FUTURE CLIMATE PROJECTIONS WITH A HIGH HORIZONTAL RESOLUTION GLOBAL CLIMATE MODEL FOR IMPACT ASSESSMENTS IN WATER SECTORS IN SOUTHEAST ASIA

Theme C: Integrated Climate Change Projection in the Program for Risk Information on Climate Change: TOUGOU-C

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***Abstract*—Future climate scenarios for impact assessments for the entire world have been provided with a Meteorological Research Institute (MRI) global climate model (GCM) with high horizontal resolution of 20 km (MRI-AGCM) under a research program, Integrated Climate Change Projection in Japan. Reliable impact assessments requires a precise physical-based model for each sector. Such a model often requires its high-horizontal-resolution forcing data such as meteorological variables, land cover, soil types, and river cross section. Therefore, we have provided the data of future climate scenarios for impact assessments for foreign impact assessment researchers and investigated impact assessments on water resources with collaboration with impact assessment researchers. First, we evaluated a present-day climate simulation in Southeast Asia with MRI-AGCM against observations and obtained good reproducibility of the present-day climates. Indeed, future changes in surface air temperature extreme indices are projected to increase in the entire Southeast Asia, but future changes in precipitation extreme indices is projected to vary with area even within Southeast Asia. Five day rainfall totals is projected to increase in more than half of land area of Southeast Asia with high confidence and to decrease in spotty areas scattered in Southeast Asia with less confidence. We also assessed water resources in Chao Phraya River in a late 21st century under SRES A1B and obtained a peak of river discharge at Nakhon Sawan located in the central region in September, a delay of one month after the maximum monthly mean precipitation.**

Keywords—future climate; impact assessment; water resources; global; Southeast Asia; global climate model

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I. INTRODUCTION

Future climate projections are essential for impact assessments on each sector of industries for infrastructure designs, and decision making against the impacts. We developed a Meteorological Research Institute (MRI) global climate model (GCM) with high horizontal resolution of 20 km (MRI-AGCM) under a research program, Integrated Climate Change Projection in Japan to precisely project future climate changes. Due to high horizontal resolution, the projections are being used for impact assessments of future climates on many sectors of industries, especially on water sectors.

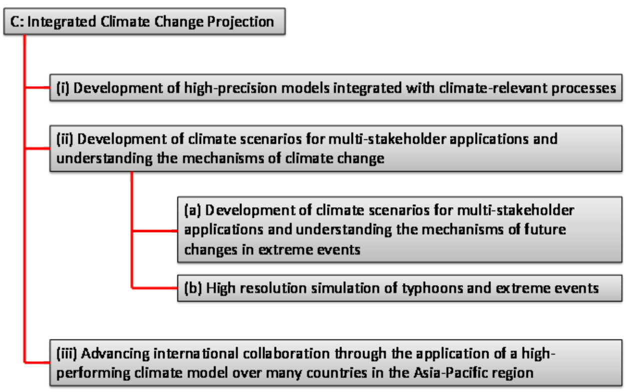

Fig. 1. Structure of Integrated Climate Change Projection in the Program for Risk Information on Climate Change: TOUGOU-C. Courtesy of Dr. Takayabu (PI: MRI)

We have participated in a research program, the future climate projections under a research program the Program for Risk Information on Climate Change (TOUGOU) and studied future climate projections in Theme C: Integrated Climate Change Projection in the Program for Risk Information on Climate Change: TOUGOU-C. TOUGOU-C is composed of 3 components (Fig.1). This overview reported some good practices about impact assessments of climate changes on water sectors with future climate projections with the MRI-AGCM by using climatic indices.

II. MODEL, EXPERIMENT SETUPS, AND METHODS

A. *Model*

The MRI-AGCM used in this study has been developed based on an operational global weather forecast model in Japan Meteorological Agency. MRI-AGCM is atmospheric model with a land-surface bio hydrological model. Semi-Lagrangian scheme is used in the dynamical core to allow stable and fast numerical integration which is impossible in a conventional Eulerian scheme. Convection scheme used here is Yoshimura scheme [2]. Shortwave radiation scheme is developed by Shibata and Uchiyama (1992) [3], longwave radiation scheme is developed by Shibata and Aoki (1989) [4], and land-surface bio hydrology: MJ-SiB: SiB with 4 soil-layers and 3 snow-layers. Mellor & Yamada (1974,1982) level-2 closure model is used as planetary boundary later scheme. The horizontal resolution is TL959 or about 20-km grid spacing with 60 vertical layers. Another version of MRI-AGCM with middle horizontal resolution of TL319 or about 55-km grid spacing is also used to quantify uncertainty in future climate projections to allow multiple experiment setups since MRI-AGCM with 55-km grid spacing runs more than 10 times faster than MRI-AGCM with 20-km grid spacing. We perform regional dynamical downscaling with a Non-Hydrostatic Regional Climate Model (NHRCM) for Japan region from MRI-AGCM outputs, while visiting scholars do so for their own country's region.

B. *Experiment setups*

MRI-AGCM with 20-km grid spacing is atmospheric GCM and sea surface temperatures (SSTs) must be prescribed in all experiments. For the present-day climate simulation, observed SSTs are used. For future climate simulation, SSTs are obtained as the CMIP5 multi-model ensemble mean.

We performed future climate projections with a variety of experiment setups in order to estimate uncertainty in future climate projections with 60-km grid spacing version of MRI-AGCM due to computer efficiency/resources although a fast supercomputer the Earth Simulator is available for these simulations. First we used four different future projected SSTs to quantify the effect of the uncertainties in projected SSTs on the future climate projections. The projected SSTs are developed by performing a cluster analysis of future SSTs projected by CMIP5 multi model ensemble. Second, we used three different convection schemes to quantify the uncertainty in subgrid-scale cumulus parameterization. Therefore, we performed twelve simulations with different experiment setups.

We performed future climate projections under SRE SA1B, RCP 8.5 scenario and currently performed those under RCP 2.6 Time-slice experiments shown in Fig. 2. is chosen due to high computer burdens. In this overview, we used future climate projections under SRES A1B and RCP 8.5. We defined the present-day climate as a period from 1979 to 2003, and the future climate as a period from 2075 to 2099.

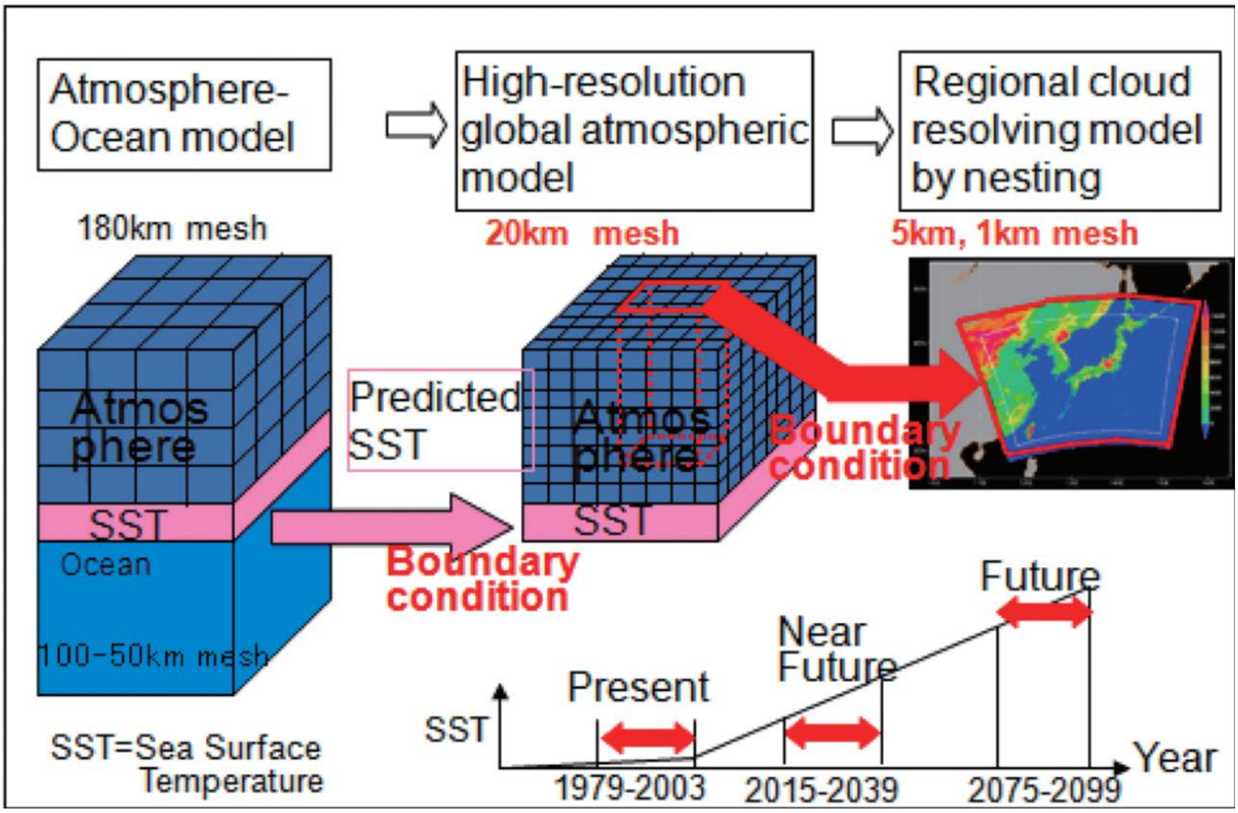

Fig.2 A schematic of the experiment after Kitoh et al. (2009) [1]

C. *Analysis method*

We analyze future changes in the annual maximum 5-day rainfall total (Rx5d) and consecutive dry days (CDD) since these climatic extreme indices represent water excess and water scarcity as a meteorological forcing. In this analysis we defined dry day as day when the daily rainfall amount is equal to or greater than 0.1 mm/day and the count of the CDD do not exceed a calendar year.

Although we performed ensemble climate simulations with 60-km grid spacing with different convection schemes, we present the results with ensemble climate simulations with 20-km grid spacing with the Yoshimura scheme.

III. EVALUATION OF PRESENT-DAY CLIMATE SIMULATION

First, we evaluate the climatological mean annual, June-July-August, and December-January-February precipitation against the observations. Overall capability of presipitation simulated in MRI-AGCM is reasonable and better than CMIP5 AOGCMs primarily due to use of the present-day observed SST and high horizontal resolution.

We compared Rx5d of the present-day climate simulations with that of observations. The large-scale distribution of Rx5d is well captured in the present-day climate simulations with MRI-AGCM. However, the absolute values in some regions are over- and underestimated (figure not shown). These differences between the simulation and the observations is due to horizontal resolution, representation of convection, and others since a GCM is tuned so that global-scale model's simulation with proper physics is optimized.

Capability of CDD similar to Rx5d is obtained; good geographical distributions of CDD but with over- and underestimations in some regions.

These results allow us to further analyze the future changes in Rx5d and CDD.

IV. RESULTS

A. *Rx5d.*

Figure 3 shows future changes in annual maximum 5-day rainfall total (Rx5d) in Southeast Asia. Most of the land areas has significant increases in Rx5d in ensemble mean (Fig. 3.a). It means that water excess or flood in the future climate often occurs and become larger in magnitude than those in the present-day climate. The increase exceed 60 mm/5-days in some areas such as the Malaysia and Miramar, suggesting distinct increase in flood damages.

However, the mainland of Thailand, Vietnam, and the Luzon Island do not so. These areas are located between 10°N -20°N and adjacent to a northern part of the South China Sea. This insignificant changes are consistent among the each

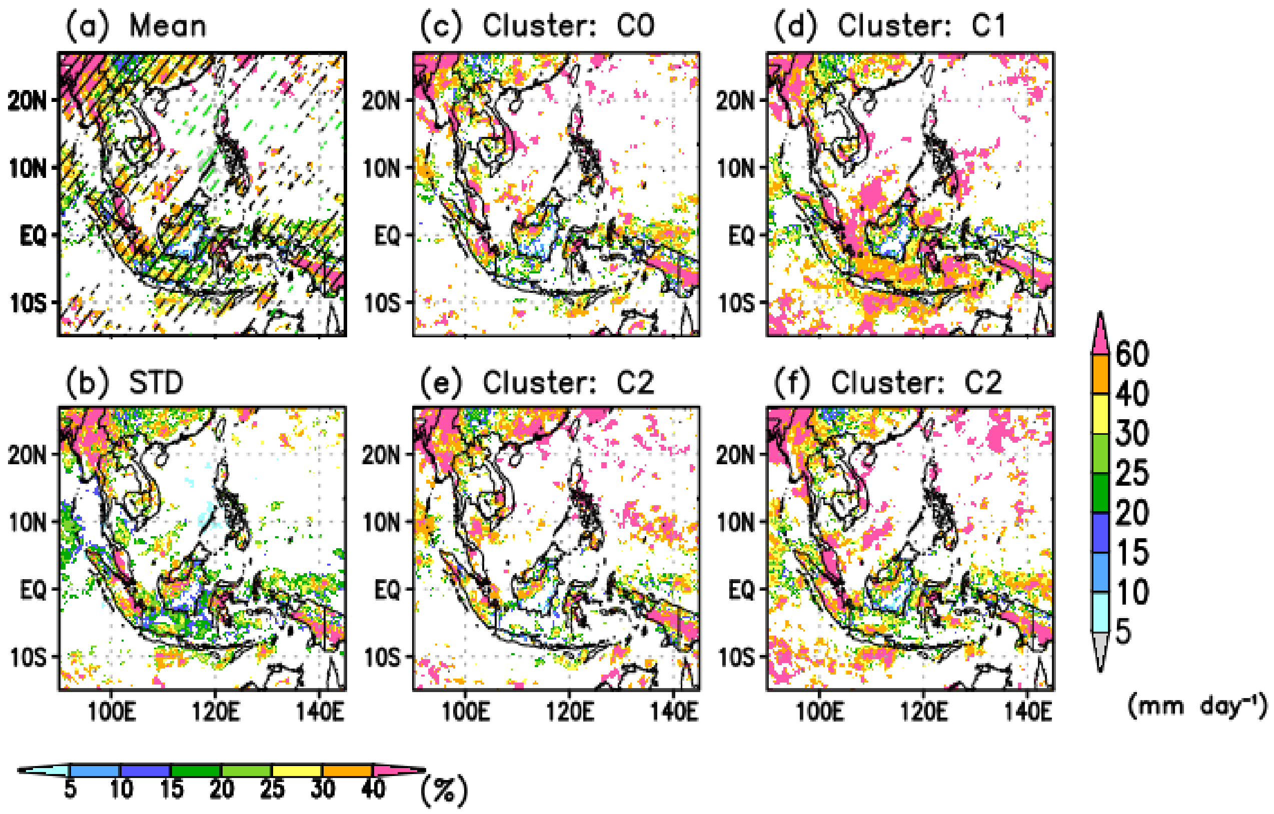

Fig. 3 Future changes in annual maximum 5-day rainfall total (Rx5d) in Southeast Asia. (a) ensemble mean of the 4 experiments with 4 different projected SSTs, (b) standard deviation of the ensemble members of the 4 different experiments with 4 different projected SSTs, (c) to (f) each of the 4 experiments with different projected SSTs. Colored areas denotes statistically significant change at 95% level while hatched areas denote consistent changes among the 4 different experiments.

member of the 4 experiments (Fig. 3c to 3f). One possible reason is a large difference among the projected SST used for each member of the 4 experiments. No consistent changes are seen in these areas.

Most of the oceans in Southeast Asia except for in the Thai Bay, the Java Sea, and others have insignificant changes. However, consistent changes are seen n some of these ocean areas.

B. CDD

Figure 4 shows future changes in annual maximum consecutive dry days (CDD) in Southeast Asia. Statistically significant changes are not seen in most of the land areas except for scattered spotty areas. However, the Malay Peninsula and the Sumatra Island show the significant increase in CDD in the future climate with high consistency. This result suggest that water scarcity or drought may reduce in the future climate. CDD only represent information about the annual maximum of dry days but does not that of monthly to seasonal mean rainfall total. Both should be considered for a good practices in water sector.

C. River discharges in Chao Phraya River

As an example of impact assessments of climate changes on the water sector using MRI-AGCM, Chao Phraya River is taken up[5]. Projections of river discharges at Nakhon Sawan located in the central region of the Chao Phraya River in the future climate is performed using outputs from MRI-AGCM and a river routing model, Global River-flow model using TRIP or GRiVET [6]. The inputs to GRiVET from MRI-AGCM are summation of surface and subsurface runoff computed in one-dimensional land-surface model, hereafter referred to as total runoff.

River discharge at Nakhon Sawan is projected to reach the peak in September in the future climate, a delay of one month after the maximum monthly mean precipitation.

V. CONCLUDING SUMMARY

Future climate changes with MRI-AGCM with 20-km grid spacing are investigated in this overview. Five day rainfall totals (Rx5d) is projected to increase in more than half of land area of Southeast Asia with high confidence and to decrease in spotty areas scattered in Southeast Asia with less confidence. Consecutive dry days (CDD) is projected to increase in small spotty areas confined except for the Malay Peninsula and the Sumatra Island.

Water resources in Chao Phraya River in a late 21st century under SRES A1B are projected and the following result is obtained: a peak of river discharge at Nakhon Sawan located in the central region in September, a delay of one month after the maximum monthly mean precipitation.

We demonstrated future impact of climate changes on the river discharges using total runoff of MRI-AGCM. Instead of using total runoff, surface meteorological forcings such as radiations, surface air temperature, and precipitation, one can perform hydrological simulations with a land-surface model

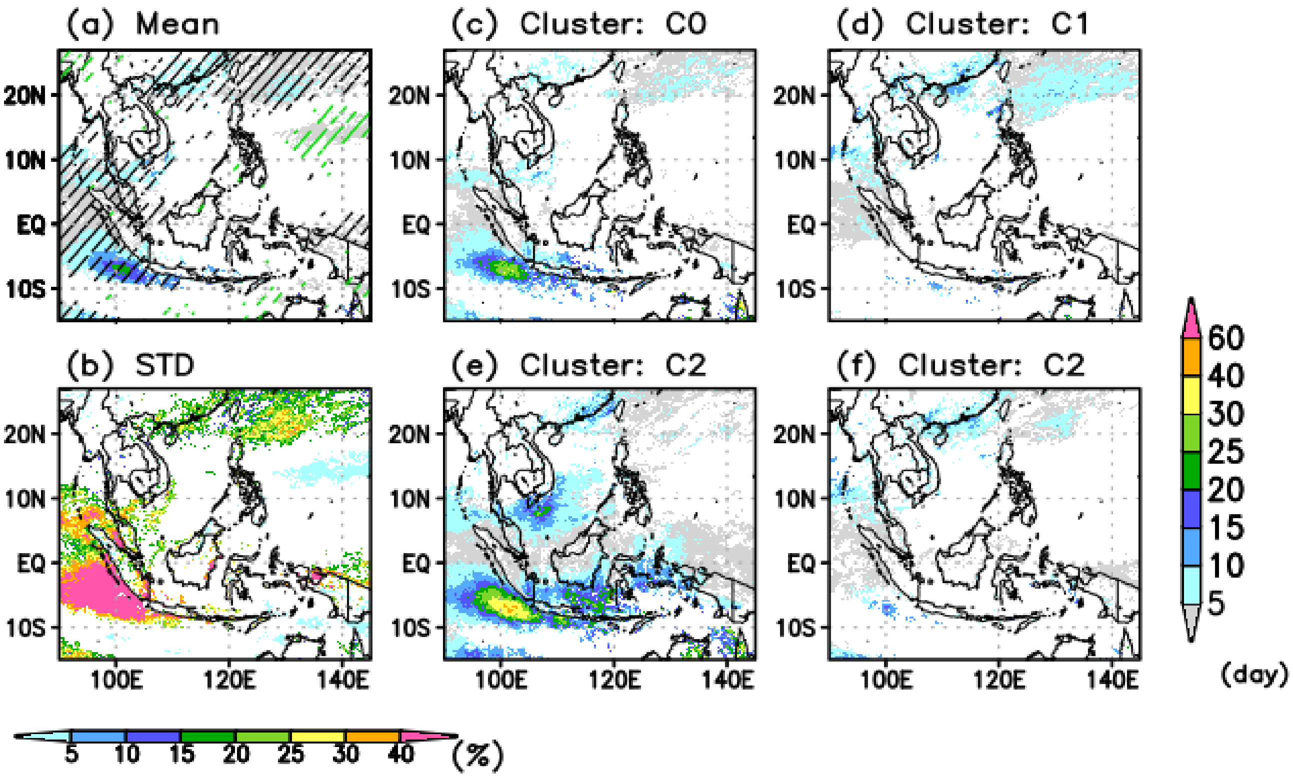

Fig 4. Same as in Fig. 3 but for consecutive dry days.

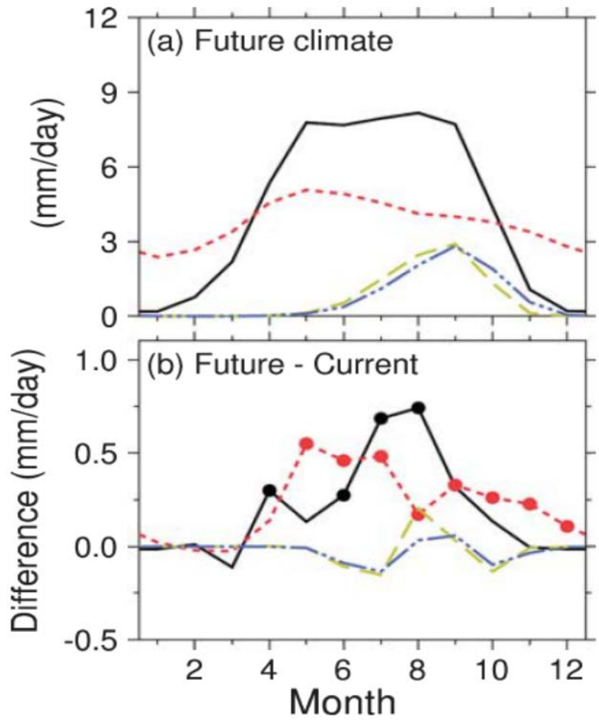

Fig 5. Climatological monthly mean hydrological variables at Nakhon Sawan in the late 21st century using the 20-km mesh MRI-AGCM. Black solid, red dashed, green centered and blue cutting-planed lines denote precipitation, evaporation, total runoff, and river discharge, respectively. Circles denote statistically significant change (P < 5%) compared to the present-day values. (a): The amount of the projected future climate, (b): The changing amount of the projected future climate. After Champathong et al. (2013) [5].

and a river routing model.

We have already performed future climate projections under RCP 8.5 and have been performing those under RCP2.6, will be available. The former is already available on request and the latter will be so.

Most hydrological and water resources scientists often request outputs with more high resolution than 20 km. Regional-scale dynamical downscaling may answer this questions. We have already done the dynamical downscaling with 5-km grid spacing over the entire Thailand and will be available very soon.

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