B-061 Qualitative Assessment and Prediction of Asian Monsoon Change Induced by Human Activities（Abstract of the Final Report）

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[Abstract]

In the past 50-100 years, the summer monsoon rainfall shows some increasing trends in east Asia and part of south Asia, but this tendency is not clear for the whole of the Asian monsoon region. These observational results, combined with those from the CGCM experiments forced by GHG increase and aerosol forcings, have suggested that the enhancement of the monsoon rainfall induced by GHGs and suppressed monsoon rainfall by the aerosol forcings are likely to be antagonistic to each other, but their polarity was opposite. We found that the twentieth-century precipitation trend remote from the anthropogenic aerosol emission source had a large projection onto the principal mode of natural variability. The impact of increased greenhouse gases and anthropogenic aerosols tended to appear as a modulation of the natural variability.

Aerosol processes are important to consider for precise evaluations of changes in Asian monsoon precipitation in the twentieth century. To assess the impact of aerosol forcing more precisely, a new chemistry-aerosol model including process of nitrate aerosols has been developed. A numerical model experiment for reproducing the past (preindustrial) and the present and the past radiative forcings showed strong cooling effects (-1 W m^{-2}) due to increase in nitrate aerosols and strong heating effects (+0.5 to +1 W m^{-2}) due to decrease in SOA particularly in India and Bangladesh

The impacts of the historical land cover/use changes during the pre-industrial period (1700-1850) on the Asian monsoon climate were investigated by using a global climate model (GCM). Monsoon rainfall decreased because of the reduced vapor convergence resulted from the reduced surface wind induced by the small surface roughness of cultivated land. The rainfall decrease qualitatively and quantitatively agreed with the long-term rainfall variation estimated from analysis of the ice-core in the Himalayas. Cultivation also induced a remarkable surface dryness in spring over Indian subcontinent, which could be related to the late onset and the early

retreat of Asian monsoon. The experiments using a regional cloud-resolving climate model have shown that cultivation in Indochina peninsula enhanced surface heating and hence precipitation, and that irrigation along Yellow River restrained cloud formation by surface cooling. The low-resolution RCM experiments have revealed that the position of the Baiu Polarfrontal Zone (BPZ) was considerably affected by the land use change.

1. Introduction

Prediction of climate change due to the anthropogenic forcings of greenhouse gas increase has been an urgent and important issue for us human beings. IPCC-AR4 report has been issued very recently, where temperature change is a matter of great concern for many of the countries and people living on the earth.

However, prediction of change of Asian monsoon system, including the human impacts is an urgent and important issue, when we consider the current situation of huge population and economic & agricultural activities in monsoon Asia, though prediction of Asian monsoon change and variability is one of the most challenging issues.

World Climate Research Programme (WCRP) has proposed the monsoon prediction as one of the most important items. A new integrated project on modeling & prediction on change and variability of the Asian monsoon system may be urgently required, based upon the recent observational studies of GAME, INDOEX, ABC and ACE-Asia, and modeling studies related to the IPCC-FAR.

2. Research Objectives

Based upon these scientific and societal backgrounds, we focus the objectives of this study as follows:

1) To quantitatively assess human impacts on changes of Asian monsoon rainfall and water cycle in the last several decades (or more), based on comprehensive data analyses and modeling studies using various state-of-the-art climate models. Three major components of the human impacts are specified as follows:

a. increase of global-scale greenhouse gas (GHG)
b. changes of aerosol parameters in Asia
c. changes of land use/land cover (LULC) and vegetation in Asia

2) To quantitatively assess relative importance of single or multiple components for future projection of monsoon changes, and to predict future changes based on several scenarios of changes in the single or multiple components.

The four sub-themes are set for implementing the research as follows;

Theme 1: Detailed analysis of Asian monsoon precipitation in the past several decades
Theme 2: Assessment and prediction of Asian monsoon change due to greenhouse gases and aerosol forcings by climate models
Theme 3: Detailed assessment of aerosol forcings on the Asian monsoon climate based

on chemistry-aerosol climate model experiments

Theme 4: Assessment of Asian monsoon climate change induced by "LULC changes" using climate models

Theme 5: Integrated assessment of these four themes

The strategic framework of this study based on these five themes is illustrated in Figure 1.

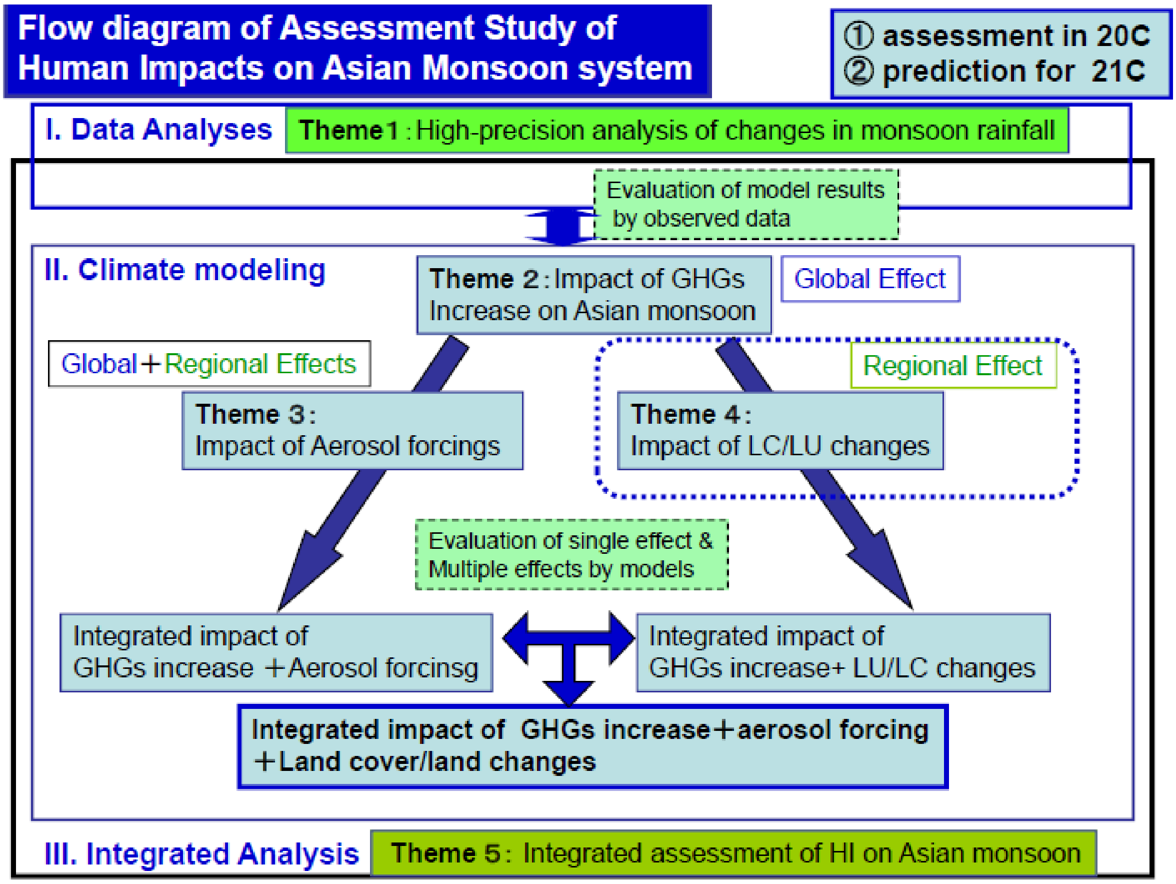

Fig. 1: Flow diagram of assessment study of human impacts on Asian monsoon system

3. Research method

Detailed analysis of Asian monsoon precipitation changes

By utilizing monthly grid dataset "VASclimO" (Variability Analysis of Surface Climate Observations) prepared by the GPCC (Global Precipitation Climatology Centre) Project under the WCRP, long-term trends of warm season seasonal and monthly precipitation over Asian monsoon region for the period 1951-2000 are analyzed.

(1) Assessment and prediction of Asian monsoon change due to greenhouse gases and aerosol forcing

The future projection of the Asian monsoon has been conducted by using atmosphere-ocean coupled models, which take into account anthropogenic influences (i.e., green house gas increase and aerosol change).

(3) Detailed assessment of aerosol forcings on the Asian monsoon climate based on chemistry-aerosol climate model experiments

The effects of various aerosols on the Asian monsoons are investigated using a chemistry-aerosol climate model.

(4) Assessment of Asian Monsoon climate change induced by "LULC changes" using climate models

Impacts of the land use change on Asian Monsoon are evaluated quantitatively and qualitatively by specifying historical land use data to climate models (AGCM and regional climate models)

(5) Integrated analysis using observational data and model outputs.

By using the observational data analysis outputs from subgroup 1 and model outputs from groups 2, 3 and 4, integrated analysis will be made to understand dynamics of human-induced precipitation change in the past centuries. The results of this part are included in the discussion.

4. Results of research

Detailed analysis of Asian monsoon precipitation changes

By utilizing several existing gridded precipitation datasets, similarities and differences of the past rainfall trend and its seasonal and regional characteristics in Asian monsoon region during the past century have been analyzed among several existing datasets. The new dataset has been also constructed by compiling the original data obtained from each meteorological agency in Asian countries. The differences are generally small in India and/or China, while relatively large differences have been observed over Indochina where the original data seem to be poor in the existing datasets. As a long-term trend of precipitation changes, the increasing trend has been detected in the southeastern part of the Tibetan Plateau, Bangladesh, and the Yangtze River Basin in summer monsoon season. Since significant changes have been observed in India during spring and summer, the detailed analyses have been conducted in Indian region. As a cause for the long-term rainfall trend, the weakening of westerlies in the Arabian Sea region in summer and the changes of intraseasonal changes in spring have been pointed out. Minute daily meteorological data in the Philippines during the period 1901-1940 have been discovered in this study and some of the data including typhoon tracks have been digitized, and the long-term changes in precipitation characteristics, onset of rainy season, typhoon land falls have been analyzed. The onset of summer rainy season has been delayed recently, and its inter-annual variations have become larger since the 1980s. The number of typhoon landfalls over the Philippines showed multi-decadal variations and no long-term trend has been found.

(1) Assessment and prediction of Asian monsoon change due to greenhouse gases and aerosol forcing

We investigated the long-term trend in summertime Asian monsoon precipitation using an atmosphere-ocean coupled model, and identified the main factors influencing precipitation trends during the twentieth century. From an analysis of four kinds of experiments with different external forcings, we obtained the following conclusions:

- The effects of anthropogenic aerosols and greenhouse gases dominated the summertime precipitation trend during the twentieth century.
- The amplitude of the effect of anthropogenic aerosols on the precipitation trend over the Asian monsoon area is comparable to that of greenhouse gases, but opposite in sign.

There are two kinds of precipitation response to the external forcings; one is due to the local SST change near the aerosol emission source in East Asia, and the other is modulation of the natural variability at lower latitudes of the Asian monsoon region over the tropical Indian Ocean and the subtropical western Pacific.

(3) Detailed assessment of aerosol forcings on the Asian monsoon climate based on chemistry-aerosol climate model experiments

To clarify the effects of various aerosols on the Asian monsoon climate, we developed a chemistry-aerosol climate model, performed numerical model experiments with the model, and obtained the following results. 1) We reformed schemes of aerosol and cloud formation processes in the aerosol climate model SPRINTARS. We also constructed database of emissions of aerosols or aerosol source gases on the basis of available data, with focus on the East Asia region. 2) We improved schemes of the formation processes of the aerosols deeply related with atmospheric chemistry such as nitrate aerosols (NO_3^-) (nitrate is considered to increase in concentration more than sulfate in Asia in the future) by introducing an aerosol thermodynamic equilibrium module for SPRINTARS to couple with a chemistry climate model CHASER, and developed a chemistry-aerosol climate model. Our simulation shows that there are anomalously high concentrations of nitrate aerosols in South Asia, particularly around India, coming from abundant ammonium and less sulfate in this region. In India, tropospheric mixing ratio and number concentration of nitrate are both larger than those of sulfate in winter to early summer. This result suggests that nitrate aerosols may play an important role in the observed changes in the Asian monsoon climate. 3) Organic aerosols as well as sulfate and nitrate aerosols may dissolve into water to work as cloud condensation nuclei. Secondary organic aerosols (SOA) that are produced by oxidation of biogenic organic carbons emitted from vegetation may change in concentration with land use changes. To perform numerical model experiments on how the change in SOA affects the Asian monsoon climate, we constructed a database of SOA emissions from vegetation in cooperation with the sub-theme 4. 4) To clarify the effect on climate of the changes in nitrate aerosols and SOA associated with land use change, we performed numerical model experiments of reproducing the past (preindustrial) and the present to estimate the radiative forcings. The experiments clarified that strong cooling effects ($-1\ W\ m^{-2}$) due to increase in nitrate aerosols and strong heating effects (+0.5 to +1 W m^{-2}) due to decrease in SOA may have occurred in South Asia mainly India and Bangladesh

(4) Assessment of Asian Monsoon climate change induced by "LULC changes" using climate models

The impacts of land cover/use changes in the pre-industrial period (1700-1850) were examined by the GCM experiments with the historical land cover/use data. Monsoon rainfall was shown to decrease because of the reduced vapor convergence resulted from the small deceleration of surface wind due to the small surface roughness of cultivation (Fig. 2). The rainfall decrease agreed, qualitatively and quantitatively, with the long-term rainfall variation estimated from analysis of the ice-core in the Himalayas(4-6). Cultivation also induced a remarkable surface dryness in spring over Indian subcontinent, which could be related to the late onset and the early retreat of Asian monsoon. Besides, a time series of global leaf biomass distributions in 1850-1992 was estimated, in preparation to investigate compounded effects of the land cover/use changes and the changes in aerosol emission that proceeded from that.

The decreasing trend in September precipitation in Indochina peninsula in the last 30 years was shown to have correlation with the number of tropical cyclones, rather than land cover/use change, from analysis of the global reanalysis data (Takahashi and Yasunari, 2008) and from the high-resolution RCM experiment (Fig. 3). The characteristic cloud distribution in the irrigated area in semi-arid region along Yellow River was shown by the high-resolution satellite data. The cloud-resolving RCM experiment revealed the local circulation induced by the horizontal temperature gradient due to the land cover/use change (irrigation) produced the observed cloud distribution (Fig. 4; Kawase et al., 2008).

By conducting sensitivity experiments of land use change with the low-resolution RCM, it was shown that the position of BPZ was considerably shifted according to the land use change. The long-term trend of BPZ in the last 30 years was successfully reconstructed by the pseudo climate simulations using the RCM. In addition, it is shown that the uncertainties in the climate projections by GCMs could be notably reduced by using the pseudo climate simulation method.

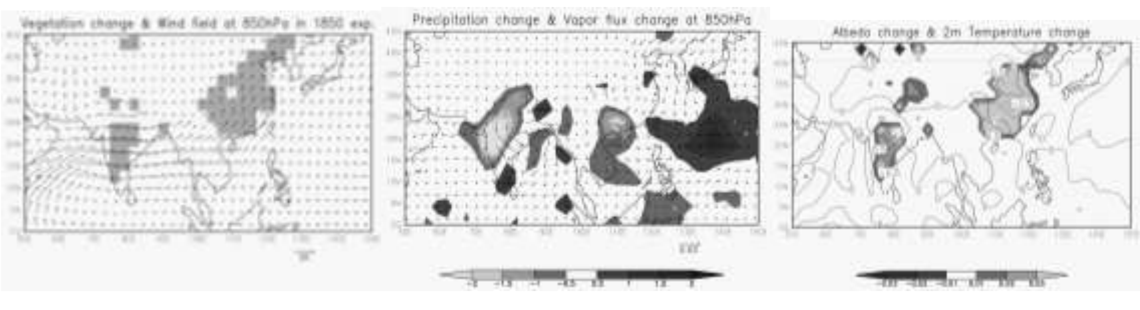

Fig. 2 Left panel shows summer mean 850 hPa wind field (vectors) in 1850 experiment and land cover/use change from 1700 to 1850 (shades). Middle panel shows summer mean precipitation

changes (shades) and vapor flux changes (vector). Right panel shows summer mean albedo changes (shades) and surface air temperature change (contours).

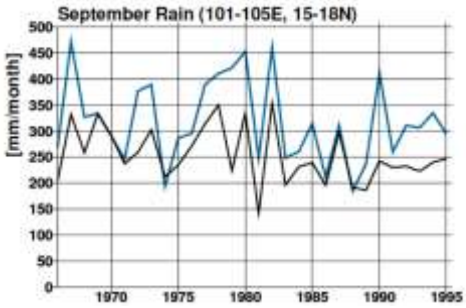

Fig. 3 30-years September precipitation in Indochina peninsula. Model result (gray line) and observation (black line).

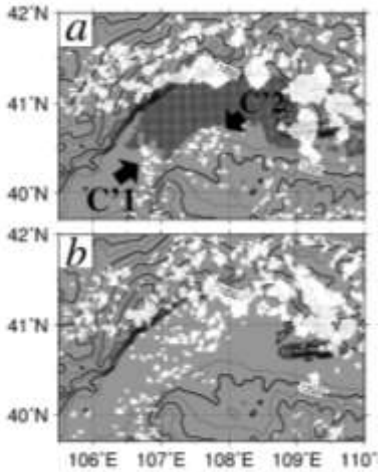

Fig. 4 Simulated cloud distribution at 2 p.m. (a) in irrigated experiment and (b) in dry experiment.

5. Discussion and remarks

Integrated assessment of these four themes have been made based on the results obtained through theme one to four, and some new aspects are noticed as follows;

1) In the past 50-100 years, the spring and summer monsoon rainfalls show some increasing trends in east Asia and part of south Asia, which are related to weakening of westerlies in the Arabian Sea in summer and the changes of intraseaonal variations in spring. Relatively large differences among the existing datasets have been found in the long-term changes of precipitation in Southeast Asia; therefore, the usage of these global datasets for the long-term climatic changes may cause a problem on the data quality. In the Philippines, the delay and the growing of the interannual variations of summer rainy season onset have been found to be the recent significant changes in monsoon seasonal changes.
2) The results, combined with those from the CGCM experiments forced by GHG

increase and aerosol forcings, have suggested that the enhancement of the monsoon rainfall induced by GHGs and suppressed monsoon rainfall by the aerosol forcings are likely to be antagonistic to each other. This also may imply that the aerosol forcings are as equally important as those of GHGs for Asian monsoon change. We also have noticed that the aerosol forcing is particularly important over land areas, while the GHG forcing is more concentrated over ocean areas.

3) The impact of LCLU changes since 1700 on the global climate is particularly significant in the 1700 to 1850 in the pre-industrial period, when the forcings of GHGs and anthropogenic aerosols were negligible. The overall effect of forested condition in the 18th century was enhancement of Indian summer monsoon rainfall. This is partly evidenced by the ice-core study of the Himalayas. The impacts have proved to appear more significantly in the tropics (e.g., India) compared to mid-latitudes (e.g., central to north China).

4) The effect of vegetation change on local rainfall or hydro-climate (represented by Indo-China monsoon region) has proved to be more complicated, depending upon the large-scale atmospheric circulation, orographic condition, surface wetness (dryness). Further modeling studies including cloud-resolving models may be required.

5) To assess the impact of LCLU on precipitation, the role of moisture convergence and evapopranspiration need to quantitatively be estimated using surface and atmospheric energy and water budget analysis.

6) A numerical model experiment on the effect of aerosols of nitrate and SOA has suggested that a combined effect of LCLU changes and aerosol forcings will be important particularly for south Asian monsoon region. This aspect needs to be examined further using the newly-developed aerosol chemistry-climate model.

Major Publications

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2) Endo, N., J. Matsumoto, N. Yamamoto and A. Fukushima (2007), Long-term change of precipitation and its characteristics in the world. Journal of Geography, 116: 824-825 (in Japanese with English Abstract) .

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7) K. Saito: J. Geophys. Res. 113, D21106, doi:10.1029/2008JD009880 (2008), "Arctic Land Hydro-thermal Sensitivity under Warming: Idealized Off-Line Evaluation of Physical Terrestrial Scheme in Global Climate Model"

8) K. Saito: Proc. 9th International Conference on Permafrost, 1555-1560 (2008), "Refinement of Physical Land Scheme for Cold-region Subsurface Hydro-thermal Processes and its Impact on Global Hydro-climate"

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