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Influence of Dry-line on the Formation of Severe Local Convective Storms of Bangladesh: A Case Study

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Synopsis

This study analyzes the atmospheric instability and trigger mechanisms of a Severe Local Convective Storm (SLCS) initiation over Bangladesh and adjoining Indian Territory of 4 April 2011. Two types of data, JRA-25 1.125 degree resolution reanalysis data and Global Spectral Model (GSM) 20 km resolution analyses data, both by Japan Meteorological Agency (JMA), have been used and comparisons between two products are illustrated for this case. JRA-25 reanalysis data analyses specific humidity gradient greater than 3 g/kg over 100 km, whereas the GSM data analyses specific humidity gradient greater than 10 g/kg over 100 km since sharper gradient of specific humidity is resolved in this analysis. GSM data significantly identify dry-line and can calculate instability precisely which suggests that the dry-line influences the initiation of convection in this case.

Keywords: Severe Local Storms, Tornado, Bangladesh disaster, Dry-line

1. Introduction

Severe Local Convective Storms (hereinafter referred to as SLCS) are very devastating phenomena in Bangladesh and North-eastern part of India in the pre-monsoon seasons (March, April and May). They cause huge damages to our lives and properties in a very short time. These storms are locally termed as Nor'wester (*Kalaishakhi*- in Bengali) since the systems migrate from north-west to south-east. Those are often associated with tornadoes. Every year the SLCS of Bangladesh cause the highest death toll in the World. Annual death toll accounts for 179 deaths per year caused by only from tornadoes in Bangladesh from the period of 1967-96 (Ono 2001).

In the pre-monsoon season, sufficient low level southerly warm moist wind flows from Bay of Bengal and moderate to strong cold dry westerly wind flows from mid-upper level towards Bangladesh that influences the convection. The cold advection often associated with westerly jet. These settings of wind pattern in this season are identified the favorable environmental condition for SLCS development (Weston, 1972; Prasad, 2006; Yamane and Hayashi, 2006). Previous studies identified the preferred location of SLCS formation in Bangladesh (Peterson and Meheta, 1981; Yamane et al 2010a). Some other studies also focused on the dynamic and thermodynamic aspects of the initiation of SLCS (Lohar and Pal, 1995), a study also identified the propagation and modes of organization of Mesoscale Convective Systems (Dalal et al 2012), and another study indicates the lower and mid-upper tropospheric features for initiating of Nor'westers (Ghosh et al 2008). Contrarily, the physical process and trigger mechanisms of SLCS organization are rarely studied due to the scarcity of observation data in the study area.

SLCS are very frequent and well-studied over the Great Plains of the United States. Thunderstorms over the Great Plains are frequently formed along dry-lines. Number of climatological studies proves that the initiations of severe storm outbreaks in the United States are triggered by dry-line (Reha 1966; Bluestein and Parker 1993; Ziegler et al. 1997 and Hane 1997). Dryline is a mesoscale narrow boundary separating moist maritime tropical air masses of Gulf of Mexico from continental dry air of the arid areas in the western Great Plains during the warm season (Fujita 1958; Miller 1959; Rhea 1966).

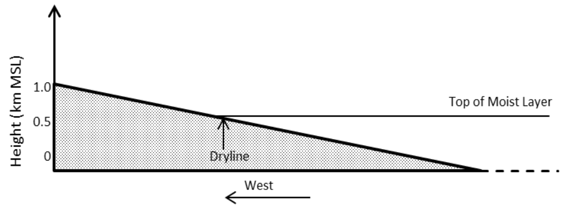

Fig 1. Schematic vertical cross section of the dry-line and its relationship with topography (Adapted from Bluestein 1993)

The gently sloping terrain of the Great Plains contributes to dry-line formation, because dry-lines essentially represent the intersection of the top of the maritime tropical boundary layer with the ground (Fig.1, Bluestein 1993). Climatological study of the Great Plains found the dry-line positions in the region where the topography of the plains rapidly increases from east to west (Hoch and Markwowski 2005).

Bangladesh belongs to the Gangetic Delta and its topography is very flat nearly sea level. The altitude gradually increases to the West and elongated to Chotanagpur platue (23˚N 85˚E; average elevation of 539 m above sea level) in the Indian Territory. Although topography plays significant role on dry-line formation, no evidences has been demonstrated in the study region. Dry-line features in North-east India were identified by Weston (1972). He mentioned that pre-monsoon deep convection is favored near the region of low-level moisture gradients. Strong localized convergence and abundant moisture often make the dry-line a preferred location for SLCS initiation. Carlson (1998) and Bluestein (1993) also mentioned about presence of dry-line in Northern India. However, the origin, structure and mechanism of dry-line in this region are rarely investigated.

The major objective of this study is to identify the dry-line and investigate whether it influences the development of SLCS in Bangladesh in a way analogous to the features in the United States. Therefore, a detailed climatological investigation is carried out to determine pre-monsoon dry-line characteristics along with synoptic environment. A case of tornadic outbreak, which swept through seven districts of northern Bangladesh on 4 April, 2011 in the afternoon, causing twelve deaths and more than one hundred and fifty injuries, was closely investigated as an example. Section two define dry-lines for the study region, section three includes description of the data sources and dry-line identification methods, Section four contains results and discussion, and Section five provides a summary in this paper.

2. Definition of dry-line

Dry-line is a confluent boundary separating dry air masses from more moist air masses. The most significant signature of dry-line is a sharp moisture discontinuity (Schaefer 1974a). In the present study horizontal specific humidity was used to determine the moisture discontinuities. A set of variables were considered to identify dry-lines in the Great Plains. Specific humidity was used in coordination with dew point temperature (Schaefer 1974a; Hoch and Markowski 2005) since the nature of the elevation differs across the study region. Unlike Great Plain region the elevation does not vary in the target area of the present study. Therefore we only consider specific humidity gradient that was equal or exceeding 3g/kg/100km (Schaefer 1974a) as the dry-line features for climatological studies. We also consider surface temperature, pressure and wind profiles to avoid any localized disturbances. To exclude local variations within an air mass, the discontinuity had to remain identifiable for at least 6 hours. Moreover, we used terrain following data for our calculation.

3. Data and Methodology

Initially, we used JRA-25 1.125 degree resolution reanalysis model level data by Japan Meteorological Agency (JMA) to analyze synoptic features for 35 years climatology (between 1979 and 2013) in the pre-monsoon seasons. The

Japanese 25-year reanalysis (JRA-25) was created with an up-to-date numerical assimilation and forecast model. It covers the period 1979 to 2004, which are 25-years. The data set is continued to this day as the JMA Climate Data Assimilation System (JCDAS) in every 6 hours. Temperature, wind, relative humidity, air pressure (on model-level), brightness temperature (satellite), and precipitable water have been assimilated. The model calculation was performed with a spectral resolution about 1.125 degree and 40 height levels (top at 0.4 hPa).

Alternatively we used JMA's GSM analysis data to see the more localized features. The data are one of very high horizontal resolution of 0.1875 degrees, approximately 20 km among the operational global model in the world. In the vertical, it has 60 layers from surface to 0.1 hPa. The vertical resolution is finer near the surface for better representation of the planetary boundary layer processes. The data are provided 6 hourly from 2007. The available variables are wind (zonal and meridional), temperature, specific humidity, surface pressure and cloud water content.

In the present study to understand environmental stability condition several stability indices are computed such as Lifted Index (LI), Convective Available Potential Energy (CAPE), Showalter Stability Index (SSI) etc. and the details of the indices are already explained to our previous work Yamane et al. (2010b). To calculate LI, SSI and vertical profile we converted original GSM model level data to pressure level data.

Dry-lines are identified from a horizontal specific humidity gradient. Specific Humidity gradient is denoted as ∇Q. Here q is specific humidity (g/kg).

$$|\nabla . Q| = \sqrt{\left(\frac{\partial q}{\partial x}\right)^2 + \left(\frac{\partial q}{\partial x}\right)^2}$$

The critical magnitude of defining dry-line should depend on the horizontal resolution of the data. A criterion of $3 \times 10^{-8} m^{-1}$, equivalent to 3 g/kg difference of specific humidity over 100 km, was used by Schaefer (1974a) Hoch and Markowski (2005) and Coffer et al. (2013). The same criterion is applied in our analysis with 1.125° resolution of JRA-25 data. For GSM analysis of 0.1825 degree resolution, however, the more strict criterion of $1 \times 10^{-9} m^{-1}$, equivalent to 10 g/kg difference of specific humidity over 100 km, was used since more sharp gradient of specific humidity is resolved in GSM analysis. For dry-line analysis time, we mainly refer to the field at 12 UTC (18 BDT, Bangladesh Local Time) and 18 UTC (00 BDT), since the surface dry-line feature is the most evident in these synoptic times.

Though the data are global, we restrict our analysis area to south Asia in bigger domain between 65°-100°E longitude and 05°-29°N latitude. For detail analysis we take smaller domain between 84°-94°E longitude and 18°-26° N latitude which focus on Bangladesh and the West Bengal of India. To see the large scale convective phenomena the IR imageries of Multi-functional Transport Satellite (MTSAT) of JMA are used. MTSAT provides imagery for the target area every 30 minutes, which are used to monitor clouds, sea surface temperatures and distribution of water vapor.

4. Result and Discussion

4.1 Synoptic overview

Synoptic scale processes play very significant role in regulating dry-line formation and intensity. Climatology of pre-monsoon seasons shows typical diurnal variations from morning to evening. In the present study southerly or south-westerly tongue of moist warm wind flow from the Bay of Bengal to the land and dry warm westerly wind flowing from the Indian high lands to Bangladesh are identified. Low level temperature exhibits comparatively higher values in the central India than in Bangladesh. At upper troposphere, Westerly to North-westerly wind is very strong over Bangladesh. Cold and low moisture air flows toward Bangladesh at 500 hPa. Most of the days in April upper air westerly is much stronger than in March and May over Bangladesh. Surface moist tongue of southerly to southwesterly is very prominent in April and May.

The study also identifies very high surface moisture content everywhere over Bangladesh and surface specific humidity values approximately ~16 g/kg (max. in May18g/kg, min. in March 12g/kg). In contrast moisture content is very low over Indian Territory.

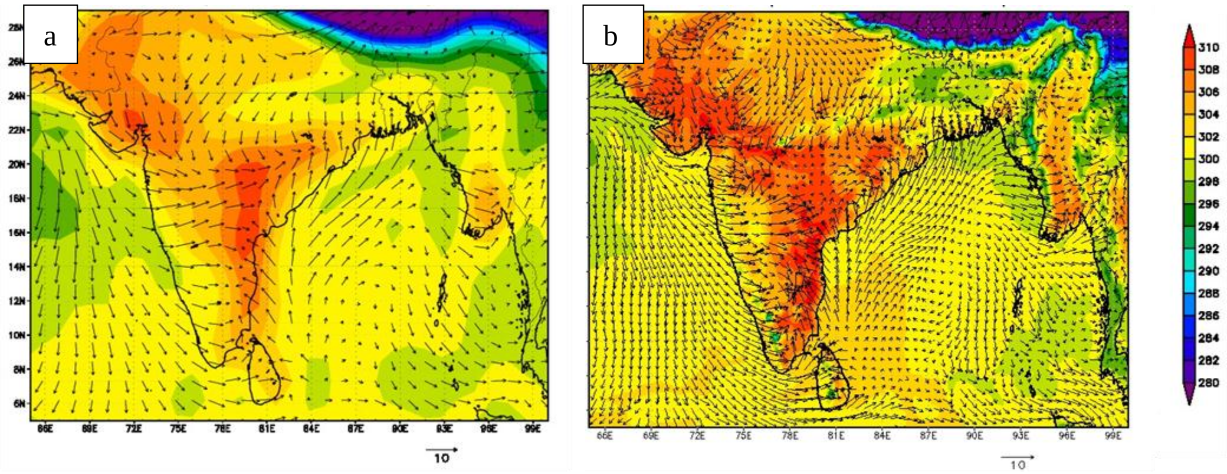

Fig. 2 The two panels show surface analysis, shaded temperature (K) and vector wind (m/s) by (a) JRA-25 and by (b) GSM for the SLCS case on 12UTC 4 April, 2011

Fig. 2 shows strong southerly to south westerly wind flows northward from the Bay of Bengal. Temperature distribution shows comparatively higher value over Indian high land. Severe convection usually requires intense heating near the surface and it influences upward motion for ascending layer parcels.

Fig. 3 (a-d) shows strong south westerlies over 500 hPa. From surface to 800 southerly to south westerly is strong over Bangladesh. Dry hot air blowiwng toward Bangladesh from Indian Territory is analyzed. Above 700 hPa dry cold air blows over Bangladesh. Surface temperature increases over Indian Territory as day advances.

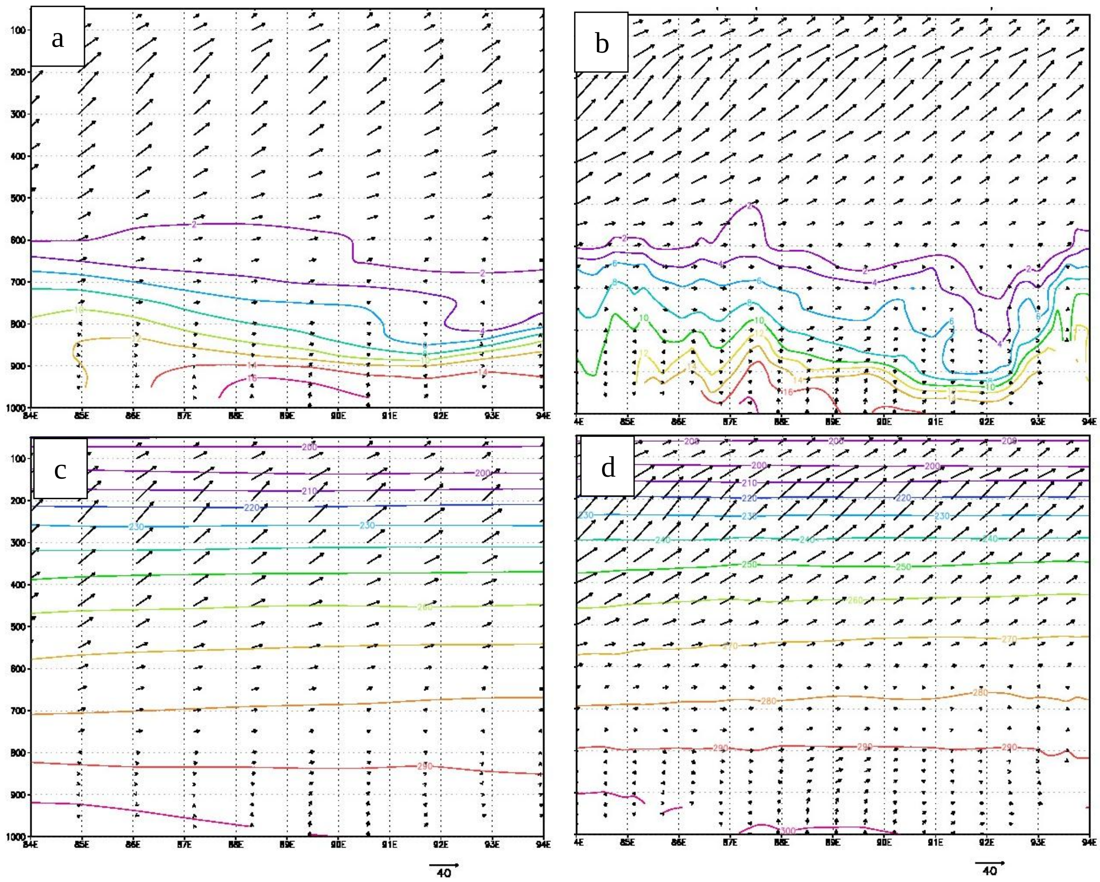

Fig 3. Vertical distribution contour of specific humidity g/kg and wind vector m/s a) JRA-25, b) GSM; wind vector m/s and temperature (K) c) JRA-25, d) GSM on 12UTC 4 April, 2011

In the upper atmosphere above 300 hPa, analysis shows stronger south westerly wind and the wind speed becomes stronger over the Indian subcontinent at the mid of the day.

From the vertical cross section we can see east to west decrease of specific humidity content near the surface at 87°E that corresponds to the position of dry-line (referred to Fig 3 a-b again). Surface specific humidity reaches approximately ~16 g/kg all over Bangladesh. The distribution of vertical temperature shows no gradient between dry and moist air masses (Fig 3 c-d). Intense heating of moist air near the surface produces significant upward motion for ascending layer parcel.

A Specific humidity gradient is observed between moist and warm air masses that is the confluent zone for separating moist air masses from Bay of Bengal in the south to dry continental air masses in the west (Fig. 4a-b). JRA-25 reanalysis data analyses specific humidity gradient greater than 3 g/kg but GSM data analyses specific humidity gradient greater than 10 g/kg over 100 km (Fig. 4c-d).

Southerly wind blows at the east side of dry-line which carries sufficient moisture to the land. This is a potential source for the initial growth of clouds. Sufficient moisture and localized upward motion near dry-line enables successive convection occurrence and maintains long lasting storms. This feature is consistent with Great Plain case reported by Hane et al. (1997).

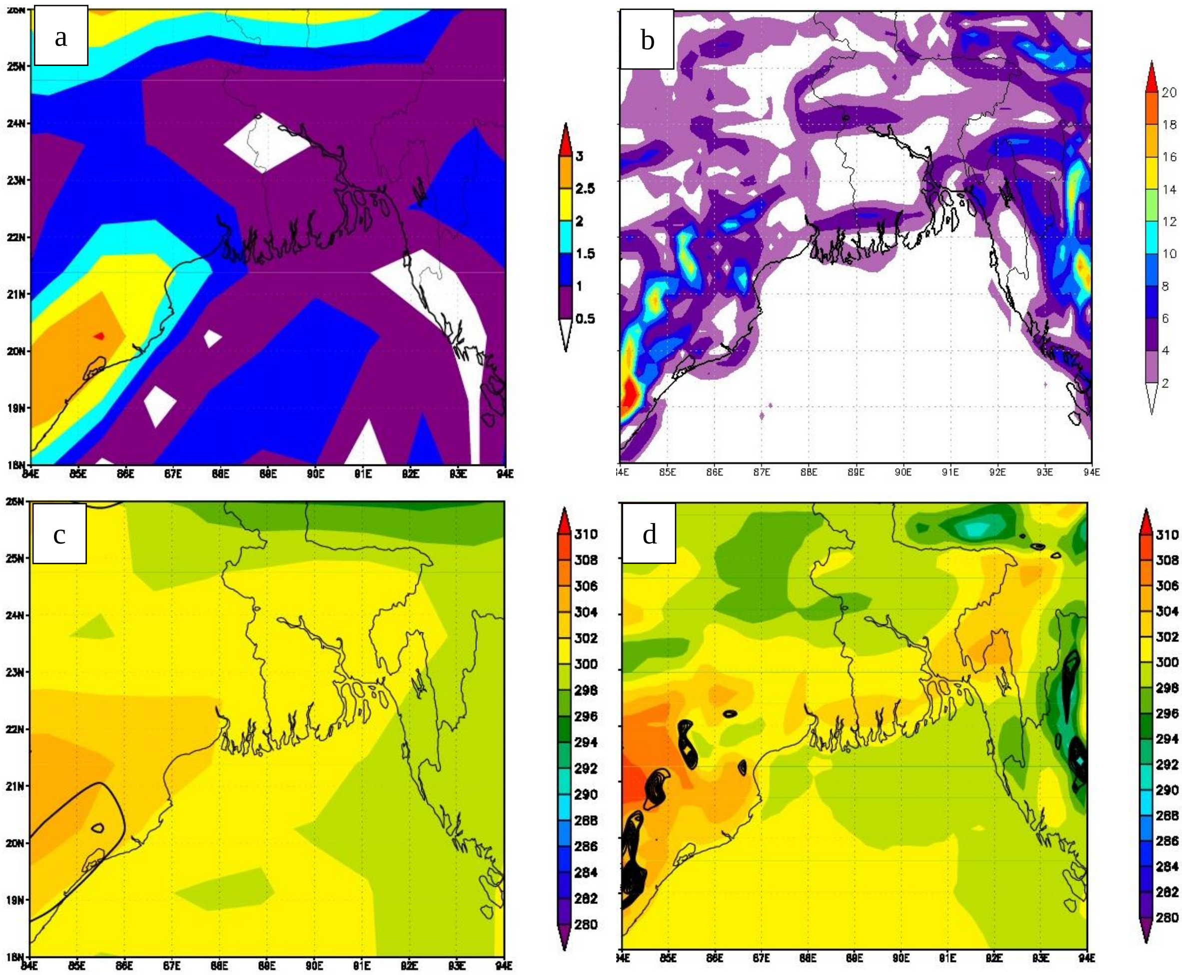

Fig 4. Shaded gradient of specific humidity (g/kg/100km) (a) JRA -25 (b) GSM: Shaded temperature and contoured specific humidity gradient; (c) (≥3g/kg/100km) using JRA-25 data; d) (≥10g/kg/100km) by GSM on 12 UTC 4th April, 2011

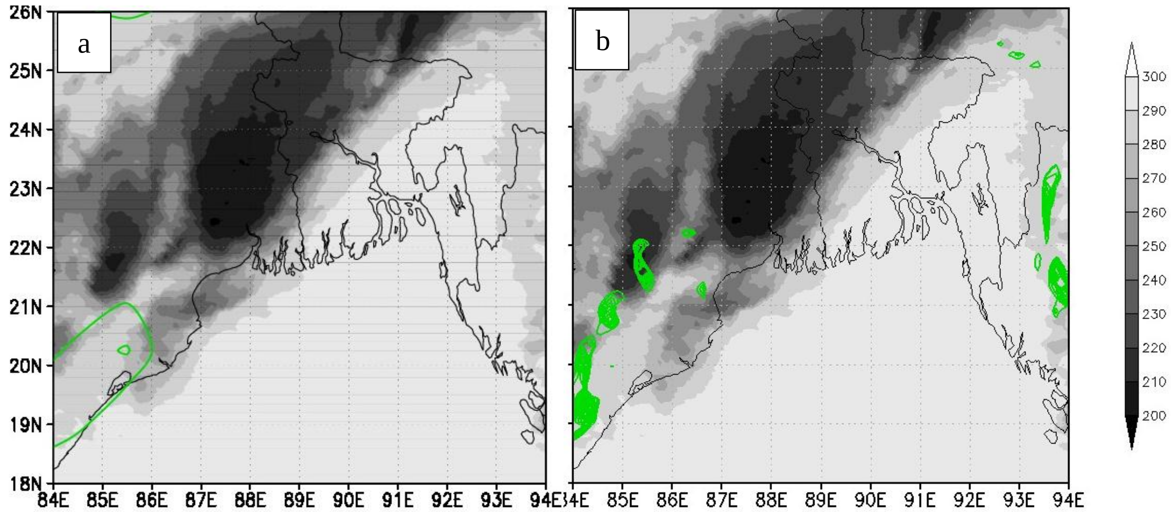

Fig 5. Shaded black body temperature TBB and contoured specific humidity gradient (a) (≥3g/kg/100km) using JRA-25 data; (b) (≥10g/kg/100km) by GSM on 12 UTC 4th April, 2011

The satellite IR imageries of Multi-functional Transport Satellite (MTSAT) of JMA are coupled with specific humidity gradient at 12UTC shows some eastward moving cloud initiated along the dry-line (Fig 5 a-b). From this figure we can depict that dry-line exists near the cloud initiation position which suggests that dry-line contributes to the initiation of SLCS in this case.

4.2 Atmospheric Instability

Atmospheric instability is a major determinant to estimate the possibility of the development of SLCS. Many examples of localized convective development also along the dry-line in Great Plains have been noted Bluestein and Parker (1993) and Hane (1997).

Yamane and Hayashi (2006) showed that the magnitude of potential instability and vertical wind shear increase in the pre-monsoon seasons which is an important factor to form severe thunderstorms. Atmospheric environment has high potential instability on severe local convective storms days of Bangladesh (Yamane et al, 2010b; 2012).

According to Yamane et al, (2010b; 2012) Lifted Index (LI), Precipitable Water (PW) and Convective Available Potential Energy (CAPE) have relatively higher forecast skill for SLCS (Yamane 2010b). They also mentioned that spatial distribution of CAPE and PW value are higher and LI is lower over sea than the land (Yamane et al. 2012).

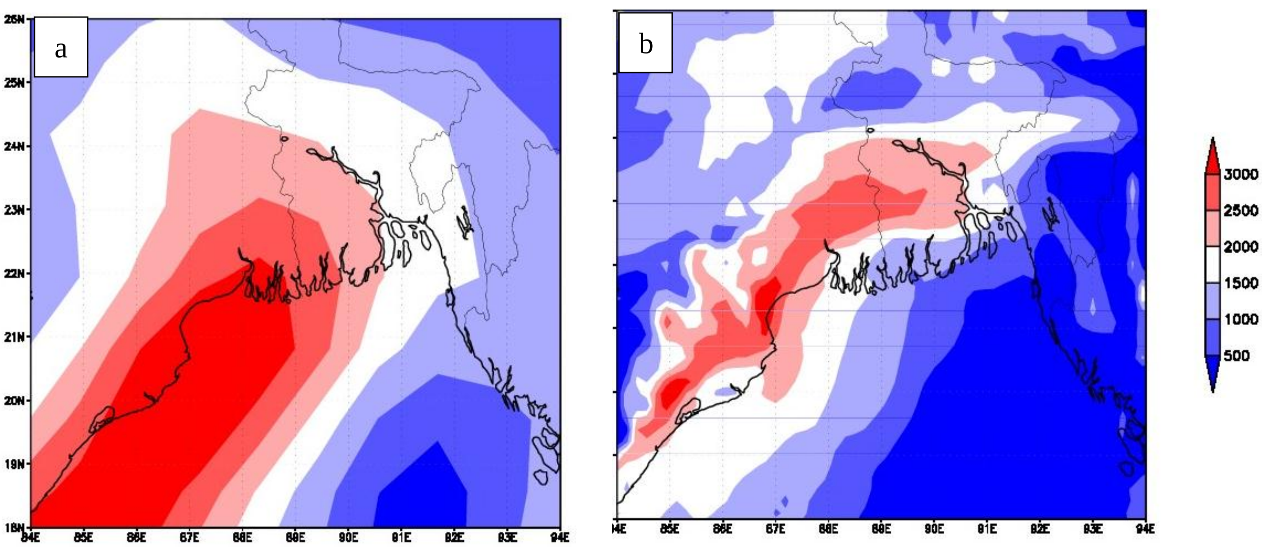

Fig 6. Shaded CAPE J/kg a) JRA-25, b) GSM at 1200 UTC on 4th April, 2011

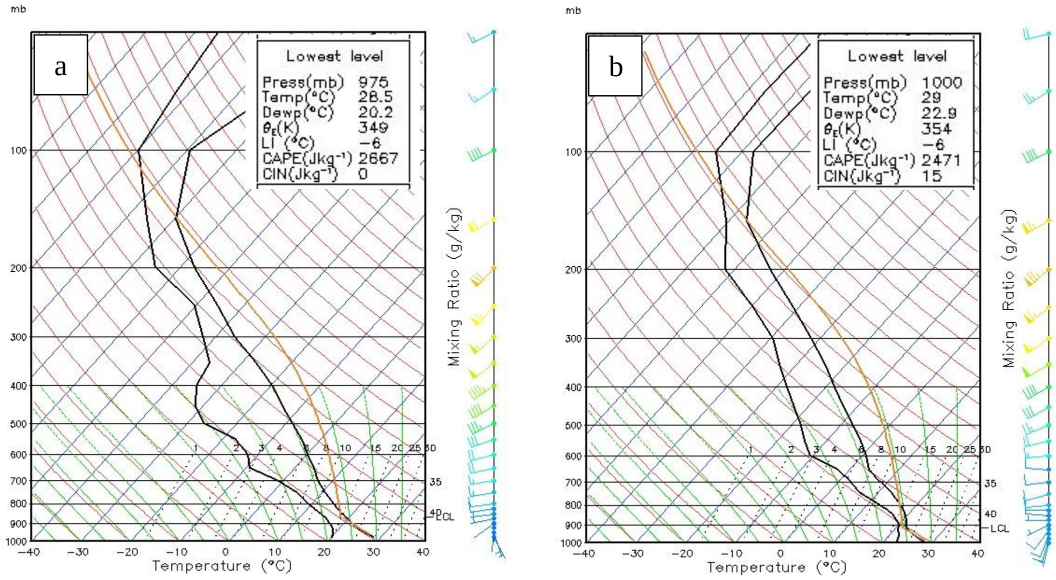

Fig 7. At the cross section of 22° N latitude and 87° E longitude a) 2667 J/kg by JRA-25, b) 2471 J/kg by GSM data

Fig. 6 a-b shows CAPE distribution over the study area using JRA-25 data and GSM data respectively. CAPE values are high in the east side (moist part) of the gradient and it is significantly increased as the day advances. It reaches more than 2400 (J/kg) over the 22° N latitude and 87° E longitude at 1200 UTC. The Lifted Index (LI) is a measure of the thunderstorm potential which takes into account the low level moisture availability and can be used as a predictor of latent instability. Karmakar and Alam (2006) studied a number of thunderstorm cases over Dhaka and concluded that thunderstorms are likely to occur over Bangladesh when LI ≤ 0 and, severe Nor'westers with tornadic intensity are possible when LI < -3 over Bangladesh. In this study LI values -6 in both analyses (Fig 7a; 7b) at the same area. Negative Showalter Stability Index (SSI) is an indicator for possible severe convective activity. SSI is analyzed -1 by JRA-25 and -5 by GSM at the same location (figure didn't include). Two different analysis data of different horizontal resolution indicates that the instability around the moist part of dry-line which triggers the severe convection over the region. Though the JRA-25 analysis only gives vague information of unstable region, the use of fine grid data specifically locates the very unstable region where convection be initiated.

5. Summary

In the present study, we examined the environmental condition for the severe storm case on April 4, 2011. The interest is focused on the dry-line feature which is formed between the moist air originates in Bay of Bengal and the dry air from Indian sub-continent. This case study suggests that the dry-line has certain influence to trigger severe storm similar to the dry-line in the Great Plain of the United States. The use of fine grid analysis proved to be very powerful to locate the specific location of convection initiation.

The low resolution JRA-25 data is available since 1979 and the fine resolution data from 2008. Combining both data, climatological study on the relation of dry-line and SLCS is to be continued following the present study.

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References

Bluestein, H.B. (1993): Fronts and Jets. Vol. 2, Synoptic Dynamic Meteorology in Midlatitudes, Oxford University Press, 288.

Bluestein, H.B. and Parker,S.S. (1993): Modes of isolated, severe convective storm formation along the dryline. Mon. Wea. Rev., 121, 1354–1372.

Coffer, B.E., Maudlin, L.C., Veals, P.G., and Clark, A. (2013): Dryline Position Errors in experimental convection-allowing NSSL-WRF Model Forecasts and the operational NAM. Weather and Forecasting

Dalal, S., Lohar, D., Sarkar, S., Sadhukhan, I., Debnath, G.C. (2012): Organizational modes of squall-type Mesoscale Convective Systems during premonsoon season over eastern India. Atmospheric research 106, 120-138

Fujita, T. T, (1958): Structure and movement of a dry front. Bull. Amer. Meteor. Soc., 39, 574–582.

Ghosh A, Lohar D and Das J. (2008): Initiation of Nor'wester in relation to mid-upper and low-level water vapor patterns on METEOSAT-5 images. Atmos. Res. 87 116.135.

Hane, C. E., Bluestein, H.B., Crawford, T.M., Baldwin, M.E. and Rabin, R.M. (1997): Severe Thunderstorm Development in Relation to Along-Dryline Variability: A Case Study. Monthly Weather Review, vol.125.2, Pp 231-51

Hoch, J. and Markowski, P. (2005): A climatology of springtime dryline position in the 610 U.S. Great Plains region. J. Climate., 18, 2132–2137

Karmakar, S. and Alam, M. (2006): Instability of the Troposphere Associated with Thunderstorms /nor'westers over Bangladesh during the pre-monsoon season. Mausam 57(4): 629-638.

Lohar, D and Pal, B. (1995): The effect of irrigation on pre-monsoon season precipitation over south West Bengal. India J. Climate, 8, pp. 2567–2570

Ono, Y. (2001): Design and adoption of household tornado shelters to mitigate the tornado hazard in Bangladesh. PhD Dissertation, Kent State University

Peterson, R.E and Mehta, K.C. (1981): Climatology of Tornadoes of India and Bangladesh. Arch. Met. Geoph. Biokl., Ser.B, Vol. 29

Prasad, K. (2006): Environmental and synoptic conditions associated with no'westers and tornadoes in Bangladesh – An appraisal based on numerical weather prediction (NWP) guidance products. 14th report of SAARC Meteorological Research Center, Dhaka, Bangladesh.

Rhea, J. O. (1966): A study of thunderstorm formation along dry lines. J. Appl. Meteor., 5, 58–63.

Schaefer, J. T. (1974a): The Life Cycle of the Dryline. J. Appl. Meteor., 13, 444–449.

Yamane, Y. and Hayashi, T. (2006): Evaluation of environmental conditions for the formation of severe local storms across the Indian subcontinent. Geophys. Res. Lett. 33, L17806.

Yamane Y, Hayashi T, Dewan A.M, Akter, F. (2010a): Severe local convective storms in Bangladesh: Part 1. Climatology. Atmospheric Research 95: 400-406.

Yamane Y, Hayashi T, Dewan AM, Akter, F, (2010b): Severe local convective storms in Bangladesh: Part 2. Environmental conditions. Atmospheric Research 95: 407-418.

Yamane, Y., Hayashi, T., Kiguchi, M., Akter, F. and Dewan, A. M. (2012): Synoptic situations of severe local convective storms during the pre-monsoon season in Bangladesh. International Journal of Climatology,

Weston, K.J. (1972): The dryl-ine of Northern India and its role in cumulonimbus convection. Quarterly Journal of the Royal Meteorological Society 98 (417): 519–531

Ziegler, C. L., Lee, T.J. and Pielke, R.A. (1997): Convective Initiation at the Dryline: A modeling study perspective. Mon.Wea. Rev. 125,1001-1026

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