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Low pressure change and agriculture growth: Case study for localize rainfall impact assessment

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Abstract: Every region around the globe has its unique climatic conditions which are set based on different orographic constant and atmospheric dynamic features. These features posses' variability on different time scales. Some of them are anthropogenic like release of GHG into the atmosphere. This leads to temperature increase that causes decrease in cloud formation and results in decreased precipitation and decrease agriculture yield which in-turn effects the national growth of countries, as a big portion of GDP comes from agricultural products. Agriculture sector employs a big chunk of population. The increased warming also increases the social inequality amongst civil societies. The efforts for poverty alleviation are hindered as well. The temperature and cloud data of last few decades have been analyzed and found to follow a trend which is also not suitable for the economy. This paper attempts to analyze rainfall in local domain and its economic impact on agriculture production. The warming aspect of climate change is considered. The COA approach is applied to analyze the low-pressure formation in the observed region under study. The said approach is also more feasible to use for rainfall instead of Southern Oscillation Index (SOI). A possible solution is in transition towards green revolution/economy. As deforestation contributes significantly in increasing temperatures, trees planting will not only decelerates the increasing trend in temperature but in long run will be productive for the economic growth.

Key words: *Climate change; Low pressure system; Economic growth: Agricultural growth*

1. Introduction

Many of the big economic questions in coming decades will come down to just how extreme the weather will be, and how to value the future versus the present. Now it is also well established that there is an observed increase in average global temperature along with change in rainfall patterns/rates during the 20th century (Easterling, 1999; IPCC, 2001; Jung et al., 2002; Balling Jr and Cerveny, 2003; Fauchereau et al., 2003) around the world. The extreme weather is a consequence of accumulation of greenhouse gas (GHG) in the troposphere due to human activity, around the globe and result's in social, economic and environmental changes (IPCC (Intergovernmental Panel on Climate Change), 2007). The economic cost of climate change can be measured where impacts are linked to market transactions (Smith *et al.*, 2001) and directly affect the national growth. On the other hand non-marketing impacts e.g. impact on human health and ecosystem, are difficult to assess. The increase in Carbon dioxide (CO_2) apart from other GHGs will increase the productivity of plant growth, but climate change, and changes in certain environmental system/ phenomenon are altered in overall negative sense. Some regions have experienced an increased in crop yield due to increased concentration of CO_2. The major crop growing seasons are two with reference to climatic seasons. One is *Kharif* where growing season starts from June and lasts up to September which is also the summer monsoon season. This crop includes rice, maize, sugarcane, cotton, jute, groundnut, soybean and pearl millet (*bajra*) etc. The other is *Rabi* crop growing season is after summer monsoon and goes up to the start of the spring. The post-monsoon season (October-November) provides the all important moisture to the soil for the *rabi* crop. It includes wheat, barley, mustard, gram, onion, potato etc. Hence the monsoon rainfall has a crucial role in both crop productions in the country. Especially the Indian Economy where agriculture sector consists of 18% of the total GDP and more than 60% of the total labor force.

The summer monsoon rainfall is important to the *kharif* crop, since it contributes more than 50% of the food-grain production and 65% of the oilseeds production in the country. The annual fluctuation in monsoon rainfall in India results in large-scale floods and droughts, leads to a major effect on Indian food grain production (Parthasarathy and Pant, 1985; Parthasarathy et al., 1992; Selvaraju, 2003; Kumar et al., 2004) and on the growth of the country (Gadgil et al., 1999a; Kumar and Parikh, 1998). The arable land per capita is also declining rapidly from 0.48 ha in

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1950 to 0.15ha in 2000 and will be 0.08ha by 2020, due to urbanization and industrialization. On the national scale 40% of the total cultivable land is given water via irrigation and the rest 60% is dependent on the uncertainties of monsoon rainfall. The climate change itself is identified by applying well established statistical technique on different climatic parameters over a period of 30 years or more. The change in this parameter is attributed directly or indirectly to human activity. The variation in behavior of these parameter (atmospheric and oceanic) persists for an extended time, namely over a decade or a longer durations (IPCC, 2007)

The importance of monsoon is evident for the economic growth of an agro base productivity. Understanding monsoon has its dividends. Weather is a highly complex and nonlinear system. A fluttering of butterfly wing can cause hurricane in some far of place, called 'butterfly effect' by Lorenz (1963). Meaning that small external disturbance in a climatic parameter can be devastating at some distant location. Circulation of Asian monsoon affects most of the subtropics and tropics in Eastern hemisphere and more than 60% of Global Inhabitants (Webster et al., 1998). Monsoon variation poses a serious threat to economic and social structure of a developing economy. There is a desperate need for an effective and reliable mitigation protocol for monsoon variation especially in the global warming scenario, where human activity has tempered with the nature and now facing the dire consequences. An efficient long term prediction of monsoon rainfall can improve planning to lessen the adverse impacts of rainfall variability and take advantage of beneficial conditions. For monsoon study of Indian subcontinent the empirical forecasting has been performed using different combinations of climatic parameters (Parthasarathy et al., 1988; Shukla and Mooley, 1987) such as wind, snow cover, atmospheric pressure, sea surface temperature (SST), and different phases of El Nino-Southern Oscillation (Hastenrath,1986; 1987; Wu, 1985; Iqbal and Quamar, 2008). There are some attempts where regression modeling is also attempted based on the correlation of some climatic parameters (Harzallah and Sadourny, 1997; Sadhuram, 1997) and have been able to yield a 60-80% efficiency in predicting the seasonal rainfall by month of May that is preceding the monsoon (Hastenrath, 1994).

The summer monsoon is driven by tropospheric latent heat and differential sensible heating (Clemens et al., 1991). Every surface has its own ways to balance the outgoing heat and incoming radiation losses through sensible heat and evapotranspiration (Fig. 1). Now subtropical ocean has a lower sensible heat than subtropical land; therefore land gets heat up quickly then ocean. As a result, in South Asia during summer on land, we have a low pressure system developed. This low pressure system causes wind to blow from southeast from April to October. The rain causing wind blows from southwest over the relatively warm waters of the Indian Ocean. Another possible reason which strengthens this wind is the development of mid tropospheric heating due to Tibetan plateau from March to May. This locally developed system causes the changes in the direction and intensity of wind. And hence these winds carry clouds from nearby seas and set the stage for precipitation.

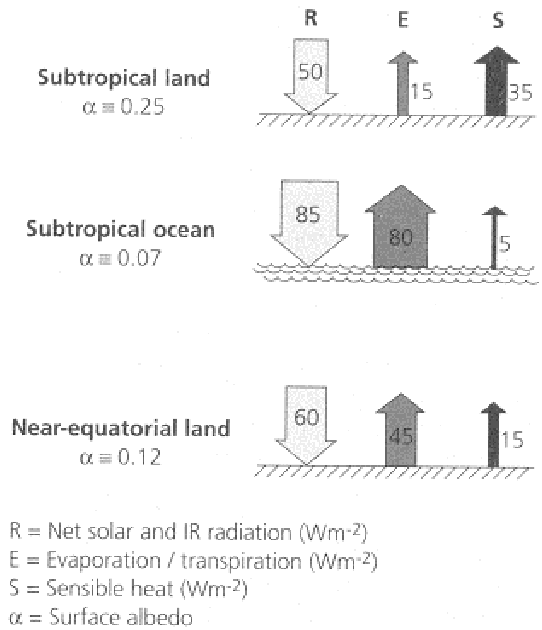

Fig. 1: Effects of three different surfaces on heat balance

The distribution of sea level pressure and the wind pattern in the months from June to September averaged for 1971-2000 (Fig. 2). The prevailing low pressure which spread from Northern India, Pakistan all over to eastern Saudi Arabia is visible. The accompanying cyclonic flow around the low pressure brings moisture laden winds from Arabian Sea into Central Indian Region. This low pressure system changes year to year and its fluctuation affects the Indian monsoon rainfall. A technique center of action (COA) (Bakalian et al. 2007) is used to assess this impact of low pressure variation over Indian monsoon rainfall (Iqbal et al., 2011).

In the following section we will discuss about the source of data for monsoon rainfall followed by the methodology to work out more appropriate technique to say something about the monsoon rainfall. After this section we shed some light on the model output and compare it with actual situation on ground. At the end we will conclude with the summery and outlook of this effort.

2. Data

For the economic side we used published data of agriculture sector and for the monsoon summer rainfall we use monthly temperature and rainfall data which is obtained from Climate Research Unit, University of East Anglia (http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_2.10) for the duration of 1951 to 2002. Averaged gridded monthly sea level pressure (SLP) data is used for calculating monthly averaged pressure, latitude, and longitude of the Indian Ocean low pressure as described by Bakalian et al. (2007). These are also called the three COA indices. SOI monthly indices are available at the Climate Data Center, National Center for Environmental Prediction (CDC/NCEP).

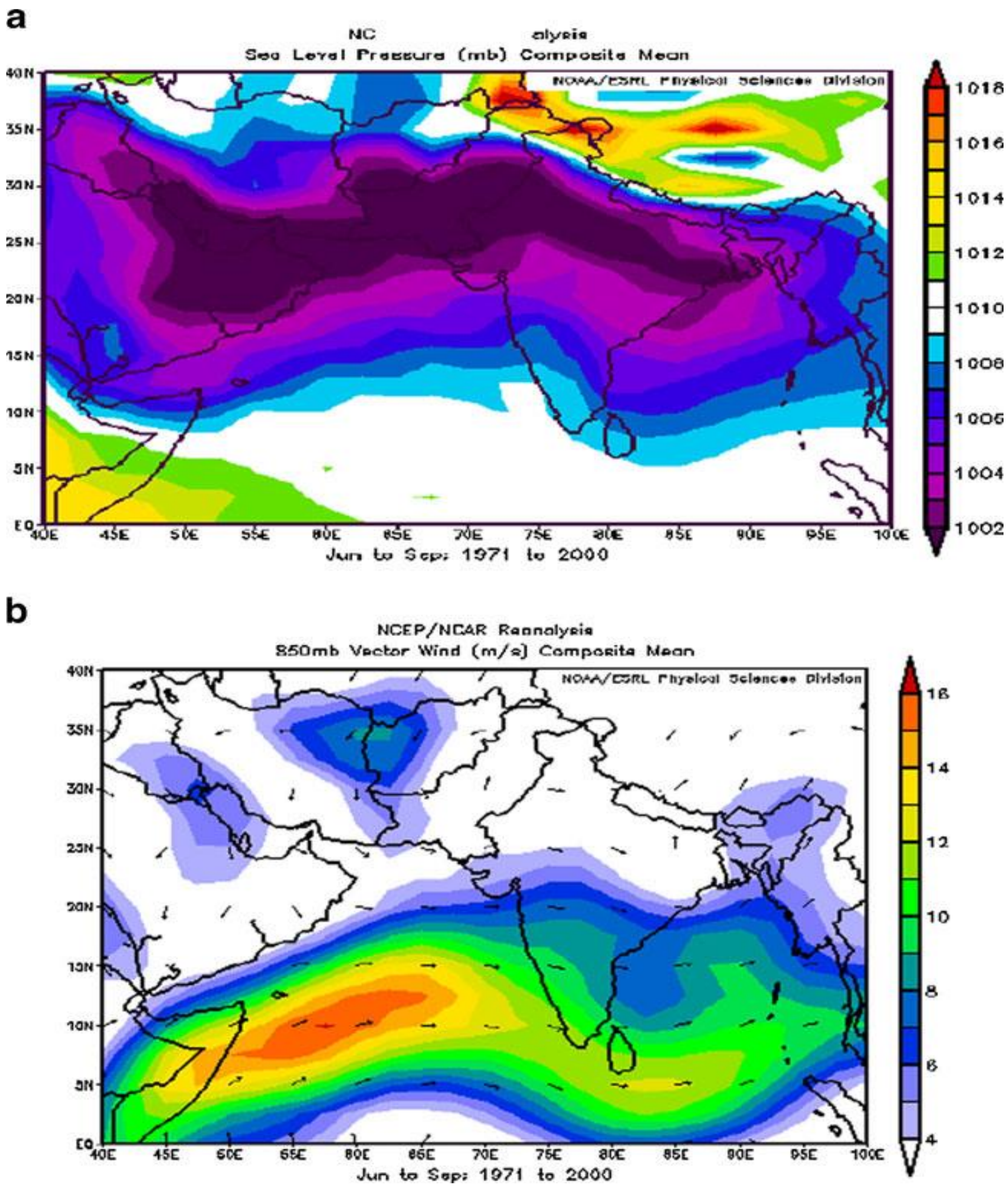

Fig. 2: Note that pressures less than 1,002 mb in the South Asia low extends from north India to Saudi Arabia (a). The cyclonic flow around the low brings the moisture laden winds from the Arabian Sea into the Central Indian region (b)

3. Methodology

In order to determine the impact of atmospheric pressure on summer rainfall variability we calculate the pressure index I_p of a low pressure system which is defined as the area-weighted pressure departure form a threshold value over the domain (I, J):

$$I_{p,\Delta t} = \frac{\sum_{i,j=1}^{I,J}\left(P_{ij,\Delta t} - P_t\right)\cos\left(\emptyset_{ij}\delta_{ij,\Delta t}\right)}{\sum_{i,j=1}^{I,J}\left(\cos\left(\emptyset_{ij}\delta_{ij,\Delta t}\right)\right)}$$

where $P_{i\,j,\,\Delta t}$ is the SLP value at grid point (i, j) taken over a time interval Δt, P_t is the threshold SLP value (P_t= 1013mb). If the factor $\left(P_{ij,\Delta t} - P_t\right)$ is greater than zero then we put $\delta = 1$ and 0 otherwise. The intensity is thus a measure of the anomaly of the atmospheric pressure over the section (I, J). Almost similar formulas are for the other two indices (latitudinal $\emptyset_{ij}$ and longitudinal λ_{ij}) (Bakalian et. al., 2007). The domain for South Asia Low was taken as 10ºN to 35ºN and 35ºE to 95ºE. This domain was chosen after examining the geographical ranges in the NCEP reanalysis data for the period 1948 – 2006. The working of the COA approach is such that it not only examines the influence of South Asia low pressure (SALP) on the variability of associated climatic parameter but also determines the impact of its zonal and meridional (latitudinal and longitudinal) movement of SALP on climatic variability.

4. Results and discussion

Over central Indian region (17º–25° N, 67º–82° E), the South Asian low heat on summer time (JJAS) monsoon rainfall is strongly correlated over a large part of the region (Fig. 3). It also shows that summer rainfall is also influenced by low pressure in the Arabian Sea. On the other hand the SOI is also strongly correlated with summer monsoon rainfall (Fig. 4). To further investigate the impact we compute the correlation between three indices of COA and SOI with summer monsoon rainfall for the area mentioned above.

The SALP and SOI has correlation -0.53 and 0.33 respectively with mean summer monsoon rainfall (Table 1). This table shows that SALP accounts for 28% of the variability in summer monsoon rainfall while the SOI accounts for only 11% of the variability. To further establish the dominance on the summer rainfall, we calculated the partial correlation of the two SALP and SOI with summer rainfall. Table 2 shows the results. Thus, -0.45 partial correlation of SALP on summer rainfall has a direct and significant effect over central India while SOI index and rainfall has partial correlation of 0.16 at 95% confidence interval. Thus establishes the dominant influence of SALP over the central Indian summer monsoon rainfall. Then we construct the linear regression model for the Central Indian Summer Monsoon rainfall (CISR) using SALP as predictor, which yields:

$$CISR = 80124.54 - 78.90 \times (SALP)$$

Coefficient of determination for the region is 0.28 which is a significant gain over 0.11 due to SOI. The south Asia Low Pressure (SALP) captures the big portion of the summer monsoon rainfall from 1952 to 2002 over central India (Fig. 5).

Table 1: Correlation Matrix Of Summer Monsoon Rainfall For Central India Summer Monsoon Rainfall

SOI (JJAS)	0.335356
SALPS (JJAS)	−0.526748
SALT (JJAS)	0.011014
SALN (JJAS)	−0.031927

Table 2: Partial Correlation Matrix for Summer Rainfall over Central India with Respect to SOI, South Asia Low Pressure (SALP).

Variables	Partial Correlation Coefficients
SOI index and Rain	0.16
SALP	−0.45

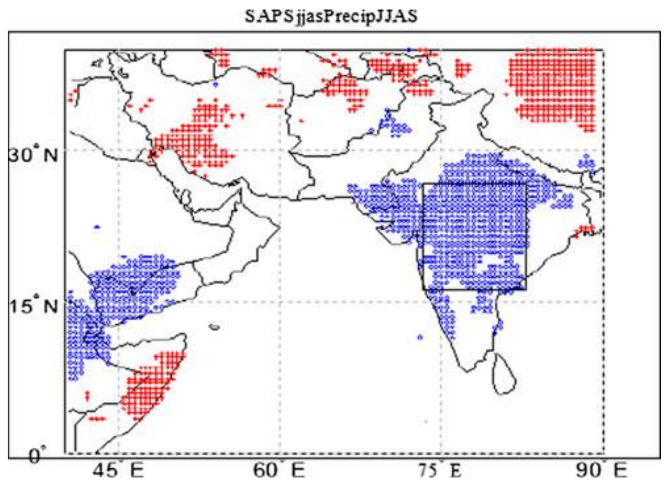

Fig. 3: Area of significant correlation between JJAS rainfall and JJAS SALPS during 1952 to 2002. Positive and negative correlation are shown by red and blue colors with p=0.05

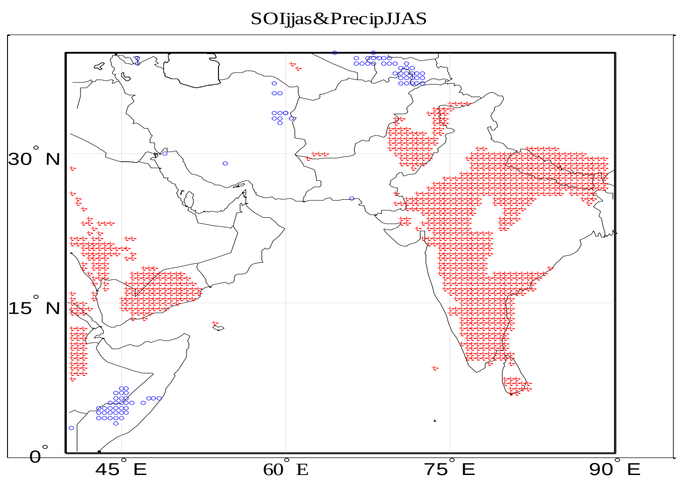

Fig. 4: Area of significant correlation between JJAS rainfall and JJAS SOI during 1952 to 2002. Positive (negative) correlations are shown by red (blue) colors with $p < 0.05$

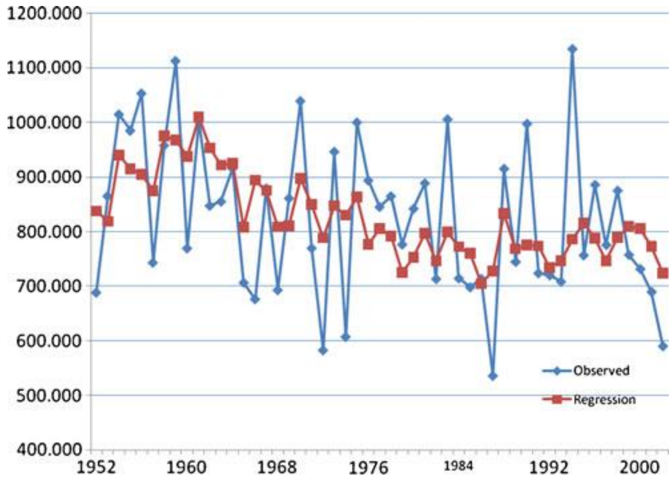

Fig. 5: A comparison between summer rainfall in Central India and modeled values (1952–2002). The independent variable in our model is averaged South Asia low pressure (JJAS). The winter rainfall variance explained by our model is R^2= 0.28

5. Summary and outlook

In global warming scenario the agriculture in the Central India has suffered a decrease of 10 – 15% for the same duration. Summer monsoon rainfall accounts for the Khrif crop, since its production season is the same but rainfall also accounts for the Rabi crop as well since it start with the moisture of the concluded rainfall. The significant portion (60%) of cultivable land depends on rainfall per capita in India (Mall, 2006), so all efforts to better the forecasting the Indian summer monsoon rainfall when easterlies are in action can be achieved by using the SALP in place of SOI. It is also observed that westerly is weakening due to increased interruption of western disturbance (Chang et al., 2001) and South Asia Low Pressure (SALP) is created due to easterlies. Hence there can be significant gain in the prediction of summer monsoon rainfall. The decreasing trend in rainfall is also predicted by the modeled equation (Figure 5) for the last half century. Hence this approach gives the decision makers more information about the rainfall then the other mostly used (till now) parameter SOI for forecasting Indian summer monsoon rainfall.

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