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

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KAKUSHIN

Innovative Program of Climate Change Projection for the 21st Century

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

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.




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

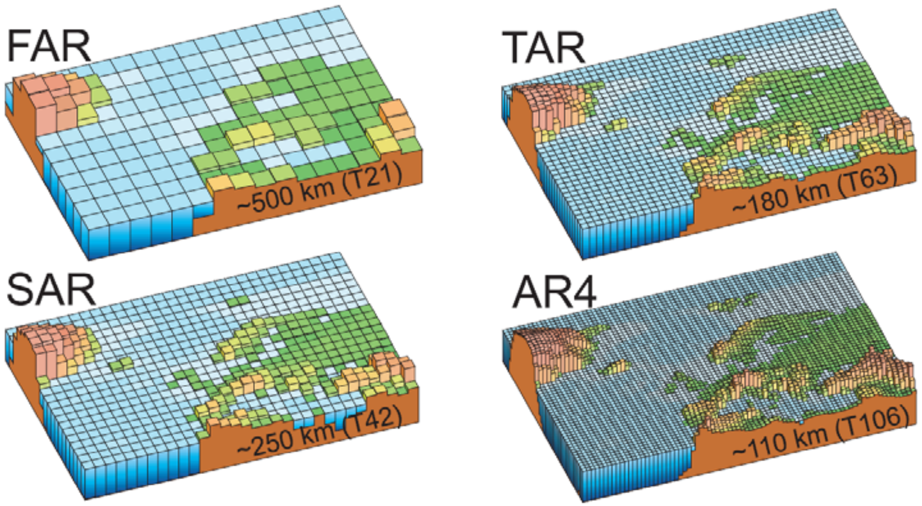
- Future river flow changes in the Tone River basin, Japan, were investigated using a distributed hydrologic model considering multiple dam reservoir operations and current water usage condition.

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.



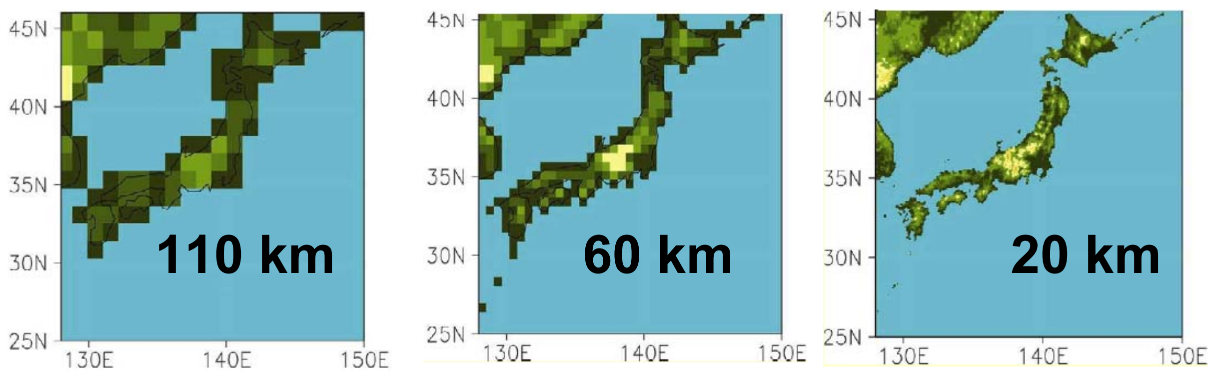
Source: IPCC AR4 (WG1)

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**

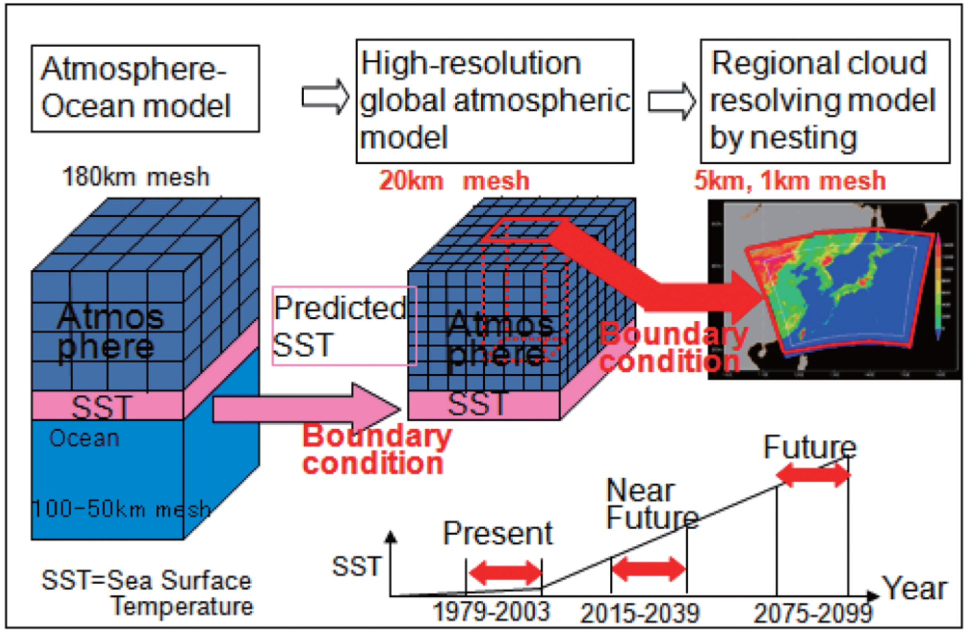
  1920 × 960 grid cells (20 km) with 60 vertical levels (TL959L60)
- **Temporal Resolution**

  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°temperature increase and 720 ppm of CO_2 concentration by 2100



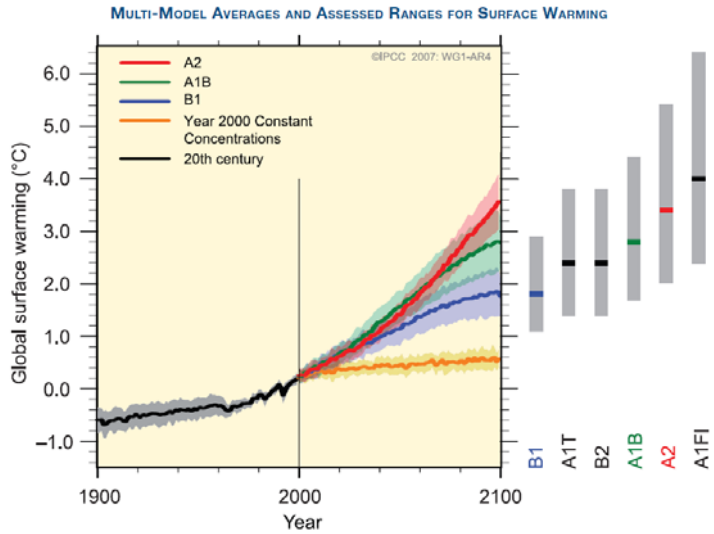
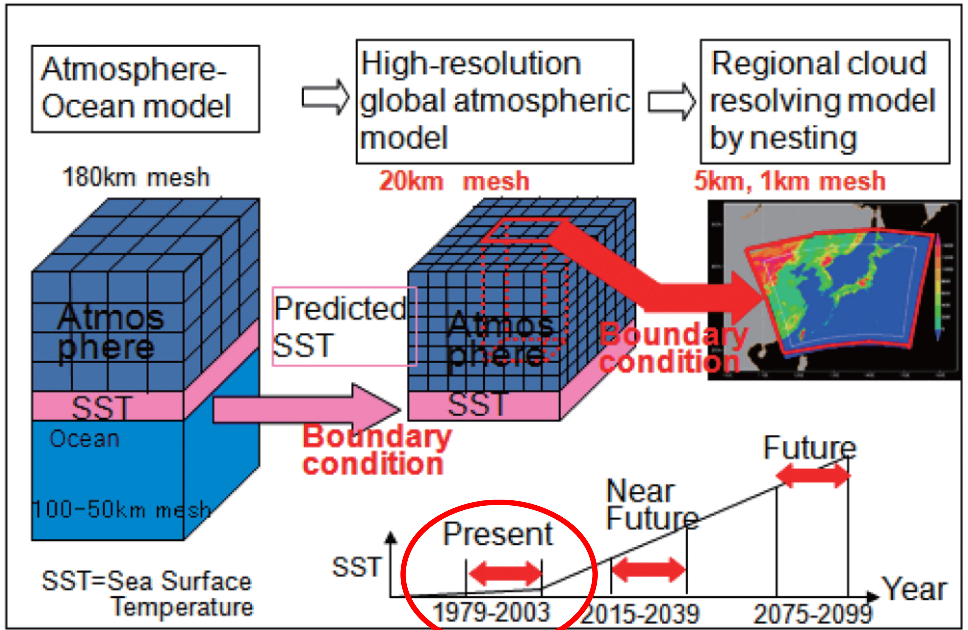


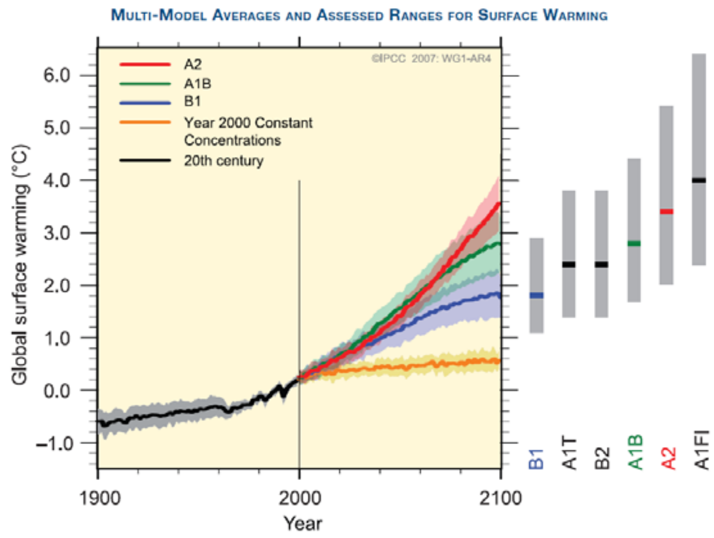
Figure SPM.5. *Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the* ***likely*** *range assessed for the six SRES marker scenarios. The assessment of the best estimate and* ***likely*** *ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. {Figures 10.4 and 10.29}*

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.





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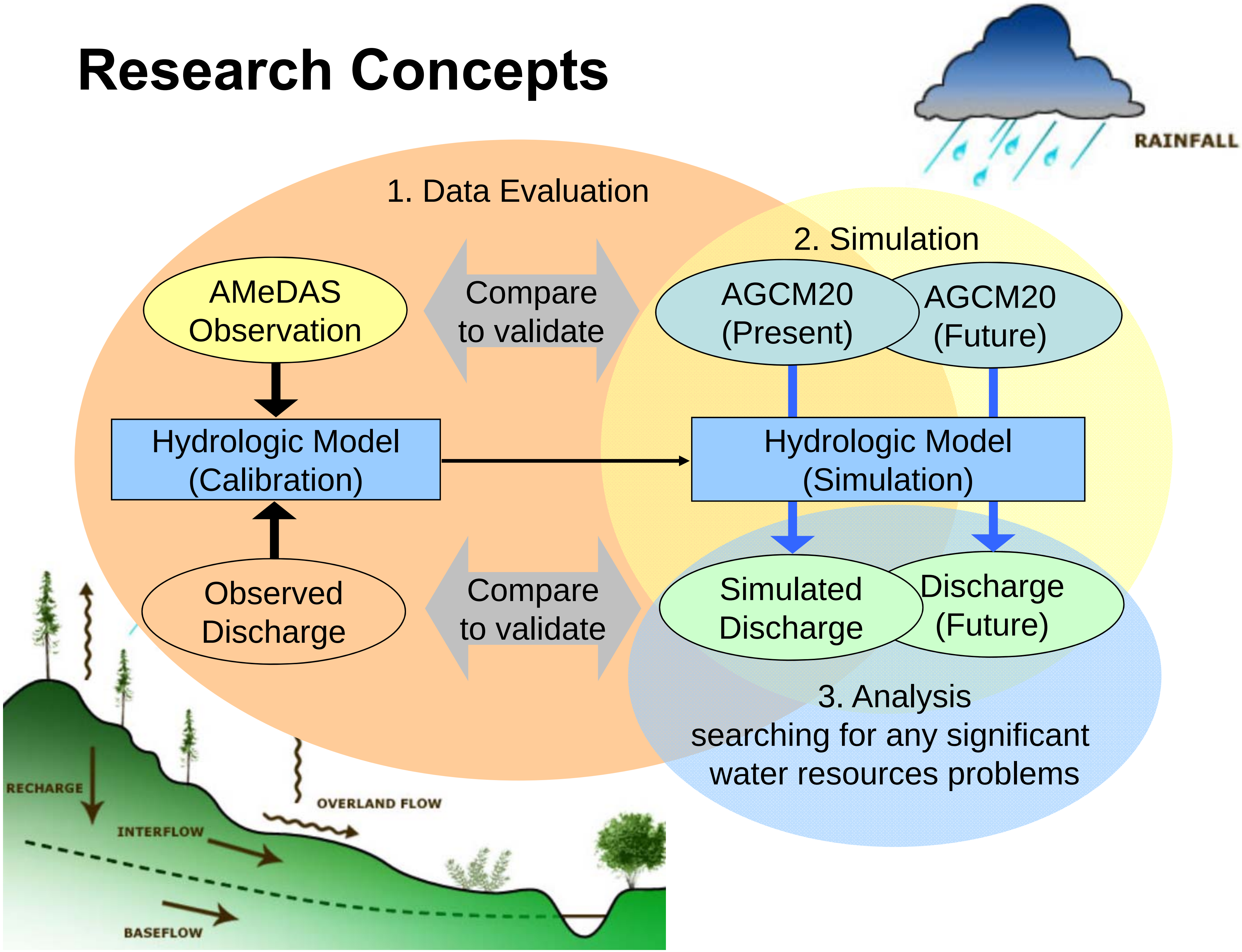
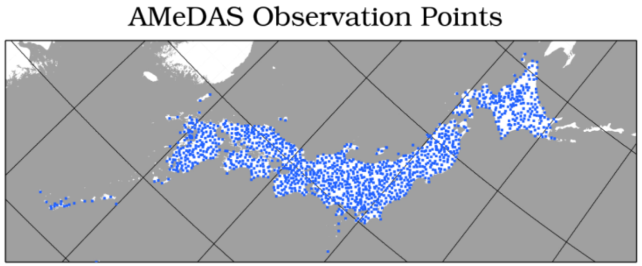
Research Concepts



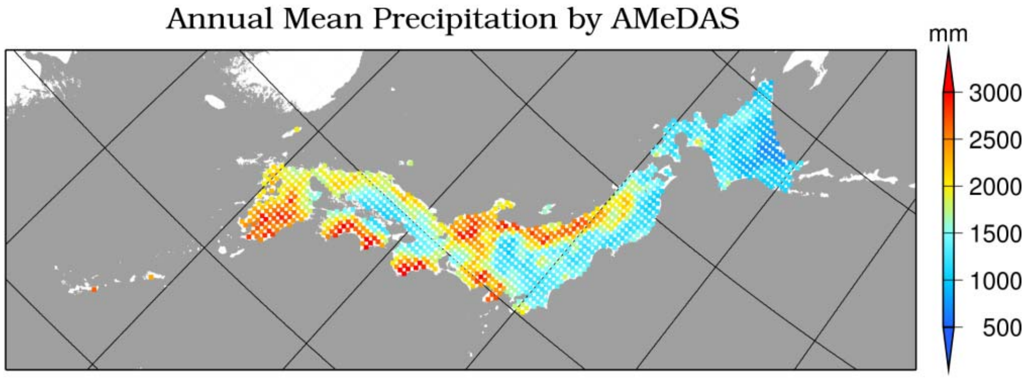
AGCM20 Output Evaluation



Using the AMeDAS observation of over 1,300 gauging stations
(averagely 17 km distance to each other)

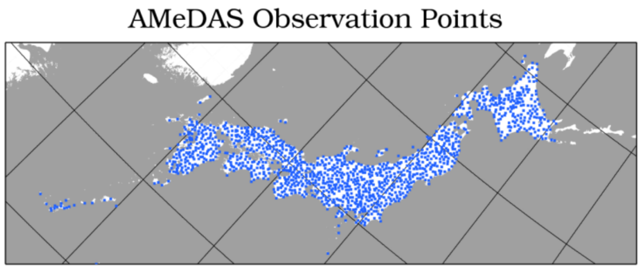
point gauged data → 20km grid data

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



AMeDAS 1684.25mm

AGCM20 Output Evaluation



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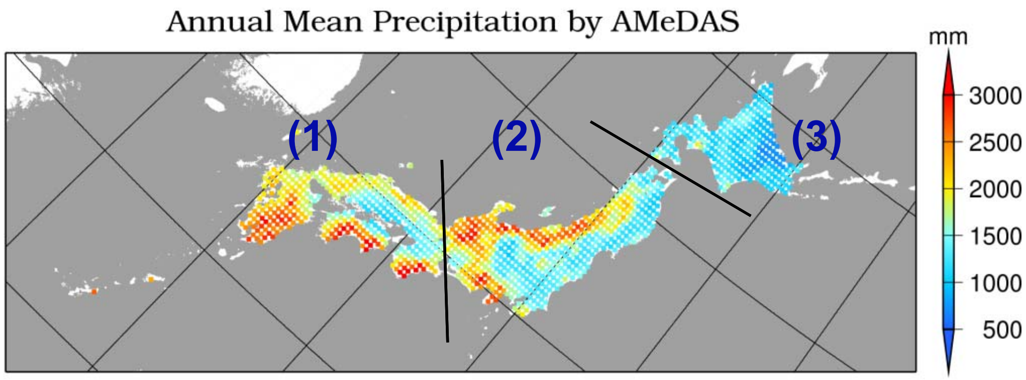
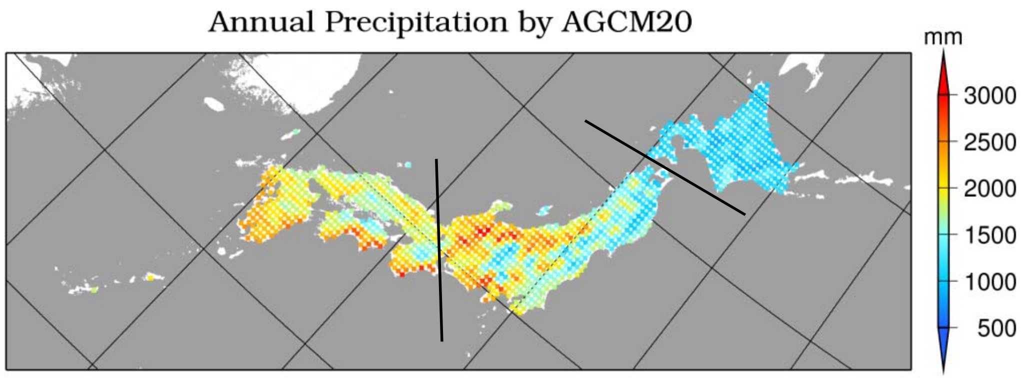




AMeDAS 1684.25mm

AGCM20 1695.24mm

(1) 1985.81mm vs. 1959.09mm

(2) 1753.25mm vs. 1797.28mm

(3) 1128.93mm vs. 1129.56mm

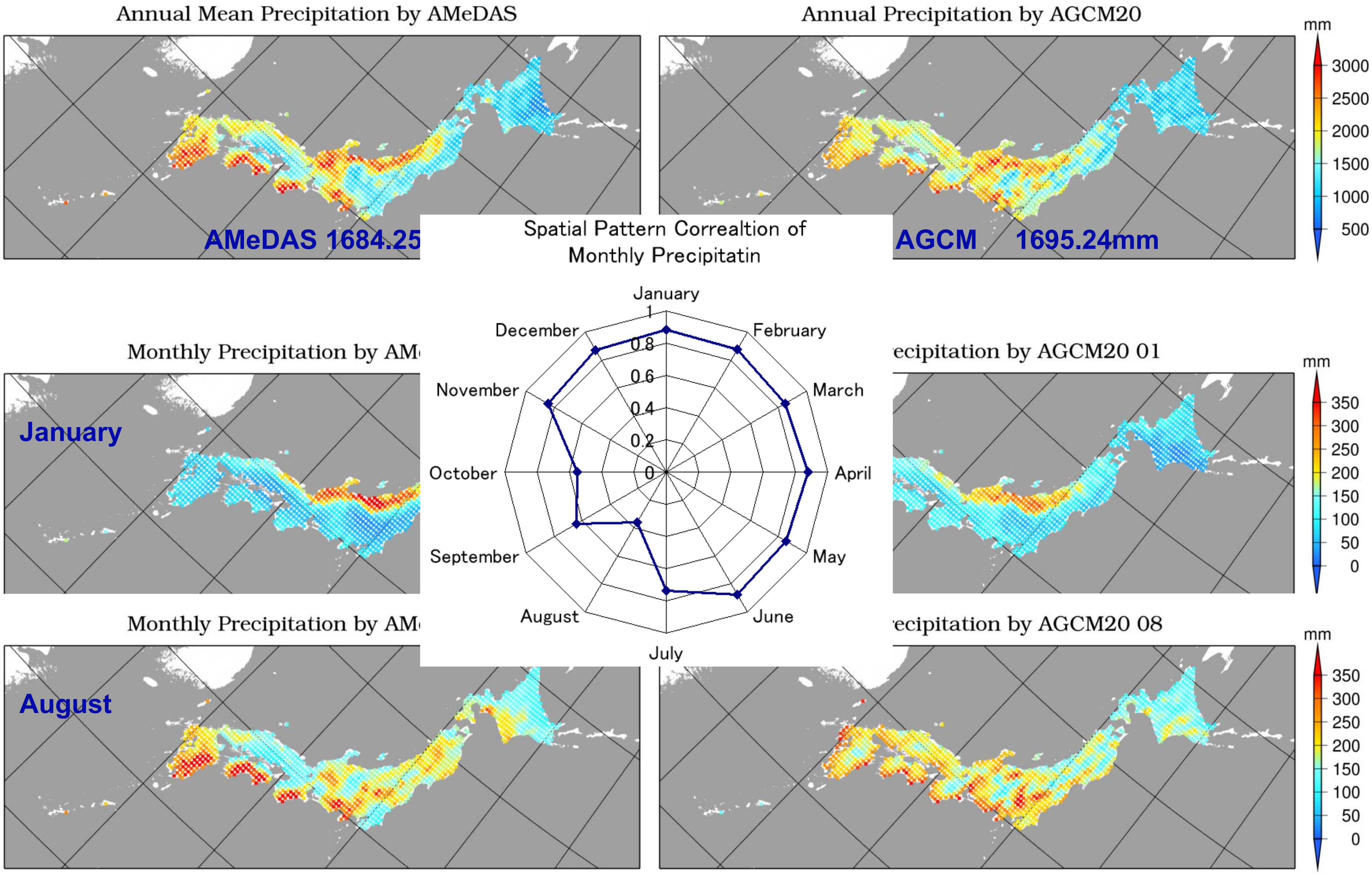
Spatial Pattern Correlation

0.781

Overall matches of the amounts but, smoothen spatial pattern

→ 20-km resolution grid

AGCM20 Output Evaluation



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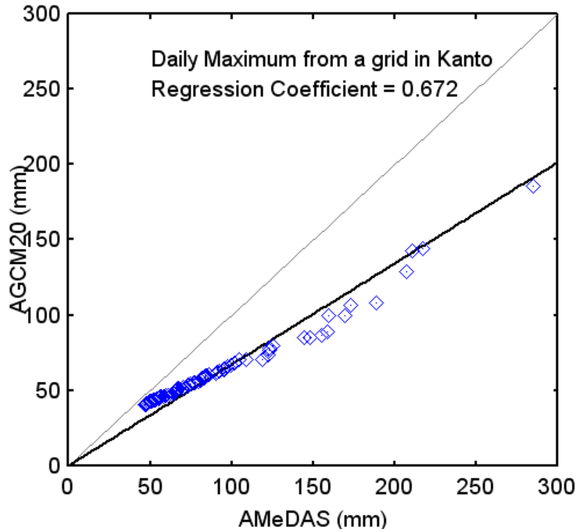
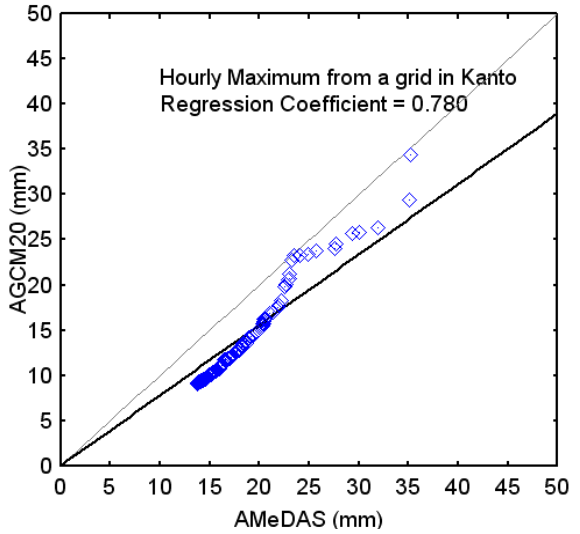


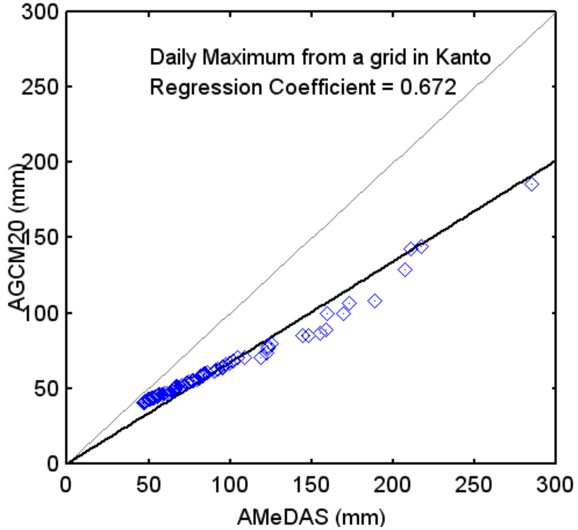


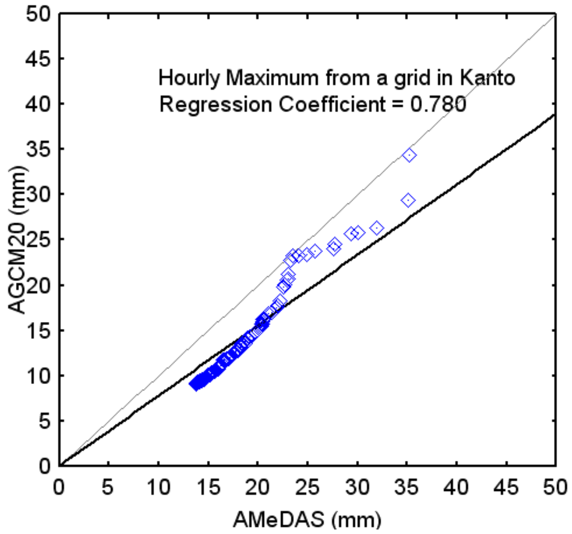
- **Reproducibility of daily and hourly maximum** was evaluated by **checking 100 maximums** of **AGCM20** output and **AMeDAS** observation.

- 100 maximums = 4 maximums × 25 years.

Underestimated Extreme Values

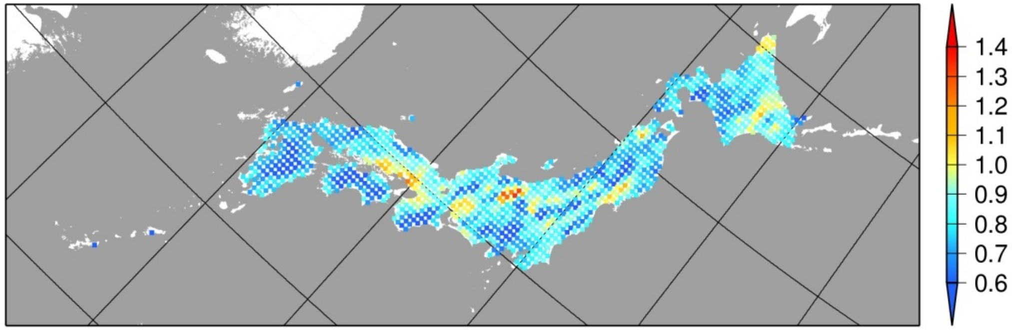
AGCM20 Output Evaluation



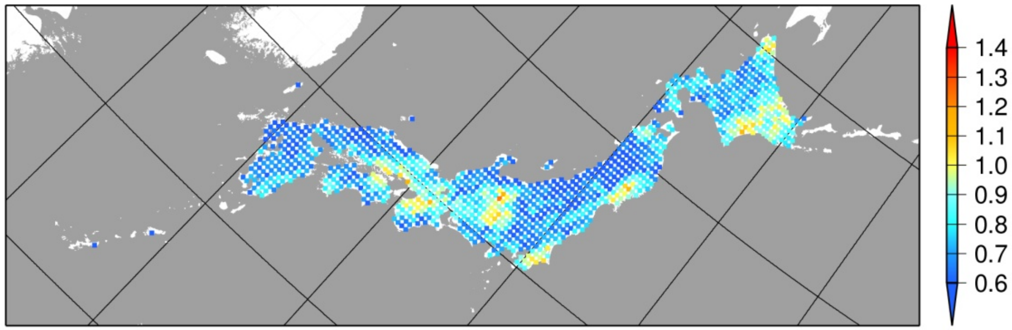


- **Reproducibility of daily and hourly maximum**
-

Regression Coefficients of 100 Daily Maximum



Regression Coefficients of 100 Hourly Maximum

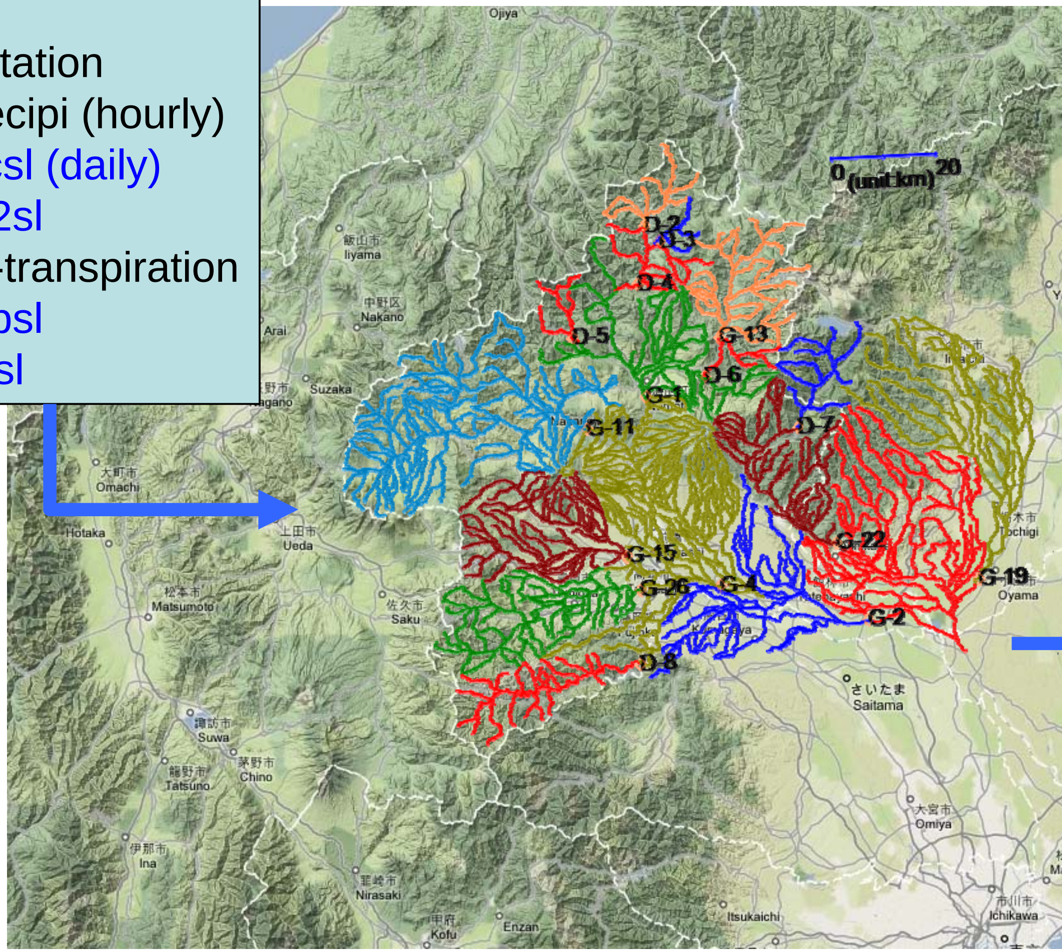


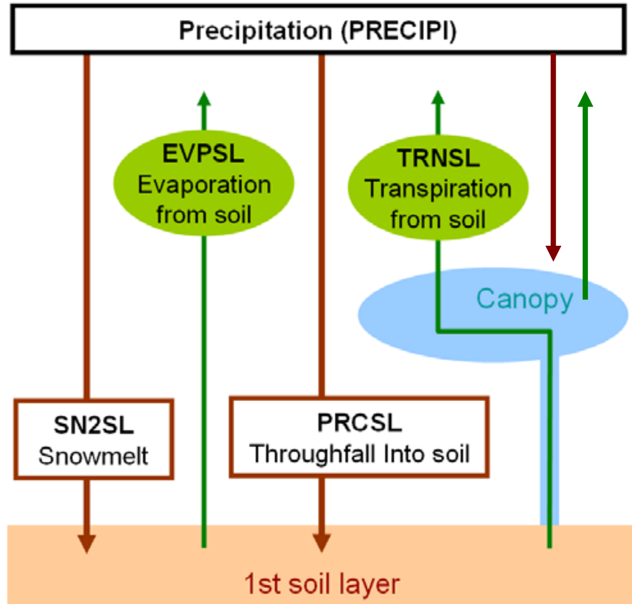
Underestimated Extreme Values

Long-term Simulation using MRI-AGCM20km Output Data

INPUT
Precipitation
- -precipi (hourly)
- -prcsl (daily)
- -sn2sl

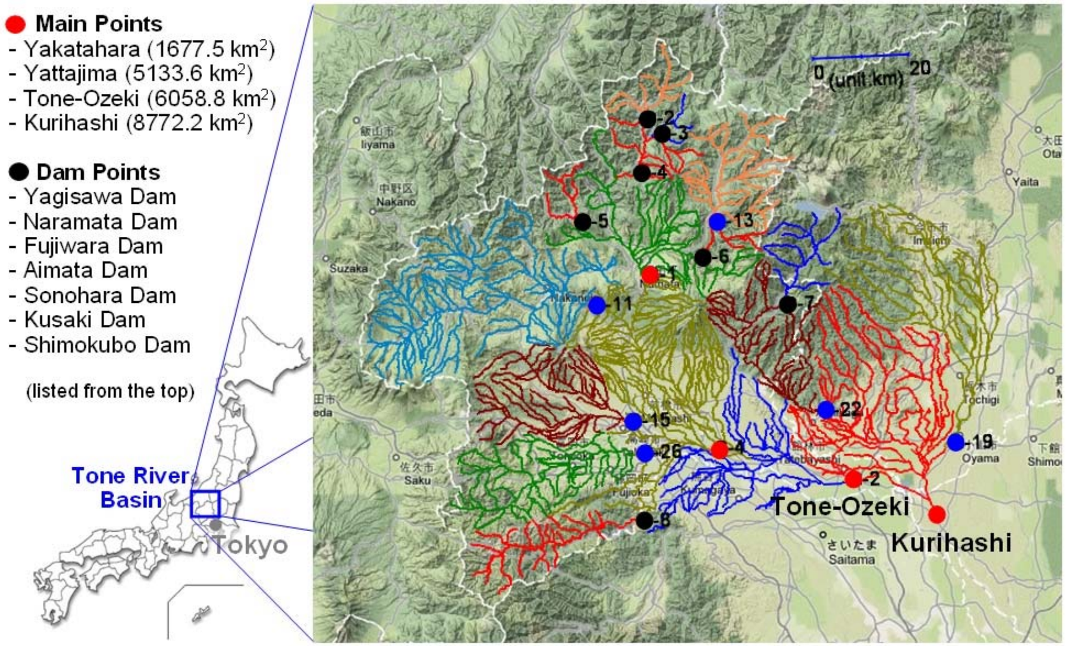
Evapo-transpiration
- -evpsl
- -trnsl





OUTPUT
Hourly discharges
at every point
in the basin

Modeling the Tone River Basin (8,772 km²)

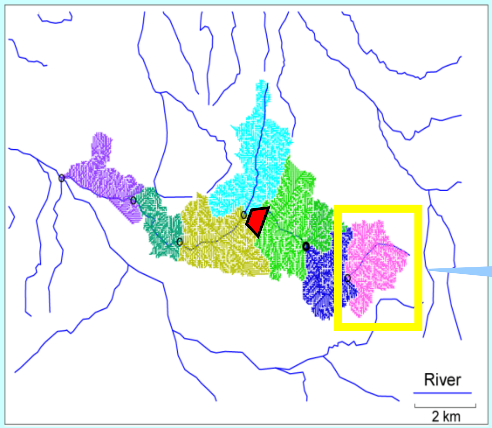


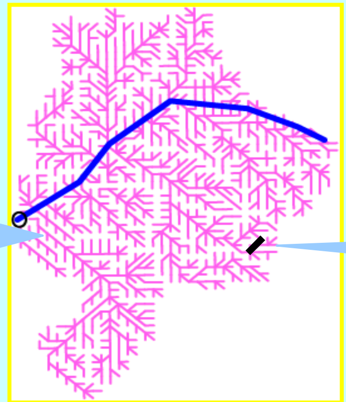
16 sub-basins including
7 dam-basins.

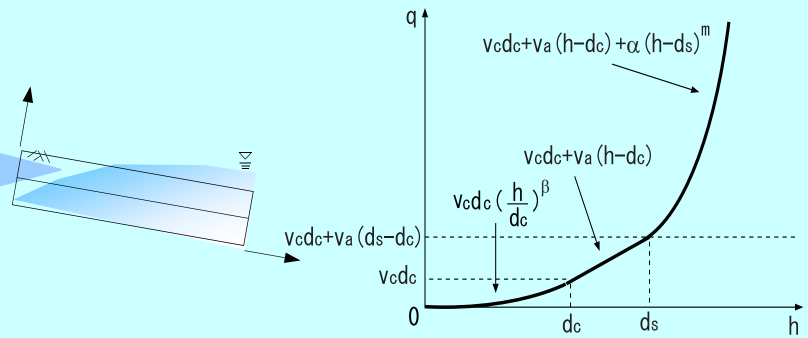
Parameters have been
optimized for each sub-basin.

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)

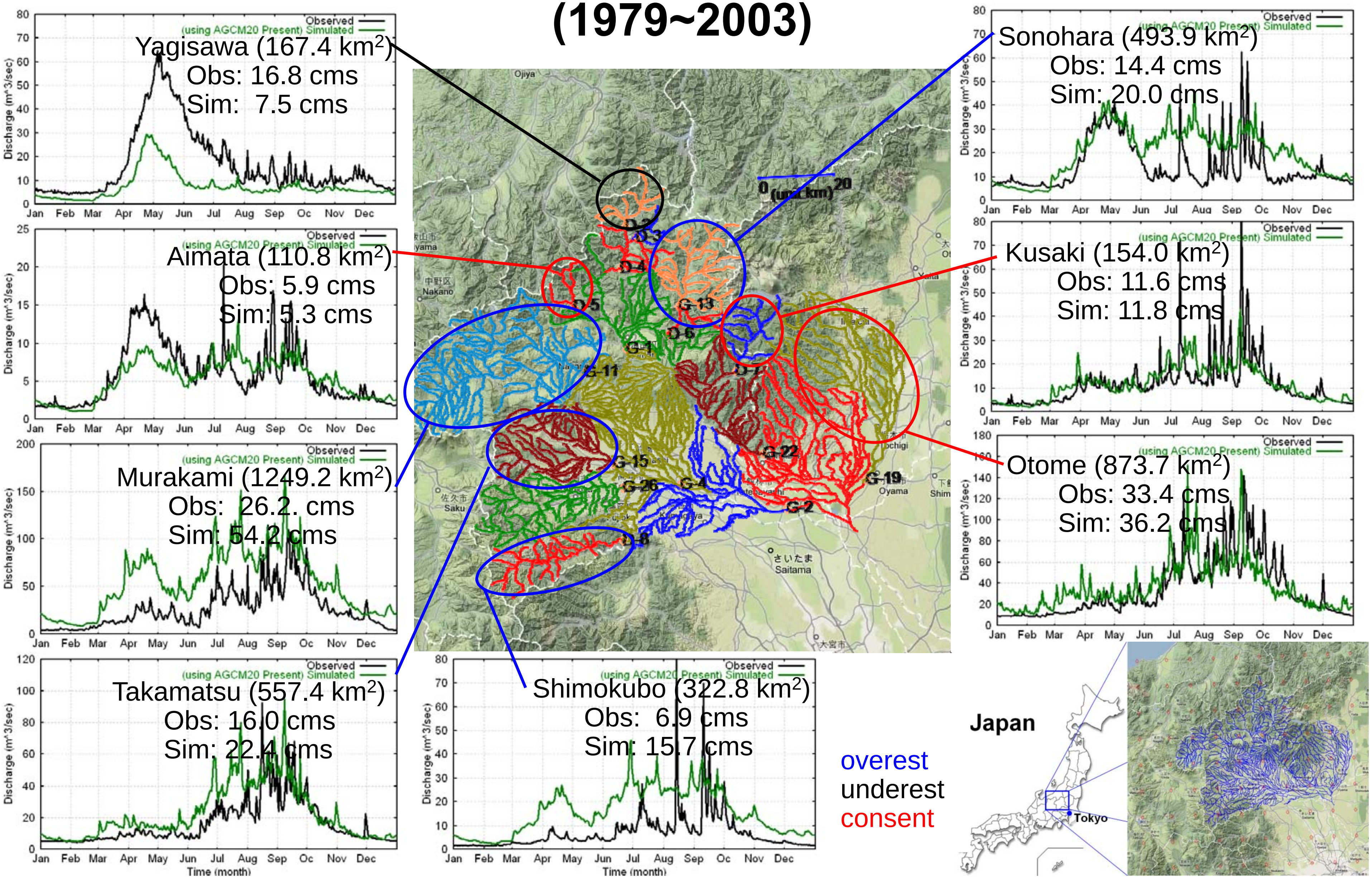






Rainfall-Runoff Simulation Results using AGCM20 Present Climate Output

(1979~2003)

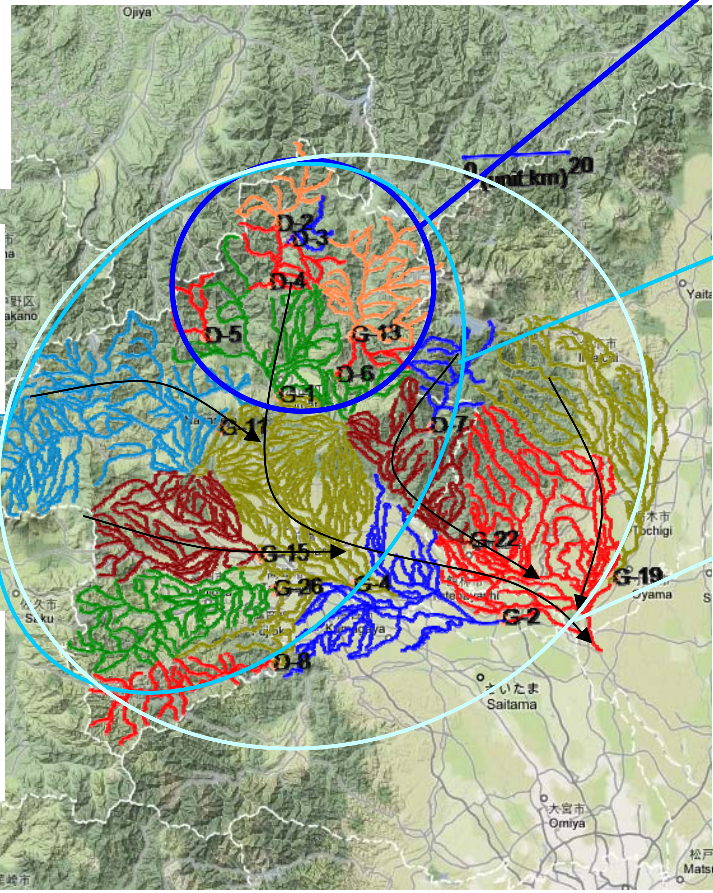


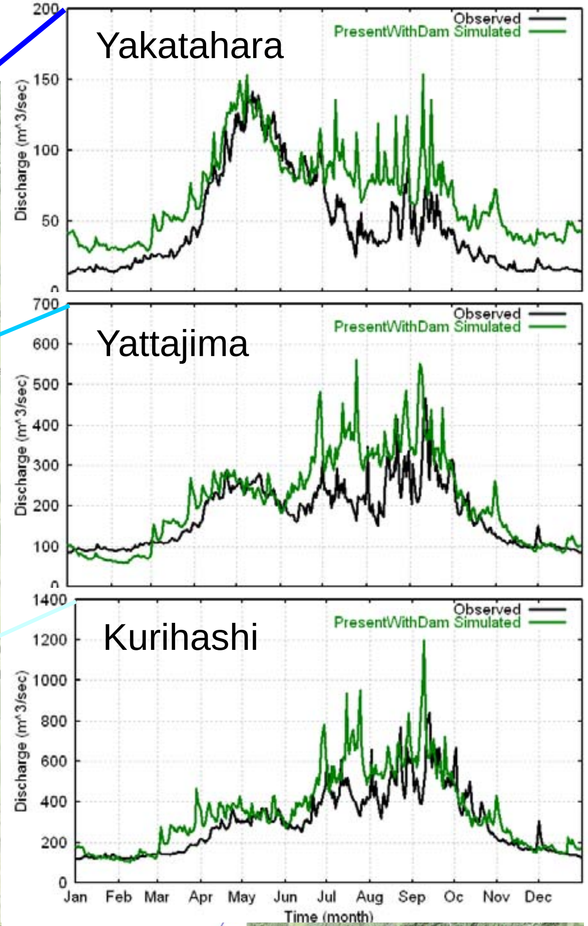
Rainfall-Runoff Simulation Results using AGCM20 Present Climate Output

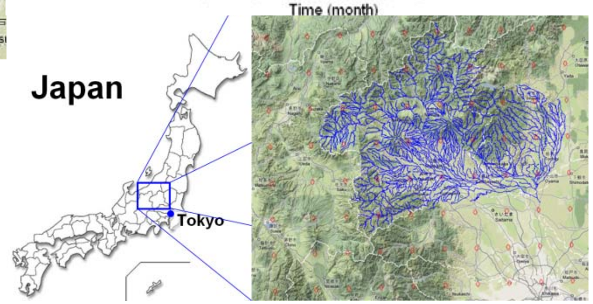
<u>Yakatahara (1677.5 km^2)</u>
Obs. flow: 47.1 cms (884.8 mm)
Sim. flow: 65.5 cms (1230.6 mm)
39.1 % overestimation

<u>Yattajima (5133.6 km^2)</u>
Obs. flow: 177.6cms (1090.8mm)
Sim. flow: 212.9cms (1308.1mm)
19.9 % overestimation

<u>Kurihashi (8772.2 km^2)</u>
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 × 3 grids (?)

Reproducibility of the AGCM20 Output

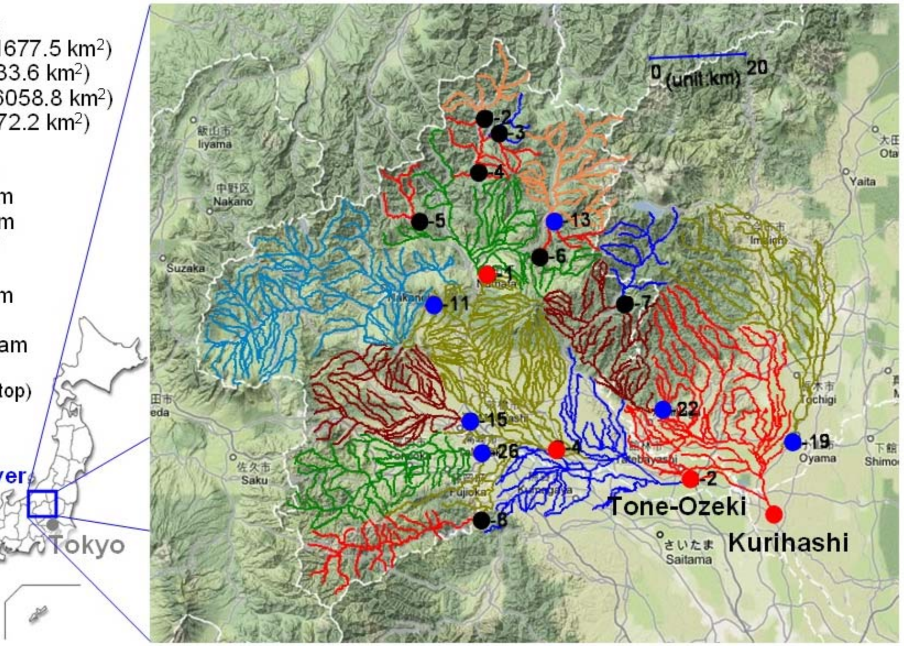
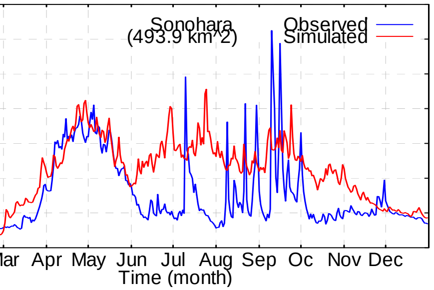
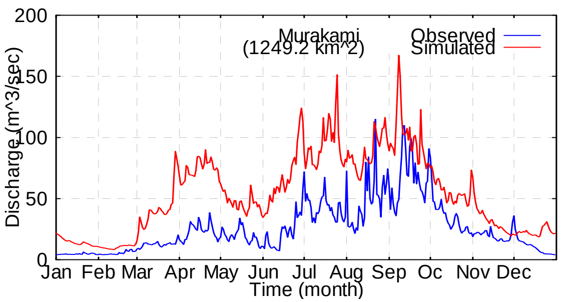


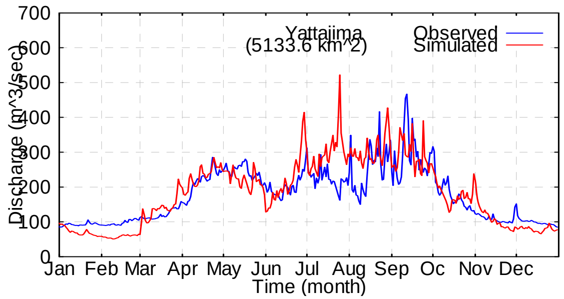
Table 1 Reproducibility of Each Sub-basin

Basin Name	Area (km^2)	NSC	Vol. Ratio
Aimata	110.8	0.54	-10.2 %
Kusaki	154.0	0.39	+1.1 %
Yagisawa	167.4	0.13	- 55.3 %
Sonohara	493.9	-0.18	+39.6 %
Takamatsu	557.4	0.14	+39.9 %
Otome	873.7	0.39	+18.5%
Murakami	1249.2	-1.74	+49.2%
Yakatahara	1677.5	0.65	+26.1%
Yattajima	5133.6	0.49	+3.5%
Tone-Ozeki	6058.8	0.45	- 7.3 %
Kurihashi	8772.2	0.59	- 2.0 %

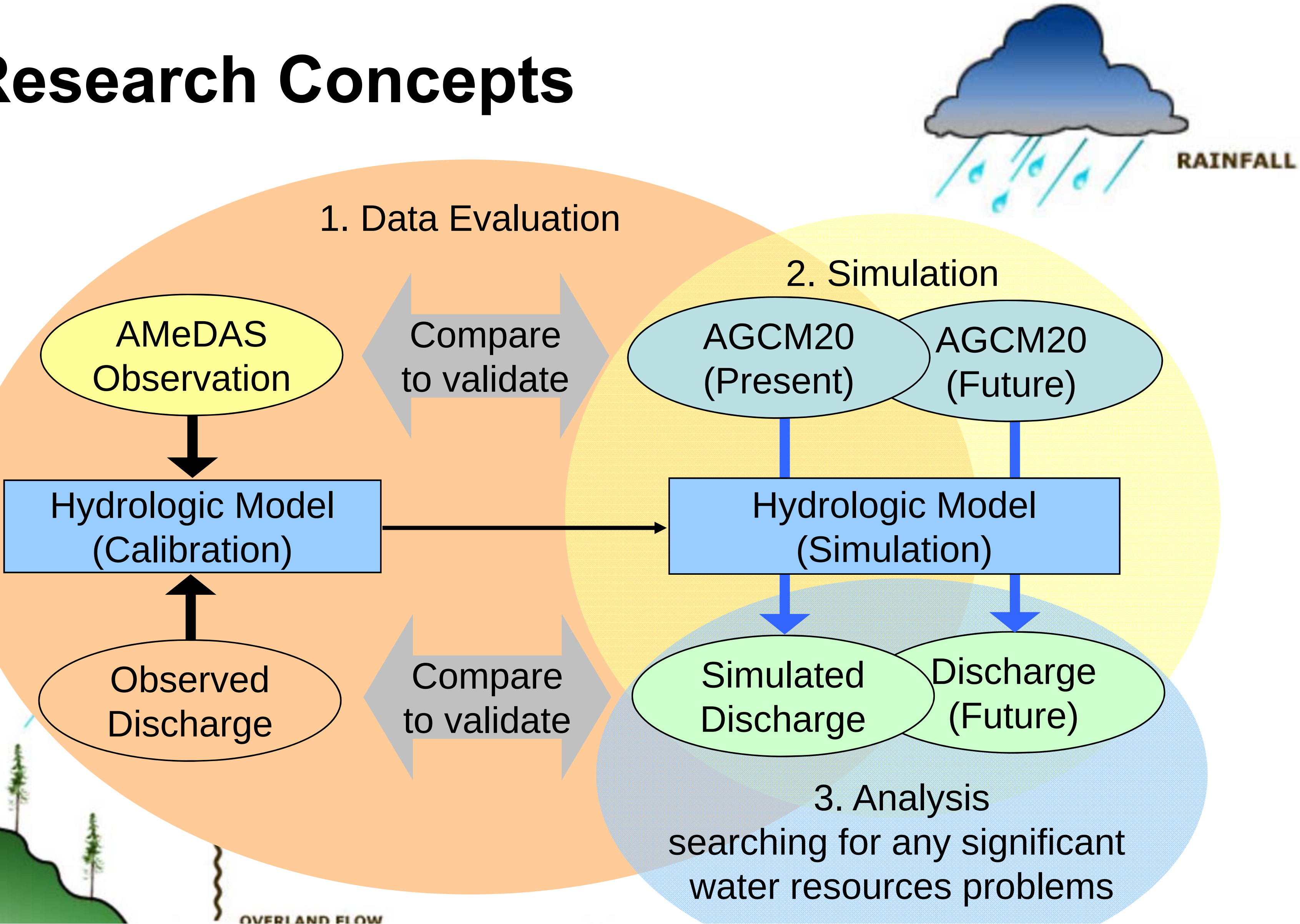
*NSC: Nash-Sutcliffe Coefficient







Research Concepts



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

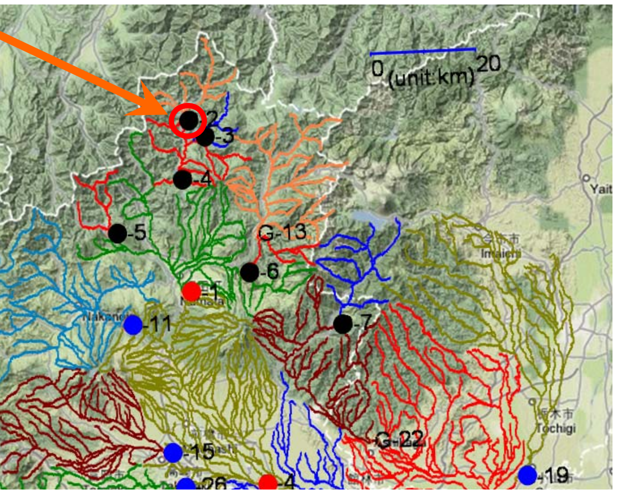
Reservoir Operation Model

Future Water Resources Analysis

- **Flow Duration Curves**
- **Mean Flow and Minimum Flow**

Dam Reservoir Operation Model

sawa Dam (167.4 km^2)

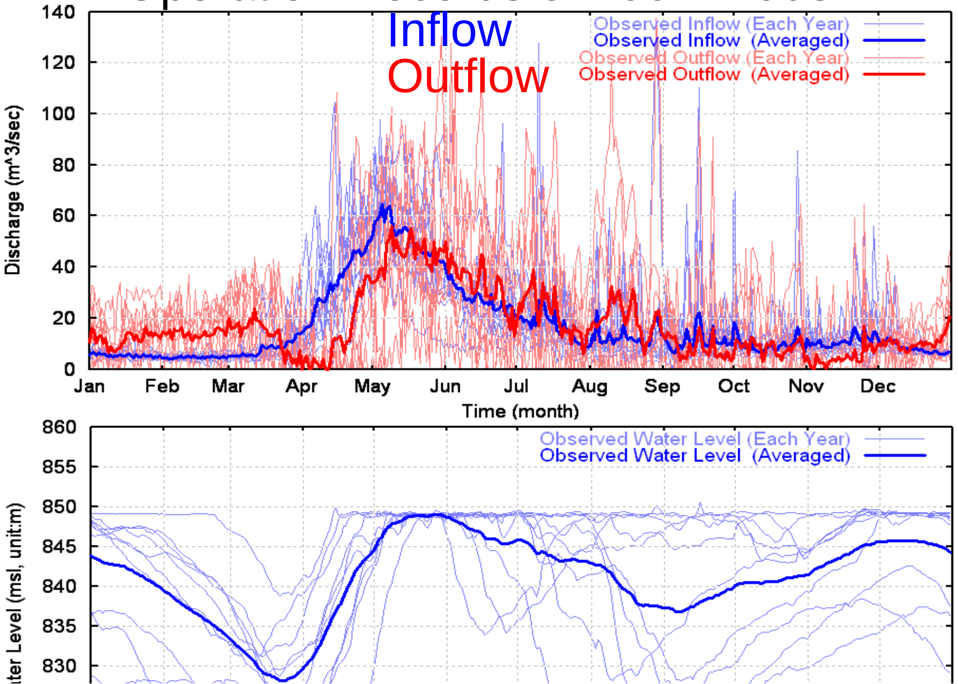


Hard to find the standard operation rule

Depending on precipitation amount and water demand of each year

Averaging the recent 10 years operation

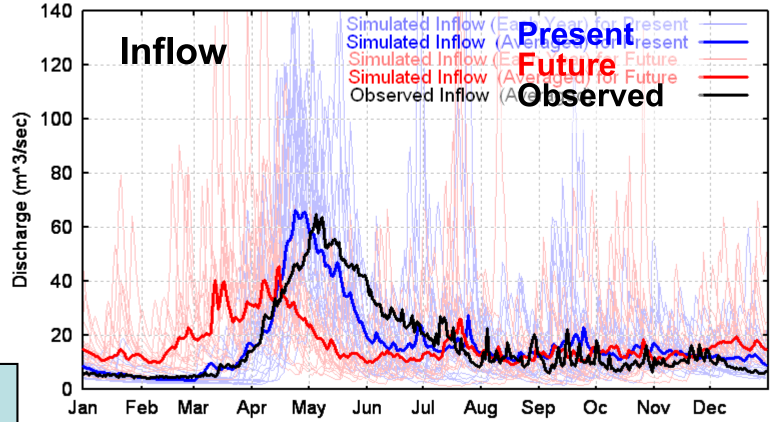
Operation Records of 1994~2003

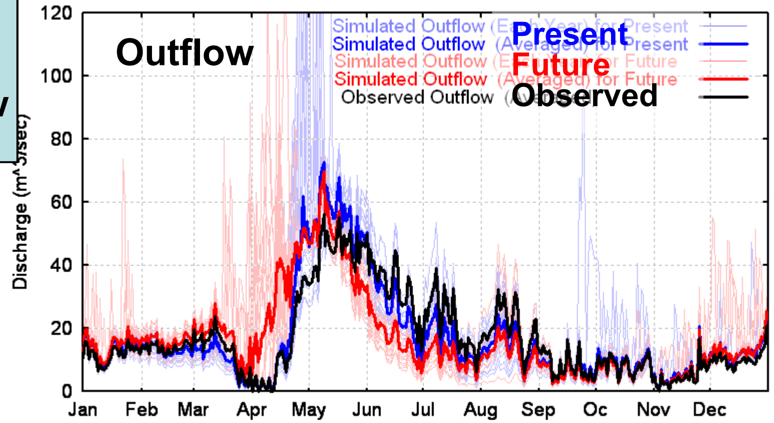


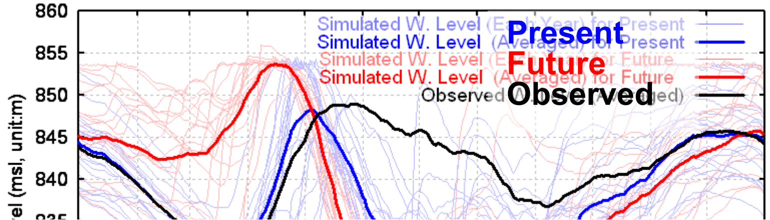
Dam Reservoir Operation Model

n Rules: Release
given outflow amounts
raged obs. Outflow of 10 yrs)

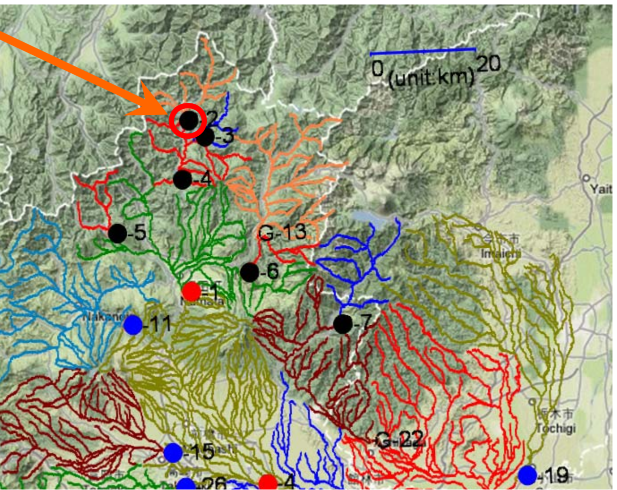
Dam Model
to reproduce current Outflow





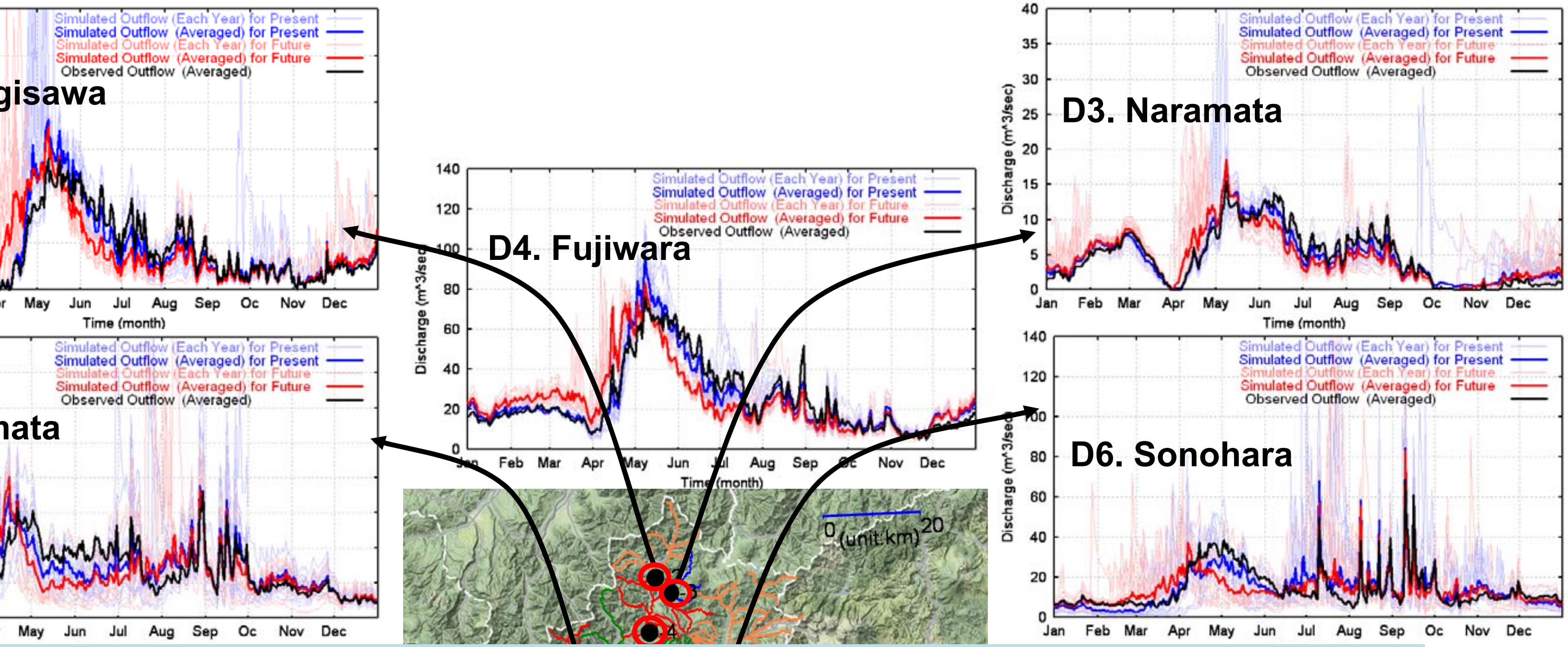


sawa Dam (167.4 km^2)



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)

ne future river flow will be able to meet the current water demand
er the current reservoir operation rules?

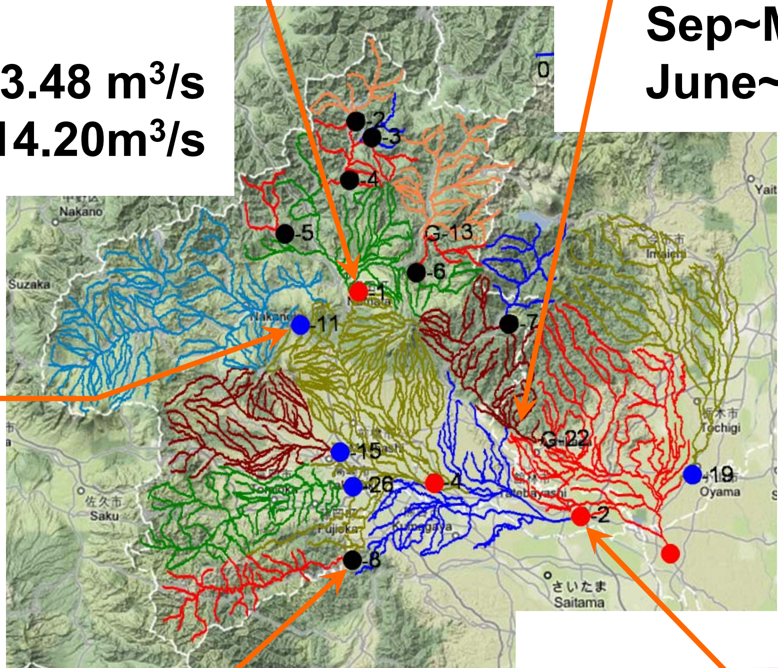
Current Water Demand in the Tone River Basin

Yakatahara

- g water: 3.09 m³/s
- ultural water:
  - May 1.39 ~ 3.48 m³/s
  - ~Sep 12.17~14.20m³/s

Ota-Tousyukou

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



bukawa

- ultural water:
  - ~ 46.10 m³/s

Wakaizumi

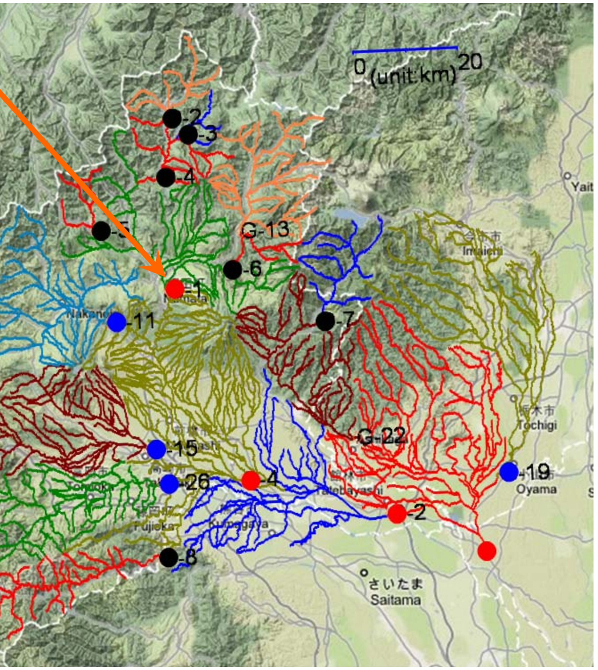
- ultural water:

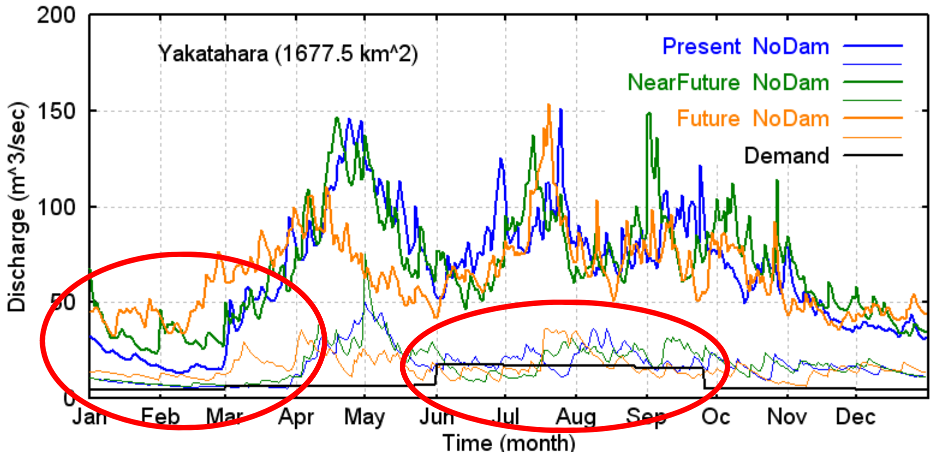
Tone-Ozeki

- Living water: 37.43 m³/s
- Industrial water: 2.08 m³/s

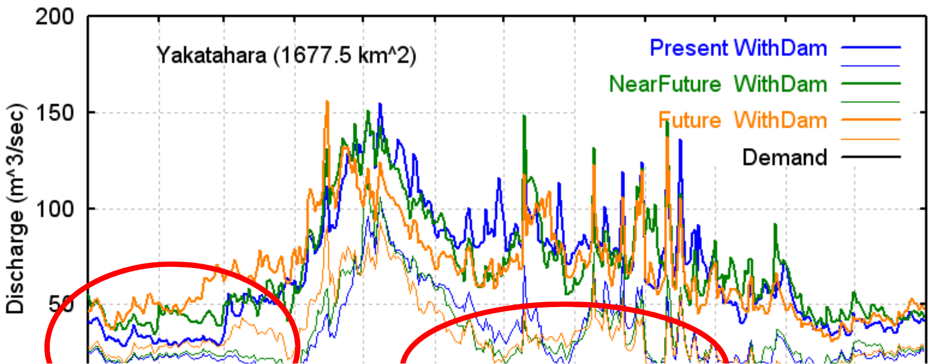
m Control Effects at

katahara (1677.5 km2)





- **Controlled reservoir operation for stable water usage in winter season**

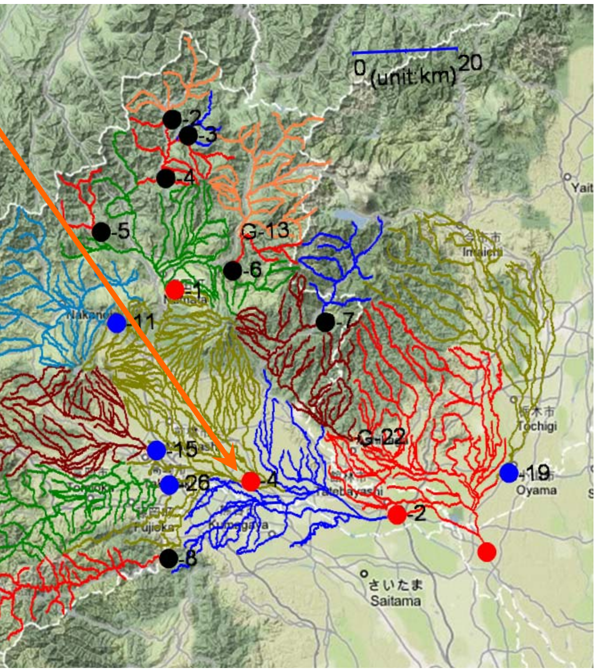


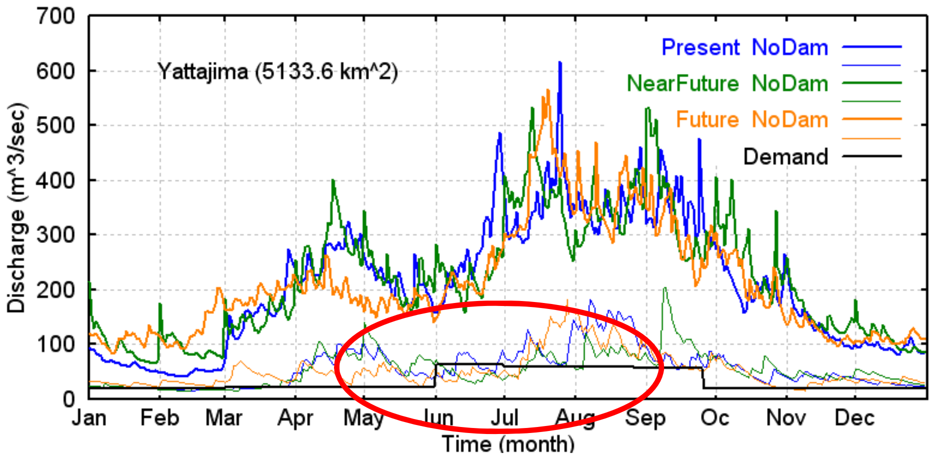
um Demand

ng water: 3.09 m³/s

cultural water:

m Control Effects at ttajima (5133.6 km^2)





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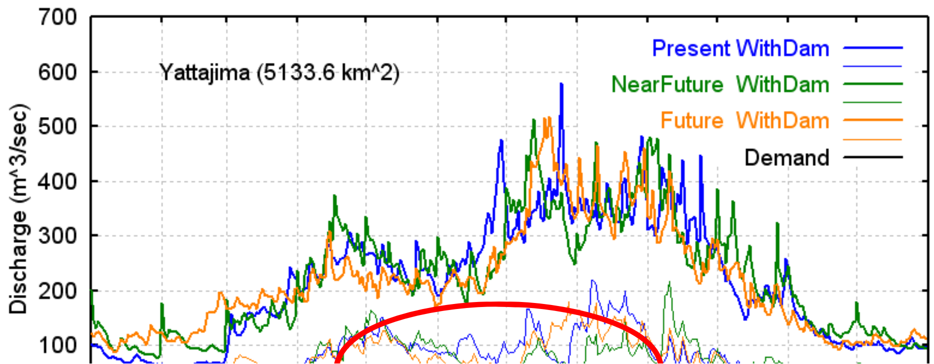
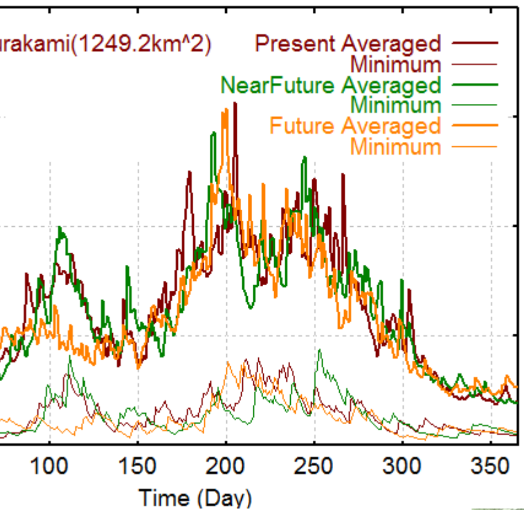


um Demand

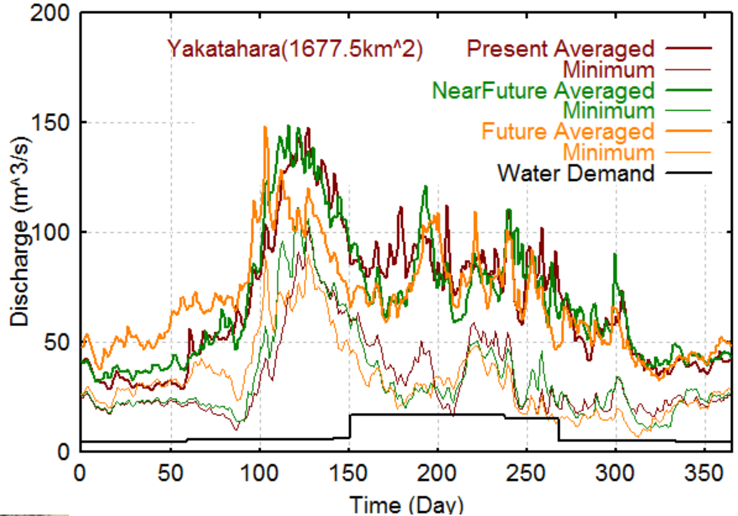
ng water: 3.09 m^3/s

cultural water:

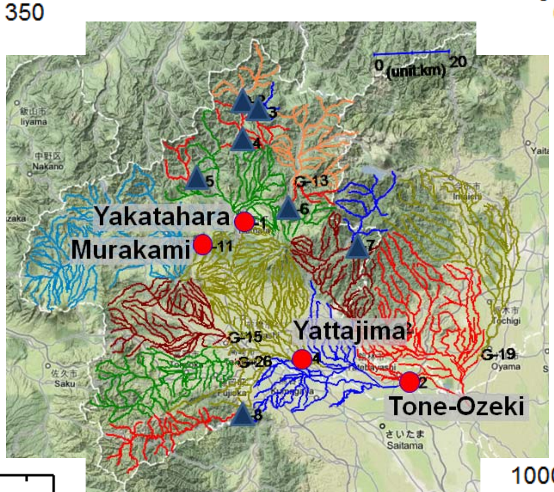
Mean & Lowest Flow



akami ($1249.2km^2$)

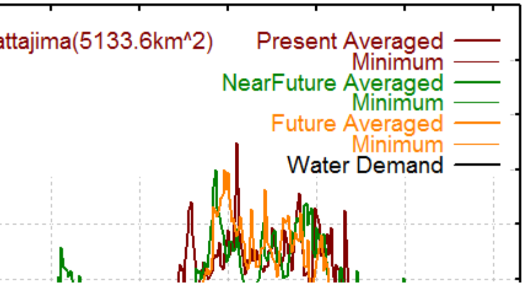


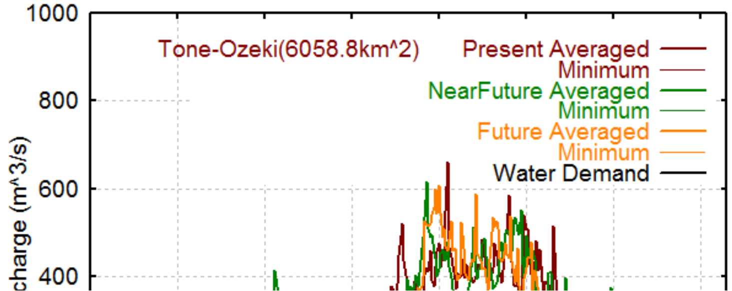
Yakatahara ($1677.5km^2$)

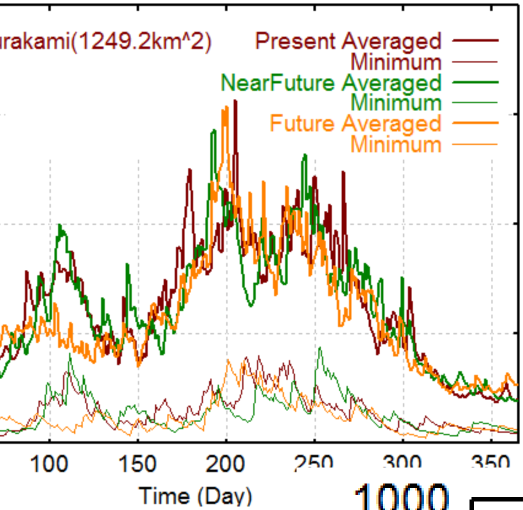


ajima ($5133.6km^2$)

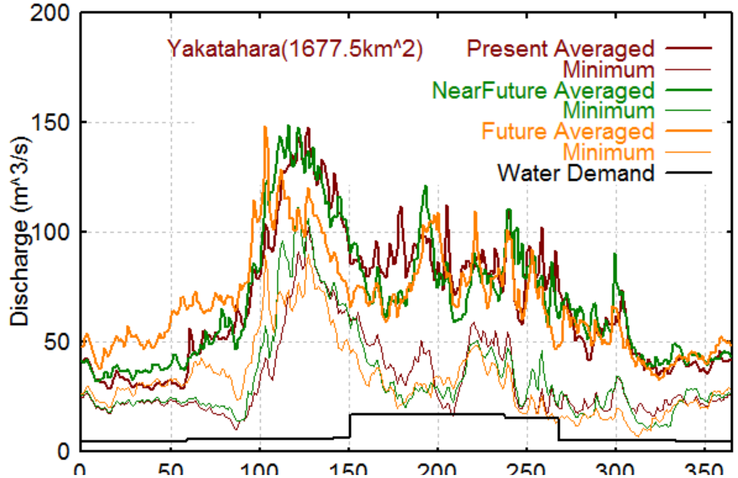
Tone-Ozeki ($6058.8.5km^2$)

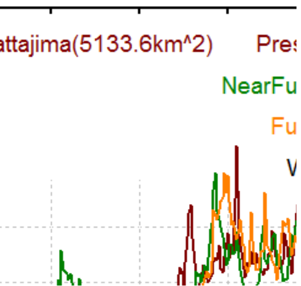


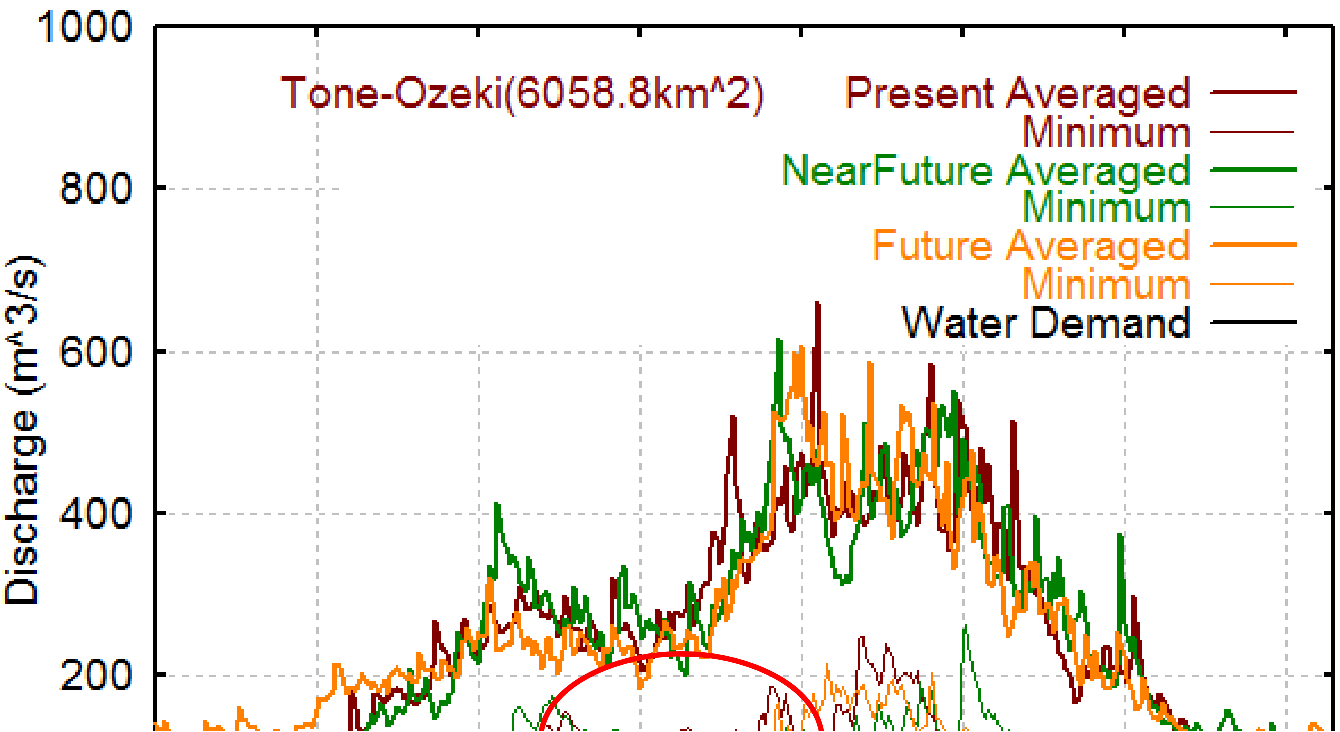




Mean & Lowest Flow







Changes in Precipitation
Seasonal Pattern

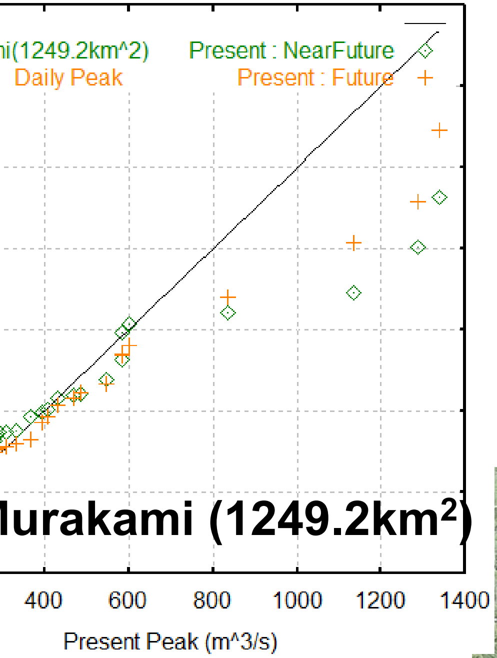
nate change would
elerate water cycles
more precipitation and
eased evapotranspiration.

cipi – Evapotranspiration →

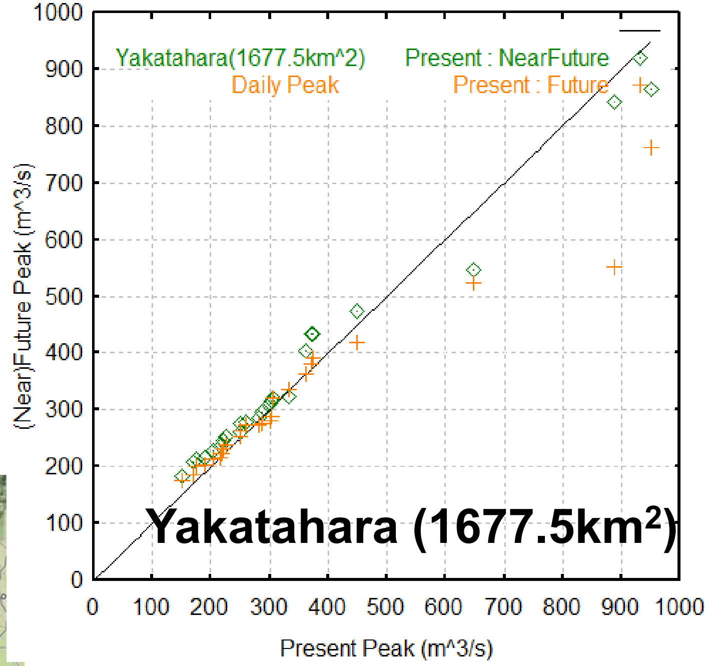
imited water resources
n some regions

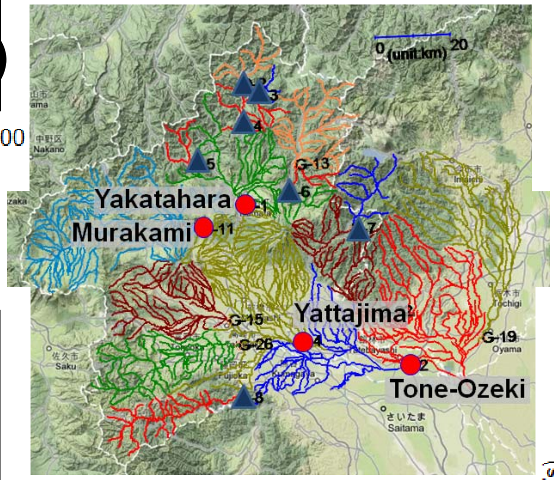
Table 1. Net-water-resources amount in each region (annual amount averaging 25 years)

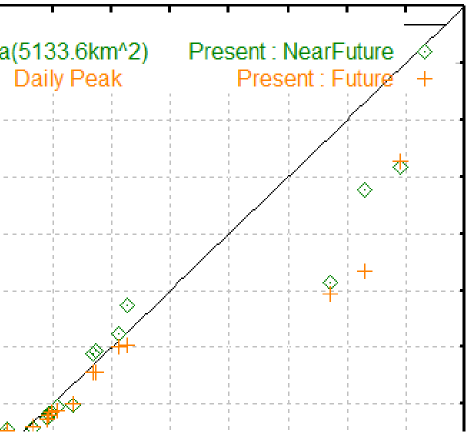
Region	**Present** (unit: mm)	**NearFuture** (changes: %)	**Future** (changes: %)
Hokkaido	607.6	648.2 (6.68)	645.2 (6.19)
Tohoku	834.4	838.0 (0.43)	789.7 (-5.72)
Kanto	1038.5	1043.7 (0.50)	1002.0 (-3.51)
Chubu	1359.4	1369.0 (0.71)	1296.7 (-4.61)
Kinki	1173.4	1180.1 (0.58)	1152.7 (-1.76)
Shikoku	1268.1	1256.5 (-0.91)	1254.3 (-1.09)
Chugoku	1041.4	1091.4 (4.80)	1063.8 (2.15)
Kyushu	1263.1	1264.8 (0.14)	1290.9 (2.20)
Japan	**1010.1**	**1027.25 (1.70)**	**997.79 (-1.22)**

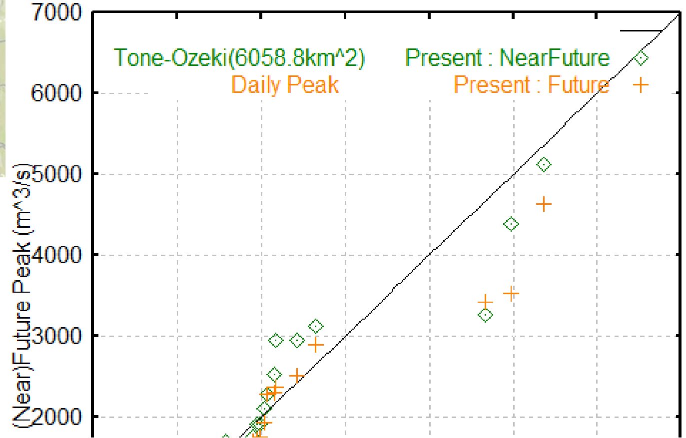


Peak Discharges DAILY

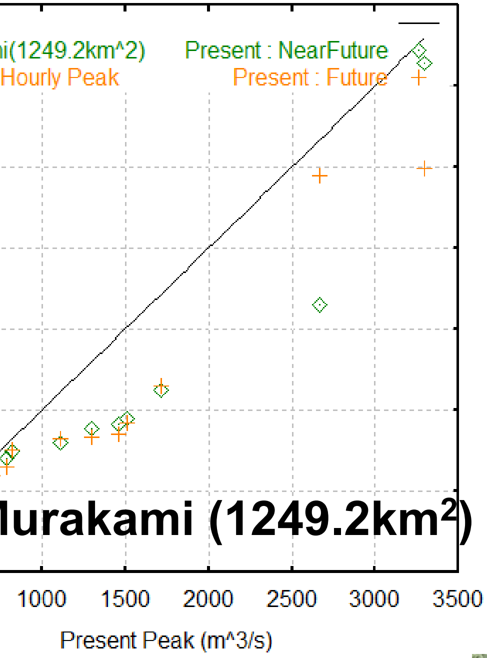


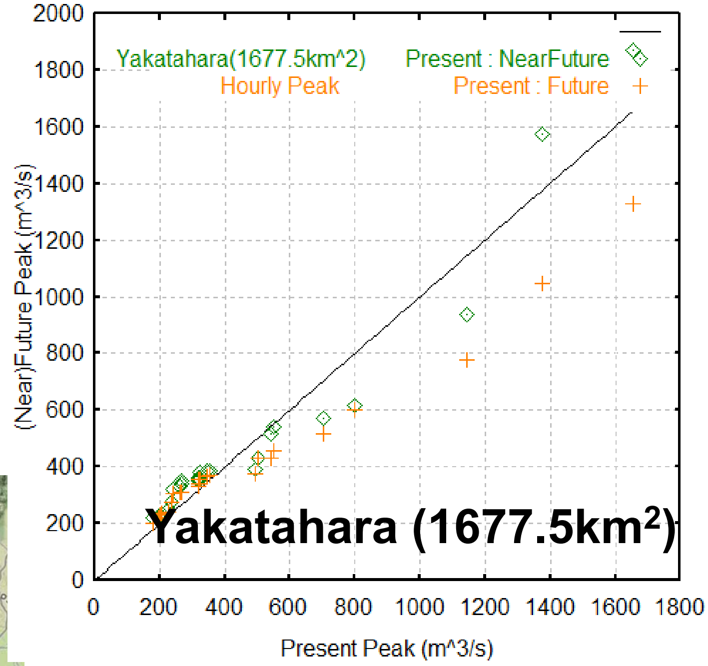


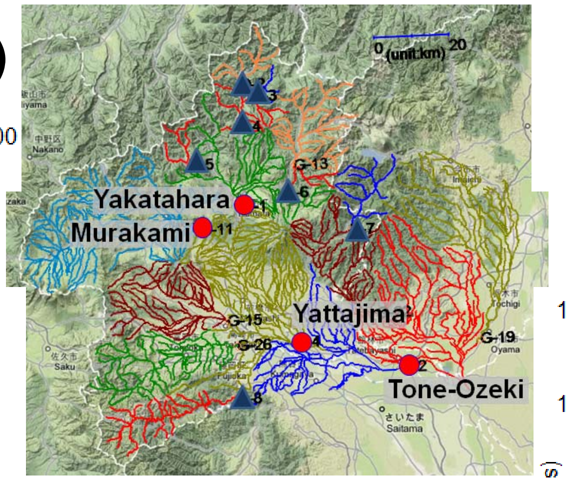


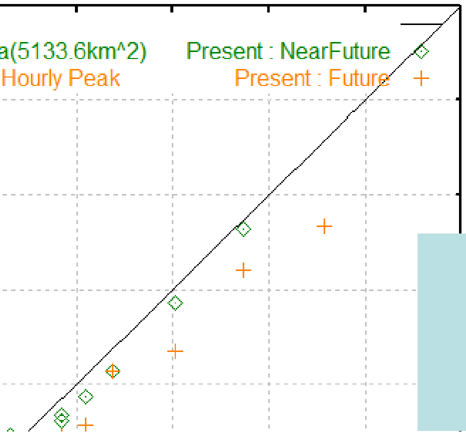


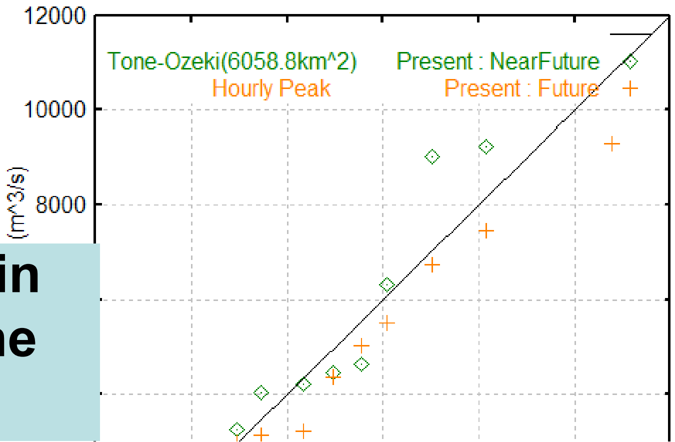
Peak Discharges HOURLY





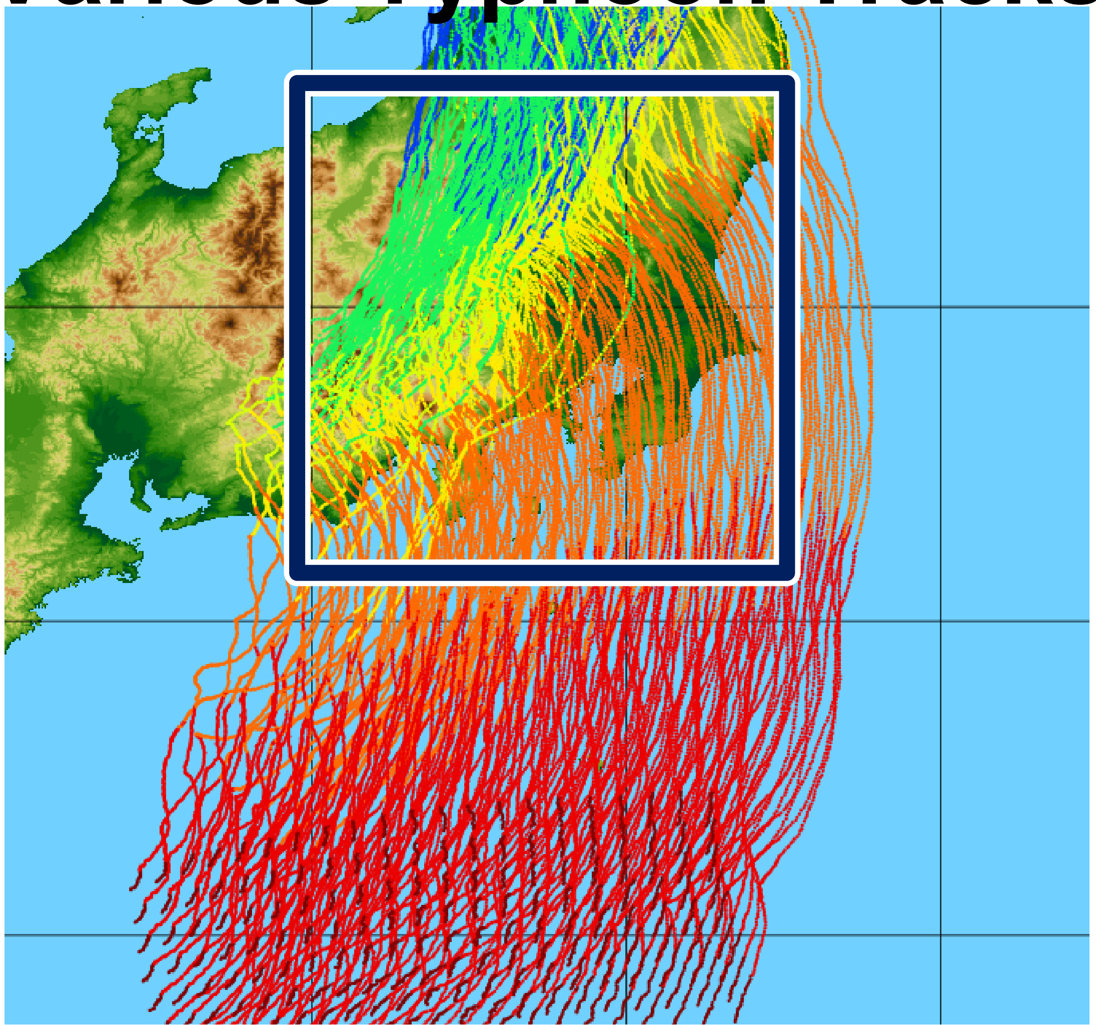




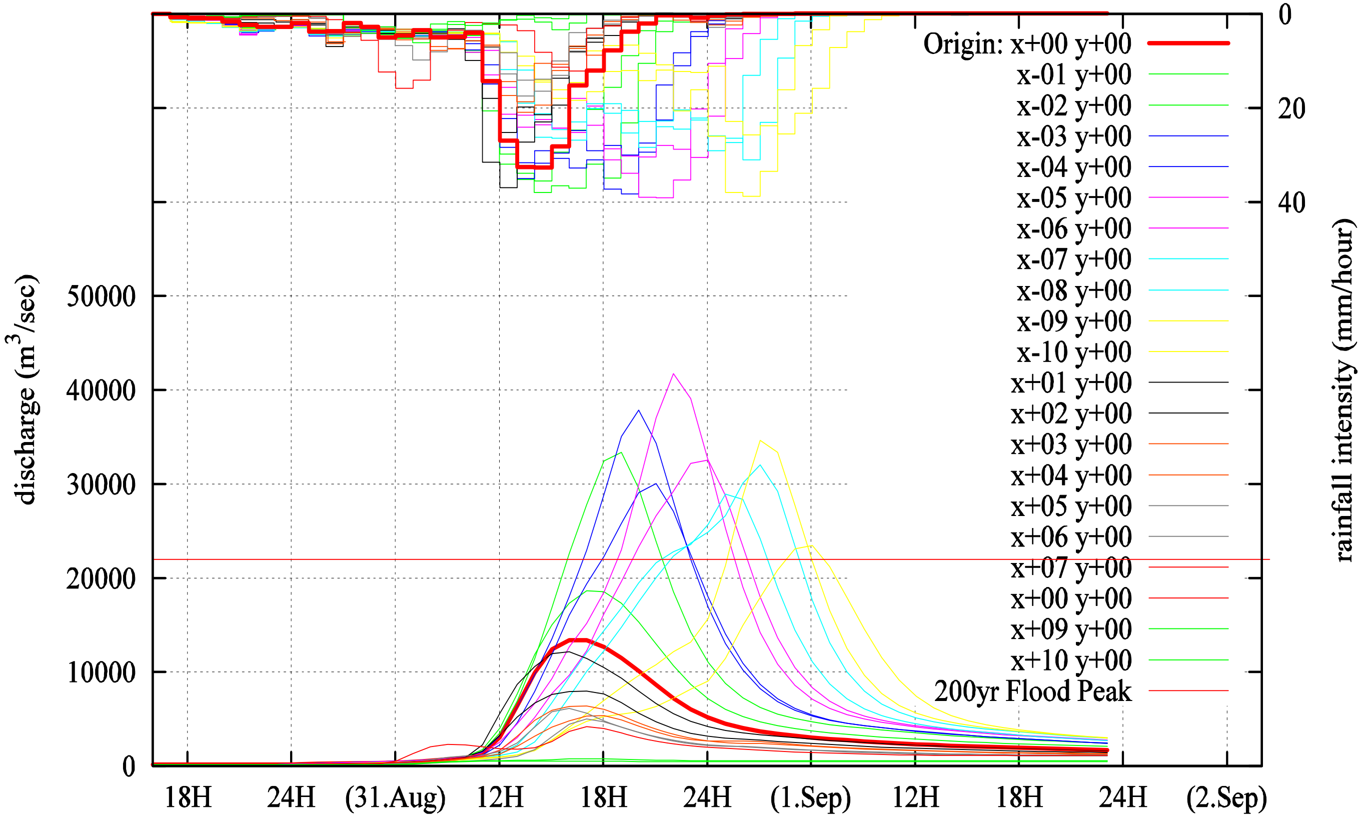


No Severe Changes in Extreme Events in the Tone River Basin

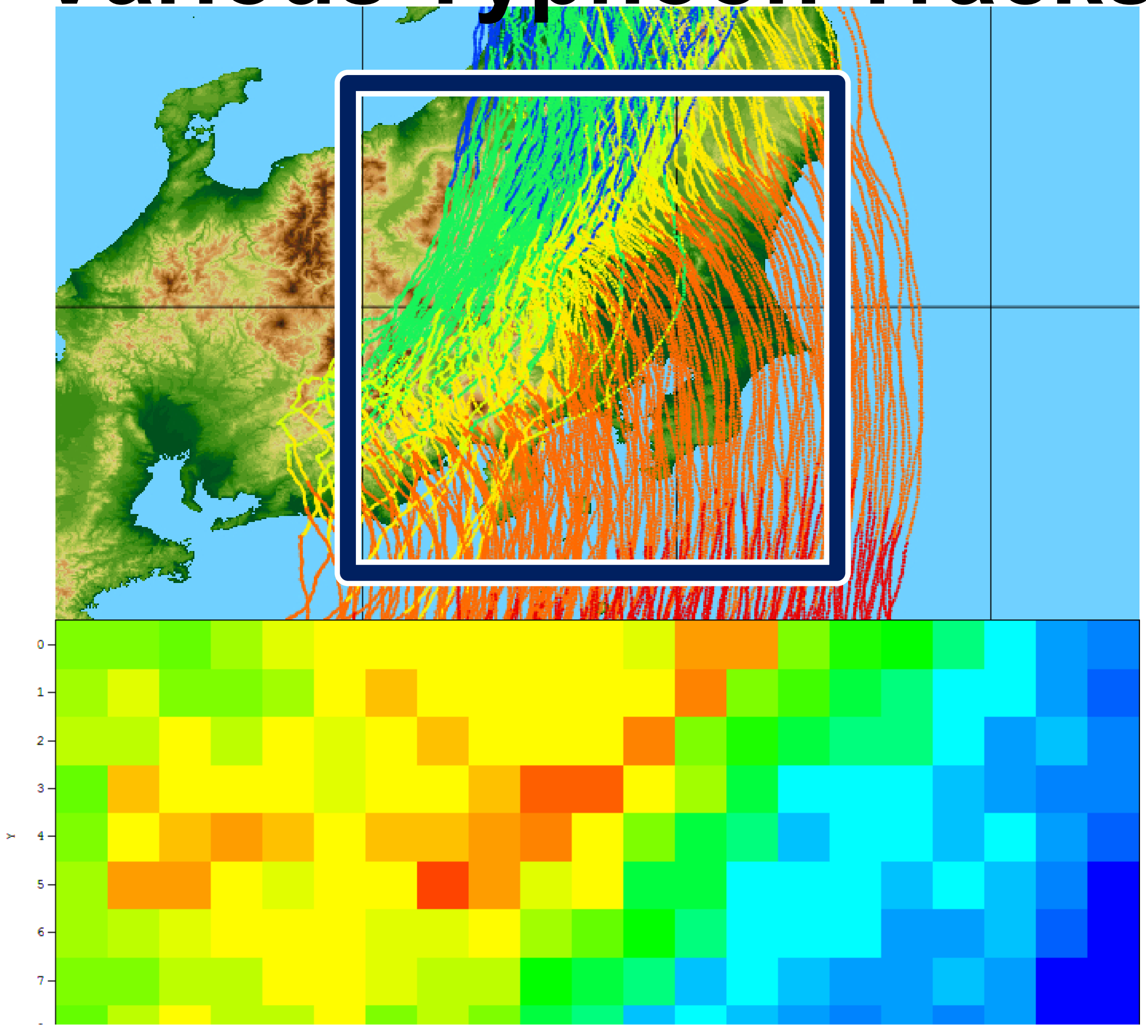
Possible Extreme Events
- Various Typhoon Tracks -



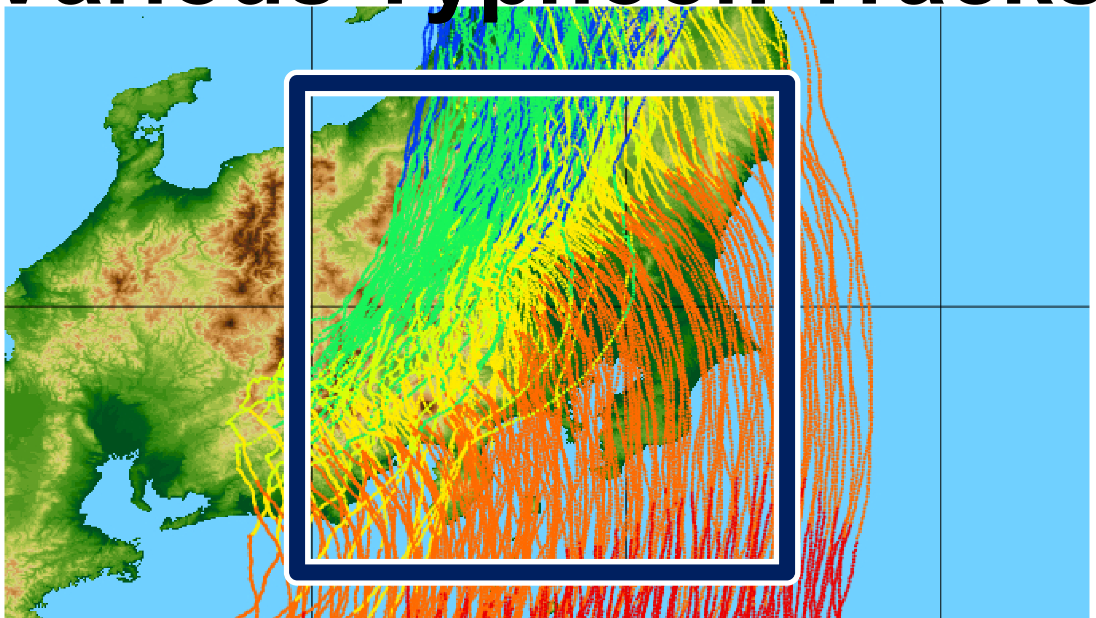
Flood Simulations with Possible Extreme Events

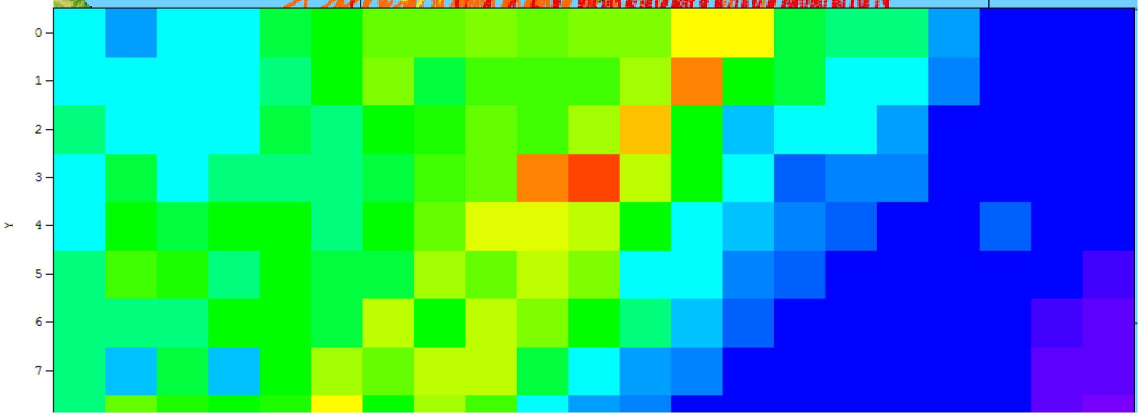


Possible Extreme Events
- Various Typhoon Tracks -



Possible Extreme Events
- Various Typhoon Tracks -





Summary

nate change impacts analysis on the Tone River Basin

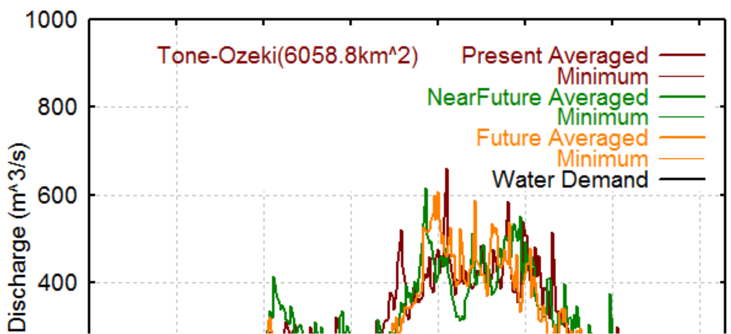
Using the super high resolution GCM output (20km/spatial & 1hr/temporal)
Distributed hydrologic model considering multiple dam reservoir operations
Dam model to reproduce the current dam release patterns
Assuming that the future water demand will be the same to the present one

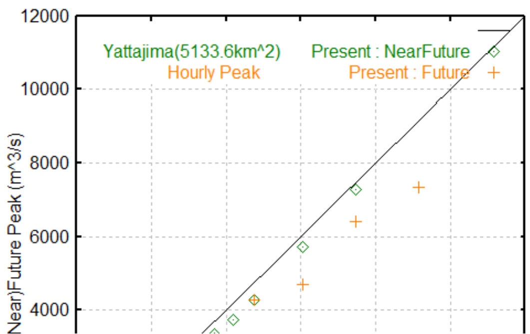
rent dam reservoir operation rules are effective

Especially at the right downstream of the dam reservoirs
For most of the season except the late spring season

e-Ozeki has high possibility of water shortage in the future

Necessary to modify the operation rules for the late spring season water supply

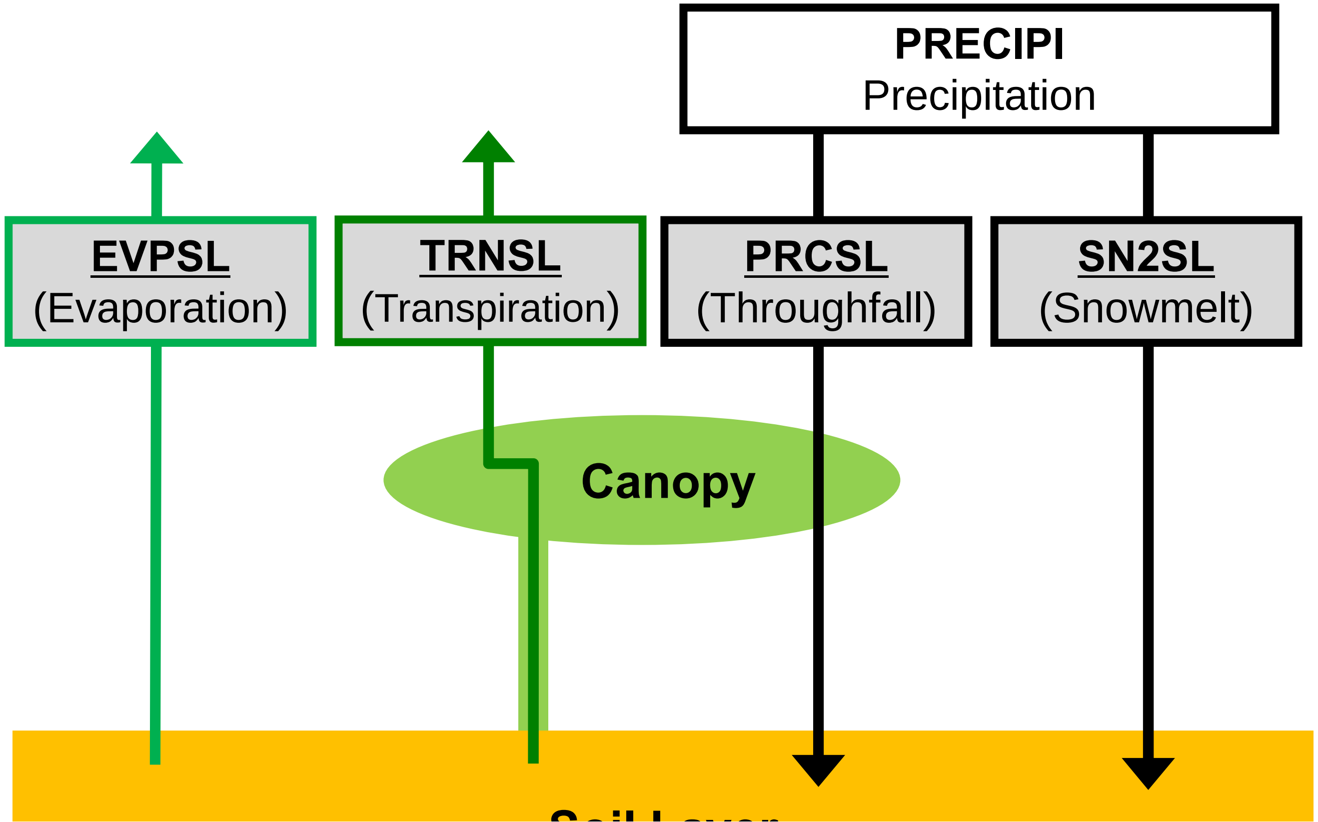




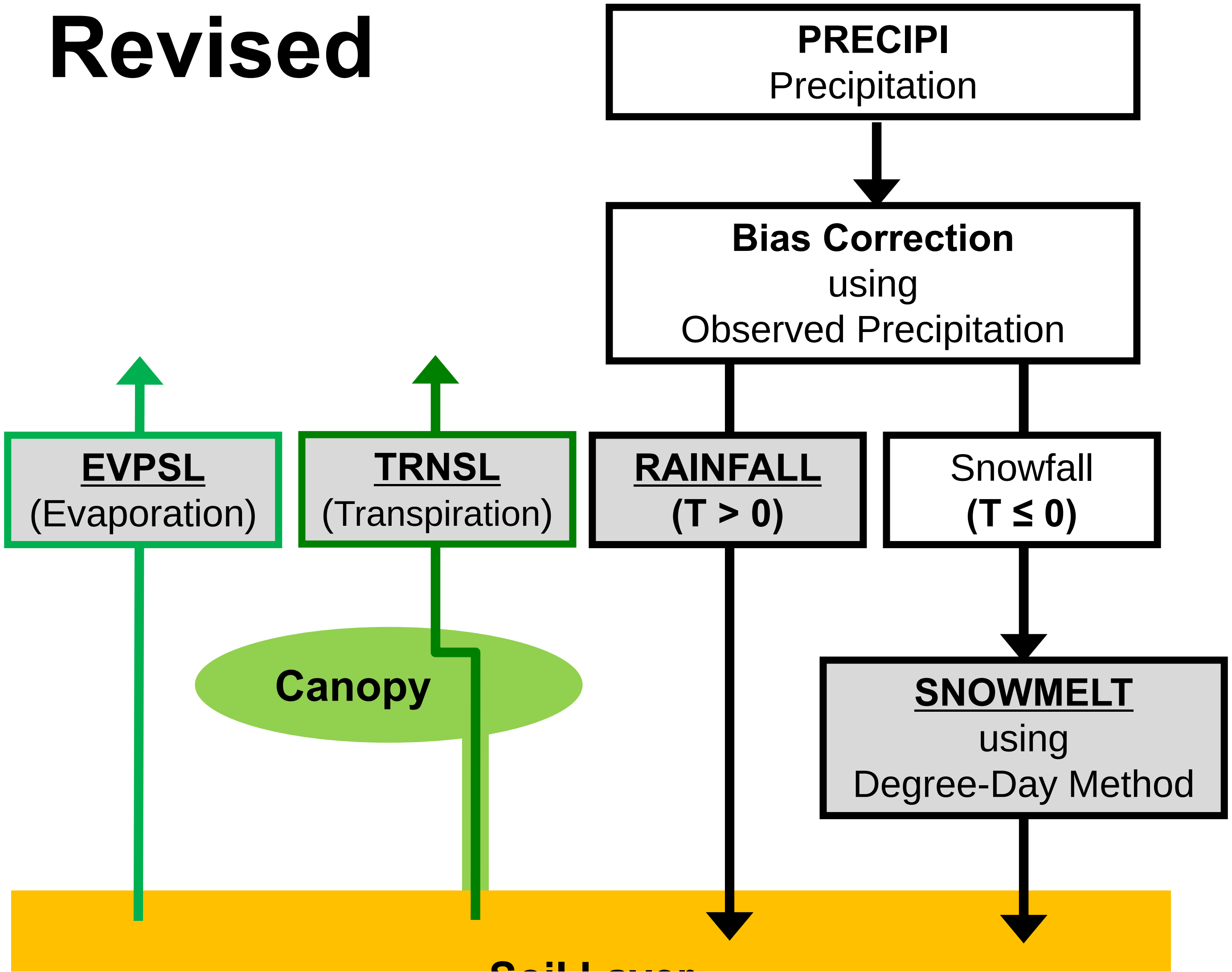
Thank you very much!

further information
sunmin@hywr.kuciv.kyoto-u.ac.jp

revious Method

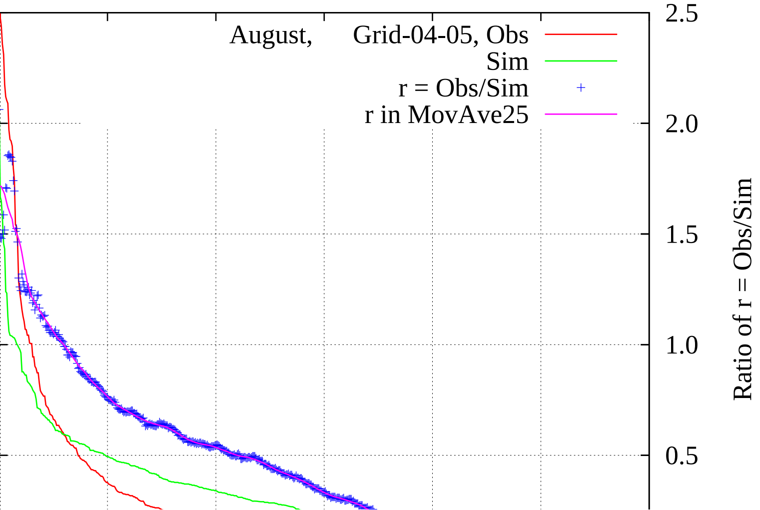


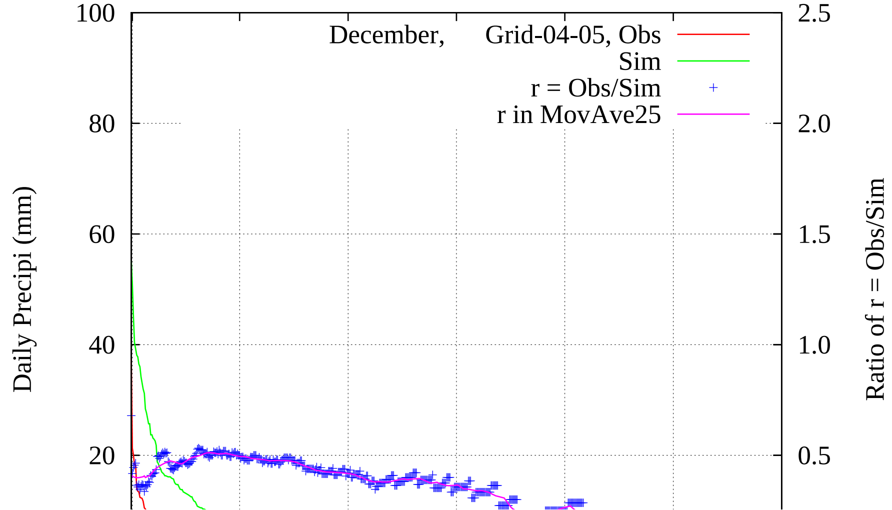
Revised


PRECIPI
Precipitation
Bias Correction
using
Observed Precipitation
EVPSL
(Evaporation)
TRNSL
(Transpiration)
RAINFALL
(T > 0)
Snowfall
(T ≤ 0)
Canopy
SNOWMELT
using
Degree-Day Method

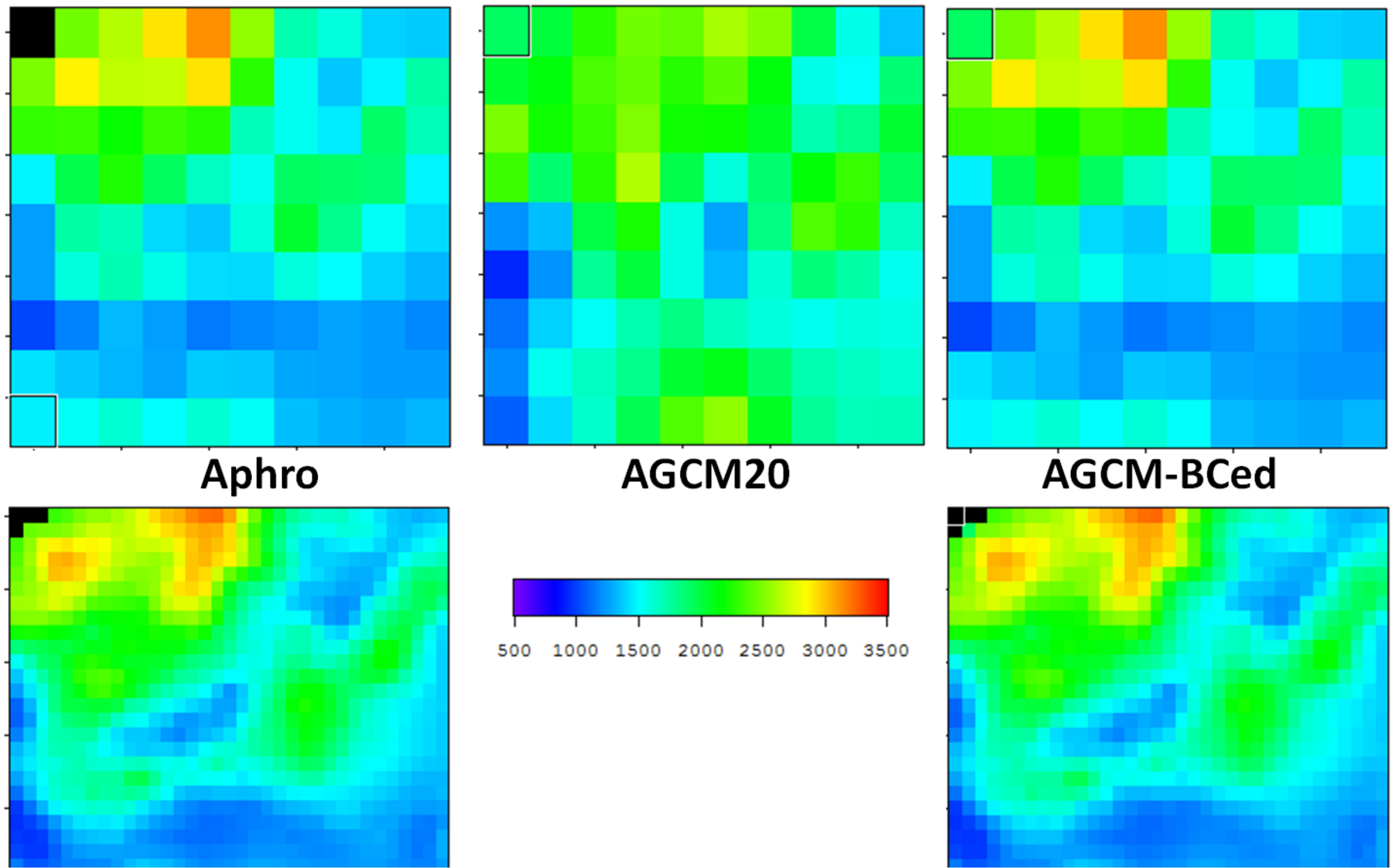
Bias Correction with Daily Scaling Method

ple of sorted daily precipitation from the AphroJP observation and
:M20 output with the ratio of these two values ($r=P_{sim}/P_{obs}$) for April
, August (middle), and December (right). Each month has different
pe of ratio values. This sample data comes from the nearest grid point
e Yagisawa Dam Basin.

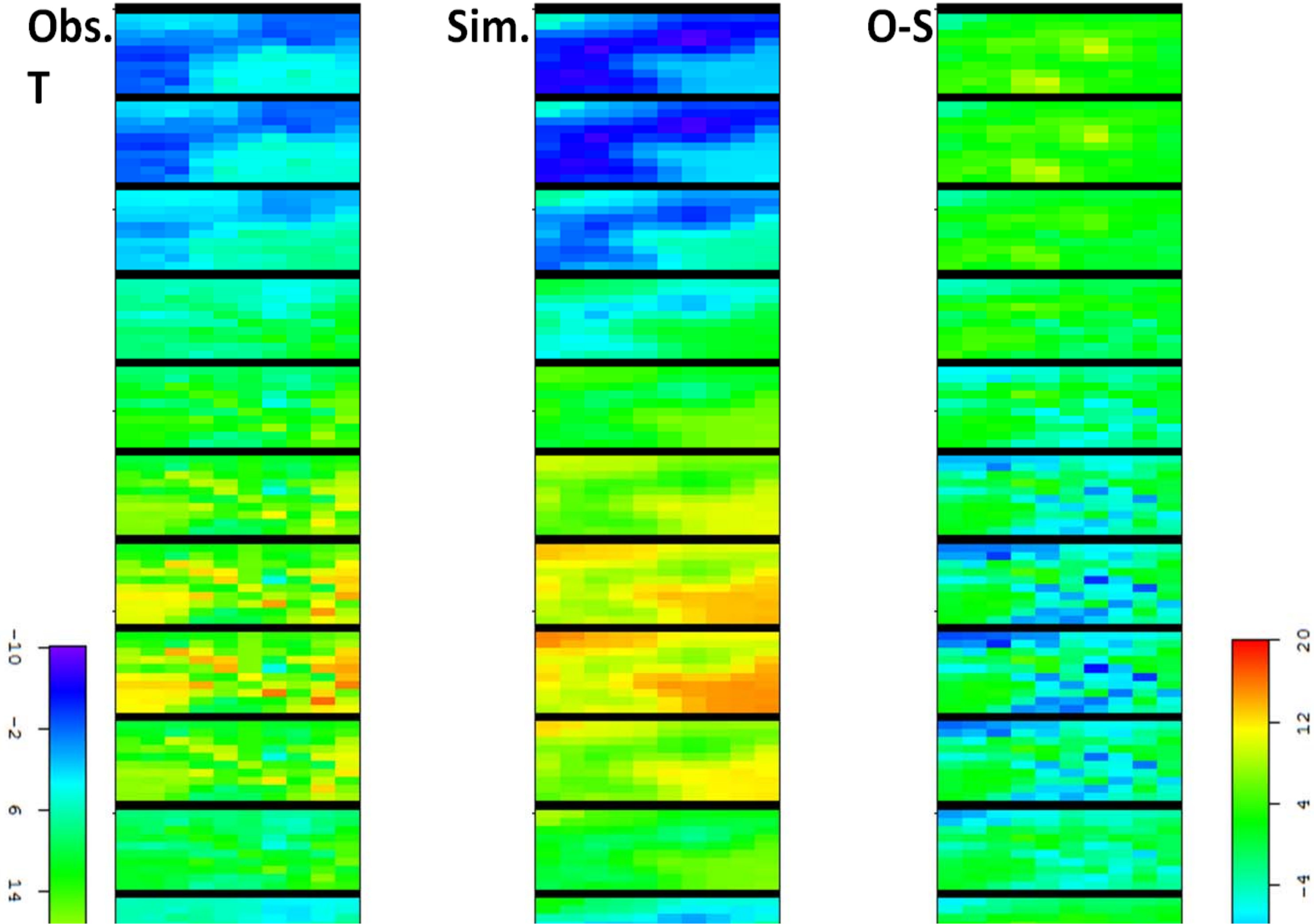




Bias Corrected Precipitation
Annual mean Precipi



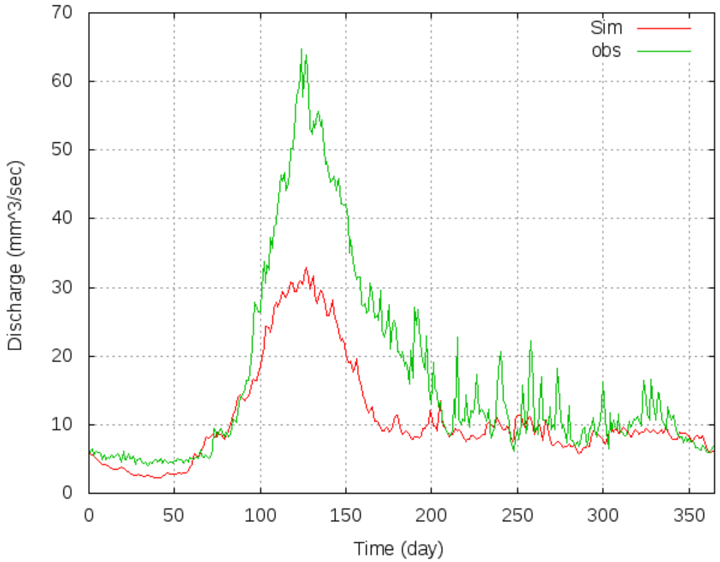
Temperature Evaluations

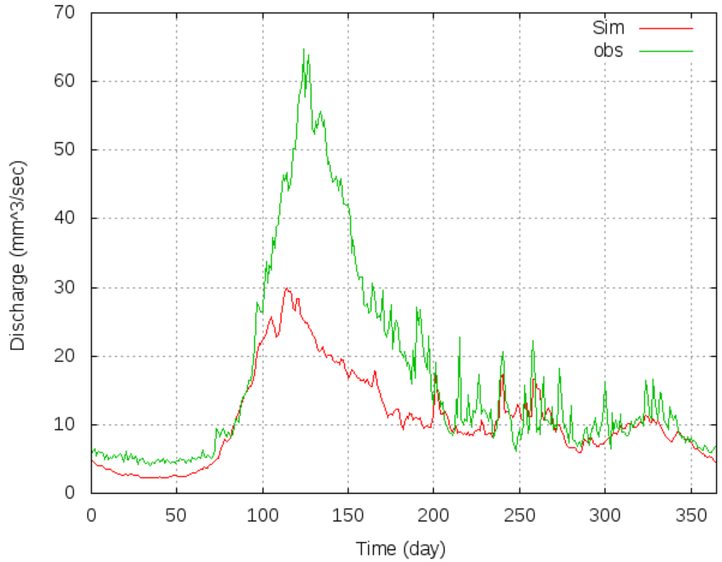


mproved Simulation Results (Yagisawa Dam Basin)

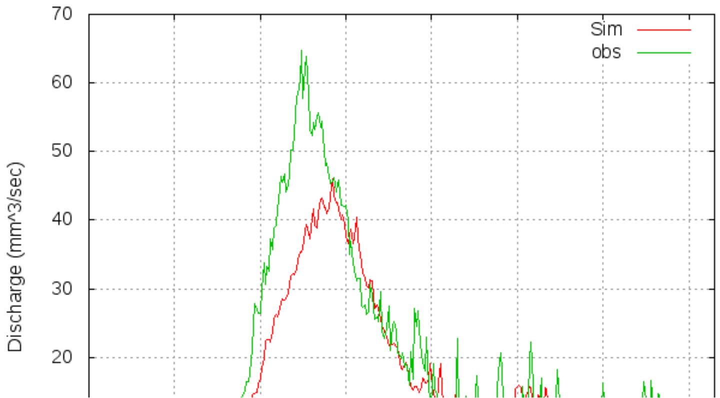
AGCM-3.1S AGM-3.2S

, PRCSL





orrected
itation



onsidering Social Vulnerability Change

isaster = f_1 (Meteorological f., Geomorphologic f., Social factors)

anges in meteorological factors (*ΔM.F.*) are apparent in the coming century
anges in geomorphologic factors (*ΔG.F.*) are negligible.
anges in social factors (*ΔS.F.*) also should be considered in the climate change esearch to propose successful adaptation methods.

Disaster = Δ f_1 (*ΔM.F., ΔS.F.*)

ood 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

ater 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

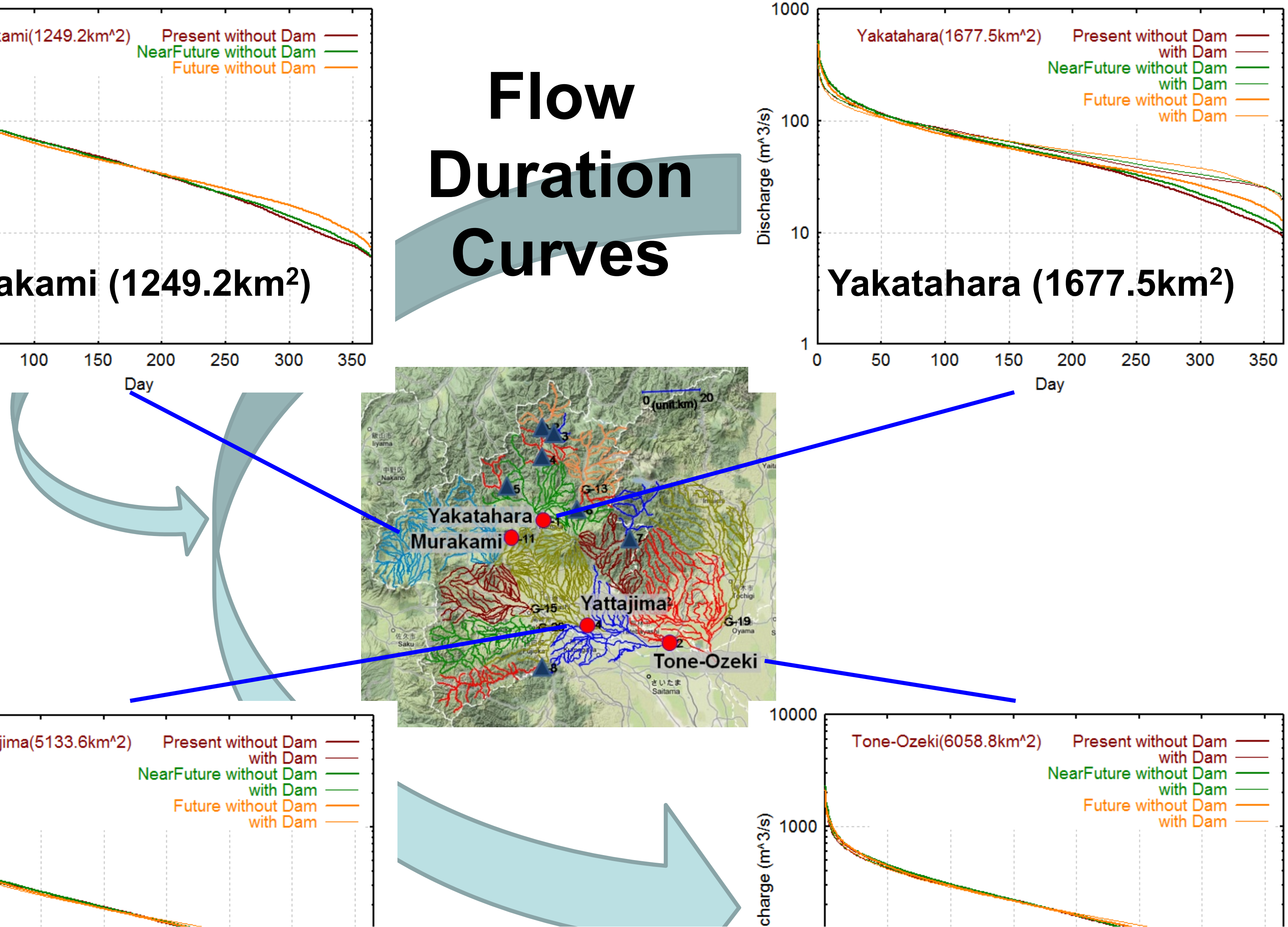
– Water demand changes as society changes
– Natural water usage such as agricultural usage will be changed.

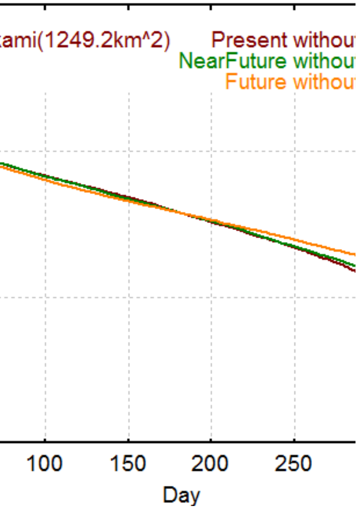
To identify the uncertainty in the future projection

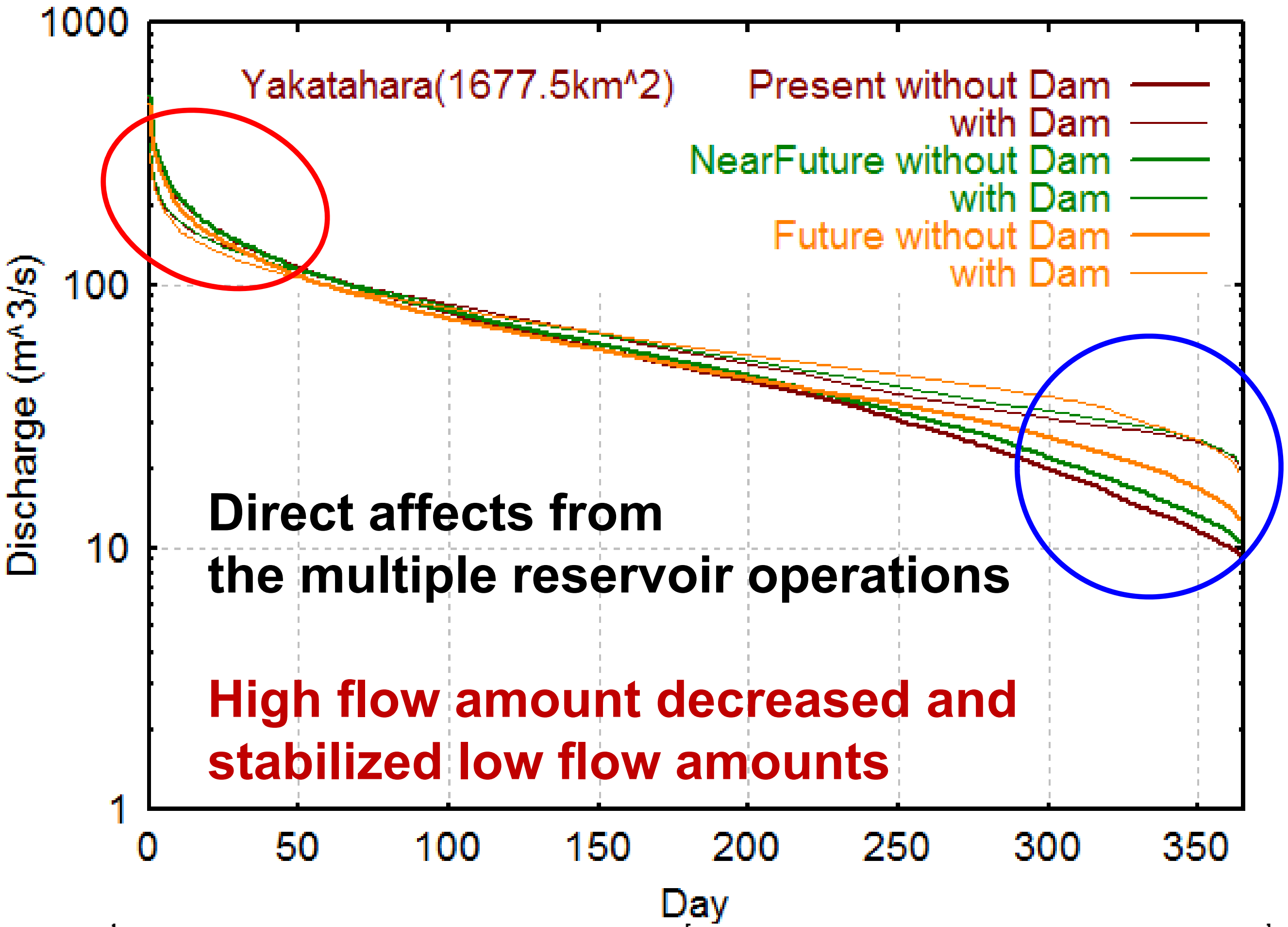
– Uncertainty in the AGCM20 output
– Uncertainty in the water resources assessments

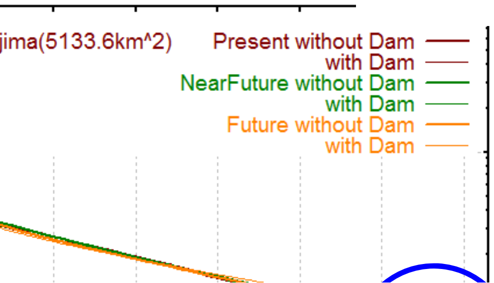
To improve the accuracy of the input and output

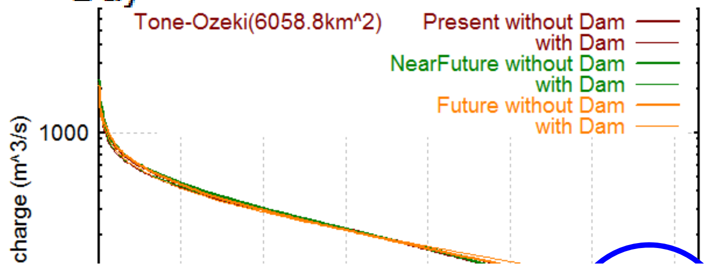
– Downscaling & bias correction, especially for small basin
– Improving the model performances under the various situations


Flow Duration Curves
kami(1249.2km^2)
Present without Dam
NearFuture without Dam
Future without Dam
akami (1249.2km²)
100
150
200
250
300
350
Day
Yakatahara(1677.5km^2)
Present without Dam
with Dam
NearFuture without Dam
with Dam
Future without Dam
with Dam
1000
100
10
1
Discharge (m^3/s)
Yakatahara (1677.5km²)
0
50
100
150
200
250
300
350
Day
0 (unit:km) 20
Yakatahara
Murakami
Yattajima
Tone-Ozeki
G-13
G-15
G-19
jima(5133.6km^2)
Present without Dam
with Dam
NearFuture without Dam
with Dam
Future without Dam
with Dam
Tone-Ozeki(6058.8km^2)
Present without Dam
with Dam
NearFuture without Dam
with Dam
Future without Dam
with Dam
10000
1000
charge (m^3/s)


ami(1249.2km^2)
Present withou
NearFuture withou
Future withou
100
150
200
250
Day


Yakatahara(1677.5km^2)
Present without Dam
with Dam
NearFuture without Dam
with Dam
Future without Dam
with Dam
Discharge (m^3/s)
1000
100
10
1
0
50
100
150
200
250
300
350
Day
Direct affects from
the multiple reservoir operations
High flow amount decreased and
stabilized low flow amounts


jima(5133.6km^2)
Present without Dam
with Dam
NearFuture without Dam
with Dam
Future without Dam
with Dam


Tone-Ozeki(6058.8km^2)
Present without Dam
with Dam
NearFuture without Dam
with Dam
Future without Dam
with Dam
charge (m^3/s)
1000