B-12 **Impact Assessment of Future Climate Change Using High-Resolution Climate Change Scenarios Including Extreme Events（Abstract of the Final Report）**

Contact person Seita Emori
Chief, Climate Risk Assessment Research Section
Center for Global Environmental Research
National Institute for Environmental Studies
16-2, Onogawa, Tsukuba, Ibaraki, 305-8506 Japan
Tel:+81-29-850-2724 Fax:+81-29-850-2960
E-mail:emori@nies.go.jp

Total Budget for FY2004-FY2006 127,400,000Yen (**FY2006**; 49,400,000Yen)

Key Words Impact Assessment of Climate Change, Extreme Events, High-Resolution Climate Model, Validation of Climate Model, Climate Change Mechanisms

1. Introduction

Conventional researches on impact assessment of future climate change are mostly based on the projected changes in monthly and multi-year mean values of temperature and precipitation. However, it has been increasingly recognized that what is of particular importance for impact research is the changes in extreme events including extreme heat waves, torrential rains and long dry spells, rather than the mean states. One of the reasons of the lack of extreme events in conventional research is that the extreme events simulated by climate models have been considered to be less reliable than the mean states, partly due to limited spatial resolution of conventional climate models. Recently, a higher-resolution climate modeling has been possible in Japan, thanks to one of the world fastest super computers, the Earth Simulator.

2. Research Objective

This project aims at more concrete and convincing impact assessment of future climate change than conventional ones, by conducting impact research based on climate scenarios that can represent extreme events, and by discussing its effectiveness and uncertainty. We use climate change experiments conducted by a coupled ocean-atmosphere climate model at the world highest resolution on the Earth Simulator. After the simulated extreme events by the model are validated against observed data, climate change scenarios for impact researches are constructed. Using this scenario, we assess climate change impacts on water resource, agriculture, and human health. Adaptation policies for those impacts are also discussed. Finally, the mechanisms of climate change that causes serious impacts are investigated, and model dependence of the mechanisms is also discussed to evaluate the uncertainty in the impact research.

3. Results

Sub-Theme 1: Validation of Climate Models and Coordination of Data Required by Impact Research

The objective of the sub-theme 1 is to validate the reproducibility of extreme events by the climate models against observational data. To cover a range of aspects of validation of climate models that are important for impact research, the following topics have been investigated: (1) Validation of precipitation characteristics focusing on daily extremes, (2) Validation of the number of dry days, (3) Validation of historical changes in extreme indices, (4) Validation of inter-annual variability of summer climate over the East Asia and Asian monsoon regions, and (5) Coordination of climate model output required by impact research.

On the validation of precipitation characteristics focusing on daily extremes, daily precipitation simulated by the climate models was validated mainly against satellite estimates. It was found that the model realistically represents the intensity of extreme daily precipitation and its geographical distribution (Fig. 1a, c). Increased resolution generally improved the simulation of regional and extreme precipitation. On the other hand, it was shown that the simulation of extreme precipitation can be strongly dependent on parameterizations (Fig. 1a, b).

On the validation of the number of dry days, the number of dry days simulated by the climate models was validated against satellite estimates. It was found that the model realistically represents the annual total number of dry days and its geographical distribution except that it is significantly underestimated over storm-track areas over the oceans in the both hemispheres. The simulated frequency distribution of consecutive dry days over various areas in the world was also compared with observation and found to be realistic.

On the validation of historical changes in extreme indices, extreme indices

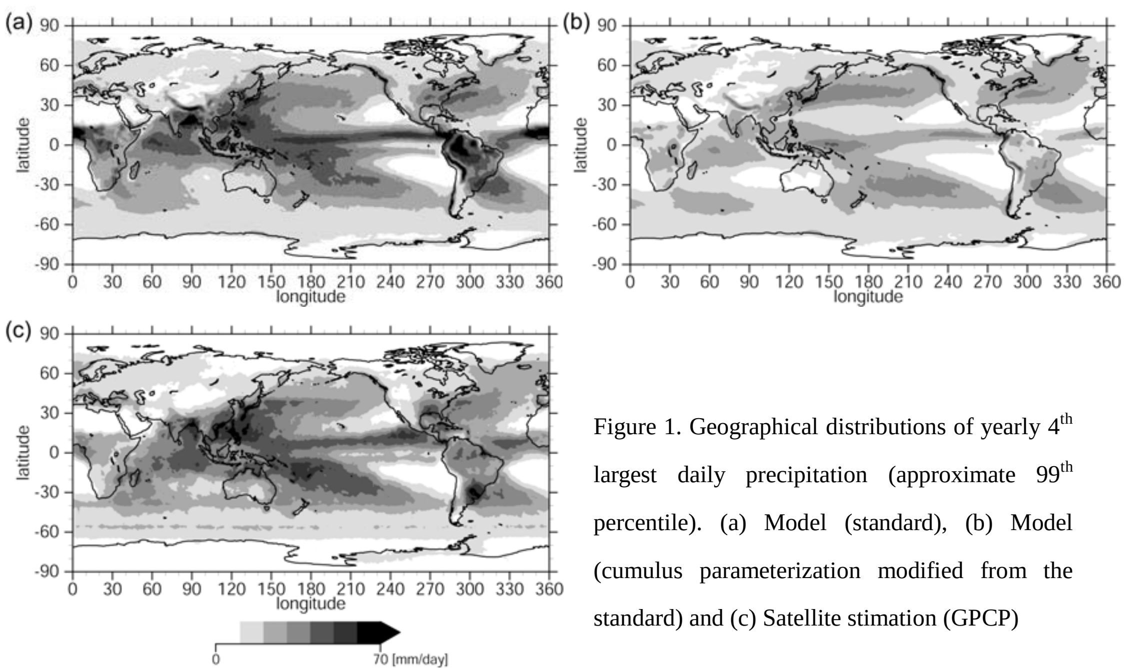

Figure 1. Geographical distributions of yearly 4th largest daily precipitation (approximate 99th percentile). (a) Model (standard), (b) Model (cumulus parameterization modified from the standard) and (c) Satellite stimation (GPCP)

simulated in the 20th century reproduction experiments, in which the models were forced by natural and anthropogenic historical data, were validated against observed data for last 50 years. A new data set of historical daily maximum and minimum temperature provided by the Hadley Centre, UK was used. A statistical analysis showed that the simulated variation of the yearly warmest night and the number of frost days agree with historical record within the uncertainty of natural variability.

On the coordination of climate model output required by impact research, high-temporal-resolution output of near-surface variables from climate models were obtained as required for sophisticated river model or agriculture model for impact research.

Sub-Theme 2: Impact Research Based on Climate Change Scenarios Including Extreme Events

The objective of the sub-theme 2 is to assess climate change impacts on water resource, human health, and agriculture at global scale with utilizing the daily simulation outputs of the high-resolution climate model (MIROC3.2-hires) that are supplied by the sub-theme 1. Following the preliminary research in the first fiscal year, which covers (1) Estimation of probability distribution function of precipitation simulated by the climate model (water resource) and (2) Comparison of potential crop productivities estimated from daily-mean and monthly-mean climate model outputs (agriculture), the following topics have been investigated: (3) Global projections of changes in risks of floods and droughts (water resource), (4) Projection of snowfall using statistical model at spot scale (water resource) (5) Global projections of changes in mortality due to heat stress (human health), and (6) Global projections of changes in potential crop productivities with considering extreme climate events (agriculture).

On the estimation of probability distribution function of precipitation simulated by the climate model, 14 different types of probability distribution functions were estimated for precipitation amount with 3 different methods to estimate parameters of the functions. As a result of cross validation, Pearson III function with two parameters estimated with the moment method was found to be the most suitable for reproducing annual-maximum daily precipitation at Tokyo.

On the comparison of potential crop productivities estimated from daily-mean and monthly-mean climate model outputs, potential productivities of rice and wheat were estimated using daily-mean as well as monthly-mean climate model outputs. Potential productivity estimated using the monthly-mean model output tended to be much larger than that estimated using the daily-mean model output.

On the global projections of changes in risks of floods and droughts, simulated daily discharge data derived from MIROC3.2-hires were used to investigate changes in the risks of global discharge extremes due to climate change. The present-day GCM simulation reproduced the magnitude of discharge in 100-year return periods and the global distribution of the flood parameter. The frequency of extreme floods was projected to increase over many regions, except for continental North America and middle to western

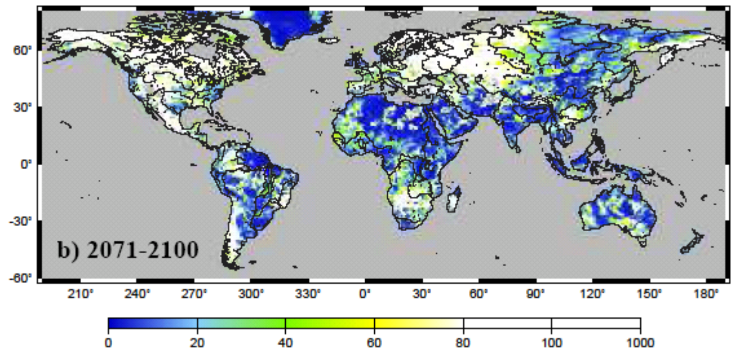

Figure 2. Return period [year] of 100-year floods from 2071-2100 against those from 1941-2000.

Eurasia (Fig.2). The drought frequency was shown to increase in most regions except over the northern high latitudes, eastern Australia, and eastern Eurasia.

On the projection of snowfall using statistical model at spot scale, we have developed a method for projecting daily snowfall at point scale using observed climate data at point scale and future climate projection provided by climate model as an averaged value of large area. As a case study, daily snowfall depth in this century at Takada city in Niigata prefecture was projected. According to the projection, though the risk of high intensity snowfall is expected to decrease gradually in future due to climate change, there still remains a risk of heavy snow more than 230cm in ten days until 2040.

On the global projections of changes in mortality due to heat stress, we have developed a method to assess future changes in mortality due to heat stress with the entire globe as the target, and performed trial calculations using this method. Assuming that no adaptation or acclimation takes place, the results showed the increases in the excess mortality due to heat stress by approximately 100 to 1000%. High rate of the increase in excess mortality due to heat stress is expected in Tibet, Mexico, the northern part of South America, the area around the Mediterranean Sea, and the southern part of the African continent, where large increases in temperature are projected (Fig.3). With considering present population density together, significant increases in excess mortality density could be seen in China, India, and Europe.

On the global projections of changes in potential crop productivities with considering extreme climate events, climate change impacts on rice productivity at global scale were estimated with considering future change in typhoons and heat waves, which were projected by MIROC3.2-hires. According to the simulation, the damage caused by the heat wave will significantly increase all over the world by the middle 21st century, and the loss of productivity caused by the

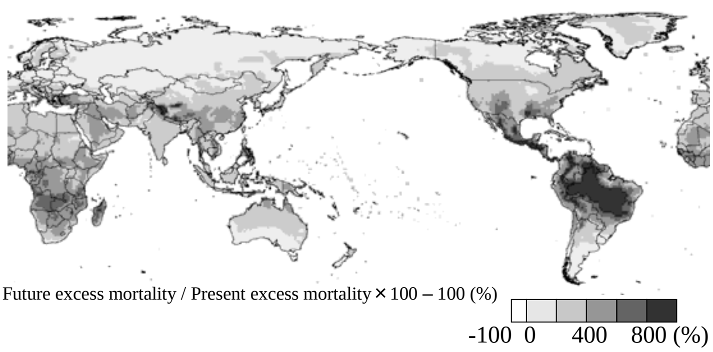

Figure 3. Ratio of change in excess mortality due to heat stress (Future excess mortality / Existing excess mortality x 100 – 100 [%])

heat wave may reach 10 % in the regions most severely damaged. The share of the change in crop productivity due to the change in extreme climate events in the total change is relatively higher in the central part of African continent, the central part of US, South America, and the northern part of India.

Sub-Theme 3: Understanding Climate Change Mechanisms and Its Uncertainty

The objective of the sub-theme 3 is to understand climate change mechanisms and investigate its model dependence to estimate the uncertainty of climate change projection used for impact research. To cover a range of mechanisms of climate change that are important for impact research, the following topics have been investigated: (1) Mechanisms of climate change over and near Japan and its relation to inter-annual variability, (2) Future projection of mean and extreme precipitation and understanding its mechanisms on global scale, (3) Mechanisms of changes in tropical cyclones and associated precipitation, and (4) Near-term prediction of changes in extreme events considering the uncertainty due to natural variability.

On the mechanisms of climate change over and near Japan and its relation to inter-annual variability, a future climate change experiment based on the SRES-A1B scenario and a 20th century reproduction experiment by the high-resolution coupled climate model were mainly compared. The stronger Baiu front and its later retreat in the future climate than in the present climate, a "cool-summer" type pressure pattern, are projected. Its mechanisms are proposed based on two high pressure anomalies; one is to the south of Japan related to temperature rise over the equatorial Pacific and the other is to the north of Japan related to temperature rise over the Eurasian continent (Fig. 4). The projected "cool-summer" type pattern was further analyzed in relation to natural inter-annual variability. The simulated climate states of each year under changed climate were projected on the principal modes of inter-annual variability in the simulated present climates for the East Asia and Asian monsoon regions, both of which represent the variation between "cool summer" and "hot summer" over Japan. It was found that the probability of the realization of

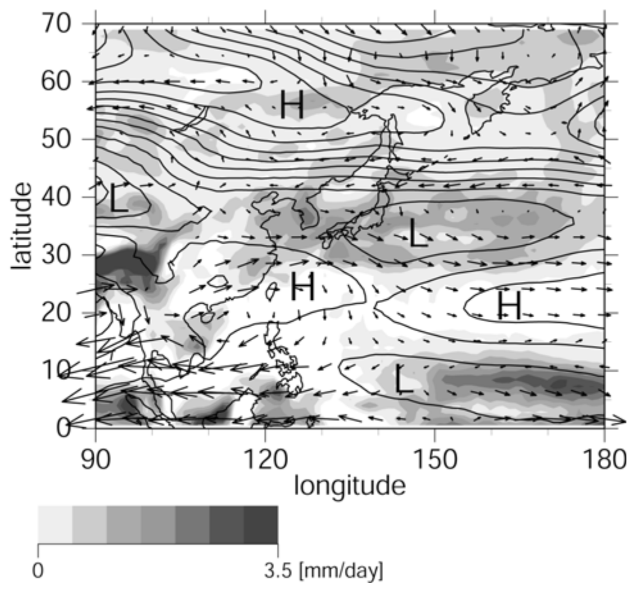

Figure 4. Climate change pattern around Japan in summer (June-July-August). Difference between 2071-2100 mean and 1971-2000 mean. Contour, vector and shade denote the changes in 500 hPa height, 850 hPa wind and precipitation, respectively. H and L denote relative high and low pressure anomaly, respectively.

"cool-summer" year is significantly increased in the future climate.

On the future projection of mean and extreme precipitation and understanding its mechanisms on global scale, daily precipitation data from various climate models were analyzed related to daily vertical velocity data as a proxy of dynamic disturbance. It was projected that the percentage increase in extreme precipitation is larger than that in mean precipitation only over limited areas of globe mainly over subtropics. The changes in mean and extreme precipitation were separated into the 'thermodynamic' component due to the increase in atmospheric moisture content and the 'dynamic' component due to the change in dynamic disturbance. The different changes in mean and extreme precipitation were shown to be caused by the thermodynamic component. It was also found that, over the northern middle-to-high latitudes land areas, dynamic changes are generally small and thermodynamic changes for mean and extreme precipitation are comparable, resulting in comparable total changes in mean and extreme precipitation. The thermodynamic increase in mean precipitation over middle-to-high latitudes was found to be consistent with the results of a global cloud resolving model.

On the mechanisms of changes in tropical cyclones and associated precipitation, tropical-cyclone-like vortices were selected in the simulated results and the change in their occurrence and associated precipitation due to climate change were analyzed. It was suggested that the precipitation associated with a tropical cyclone would be generally intensified due to the increase in atmospheric moisture content in a warmer climate. Furthermore, the change in frequency distribution of tropical cyclone intensity projected with a coupled ocean-atmosphere climate model was compared with that projected with an atmospheric model forced by prescribed sea-surface temperature taken from the coupled model results. It was found that the increase in intense tropical cyclones in a warmer climate projected with the atmospheric model is moderated in the coupled model results due to the enhanced upper-ocean cooling by a tropical cyclone, which is not represented in the atmospheric model.

On the near-term prediction of changes in extreme events considering the uncertainty due to natural variability, we have examined whether human contributions to changes in extreme temperature indices have larger amplitudes than uncertainty due to natural variability in near future (up to 2030) climate prediction. We performed 10 runs of the initial condition perturbed ensemble of a coupled atmosphere-ocean climate model under the SRES A1B scenario. In the near future, over most land areas, all 10 runs predict more frequent occurrences of warm nights and warm days, and less frequent cold nights and cold days, suggesting that human influences have become larger than natural variability.

4. Discussion

By combining the results of the three sub-themes, we have obtained the following new findings that are useful for advancing climate change and impact assessments.

On the change in summer climate over Japan, the "cool-summer" type change in pressure pattern discussed in the sub-theme 3 was further elaborated in terms of the modulation of inter-annual natural variability, which is underpinned by the successful validation of the principal modes of natural variability represented in the climate model in the sub-theme 1. Similarly, the discussion of the change in extreme daily precipitation over Japan (sub-theme 3) is supported by the validation of extreme precipitation represented in the model (sub-theme 1).

On the flood and drought risk assessment, the modeled extreme daily precipitation and the consecutive dry days were validated as a basis (sub-theme 1). The result of assessment using daily precipitation data showed that both the flood and drought risks were projected to increase over some regions (sub-theme 2). This was interpreted by a finding that the extreme precipitation is projected to increase while the mean is not over those regions (sub-theme 3), together with the expected increase in potential evapotranspiration in a warmer climate.

On the assessment of mortality due to heat stress, the modeled historical tendency of the frequency of extreme hot days was validated as a basis (sub-theme 1). The result of assessment using daily temperature data showed a significant increase in mortality (sub-theme 2). Related to this, the possibility of significant increase in extreme hot days and nights in near future was further examined in the sub-theme 3.

On the assessment of potential crop productivities, an analysis taking into account the extreme events including heat waves and tropical cyclones was conducted (sub-theme 2). Though the impact of the change in tropical cyclones was not significant likely due to insufficient spatial resolution of the climate model, the change in tropical cyclones were further analyzed in the sub-theme 3 and the increase in precipitation associated with tropical cyclones was projected.

Based on these research results, we can propose a set of criteria on the reliability of climate change projection for impact studies as follows:

a. The climate change signal is distinguishable from natural variability (statistical significance),
b. The change is found in many different models (inter-model consistency),
c. The physical interpretation of the change is clear and reasonable (interpretability),
d. The key processes to the change are realistically represented in the model and well validated against observational data for the current climate (validity of key processes).
e. A signal similar to the projected change is found in recent observed record (consistency with observation).

A care is needed when applying the criterion e, as the uncertainty due to natural variability should be taken into account.

We have claimed that the assessment of reliability of climate change projection based on a consideration like the above is necessary to improve the reliability of the climate change impact assessment. However, the above criteria are still rather subjective “expert judgment”. As a next step, a more objective way of assessing the reliability, such as a probabilistic representation of uncertainty in prediction, is desired. We are afraid that not much work had been done in this project on adaptation to climate change, while effort has been made for clarifying the concept of adaptation. The analysis on adaptation policies with a particular attention to the reliability of underlying climate change projections is left for future work.

Major Publications

1) Emori, S., A. Hasegawa, T. Suzuki and K. Dairaku: Geophys. Res. Lett., 32, L06708, doi:10.1029/2004GL022306 (2005)
“Validation, parameterization dependence, and future projection of daily precipitation simulated with a high-resolution atmospheric GCM”
2) Kimoto, M., N. Yasutomi, C. Yokoyama and S. Emori: SOLA, 1, 85-88, doi: 10.2151/sola. 2005-023 (2005)
”Projected changes in precipitation characteristics near Japan under the global warming”
3) Hirabayashi, Y., S. Kanae, I. Struthers and T. Oki: J. Geophys. Res., 110(D19), D19101, doi:10.1029/2004JD005492 (2005)
“A 100-year (1901-2000) global retrospective estimation of terrestrial water cycle”
4) Kimoto, M.: Geophys. Res. Lett., 32, L16701, doi:10.1029/2005GL023383 (2005)
“Simulated change of the east Asian circulation under global warming scenario”
5) Hasegawa, A. and S. Emori: SOLA, 1, 145-148, doi:10.2151/sola.2005-038 (2005)
“Tropical cyclones and associated precipitation over the western North Pacific: T106 atmospheric GCM simulation for present and doubled CO2 climates”
6) Emori, S. and S. J. Brown: Geophys. Res. Lett., 32, L17706, doi:10.1029/2005GL023272 (2005)
“Dynamic and thermodynamic changes in mean and extreme precipitation under changed climate”
7) Dairaku, K. and S. Emori: Geophys. Res. Lett., 33, L01704, doi:10.1029/2005GL024754 (2006)
“Dynamic and thermodynamic influences on intensified daily rainfall during the Asian summer monsoon under doubled atmospheric CO2 conditions”
8) Hirota, N., M. Takahashi, N. Sato, and M. Kimoto: SOLA, 1, 137-140, doi:10.2151/sola. 2005-036 (2005)
“Change of the Baiu season climate in the East Asia during 1979 to 2003”
9) Emori. S.: Global Environmental Research, 10, 143-149. (2006)
“The Reliability of Future Climate Change Projection by High-Resolution Climate Models”
10) Takahashi, K.: Global Environmental Research, 10, 243-252 (2006)
“Impacts of global warming on agricultural production and adaptations in response”
11) Shiogama, H., N. Christidis, J. Caesar, T. Yokohata, T. Nozawa, and S. Emori: SOLA, 2, 152-155, doi:10.2151/sola.2006-039 (2006)
“Detection of greenhouse gas and aerosol influences on changes in temperature

extremes”

12) Yokohata, T., S. Emori, T. Nozawa, T. Ogura, N. Okada, T. Suzuki, Y. Tsushima, M. Kawamiya, A. Abe-Ouchi, H. Hasumi, A. Sumi, M. Kimoto, Geophys. Res. Lett., 34, L02707, doi:10.1029/2006GL027966 (2007)
“Different transient climate responses of two versions of an atmosphere-ocean coupled general circulation model”

13) Hasegawa, A. and S. Emori: Geophys. Res. Lett., 34, L05701, doi:10.1029/2006GL028275. (2007)
“The effect of air-sea coupling in the asessment of CO2-induced intensification of tropical cyclone activity”

14) Takahashi, K., Honda, Y. and Emori, S.: Journal of Risk Research, 10, 339-354 (2007)
“Assessing mortality risk from heat stress due to global warming”

15) Kiktev, D., J. Caesar, L. Alexander, H. Shiogama, and M. Collier: Geophys. Res. Lett. (2007)
“Comparison of observed and modeled trends in annual extremes of temperature and precipitation using the results of several climate models” (in press)

16) Shiogama, H., T. Nozawa, and S. Emori: Geophys. Res. Lett. (2007)
“Robustness of climate change signals in near term predictions up to the year 2030: Changes in the frequency of temperature extremes” (in press)