

Water Resources of the South Asian Region in a Warmer Atmosphere

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ABSTRACT

The global mean surface temperature may rise by about 0.3°C per decade during the next few decades as a result of anthropogenic greenhouse gas emissions in the earth's atmosphere. The data generated in the greenhouse warming simulations (Business-as-Usual scenario of IPCC) with the climate models developed at Max Planck Institute for Meteorology, Hamburg have been used to assess future plausible hydrological scenario for the South Asian region. The model results indicate enhanced surface warming (2.7°C for summer and 3.6°C for winter) over the land regions of South Asia during the next hundred years. While there is no significant change in the precipitation over most of the land regions during winter, substantial increase in precipitation is likely to occur during summer. As a result, an increase in soil moisture is likely over central India, Bangladesh and South China during summer but a statistically significant decline in soil moisture is expected over central China in winter. A moderate decrease in surface runoff may occur over large areas of central China during winter while the flood prone areas of NE-India, Bangladesh and South China are likely to have an increase in surface runoff during summer by the end of next century.

Key words: Global warming, Climate change, Regional impacts, Hydrology of South Asian region, Surface runoff and soil moisture

1. INTRODUCTION

The world faces unprecedented global warming with potentially disastrous effects largely as a result of combustion of fossil fuels, deforestation and extensive land use. The global surface temperature will rise by 0.3°C per decade (with an uncertainty range of 0.2 to 0.5°C), during the next few decades, if human activities which cause greenhouse gas emissions continue unabated (IPCC, 1990). This greenhouse gas-induced warming of the earth-atmosphere system is likely to alter water resources, their distributions in space and time, the hydrological cycle of the water bodies, water quality and requirements for water resources in different regions. Quantitative estimates of hydrological effects of climate change on regional scale are essential for understanding, planning and management of future water resources.

A numerical modelling approach seems a reliable way to assess the future climatic change that may result from the increased concentration of CO_2 and other greenhouse gases (GHGs). The evolution of changes in surface meteorological as well as hydrological parameters during the course of transient numerical experiments with the current state-of-the-art coupled climate models at leading research centres in the world have exhibited a number of similar global and regional features in their response to increasing GHGs in the atmosphere (IPCC, 1992). These transient experiments hold much promise for a better understanding of the simulation of interannual variability of climate and its change on regional scale for developing adaptive response strategies.

The vulnerability of the South Asian subcontinent to the impact of changing climate is vital for large population that ekes out a living at bare subsistence level from degraded land areas. An assessment of future changes in the mean and/or variances of hydrological parameters due to an anthropogenic increase of GHGs is much warranted for South Asia which is weak and deficient in infrastructure to deal with crises and adverse impacts to its development programmes that may have to be faced as a result of global warming.

The numerical experiments performed with the coupled ocean-atmosphere climate model (horizontal resolution is $\sim 600 \text{ km} \times 600 \text{ km}$ at T21) developed at Hamburg are able to provide projections of the possible perturbations in the key climatic elements in time scales of upto 100 years (Cubasch et al., 1992) for future greenhouse gas emission scenarios (scenario *A* in which future emissions of GHGs are allowed to increase unrestricted and scenario *D* expected through a set of stringent abatement policies for future emissions) as outlined in the report of the Working Group 3 of the Intergovernmental Panel on Climate Change (IPCC, 1990). Recent numerical experiments with the Hamburg climate model at T42 resolution have demonstrated that a finer horizontal resolution ($\sim 300 \text{ km} \times 300 \text{ km}$) in the model coupled with refined parameterization of cumulus convection produces distinct improvements in the spatial distribution of rainfall over the Indian subcontinent (Lal, 1993). The results of the analysis of the data generated in the reference control experiment with this climate model on seasonal as well as annual scale in simulating the present-day hydrological parameters over the Indian subcontinent are encouraging (Lal & Chander, 1993). A plausible future hydrological scenario for the South Asian region based on the numerical results obtained from greenhouse warming simulation (Business-as-Usual scenario of IPCC) with the Hamburg climate model is presented in this paper.

II. THE MODEL

The Hamburg coupled climate model {atmospheric component is version 1 of European Community HAMburg model (ECHAM1)+oceanic component is Large Scale Geostrophic ocean model (LSG)} developed at Max Planck Institute for Meteorology (MPIM) in Hamburg has demonstrated substantial skill in the simulation of characteristic features of the Asian summer monsoon as well as the broad circulation features over the Indian subcontinent (Lal et al., 1993). The horizontal resolution in the coupled climate model (ECHAM1+LSG) at T21 resolution (5.625° in latitude and longitude) is, however, typically too coarse to provide confident regional scale information on climate change required for impact analysis. The control and greenhouse warming simulations carried out with the coupled climate model provided the sea surface temperature (SST) forcings for a set of recent numerical experiments with the version 3 of the ECHAM model which has a horizontal resolution of 2.81° in latitude and longitude (T42) and employs a comprehensive mass flux scheme for cumulus convection. The present-day mean hydrological parameters are inferred from the ECHAM3 model experiments using the global climatological SST forcing while the future projections of hydrological parameters are inferred from the experiment using the global SST forcing (average of years 2075–2084) obtained from 100 year's climate change integration with T21 coupled climate model under IPCC's scenario *A* conditions. The model output generated from ECHAM3 simulations following a time-slice method (Perlwitz et al., 1992) provide a realistic account of the present-day global annual hydrological cycle (as compared to the observations). For further details on the description of the models and the experiments, reader is referred to Cubasch et al. (1992), Perlwitz et al. (1993) and MPI (1992).

III. RESULTS

The South Asian region selected for this study is bounded by latitudes 10°S – 40°N and longitudes 60°E – 140°E . The study area has a total of 504 grid points (195 on land and 309 over the ocean). We have analysed the data from the reference control and greenhouse warming experiments (mean of 10 year's integration) for annual mean conditions as well as for the two seasons namely winter (December to February) and summer (June to August) for validation of the regional scale model-simulated hydrology and the assessment of future change in the hydrology of the region the findings on which are discussed here.

IV. HYDROLOGY OF THE REGION: THE CONTROL EXPERIMENT

In a previous study, it has been shown that the ECHAM3 model simulation is capable of reproducing the observed spatial distribution of summer monsoon precipitation rate over India (Lal, 1993). In terms of the total annual and seasonal precipitation, the model is, however, able to produce only about 75% of the observed rainfall. As observed in climatological records, the northern summer monsoon sets in during May over Thailand and South China and during June over South India in the reference control simulation.

Evaporation and soil moisture over the land surface have a significant control on ecosystems, agriculture and water resources. None-the-less, these are the most complex hydrological parameters in the physics of the model and more so over the monsoon region with its varied topography and complex interactions between the land and the oceans in the region. The maps for mean annual soil moisture and the first harmonic of seasonal changes for the South Asian region (Willmott et al., 1985) show that the time of maximum wetness here is in the mid-to-late summer. When compared with the Mintz and Serafini's (1981) observational estimates, the control experiment with the ECHAM3 climate model has been able to faithfully reproduce the observed features of the annual and seasonal spatial distribution of surface evaporation over the South Asian region. The model-simulated spatial distribution of soil moisture over the region is also in fair agreement with the observed climatology of Mintz and Serafini (1989).

About 40% of the precipitation reaching the surface over the Asian continent makes its way towards streams, lakes and oceans as surface runoff and forms an important component of the water resource potential of a region. The model-simulation of the general features of the seasonal cycles of surface runoff (in terms of units of discharge computed based on monthly runoff data at selected grid boxes) for the Brahmaputra / Ganges and Indus river basins is in fair agreement with the climatological river gauge data.

These results demonstrate that the Hamburg climate model has a skill in simulating the present-day hydrometeorological parameters and its interannual variability over the study region.

V. EFFECT OF GREENHOUSE WARMING ON REGIONAL HYDROLOGY

The results from greenhouse warming simulation of the Hamburg climate model suggest a rise in annual mean surface air temperature of about 1.0 to 2.5°C over ocean and between 2.0 to 4.5°C over the land regions of south Asia during the next hundred years. This warming is likely to be most pronounced over the northwest margins of India (Thar Desert). During the NH-winter, the surface warming in the land regions of India and China is considerably higher (2.5 to 4.5°C) than during the NH-summer (1.0 to 3.0°C). No significant seasonal changes in the surface warming over the oceans are simulated (Fig. 1). The significant

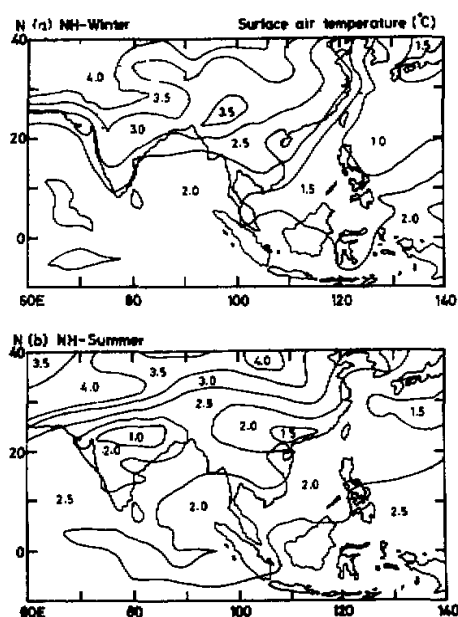


Fig. 1. Model-simulated rise in seasonal surface air temperature (°C) expected over South Asia by the year 2080.

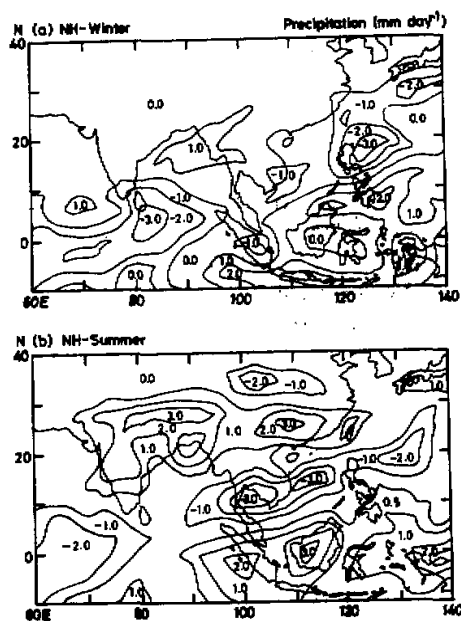


Fig. 2. Seasonal changes in rainfall over South Asia expected due to greenhouse warming.

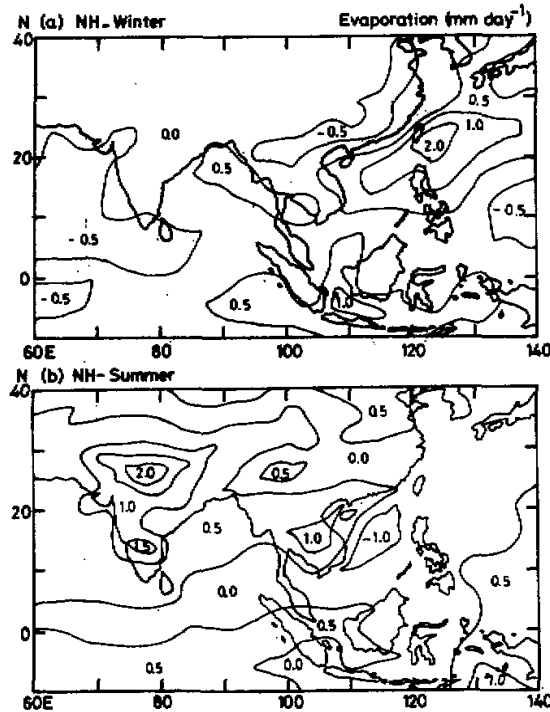


Fig. 3. Seasonal changes in surface evaporation over South Asia as inferred from the model simulation.

consequence of higher surface temperatures could be expected on the rainfall distribution of the region. In IPCC's scenario A, the model simulates an increase in total (averaged for the land points over the study area) annual precipitation of about 16 cm per year. This increase in annual precipitation is largely due to enhanced rainfall over central and north-east India, Bangladesh, South China and Indonesia. In a warmer atmosphere, the monsoon trough over India is likely to advance further northward as a result of an enhanced ocean-continent pressure gradient during NH-summer (itself a consequence of more intense warming of the land surface). If it were to occur, the monsoon rainfall could increase over the central plains of the India as is indeed observed in the model-simulated change in precipitation during the NH-summer (Fig. 2). An increase in precipitation is also expected over Bangladesh, Indonesia, Malaysia and South China during NH-summer (statistically significant at 90% confidence level) while a decline in rainfall is likely over Thailand. The spatial distribution of changes in precipitation over the study area during NH-winter and NH-summer seasons is depicted in Fig. 2. During NH-winter, a marginal decrease in precipitation might be expected over southern peninsular India and north Phillipines.

The saturation vapour pressure of water increases nonlinearly with temperature so that, at higher temperatures, proportionately more of the increase in radiative heating of the surface is used to increase evaporation. The model simulation under enhanced greenhouse conditions suggests a moderate increase in surface evaporation over the land regions of

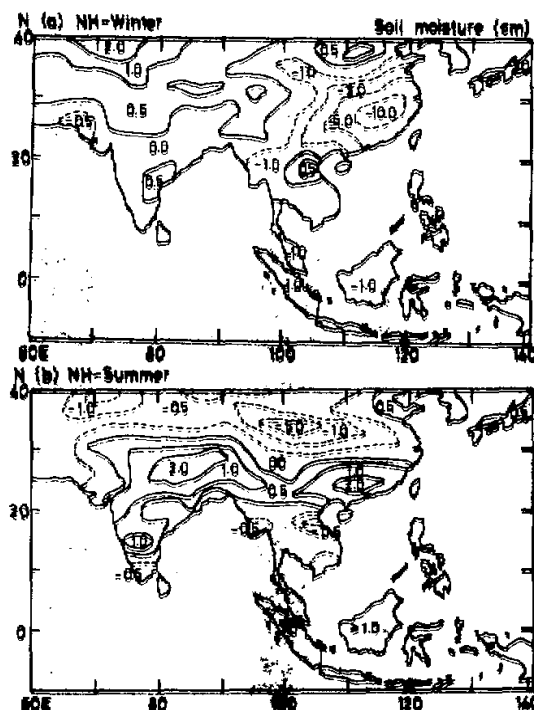


Fig. 4. Model-simulated seasonal changes in soil moisture over south Asia expected due to greenhouse warming.

South Asia on an annual mean basis. During the NH=summer season, no significant change in evaporation is simulated over the oceanic regions. However, substantial increase in surface evaporation is simulated over parts of central India during the NH=summer season (Fig. 3). The model results indicate enhanced soil wetness over India for annual mean conditions. The area-weighted annual mean soil moisture over the study area is likely to go up by about 5% by the year 2080. Also, a decline in soil moisture could be expected over central China. This depletion in soil moisture is statistically significant at 90% confidence level during the NH=winter. During NH=summer (Fig. 4), an increase in soil moisture is possible over central India, Bangladesh, South China, Indonesia and Malaysia. However, the soil wetness is likely to decline over North China during NH=summer. This depletion of soil moisture may reduce evapotranspiration as well as boundary layer convergence in this region such that less rainfall is likely here during the monsoon season.

The major river systems over the South Asian region are largely still unregulated and, therefore, most vulnerable to hydrometeorological change associated with the greenhouse warming. The mean annual increase in surface runoff over the study area simulated by the model for the year 2080 is about 15%. Much of this increase in surface runoff is largely confined to northeast India, South China and Indonesia. During NH=summer, a significant increase in runoff over northeast India, Bangladesh and South China is likely under enhanced greenhouse conditions (Fig. 5). A decline in surface runoff is also possible over North China and Thailand. No significant change in surface runoff during NH=winter is simulated by the

model over the study region. A marginal decrease in surface runoff is, however, likely over central China.

Fig. 6 depicts a plausible scenario of the greenhouse gas-induced temperature change (seasonal means) expected over the South Asian region as available from a recent climate model simulation and the associated impacts on hydrometeorological parameters. This scenario is only a broad picture of what the changed climate might be like in 2080 AD. Given the uncertainties in current model predictions, these should primarily be useful only for appropriately flexible planning strategies.

VI. CONCLUSIONS

The model results clearly indicate an enhanced surface warming over South Asia by the end of next century under scenario *A* (Business-as-Usual) of the *Intergovernmental Panel on Climate Change*. The net effect of this warming is to increase the precipitation and hence runoff in flood-prone areas of the northeast India and South China during summer season, with no substantial change during winter. The model also indicates a marginal decrease in summer precipitation and, therefore, runoff over North China.

The current estimates on the impact of global warming on regional scale have low confidence due to disagreement between various general circulation model results. The control simulations of coupled climate models still contain a number of systematic errors in comparison to the observed climate and the causes of these deficiencies are being explored.

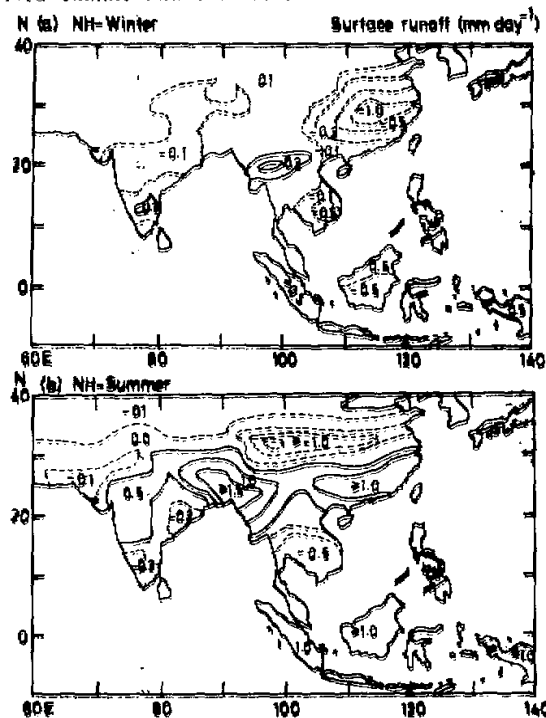


Fig. 5. Model-simulated seasonal changes in surface runoff over South Asia expected due to greenhouse warming.

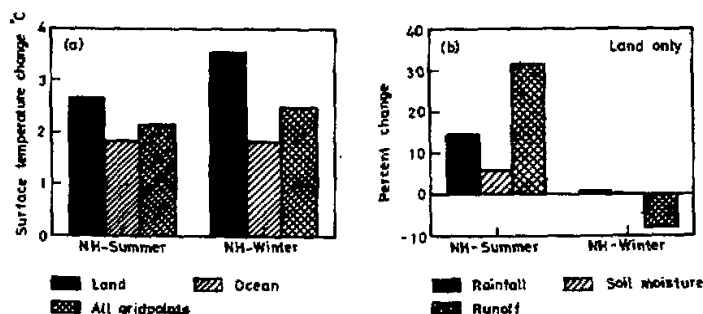


Fig. 6. Area-weighted changes in seasonal mean surface air temperatures (a), and precipitation, soil moisture and surface runoff (b, in percent) simulated by the model for the South Asian region.

The subgrid scale physical processes (in particular cloud feedback) could contribute further to the uncertainty in the simulation of the regional climate.

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