Journal of Agroforestry and Environment

Volume 15, Issue (1), 2022

Journal DOI: https://doi.org/10.55706/jae
Journal homepage: www.jagroforenviron.com

Synoptic Climatology of Air Temperatures behind Extreme Cyclone Events over the Bay of Bengal of Southern Bangladesh

M.A. Farukh[1]*, M.A.M. Hossen[2], M.A. Badhan[3], M.S.H. Sarker[4] and A.C. Das[1]

[1]Department of Environmental Science, Bangladesh Agricultural University, Mymensingh, Bangladesh.
[2]Nippon Koei Bangladesh Ltd., Dhaka, Bangladesh.
[3]Department of Disaster Management, Begum Rokeya University, Rangpur, Bangladesh.
[4]Ceres Agro farming Ltd., Dhaka, Bangladesh.

*Correspondence: farukh_envsc@bau.edu.bd, Tel: +8801712106603

Received: 14/05/2022

Accepted: 23/05/2022

Available online: 29/05/2022

Abstract: Cyclones have occurred more frequently in recent decades in a disaster-prone country like Bangladesh. Twenty-two (22) extreme cyclone events that occurred from 1975-2014 were investigated in this study with respect to air temperature climatology. Air temperature, sea level pressure, rainfall, relative humidity (R_{hum}), and sunshine hours (SS_{hr}) have been analyzed to find out the impact of air temperatures behind cyclogenesis. Historical cyclone data were obtained from Bangladesh Meteorological Department; Bangladesh Bureau of Statistics and Disaster Preparedness Centre (AIT). Historical weather data was collected from the Climate Division of BMD. Principal Component Analysis (PCA) and Clustering were used to find out the whole atmospheric air temperature impact on cyclogenesis. The NCEP–NCAR reanalysis data were used to find out the distribution of air temperature anomaly over Bangladesh and Bay of Bengal (BB). Among the 22 cyclones, cluster 2 belongs to 9 cyclones and cluster 3 comprises of 12 cyclones. Clusters 2 and 3 indicate that temperatures of about 34 to 35°C were mostly responsible for the formation of a total of 21 cyclones from 1975 to 2014. The existence of a relatively cooler zone (strong negative anomaly) near to surface level, in association with a relatively warmer zone (strong positive anomaly) at 850, 700, 500, and 300hPa level were firmly responsible for cyclogenesis over BB. The larger, warmer air mass in the upper atmosphere could have a significant impact on the development of huge instability throughout the entire atmospheric column, potentially leading to the formation of extreme weather phenomena such as severe cyclones in southern Bangladesh.

Keywords: Air temperature anomaly; Clustering; Cyclogenesis; Synoptic climatology.

INTRODUCTION

Extreme weather events in regard to climate variability affect society more than changes in the mean climate (IPCC, 2001), implies a visible human influence on global climate (AR4, 2007). It is predicted that, Bangladesh may suffer the most severe impacts of climate change (Akter and Ishikawa, 2014) with numerous extreme weather events. The impact of higher temperature with more extreme weather events such as floods, cyclone, lightning, severe drought etc. are already being felt in south Asia (Huq et al., 1999; Ali, 1999). The southern regions of Bangladesh have already faced some super cyclones in recent past where, the northern areas are impacted by drought almost every year. The southern coastal regions of Bangladesh experiences cyclone almost every year and suffers some havoc destruction. Literature shows that, changes in temperature played a great role to cause such disastrous cyclones in the southern coastal regions especially over Bay of Bengal (BB) of Bangladesh.

A couple of studies conclude that one of the main reasons behind cyclone occurrence is the temperature extremes (Mearns et al., 1984; Hansen et al., 1988). Alexander et al. (2006) described that annual trend in the lowest and highest daily minimum and maximum temperatures in the latter half of the 20th century increased at many locations throughout the world. Moreover, global warming ranging between 1.4 to 5.8°C is expected by the end of the 21st century (IPCC, 2007), which could also lead to an increase in temperature extremes. Few researches on Bangladesh context (e.g., Mahtab, 1989; Pramanik, 1983; BCCCSP, 1997; Farukh and Baten, 2015) have the same view that Bangladesh is one of the foremost countries extremely susceptible to the unpleasant effects of extreme temperature events. The average annual temperature of Bangladesh is expected to increase by 1.4 ± 0.6°C by 2050 (IPCC, 2007; MoEF, 2008). The BUP-CEARS-CRU (1994) study reported 0.5 to 2.0°C rise in temperature by 2030. Again, the greater the sunshine hour (SS_{hr}), the greater the temperature (Matuszko and Weglerczyk, 2014) though it depends on some other factors too. Jeglic (2006) reported July with the highest SS_{hr} in Slovenia, whilst Lorenzo et al. (2009) showed similar result in the Iberian Peninsula, Goodale et al. (1998) found highest SS_{hr} in May and June in Ireland. Conversely, in Bangladesh, SS_{hr} is the lowest in May and August (CDMP II, 2014). It has been said that the average total SS_{hr} is decreasing day by day which is also known as dimming around the world reported in many articles (Farukh et al., 2019; Singh et al., 2012; Sayeda and Nasser, 2012). It has been proved by several studies that increase in temperature increases the relative humidity (R_{hum}) (Lawrence, 2004; Skilling, 2009). The worldwide scenarios of R_{hum} shows the increasing trend over the years including Bangladesh (Islam, 2014; CDMP II, 2014) with the maximum in the southern Bangladesh (Saniruzzaman et al., 2015). This increasing R_{hum} possess severe effect on the occurrence of cyclone (Wu et al., 2012) with its intensification. As a variable-reduction procedure similar to factor analysis, Principal component analysis (PCA) and Clustering have been used effectively all over the world. PCA were successfully utilized in predicting flooding in Chile (Hebenstreit et al., 1985), run-up and back-wash with the wave front condition (Hibberd and Peregrine, 1979), synoptic climatology related to extreme snowfall (Farukh and Yamada, 2014) etc. Moreover, PCA assists to determine the number of components to retain, interpret the rotated solution, create factor scores, and summarize the results (Fernandez, 1995). Likewise, General circulation model (GCM) of a planetary atmosphere based on the Navier–Stokes equations is the main tool available for developing projections of an extreme weather event (Houghton et al., 2001). Despite continuous model development, GCMs still have systematic preferences in simulating the East Asian summer monsoon (Kang et al., 2002). Therefore, nowadays the use of GCMs for climatic variables is indispensable to assess extreme weather event like cyclone. Keeping these things in mind, the present study has been done to find out the synoptic climatology of extreme temperature induced cyclone events in Bangladesh.

MATERIALS AND METHODS

Study Area

Adjacent to the BB, the southern 16 coastal districts namely Satkhira, Khulna, Mongla, Khepupara, Barishal, Bhola, Patuakhali, Hatiya, Chandpur, Feni, Sandwip, Sitakunda, Chittagong, Kutubdia, Cox's Bazar and Teknaf were selected as study areas (Figure 1).

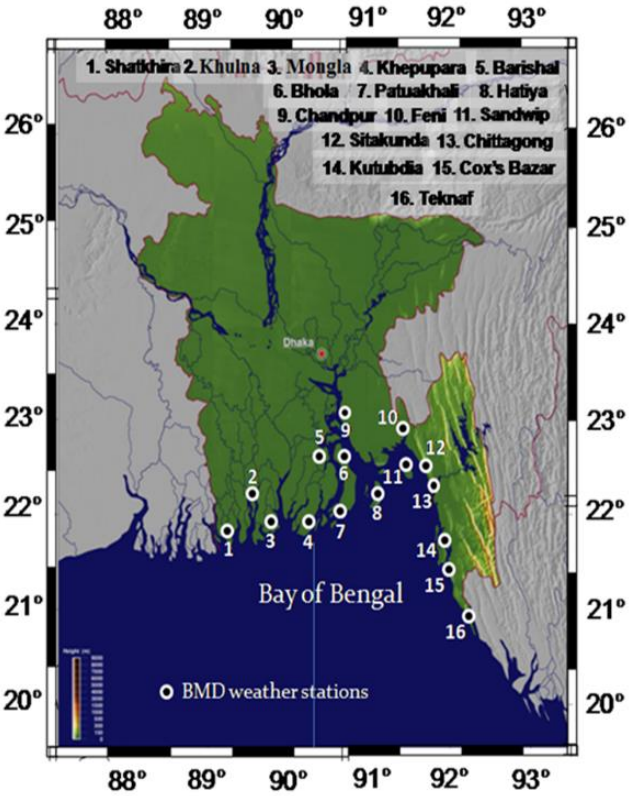

Figure 1. Study areas (numbered as 1 to 16 with while circles).

Weather Data

The data of climatic variables from 1975 to 2014 were collected from BMD at 16 measuring points (Figure 1).

Cyclone Data

Twenty-two (22) extreme cyclone events attacked on the southern coastal regions of Bangladesh were taken under investigation (Table 1). Here, the extreme cyclone event denotes the deadliest 22 cyclone occurring days from 1975 to 2014. Historical data of these tropical cyclones impacted on Bangladesh were collected from Disaster Preparedness Center, Asian Institute of Technology (AIT), Bangkok, and Bangladesh Bureau of Statistics (BBS).

General Circulation Model (GCM)

The daily air temperature dataset for the extreme 22 cyclone occurring days were obtained from Japanese 25-year reanalysis project (JRA-25) by the Japan Meteorological Agency (Onogi et al., 2007), encompassing the region 10°N–35°N by 75°E–110°E with a 1.125° spatial resolution. The composite mapping for GCM were done using the National Centers for Environmental Prediction (NCEP)–National Center for Atmosphere Research (NCAR) reanalysis project (Kalnay et al., 1996), which ensures a good resolution of atmospheric data with a grid of 2.5° resolution.

Principal Component Analysis (PCA) and Clustering

The PCA were carried out based on S mode data matrix (Yarnal, 1993), where the correlation matrix provided the

DOI: https://doi.org/10.55706/jae1502

most efficient representation of variance in the dataset (Barry and Carleton, 2001). The non-hierarchical K-means clustering was used to cluster the observations (Hair et al., 1998). To decide the number of groups and centroids, the spatial variation patterns established by PCA was considered, i.e., components in positive and negative phases as potential groups for circulation patterns were used. To create the centroids of the groups, Birkeland et al. (2001), and Tait and Fitzharris (1998) method were followed. Finally, the centroids were obtained from the average of the cases included into every group. The K-means also produces the final classification of all observations (days) with similar distribution of temperature. The synoptic maps of the atmospheric circulation groups were constructed for atmospheric variables firmly contributed to cyclone occurrences.

Table 1. Historical extreme cyclone events (22) from 1975 to 2014 in Bangladesh.

Year	Date	Impact Area	Impact SLP (hPa)	Temperature (°C)	Cluster Centroid
1975	9-12 May	Satkhira	995.7	41.7	1
1976	19-20 Oct	Barishal	996.7	32.2	2
1977	9-12 May	Khepupara	988.2	37.8	3
1978	30 Sep - 3 Oct	Feni	997.6	33.6	3
1983	15-Oct	Patuakhali	991.8	33.6	3
1983	9-Nov	Chand+Sat	994.7	30.0	3
1985	24-25 May	Satkhira	980.5	35.5	3
1986	9-Nov	Bhola	998.3	33.0	3
1988	29-Nov	Barishal	981.9	31.5	3
1990	7-8 Oct	Feni	1000.0	34.1	2
1991	29-Apr	Satkhira	980.2	34.7	3
1991	31 May - 2 Jun	Khulna	989.3	33.2	2
1994	29 Apr - 3 May	Satkhira	986.6	37.5	2
1995	21-25 Nov	Kutubdia	989.5	31.0	3
1997	16-19 May	Barishal	981.1	35.6	2
1997	25-27 Sep	Chandpur	981.0	33.5	3
1998	16-20 May	Mongla	984.1	38.8	2
1998	19-22 Nov	Bhola	999.6	33.0	2
2007	11-16 Nov	Hatiya	987.7	30.6	2
2008	26-27 Oct	Chandpur	996.0	36.2	3
2009	27-29 May	Cox's Bazar	979.8	36.5	2
2013	16-17 May	Satkhira	999.7	34.4	3

RESULTS AND DISCUSSIONS

Ensemble Means

Figure 2 (a) represents the comparison of mean values of temperatures for 16 coastal areas of Bangladesh. It is seen from the figure that, except Satkhira, Khulna, Mongla, Cox's Bazar and Teknaf, the other 11 stations showed almost homogenous trend from July where the temperature was 27.5 to 28.5°C. Cox's Bazar and Teknaf shows little deviation of temperature than that of others areas. The total mean of July (28.04°C) also indicates moderately warm days in monsoon in the coastal regions. In July and August, all the stations show rising of temperatures, except Satkhira, Mongla and Khepupara. In Cox's Bazar, the trend has dropped in September to October and rises again in late October. Farukh and Baten (2015) reported that the months of September and October is mostly vulnerable for cyclone occurrence. In fact, more than 50% of cyclone from 1952-2010 has occurred in these months (Ali, 1999; Farukh and Baten, 2015). Shamsad et al. (2012) reported that, an increase of 0.5°C temperature from August to September may accelerate an average of 40% cyclonic activity. Ali (1999), Farukh and Baten (2015) again in their study stated that, March to June is the 2nd most vulnerable duration for cyclogenesis whilst, around 45% cyclone from 1952-2010 has been reported during this period.

The figure 2(b) represents the ensemble means of SLP for 16 stations. The figure illustrates that, the SLP was decreasing from January and got the lowest in June. SLP was increasing slightly in September and then a rapid increasing was observed from October to December. Among all the stations, the lowest SLP was observed in Khulna and the highest in Teknaf in June and July. The rapid change of SLP in September and October leads to a great possibility of extreme weather events like cyclone. Many researchers also agreed with the similar findings (Farukh and Baten, 2015; Chowdhury, 1992). March to June is the 2nd most vulnerable time for cyclogenesis where around 45% of all cyclones from 1952-2010 has occurred during this period (Ali, 1999) e.g., severe cyclone like *Aila*, *Komen* and *Royanu*. Rahman and Ferdousi (2011) stated that, one of the main causes of cyclone formation in BB is the presence of low pressure area. As the fluctuation of SLP

DOI: https://doi.org/10.55706/jae1502

was higher in the summer season, the possibility of cyclone occurrence also rises. The means of SS_{hr} for 16 stations have been represented in the figure 2(c). In July, SS_{hr} ranges from 3.12 to 4.15 hours whilst, from November to April, the mean lines are inhomogeneous with lots of fluctuations. Though SS_{hr} has no direct effect on cyclogenesisbut shows some positive relationship with the temperature (Matuszko and Weglerczyk, 2014). Figure 2(d) depicts mean values of relative humidity (R_{hum}) for 16 stations. The air temperature and R_{hum} has a good relation to each other (Lawrence, 2004; Skilling, 2009) whereas, R_{hum} inserts influence on the formation of cyclone (Kaplan and DeMaria, 2003; Emanuel et al., 2004; Hendricks et al., 2010; Kaplan et al., 2010). From the figure, it is clearly seen that all the stations show almost similar relationship at its starting point except Chittagong and Satkhira. In July and August, the entire trend is decreasing except Satkhira and Mongla. For the preceding months, the mean value has started to fall and continued up to February and March. The maximum R_{hum} is found in July (88%) which was much higher than the average (82%) for whole of Bangladesh (BBS, 2009). Both the durations from August to October (84~88%) and from May to June (82-86%) indicate favorable environment for cyclogenesis as Wu et al. (2012) showed and in fact, during these seasons the southern parts of Khulna, Mongla, Khepupara and Barisal possess deep depression zones with huge R_{hum} to form cyclones. Figure 2(e) shows the ensemble means of rainfall with the lowest in Sitakunda and the highest in Swandip. The rainfall of Barishal, Bhola, Chandpur, Mongla, Sitakunda and Khulna is lower than all other districts. Rainfall in association with moisture is an important indicator of unstable weather as lower rainfall results higher temperature which can accelerate many cyclonic events in these areas.

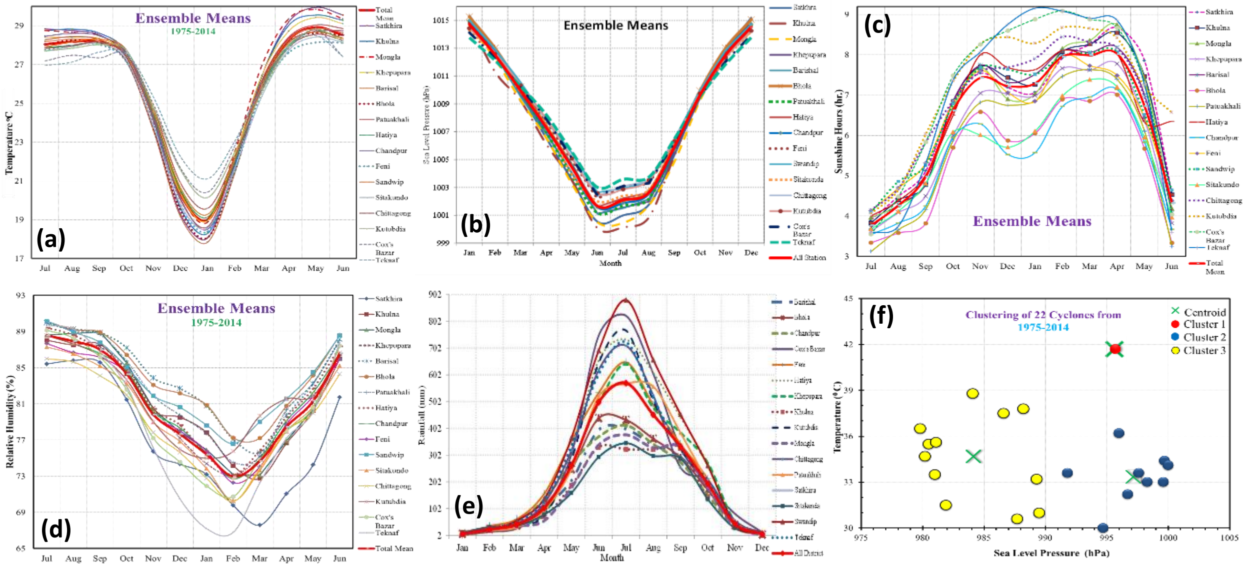

Figure 2. Ensemble means of 16 coastal stations from 1975-2014 for (a) air temperature (in °C), (b) sea level pressure (in hPa), (c) sunshine hours (in hr.), (d) relative humidity (in %), (e) rainfall (in mm) and (f) clustering of 22 cyclones

Figure 2(f) represents the clustering of 22 cyclones from 1975-2014 considering main two variables behind cyclogenesis i.e., temperature and SLP. However, it is seen from the figure 2(f) that, the ultimate factors (SLP and temperature) responsible for the formation of 22 cyclones have grouped into 3 clusters (centroids). The cyclonic factors which have similar characteristics belongs to the same centroid. The circle with red color is considered as centroid 1 where the temperature was 41.7°C and SLP was 996hPa. So, centroid 1 indicates that 41.7°C temperature is responsible for only 1 cyclone out of 22 from 1975-2014. Considering centroid 2, 9 circles with blue color represent cyclones with same characteristics in these 40 years duration. The temperature triggered behind the formation of 9 cyclones was from 30 to 36.2°C where the SLP was from 992 to 1000hPa. The centroid 2 with a cross (x) mark is pointing at 33.5°C which is the average of 9 blue circles. So, these results indicate that temperature of above 30°C is very much favorable for atmospheric low pressure development which in consequence, turn into cyclonic activity. The rest of the 12 yellow circles under 3rd centroid represent cyclones with similar atmospheric characteristics.

Synoptic Climatology using GCM

The composite geographical distributions of synoptic temperature anomalies compared with the climatology from 1975-2014 for the cyclone occurring days are shown in figures 3-5. Composite geographical distribution of air temperature anomalies was constructed for the analyzed 3 clusters and are compared for surface, 850hPa, 700hPa, 500hPa and 300hPa level. Figure 3 illustrates temperature distribution (in °K) for cluster 1 on the cyclone occurring days where the surface temperature (3a) in Bangladesh along with the south-western India was comparatively warmer than the south-eastern Myanmar, Thailand and Laos. The positive surface air temperature anomaly zone was prominent over the west to south-western Bangladesh. Figure 3(b), (c), (d), and (e) show temperature anomalies at

DOI: https://doi.org/10.55706/jae1502

850, 700, 500, and 300hPa level of atmosphere on the days of cyclone occurrence, respectively.

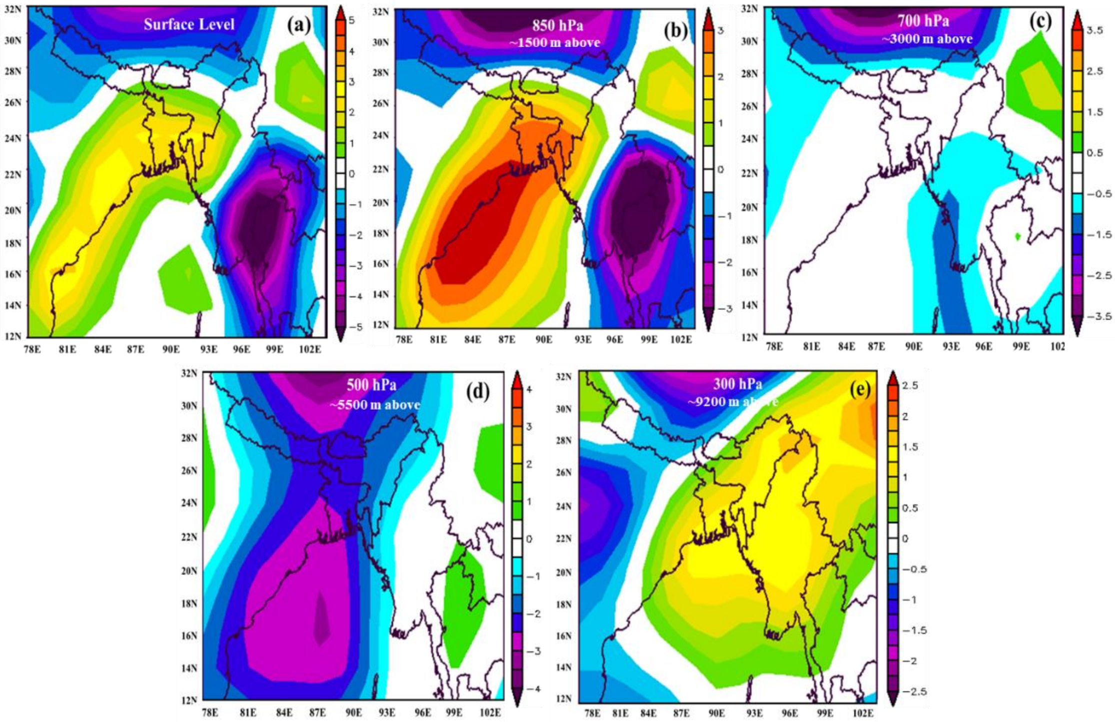

Figure 3. The patterns of composite air temperature (°K) anomaly for cluster 1 compared with 1975– 2014 climatology for cyclone occurrence at (a) surface, (b) 850hPa, (c) 700hPa, (d) 500hPa, and (e) 300hPa level

Figure 3(b) depicts a strong elongated positive temperature anomaly zone extends over the south-western Bangladesh at 850hPa level. In fact, the whole of Bangladesh was covered by this anomaly zone whilst, the transition between positive and negative anomalies existed over the central part of Myanmar keeping one strong negative anomaly zone over the south-western Myanmar. But at around 3,000m above (700hPa) from the surface, there was complete disappearance of positive anomaly zone (Figure 3c) suggests 700hPa temperature would not effect on unstable atmospheric condition Figure 3(d) shows the anomaly of temperature at the most influential weather zone of upper atmosphere (500hPa). A strong negative zone encircled over the south-western part of Bangladesh and over the BB indicates development of a cooler zone at around 6,000 m (500hPa) above the surface. The most dramatic phenomena is seen at 300hPa (nearly 10,000m above from surface; Figure 3e) where, a huge area is covered by positive anomaly extending from Tibet to North Indian Ocean (NIO) via eastern Indian territory. The whole of Bangladesh was dominated by positive anomaly implies formation of a deep warmer zone over these regions. This larger warmer air mass at upper atmosphere could influence a lot to develop huge instability throughout the whole atmospheric column.

Comparison of composite geographical distribution of synoptic temperatures for cluster 2 are shown in Figure 4. Figure 4(a) shows the surface temperature anomaly where a positive anomaly zone is prominent over the eastern part of Bangladesh. On the day of cyclone occurrences, the strong negative anomaly zone from the south-western India expanded toward Bangladesh. Additionally, another negative anomaly zone is also evident over the south-eastern part of Myanmar. This coexistence of negative zones suggests dominance of relatively cooler air temperatures in the southern Bangladesh at surface level especially on the day of cyclone prevalence. Figure 4(b), (c), (d), and (e) shows the composite air temperature anomalies at 850, 700, 500, and 300hPa level of atmosphere, respectively where figure 4(b) depicts a strong positive anomaly over the north-eastern Bangladesh at 850hPa. The transition zone between positive and negative anomalies existed over the BB keeping the negative zones over the south-eastern India and the southern Myanmar. Conversely, at around 3,000m above (700hPa; figure 4c) from surface, there was complete disappearance of negative anomaly zones. The positive zone expanded from the north-east toward the south-east and over the BB. Thus, this warmer zone at relatively upper atmosphere could make unstable atmosphere through the thermal instability interacting with the surface layer. At 300hPa level, the whole of Bangladesh was dominated by positive anomaly implies formation of a deep warmer zone over these regions. This larger warmer air mass at upper atmosphere could influence a lot to develop huge instability throughout the whole atmospheric column which may accelerate the favorable situation of cyclogenesis.

DOI: https://doi.org/10.55706/jae1502

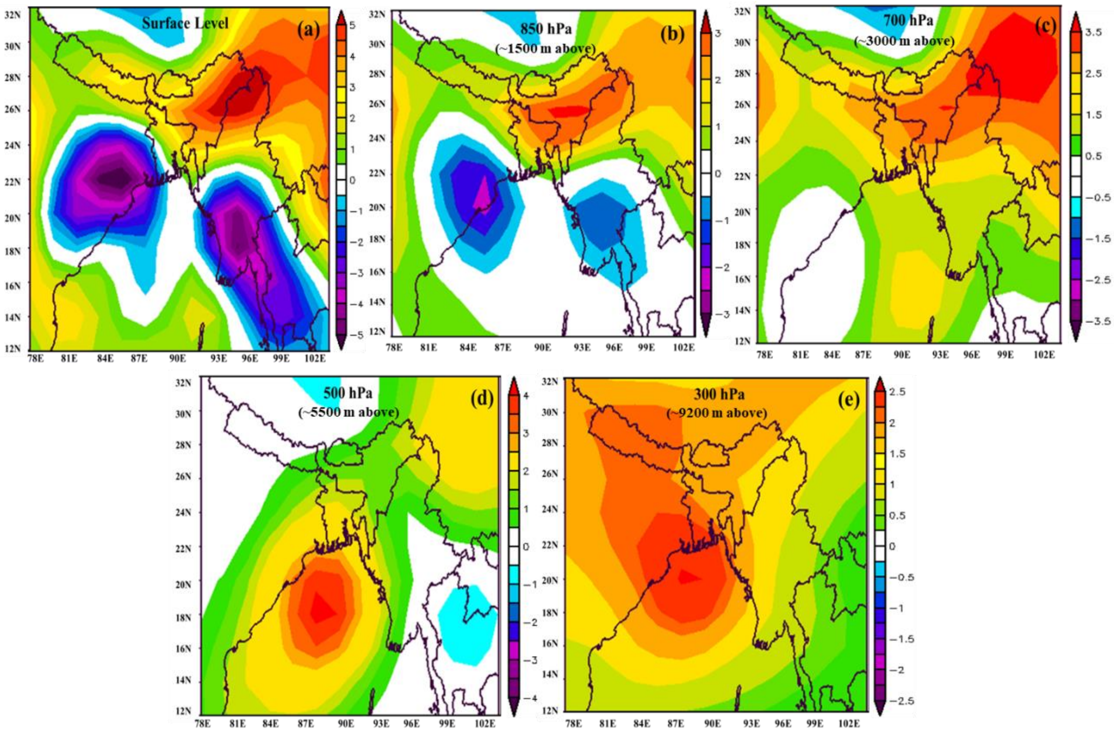

Figure 4. The patterns of composite air temperature (°K) anomaly for cluster 2 compared with 1975– 2014 climatology for cyclone occurrence at (a) surface, (b) 850hPa, (c) 700hPa, (d) 500hPa, and (e) 300hPa level.

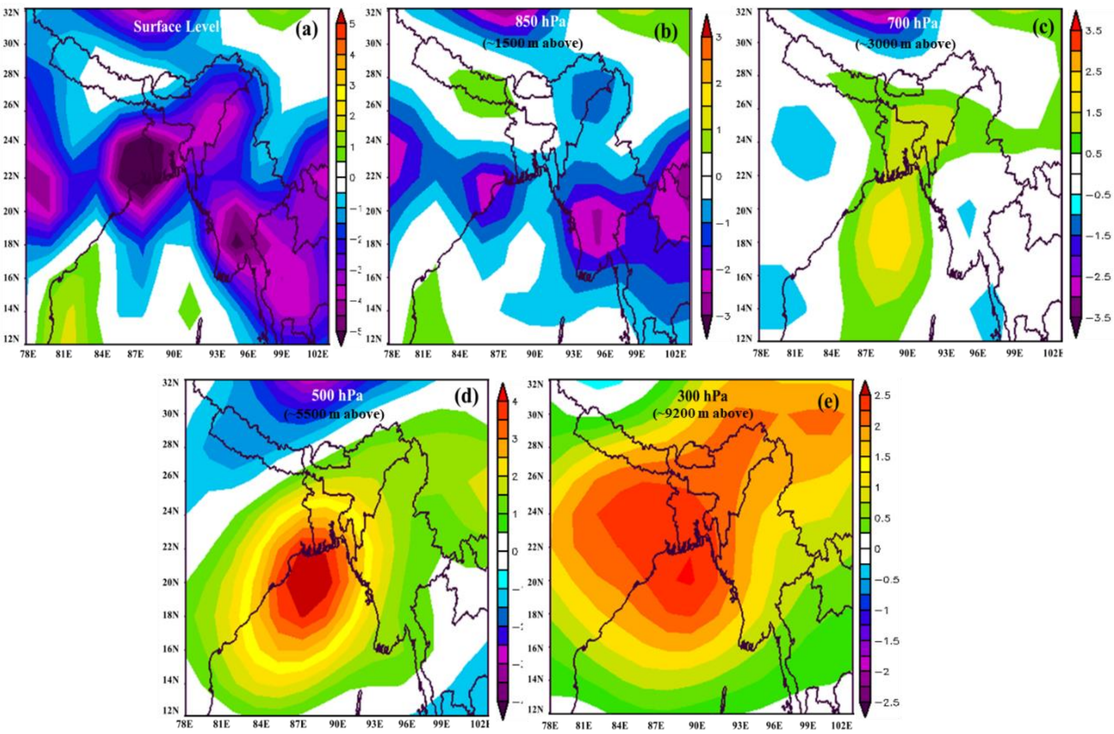

Figure 5. The patterns of composite air temperature (°K) anomaly for cluster 3 compared with 1975– 2014 climatology for cyclone occurrence at (a) surface, (b) 850hPa, (c) 700hPa, (d) 500hPa, and (e) 300hPa level

The synoptic temperatures for cluster 3 are seen in Figure 5. Figure 5(a) shows the surface temperature anomaly where the positive anomaly zone was almost disappeared over Bangladesh except a minute weak area over NIO. The result suggests dominance of relatively cooler temperatures in the southern zone near to surface especially on the day of cyclone prevalence. Figure 5(b) illustrates a moderate negative temperature anomaly over the south-western Bangladesh at 850hPa. At 700hPa level there was complete disappearance of negative anomaly

DOI: https://doi.org/10.55706/jae1502

zones over Bangladesh (Figure 5c) with an expansion of positive zone from the southern Bangladesh. The temperature distribution at Figure 5(d) shows a strong positive zone encircled over the south-western Bangladesh originating from the BB, indicates development of a warmer zone. The most unusual scenario is noticed at 300hPa level where, a huge warmer area with positive temperature anomaly exists over Bangladesh extending from the south-west (Figure 5e). This condition implies formation of a deep warmer zone over Bangladesh that could influence a lot to develop huge instability throughout the whole atmospheric column to form extreme cyclones.

CONCLUSION

In this study, we mainly investigated 22 cyclones that occurred in Bangladesh from 1975 to 2014. Some important climatic variables like temperature, relative humidity, sea level pressure, rainfall, and sunshine hours have been studied for 16 coastal stations to find out the effectiveness of variables behind cyclogenesis. The data of these climatic variables was provided by the BMD. Temperature, the most effective variable of cyclogenesis has shown homogenous trend where the mean and maximum temperature is ranging from 18 to 30°C and 28 to 42°C, respectively. The most extreme values of maximum and mean temperatures have been found in April and May, which correspond to the peak of cyclone season. The most effective climatic variable, i.e., temperature in combination with sea level pressure produces 3 clusters through the PCA and clustering analyses. The results show that among 22 cyclones, cluster 1 possess only 1 cyclone that was formed due to extreme high temperature (41.7°C). Again, cluster 2 yield 9 cyclones where the temperature ranged from 30 to 36.5°C with the centroid at 33.5°C. The cluster 2 indicates that, temperatures within this range may trigger cyclonic activity in the coastal areas. Cluster 3 indicates that, temperatures from 30.5 to 39°C were mostly responsible for the formation of the remaining 12 cyclones with the centroid at 34.5°C. The synoptic features of 22 cyclones have been represented using AIT, BBS, and NCEP–NCAR reanalysis data to assess the upper atmospheric temperature anomalies related to severe cyclone events in the southern coastal regions of Bangladesh mainly over BB. The climatological anomaly of air temperatures for clusters at different levels of the atmosphere shows the dominance of relatively cooler air temperature in the southern zone near to surface level especially on the days of cyclone prevalence. Just a few kilometers above the surface, the whole vertical atmospheric column started to increase its temperature especially from 850 to 300hPa levels. These warmer zones in the relatively upper atmosphere could make unstable situations through thermal instability interacting with the surface layer. Finally, the whole of Bangladesh was dominated by positive anomalies up to 300hPa level implies formation of a deep warmer zone over this region. The larger warmer air mass at upper atmosphere creates profound influence to develop huge instability throughout the whole atmospheric column that may led to extreme weather phenomenon like severe cyclones. The results found from this study, especially temperature variations at surface, 850hPa, 700hPa, 500hPa, and 300hPa levels during the cyclone occurring days could be very useful and important findings for environmental scientists to forecast as well as to understand the process of cyclogenesis in the coastal areas of Bangladesh.

ACKNOWLEDGEMENT

The authors were the recipients of generous support and research fund for the work reported here and wish to thank: 1. Information & Communication Technology Division (ICTD), Govt. of the People's Republic of Bangladesh, ICT Tower, Agargaon, Dhaka; 2. The Physical Science Division: Data Management of NOAA, Boulder, Colorado, USA; 3. Climate Division of Bangladesh Meteorological Department (BMD) for providing various reliable datasets and resultant stimulating findings which encourages the authors being enabled research on this issue.

REFERENCES

Akter, F. and Ishikawa, H. 2014. Synoptic features and environmental conditions of the tornado outbreak on March 22, 2013 at Brahmanbaria in the east-central region of Bangladesh, Natural Hazards, doi: 10.1007/s11069-014-1252-y.

Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J. and co-authors. 2006. Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research, 111: D05109. doi:10.1029/2005JD006290.

Ali, A. 1999. Climate change impacts and adaptation assessment in Bangladesh, Climate Research, 12:109-116.

AR4 (4th Assessment Report). 2007. Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the 4th Assessment Report of the Intergovernmental Panel on Climate Change, Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds), IPCC, Cambridge University Press, Cambridge, 996p.

Barry, R.G. and Carelton, A.M. 2001. Synoptic and Dynamic Climatology. 11 New Fetter Lane, London: Routledge.

BBS (Bangladesh Bureau of Statistics). 2009. Bangladesh Bureau of Statistics, Statistics Division, Ministry of Planning, Statistical Year Book of Bangladesh – 2008, BBS, Dhaka, Bangladesh.

BCCCSP (Bangladesh Climate Change Country Study Program). 1997. Assessment of vulnerability and adaptation to climate change. Final report, Department of Environment, Govt. of Bangladesh.

Birkeland, K.W., Mock, C.J. and Shinker, J.J. 2001. Avalanche extremes and atmospheric circulation patterns. Annals of Glaciology, 32" 135-140.

BUP-CEARS-CRU (Bangladesh Unnayan Parishad-Centre for environmental and Resource Studies-Climate Research Unit). 1994. Bangladesh: Greenhouse Effect and Climate Change, Briefing Documents No. 1-7.

CDMPII (Comprehensive Disaster Management Program 2nd Phase). 2014. Climate Change and Bangladesh: Annotated Bibliography. MoDMR, Government of the People's Republic of Bangladesh.

Choudhury, B.J. 1992. Multispectral Satellite Observations for Arid Land Studies. ISPRS J. Photo. Remote Sensing, 47:101-126.

DOI: https://doi.org/10.55706/jae1502

Emanuel, K., DesAutels, C., Holloway, C. and Korty, R. 2004. 380 Environmental control of tropical cyclone intensity. Journal of Atmospheric Science, 61: 843–858, doi: 10.1175/1520-0469(2004)061<0843: ECOTCI>2.0.CO;2.

Farukh, M.A. and Baten, M.A., 2015. Temperature Anomaly and Severe Cyclone Events in the southern Coastal regions of Bangladesh, Journal of Environmental Science & Natural Resources, 8(1): 35-40. doi:10.3329/jesnr.v8i1.24661.

Farukh, M.A. and Yamada, T.J. 2014. Synoptic climatology associated with extreme snowfall events in Sapporo city of northern Japan. Atmospheric Science Letters, 15:259–265. doi:10.1002/asl2.497. doi:10.1002/asl2.497.

Farukh, M.A., Islam, A., Akter, L. and Khatun, R. 2019. Trend and variability analysis of sunshine duration in the divisional headquarters of Bangladesh, Journal of Environmental Science & Natural Resources, 12(1&2):127-133, doi: https://doi.org/10.3329/jesnr.v12i1-2.52008

Fernandez, G. 1995. Principal Component Analysis, 11 New Fetter Lane, London: Routledge, ERS701D.

Goodale, C.L., Aber, J.D. and Ollinger, S.V. 1998. Mapping monthly precipitation, temperature, and solar radiation for Ireland with polynomial regression and a digital elevation model. Climate Research, 10: 35–49.

Hair, J.F., Anderson, R.E., Tatham, R.L. and Black, W.C. 1998. Multivariate Data Analysis, 5th ed. Prentice-Hall International: New Jersey, NJ.

Hansen, J.I., Fung, I., Lacis, A., Rind, D. and Lebedeff, S. 1988. Global climate changes as forecast by Goddard Institute for space studies three-dimensional model. Journal of Geophysica; Research, 93: 9341–9364.

Hebenstreit, G.T., Gonzalez, F.I. and Morris, A.F. 1985. Near-shore tsunami simulation of Valparaiso Harbor, Chile. Proc. Int. Tsunami Symp, T.S. Murty and W.J. Rapatz (eds.), Inst. Ocean Sciences, Sidney, B.C.

Hendricks, E.A., Peng, M.S., Fu, B., and Li, T. 2010. Quantifying environ- 394 mental control on tropical cyclone intensity change. Monthly Weather Review, 138:3243–3271, doi:10.1175/2010MWR3185.1.

Hibberd, S. and Peregrine, D.H. 1979. Surf and run-up on a beach: a uniform bore. Journal of Fluid Mechanics, 95: 323-345.

Houghton, T., Ding, Y., Griggs, D.J., Noguer, M., Linden, P.J.V.D., Dai, X., Maskell, K. and Johnson, C.A. 2001. Climate Change 2001. The Scientific Basis. Contribution of Working Group I to the 3rd Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. 881p.

Huq, S., Karim, Z., Asaduzzaman, M. and Mahtab, F. 1999. Vulnerability and Adaptation to Climate Change in Bangladesh. Kluwer, Dordrecht, 147p.

IPCC (Intergovernmental Panel on Climate Change). 2001. Intergovernmental Panel on Climate Change, Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the 3rd Assessment Report of the Intergovernmental Panel on Climate Change. In: JT Houghton, Y Ding, DJ Griggs, M Noguer, PJ van der Linden, X Dai, K Maskell and CA Johnson (Editors), Cambridge University Press, Cambridge, United Kingdom and New York, USA. 881p.

IPCC (Intergovernmental Panel on Climate change). 2007. Climate Models and Their Evaluation. Climate Change 2007: The Physical Science Basis, URL: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter8.pdf

Islam, M.M. 2014. Regional Differentials of Annual Average Humidity over Bangladesh. ASA University Review, 8(1): 1-5.

Jeglic, T.O. 2006. Sunshine Duration. Climate of Slovenia 1971–2000, the Environmental Agency of the Republic of Slovenia, Vojkova 1b, SI-1000 Ljubljana, Slovenia.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G.,Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K.C., Ropelewski, C., Wang, J., Leetma, A., Reynolds, R., Jeene, R. and Joseph, D. 1996. The NCEP/NCAR 40-year reanalysis project. Bulletin of the American Meteorological Society, 77: 437–471.

Kang, I.S., Jin, K., Wang, B., Lau, K.M., Shukla, J., Krishnamurthy, V., Schubert, S.D., Wailser, D.E., Stern, W.F., Kitoh, A., Meehl, G.A., Kanamitsu, M., Galin, V.Y., Satyan, V., Park, C.K. and Liu, Y. 2002. Intercomparison of the climatological variations of Asian summer monsoon precipitation simulated by 10 GCMs. Climate Dynamics, 19:383-95.

Kaplan, J. and DeMaria, M. 2003. Large-scale characteristics of rapidly 404 intensifying tropical cyclones in the North Atlantic basin. Weathar Forecasting, 18(6):10931-108.

Kaplan, J., DeMaria, M. and Knaff, J.A. 2010. A revised tropical cyclone rapid intensification index for the Atlantic and eastern North Pacific basins. Weather Forecasting, 25:220–241.

Lawrence, M.G. 2004. The relationship between relative humidity and the dewpoint temperature in moist air simple conversion and applications. Max Planck Institute for Chemistry, Junior Research Group, Department of Atmospheric Chemistry, Postfach 3060, 55020 Mainz, Germany.

Lorenzo, A.S., Calbo, J., Brunetti, M. and Deser, C. 2009. Dimming/brightening over the Iberian Peninsula: Trends in sunshine duration and cloud cover and their relations with atmospheric circulation. Journal of Geophysical Research, 114: D00D09.

Mahtab, F. 1989. Effect of climate change and sea level rise on Bangladesh. Expert Group on climate change and sea level rise, Commonwealth Secretariat, London, UK.

Matuszko, D. and Weglerczyk, S. 2014. Relationship between sunshine duration and air temperature and contemporary global warming. International Journal of Climatology, 35(12):3640-3653.

Mearns, L.O., Katz, R.W. and Schneider, S.H. 1984. Extreme high temperature events: changes in their probabilities with changes in mean temperature. Journal of Climatology & Applied Meteorology, 23:1601–1608.

MoEF (Ministry of Environment and Forest). 2008. Bangladesh Climate Change Strategy and Action Plan 2008. Dhaka, Bangladesh: Ministry of Environment and Forests, Government of the People‘s Republic of Bangladesh.

Onogi, K., Tsutsui, J., Koide, H., Sakamoto, M., Kobayashi, S., Hatsushika, H., Matsumoto, T., Yamazaki, N., Kamahori, H., Takahashi, K., Kadokura, S., Wada, K., Kato, K., Oyama, R., Ose, T., Mannoji, N. and Taira, R. 2007. The JRA-25 reanalysis. Journal of Meteorological Society of Japan, 85:369–432.

Pramanik, M.A.H. 1983. Remote sensing applications to coastal morphological investigations in Bangladesh. PhD dissertation, Jahangirnagar University, Savar, Dhaka.

Rahman, M.M. and Ferdousi, N. 2011. Rainfall and temperature scenario for Bangladesh using 20km mesh AGCM, International Journal of Climate Change 4(1): 66-80, doi:10.1108/17568691211200227.

Saniruzzaman, Haider, M.M., Duti, B.M., Khan, M.F.A. and Aktar, M.N. 2015. Climate change trends in Bangladesh: A spatial and temporal observation of climatic parameters. 5th International Conference on Water & Flood Management (ICWFM-2015).

DOI: https://doi.org/10.55706/jae1502

Sayeda, J.A. and Nasser, M. 2012. Trend and variability analysis and forecasting of sunshine-hour in Bangladesh. Journal of Environmental Science & Natural Resources, 5(2):109-118.

Shamsad, Farukh, M.A., Chowdhury, M.J.R. and Basak, S.C. 2012. Sea surface temperature anomaly in the Bay of Bengal. Journal of Environmental Science & Natural Resources, 5(2):77- 80. https://doi.org/10.3329/jesnr.v5i2.14797

Singh, J., Kumar, M. and Bhattacharya, B.K. 2012. Global radiation, transmissivity and bright sunshine hour trend over Nagpur in pre-monsoon and monsoon seasons. Atmosphere & Climate Science, 2:206-209. doi.10.4236/acs.2012.22021.

Skilling, T. 2009. The relationship between relative humidity, temperature and dew point. Chicago Tribune, November 15.

Tait, A.B. and Fitzharris, B.B. 1998. Relationship between New Zealand rainfall and south-west Pacific pressure patterns. International Journal of Climatology, 18:407–424.

Wu, L., Su, H., Fovell, R.G., Wang, B., Shen, J.T., Kahn, B.H., Hristova-Veleva, S.M., Lambrigtsen, B.H., Fetzer, E.J. and Jiang, J.H. 2012. Relationship of environmental relative humidity with North Atlantic tropical cyclone intensity and intensification rate. Geophysical Research Letters, 39(1): L20809.

Yarnal, B. 1993. Synoptic Climatology in Environmental Analysis (A Primer), Belhaven Press, 25 Floral Street, Covent Garden, London, United Kingdom. pp.1-2.

DOI: https://doi.org/10.55706/jae1502