Global Warming and Atmospheric Brown Cloud Effects on Local Climate and Rice Production

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Background

Rainfall observations in Sri Lanka have shown a consistent decrease of rainfall during the inter-monsoon rain period from February to April since early 1970's. Herath and Ratnayake (2003) analyzed the South-West Monsoon (swm) from May to September, the North East Monsoon (nem) from December to February, the First Inter-Monsoon (fim) defined from March to April and the Second Inter-Monsoon (sim) from October to November rainfalls of 62 rain gauges selected from the central region covering the period from 1963-1993. The analysis has shown that the rainfall of all the gauges had a decreasing rainfall trend for the first inter-monsoon season from March to April. The anecdotal evidence from farmers and residents in the region also confirms the changes in the weather during the past 30 years. An analysis of the causes for this decrease has pointed to the possible links of rainfall decrease to the Atmospheric Brown Cloud that forms over the region due to high concentration of aerosols in the atmosphere.

Introduction

Since beginning of the 1980s climate change due to global warming has attracted much attention as a threat to agriculture. Many climatologists predict significant global warming in the coming decades due to increasing concentration of CO_2 and other trace gases (green house gases) in the atmosphere. The CO_2 concentration has been projected to increase to 670 to 760 μmol mol^{-1} by the year 2075 mainly due to continued burning of fossil fuel (Rotty and Marland, 1986).

Besides global warming, it has been recognized and experimentally observed by an international study, the Indian Ocean Experiment, or INDOEX, that there is a thick layer of haze hovering over the Asian region, prevalent in the dry season from December to April. Named as the Atmospheric Brown Cloud, it covers most of the tropical Indian Ocean bounded approximately between the latitudes 25°N and 5°S, and spreads over an area far beyond the sources of pollution. Preliminary findings point to the conclusion that biomass burning plays a major role in gaseous pollution such as carbon monoxide while fossil fuel combustion and biomass burning contribute to particulate (aerosol) pollution. Based upon limited observational data and GCM simulations, the following undesirable effects have been attributed to the Asian Brown Cloud (UNEP, 2002):

- Disturbance to the solar radiation balance
- Reduction of surface temperature leading to surface cooling which can have implications to the hydrological cycle and to agriculture
- Perturbation of the hydrological cycle - Reduction of total mean evaporation and therefore seasonal precipitation.
- Reduction of agricultural productivity- Reduction of photosynthesis as a result of decreased solar radiation reaching the surface leading to reduction in agricultural productivity.

The aerosol affects the incoming short wave radiation while the effects on the outgoing long wave radiation can be neglected. Therefore the effects are different from the green

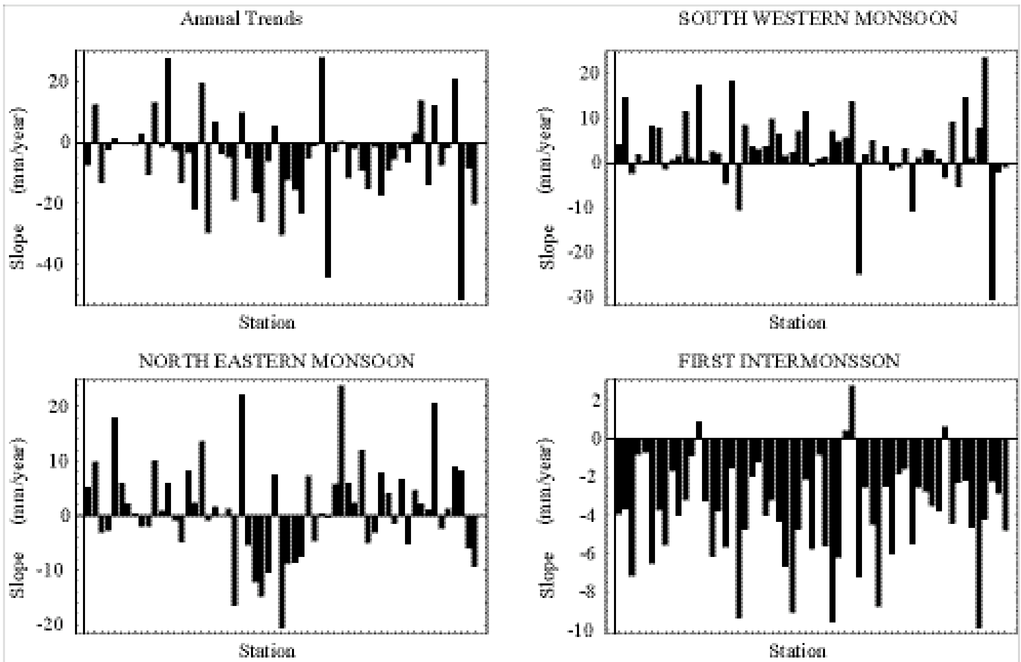

Figure 1. Rainfall trend gradient for 60 stations from 1963 to 1993 in Central Sri Lanka

house gasses, which mainly affect the outgoing long wave radiation. The energy absorption by the atmosphere can have a direct impact on the cloud formation and hence on the rainfall. The reduced temperature at the ground surface may affect the evapotranspiration that would adversely affect the long-term rainfall trends.

The effect of climate change due to global warming or seasonal appearance of ABC is a major concern to agriculture, particularly rice production in Asia, which accounts 80 to 90 % of world's production and consumption. Global warming will affect agricultural yield directly because of alterations in temperature and rainfall, and indirectly through changes in soil quality, pests, and diseases. In particular, the yield of food crops (Rice, wheat, Maize, etc.) is expected to decline in Asia and Africa. The most direct effect of ABC is a significant reduction in the solar radiation reaching the earth surface, reduction in the precipitation efficiency by inhibiting the formation of larger raindrop size particles; which results in reduction of agricultural productivity (UNEP, 2002).

Objectives

Motivated by the necessity of carrying out research on ABC effect on climate, and there by agriculture, following are the main objectives of the study.

- Investigate the mechanism of ABC
- Investigate the ABC impact on rice production and compare with the impacts on global warming

ABC impacts through rainfall downscaling

The immediate and long term effects of ABC would reduce the crop productivity due to reduced rainfall and radiation, and at the same time the changes to seasonal rainfall would affect other water using sectors of the country.

Modeling rice yield

CERES-rice is a dynamic crop model developed under the auspices of the International Benchmark Site Network for Agro technology Transfer Project (Uehara & Tsuji, 1993). This model based on vegetative and reproductive development, growth, water flow relationships, and soil, floodwater, and plant N dynamics (Singh, 1993; Godwin & Jones, 1991). The model simulates growth and development of a rice crop on the basis of physiological processes as determined by the crop's response to soil and aerial environmental conditions. It simulates water balance under fully flooded conditions, rain fed conditions with fluctuating water regime, and fully upland conditions where the soil is never flooded.

Methodology

a. Rainfall

Atmospheric aerosols may affect the rainfall in a number of ways. They are 1) Direct microphysical effects related to cloud condensation, 2) effects due to changes to the radiation budget due to absorption and 3) due to reduced atmospheric vapor as a result of radiation reduction on the ground. The descent of solar radiation down a clean layer of atmosphere is affected by 1) Raleigh aerosol scattering of air (Sc), 2) Layer vapor absorption (Lacis and Hanson, 1974) of air (Sa), 3) Reflection by clouds based on albedo (Scs) and 4) Absorption by clouds (Sca). The absorption of shortwave radiation due to (2) and (4) above is translated into layer temperature tendencies. The downwelling shortwave radiation per unit area at an altitude z can be expressed by

$$S_d(z) = \mu S_o - \int_z^{top} (dS_s + dS_a + dS_{cs} + dS_{ca}) \qquad (1)$$

where S_0 and m are the solar constant and the cosine of the solar zenith angle. We propose to parameterize the aerosol affects using four multipliers (FTOTABS, FXCA, for absorption and scattering of clear air and FABSC, FALBA for absorption and reflection from clouds, respectively). In this study we estimate the effects of radiation absorption by modifying the radiation forcing parameterization. The modification is done to satisfy the aerosol content to radiation absorption estimates made by the ABC science panel (UNEP and C^4, 2002).

The crop simulation model CERES (Crop Environment Resource Synthesis)-Rice of DSSAT (Decision support system for agro-technology transfer) v 4.0 was used for this study. The model was calibrated and validated with field experimental data of wet seasons (June-December) 2001 and 2002 for the rain fed agro-ecosystem at Cuttack ($20^0$28'N, $85^0$54'E), India. Experimental data on biomass, leaf area index and grain yield of two medium duration (120-125 days maturity) rice cultivar: "IR 36" and "Mahamaya" and two long duration (145-150 days maturity) cultivar: "Ranjit" and "Swarn" were used for calibration and validation of the model. The model was applied for grain yield simulation using a) Global warming scenario and b) ABC scenario

b. Global warming

Rice grain yield was simulated for fixed climate change scenarios due to global warming at Cuttack, India. The scenarios are a combination of five CO_2 levels (ppm): 360, 450, 540, 630, and 720 and four levels of rise in temperature (^{0} C): 0, 1, 2, and 4. The total climatic scenario combination was 5 (CO_2 level) x 4 (temperature level) =20. These 20 scenarios which include one normal (normal CO2 level and temperature) and 19 climate change scenarios were employed to historical weather data for grain yield simulation.

c. ABC

Simulations were conducted for the cases of with and without aerosol impacts at Kandy, Sri lanka. Only one aerosol level was considered and the parameterization of the Limited Atmospheric Model was adjusted to that the short wave radiation received at ground has a reduction of about 25%. The resulting data were accumulated at daily scale and the relationships between changes to short wave radiation at ground level, rainfall reduction due to ABC, changes to maximum daily temperature as a function of solar radiation was determined. The developed ABC scenario was deployed for grain yield simulation of cultivar Bg 301 in both "Maha" and "Yala" season rice cultivation in Sri Lanka

Sensitivity analysis

Sensitivity analysis was done to determine adaptation strategies like alternate planting date and cultivars selection for the purpose of mitigating the adverse impact of climate change on rice yield.

Results and Conclusions

Rainfall changes

The rainfall of Southern Sri Lanka covering roughly 2/3 of was simulated using 3 levels of nesting to obtain 4 km spatial resolution grid data (see Pathirana and Herath, [2004] for details). The simulation was carried out from Nov 2002 to July 2003 with outputs recorded at 10 min. intervals. Simulations were conducted for the cases of with and without aerosol impacts. The resulting data were accumulated at daily scale and the relationships between changes to short wave radiation at ground level, rainfall reduction due to ABC, changes to maximum daily temperature as a function of solar radiation were obtained.

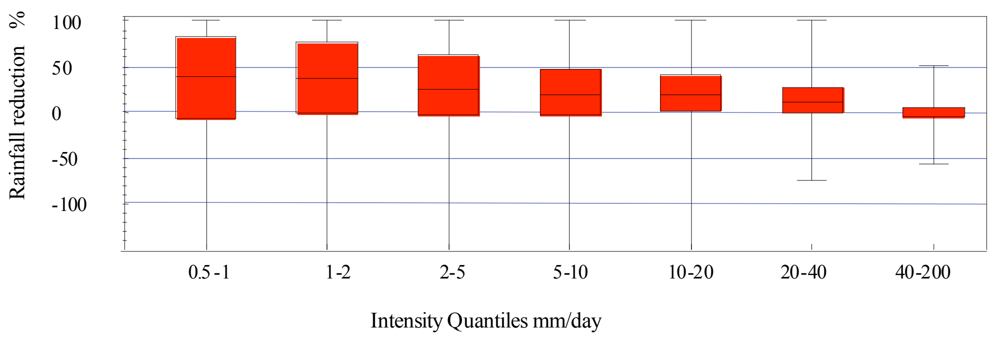

Fig. 2 Reduction of rainfall due to ABC impacts

Figure 2 shows the percentage reduction of rainfall obtained by comparing the rainfall scenarios with and without ABC impacts. Initially the rainfall data were analyzed with respect to 5 levels of rainfall intensities, and it was found that the effects were most significant for the low intensity rainfalls. As can be seen from the figure, the effects are most significant for small rains as observed during the period from mid February to mid May. Figure 3 shows the decrease of maximum temperature with ABC compared to non-ABC scenario. As can be seen, the difference is greater at lower solar radiation levels, but tends to reduce as the radiation level increases. Figure 4 shows the trend of minimum temperature with and without ABC influence. As can be seen from the figure, minimum daily temperature is affected to a very small degree and it is not influenced by the level of the radiation. Using these relations, climate data sets were created for with and without ABC influence cases in central Sri Lanka for the 2002 November to 2003 July period.

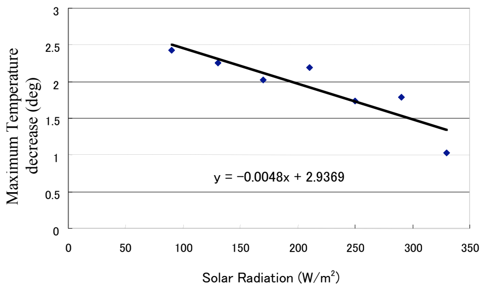

Fig. 3. Variation of daily maximum temperature with solar radiation

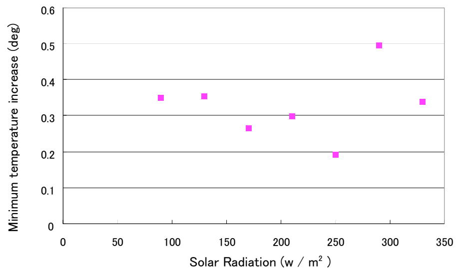

Fig. 4. Variation of daily minimum temperature with solar radiation

Rice yield

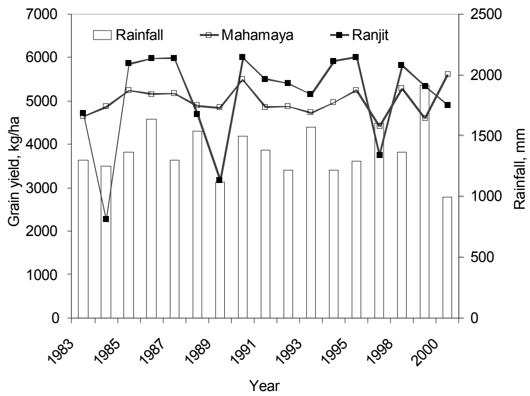

Fig. 5 Variation in simulated grain yield of cultivar Mahamaya and Ranjit and rainfall during the growing season in individual years during 1983-2000

The simulated grain yield of "Mahamaya" and "Ranjit" at 80 kg N/ha application in individual years (1983-2000) was compared with the amounts of rainfall received during the growing seasons (Fig. 5). Variation in grain yield of "Mahamaya" was in the range 4413 kg/ha during the year 1997 to 5606 kg/ha during the year 2000. "Ranjit" registered a larger variation in grain yield ranging from 2266 kg/ha during the year 1984 to 6015 kg/ha during the year 1995. Annual rain distribution, especially during the growing season affects the yield. Large variation in grain yield of "Ranjit" over years is related to low rainfall during the growing season.

Elevated CO_2 level has increased grain yield of both the cultivars "Mahamaya" and "Ranjit" (Fig. 6). Rise in temperature from 1 to 4^0C, decreased grain yield of

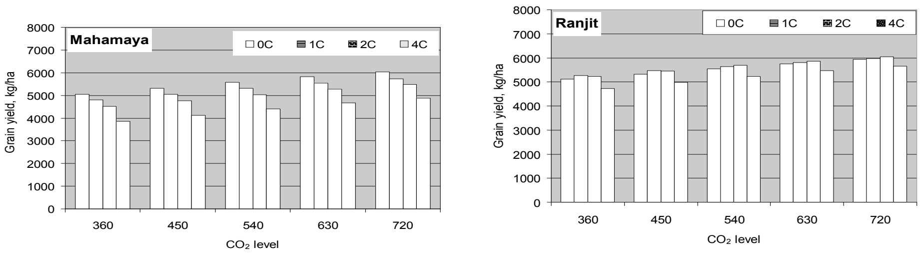

Fig. 6 Variation in simulated grain yield of "Mahamaya" and "Ranjit" with increased CO_2 level and rise in temperature (averaged over 1983-2000)

"Mahamaya". Whereas, grain yield of "Ranjit" was marginally increased with increasing temperature up to 2^0C, beyond which a decline in yield was simulated. Rise in temperature from 1 to 4^0C, shortened the phenological events like flowering and maturity days by 2 to 10 days in all the cultivars. In general, cultivar "Mahamaya" registered a decrease in grain yield by <2% and "Ranjit" registered an increase in grain yield by 6% with elevated CO_2 and temperature.

Rice grain yield under changing climatic scenario due to ABC for the agro ecology of Mid Country Intermediate Zone (MCIZ) of Sri Lanka was carried out. Rice is grown in this zone during both "Maha" (October – March) and "Yala" (April – September) seasons. The rice cultivar Bg 301 of 90 days maturity duration as a recommended variety for rain fed dry and intermediate zone in Sri Lanka was chosen for the study. Following

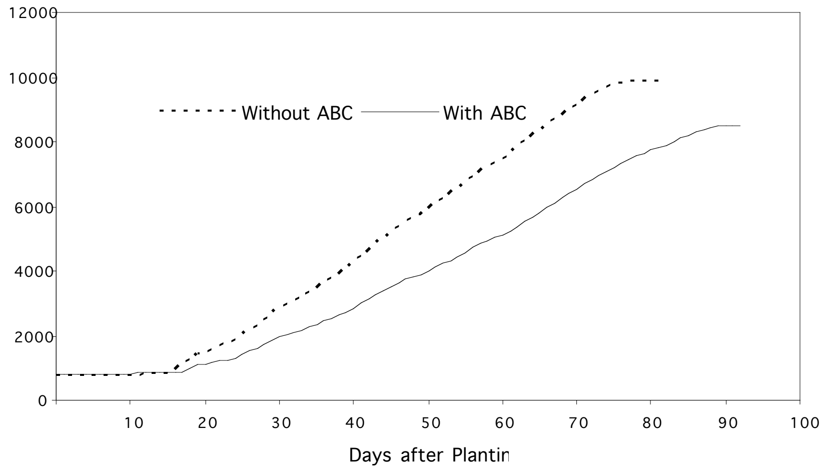

Figure 7 Biomass of rice variety Bg 301 as influenced by Atmospheric Brown Cloud (ABC) during "Maha" season of 2002-03 at Kandy, Sri Lanka

conditions were assumed in the simulation. The crop was planted on 15 December in

"Maha" season (2002-03) and on 15 April (2003) in "Yala" season using 15-20 days old seedling with 90 plants/m^2 of planting density. The fertilizer dose 80:40:40 kg ha^{-1} of $N:P_2O_5:K_20$ was used for both seasons. The fertilizer P was applied as basal. The N fertilizer was applied in three splits: 5 kg as basal, 35 kg at 2 weeks after planting (WAP) and 40 kg at 5 WAP. The K fertilizer was used in two splits: 20 kg as basal and 20 kg at 5 WAP. The crop was grown as rain fed condition. The grain yield was simulated using weather data of 2002 and 2003 on Immature Brown Loam (IBL) soil of Kandy, Sri Lanka

Without ABC, the grain yield was 5573 kg ha^{-1} during "Maha" seasons. Whereas with ABC, the corresponding grain yield was 4599 kg ha^{-1}, reflecting a reduction in grain yield of 17 %. "Yala" season yield is highly sensitive to planting date as ABC impact is significant for low intensity rainfall during the March-May planting season.

Conclusions

As the preliminary studies show, there is a marked impact on the rice yield by ABC if adaptation strategies are not undertaken. Also the preliminary study already points to several features of the phenomena that can be used in defining the adaptation strategies. The most important one being the low intensity rainfalls, that are affected by ABC and thus making it necessary to adopt alternate cropping patterns or rice varieties to minimize the impacts. Of the two rice varieties simulated the, medium range variety is resilient to changes in small rainfalls during the growing and flowering, where as the long range variety showed robustness against global warming scenario. The reduction of radiation at maturity also can be seen to make a significant impact on the yield.

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