessment Reports after the FAR were typically run with the previous generation’s resolution. Vertical resolution in both atmosphere and ocean models is not shown, but it has increased comparably with the horizontal resolution, beginning typically with a single-layer slab ocean and ten atmospheric layers in the FAR and progressing to about thirty levels in both atmosphere and ocean.
MRI-AGCM20km

- Rapid evolution of GCMs in the last three decades allows us to expect reasonable hydrologic dataset from the model output.

- In 2007, Japan’s Ministry of Education, Culture, Sports, Science, and Technology (MEXT) launched the Innovative Program of Climate Change Projection for the 21st Century (Kakushin21), and have developed a super-high-resolution atmospheric model having 20-km spatial and 1-hour temporal resolution (AGCM20).
MRI-AGCM20km

- **Spatial Resolution**
  1920 × 960 grid cells (20 km) with 60 vertical levels (TL959L60)

- **Temporal Resolution**
  Hourly precipitation with other daily variables

- **SST Boundary Condition**
  Observed HadISST1 dataset for controlled run
  Ensemble Mean of CMIP3 A1B scenario for projection run

- **A1B scenario** of Special Report on Emissions Scenarios (SRES)
  2.5°C temperature increase and 720 ppm of CO₂ concentration by 2100
AGCM20 Output Evaluation

How much we can trust the AGCM20 output?

Reliance on the model output can be achieved by evaluating the output for the present climate.
1. Data Evaluation

- AMeDAS Observation
- Hydrologic Model (Calibration)
- Observed Discharge

2. Simulation

- AGCM20 (Present)
- AGCM20 (Future)
- Hydrologic Model (Simulation)
- Simulated Discharge
- Discharge (Future)

3. Analysis

Searching for any significant water resources problems
AGCM20 Output Evaluation

Using the AMeDAS observation of over 1,300 gauging stations (averagely 17 km distance to each other) point gauged data → 20km grid data

Annual Mean Precipitation of 25-yrs (1979~2003)

AMeDAS 1684.25mm
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Annual Mean Precipitation of 25-yrs (1979~2003)

AMeDAS 1684.25mm
AGCM20 1695.24mm

(1) 1985.81mm vs. 1959.09mm
(2) 1753.25mm vs. 1797.28mm
(3) 1128.93mm vs. 1129.56mm

Spatial Pattern Correlation
0.781

Overall matches of the amounts but, smoothen spatial pattern → 20-km resolution grid
AGCM20 Output Evaluation

Annual Mean Precipitation by AMeDAS

AMeDAS 1684.25 mm

Annual Precipitation by AGCM20

AGCM 1695.24 mm

Spatial Pattern Correlation of Monthly Precipitation

January

Monthly Precipitation by AM

December

February

March

April

May

June

July

August

October

November

Spatial Pattern Correlation of Monthly Precipitation by AGCM20 01

Spatial Pattern Correlation of Monthly Precipitation by AGCM20 08
Reproducibility of daily and hourly maximum was evaluated by checking 100 maximums of AGCM20 output and AMeDAS observation.

- 100 maximums = 4 maximums × 25 years.

Underestimated Extreme Values
Reproducibility of daily and hourly maximum was evaluated by checking 100 maximums of AGCM20 output and AMeDAS observation.

100 maximums = 4 maximums × 25 years.

Underestimated Extreme Values
Long-term Simulation using MRI-AGCM20km Output Data

**INPUT**
- Precipitation
  - precipi (hourly)
  - prcsl (daily)
  - sn2sl
- Evapo-transpiration
  - evpsl
  - trnsl

**OUTPUT**
- Hourly discharges at every point in the basin
Modeling the Tone River Basin (8,772 km²)

- 16 sub-basins including 7 dam-basins.
- Parameters have been optimized for each sub-basin.
- Calibration with 1995~1999 non-snowfall/melt season with hourly precipitation and monthly averaged evaporation data.

Runoff Simulation using Kinematic Wave Model (250m resolution DEM)
Rainfall-Runoff Simulation Results using AGCM20 Present Climate Output (1979~2003)

Yagisawa (167.4 km²)
Obs: 16.8 cms
Sim:  7.5 cms

Aimata (110.8 km²)
Obs:  5.9 cms
Sim:  5.3 cms

Sonohara (493.9 km²)
Obs: 14.4 cms
Sim:  20.0 cms

Kusaki (154.0 km²)
Obs: 11.6 cms
Sim: 11.8 cms

Murakami (1249.2 km²)
Obs: 26.2 cms
Sim: 54.2 cms

Takamatsu (557.4 km²)
Obs: 16.0 cms
Sim: 22.4 cms

Otome (873.7 km²)
Obs: 33.4 cms
Sim: 36.2 cms

Shimokubo (322.8 km²)
Obs:  6.9 cms
Sim: 15.7 cms

Japan
Tokyo
overest
underest
consent
Rainfall-Runoff Simulation Results using AGCM20 Present Climate Output

Yakatahara (1677.5 km²)
Obs. flow: 47.1 cms (884.8 mm)
Sim. flow: 65.5 cms (1230.6 mm)
39.1 % overestimation

Yattajima (5133.6 km²)
Obs. flow: 177.6cms (1090.8mm)
Sim. flow: 212.9cms (1308.1mm)
19.9 % overestimation

Kurihashi (8772.2 km²)
Obs. flow: 296.7cms (1066.6mm)
Sim. flow: 353.9cms (1272.4mm)
19.3 % overestimation

Scale Inconsistency:
Not enough for small basin (scale), but
Good enough for larger basin (scale)
Criteria is somewhere around $3 \times 3$ grids (?)
Reproducibility of the AGCM20 Output

Table 1 Reproducibility of Each Sub-basin

<table>
<thead>
<tr>
<th>Basin Name</th>
<th>Area (km²)</th>
<th>NSC</th>
<th>Vol. Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aimata</td>
<td>110.8</td>
<td>0.54</td>
<td>-10.2 %</td>
</tr>
<tr>
<td>Kusaki</td>
<td>154.0</td>
<td>0.39</td>
<td>+1.1 %</td>
</tr>
<tr>
<td>Yagisawa</td>
<td>167.4</td>
<td>0.13</td>
<td>-55.3 %</td>
</tr>
<tr>
<td>Sonohara</td>
<td>493.9</td>
<td>-0.18</td>
<td>+39.6 %</td>
</tr>
<tr>
<td>Takamatsu</td>
<td>557.4</td>
<td>0.14</td>
<td>+39.9 %</td>
</tr>
<tr>
<td>Otome</td>
<td>873.7</td>
<td>0.39</td>
<td>+18.5 %</td>
</tr>
<tr>
<td>Murakami</td>
<td>1249.2</td>
<td>-1.74</td>
<td>+49.2 %</td>
</tr>
<tr>
<td>Yakatahara</td>
<td>1677.5</td>
<td>0.65</td>
<td>+26.1 %</td>
</tr>
<tr>
<td>Yattajima</td>
<td>5133.6</td>
<td>0.49</td>
<td>+3.5 %</td>
</tr>
<tr>
<td>Tone-Ozaki</td>
<td>6058.8</td>
<td>0.45</td>
<td>-7.3 %</td>
</tr>
<tr>
<td>Kurihashi</td>
<td>8772.2</td>
<td>0.59</td>
<td>-2.0 %</td>
</tr>
</tbody>
</table>

*NSC: Nash-Sutcliffe Coefficient
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- Flow Duration Curves
- Mean Flow and Minimum Flow
Dam Reservoir Operation Model

Hard to find the standard operation rule
Depending on precipitation amount and water demand of each year

Averaging the recent 10 years operation

Operation Records of 1994~2003

Inflow
Outflow

Discharge (m³/s)

Time (month)

Observed Water Level (Averaged)
Dam Reservoir Operation Model

Operation Rules: Release
Based on given outflow amounts
(averaged over observed outflow of 10 yrs)

Sawawa Dam (167.4 km²)

Dam Model to reproduce current Outflow

Inflow

Outflow

Discharge (m³/Sec)

Present  Future  Present  Future  Observed  Observed

Present  Future  Present  Future  Observed  Observed
Controlled Outflow of Present & Future

By the designed dam reservoir operation, it was able to realize similar pattern to the current one.

Different inflow → Controlled outflow (current release pattern)

The future river flow will be able to meet the current water demand under the current reservoir operation rules?
Current Water Demand in the Tone River Basin

**Yakatahara**
- Living water: 3.09 m³/s
- Cultural water:
  - May: 1.39 ~ 3.48 m³/s
  - June~Sep: 12.17~14.20 m³/s

**Bukawa**
- Cultural water: ~46.10 m³/s

**Wakaizumi**
- Cultural water:
  - Sep~May: 2.82 ~ 7.43 m³/s
  - June~Sep: 14.33~18.15 m³/s

**Ota-Tousyukou**
- Agricultural water:
  - Sep~May: 2.82 ~ 7.43 m³/s
  - June~Sep: 14.33~18.15 m³/s

**Tone-Ozuki**
- Living water: 37.43 m³/s
- Industrial water: 2.08 m³/s
- Agricultural water:
Controlled reservoir operation for stable water usage in winter season

Yakatahara (1677.5 km²)

- Controlled reservoir operation for stable water usage in winter season

Demand: 3.09 m³/s
Agricultural water:
Controlled reservoir operation for stable water usage in winter season

- Controlled reservoir operation for stable water usage in winter season

Yattajima (5133.6 km²)

• Maximum Demand
  - Domestic water: 3.09 m³/s
  - Agricultural water: 155.0 m³/s
Mean & Lowest Flow

Murakami (1249.2km²)

Yakatahara (1677.5km²)

Yattajima (5133.6km²)

Tone-Ozeki (6058.8.5km²)
Mean & Lowest Flow
Changes in Precipitation Seasonal Pattern

Climate change would accelerate water cycles, leading to more precipitation and decreased evapotranspiration. Limited water resources in some regions.

Table 1. Net-water-resources amount in each region (annual amount averaging 25 years)

<table>
<thead>
<tr>
<th>Region</th>
<th>Present (unit: mm)</th>
<th>NearFuture (changes: %)</th>
<th>Future (changes: %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hokkaido</td>
<td>607.6</td>
<td>(6.68)</td>
<td>(6.19)</td>
</tr>
<tr>
<td>Tohoku</td>
<td>834.4</td>
<td>(0.43)</td>
<td>(5.72)</td>
</tr>
<tr>
<td>Kanto</td>
<td>1038.5</td>
<td>(0.50)</td>
<td>(3.51)</td>
</tr>
<tr>
<td>Chubu</td>
<td>1359.4</td>
<td>(0.71)</td>
<td>(4.61)</td>
</tr>
<tr>
<td>Kinki</td>
<td>1173.4</td>
<td>(0.58)</td>
<td>(1.76)</td>
</tr>
<tr>
<td>Shikoku</td>
<td>1268.1</td>
<td>(-0.91)</td>
<td>(-1.09)</td>
</tr>
<tr>
<td>Chugoku</td>
<td>1041.4</td>
<td>(4.80)</td>
<td>(2.15)</td>
</tr>
<tr>
<td>Kyushu</td>
<td>1263.1</td>
<td>(0.14)</td>
<td>(2.20)</td>
</tr>
<tr>
<td>Japan</td>
<td>1010.1</td>
<td>(1.70)</td>
<td>(1.22)</td>
</tr>
</tbody>
</table>
Peak Discharges DAILY

Murakami (1249.2 km²)

Yakatahara (1677.5 km²)

Tone-Ozeki (6058.8 km²)
Peak Discharges HOURLY

No Severe Changes in Extreme Events in the Tone River Basin
Possible Extreme Events
- Various Typhoon Tracks -
Flood Simulations with Possible Extreme Events
Possible Extreme Events
- Various Typhoon Tracks -
Possible Extreme Events

- Various Typhoon Tracks -
Summary

Climate change impacts analysis on the Tone River Basin

Using the super high resolution GCM output (20km/spatial & 1hr/temporal)
Distributed hydrologic model considering multiple dam reservoir operations
Dam model to reproduce the current dam release patterns
Assuming that the future water demand will be the same to the present one

Current dam reservoir operation rules are effective
Especially at the right downstream of the dam reservoirs
For most of the season except the late spring season
Tone-Ozuki has high possibility of water shortage in the future
Necessary to modify the operation rules for the late spring season water supply
Thank you very much!

further information
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Soil Layer
Canopy

TRNSL (Transpiration)
EVPSL (Evaporation)
PRCSL (Throughfall)
SN2SL (Snowmelt)

PRECIPI
Precipitation

Previous Method
Revised

- Soil Layer
- Canopy
- PRECIPI (Precipitation)
  - Bias Correction using Observed Precipitation
    - RAINFALL \((T > 0)\)
    - Snowfall \((T \leq 0)\)
      - SNOWMELT using Degree-Day Method
- EVPSSL (Evaporation)
- TRNSL (Transpiration)
Bias Correction with Daily Scaling Method

Example of sorted daily precipitation from the AphroJP observation and M20 output with the ratio of these two values \( r = \frac{P_{\text{sim}}}{P_{\text{obs}}} \) for April, August (middle), and December (right). Each month has different range of ratio values. This sample data comes from the nearest grid point at the Yagisawa Dam Basin.
Bias Corrected Precipitation
Annual mean Precipitation

Aphro
AGCM20
AGCM-BCed
Temperature Evaluations

Obs.  Sim.  O-S
Improved Simulation Results (Yagisawa Dam Basin)

AGCM-3.1S

AGM-3.2S
Considering Social Vulnerability Change

\[ \text{Disaster} = f_1 (\text{Meteorological f., Geomorphologic f., Social factors}) \]

Changes in meteorological factors (\(\Delta M.F.\)) are apparent in the coming century.
Changes in geomorphologic factors (\(\Delta G.F.\)) are negligible.
Changes in social factors (\(\Delta S.F.\)) also should be considered in the climate change research to propose successful adaptation methods.

\[ \Delta \text{Disaster} = \Delta f_1 (\Delta M.F., \Delta S.F.) \]

**Food disaster case**
Meteorological factors: heavy rainfall/snowfall, rainfall duration, etc
Geomorphologic factors: shape of catchments/river, land cover, etc
Social factors: river management, deforestation, etc

**Water resources management case**
Meteorological factors: annual precipi amount, seasonal variation, etc
Further Research

To develop proper dam operation rules for the future water regimes
- Should consider the shifted snowmelt season with decreased amount
- Plus, flood control function in the summer season

To estimate future water demands
- Water demand changes as society changes
- Natural water usage such as agricultural usage will be changed.

To identify the uncertainty in the future projection
- Uncertainty in the AGCM20 output
- Uncertainty in the water resources assessments

To improve the accuracy of the input and output
- Downscaling & bias correction, especially for small basin
- Improving the model performances under the various situations
Flow Duration Curves

Yakamori (1249.2km²)

Yakatahara (1677.5km²)

Yokotaijima (5133.6km²)

Tone-Ozeki (6058.8km²)
Direct affects from the multiple reservoir operations

High flow amount decreased and stabilized low flow amounts