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Research Article

Impact of Global Warming on South Asia Low Pressure and Regional Cloud Cover

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Abstract: Clouds perform a very unique function in whole of the atmospherics. They respond differently to the same scenario. Analyzing more than second half of the last century synoptic climatic data, it is observed that climatic parameters are sensitive to the increasing temperature. In North Atlantic cloud cover increases with temperature while it works the other way in South Asia. By using the Center of Action (COA) technique, it is suggested that the intensity of South Asia Low pressure (spread over from north India to Saudi Arabia) has been increasing from mid 70s. It is also found that the declining trend in regional cloud cover has some links with weakening low pressure system.

Keywords: Cloud cover, Center of Action, South Asia Low pressure, Indian Ocean

1. INTRODUCTION

Clouds are condensed product of water vapors, frequently observed phenomenon. They are estimated to cover between 60 and 70 % of the globe at any given time. They are directly linked to a large variety of weather phenomena and play's an important role in climate, affecting both radiation fluxes and latent heat fluxes, but the various cloud types affect climate in different ways. Marine stratus and stratocumulus clouds (MSC) have an albedo of 30-40%, while maintaining a cloud-top temperature not much below the sea-surface temperature (SST). MSC therefore have a cooling effect on climate (negative cloud radioactive effect, CRE). Randall [1] estimated that a 4% increase in MSC cover could compensate for a 2-3°C global temperature rise. By contrast, high (cirriform) clouds are thinner and colder, so their long wave effect dominates, giving them a positive CRE.

The changes in cloud cover linked with climate change and how such feedback change with climate is one of the most challenging aspects of predicting future climate and anthropogenic effects it may accompany. There have been several studies of cloud cover change over land in last decade. People have employed historical data during hot and cold periods that lasts from decade to more than a century [1, 2, 3, and 4]. Hameed [2] suggested that secular changes in the strengths of three permanent high/low pressure systems, the North Pacific high, the Icelandic low, and the Azores high, are in part related to secular changes in global climates, that is, changes in global mean surface temperature. He further suggested that the climate –induced change in cloud cover for certain regions is related to the strengths of adjacent high/low pressure systems. Hahn [5] observed 22 decadal-scale variations in cloud cover for most cloud types. He also noticed (while looking at smaller regions) possible increase in total cloud cover in central Pacific, while possible decline is seen stratiform cloud cover of persistent stratocumulus clouds. The decline in stratocumulus clouds is accompanied by an increase in SST between 1954 and 2008. Lower tropospheric stability and sea level pressure show long-term increase.

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Norris [5] also suggested a decreasing decadal trend of 1.9% of sky cover in Staturs cumulus (Sc) cloud cover from 1952-97, which can be due to a higher trade inversion, warmer SST, and/or weaker trade winds. During this period the Inferred net outgoing radiation has decreased by 0.8 Wm^{-2} in Sc regions (0.045 Wm^{-2}globally). Jaswal [1] observed a decrease in total cloud cover over large parts of India during 1961-2007. While trends in rainy days are similar to cloud cover across periods, trends in diurnal temperature have regional to seasonal preferences over the country. In Warren's [6] previous work, analyzing cloud cover over land they set forth criteria for the examination of surface observations for trends and inter-annual variations of cloud cover. The work concluded that total cloud cover was declining slightly over the global land areas and hinted that cumuliform clouds may be increasing at the expense of stratiform clouds at low and middle levels. High cloud amount was also shown to be decreasing. Dim [7] compared two satellite datasets [Advanced Very High Resolution Radiometer (AVHRR) and International Satellite Cloud Climatology Project (ISCCP)], and found a decrease in cloud cover over land, although the character of the change was different in the satellite data—[8] the observed decline was mainly caused by a decrease in low cloud cover.

These and other studies suggest the continuous updating is required in cloud data and models. Cloud cover has strong temporal and spatial behavior globally. In January cloud may have positive correlation with temperature but the same may reverse in July. In tropics and subtropics cloud cover goes against the increase in temperature while in extra tropics it seems to go with the temperature [9]. The factors which influence cloud feedback to the atmosphere may have been temperature, lower tropospheric stability, relative humidity, sea surface pressure. The uneven solar heating from equator to poles throughout the annual cycle of the Earth has the leading role. The above mentioned studies do give us some insight of cloud dynamics and their variation over the year. These observed changes in cloud amount have some localized atmospheric anomalies which fluctuates the balance in atmospheric layers at different pressure levels. Some permanent/semi-permanent high/low pressure systems might also be responsible for changing cloud amount.

South East Asia has a very different ocean--atmosphere interaction than other well-known western oceans and their climates. The sole sink and source of solar/terrestrial incoming /outgoing radiation is Indian Ocean. Other than South the Indian Ocean is surrounded by geographically different land masses. In North there is an 1800 km long and over 5000 meters high mountain range (Tibetan plateau). In East, there is a cluster of a few islands and Australian continent working as a sparse boundary between Pacific and Indian Ocean. The Western side consists of East African plains. Due to this structural setting climate of south Asia is dominated by temperature gradient. Sometime these gradients are due to persistent cloud cover on the same surface as well as different surfaces (ocean-land). In the past, warm periods have shown an increase in cloud cover in contrast to cold period [10]. As described above the climate of south Asia has its differences and there is no previous attempt to understand the change in cloud cover to relate with other aspects of atmospheric circulation, that is, the change in global climate has altered the cloud cover. This would seem to be a particularly relevant endeavor, given the importance of understanding how clouds interact with the change in climate. For this purpose we have averaged the data over central and south India and have found a decrease in cloud cover with the increasing temperature and this decrease in cloud cover is also observed in increasing low heat, suggesting a possible link between regional cloud cover change and the strengths of related low pressure systems.

2. Radiative cloud effects

Clouds interact with radiation from both sides. If clouds form on an otherwise sunny day the maximum temperature near the surface will be lower due to the reflection of sunlight by clouds (from side away from earth), in comparison to the temperature without clouds. Cloud cover (from side towards earth) traps the outgoing terrestrial radiation which leads to warming the covered area. Likewise, if the sky is covered by low clouds at night the near-surface temperature will not drop as low as under clear sky conditions due to the trapping of terrestrial radiation by the clouds.

The overall impact of clouds on the radiation budget can be measured by comparing the radiative fluxes in cloudy to those in clear-sky conditions.

The difference between the two has been termed cloud radiative forcing [11] and can be defined separately for the solar (short wave radiation) and terrestrial (long wave radiation) parts of the spectrum. The major source for radiative fluxes is satellite data, which measure radiation at the top of the atmosphere (TOA). There have been numerous studies 12, 13, 14, 15, 16] to establish the effect clouds have on the TOA radiation budget many of which are based on satellite data from the Earth Radiation Budget Experiment [17].

3. Datasets

Investigating cloud-cover change in south Asia associated with local climate change, we have adopted global mean temperature and cloud-cover data for the period of 1948 to 2012 from an online facility provided by National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR). For current investigation monthly means cloud cover and global temperatures with a $0.52^o \times 0.52^o$ latitude-longitude resolution data is used. Land area cloud cover is included (falling under the region from $8^o - 22^o$N to $73^o - 83^o$E).

Additional dataset consists of the intensities of the subtropic pressure system situated in central and southern India and Northern Indian Ocean is used. These were evaluated by Iqbal [11] from sea level pressure (SLP) data. The pressure index *Ip* of a low pressure system is defined as an area-weighted pressure departure from a threshold value over the domain (I, J):

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

Similarly, the latitudinal index, is defined as:

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

Where $I_{\phi,\Delta t}$ is the latitudinal index (SALT) of South Asia Low pressure (SALP), $P_{ij,\Delta t}$ is the SLP value at grid point (i, j) averaged over a time interval Δt, in this case monthly SLP values are taken from NCEP/NCAR reanalysis, P_t is the threshold SLP value, φ_{ij} is the latitude of the grid point (i, j). Here M = 0 for the High and 1 for the Low is used. $\delta = 1$ if $(P_{ij,\Delta t} - P_t) > 0$ and $\delta = 0$ if $(P_{ij,\Delta t} - P_t) < 0$, this makes sure that the pressure difference is due to the Low pressure system. The intensity is thus a measure of the anomaly of the atmospheric mass over the section (I, J) [2]. The domain of the South Asia Low pressure (SALP) was chosen as 10^oN to 35^oN and 35^oE to 95^oE, since this is the region where the Inter tropical Conversion Zones (ITCZ) moves to in summer, the rest of the year it is found near the equator (on either side north or south). The Low pressure and their threshold values P_t were chosen by examining their geographical ranges in NCEP/NCAR reanalysis data over the period 1948-2006. Similarly, the South Asia longitudinal index (SALN) is defined. Cloud cover data is examined by performing smoothing to remove the short term fluctuations without distorting the dynamics of the variables. Only daytime values are analyzed, in order to avoid any day/night sampling biases. [The analysis was also done using the day/night averages, and very similar results were obtained].

4. Analysis

Different surface types have different balances between incoming radiation, and outgoing heat

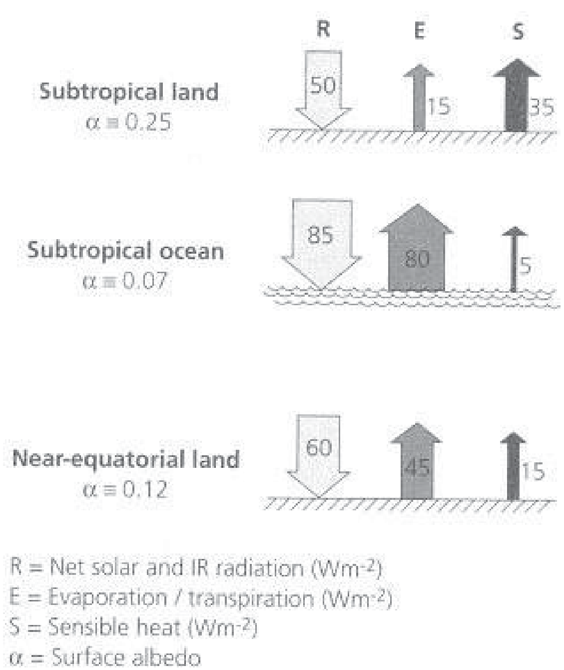

Fig. 1. Effects of three different surfaces on heat balance. After [3]

losses through sensible heat and evapotranspiration displayed in Fig.1. Subtropical land has higher sensible heat than subtropical ocean; the land shows a prompt response to any increase in temperature than ocean. As a result, over land we have low pressure systems developed in South East Asia during summer monsoon. Prevailing pressure system causes monsoon winds to blow from the southeast from April to October. From November to March they blow from the northeast. This dry air prevails to create the dry season. The monsoon brings rains when it blows from the southwest across the warm waters of the Indian Ocean. This wind is blown due to the presence of Low pressure system developed due to the mid troposphere heating of the Tibetan plateau from March to May. The change in the direction and intensity of wind is due to locally developed pressure systems. These winds also carry clouds formed at neighbouring seas and create a cover for precipitation.

Over the years (mostly since mid 1950s) cloud cover and temperature have shown some consistent variability together in Fig. 2 & in Fig. 3. The negative correlation found between the two variables displayed in (Fig. 4a, b, c) may be due to the type of stratocumulus (MSC) cloud found at low latitudes. In north Atlantic the cloud cover goes with the increasing temperature [14] which is contrary to our findings for south Asia. There can be two possible mechanisms for this negative correlation, one is when the landmass heats up (via solar radiation) the increased sensible heat carries less water vapours and results in decreased cloud cover. For the other possibility this has been found in numerous studies [15, 21, 7] that marine stratiform cloud cover should and does correlate negatively with SST. The hypothesized mechanism for this relationship is a destabilization of the lower troposphere by the warming SST, reducing static stability and entering more dry air into the cloud layer. Taking this possibility further, the destabilization doesn't stop there but it also decreases the intensity of the associated low pressure as shown in Fig. 5. In North Atlantic the sea level pressure and temperature have similar association [15]. Although a correlation does not necessarily establish the cause-n-effect relationship, but still it gives a clue of probable association. The implied result from this analysis is that the decrease in the intensity of low pressure may decrease the cloud cover Fig. 6. The longitudinal component of SALP

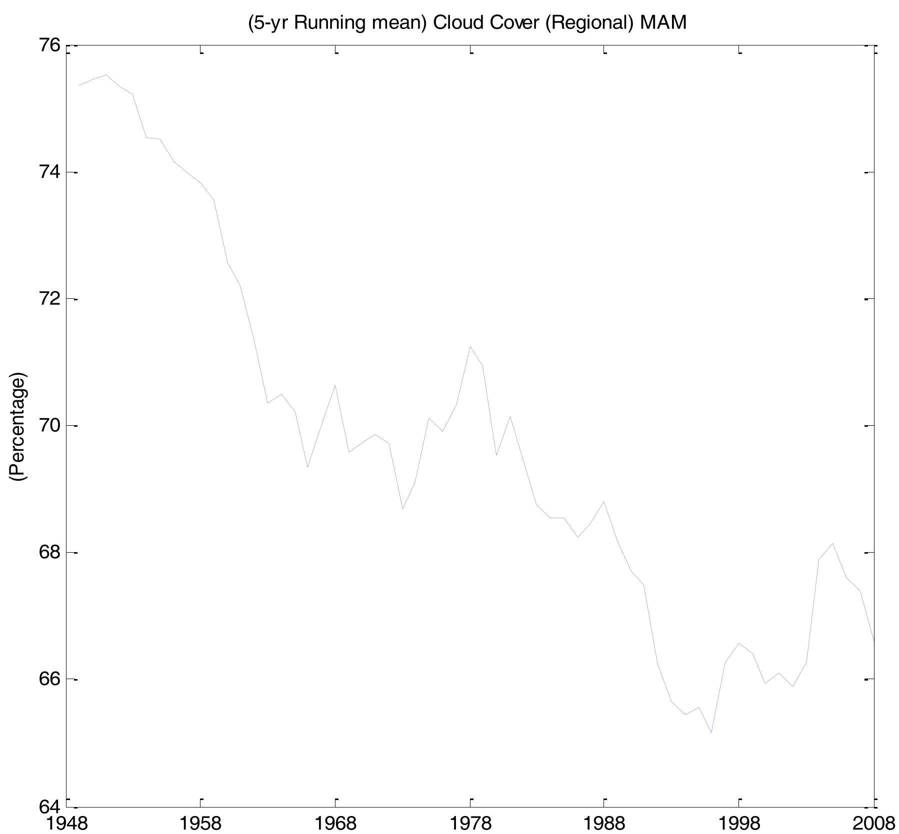

Fig. 2. Decadal variation in cloud cover during pre-monsoon for investigated region

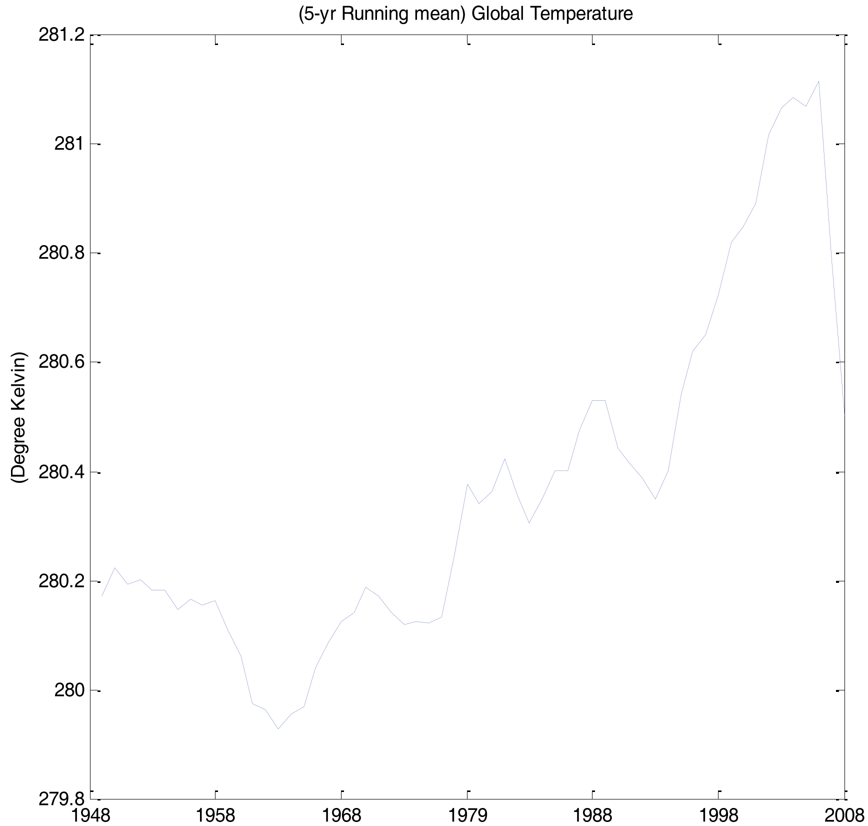

Fig. 3. Global temperature increase for the investigated duration

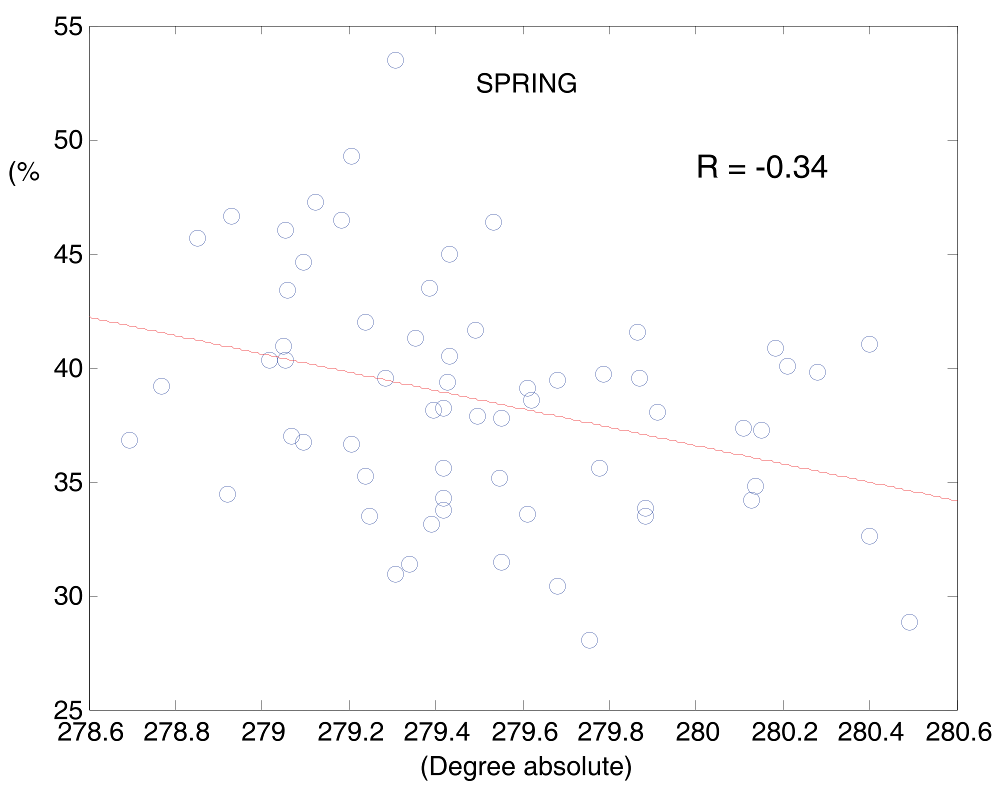

Fig. 4a. Global temperature Vs Regional cloud cover (Spirng)

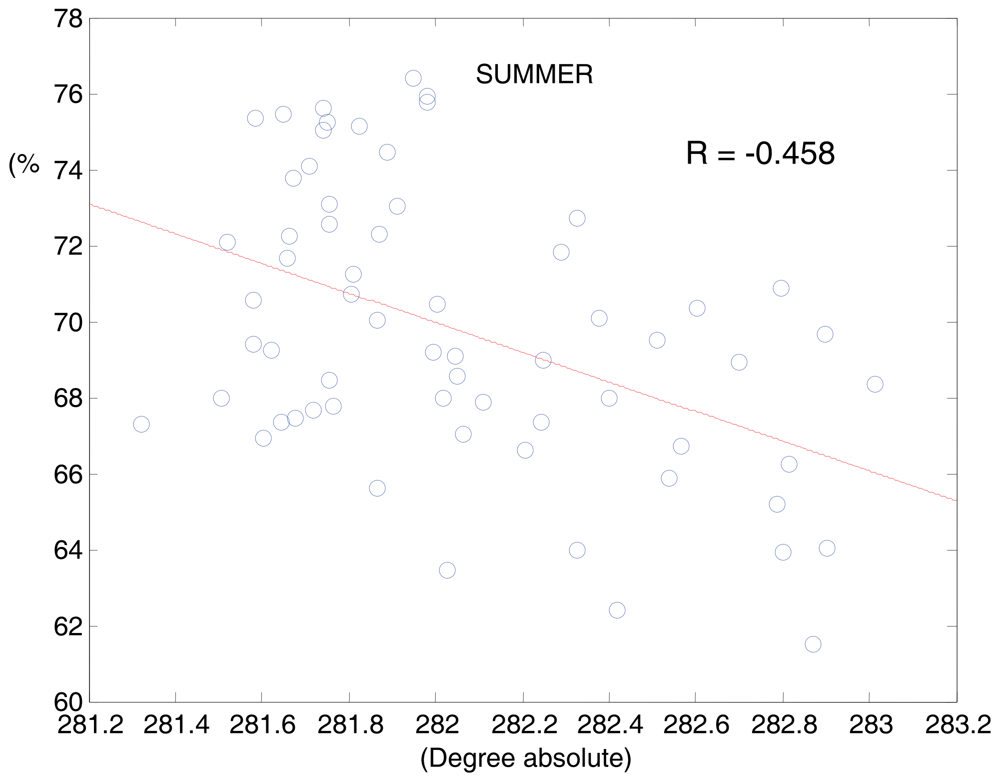

Fig. 4b. Global temperature Vs Regional cloud cover (Summer)

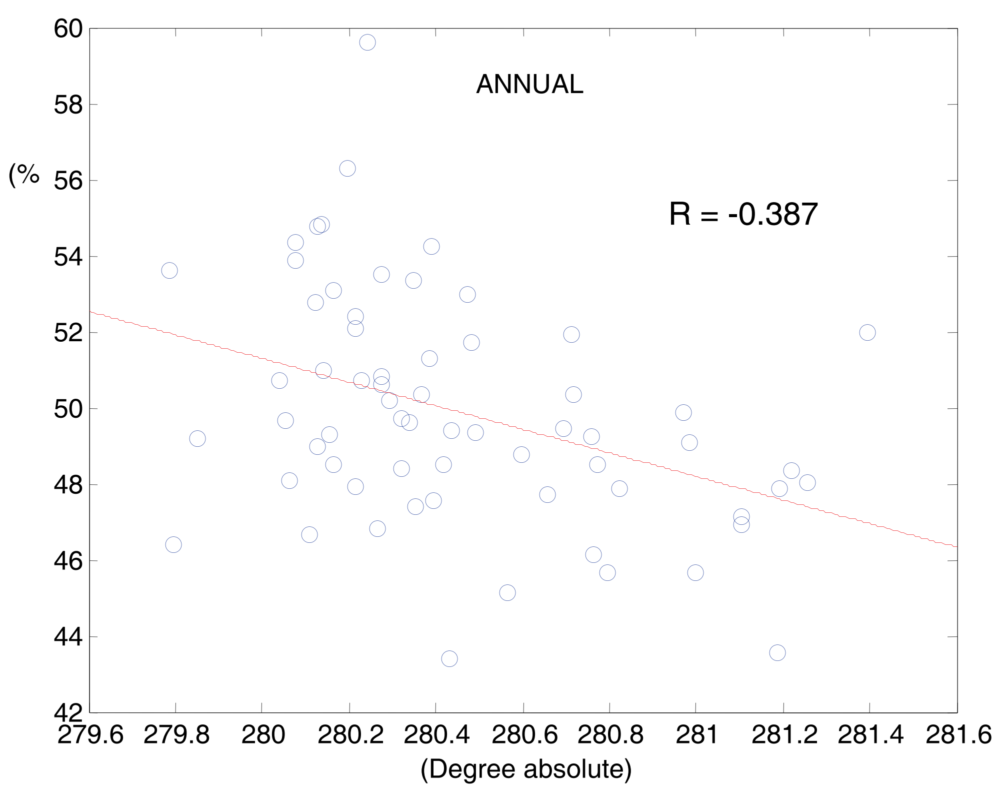

Fig. 4c. Global temperature Vs Regional cloud cover (Annual)

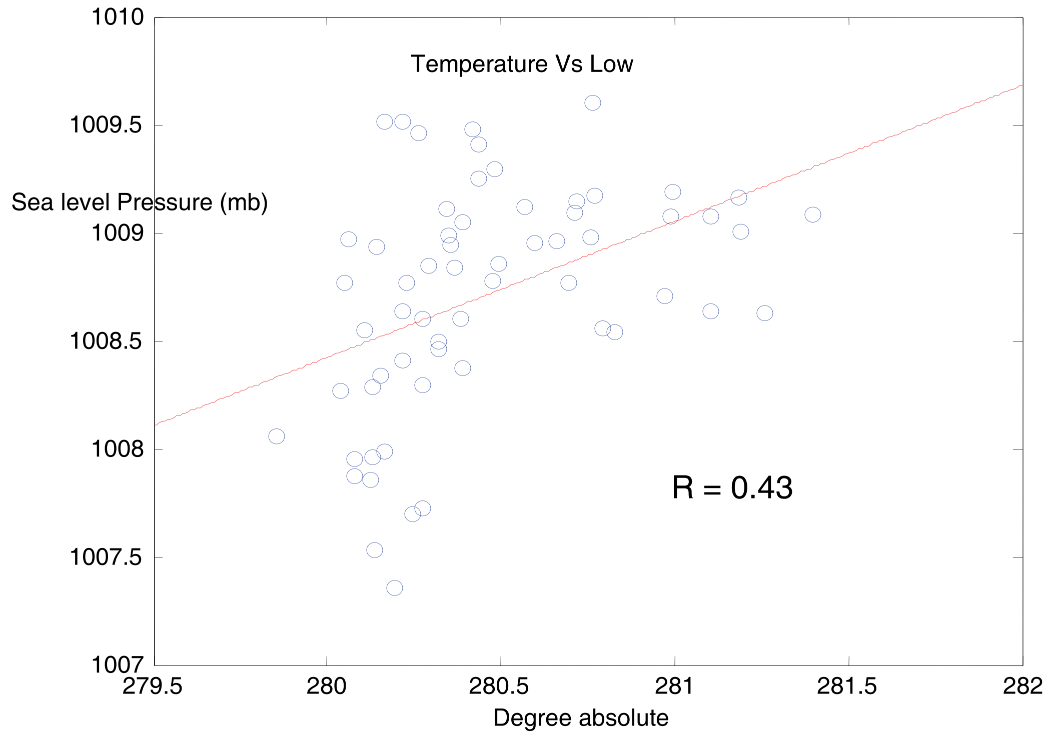

Fig. 5. Temperature increase decreases the intensity of low pressure

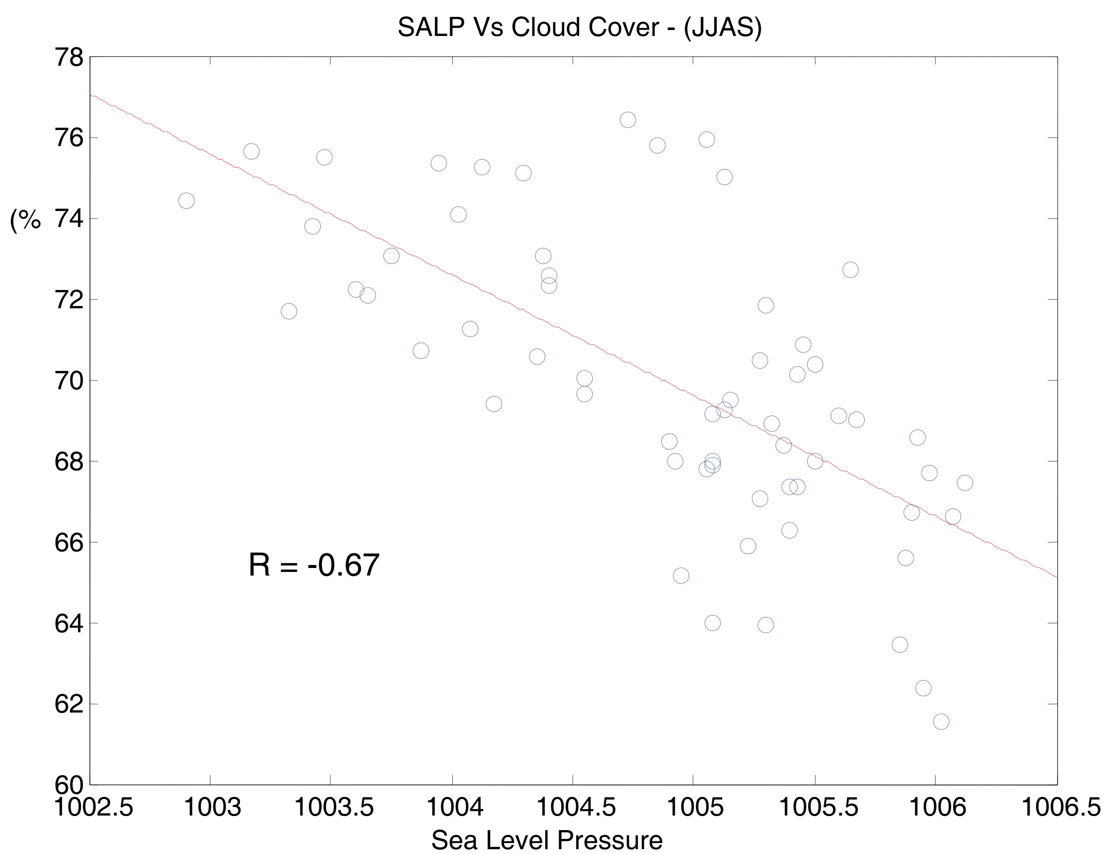

Fig. 6. Cloud cover decreases with decreasing low pressure system Negative correlation (p = 0.05)

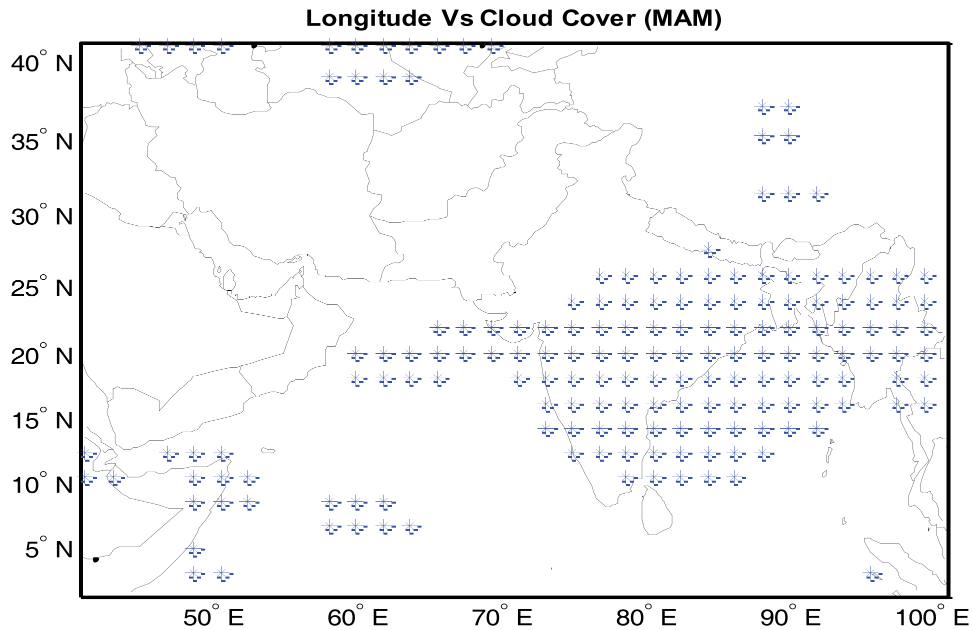

Fig. 7. SALN has significant negative correlation with cloud cover (p = 0.05) in pre-monsoon season

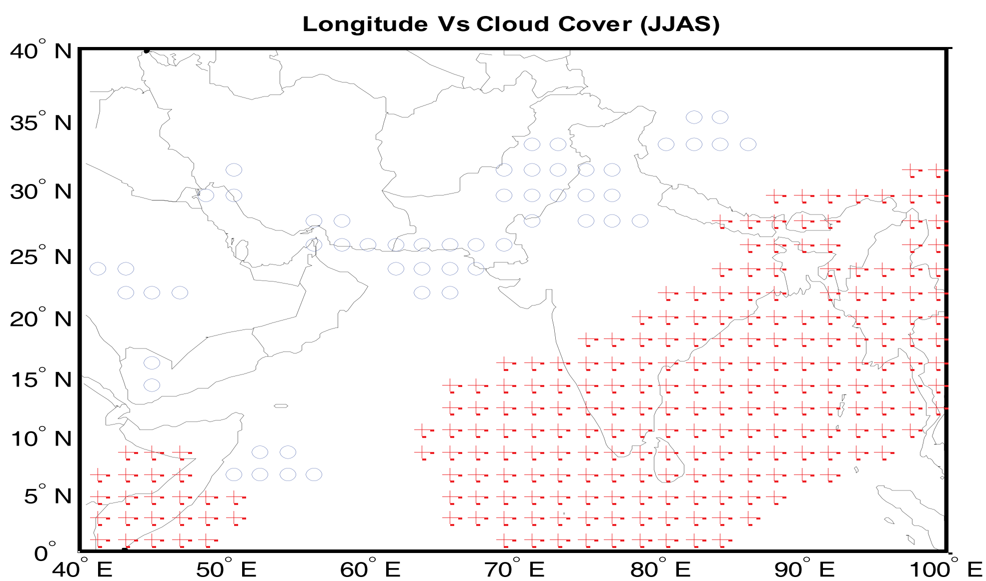

Fig. 8. SALN has significant positive (red) correlation with monsoon cloud cover (p = 0.05)

seems to play the major role in the above mentioned relationship. At pre-monsoon (MAM) stage of the low pressure in Bay of Bengal, eastern coast of India along with southern and central India are all under the influence of South Asia's longitudinal component (SALN), in the form of decreased cloud cover (Fig.7). In the following monsoon season (JJAS) this pressure system develops and supports the cloud formation (Fig.8) for monsoon precipitation.

5. Concluding remarks

Landmass tends to heat and cool quickly in comparison to oceans. This decreases lower trophospheric stability at different pressure levels (at 700, 850 and 1000 mb). As a result the pressure gradient so formed influences the formation of cloud cover at different pressure levels.

The land cloud cover is created over ocean (i.e., Indian Ocean) and then travels to its neighbouring low pressure. Cloud cover is more sensitive to increase in temperature than stable or decreasing temperature (Fig.1 & Fig. 2), especially lower level clouds. On the other side decreasing intensity of low pressure seems to decrease cloud cover. As other regional climates, South Asian climate also appears to depend upon the development and intensity of low pressure systems which also contributes to the Indian summer monsoon season.

The inter-annual and decadal scale decrease in cloud cover is attributed to the increase in temperature. As the persistent declining trend of low pressure system does not favour the formation of cloud cover, it also contributes partly, in decrease of monsoon rainfall over South Asian region. Since increase in temperature diminishes both, the associated low pressure system and the regional cloud cover, with every degree rise in regional temperature the climatic parameters will become more severe.

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