

Impact of Climate Change and Surface Energy (Im) Balance on North-East India Monsoonal Rainfall

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Abstract: In recent decades, climate change and its impact on the ecosystem has remained a concern from global to regional to local scale. Many studies performed over India have highlighted the change in precipitation associated with the Indian summer monsoon (ISM) and its linkage with changed land surface processes. Over North-East India (NEI), changed surface and atmospheric energy imbalance due to increase in wasteland, deforestation and over cultivation have made the soil barren. In addition, soil moisture of barren land has decreased, latent (sensible) heat decreased (increased) with stimulating ground heat increment. This led to lower evapotranspiration and convection leading to precipitation decrement. To analyse this in detail, the present study shows a lower increase in the near surface temperature during 1956-1985 (period I), but a higher increasing trend has been seen during 1986-2015 (period II). In the case of precipitation trends, an increase during period I and a decrease at a 95% significant level during period II are seen. The average air temperature warming rate increase of 0.09 °C/year is observed. The monsoonal precipitation has decreased significantly in recent years (1986-2015) than that in the past (1956-1985). In addition, a decrease in monsoonal precipitation at 0.35 mm/year rate during period II is seen over NEI. A prominent increment of 0.12 W/m² is observed in surface sensible heat flux over NEI. Land use land cover change (LULCC) is continuously altering the local rate of change of thermal radiation, evapotranspiration and convection, and has also played a critical role in defining monsoonal precipitation over NEI. However, the surface net solar and thermal radiation change are in equilibrium with the surface sensible and latent heat for sustaining the surface energy budget. Hence, a small change in surface net radiation causes an imbalance of surface energetics. It is one of the most prominent causes for the precipitation pattern changes over NEI. The LULCCs and earth's surface energy imbalance reinforce climate variability and climate change over the study region.

Keywords: LULCC; Latent heat; Sensible heat; Evaporation; Solar radiation; Thermal radiation; Temperature and precipitation.

Introduction

Sun is the primary source of energy for all living and nonliving organisms on our planet (Vernadsky, 2012). As solar energy reaches the Earth, it is utilised for various atmospheric, oceanic and land (micro, meso and synoptic scale) processes. At the molecular level, solar radiation directly or indirectly triggers some molecules and aids in energy transport. In the earth's energy budget system, water molecules play a major role in controlling most of the weather and climate events. As the solar

radiation hits the Earth's surface, it gets absorbed in various ways and is released as thermal energy or radiation. This thermal radiation is absorbed by various particles, moisture and gases in the vicinity of the atmosphere and the Earth's surface (Modest, 2013). These molecules once excited increase their kinetic energy and due to massive collision and reradiation, lead to temperature rise (Turner, 1928), causing warmer surroundings. Natural and anthropogenic forcings have contributed to rapidly increasing global annual mean temperature with respect to long-term averages

(Trenberth et al., 2009; Paul et al., 2016), which in one way leads to global to regional to local changes in temperature and precipitation climatology and trends.

The increasing urbanisation and demand for livelihood are leading towards the modification of land, deforestation, cultivation/croplands, etc. In addition, increasing population and modern human lifestyle changes are creating extreme challenges among all the living being. India is an agriculture-dependent country, mostly monsoon-dependent, is also struggling with these issues. Indian summer monsoon (ISM) provides 80% of annual rainfall over India (Jain and Kumar, 2012; Sahana et al., 2015; Paul et al., 2016) and majorly controls the agricultural yields (Prasanna, 2014); NEI (Figure 1) receives the maximum amount of precipitation annually because of its specific orographic distribution having high precipitation variability (Goswami et al., 2006; Dimri et al., 2018). In addition, NEI is well known for its biodiversity, vegetation richness and is one of the biodiversity hotspots (Myers et al., 2000; Majumder et al., 2012). However, the biodiversity of this region is under threat because of deforestation and habitat moderation (Majumder et al., 2012). In addition, the habitat present in this region is dependent on agriculture for their livelihood. Cultivation of rice, ragi, jowar, maize, wheat, barley and pulses are major crops required for their livelihood (Dhyani and Tripathi, 1998), while at the upper region of NEI, cash crops viz., apple, cashew nut and pomegranate are cultivated (Ravindranath et al.,

2011) following traditional agricultural practices (Yadav and Kaneria, 2012). The cultivation tradition practiced in the NEI region is Jhum/slash and burn (shifting and felling) (Yadav and Kaneria, 2012; Roy et al., 2015). However, land use land cover change (LULCC) over NEI has been continuous since 1985, in particular, and before (Roy et al., 2015). Roy et al. (2015) have investigated human-forced biodiversity loss, degradation and desertification caused by LULCC (Jain et al., 2016a and 2016b; Paul et al., 2016; Nayak et al., 2021) over NEI. Besides, these built-up areas have significantly increased over NEI (Roy et al., 2015).

LULCC is an influencing monsoon precipitation as well, over the NEI region (Paul et al., 2016; Halder et al., 2016). Parthasarathy and Dhar (1974) have reported that during 1901-1960, the precipitation trend increased over north Assam, but decreased over south Assam with statistical significance. However, Jhahharia et al. (2012) reported that the precipitation trend has significantly decreased over most parts of NEI from 1975 to 2003. Mukherjee et al. (2015) have shown an increased percentage contribution of seasonal precipitation in July and September over NEI. Dash et al. (2012) have described decreased monsoon precipitation over NEI along with western and central India during 1871-2002. However, the mean, maximum, minimum and diurnal temperature range had a rising trend for the period 1901-2003 over NEI (Jain et al., 2013; Suhaila and Yusop, 2017). Jain et al. (2013) have reported negative

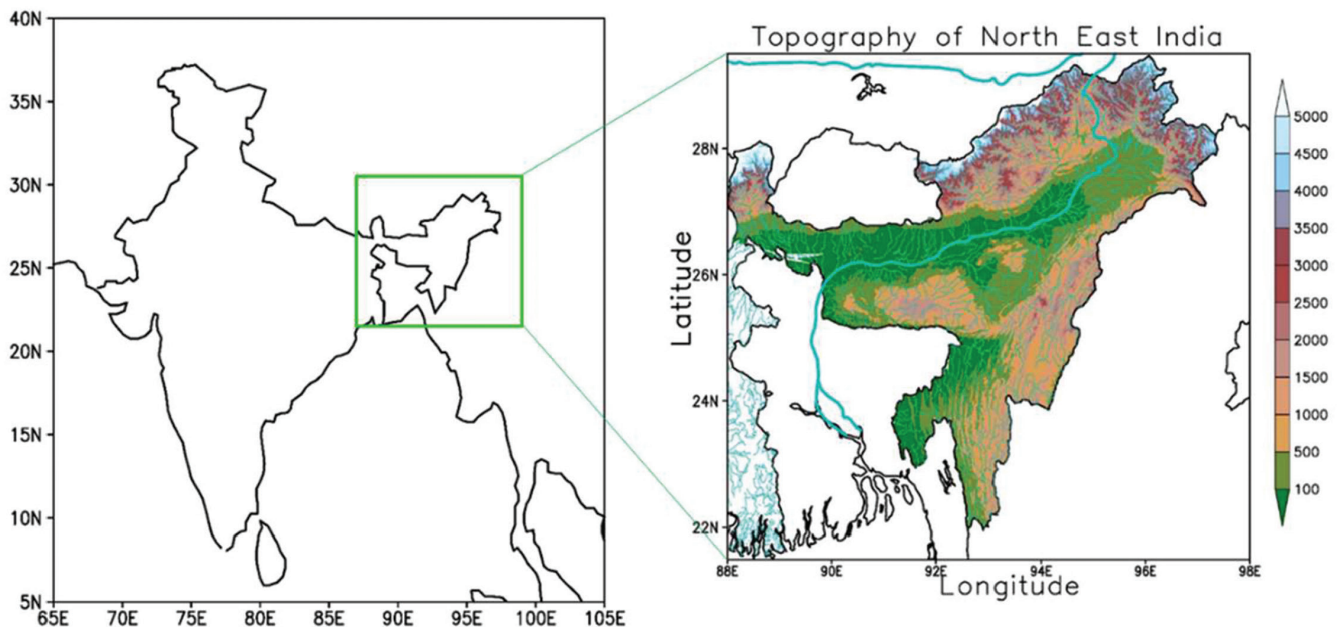


Figure 1: Topography (in metre) over North-East India (NEI). The thick line represents the Brahmaputra River and the thin lines represent tributary channels.

trends in seasonal precipitation during 1871-2008 over the whole NEI region. Most of the recent studies have only reported the precipitation and temperature changes. There a lack of understanding of climatic dynamics and surface energy processes. This motivates the present study to fill this scientific gap over the NEI region and provide a plausible associated explanation for these changes. The present study thus illustrates surface energy imbalances, LULCC prompted surface warming and atmospheric processes taking place over NEI.

Data Description and Method

Daily gridded high spatial resolution ($0.25^\circ \times 0.25^\circ$) precipitation dataset from the Indian Meteorological Department (IMD) (Pai et al., 2014; Tiwari et al., 2019) for the months June, July, August and September (JJAS) during 1956-2015 (that is further divided into two-time slices for the present study 1956-1985: period I and 1986-2015: period II) is used. IMD gridded precipitation dataset is generated using daily precipitation records collected from 6955 rain gauge stations (Pai et al., 2014). In addition, the gridded high-resolution temperature from the climate research unit (CRU TS 4.02) (Harris et al., 2014) is used. The bilinear interpolation is executed over the study region for better representation, discussion and understanding. Other climatic and derived variables are taken from National Centers for Environmental Prediction/National Center for Atmospheric Research (NCAR/NCEP; Kalnay et al., 1996; McCabe et al., 2007) and Center NOAA-CIRES Climate Diagnostics

Center (McCabe et al., 2004 and 2007). LULCC dataset is derived from RESOURCESAT-2 LISS-III satellite data having national LULC mapping at 1:50000 scale for 2011-2012 (for more details please see; Doc. No.: NRSC:SDAPSA:NDC:DEC11-364). The mean climatology of temperature, precipitation and other derived variables for the monsoon season (JJAS) has been calculated in order to evaluate the change for the two-time slices (i.e., 1956-1985: period I and 1986-2015: period II). Since the LULCC has been reported from 1985 to 2005, the present study has been selected for the time span to see the changes before 1985 and after 1985. Moreover, long-term linear trends of temperature, precipitation and other derived variables are calculated at 95% statistical significance using the Students' t-test in order to estimate the significance. Diurnal temperature range (DTR) is calculated using maximum ($T_{\max}$) and minimum ($T_{\min}$) temperature ($DTR = T_{\max} - T_{\min}$) (refer to supplementary Figure S1). Precipitation anomaly is computed as time series minus mean precipitation for the season (JJAS). The details of the data used are briefly given in Table 1.

Results and Discussion

Roy et al. (2015) have observed rapid LULCC from 1985 to 2005. However, a more recent LULCC (2011-12) over the study region is shown in Figure 2. This figure shows the distinct spatial distribution of LULCC over the NEI and respective states. LULCC has a greater role in microclimatic changes over NEI. Paul et al. (2016) have reported weakening of summer monsoon

Table 1: A brief of data sets used for the study

<i>Variables</i>	<i>Data sets</i>	<i>Years Span</i>	<i>Resolution</i>		<i>Source</i>	<i>Reference</i>
			<i>Temporal</i>	<i>Horizontal</i>		
$T_{\max}$, $T_{\min}$, rainfall	IMD (Gridded & Station)	1956-2015	Daily	$0.25^\circ \times 0.25^\circ$	IMD	Pai et al. (2014); Tiwari et al. (2019)
$T_{\max}$ and $T_{\min}$	CRU TS4.02	1956-2015	Monthly	$0.25^\circ \times 0.25^\circ$	CRU TS4.02 portal	Harris et al. (2014)
Radiation longwave, shortwave, runoff and derivative variables	NCEP / NCAR	1956-2015	Monthly / Daily	$0.5^\circ \times 0.5^\circ$	NCEP portal	Kalnay et al. (1996); McCabe et al. (2007)
LULCC	RESOURCESAT-2 LISS-III	2011-2012	Annual in Slots	1:500,000	Bhuvan portal	(RESOURCESAT-2, LISS-III, Bhuvan program); (http:// www.euromap.de/download/ R2_data_user_handbook.pdf)

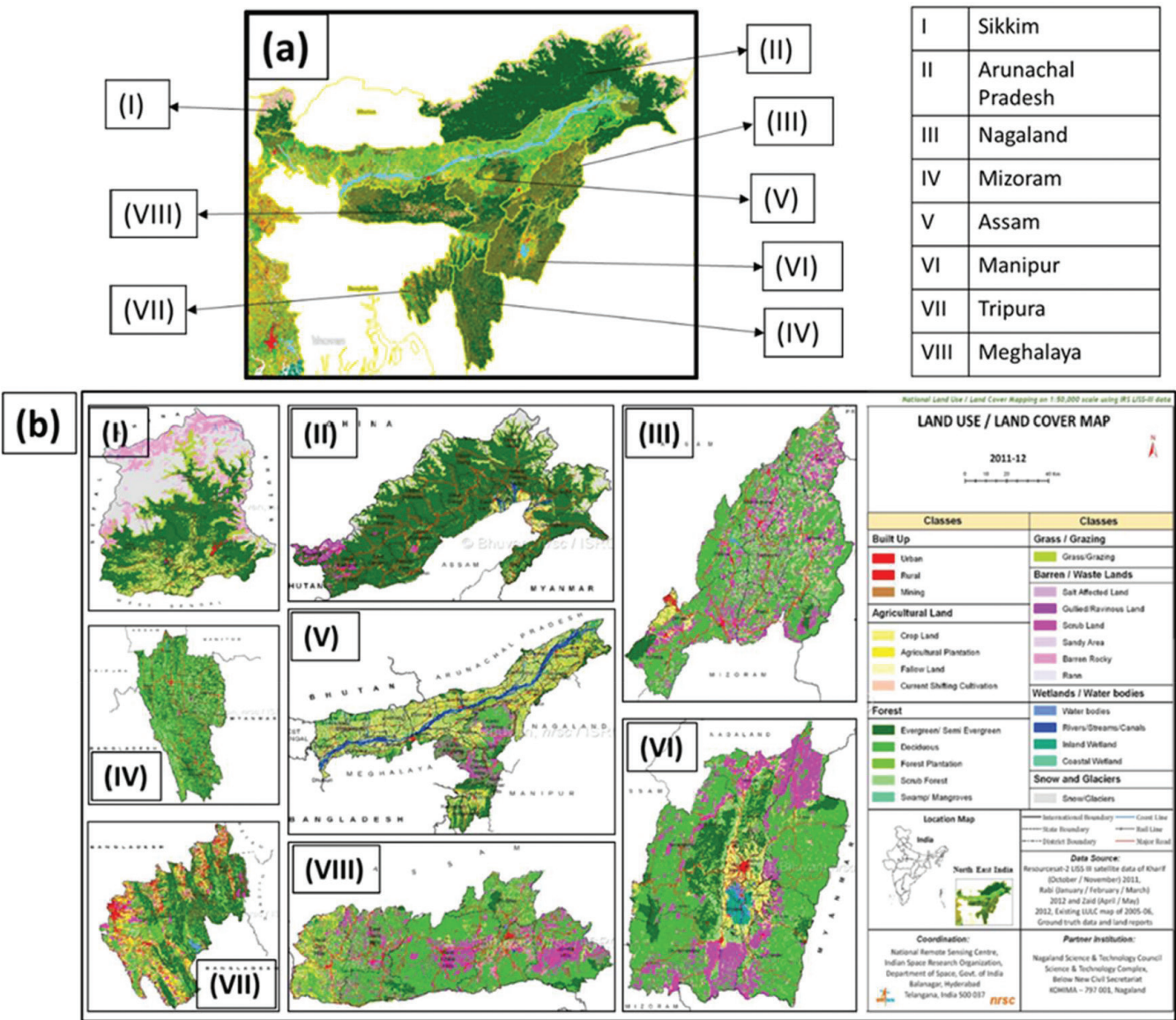


Figure 2: Land Use Land Cover (LULC) during 2011-2012, (a) over NEI, (b) over different states (i-viii); the red/pink colour shows the urban/rural land, yellow colour shows cropland. As Roy et al. (2015) already explain, LULC change of NE-India from 1985 to 2005.

precipitation due to decreased evapotranspiration through deforestation and hence LULCC. It is observed that LULCC over NEI has significantly encroached since 1985 (Roy et al., 2015). Both cropland and built areas have considerably increased since 1985. With the increase in traditional cultivation practices, forest cover has decreased and wasteland increase is also noted over NEI (Yadav and Kaneria, 2012; Roy et al., 2015). In general, these built-up areas provide strong feedback to thermal radiation (Meunier, 2007; Huber and Knutti, 2012; Jain et al., 2016a and 2016b). Theoretically, this feedback radiation gets absorbed by greenhouse gases (GHGs) and are radiated back into the

atmosphere, thus increasing the near surface temperature (global warming; Meunier, 2007). The same is shown for temperature climatology plots of the period before and after 1985 (Figure 3a and b). Figures 3a and 3b show temperature climatology for period I and period 2, respectively. However, the decreasing trend, though statistically insignificant, of temperature is noted over Assam, Meghalaya, Tripura, Manipur and Mizoram for period I (1956-1985), as shown in Figure 3c. But, Arunachal Pradesh, upper Sikkim and Nagaland have a small statistical insignificant increasing temperature trend (Figure 3c). Figure 3d shows a significantly strong increasing trend of temperature over whole NEI

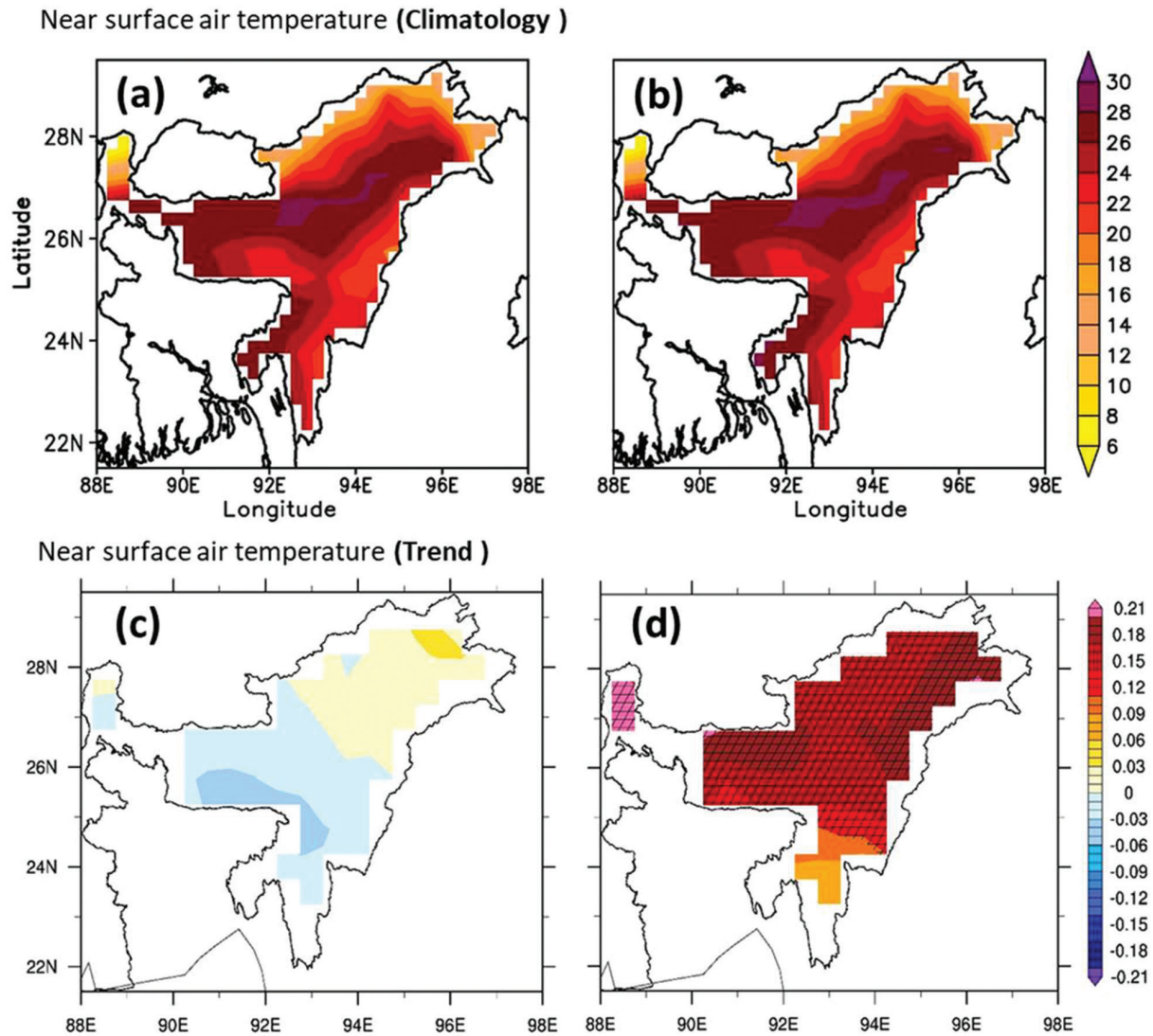


Figure 3: JJAS (June -September) temperature climatology ($^{\circ}\text{C}$) for 1956 -1985 (i.e., period I) and 1986-2015 (i.e., period II) (a and b). (c and d) The figures are same but for temperature trend ($^{\circ}\text{C}/\text{year}$) with 95% significance (hatched).

for period II. A significant average air temperature rising rate of $0.09\text{ }^{\circ}\text{C}/\text{year}$ is seen during period II. The temporal variation in air temperature averaged over each state with a small rising linear trend (no statistically significant) has been shown in Figure 4. A consistent variability in temperature changes is seen.

The cumulative precipitation climatology pattern for JJAS has changed from period I to period II (Figures 5a and b). The precipitation magnitude has also decreased over Arunachal Pradesh during period II (Figures 5a and b). In addition, the precipitation trend is noted to significantly increase over Meghalaya during period I but decreased over Arunachal Pradesh, Manipur and Nagaland (Figure 5c). Figure 5d shows a statistically

significant decreasing trend of precipitation over most parts of the NEI during period II. Kumar and Dimri (2018) have reported an increasing trend in the pre-monsoon (MAM) daily mean precipitation, but a decreasing trend in summer monsoon (JJAS) for 1970-2005 (Dimri et al., 2018). A significant mean decreasing rate of precipitation ($0.35\text{ mm}/\text{year}$) for period II is also noticed (Subash et al., 2011). The convective precipitation over the Brahmaputra basin insignificantly increased during period II than during period I, but a significant increase is noted over lower Arunachal Pradesh and Mizoram (refer to Supplementary Figure S2). The temporal variation of JJAS precipitation and its anomaly has also changed during a recent interval

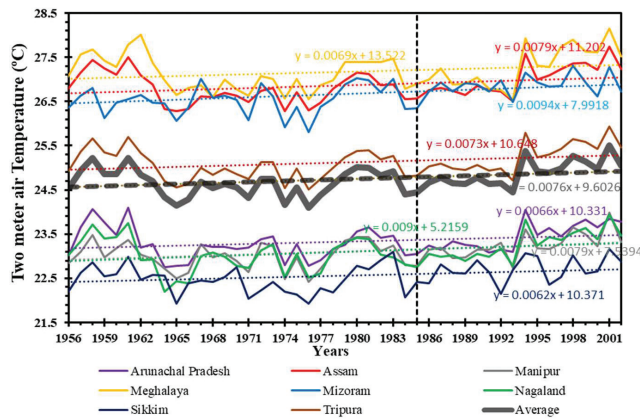
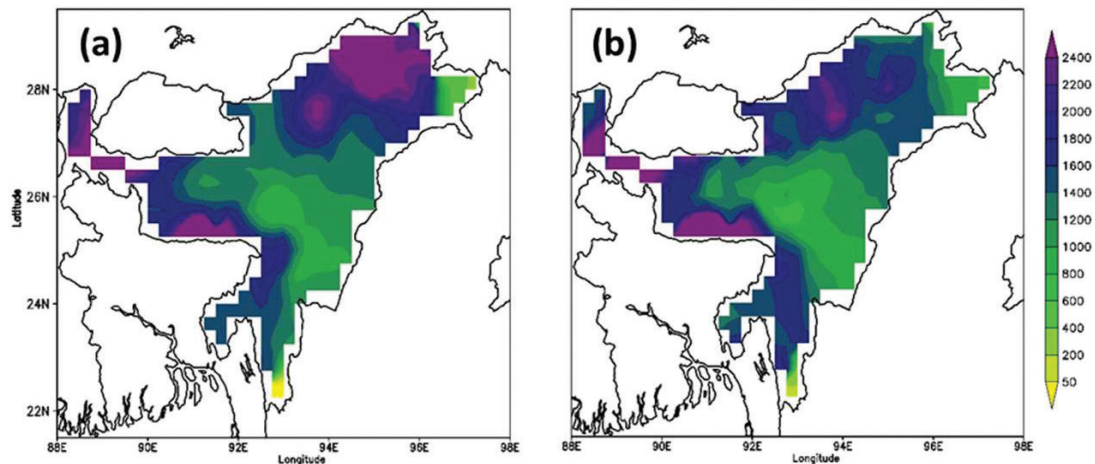


Figure 4: The temporal variation of 2m air temperature area averaged over corresponding states of NEI. The dot lines correspond to linear trends from 1956 to 2002 for the station data set.

of time (Figure 6). The precipitation fluctuation has decreased in comparison to the past interval of time (Figure 6). The climatology of surface sensible heat flux over the northern part of NEI (25° N and beyond) is positive (ranging 10-50 W/m²) for both periods. It suggests that heat is being transferred to the vicinity of the atmosphere. While values over the southern part of NEI (21- 25° N) are small negative (ranging between -2 and 10 W/m²) for both the periods (Figure 7a and b). Figures 7c and d) show that a statistically significant sensible heat flux trend pattern has changed from past to recent period. As shown in Figure 7d, a strong negative trend is found over the northern part of NEI. This suggests that heat is transferred to the Earth's surface. The rate of flux transferred is 0.12 W/m²/year, which is significant. Surface latent heat flux climatology has a similar pattern (except over Arunachal Pradesh)

Precipitation (climatology JJAS cumulative)



Precipitation (Trend)

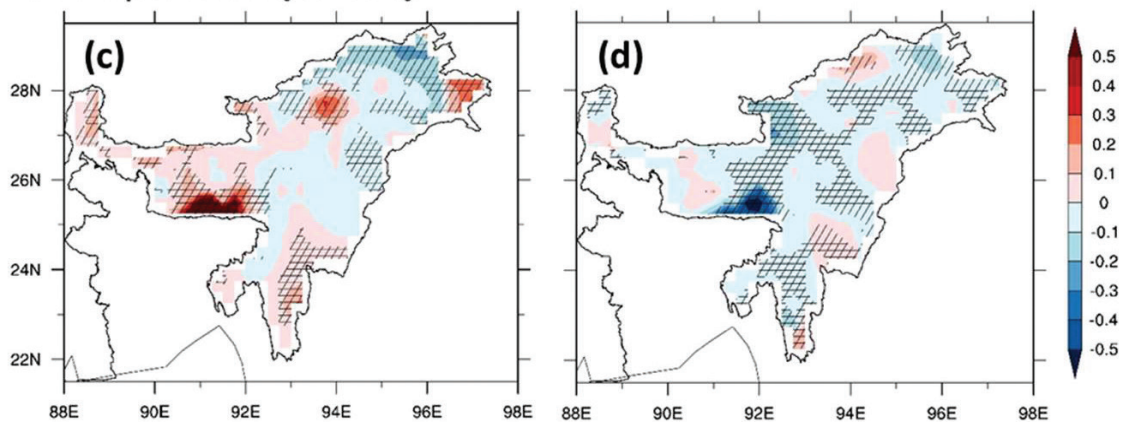


Figure 5: JJAS precipitation climatology (mm) for 1956 -1985 (i.e., period I) and 1986 -2015 (i.e., period II) (a and b). (c and d) The figures are same but for precipitation trend (mm/year) with 95% significance (hatched).

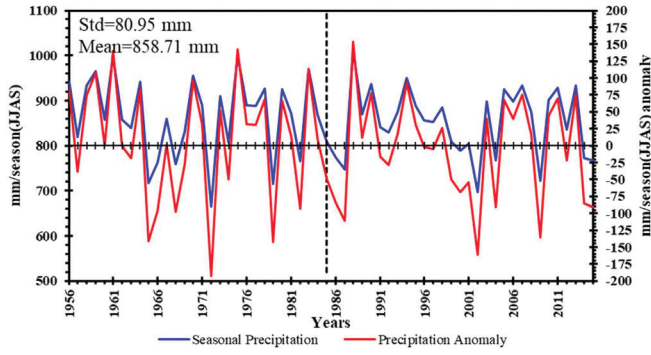


Figure 6: Accumulative seasonal (JJAS) precipitation and seasonal precipitation anomaly from long term mean (1956 to 2015) for IMD gridded data set, area averaged over NEI. (Standard deviation (Std) of period I = 87.01, period II = 75.39 and Mean of period I = 864.81, period II = 852.60).

for both periods (Figures 8a and b) (ranging between 60 and 160 W/m^2).

The latent heat flux is found higher along the Brahmaputra river basins (Li and Ma, 2015) and is observed to be highest over Kaziranga and Laokhowa national park region with averages $>140 \text{ W/m}^2$ (Chen et al., 2013). However, the statistically significant surface latent heat flux trend has completely opposite patterns. The latent heat flux trend for the recent interval is decreasing, which is statistically significant all over NEI (ranging between -0.03 to $-0.18 \text{ W/m}^2/\text{year}$). In addition to this, Earth's total energy imbalance is mostly dissipated in the terms of sensible and latent heat (Meunier, 2007). Due to anthropogenic emissions (aerosols and GHGs), the Earth's present energy imbalance is found to be 0.85 W/m^2 (Hansen et al.,

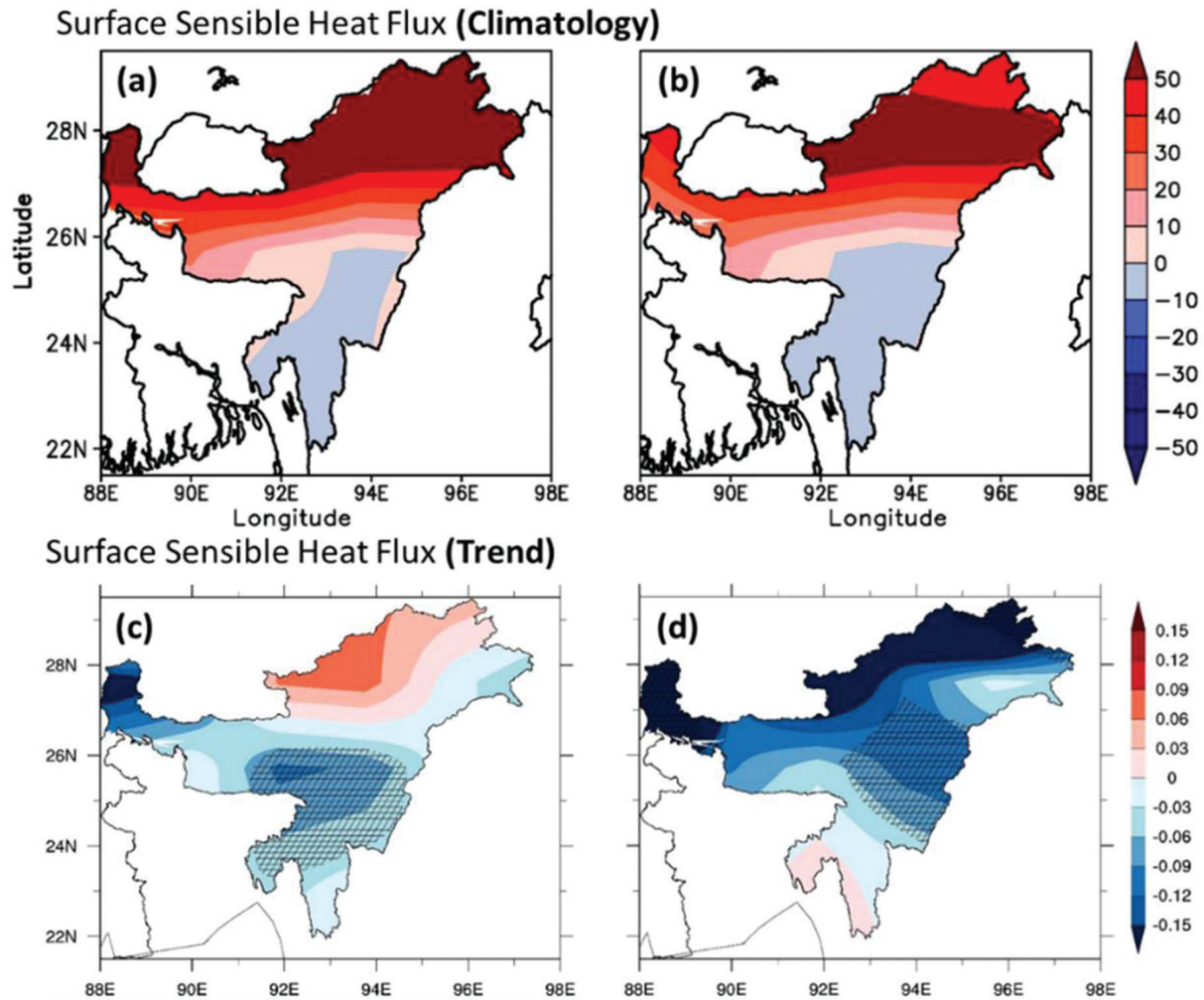
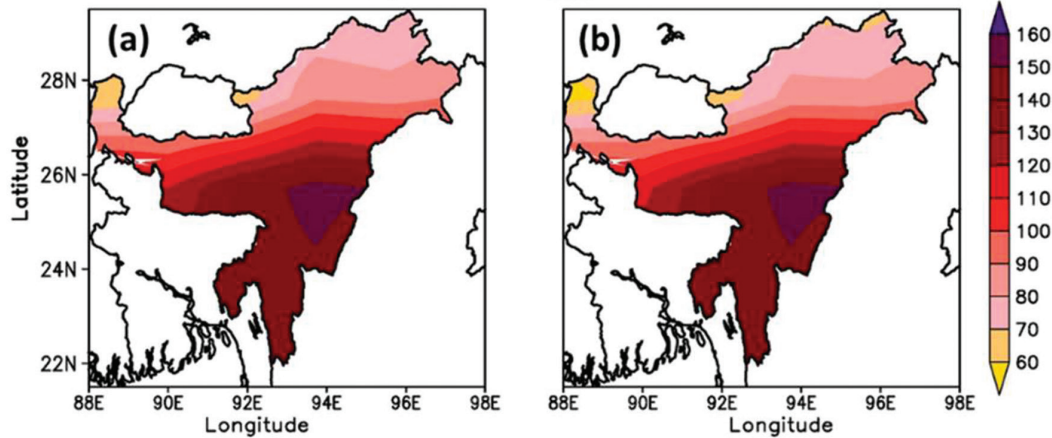


Figure 7: JJAS surface sensible heat flux climatology ($\text{W/m}^2/\text{day}$) for 1956 -1985 (i.e., period I) and 1986 -2015 (i.e., period II) (a and b). (c and d) The figures are the same but for ground heat flux trend ($\text{W/m}^2/\text{day/year}$) with 95% significance (hatched). (The trend values are shown as trend X100 for better representation).

Surface Latent Heat Flux (Climatology)



Surface Latent Heat Flux (Trend)

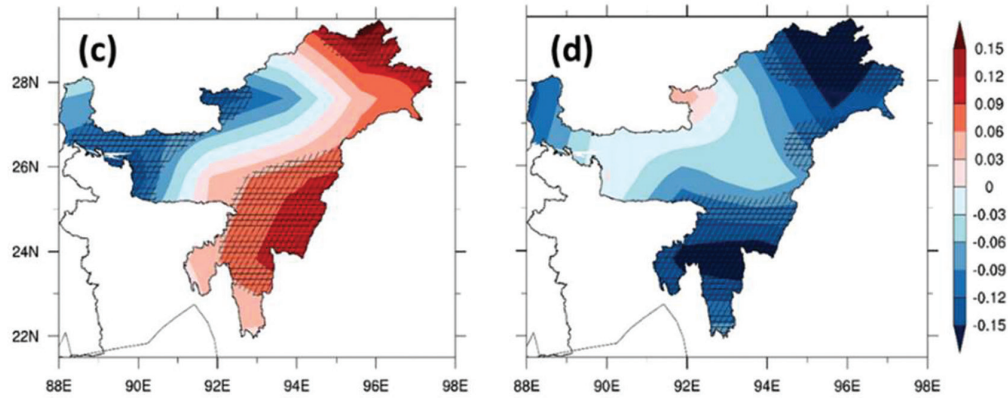


Figure 8: JJAS surface latent heat flux climatology ($\text{W/m}^2/\text{day}$) for 1956 -1985 (i.e., period I) and 1986 -2015 (i.e., period II) (a and b). (c and d) The figures are same but for ground heat flux trend ($\text{W/m}^2/\text{day/year}$) with 95% significance (hatched). (The trend values are shown as trend X100 for better representation).

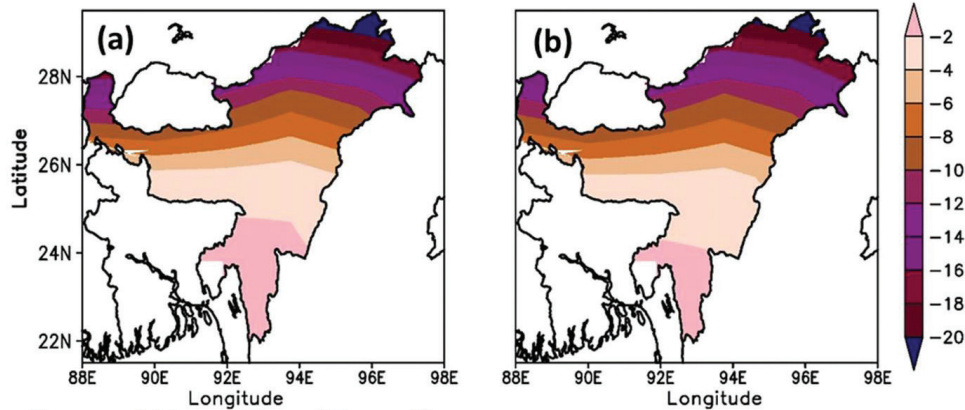
2005; Meunier, 2007). This is balanced through net solar and thermal radiation (refer to supplementary Figures S3 and S4). The climatology of ground heat flux has nearly similar patterns except over Mizoram and Tripura for both periods. The variations of ground heat flux range from -20 to -2 W/m^2 from the northern to the southern part of NEI (Figures 9a and b). The more negative values of ground heat flux are corresponding to the strong surface-soil temperature gradient (Oke, 1987). The surface must be less warm than soil (Sellers, 1969). Therefore, heat transfer takes place from soil to surface and to the vicinity of the atmosphere through conduction and convection, respectively (Sellers, 1969; Oke, 1987) (refer to Supplementary Figure S5). The surface ground heat flux trend with statistical significance shows a negative trend over most parts of the NEI for both periods (Figures 9c and d). Moreover, the recent interval shows a strong negative trend value in comparison to the past interval. In addition, a strong positive trend value is

found over Sikkim, which shows a completely opposite scenario from the rest of the region (Figure 9d). This suggests that the ground heat values are getting more negative every year over most parts of NEI.

Conclusion

The present study concludes that LULCCs, from 1985 to 2012 (Roy et al., 2015), over NEI have a notable impact on net radiation, evapotranspiration, convection, and monsoonal precipitation. The area under wasteland and cultivation has increased from the year 1985 to 2012 over NEI. A markedly strong increasing trend of temperature is observed over the entire NEI during recent time. Moreover, the striking average air temperature rising rate is found to be $0.09 \text{ }^\circ\text{C}/\text{year}$. The rise in the global temperature can also be seen in the Himalayan region. This study is all about the explanation of local forcing i.e., LULCC of

Ground Heat Flux (Climatology)



Ground Heat Flux (Trend)

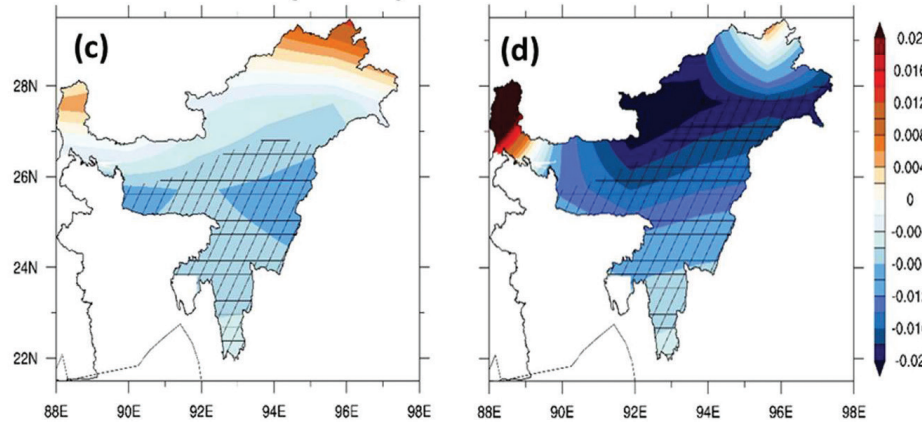


Figure 9: JJAS surface ground heat flux climatology ($\text{W/m}^2/\text{day}$) for 1956 -1985 (i.e., period I) and 1986 -2015 (i.e., period II) (a and b). (c and d) The figures are the same but for ground heat flux trend ($\text{W/m}^2/\text{day/year}$) with 95% significance (hatched). (The trend values are shown as trend X100 for better representation)

mountainous region influencing the convective, seasonal and sub-seasonal precipitation over NEI (Nayak et al., 2021). The monsoonal precipitation had significantly decreased in the recent period (1986-2015) than that in the past (1956-1985). The significant mean decreasing rate of precipitation is observed as 3.5 mm/day during the recent time (Subash et al., 2011). The Earth's surface sensible heat flux average significantly increasing rate is 0.12 W/m^2 . The latent heat flux is found to be higher along the Brahmaputra river basin and highest over the Kaziranga and Laokhowa national park region, with averages of $>140 \text{ W/m}^2$ (Chen et al., 2013; Li and Ma, 2015). The ground heat values are getting more negative year by year, over most parts of NEI. As the wasteland, deforestation and cultivation areas increase, more soil is exposed, loosened or left barren. With time, the soil moisture of barren land gets decreased, latent heat gets decreased and sensible heat increases (Sellers, 1969; Oke, 1987). This directly results in more ground heat

increment in comparison to the past period. This has led to reduced evapotranspiration, reduced convection, and resultant precipitation decrement during the recent period. This results in temperature and surface energy imbalance in the current climate change scenario (Rapp, 2014).

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Conflict of Interest

The author declares that there is no conflict of interest.

Authors Contribution

Pramod Kumar has derived the idea, executed the analysis and prepared the manuscript.

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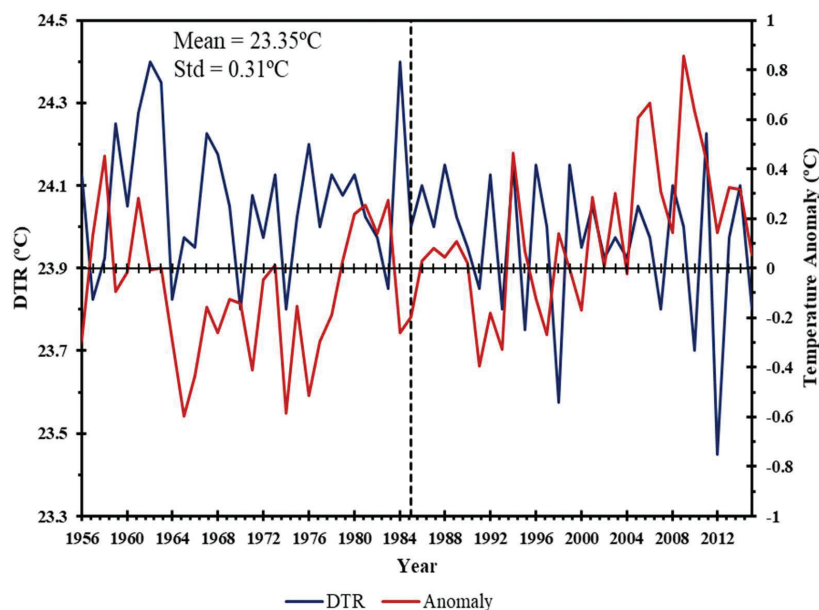


Figure S1: Diurnal temperature range (DTR) and 2m temperature anomaly from long term mean (1956 to 2015) for CRU gridded data set, area averaged over NEI.

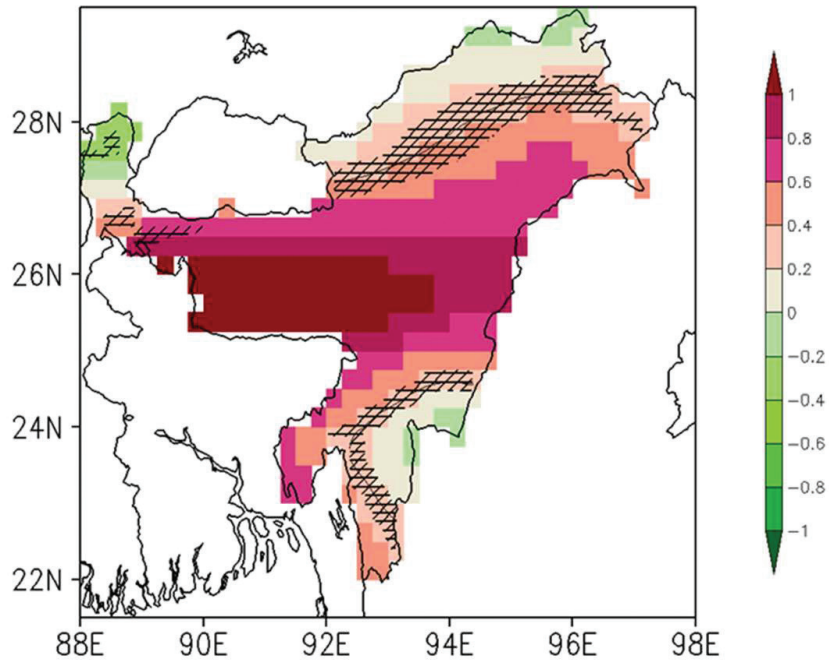
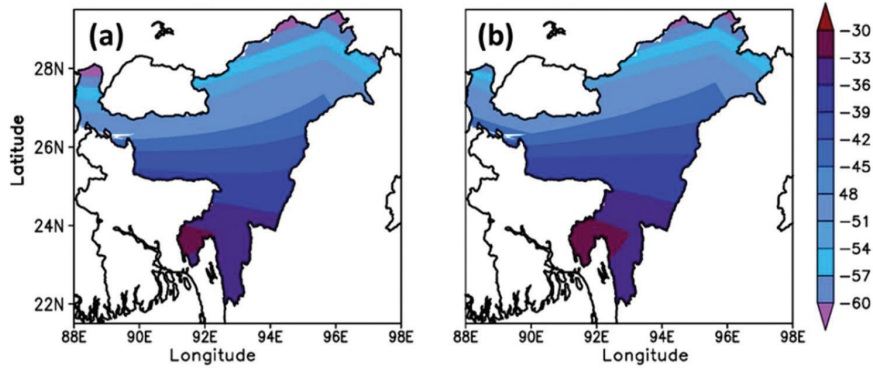


Figure S2: Convective precipitation difference recent to past (interval 1986 to 2015 minus interval 1956 to 1985) (mm/day) for JJAS at 95% significance in the pattern.

Surface Net Thermal Radiation (Climatology)



Surface Net Thermal Radiation (Trend)

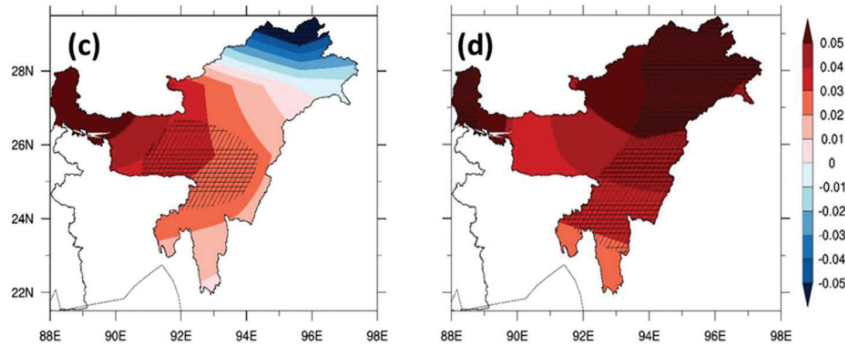


Figure S3: JJAS surface net thermal radiation flux climatology ($\text{W/m}^2/\text{day}$) for 1956 -1985 (i.e., period I) and 1986 -2015 (i.e., period II) (a and b). (c and d) The figures are the same but for ground heat flux trend ($\text{W/m}^2/\text{day/year}$) with 95% significance (hatched). (The trend values are shown as trend $\times 100$ for better representation).

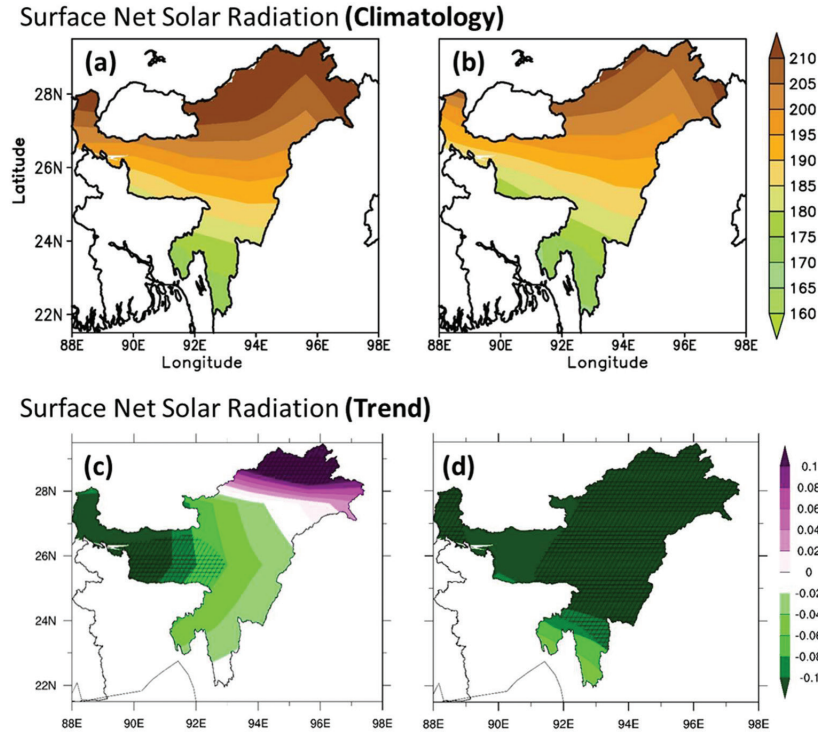


Figure S4: JJAS surface net solar radiation flux climatology ($\text{W/m}^2/\text{day}$) for 1956 -1985 (i.e., period I) and 1986 -2015 (i.e., period II) (a and b). (c and d) The figures are the same but for ground heat flux trend ($\text{W/m}^2/\text{day/year}$) with 95% significance (hatched). (The trend values are shown as trend X100 for better representation).

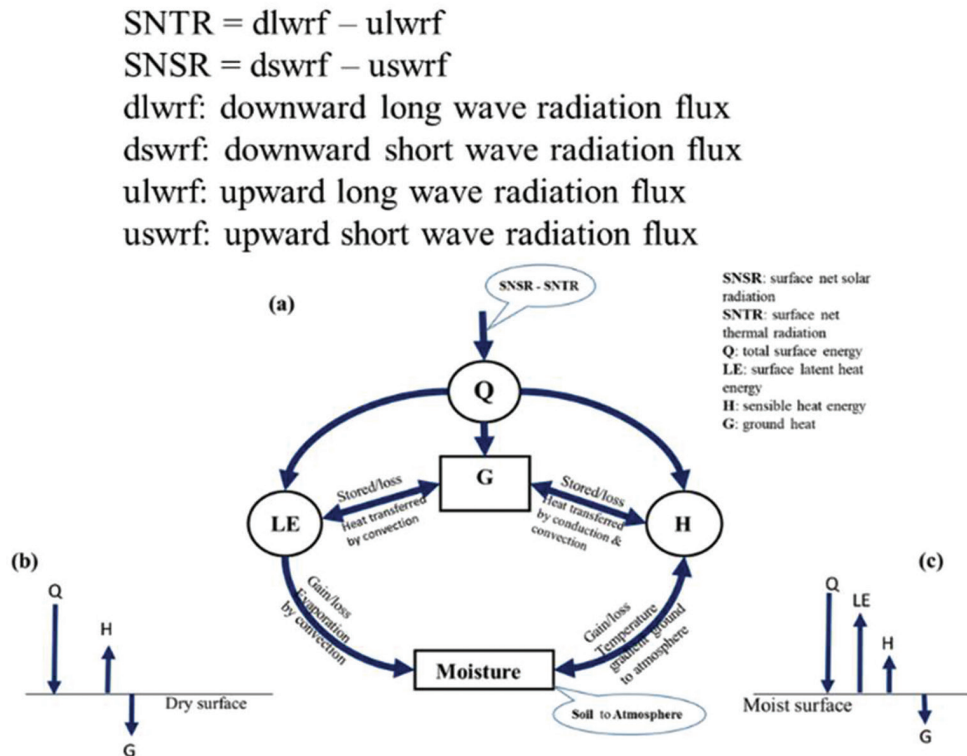
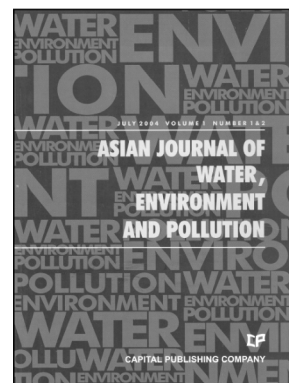


Figure S5: Schematic for the heat flux and energy transfer for dry and moist surfaces.

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Aims and Scope

Asia, as a whole region, faces severe stress on water availability, primarily due to high population density. Many regions of the continent face severe problems of water pollution on local as well as regional scale and these have to be tackled with a pan-Asian approach. However, the available literature on the subject is generally based on research done in Europe and North America. Therefore, there is an urgent and strong need for an Asian journal with its focus on the region and wherein the region specific problems are addressed in an intelligent manner. In Asia, besides water, there are several other issues related to environment, such as; global warming and its impact; intense land/use and shifting pattern of agriculture; issues related to fertilizer applications and pesticide residues in soil and water; and solid and liquid waste management particularly in industrial and urban areas.

Asia is also a region with intense mining activities whereby serious environmental problems related to land/use, loss of top soil, water pollution and acid mine drainage are faced by various communities.

Essentially, Asians are confronted with environmental problems on many fronts. Many pressing issues in the region interlink various aspects of environmental problems faced by population in this densely habited region in the world. Pollution is one such serious issue for many countries since there are many transnational water bodies that spread the pollutants across the entire region. Water, environment and pollution together constitute a three axial problem that all concerned people in the region would like to focus on.

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