Climate change impact assessment on disaster environment in Japan and expectations for regional climate models

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1. Introduction
2. Structure of DPRI’s impact assessment
3. Importance of hourly rainfall for Japanese river basins
4. Impact assessment related to river regime
5. Uncertainty in estimating return value
6. Spatial scale in which AGCM20 output can reproduce river regime & Can RCM improve reproducibility of river regime in smaller basin?
7. Expectations for RCM
8. Heading to adaptation
9. Summary

1. INTRODUCTION
Participating groups and their studies

◆ **Long-term global environmental projection**
   with an earth system model
   - Frontier Research Center for Global Change (FRCGC) et al.

◆ **Near-term climate prediction**
   with a high-resolution coupled ocean-atmosphere GCM
   - Center for Climate System Research (CCSR) of the University of Tokyo et al.

◆ **Projection of changes in extremes in the future**
   with super-high resolution atmospheric models
   - Meteorological Research Institute (MRI) et al.
   - Disaster Prevention Research Institute (DPRI), Kyoto University
   - International Centre for Water Hazard and Risk Management (ICHARM), Public Work Research Institute (PWRI)
Projection of changes in extremes in the future with very-high resolution atmospheric models

A. Projection
Extreme event projection by very high resolution atmospheric models
Meteorological Research Institute (MRI)
Japan Meteorological Agency (JMA)
Advanced Earth Science & Technology Org. (AESTO)

B. Uncertainty
Evaluation and reduction of uncertainty in global warming projection
Meteorological Research Institute (MRI)
Japan Meteorological Agency (JMA)
Advanced Earth Science & Technology Org. (AESTO)

C. Risk assessment
- Prediction and evaluation of disaster environment
  Disaster Prevention Research Institute (DPRI), Kyoto University
- Assessment of climate-change impacts on flood risk and its reduction measures on global and local scales
  International Centre for Water Hazard and Risk Management (ICHARM), Public Works Research Institute
“Design level” and “Risk management”

Design level = a return value corresponding to a specific return period

Risk management = Disaster reduction

Range for disaster prevention
= no overpass from embankment
= no inundation over flood plain

This level may become quite ambiguous in the climate change projection.

- How can we propose an adaptation way?
- How can RCM help in the proposal?
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2. STRUCTURE OF DPRI’S IMPACT ASSESSMENT
Prediction and evaluation of disaster environment in Japan

**Output from GCM**

- Hourly precipitation, temperature, water vapor, wind velocity, radiation and air pressure (25-years time series (20km) and ensemble predictions (60km) for current, near future and century end)

- Regional climate model (RCM_5km, RCM_2km, RCM_1km)

- Surface hydrological model

**Interpretation of output**

- Soil production
- Reservoir operation

**Various Models (with long-term run)**

- Soil runoff
- Sedimentation and transportation of soil
- Rainfall runoff
- River channel flow

**Evaluation**

- Decreasing of safety against landslide, debris flow, flood, draught, storm surge and strong wind.
- Assessment of current protection system and proposal of alternatives
Minimum Target of DPRI

- Precipitation: Global
- Land slide and Debris flow: mainly western Japan
- River discharge:
  Japanese major river basins (with fine resolution)
  All Japanese river basins (with medium resolution)
- Storm surge: Tokyo, Ise (Nagaya) and Osaka Bays
- Damage by strong wind: entire Japanese archipelago
- Inundation: Tokyo, Nagoya, Osaka and Fukuoka
Methods of Impact assessment

Output from GCM and/or RCM

- Hydrological Regime, Ocean wave
  Direct and continual utilization of time-series of GCM/RCM outputs

- Hazard models
  - Run-off Model
  - Ocean Wave Model

  Evaluation of changes in hazards

  Evaluation of Changes in Disaster Risks

- Strom Surge, Land Slides, Inundation
  Statistical evaluation of extreme forcing such as design rainfall, design typhoon

- Hazard models
  - Storm Surge Model
  - Land slide Model, Inundation Model

  Evaluation of changes in hazards

  Evaluation of Changes in Disaster Risks

Proposal of Adaptation Strategy
3. IMPORTANCE OF HOURLY RAINFALL FOR JAPANESE RIVER BASINS

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Basic background

- **Current state-of-the-art**: MRI-AGCM20 output
  
  - Output from AGCM20 has realized computing reasonable peak discharge and flood level of Japanese rivers.
  
  - WE CAN CHECK computed EXTREME PEAK DISCHARGE/FLOOD LEVEL of Japanese river in the current climate condition. (GCM estimation vs. Observations)
Features of Japanese River(1)

• Short length and steep slope

Height from sea level (m)

Distance from river mouth (km)
Features of Japanese River (2)

- Large peak discharge, short duration

Importance of temporal resolution of rainfall data in calculating river discharge

- Comparison of simulation results for hourly and daily rainfall data in rainfall runoff model
- Yodo river basin (Hirakata water stage stn.: 7,281km²)
  ⇒ Under-estimation of peak flow up to 50% when we use daily data.
  ⇒ WE HAVE TO CALCULATE RIVER DISCHARGE USING HOURLY RAINFALL DATA.

By Masuda, Tachikawa et al. (2006)
It is the typhoon resolving output that has realized the impact assessment of Japanese disasters.
KAKUSHIN MRI–RCM output

Very important to assess initiation of land slide and debris flow

NESTING

1-km mesh 10-minute

5-km mesh 30-minute

Precipitation (mm/h)
Output from GCM and RCM

• **GCM20** (Hourly, Globe)
  – Rainfall, storm surge and ocean wave in the world
  – Discharge from major and all Japanese rivers basins

• **RCM5 and RCM2** (30 and 20 minutes, Around Japanese Archipelago)
  – Inundation in major metropolitan areas
  – Land slide, debris flow
  – Major Japanese river basins

• **RCM1** (10 minutes, Piecewise sections in Japanese Archipelago)
  – Inundation in major metropolitan areas
  – Land slide and debris flow
  – Strong wind hazard
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4. IMPACT ASSESSMENT RELATED TO RIVER REGIME
Introducing reservoir operation models into the distributed runoff model

System of distributed runoff model

Reservoir operation model

Example of combined computation

Sayama et al. (2008), Kyoto University.
GCM Projection data for runoff simulation

- Precipitation (hourly)
- Canopy layer
  - Snow accumulation
    - Snowmelt (daily)
- Precipitation (daily)
- Soil layer
  - Surface runoff generation (daily)
  - Sub-surface runoff generation (daily)
- River Discharge

- Evaporation from soil layer (daily)
- Transpiration from root zone (daily)
Impact assessment on river regime


Water Resources: Changes in Amount of Snowfall and Snowmelt and Monthly Discharge.

Drought: Changes in Drought Discharge and Maximum Number of Continual Days without Rainfall.

Tachikawa et al., 2010, Kyoto University
Change of 100-year annual maximum hourly discharge

Flood Risk

Near future climate /Current climate

Future climate /Current climate

Quintiles of river discharge with 100-year return period estimated using GEV distribution.

Tachikawa et al., 2010
Reason for the change of annual maximum hourly discharge

Flood Risk

Yoshino River basin

Chikugo River basin

100-year annual maximum daily rainfall

100-year annual maximum hourly discharge

100-year annual maximum daily rainfall

100-year annual maximum hourly discharge
Possible changes in the number of floods requiring dam operation and emergency dam release (Yodo River)

Sayama et al. (2008), Kyoto University.
Design flood discharge for dam reservoir construction

Maximum discharge which flows through spillway

Kuzuryu Dam in Japan
Design flood discharge for dam reservoir construction

Kanto region


土木研究所資料 第1247号, 1976
Current climate experiment

Maximum flood discharge at Kanto region

Near future climate experiment

Future climate experiment

Tachikawa et al., 2010, Kyoto University
Rainfall evaluation for land slide (Total rainfall VS. Max. hourly Rainfall)

Observed relation

Related to Prof. Tsutsumi’s presentation

GCM Present

GCM End of the Century

Oku et al., 2009, Kyoto University
Change of annual maximum non-rainy days and 10-year 10th daily discharge in a year
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5. UNCERTAINTY IN ESTIMATING RETURN VALUE
Uncertainty inherent to GCM projection

1. Uncertainty in cumulus parameterization

2. We only use single 25-years time series of output for present, near future and end of the 21st century.
   - Is this enough number of years as statistical sample?
   - Re-sampling or ensemble projection will be needed.
   - Quite extreme event may not occur within single 25-years time series
   - Worst scenario experiment is required!

3. Uncertainty in CO2 release scenarios
   - We are using most likelihood A1B scenario

Projected value

Random Uncertainty

Model’s uncertainty

CO2 Scenario's uncertainty

Time
Accuracy of estimated annual max. discharge

Accuracy of 100 years return value (Jackknife method)

With 25-years single time series

Change in Annual maximum Discharge

Near Future/Present

End of the Century /Present

Normalized standard deviation of projection

The larger the projected value is, the larger the standard deviation is.
Schematic of return value’s uncertainty

With 25-years single time series

Konoshima and Nakakita (2010)
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6. SPATIAL SCALE IN WHICH AGCM20 OUTPUT CAN REPRODUCE RIVER REGIME. & CAN RCM IMPROVE REPRODUCIBILITY OF RIVER REGIME IN SMALLER BASIN?
Rainfall-Runoff Simulation Results using AGCM20 vs. RCM-5km Output (25 years average in current climate)

Reproducibility of 25 years-averaged discharge computed with AGCM20 approaches to observed one as basin scale becomes larger.

Even RCM-5km does not meet to observed discharge in a small river basin.

Kim and Nakakita (2009), Kyoto University.
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7. EXPECTATIONS FOR RCM REGIME IN SMALLER BASIN?
Expectations for RCM (1)

- Current GCM20 outputs enable us to assess,
  - Drought due to rainfall deficit
  - Flooding due to typhoon and large-scale low pressure.
  - Change of in timing and position of Baiu/Meiyu front
- Regarding flooding, the assessment may be limited to those of ‘national river scale’ including large-scale inundation.
- Small-scale catchment, landslide, inland inundation may be affected more easily by localized storm under Baiu/Maiu front. Is it possible to evaluate them with RCM?
Expectations for RCM (2)

- Computation of more extreme event
  - by sharper vortex and convergence of wind
  - by orographic enhancement
- Identification of climatic division by large-scale but narrow mountainous terrain
  - Difference of monthly or annual rainfall between both sides of the narrow chain of mountains
  - Regionalization of snowfall area and non-snowfall area due to winter monsoon
  - These are very important in water resources management.
GCM vs RCM5 (Baiu season)

- GCM sometimes can not present localized and sharp-shaped heavy rainfall area, which typically brings disastrous landslide and flash flood in Japan.
GCM vs RCM5 (Baiu season)

• The same feature can be verified in the projection for “end of the 21st century”.
Number of localized heavy rainfall during Baiu-season

By “counting by human eyes” with RCM-5 images


Near future (2015-2039)

End of 21st century (2075-2099)

Nakakita and Miyake, Kyoto University (2011)
GCM’s Spatial Bias

Air Temperature [°C]

Precipitation [mm]

Snowmelt [mm]

Evapotranspiration [mm]

By Sato et. Al, Kyoto University (2009)
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8. HEADING TO ADAPTATION
Heading to building up adaptation scenario

• Planning with design level and risk management
  – Basic planning of river improvement has been based on the design level (return value).
  – The design level (return value) under climate change induced condition may involve uncertainty.
    • We cannot predict the change of statistical properties exactly.
  – Risk management will have more important meaning.
    • Because risk management deal with phenomena beyond what we are expecting as design hazards.
    • However, single simulated time series for 25-30 years may not include the extreme hazard corresponding to risk management.
“Design level” and “Risk management”

Design level

=a return value corresponding to a specific return period

Risk management

= Disaster reduction

Range for disaster prevention
= no overpass from embankment
= no inundation over flood plain

This level may become quite ambiguous in the climate change projection.

- How can we propose an adaptation way?
- How can RCM help in the proposal?
Heading to building up adaptation scenario

1. Increasing of ensemble number
   - 1-1) Common requirement for GCM and RCM.
   - 1-2) However, increasing of GCM ensemble should be first priority if RCM would be influenced by its boundary GCM’s condition.

2. The most extreme scenario by the pseudo global warming (PGW) experiment with RCM
   Is this contradict 1-2) ?

3. The most extreme scenario by bogus [Typhoon]
Virtual Shifting of typhoon’s initial position - for making the worst scenario -

Virtual Shifting of typhoons initial position by keeping potential vorticity same (a vorgas method)

Dynamic downscale by RCM

Worst case impact assessment on
- Land: extreme wind and rainfall
- Ocean: storm surge and wave height

Ishikawa et. al, 2009, Kyoto University
Probable maximum hourly precipitation

“worst track” Central Tokyo

AGCM20

Ishikawa et. al, 2010
Track and precipitation

Ishikawa et. al, 2010
Simulation of River Discharge using Precipitation Output (Tone River Basin)

- Main Points
  - Yakatahara (1677.5 km$^2$)
  - Yattajima (5133.6 km$^2$)
  - Tone-Ozeki (6058.8 km$^2$)
  - Kurihashi (8772.2 km$^2$)

- Dam Points
  - Yagisawa Dam
  - Naramata Dam
  - Fujiwara Dam
  - Aimata Dam
  - Sonohara Dam
  - Kusaki Dam
  - Shimokubo Dam

(listed from the top)

Design Flow Rate: 22,000 m$^3$/s (200 years)

Kim et al., 2010, Kyoto University.
At the Yattajima Station:

- 13,540 ton/sec of Peak Discharge with the original route of the Typ.
- Over 45,000 ton/sec of Peak Disch. with the modified routes.
- # Dam operation for flood control is NOT included in the given results!!

River Discharge by the virtual shifting of typhoon (Tone River Basin)

Kim et al., 2010, Kyoto University.
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2. Structure of DPRI’s impact assessment
3. Impact assessment related to the topics which will be presented from DPRI in this workshop
4. Impact assessment directly related adaptation
5. Spatial scale in which AGCM20 output can reproduce river regime
6. Spatial scale in which the Climate Change becomes statistically significant
7. Can RCM improve reproducibility of river regime in smaller basin?
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10. SUMMARY
Summary (1)

1. GCM and RCM with the super-high spatio-temporal resolutions (less than “20 km”-”1 hour”) makes it possible to evaluate extreme hazard in Japan.(ex. Max. discharge).

2. We can get approximate projection on changes in return value of extreme events (i.e. design value). However, there is a risk that the return period does not have enough accuracy.

3. Roughly speaking, the uncertainty (variance) could be reduced by increasing the number of ensemble.

4. However, RCM has a large possibility to improve bias of mean return value for wide range of return period.
Summary (2)

4. Return value of extreme events (i.e. design value) has been quite important index. On the other hand, the risk management deal with phenomena beyond design hazards. In this sense, before projection of return value will be improved, it is very important to take into account the result from the worst case scenario as a one of the forcing for risk management on climate change.

5. Taking into consideration above items, I think, it is very important for climate change adaptation to discriminate more between “planning with uncertain design level” and “risk management with the worst case scenario”. 
Which track is the worst?

Which track is the “worst track” for the central Tokyo?

The maximum wind speed in the central Tokyo during typhoon period is estimated every track.

“worst track” is determined as the maximum of the maximum wind speed.

Ishikawa et. al, 2010, Kyoto University
Track and wind speed

Tracks between these thick curves cause the relatively stronger wind on the central Tokyo than outer tracks.

Dangerous for Tokyo

Ishikawa et. al, 2010
Probable maximum Wind speed

"worst track"
Central Tokyo

Ishikawa et. al, 2010