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Analysis of Land Air Temperature Variability and Climate Change

A case study of Bangladesh

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ABSTRACT: *Monthly time series (1971 to 2007) of Land Air Temperature (LAT) data were analyzed for Bangladesh. Monthly mean LAT anomalies and synoptic anomalies were determined for analyzing the LAT variability. The effect of El Nino and La Nina were also observed by using synoptic anomalies of LAT anomalies. Positive trend of LAT was established from the 37 years (1971-2007) LAT data by using synoptic anomalies. Statistical model was used to find out the best probability distribution function (PDF) for the selected study area. The warmer or cooler trends of LAT were discussed and the Log-normal curve was selected as the best-fitted PDF curve for Bangladesh. From the trends analysis it was deduced that the weather of Bangladesh getting warmer.*

KEYWORDS: *Climate change, Land Air Temperature (LAT), Environment, Temperature variability, Probability Distribution Function (PDF), Meteorology, Thermodynamics, Atmosphere and Weather*

Introduction

Determining the long-term variability in sea surface temperature (SST) and land air temperature (LAT) is important. They provide information about ocean current flow, probable distribution of sea life and land life, global energy budget, and weather and climatological trends. The use of estimated SAT has provided an enormous leap in our ability to view the spatial and temporal variation of LAT. Scientists have long yearned to decipher all the physical processes occurring in the ocean and land surface area. Over the past century, researchers have been analyzing LAT and SST variability (Xue and Shukla, 1996; Caron and O'Brien, 1998; Chelton and Davis, 1982; Smith et al., 1996; Chu et al., 2000). Interannual variability in LAT and SST has mainly been attributed to local thermodynamic interactions between the atmosphere and land and ocean (Gill and Niiler, 1973; Frankignoul and Reynolds, 1983; Frankignoul, 1985; Battisti et al., 1995, Delworth, 1996). Therefore, many researchers developed models by using SST and near-surface air temperature anomalies. To enable longer-term modeling, such models have been compared to atmospheric general circulation models (AGCM), simulations in which the land atmosphere is coupled to an ocean model in which the climatological SSTs are specified as boundary conditions (Bhatt et al., 1998; Saravanan and McWilliams, 1997). Comparatively less study has been undertaken of LAT variability arising from climate changes. Weare (1994) and Klein et al. (1995) showed that there is a strong positive feedback between anomalies in the large-scale temperature pattern and low-level stratus clouds: an increase in stratus clouds reduces the solar radiation reaching the surface, which reduces temperature and thereby increases the static stability of the boundary layer, a factor that tends to enhance cloudiness. Zhang et al. (1997) and Norris et al. (1998) have suggested that this positive feedback can lead to persistence of temperature anomalies from both summer to winter and winter to summer. Local processes within the upper ocean or land surface, such as the seasonal variation in the depth of the surface mixed layer, may also lead to temperature variability.

Bangladesh is one of the worst victim regions of climate change and El Niño/La Niña impacts. The existing geophysical and socio-economic setting of the country increases both the vulnerability and severity of the events discussed above. The country's agricultural economy depends mainly on climatic phenomena. Bangladesh is perhaps the most unique country in the world where casualties resulting from a cyclone can rise into the hundreds of thousands. For example, the October 1970 cyclone killed an estimated 500,000 people and the April 1991 cyclone killed an estimated 140,000. Sidr in 2007 fortunately landed at low tide. It killed an estimated 3,400 and damage cost was about USD450 million. Monsoon floods can devastate more than half the country causing damage in the billions of dollars. Nor'wester storms and tornadoes often demolish settlements in many parts of the country. There is a correlation between El Niño (above-normal SST) and La Niña (below-normal SST) events and variability of climatic phenomena (Islam et al., 2003). This study correlates El Niño/La Niña events and variability of climatic phenomena in the country, using the synoptic LATA.

Considerable efforts have been made to analyze LAT variability by using synoptic anomalies of LAT. Here, I use monthly mean LAT data from 1971 to 2007 for six divisions and the whole area of Bangladesh to understand the annual and seasonal variability of Bangladesh and develop statistical models for probability distribution function (PDF) of temperature anomalies.

Study Area and Basic Data

Bangladesh is a transition zone between Southwest and Southeast Asia. It forms the capstone of the arch formed by the Bay of Bengal, and because of the Tibetan plateau (massif) to the north, it is a comparatively narrow land bridge between the sub-continent of South Asia and sub-continent of Southeast Asia. More precisely, the country stretches latitudinally between 20° 34' N and 26° 33' N and longitudinally between 88° 01' E and 92° 41' E. To analyze the country-wide, divisional and also seasonal trends of LAT, monthly mean LAT data from 1971 to 2007 (total of 37 years) were collected from 34 different observatory stations of the Bangladesh meteorological department. We interpolated for some missing data by using a simple Gaussian technique to unify with other data.

Methology

Monthly Mean LAT Anomalies

Mean monthly anomalies were estimated by the following equations (Chu, P. C. et al., 1997, Islam, M. et al. 2005):

$$T_a(x_i, y_j, t_l) = T_m(x_i, y_j, t_l) - T_{em}(x_i, y_j)$$

$$T_m(x_i, y_j, t_l) = \frac{1}{\Delta_X}\sum_{1971}^{2007} T(x_i, y_j, X_k, t_l)$$

$$\Delta_X = 37 = [(2007 - 1971) + 1]$$

$$T_{em}(x_i, y_j) = \frac{1}{12}\sum_{l=1}^{12} T_m(x_i, y_j, t_l)$$

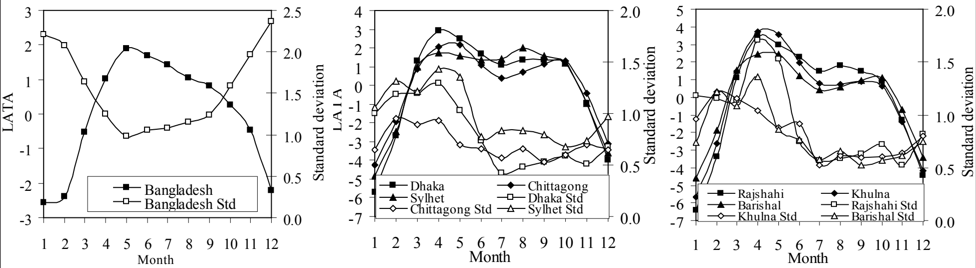
where, T_a represents mean monthly LAT anomalies (LATA), T_m long-term monthly mean, T_{em} ensemble mean of LAT. T represents the matrix of LATs in each of 34 observatory stations and 444 months; (x_i, y_j) is the station latitude and longitude; X_k (= 1971, 1972,......2007) is the time sequence in years, and t_l (= 1,2,.......12) is the monthly sequence within a year.

Synoptic anomalies were estimated by:

$$T_{sa}(x_i, y_j, X_k, t_l) = T(x_i, y_j, X_k, t_l) - T_m(x_i, y_j, t_l)$$

where, T_{sa} represent synoptic anomalies. Figure 1 plots the long-term LATA average and the standard deviation for LATA for the whole country and the six (old) divisional regions: Dhaka, Chittagong, Sylhet, Rajshahi, Khulna, and Barisal. From March to October the LATA are positive for all divisions; from November to February they are negative. For Bangladesh overall and most divisions, the standard deviations of LATA observations in summer months are lower than in winter. The synoptic LATA plots depict months that are warmer or cooler than the climatic normal for the particular month.

Figure 1: Long-term LATA average for whole country and six divisions



(a) Whole Bangladesh (b) Dhaka, Chittagong, Sylhet Division (c) Rajshahi, Khulna, Barishal Division

The monthly synoptic LATA variations over the whole area of Bangladesh for the years 1971 to 2007 are shown in Figure 2. From this figure, the trend of monthly mean temperature can be calculated. The zero line parallel to the horizontal-axis indicates the climatic average LAT for each observation station for each month. The trend line equation (5) was derived from synoptic LATA (in Fig. 2) as follows:

$$\left.\begin{aligned} TL &= 0.0016x - 0.36 \\ \text{where } x &= T_{sa} \end{aligned}\right\} \tag{5}$$

The trend line shows a positive gradient: 0.0016°C/month, which indicates that Bangladesh weather has been getting warmer over the four decades. Bangladesh seasons are broadly classified as winter or northeast monsoon, summer or pre-monsoon, southeast monsoon or monsoon and autumn or post monsoon (Habib, A. 2011). Seasonal synoptic LATA were also obtained by using Eq. 4. for winter or northeast monsoon (December to February), summer or pre-monsoon (March to May), southeast monsoon or monsoon (June to September) and autumn or post-monsoon (October to November) (Habib, A. 2011). Seasonal variations of synoptic LATA for the four seasons are shown in Figure 3.

Figure 2: Synoptic anomalies for Bangladesh from 1971 to 2007

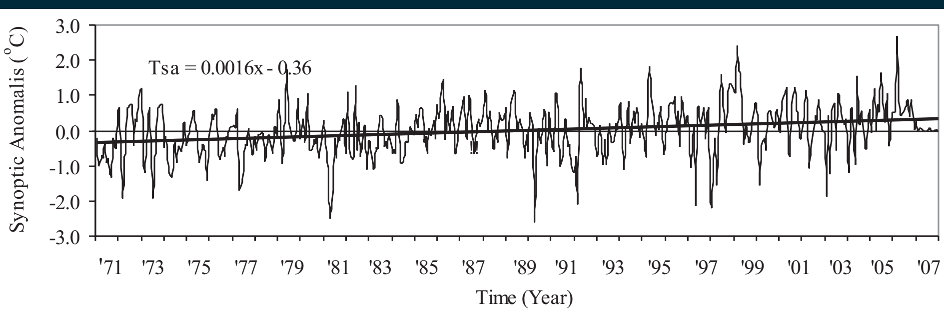
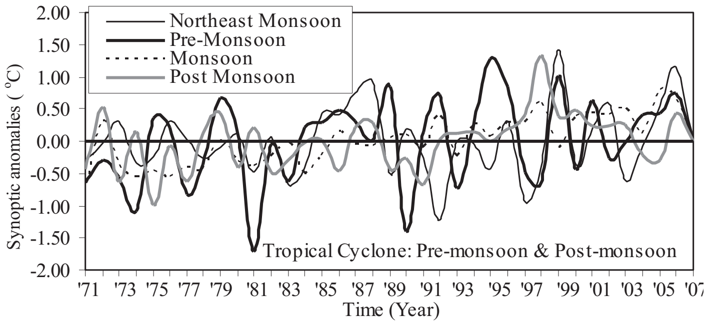


Figure 3: Seasonal Synoptic Anomalies

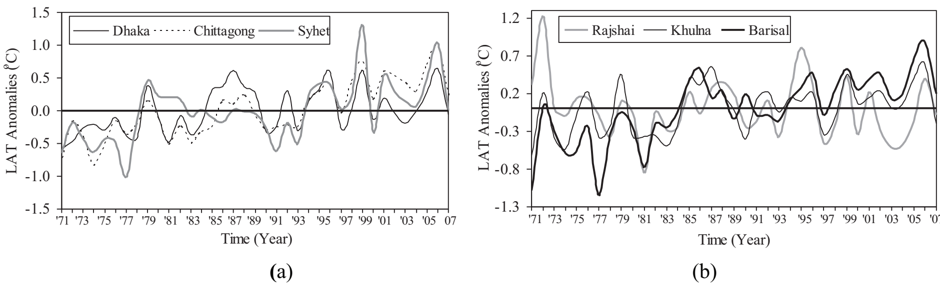


Effect of El Niño and La Niña on SSTA

Scientists have found complex correlations between El Niño/La Niña events and variability of climatic phenomena. Such events are associated with higher incidence of natural disasters, such as those mentioned above. The changes in LAT and SST are caused by local heat exchange and heat transport in accordance with advective diffusivity in the land area and ocean. The biennial variation of SST is largely related to the marked climate change systems, such as El Niño Southern Oscillation (ENSO), the biennial change of monsoon and rainfall in tropical ocean. ENSO is a biennial see-saw in tropical sea level pressure between the eastern and western hemisphere with the center of action located over Indonesia and the tropical South Pacific Ocean (Philander, 1999). The Southern Oscillation Index (SOI) is the sea level pressure difference between Darwin (12.4°S, 130.9°E) in northern Australia and Tahiti (17.5°S, 149.67°W) in the South Pacific Ocean. Large negative values indicate a cool event (La Nina) and large positive values indicate a warm event (El Nino). Fig. 3 shows the positive and negative values of synoptic anomalies with time period from 1971 to 2007 for different monsoon seasons, and Figure 4(a) and (b) show the long-term temperature anomalies for the six division of Bangladesh. The comparison between El Niño and La Niña events (years) and their effects on the temperature variations are summarized in Table 1 (see Fig. 4). .

Figure 3 exhibits negative anomalies for pre-monsoon and northeast monsoon in 1997-98. The pre-monsoon period is characterized by cyclogenesis in the Bay of Bengal. In this period, a depression may develop into a cyclone. Cyclones travel generally northwest initially, and then turn to the northeast towards the coast of Bangladesh and Myanmar. Some of these storms may attain hurricane intensity and are associated with storm surges. (A devastating cyclone hit Bangladesh in April 1991.) Figure 3 exhibits positive synoptic anomalies for post monsoon, pre-monsoon and northeast monsoon and normal for monsoon season in the year of 1988-89 periods.

Figure 4: temperature anomalies for six division of Bangladesh



Statistical Analysis

Mean Value and Standard Deviation

We estimated the mean, variance and standard deviation of monthly mean LAT for the six divisions of Bangladesh. Figure 5 shows the plots of standard deviation and monthly mean LAT average over the selected area of each division. A high mean value temperature indicates warm weather and low mean value indicates cooler weather. A high standard deviation indicates frequently changing weather and low standard deviation indicates more stable conditions (Islam and Sado,2002). On the basis of this model the summarized results are shown in Table 2

Probability Distribution Model

We have estimated relative frequency of monthly mean LAT data for all stations over the countries. Four probability frequency distributions (PDFs) were considered as options for modeling (Caron and O'Brien, 1998). PDFs provide meaningful probability information for the distribution of each LAT (Bendat and Piersol, 1986, Montgomery and Runger, 1999). The four PDFs fitted were the Normal (Gaussian), Log-normal, Extreme values distribution (maximum and minimum).

Figure 5: Monthly mean and standard deviation of LAT

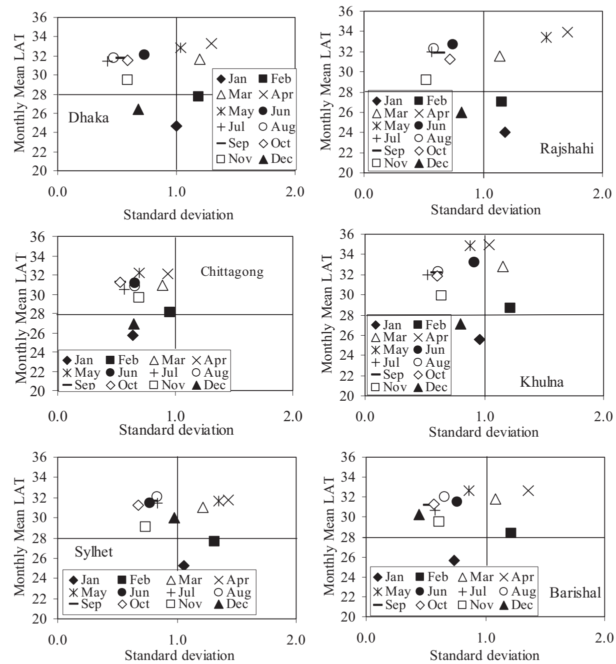


Table 1: Results from mean temperature and standard deviation model for six divisions

	High Temperature (T>28'C)		Low Temperature (T<28'C)	
Divisions	**Stable (std dev. <1)**	**Unstable (std dev. <1)**	**Stable (std dev. <1)**	**Unstable (std dev. <1)**
Dhaka	Jun, Jul, Aug, Sept, Oct	Mar, Apr, May	Dec	Jan, Feb
Chittagong	Mar, Apr, May, Jun, Jul, Aug, Sept, Oct, Nov		Dec, Jan, Feb	
Sylhet	Jun, Jul, Aug, Sept, Oct, Nov	Mar, Apr, May		Dec, Jan, Feb
Rajshahi	Jun, Jul, Aug, Sept, Oct	Mar, Apr, May	Dec	Jan, Feb
Khulna	Jun, Jul, Aug, Sept, Oct, Nov	Feb, Mar, Apr	Dec, Jan	
Barishal	May, Jun, Jul, Aug, Sept, Oct, Nov, Dec	Feb, Mar, Apr	Jan	

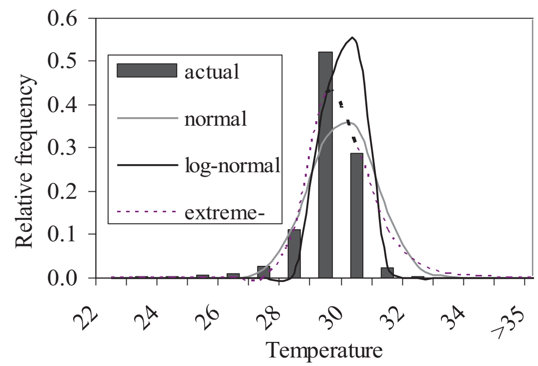
T: Mean Temperature, std dev.: standard deviation of mean temperature

PDFs have the important characteristics that

$$\sum F(x)\Delta x = 1 \qquad (6)$$

where, F(x) represents the probability and Dx is the sampling interval. The relative frequency of monthly mean LAT for whole area of Bangladesh was estimated, and each of the above four PDFs was fitted to the data. The root mean square error (RMSE) displayed the best fit in the case of the following log-normal [x=0.8769(logT-3.342): N(0, 1)], with RMSE=0.038°C, as shown in Figure 6.

Figure 6: Probability distribution functions for best-fitted curve of relative frequency of LAT



Results and Discussion

The monthly means LATs have been analyzed to observe the characteristics of the LAT pattern for the six divisional regions and the whole country. The linear relations between predicted and observed values for frequencies are shown in Figure 6.

Mean Value and Standard Deviation

Monthly mean values of standard deviation for LATA for the whole country (in Fig. 1(a)) decrease from highest (2.07°C) in January to lowest (0.98°C) in May, and increase from lowest in May to highest (2.37°C) in December; monthly mean LATA values follow the reverse curve from January to December [Fig. 1]. But for different divisional data, standard deviation curves maintain the same characteristics with LATA curves (in Fig. 1(a) & 1(b)) except the month of January to March. All six divisions of Bangladesh exhibit high monthly mean temperature (>28°C) for six months of the year with stable weather. Dhaka, Chittagong, Sylhet and Rajshahi show the unstable weather with high temperature in the months of March, April and May while Khulna and Barishal show the unstable weather with high temperature in the month of February, March and April [Fig. 5 and Table 1].

Anomalies

The synoptic LATA (in Figure 2) shows the positive slope of the trend line, which indicates the increase of temperature with time. Monthly mean LAT variation ranges from –2.6° to +2.7°C shown in Figure 2. No variation in mean temperature over the 37 years would yield a trend line following the zero line. However, the fitted trend has a positive coefficient of 0.0016°C per month. That implies an increase in predicted mean of 0.71°C from 1971 to 2007.

Seasonal Variation of Anomalies

Figure 3 shows that the northeast monsoon period exhibits the highest positive (1.42^{o}C) synoptic anomalies, followed by the post-monsoon periods of 1999 and 1998, while the highest negative (1.71^{o}C) synoptic anomalies are exhibited for the pre-monsoon period in 1981 followed by the pre-monsoon period in 1990 and by northeast monsoon period in 1992. Figure 4 shows the variation of LATA for six different divisions of Bangladesh. Among the six divisions, Sylhet shows the significant variation of temperature from climatic normal (1.3^{o}C to -1^{o}C) compare with others divisions followed by Rajshahi division (1.2^{o}C to -0.8^{o}C).

Effect of El Niño and La Niña Analysis by Synoptic LATA

Both El Niño and La Niña impact global climate patterns. In many locations, especially in the tropics, La Niña (cold episodes) produces the opposite climate variations from El Niño (warm episodes). For instance, parts of Australia and Indonesia are prone to drought during El Niño, but are typically wetter than normal during La Niña. La Niña is characterized by unusually cold ocean temperatures in the equatorial Pacific, as compared to El Niño, which is characterized by unusually warm ocean temperatures in the equatorial Pacific. Typically, a La Niña event is preceded by a buildup of cooler-than-normal subsurface waters in the tropical Pacific. Eastward-moving atmospheric and oceanic waves help bring the cold water to the surface through a complex series of events still being studied. In time, the easterly trade winds strengthen, cold upwelling off Peru and Ecuador intensifies, and sea-surface temperatures (SSTs) drop below normal. Table 1 shows the effect of El Nino and La Nina on Bangladesh over the years, which was summarized from the Fig. 3 and Fig. 4 considering whole area of Bangladesh for different monsoon seasons and for six different divisions. Figure 4 shows the positive synoptic anomalies in the period of El Nino years; 1986-1987, 1994-1995,1997-1998 and 2001-2002 and negative synoptic anomalies in the period of La Nina years; 1973-1974, 1975-1976, 1984-1985 for six divisions of Bangladesh (Table 1).Considering the above mentioned results, it can be comprehended that the effect of El Niño and La Niña by analyzing Synoptic LATA can be apprehended.

Concluding Remarks

The area of different divisional areas experience different weather conditions. The trends of LAT are related to the changes in air circulation and local thermodynamic interactions between the atmosphere and upper surface of the lan and Ocean (Gill and Niiler, 1973; Frankingnoul and Reynolds, 1983; Frankingoul, 1985; Battisti et al., 1995; Delworth, 1996). Our selected study area is therefore influenced by local thermodynamics and the circulation system of Bay of Bengal and Indian Ocean. That is why we have divided whole Bangladesh into its old six divisional region of Dhaka, Chittagong, Sylhet, Rajshahi, Khulna and Barisal. Summarizing, our results suggest that the existence of warming trends of LAT in Bangladesh and of its six divisions also. The variation of LAT is very much scattered for Sylhet then followed by Rajshai and Barisal.

The standard deviation and mean value for LAT and LATA corresponding with the month of January to December show good correlation with the stable weather with high temperature (LATA with month and standard deviation in Fig. 1(b) and (c) show the values decreasing from highest to lowest and increasing from lowest to highest, respectively) except the month of February to May which exhibit unstable weather with high temperature (in Table 1) (cyclone normally hits Bangladesh in this period. Using monthly mean LAT and standard deviation the seasonal variation such as northeast monsoon (winter), pre-monsoon (summer), southeast monsoon (monsoon) and post-monsoon (autumn) also can be co-related and comprehended. PDFs could be also modeled for seasonal variation and also for a particular month separately. LAT variability and the effect of El Niño and La Niña were observed by using synoptic LATA. Therefore, the long-term LAT variability and the effects of El Niño and La Niña can be comprehended by using the synoptic anomalies of LAT and SST of Bay of Bengal and Indian Ocean.

The analysis of Effect of El Niño and La Niña and analysis of cold and warm episode not only depends on temperature but also depends on wind stress, rainfall and SST. Therefore, to study climatic change and the effect of El Niño and La Niña in the region, abovementioned data have to be correlated and analyzed by using cross correlation method.

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