INTERNATIONAL JOURNAL OF CLIMATOLOGY
*Int. J. Climatol.* **33**: 725–734 (2013)
Published online 13 March 2012 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.3460

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# Synoptic situations of severe local convective storms during the pre-monsoon season in Bangladesh

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**ABSTRACT:** This study examines synoptic situations of severe local convective storms (mesoscale severe weather associated with deep convections such as tornado and hail) during the pre-monsoon season (from March to May) in Bangladesh. We compared composite meteorological fields on severe local convective storm days (SLCSD) with those on non-severe local convective storm days (NSLCSD). Moisture inflow from the Bay of Bengal is enhanced with intensification of southwesterly wind at 950 hPa on SLCSD compared with NSLCSD. The temperature is higher at 800 hPa over the inland area of the Indian subcontinent including Bangladesh on SLCSD than NSLCSD. At 550 hPa, a trough over Bangladesh develops on SLCSD compared with NSLCSD. This leads to the development of a thermal trough over the inland area of the Indian subcontinent and enhancement of cold advection from the northwest into Bangladesh on SLCSD at this level. This synoptic situation produces great potential instability of the atmosphere in Bangladesh on SLCSD during the pre-monsoon season. Composite distributions of lifted index, precipitable water and convective available potential energy on SLCSD and NSLCSD over south Asia show distinct differences of these parameters between these two categories with statistical significance especially in and around Bangladesh. These differences indicate that the atmospheric environment has great potential instability especially in and around Bangladesh on SCLSD under the synoptic situations shown in this study. Copyright © 2012 Royal Meteorological Society

KEY WORDS severe local convective storm; synoptic situation; Bangladesh; pre-monsoon

*Received 21 April 2011; Revised 10 February 2012; Accepted 12 February 2012*

## 1. Introduction

A severe local convective storm (henceforth, referred to simply as SLCS) is mesoscale severe weather accompanied by deep convections (e.g. tornado, hail, lightning and downburst). SLCS often causes death and destruction to property. Tornado is one of the most devastating storms and causes many deaths and damage to property and loss of crop.

Bangladesh is located in the northeastern part of the Indian subcontinent and faces the Bay of Bengal to the south and the Himalayas to the north. SLCS frequently occurs in Bangladesh and causes death and devastation of large scale. Fujita (1973) shows that tornadoes are concentrated in and around Bangladesh in south Asia. Yamane *et al.* (2010a) show that SLCS frequently occurs during the pre-monsoon season peaking in April in Bangladesh based on a vast database of SLCS. Yamane and Hayashi (2006) show that the magnitudes of potential instability and vertical wind shear, which are important factors for severe thunderstorms, are increasing in and around Bangladesh during the pre-monsoon season, also peaking in April.

Bangladesh has often experienced severe damage caused by SLCS. A tornado that, occurred in Tangail (89.9°E 24.2°N) located in the northern part of Bangladesh on 13 May 1996, caused over 700 deaths and 30 000 injuries. Gusts of wind accompanied by severe thunderstorms that, occurred over the Meghna River on 23 May 2004, capsized a launch leaving 16 people dead and 240 missing.

Understanding the environmental conditions of SLCS is important to clarify the mechanism of generation and development, and improve the prediction of SLCS. Yamane *et al.* (2010b) show the characteristics of environmental conditions of SLCS during the pre-monsoon season based on comparison of composite soundings at Dhaka (90.3°E 23.7°N) on days with reports of SLCS with those on days without reports of SLCS. They indicated intensification of southerly wind and increasing of water vapour around the level of 500 m above ground level (AGL), rising of temperature around the level of 2 km AGL and dropping of temperature around

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the level of 5 km AGL, and these conditions produce great potential instability favourable for outbreaks of SLCS.

Yamane *et al*. (2010b)'s research was based on rawinsonde data at one point in Dhaka and did not show a synoptic meteorological setting leading to the characteristics of composite soundings associated with outbreaks of SLCS. To better understand the mechanism and improve the prediction of SLCS, clarifying synoptic situations in which SLCS is generated is important. Therefore, this study attempts to clarify synoptic spatial situations accompanied by the characteristics of composite soundings associated with severe local convective storm days (SLCSD) during the pre-monsoon season shown in Yamane *et al*. (2010b).

To investigate typical synoptic conditions favourable for SLCS, averaged meteorological fields associated with SLCS has been analysed. Beebe (1956) provided tornado composite weather maps, which are averaged weather maps for past tornadoes, and shows synoptic conditions commonly found in the outbreaks of tornadoes in the United States. Lowe and McKay (1962) show that synoptic conditions of tornadoes for the Canadian Prairies based on tornado composite weather maps. Some reports have showed that synoptic features associated with SLCS during the pre-monsoon season in Bangladesh based on case studies (Ahmed, 1986; Chowdhury and Karmakar, 1986; Mowla, 1986; Shah Alam, 1986; Prasad, 2006). However, there has been little research investigating typical characteristics of synoptic situations of SLCS during the pre-monsoon season based on composite analysis.

The purpose of this study is to comprehensively clarify typical features of synoptic spatial situations of SLCS during the pre-monsoon season in Bangladesh based on composite analysis with National Centers for Environmental Prediction (NCEP) Final (FNL) Operational Global Analysis data, which uniformly covers the globe. In particular, we focus on factors of synoptic meteorological fields leading to features of composite soundings on the days of SLCS shown in Yamane *et al*. (2010b) and attempt to promote the results shown in Yamane *et al*. (2010b). We compared composite meteorological fields on the day with reports of SLCS to those on the days without reports of SLCS to clarify the synoptic situations of SLCS. This study contributes to understanding

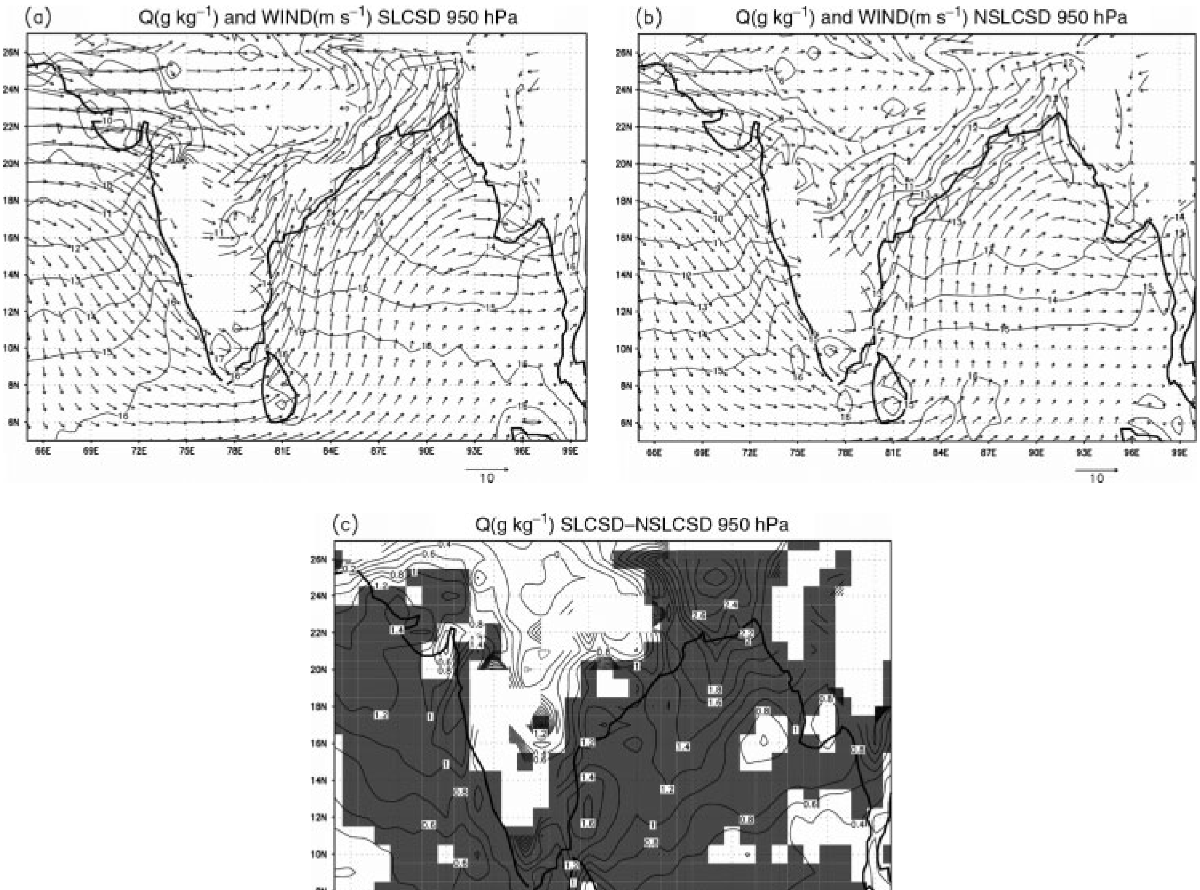


Figure 1. The distributions of specific humidity (g kg$^{-1}$) and wind (ms$^{-1}$) at 950 hPa ((a) composite field on SLCSD, (b) composite field on NSLCSD and (c) the distribution of the difference between SLCSD and NSLCSD. Shaded area indicates the difference with statistical significance of the level of 99%).

and forecasting of SLCS during the pre-monsoon season in Bangladesh.

## 2. Data and methodology

Yamane *et al*. (2010a) constructed a vast database of SLCS including 2324 events from 1990 to 2005 in Bangladesh by surveying the literature. At first, we selected SLCSD, which are the days with reports of SLCS, during the pre-monsoon season in Bangladesh from 2002 to 2005 based on our database. To focus on situations with convection, SLCSD with zero convective available potential energy (CAPE) averaged over the region 88 °E–93 °E and 20°N–27°N covering Bangladesh were excluded in this study. We focused on the pre-convective synoptic environment leading to the occurrence of SLCS and excluded data in the environment stabilized by convection from the dataset of SLCSD. The above procedure allows us to exclude data contaminated by convection. Consequently, we chose 159 SLCSD and 389 non-severe local convective storm days (NSLCSD). NSLCSD are the days without any report of SLCS, and do not include SLCSD with zero CAPE. In this study, we attempted to clarify synoptic situations of SLCS during the pre-monsoon season in Bangladesh based on comparison of composite meteorological fields on SLCSD with those on NSLCSD.

The data used in this study are NCEP FNL Operational Global Analysis data. The dataset can be downloaded freely from the National Center for Atmospheric Research (NCAR) Computational and Information Systems Laboratory (CISL) research data archive website (http://dss.ucar.edu/datasets/ds083.2/). Spatial resolution of the NCEP FNL data is 1.0° × 1.0°, and the temporal resolution is 6 h (00 UTC, 06 UTC, 12 UTC and 18 UTC).

The analysis domain in this study is 65°–100 °E and 5°–27 °N covering south Asia region. The NCEP FNL data at 00 UTC were used in this study because the results of Yamane *et al*. (2010b) are based on rawinsonde data at 00 UTC at Dhaka produced by the Bangladesh Meteorological Department (BMD) (Rawinsonde observation data of BMD are available at only 00 UTC). The major purpose of this study was to clarify synoptic spatial situations leading to characteristics of composite soundings on SLCSD shown in Yamane *et al*. (2010b). Therefore, this study also focused on the data at 00 UTC.

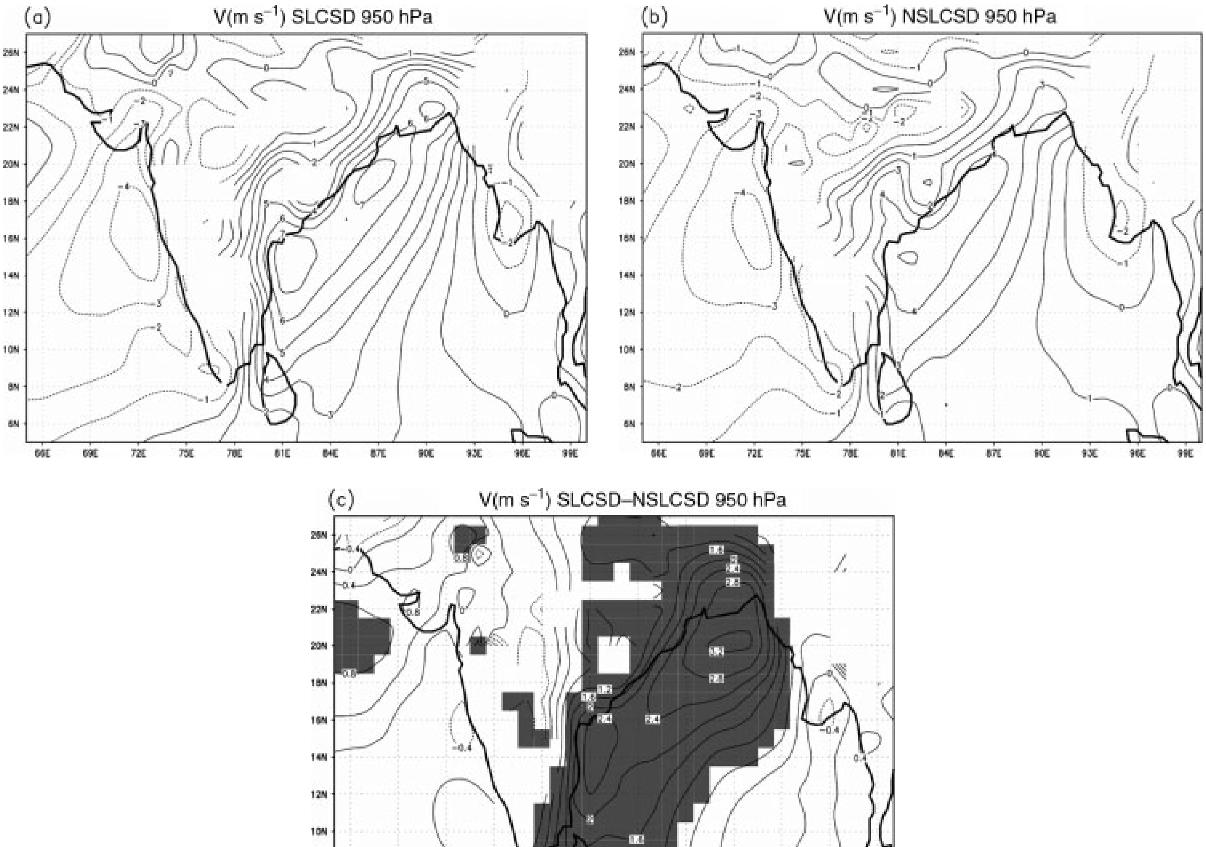


Figure 2. The distributions of meridional wind component (ms$^{-1}$) at 950 hPa ((a) composite field on SLCSD, (b) composite field on NSLCSD and (c) the distribution of the difference between SLCSD and NSLCSD. Shaded area indicates the difference with statistical significance of the level of 99%).

## 3. Results

### 3.1. Specific humidity and wind at 950 hPa

Yamane *et al.* (2010b) showed intensification of the southerly wind component and increasing of specific humidity around the level of 500 m AGL on SLCSD. To clarify the synoptic situation accompanying these characteristics at this level, we investigated specific humidity and wind fields at 950 hPa, which is nearly equivalent to 500 m AGL. The NCEP FNL data does not include specific humidity. Specific humidity was calculated from the temperature and relative humidity included in the NCEP FNL data.

Figure 1 shows the distributions of specific humidity and wind at 950 hPa on SLCSD and NSLCSD, and the difference of specific humidity between SLCSD and NSLCSD. The shaded area in the figure of the difference between the composite fields of specific humidity indicates the difference with a statistical significance of 99%. Specific humidity is high over Bangladesh, and southwest wind is prominent along the eastern coast of the Indian peninsula up to Bangladesh both on SLCSD and NSLCSD. The averaged specific humidity in and around Bangladesh on SLCSD is larger compared with that on NSLCSD. The distribution of the difference of specific humidity between SLCSD and NSLCSD shows a larger positive anomaly over Bangladesh (over about 2.0 g $kg^{-1}$) with the statistical significance. This is consistent with the result shown in Yamane *et al.* (2010b) that specific humidity increases around 500 m AGL on SLCSD.

Figure 2 shows the distributions of the meridional wind component at 950 hPa on SLCSD and NSLCSD, and the difference of the meridional wind component between SLCSD and NSLCSD. Southerly wind components are prominent along the eastern coast of the Indian peninsula up to Bangladesh on both SLCSD and NSLCSD. The southerly wind component in and around Bangladesh on SLCSD is larger compared with that on NSLCSD. The distribution of the difference of the meridional wind component between SLCSD and NSLCSD shows a larger positive anomaly with statistical significance, especially in the region including the northern part of the Bay of Bengal and the southern part of Bangladesh (over about 2.8 $ms^{-1}$). This is consistent with the result shown in Yamane *et al.* (2010b) that the southerly wind component is enhanced around 500 m AGL on SLCSD. The result of this study shows that intensification of the southerly wind component on SLCSD is found over a wide region along the eastern coast of the Indian peninsula up to Bangladesh peaking in and around Bangladesh.

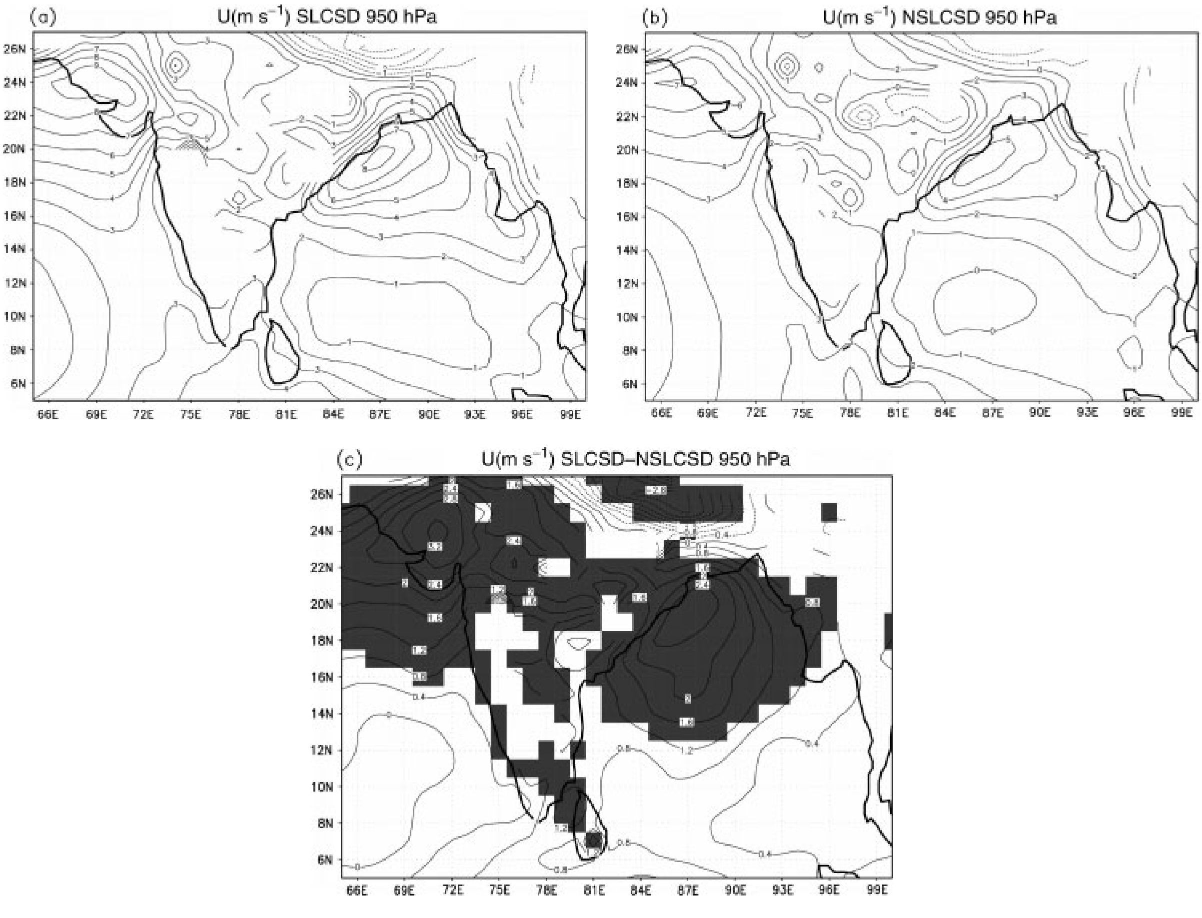


Figure 3. The distributions of zonal wind component ($ms^{-1}$) at 950 hPa ((a) composite field on SLCSD, (b) composite field on NSLCSD and (c) the distribution of the difference between SLCSD and NSLCSD. Shaded area indicates the difference with statistical significance of the level of 99%).

Figure 3 shows the distributions of the zonal wind component at 950 hPa on SLCSD and NSLCSD, and the difference of the zonal wind component between SLCSD and NSLCSD. Westerly wind components are prominent over the northern part of the Bay of Bengal on both SLCSD and NSLCSD. The westerly wind component over this region on SLCSD is larger compared with that on NSLCSD. The distribution of the difference of the zonal wind component between SLCSD and NSLCSD shows a larger positive anomaly with statistical significance over the Bay of Bengal, especially in the northern part. This enhancement of the westerly wind component over the northern region of the Bay of Bengal on SLCSD contributes to intensification of the southwesterly wind to Bangladesh on SLCSD.

The significant increase of specific humidity as shown in Figure 1 in and around Bangladesh on SLCSD is greatly due to intensification of water vapour flux from the Bay of Bengal accompanied by enhancement of the southerly wind component shown in Figure 2. To evaluate this process, we investigated the distributions of the meridional component of water vapour flux on SLCSD and NSLCSD, and the difference between SLCSD and NSLCSD (Figure 4). Southerly components of water vapour flux are prominent along the eastern coast of the Indian peninsula up to Bangladesh like the southerly wind component. The southerly component of water vapour flux in and around Bangladesh on SLCSD is larger compared with that on NSLCSD. The distribution of the difference of the meridional component of water vapour flux shows a larger positive anomaly with statistical significance, especially over the region from the northern part of the Bay of Bengal to Bangladesh (over about 40 g $\mathrm{kg}^{-1}$ $\mathrm{ms}^{-1}$). This indicates that inflow of water vapour from the Bay of Bengal is intensified on SLCSD in and around Bangladesh. Intensification of southerly components of wind and water vapour flux associated with the occurrence of SLCS has been reported in some case studies in the past (Prasad (2006)). The increased amount of water vapour in the lower layer is important for increasing the potential instability of the atmosphere on SLCSD.

### 3.2. Temperature and wind at 800 hPa

Yamane *et al*. (2010b) showed the rising of temperature around the level of 2 km AGL on SLCSD during the

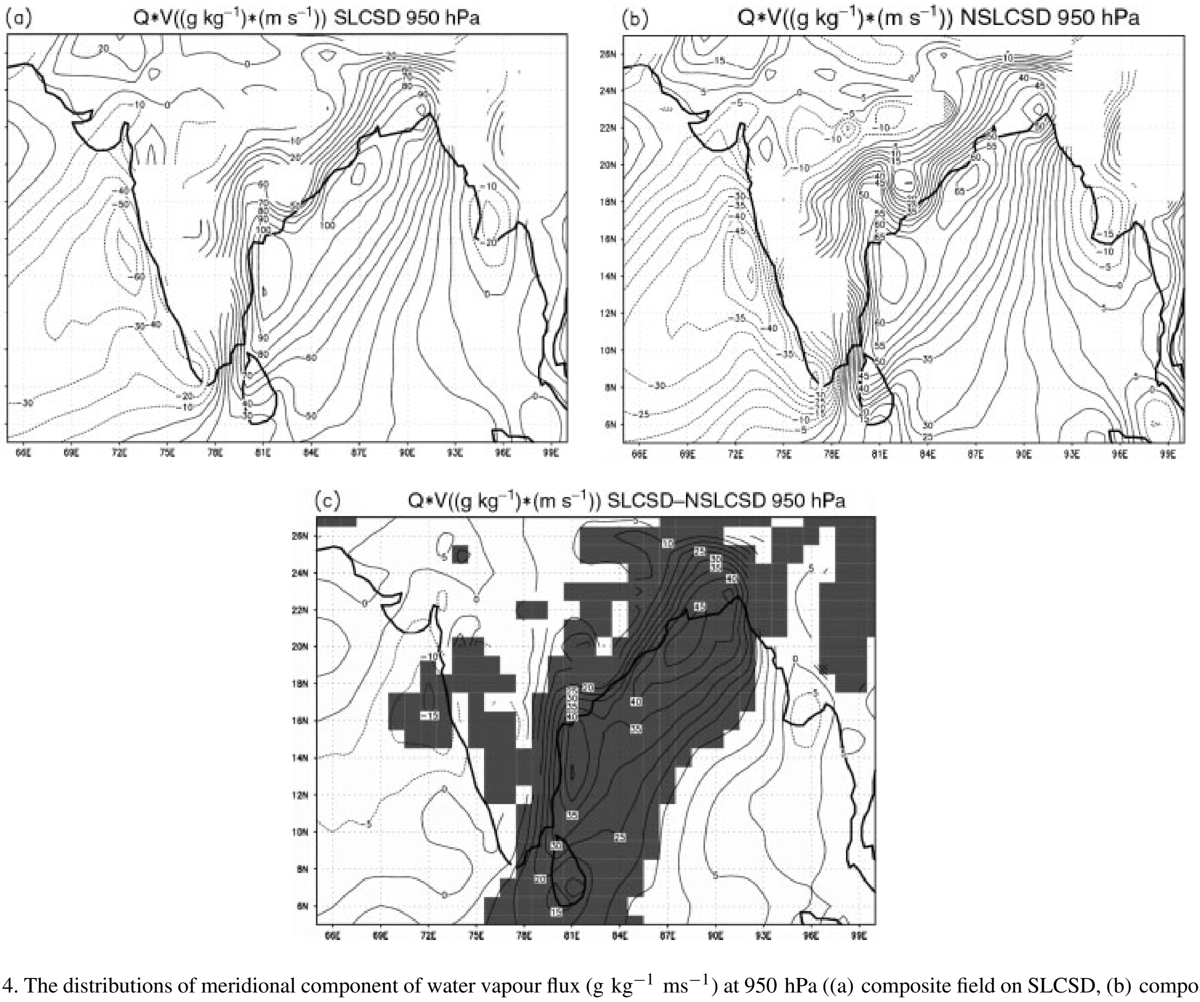
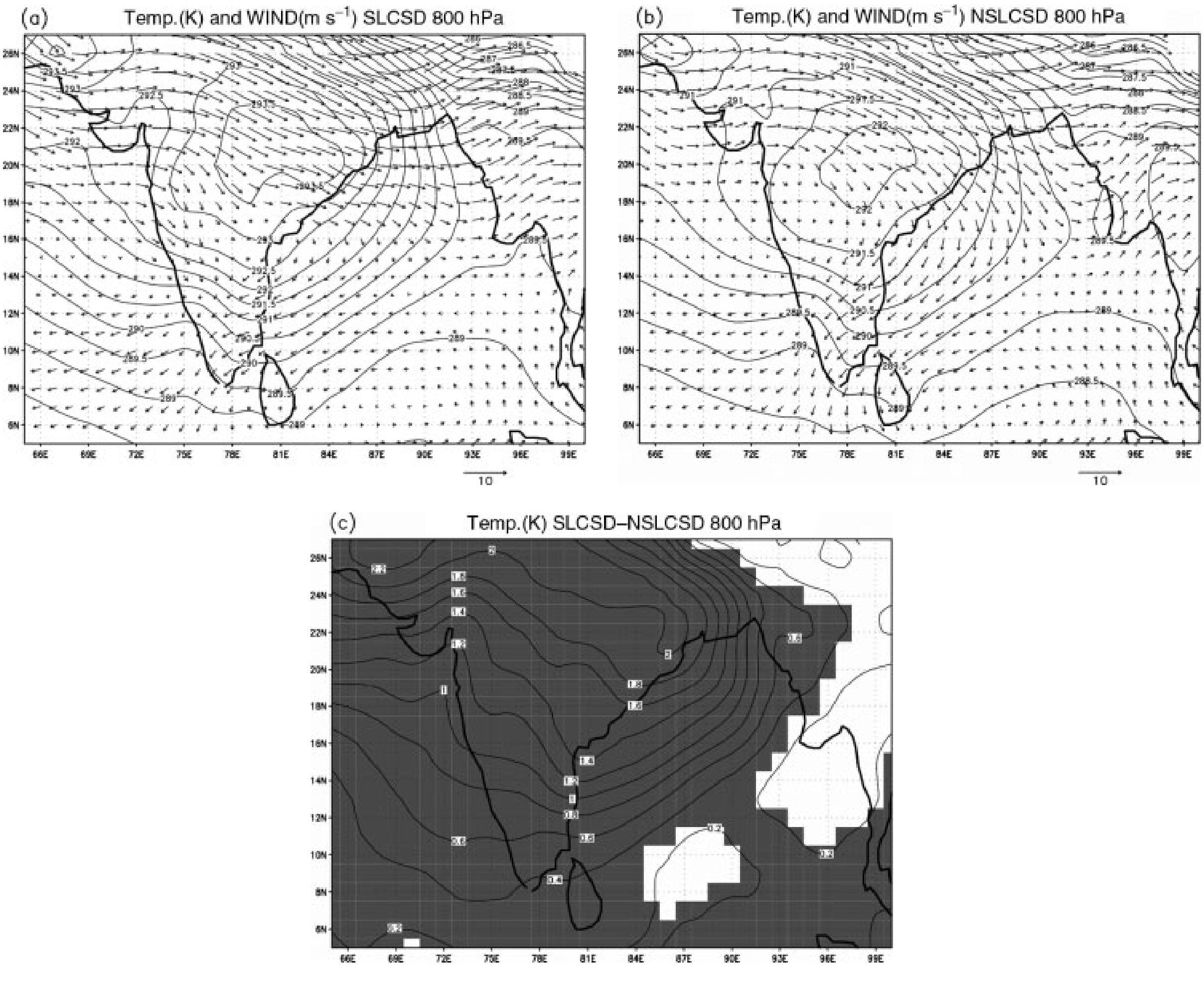


Figure 4. The distributions of meridional component of water vapour flux (g $\mathrm{kg}^{-1}$ $\mathrm{ms}^{-1}$) at 950 hPa ((a) composite field on SLCSD, (b) composite field on NSLCSD and (c) the distribution of the difference between SLCSD and NSLCSD. Shaded area indicates the difference with statistical significance of the level of 99%).

pre-monsoon season in Bangladesh. To clarify synoptic situations accompanied by the warming at this level, we investigated the temperature and wind fields at 800 hPa, which is nearly equivalent to 2 km AGL. Figure 5 shows the distributions of temperature and wind on SLCSD and NSLCSD at 800 hPa, and the difference of temperature between SLCSD and NSLCSD. We can find the region with high temperature inland in the Indian subcontinent on both SLCSD and NSLCSD. A westerly wind is prominent in and around Bangladesh, and warm advection can be found over Bangladesh. The inland temperature of the Indian subcontinent is higher on SLCSD compared to that on NSLCSD. The distribution of the difference of temperature between SLCSD and NSLCSD shows a positive anomaly with statistical significance over a wide area of south Asia including Bangladesh. The result is consistent with Yamane *et al*. (2010b), and shows that the warming around 2 km AGL found in Yamane *et al*. (2010b) is associated with the rising of temperature over a wide area in south Asia on SLCSD. Prasad (2006) reported warming and warm advection from the west at 850 hPa associated with SLCS based on case studies.

### 3.3. Temperature, wind and geopotential height at 550 hPa

Yamane *et al*. (2010b) show a dropping of temperature around the level of 5 km AGL on SLCSD during the pre-monsoon season in Bangladesh. To clarify synoptic situations accompanied by the cooling at this level, we investigated temperature, wind and geopotential height fields at 550 hPa, which is nearly equivalent to 5 km AGL. Figure 6 shows the distributions of temperature and wind on SLCSD and NSLCSD at 550 hPa, and the difference of temperature between SLCSD and NSLCSD. Thermal troughs are located across the inland region on both SLCSD and NSLCSD. Cold air is advected associated with northwesterly wind in the eastern part of the thermal troughs. The thermal trough is significantly developed with a larger amplitude on SLCSD compared with that on NSLCSD. The distribution of the difference of temperature between SLCSD and NSLCSD at 550 hPa shows a negative anomaly with statistical significance over the region from the west Bengal of India to the southern part of Bangladesh. This is due to intensification of cold air intrusion associated with the developing of the thermal trough on SLCSD.


(a) Temp.(K) and WIND(m s$^{-1}$) SLCSD 800 hPa

(b) Temp.(K) and WIND(m s$^{-1}$) NSLCSD 800 hPa

(c) Temp.(K) SLCSD–NSLCSD 800 hPa

Figure 5. The distributions of temperature (K) and wind (ms$^{-1}$) at 800 hPa ((a) composite field on SLCSD, (b) composite field on NSLCSD and (c) the distribution of the difference between SLCSD and NSLCSD. Shaded area indicates the difference with statistical significance of the level of 99%).

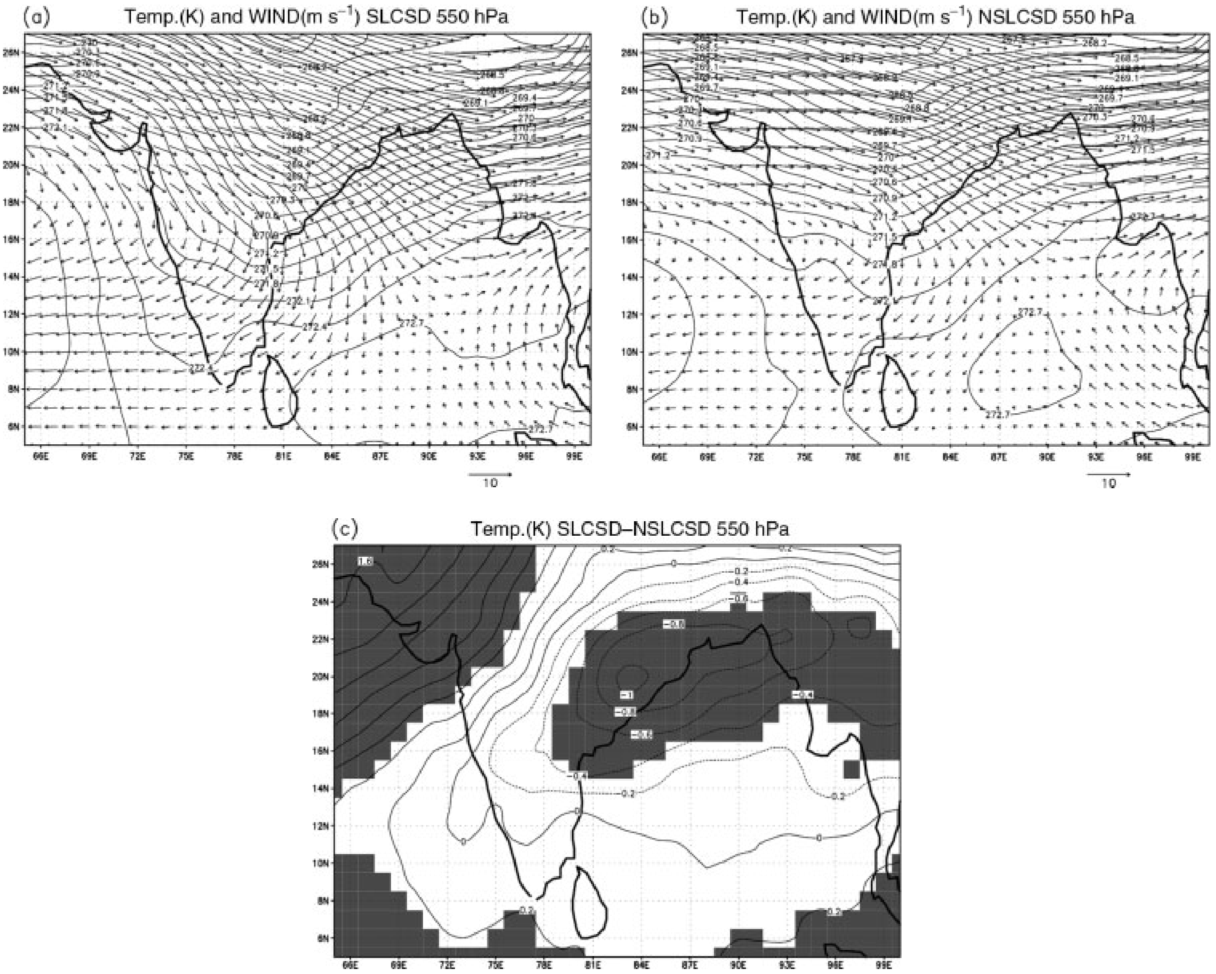


Figure 6. The distributions of temperature (K) and wind (ms$^{-1}$) at 550 hPa ((a) composite field on SLCSD, (b) composite field on NSLCSD and (c) the distribution of the difference between SLCSD and NSLCSD. Shaded area indicates the difference with statistical significance of the level of 99%).

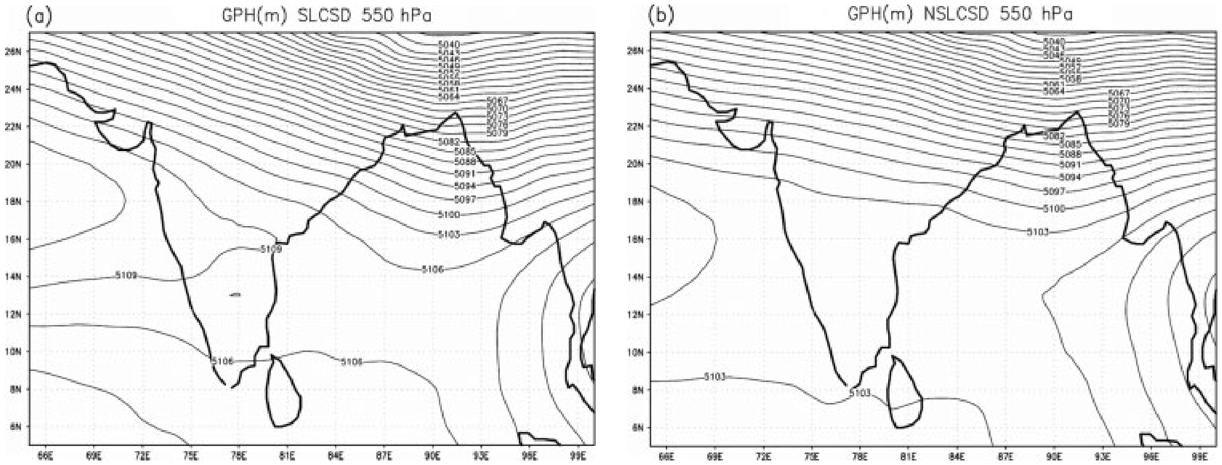


Figure 7. The distributions of geopotential height (m) at 550 hPa ((a) composite field on SLCSD, (b) composite field on NSLCSD).

Figure 7 shows the distributions of geopotential height on SLCSD and NSLCSD at 550 hPa. Troughs occur over Bangladesh on both SLCSD and NSLCSD. A trough develops with a larger amplitude on SLCSD compared with that on NSLCSD. The development of a trough enhances cold advection from the northwest in the western part of the trough across Bangladesh, and leads to the development of a thermal trough on SLCSD. Thus, the result of this study shows that cooling around 5 km AGL on SLCSD found in Yamane *et al*. (2010b) is

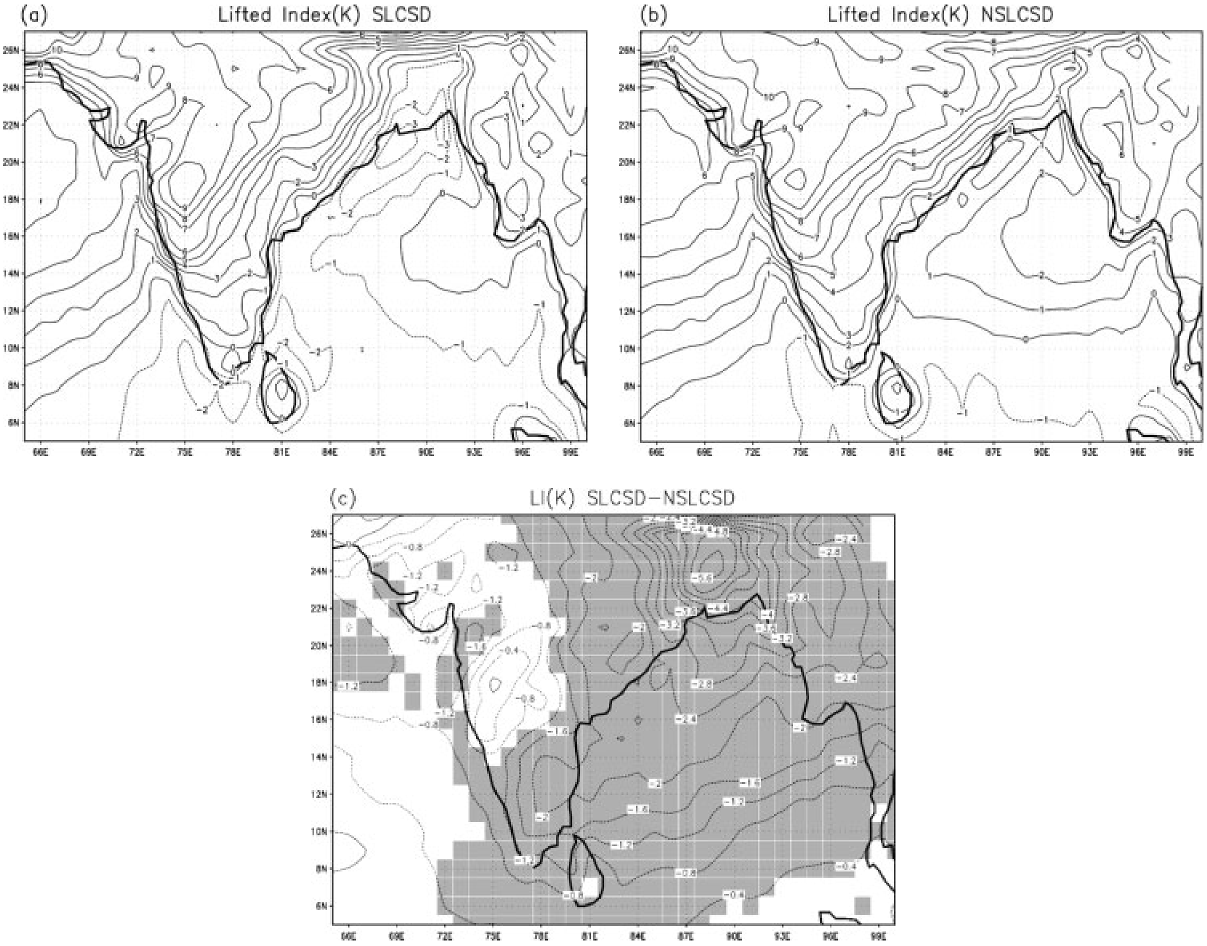


Figure 8. The distributions of LI ((a) composite field on SLCSD, (b) composite field on NSLCSD and (c) the distribution of the difference between SLCSD and NSLCSD. Shaded area indicates the difference with statistical significance of the level of 99%).

due to enhancement of cold advection from the northwest accompanied by the development of the trough across Bangladesh.

### 3.4. Spatial distributions of convective parameters

Yamane *et al.* (2010b) evaluated the forecast skill of convective parameters for SLCS using skill scores. Their results show that lifted index (LI), precipitable water (PW) and CAPE have relatively higher forecast skill for SLCS among convective parameters evaluated in Yamane *et al.* (2010b). In this study, we compare the spatial distributions of the LI, PW and CAPE on SLCSD with those on NSLCSD. These parameters are explained in detail in Yamane *et al.* (2010b).

#### *3.4.1. Lifted index (LI)*

LI is a convective parameter indicating the potential instability of the atmosphere (Galway, 1956). The negative value of the LI indicates the likelihood of convective activity. Figure 8 shows the distribution of the LI on SLCSD and NSLCSD, and the difference of the LI between SLCSD and NSLCSD. The values of the LI are high over the land and low over the sea on both SLCSD and NSLCSD. The distribution of the LI indicates that potential instability is larger over the sea than the land. The LI explicitly reflects the condition in the boundary layer. Since the amount of water vapour in the lowest layer is large over the sea, the LI is lower over the sea than the land inland. The distribution of the difference between SLCSD and NSLCSD shows that the value of the LI is considerably lower over Bangladesh on SLCSD compared with NSLCSD (under about -4K), and the negative anomaly over Bangladesh is statistically significant. The result indicates that potential instability increases especially over Bangladesh on SLCSD.

#### *3.4.2. Precipitable water (PW)*

PW is a parameter indicating the amount of water vapour contained in the atmosphere (Huschke, 1959). Figure 9 shows that the value of PW is relatively large over Bangladesh on both SLCSD and NSLCSD. The distribution of the difference between SLCSD and NSLCSD shows that the value of PW is larger over Bangladesh on SLCSD compared with NSLCSD (over about 6 kg $m^{-2}$), and the positive anomaly over Bangladesh is statistically significant. The result indicates that the amount of water vapour is increasing especially over Bangladesh on SLCSD, which may be mainly due to the increasing of water vapour in the lowest layer on SLCSD as mentioned above.

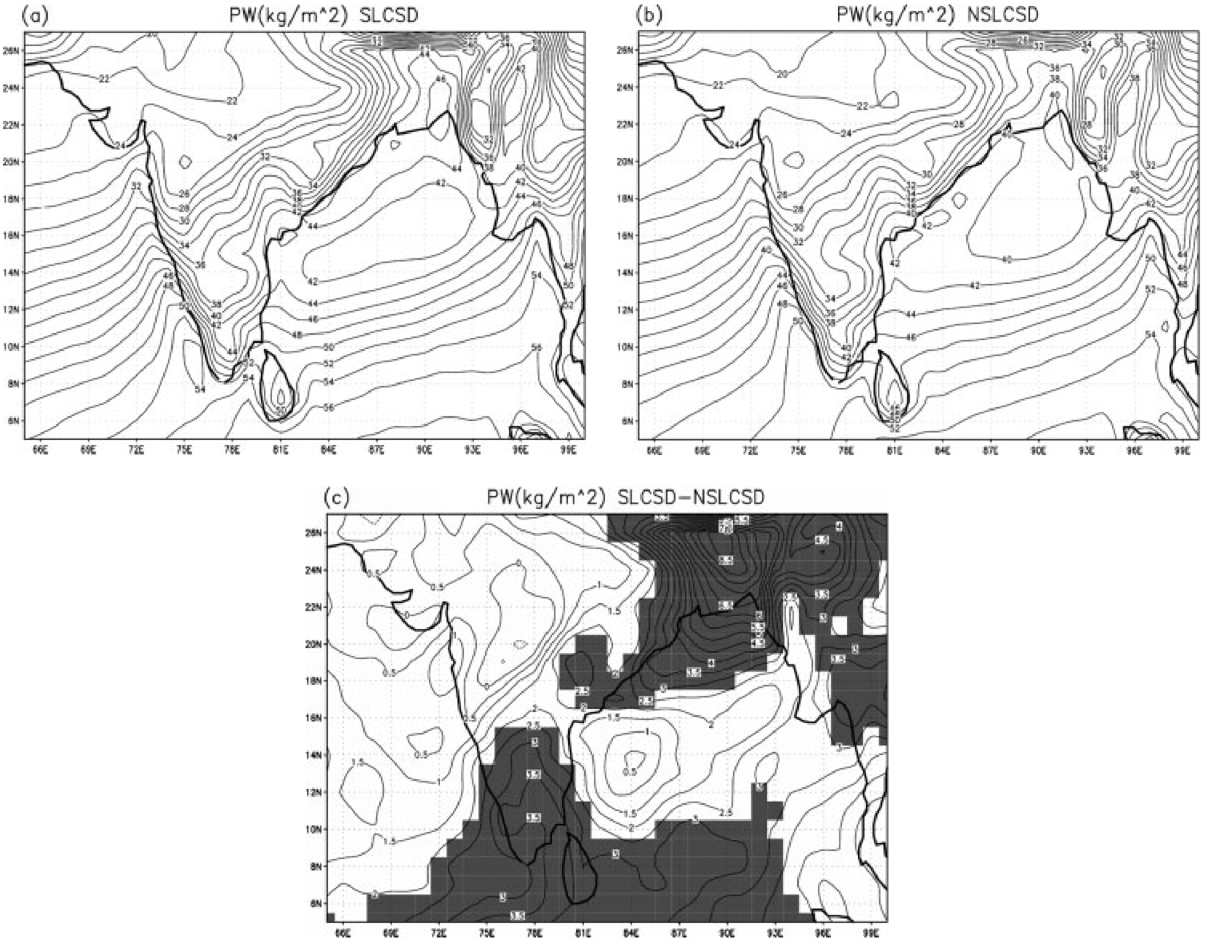


Figure 9. The distributions of PW ((a) composite field on SLCSD, (b) composite field on NSLCSD and (c) the distribution of the difference between SLCSD and NSLCSD. Shaded area indicates the difference with statistical significance of the level of 99%).

### 3.4.3. *Convective available potential energy (CAPE)*

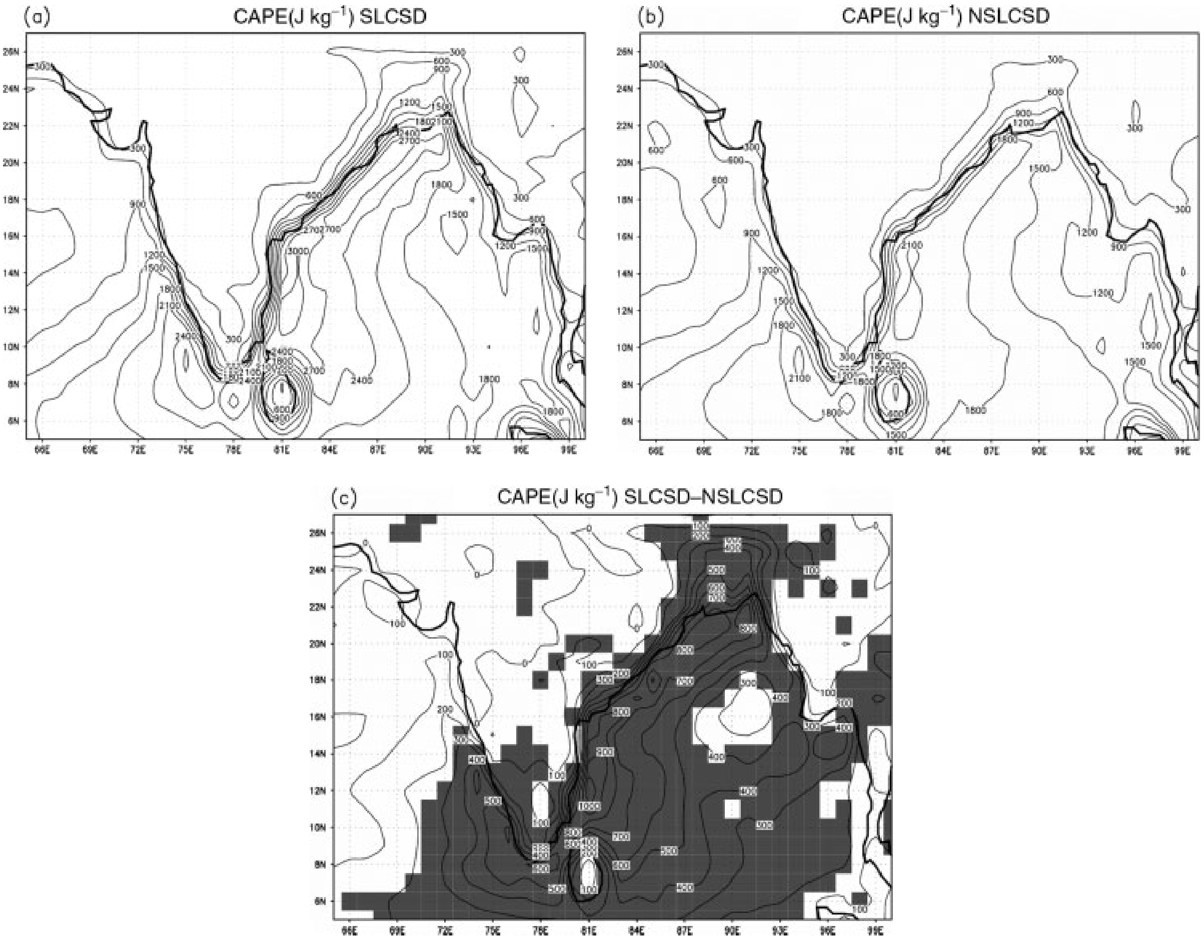
CAPE is a parameter indicating the potential instability of the atmosphere (Moncrieff and Miller, 1976). CAPE is a measure of the maximum possible kinetic energy of an air parcel provided by positive buoyancy, and is often utilized for forecasting severe thunderstorms. Figure 10 shows that CAPE is larger over sea region than inland regions on both SLCSD and NSLCSD like the LI. In the Indian subcontinent, CAPE is larger around Bangladesh on SLCSD and NSLCSD. The value of CAPE on SLCSD is higher than that on NSLCSD in and around Bangladesh. The distribution of the difference of CAPE between SLCSD and NSLCSD shows a positive anomaly with statistical significance over Bangladesh, indicating that potential instability is increasing especially in and around Bangladesh on SLCSD.

## 4. Conclusions

This study examines synoptic situations of SLCS during the pre-monsoon season (from March to May) in Bangladesh. In particular, this study attempts to clarify synoptic spatial situations associated with characteristics of composite soundings on SLCSD shown in Yamane *et al.* (2010b).

We compared composite meteorological fields on SLCSD with those on NSLCSD using NCEP FNL data. The southwesterly wind component is intensified at 950 hPa (nearly equivalent to 500 m AGL) over the region from the northern part of the Bay of Bengal to Bangladesh leading to enhanced moisture inflow from the Bay of Bengal into Bangladesh at 950 hPa on SLCSD. Rising of temperature can be found over a wide area in the Indian subcontinent including Bangladesh on SLCSD compared with NSLCSD at 800 hPa (nearly equivalent to 2 km AGL). A trough across Bangladesh is developed on SLCSD compared with NSLCSD at 550 hPa (nearly equivalent to 5 km AGL), leading to enhancement of cold advection from the northwest into Bangladesh on SLCSD at 550 hPa. The synoptic situations shown in this study produce great potential instability in Bangladesh on SLCSD during the pre-monsoon season.

We compared the spatial distribution of LI, PW and CAPE on SLCSD with those on NSLCSD. The results show distinct differences of the parameters between SLCSD and NSLCSD with statistical significance in Bangladesh. The result indicates that the atmospheric environment is favourable for SLCS especially in and around Bangladesh on SLCSD under the synoptic situations shown in this study.


(a) CAPE($J\ kg^{-1}$) SLCSD

(b) CAPE($J\ kg^{-1}$) NSLCSD

(c) CAPE($J\ kg^{-1}$) SLCSD–NSLCSD

Figure 10. The distributions of CAPE ((a) composite field on SLCSD, (b) composite field on NSLCSD and (c) the distribution of the difference between SLCSD and NSLCSD. Shaded area indicates the difference with statistical significance of the level of 99%).

BMD does not have an effective method of forecasting SLCS. This study is helpful for forecasting SLCS during the pre-monsoon season.

In this study, we did not investigate the dynamical process of the synoptic situation shown in this study. For example, the dynamical mechanism of intensification of the southerly wind component along the eastern coast of the Indian peninsula up to Bangladesh is not clarified in this study. In the future, we will conduct synoptic dynamical analysis to clarify the dynamical processes of the synoptic situations shown in this study based on case studies.

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