# Indian Monsoon: Contribution to the Stern Review

**Andrew Challinor, Julia Slingo, Andrew Turner and Tim Wheeler**

**University of Reading**

## Introduction:

India's economy and societal infrastructures are finely tuned to the remarkable stability of the monsoon[1], with the consequence that vulnerability to small changes in monsoon rainfall is very high. In 2002 the monsoon rains failed during July, resulting in a seasonal rainfall deficit of 19% and causing profound loss of agricultural production with a drop of over 3% in India's GDP. Neither the prolonged break in the monsoon, nor the seasonal deficit was predicted.

In the future, the pressures of an increasing population will bring additional stresses on society and the environment, with implications for water resources, health and food security. Consequently, climate change and the potential for the monsoon to become more volatile have major implications for India, itself, and for economies, worldwide.

## Current levels of skill:

Current capabilities, world-wide, in predicting the behaviour of the monsoon within a season, for a season ahead and for the coming century are very limited. This is due to an incomplete understanding of monsoon processes and the poor performance of current climate models in this challenging and critical region where the ocean, atmosphere, land surface and mountains all interact. Yet we know that biases in the mean simulation of the monsoon compromise our ability to represent year-to-year variations and their links with El Nino (Turner et al. 2005), as well as introducing additional uncertainties in projections of monsoon behaviour in the 21st century under global warming (Turner et al. 2006a).

## Future changes in mean monsoon:

The general consensus amongst climate models is that the mean summer rainfall for All India will increase slightly, by about 10% by the end of the century, largely because of the warmer Indian Ocean and the fact that warmer air can hold more water. This increase in rainfall will not necessarily be accompanied by stronger monsoon winds. There are, however, likely to be much larger regional variations across India, with indications that the northern states will see much of that increase, although these changes are considerably more uncertain.

As part of the more intense hydrological cycle, some models indicate that the intensity of heavy rainfall events may increase (the Mumbai floods of 2005 may be an example) whilst the number of rainy days may decrease. This suggests changes in the temporal characteristics of the water cycle which could have profound effects on agriculture and management of water resources.

Temperatures will increase for all months. Consequently, during the dry pre-monsoon months of April and May, the incidence of extreme heat is likely to increase, leading to greater mortality (DEFRA, 2005). Higher mean temperatures during the wet season will also have implications for the viability of some crops.

Meltwater from Himalayan glaciers and snowfields currently supplies up to 85% of the dry season

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[1] Over the past 100 years the standard deviation of the seasonal mean monsoon rains has been close to +/- 10% for All India. More regionally however the interannual variability tends to be larger particularly in the more arid parts of NW India where the standard deviation approaches +/- 30% (see Pant and Rupa Kumar 1997).

flow of the great rivers of the Northern Indian Plain. Initial modelling suggests that this could be reduced to about 30% of its current contribution over the next 50 years, if forecasts of climate change and glacial retreat are realised. This will have major implications for water management and irrigated crop production, as well as introducing additional hazards to highland communities through increasingly unstable terrain.

## Future changes in monsoon variability:

India is already vulnerable to variations in the monsoon, both from year-to-year and within the season. One of the key questions in climate change is whether the remarkable stability of the monsoon rains will continue, or whether the monsoon will become more volatile.

Most models predict a modest increase in interannual variability but to differing degrees. At the heart of this are the projections of what will happen to El Nino - whether it will become stronger and/or more frequent - since El Nino has a dominant influence on monsoon variability. New studies with the Hadley Centre model (HadCM3), incorporating a more faithful representation of the influence of El Nino on the monsoon, suggest that changes in the level of interannual variability, as a fraction of the seasonal mean, will be small. However, when viewed in the context of the overall increase in monsoon rainfall, this equates to changes of up to 14% in the standard deviation of total rainfall, with the implication that floods could become more extreme, but droughts remain just as likely (Turner et al. 2006). Furthermore, these new model results suggest that the recent observed weakening of the influence of El Nino on the monsoon is likely to be due to natural, interdecadal variability in the climate system. This interdecadal variability will itself introduce uncertainties in the projections of monsoon behaviour in the coming decades (Turner et al. 2006).

Following the failure of the monsoon in July 2002 and the devastating Mumbai floods of August 2005, it has become increasingly clear that variations of monsoon intensity within the season, known as active/break cycles, can have devastating consequences. Changes in the intensity, duration and frequency of these cycles may constitute the most profound effects of climate change. Yet climate models currently have very limited skill in simulating active/break cycles and the weather and extreme events (e.g. monsoon depressions) associated with them. The total failure to predict the 2002 drought, even by the most sophisticated models, is a notable example of our limited knowledge of processes leading to extreme monsoon anomalies.

## Impacts on Agriculture:

The population of India is expected to increase to about 1.5 billion by 2030. Food production must increase by 5 million tons per year to keep pace with this increase and ensure food security. Much of this extra production will need to come from rain-fed agriculture that comprises 70% of the farmed land - but these rain-fed farming systems are acutely vulnerable to climate variability and change. Current ability to forecast crop yields for a season ahead is very limited and improved predictions of rainfall and its space-time characteristics are vital for making progress.

Projections of food production in India in the future are limited by our knowledge of how climate change will impact on the complex biophysical, social and economic processes that interact to influence food chains, and on specific science questions concerned with how crops will respond to elevated CO2, extremes of temperature and water supply. More basic research on crop responses and better assessment of the potential to transgress key thresholds associated with weather events are needed. The evidence to date suggests that the changes in water and temperature described above will have serious consequences for agriculture.

The impact of less rainy days and increased intensity of rainfall events is to reduce the amount of water available for crop growth, since more water is likely to be lost to runoff and drainage. This in turn leads to a reduction in crop yield. Changes in the active/break cycles of the monsoon will also lead to reduced yield if a break occurs at a time when water availability is critical for the crop

(Challinor et al., 2004).

Changes in both the mean and the variability of temperature will also affect crop yield. Critical temperatures, above which damage to crops increases rapidly, are likely to be exceeded more frequently; also the expected increases in seasonally-averaged temperature often hasten the maturity of a crop. These changes could reduce mean crop yields at the end of this century by up to 70% (Challinor et al. 2006).

Adaptation to these changes is possible: a change of crop variety can mitigate the impact of extremes (Challinor et al, 2005a), for example. Mean changes in planting date may also provide some adaptation (Mall et al., 2004). Weather forecasts can aid the shorter-term scheduling of planting and irrigation: the potential to forecast a season ahead exists in some regions (Challinor et al., 2005b) and benefit can be derived if the information is distributed in a timely fashion (Gadgil et al., 2002).

Some of the processes described above are included in studies of regional changes in crop yield. One such study (DEFRA, 2005) suggests that for a warming of 2°C the yields of both rice and wheat will fall in most places, with the beneficial effect of increased $CO_2$ being more than offset by the temperature changes. Similar results have been found for soybean (Mall et al., 2004). Furthermore, rainfed crops are likely to be worse hit because of the limited mechanisms for coping with variability in precipitation (DEFRA, 2005).

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