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AN OBJECTIVE METHOD FOR FORECASTING THUNDERSTORMS OVER AGARTALA USING STABILITY INDICES

1. An attempt has been made to understand the role of various stability indices and obtain their threshold values for forecasting of thunderstorms during pre-monsoon season over Agartala, the capital of Tripura and an important city in the northeastern region of India. Agartala is very prone for the occurrence of thunderstorms, with annual frequency of 81 thunderstorm days (based on climatology of 1981-2010). It also records severe squalls and occasional hailstorms, mainly during the pre-monsoon season, which causes serious damage in the city and its neighbouring areas. This study is likely to help the forecasters to issue forecast/nowcast with higher degree of accuracy.

2. The daily observed data of thunderstorms are obtained from Meteorological Centre, Agartala, India Meteorological Department. The Radiosonde/Radio wind (RS/RW) observations are also taken at Meteorological Centre, Agartala daily at 0000 UTC and the data are transmitted worldwide. Various stability indices can be derived from the data, which indicates whether the atmosphere is favourable for occurrence of thunderstorms. The calculated stability indices are also available in the website of University of Wyoming. In this study, the indices for the period of 2016-2020 are taken from their website (http://www.uwyo.edu/). The indices considered for this study have been described in Table 1.

A higher negative value of Showalter Index (SHOW) and Lifted Index (LI) indicates more instability in the atmosphere. Showalter (1953) found that thunderstorms have increasing probability as the value of his index falls from +1°C to -2°C and a value of -3°C or less is indicative of severe thunderstorms. Mukhopadhyay *et al*. (2003) investigated the values of certain parameters for thundery/non-thundery days over three northeastern stations, namely, Agartala, Guwahati and Dibrugarh and the value of Lifted Index less than -0.2°C was found to have more potential for thunderstorm development. Singh *et al*. (2014) considered the values of less than 2°C and less than 0°C respectively for the two indices, as threshold for occurrence thunderstorm over Agartala.

TABLE 1

Definition and description of Stability Indices

Index with equation	Description
Showalter Index (SHOW)= $T_{500} - T_{parcel}$	T_{500} = Temperature at 500 hPa T_{parcel} = Temperature at 500 hPa of a parcel of air lifted from 850 hPa
Lifted Index (LI)= $T_{500} - T_{parcel}$	T_{500} = Temperature at 500 hPa T_{parcel} = Temperature at 500 hPa of a parcel of air lifted from near the surface
Total Totals Index (TTI)= $(T_{850} - T_{500}) + (TD_{850} - T_{500})$	T_{850} = Temperature at 850 hPa TD_{850} = Dewpoint temperature at 850 hPa T_{500} = Temperature at 500 hPa
K-Index (KINX)= $(T_{850} - T_{500}) + TD_{850} - (T_{700} - TD_{700})$	T_{850} = Temperature at 850 hPa T_{500} = Temperature at 500 hPa TD_{850} = Dewpoint temperature at 850 hPa T_{700} = Temperature at 700 hPa TD_{700} = Dewpoint temperature at 700 hPa
Severe Weather Threat Index (SWEAT)= $12 \times TD_{850} + 20 \times TERM2 + 2 \times SKT_{850} + SKT_{500} + SHEAR$	TD_{850} = Dewpoint temperature at 850 hPa *TERM2* = MAX (TTI - 49, 0) *TTI* = Total Totals Index SKT_{850} = wind speed in knots at 850 hPa SKT_{500} = wind speed in knots at 500 hPa *SHEAR = 125 × [SIN (DIR500 - DIR850) + .2]* DIR_{500} = wind direction at 500 hPa DIR_{850} = wind direction at 850 hPa

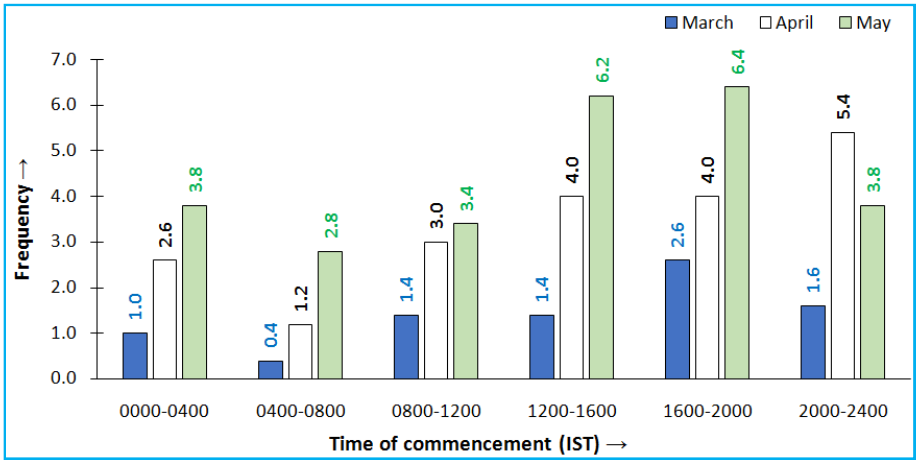

Fig. 1. Month wise diurnal variation of thunderstorms based on time of commencement

TABLE 2

Month wise frequency of thunderstorm days at Agartala (March - May)

	March	April	May	Total
Frequency of thunderstorm days	6	12	19	37
% of days, when thunderstorm occurs	19%	40%	63%	40%

Higher values of K-Index (KINX) and Total Totals Index (TTI) are more favourable for development of thunderstorms. Tyagi *et al*. (2011) found the values of KINX and TTI to be ≥ 24°C and ≥ 46°C respectively for higher possibility of thunderstorm development in Kolkata. Singh *et al*. (2014) used the thresholds of 24°C and 45.5°C respectively for favourability of thunderstorm over Agartala. Severe Weather Threat Index (SWEAT) considers the low-level moisture availability at 850 hPa level, instability in terms of Total Totals Index, wind direction and speed at lower and middle-levels of 850 and 500 hPa. Singh *et al*. (2014) considered the values of SWEAT > 100 as threshold for thunderstorm over Agartala.

3. Skill scores are objective way to determine the thresholds of the indices. To obtain skill scores of an index, a 2×2 contingency table is prepared with number of occurrence of events correctly forecasted, known as Hits (A), number of events occurred but not forecasted, known as Misses (B), number of events forecasted but did not occur, known as False Alarms (C) and number of correctly forecasted non-occurred events (D). Many skill scores can be calculated based on the contingency table. Five skill scores namely, Percent Correct (PC), Probability of Detection (POD), False Alarm Rate (FAR), Critical Success Index (CSI), Heidke Skill Score (HSS) have been used in this study, to find the usefulness of each index.

4. *Month wise and diurnal distribution of thunderstorms* - Table 2 shows the month wise frequency of thunderstorm days during the three months of pre-monsoon season at Agartala during 2016-2020. The highest frequency of thunderstorm days is observed in May (63% days of the month), followed by April and March respectively (40% and 19%). The month wise frequency distributions of thunderstorm events based on their time of commencements during early hours (0000-0400 IST), morning (0400-0800 IST), forenoon (0800-1200 IST), afternoon (1200-1600 IST), evening (1600-2000 IST) and night (2000-2400 IST) have been shown in Fig. 1. It has been observed that the highest percentage of thunderstorms (more than 60%) occur during second half of the day (1200-2400 IST) in all the three months. In March and May, the frequency is highest during evening hours, whereas, it is highest during night in April. Srinivasan *et al*. (1973) also observed that Tripura has a thunderstorm frequency maximum in the afternoon/ evening.

5. *Month wise comparison of stability indices* - Fig. 2 shows the month wise Box Whiskers plot of the six parameters, namely, Showalter Index (SHOW), Lifted Index (LI), K-Index (KINX), Severe Weather Threat Index (SWEAT) andTotal Totals Index (TTI) during thunderstorm and non-thunderstorm days at Agartala derived from the 0000 UTC RS/RW accents.

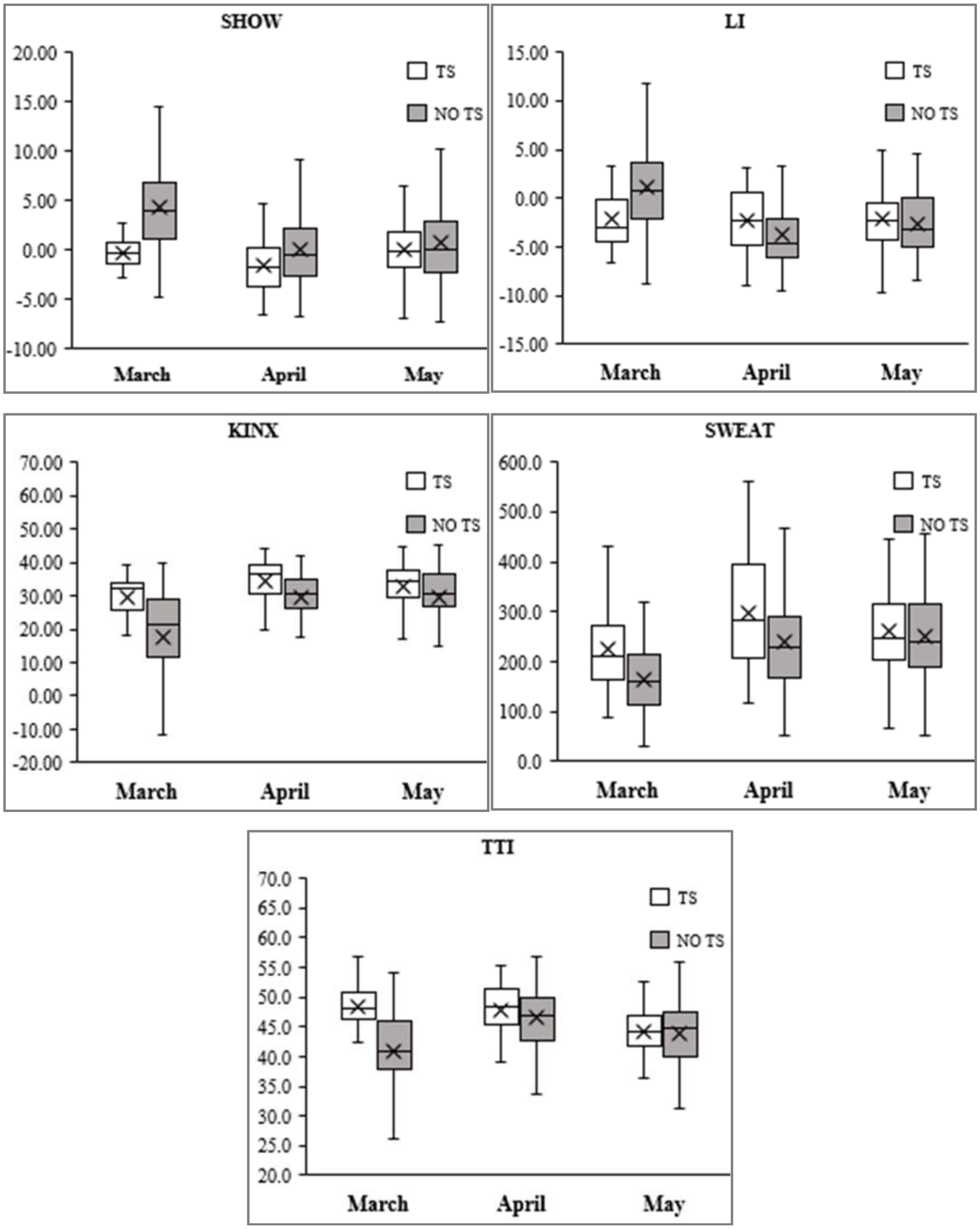

Fig. 2. Month wise Box Whiskers plot of the five parameters, Showalter Index (SHOW), Lifted Index (LI), K-Index (KINX), Sweat Index (SWEAT) and Total Totals Index (TTI) on thunderstorm (TS) and non-thunderstorm (NOTS) days (× indicates the mean value)

The month wise Box Whiskers plots of the indices are shown in Fig. 2, to get a general idea of the variation of the indices during thunderstorm and non-thunderstorm days. It is clearly seen that there is a significant difference in the values of the indices between thunderstorm and non-thunderstorm days during March. However, the difference is not very prominent during May, with all the indices. The Lifted Index (LI) does not seem to be a good indicator of thunderstorm/non-thunderstorm days during April and May, as lower values of LI are normally more favourable for thunderstorm occurrence, but the reverse has been observed during these two months.

TABLE 3

Mean, Median and Standard Deviation of stability indices for thunderstorm and non-thunderstorm days

Month	Index	Mean		Median		Standard Deviation	
		TS	NO TS	TS	NO TS	TS	NO TS
March	SHOW	-0.43	4.21	-0.32	4.01	2.29	4.62
	LI	-2.12	1.14	-3.06	0.86	3.67	4.72
	KINX	29.4	17.4	32.3	21.3	9.7	16.4
	SWEAT	224.2	164.9	211.2	159.7	77.0	71.7
	TTI	48.4	40.8	48.0	40.9	4.0	8.7
April	SHOW	-1.64	-0.03	-1.72	-0.55	2.96	3.34
	LI	-2.27	-3.75	-2.38	-4.57	3.66	3.50
	KINX	34.1	29.4	36.3	30.5	6.1	8.7
	SWEAT	296.4	239.7	281.4	227.2	110.1	92.3
	TTI	47.9	46.5	48.4	46.9	4.3	5.0
May	SHOW	0.07	0.77	-0.17	0.09	3.52	4.29
	LI	-2.12	-2.58	-2.35	-3.16	3.27	2.92
	KINX	32.6	29.3	34.5	30.6	7.6	11.0
	SWEAT	262.2	249.8	247.0	240.9	96.6	103.6
	TTI	44.3	43.8	44.3	44.8	5.1	6.1

TABLE 4

Proposed threshold values and corresponding skill scores

Month	Index (Threshold)	PC	POD	FAR	CSI	HSS
March	SHOW (≤ 0.8)	0.72	0.79	0.47	0.47	0.42
	LI (≤ -1.5)	0.71	0.72	0.47	0.44	0.38
	KINX (≥ 31)	0.72	0.65	0.46	0.42	0.38
	SWEAT (≥ 190)	0.61	0.71	0.57	0.36	0.24
	TTI (≥ 42)	0.64	1.00	0.53	0.47	0.36
April	SHOW (≤ 0.9)	0.57	0.86	0.51	0.46	0.19
	LI (≤ 0.6)	0.41	0.78	0.60	0.36	-0.08
	KINX (≥ 30)	0.62	0.80	0.47	0.47	0.26
	SWEAT (≥ 200)	0.57	0.80	0.51	0.44	0.17
	TTI (≥ 43)	0.53	0.90	0.53	0.45	0.14
May	SHOW (≤ 2.3)	0.61	0.78	0.34	0.56	0.12
	LI (≤ 0.3)	0.62	0.83	0.34	0.58	0.09
	KINX (≥ 27)	0.64	0.87	0.34	0.61	0.14
	SWEAT (≥ 150)	0.64	0.92	0.35	0.62	0.11
	TTI (≥ 41)	0.65	0.85	0.32	0.61	0.18

TABLE 5

Proposed threshold values and corresponding skill scores considering 925 hPa and / or 850 hPa winds favourable

Month	Index (Threshold)	PC	POD	FAR	CSI	HSS
March	SHOW (≤ 0.8)	**0.77**	0.75	**0.45**	0.46	**0.47**
	LI (≤ -1.7)	0.68	0.71	0.56	0.37	0.32
	KINX (≥ 31)	**0.76**	**0.67**	0.47	**0.42**	0.27
	SWEAT (≥ 190)	**0.66**	**0.71**	0.59	0.35	**0.29**
	TTI (≥ 45)	**0.73**	0.83	**0.51**	0.44	**0.42**
April	SHOW (≤ 0.9)	**0.58**	**0.89**	**0.48**	**0.49**	**0.20**
	LI (≤ 0.6)	**0.41**	**0.80**	**0.58**	**0.38**	-0.09
	KINX (≥ 32)	**0.63**	0.71	**0.43**	0.46	**0.26**
	SWEAT (≥ 190)	0.54	**0.88**	**0.51**	**0.45**	0.13
	TTI (≥ 43)	**0.55**	**0.91**	**0.51**	**0.47**	**0.15**
May	SHOW (≤ 1.9)	**0.63**	**0.79**	**0.31**	**0.58**	0.11
	LI (≤ 0.3)	**0.62**	**0.85**	**0.34**	**0.60**	0.02
	KINX (≥ 27)	**0.65**	**0.87**	**0.31**	**0.62**	0.11
	SWEAT (≥ 150)	**0.65**	**0.92**	**0.33**	**0.63**	0.06
	TTI (≥ 41)	**0.67**	**0.87**	**0.30**	**0.63**	0.17

Table 3 shows the month wise mean, median and standard deviation of each of the parameters separately for thunderstorm and non-thunderstorm days. Again, a prominent difference in mean and median are observed during March for thunderstorm and non-thunderstorm days, indicating distinction between the two events. However, the differences are comparatively less during April and May.

5.1. *Computation of thresholds* - The month wise proposed thresholds of the selected stability indices based on the best combination of skill scores are shown in Table 4. It has been observed that there is a significant month to month variation in the thresholds of some indices. All the indices during March show POD of ≥ 0.65, but they also have a high FAR of≥ 0.40. From the point of view of POD, TTI ≥ 42 gives the best score of 1.00 during this month, which indicates that no thunderstorm has occurred when the value of TTI < 42. The HSS also has values ≥ 0.24 for the indices, indicating good forecast skills. The PODs in April are comparatively better than in March but the FAR also rises to the range 0.45-0.60. TTI once again has the best POD (0.90) out of the selected indices. The indices show better skills in May with all of them having POD > 0.75 and FAR also dropping to≤ 0.35.

6. *Computation of thresholds considering favourable wind at lower level* - Along with the stability indices, the lower level winds also play an important role in occurrence of thunderstorms. The Bay of Bengal located towards south of Agartala acts as a huge source of moisture for the region. Hence, southerly winds at lower levels over the region works significantly as moisture feeding agent for occurrence of thunderstorms. Similar observation was considered by Pradhan *et al.* (2012) for Gangetic West Bengal (GWB) which states that if the wind direction at lower levels (up to 0.9 km) is either Southerly or South-Easterly then moisture incursion takes place over the GWB area from Bay of Bengal and the chances of formation of thunderstorm is very high. In the present study, it has been found that, out of all the thunderstorm days during the study period, on 82% of the days the wind direction at 925 hPa obtained from 0000 UTC RS/RW accent at Agartala is between 160°-270° (southeasterly to westerly). Similarly, on 83% of the days wind direction at 850 hPa is in the same range. Based on this fact, the wind direction between 160°-270° at

TABLE 6

Proposed threshold values and corresponding skill scores considering both 925 hPa and 850 hPa winds favourable

Month	Index (Threshold)	PC	POD	FAR	CSI	HSS
March	SHOW (≤ 0.8)	**0.78**	0.76	**0.30**	**0.57**	**0.55**
	LI (≤ -1.5)	0.60	0.71	0.52	0.41	0.22
	KINX (≥ 31)	**0.73**	**0.71**	**0.37**	**0.50**	**0.44**
	SWEAT (≥ 160)	**0.62**	**0.86**	**0.50**	**0.46**	**0.29**
	TTI (≥ 42)	**0.71**	**1.00**	**0.43**	**0.57**	**0.46**
April	SHOW (≤ 0.8)	**0.59**	**0.90**	**0.47**	**0.50**	**0.21**
	LI (≤ 0.6)	**0.58**	**0.87**	**0.53**	**0.44**	**0.02**
	KINX (≥ 32)	**0.65**	0.77	**0.40**	**0.51**	**0.32**
	SWEAT (≥ 200)	**0.59**	**0.90**	**0.47**	**0.50**	**0.21**
	TTI (≥ 43)	**0.57**	**0.90**	**0.48**	**0.49**	**0.19**
May	SHOW (≤ 1.9)	**0.65**	**0.80**	**0.28**	**0.61**	0.10
	LI (≤ 0.3)	**0.65**	**0.88**	**0.30**	**0.64**	0.03
	KINX (≥ 28)	**0.67**	0.85	**0.28**	**0.64**	0.13
	SWEAT (≥ 150)	**0.66**	**0.92**	**0.31**	**0.65**	0.01
	TTI (≥ 41)	**0.68**	**0.87**	**0.27**	**0.65**	0.15

925 hPa and 850 hPa is considered as favourable wind for occurrence of thunderstorms at Agartala. Hence, in expectation of better forecasting skills, the month wise thresholds for all the indices are also obtained (*i*) when either 925 hPa or 850 hPa or both winds favourable and (*ii*) when both 925 hPa and 850 hPa winds favourable for occurrence of thunderstorms.

Table 5 shows the prescribed threshold values of stability indices along with their skill scores when either 925 hPa or 850 hPa or both winds over Agartala are from direction 160° - 270°. The bold figures indicate same or a better skill score than those obtained for the corresponding month, without taking wind into consideration. The Lifted Index does not show any improved skill score during March when lower level winds were favourable, however it shows better scores in three categories in other indices. The PODs are > 0.70. CSIs are > 0.40 and HSS > 0.20 for all the indices during March. In April, it shows better FAR for all the indices, better POD and CSI for SHOW, LI, SWEAT and TTI. The PODs in these indices have improved to ≥ 0.80. The HSS has also improved for SHOW, KINX and TTI. All the skill scores except HSS have shown improvement in May with POD ≥ 0.79 and FAR dropped to < 0.35.

Table 6 shows the computed threshold values and their corresponding skill scores on the days when both 925 hPa and 850 hPa winds are from favourable direction. There is an improvement in skill scores in all the categories for KINX, SWEAT and TTI during March and in four categories for SHOW. However, the scores do not show any improvement in LI. All the PODs are > 0.70 in March and FARs are also ≤ 0.50. In April, three indices, namely SHOW, SWEAT and TTI gives PODs of 0.90 indicating very less probability (0.10) of missing the thunderstorm events. Other two indices (LI and KINX) also have PODs > 0.75. Except LI, all other indices have FAR < 0.50 and HSS ≥ 0.19. During May, except HSS, all other categories show improved forecasting skills. The PODs are ≥ 0.80, CSIs are > 0.60 and FARs are ≤ 0.31, showing good skill in forecasting the events. The SWEAT index gives the best POD (0.92) for value ≥ 150 among all the indices. This value of POD remains same, with or without considering the wind, but lower false alarms when wind is favourable. A month wise comparison of the skill scores suggest that the PODs are better in April, however the false alarm cases also increase with that. The cases with false alarms have the best values in May, falling close to 0.30. The values obtained from Table 6 indicates that, wind direction in the range 160° - 270° has an important role in occurrence of thunderstorms over Agartala. Higher False Alarm Rates (FAR) in most of the cases, without considering the wind indicates that although in some cases the stability indices were favourable for occurrence of thunderstorms, unfavourable winds did not allow their occurrences.

7. In this study, atmospheric instability conditions related to the occurrence of pre-monsoon thunderstorms at Agartala have been studied. Agartala, a major city and an airport in the north-eastern region of India, experiences very high frequencies of thunderstorms, mainly during this season, with 40% thunderstorm days. The frequency keeps on increasing from March (19%) to May (63%). Five stability indices, namely Showalter Index (SHOW), Lifted index (LI), K-Index (KINX), Severe Weather Threat Index (SWEAT) and Total Totals Index (TTI) have been studied for the period 2016-20. The threshold values of the indices for each month have been obtained based on the values of five skill scores, PC, POD, FAR, CSI and HSS. The prescribed thresholds and their corresponding skill scores show variation in the three months. The difference between POD and FAR are greater than 0.10 in all the cases, showing higher detection of events than false alarms. The CSIs are all higher than 0.30 and most of the HSSs are having positive values showing good forecasting skills.

The lower level southeasterly to westerly winds have a very important role to play for occurrence of thunderstorms over the region, which helps in moisture incursion from the Bay of Bengal. The lower level winds direction at 925 hPa and 850 hPa are found to be in the range 160°-230° in more than 80% of thunderstorm days. Hence this range of wind direction is considered as favourable for occurrence of thunderstorms at Agartala. An analysis has also been done to find out the possible thresholds of the selected indices when (*i*) either 925 hPa or 850 hPa or both the winds are favourable and (*ii*) both 925 hPa and 850 hPa winds are favourable. Better forecasting skill scores are obtained for most of the indices when wind direction at lower level is favourable for occurrence of thunderstorms. The PODs have been found > 0.70 in all the cases. The difference between PODs and FARs are also found to be in the range 0.30-0.60 in most of the cases. Higher CSIs with all > 0.40 have been observed. The HSSs are also positive in all the cases except one. Hence, it clearly indicates that southerly to westerly winds at lower levels is a favourable condition for occurrence of thunderstorms at Agartala and the possibility of thunderstorms also increases in such cases.

These proposed thresholds of stability indices are likely to be helpful for the operational forecasters in forecasting the hazardous thunderstorms at Agartala.

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References

India Meteorological Department, "Climatological tables of observatories in India 1981-2010".

Mukhopadhyay, P., Sanjay, J. and Singh, S. S., 2003, "Objective forecast of thundery/nonthundery days using conventional indices over three northeast Indian stations", *MAUSAM*, **54**, 4, 867-880.

Pradhan, D., De, U.K. and Singh, U.V., 2012, "Development of nowcasting technique and evaluation of convective indices for thunderstorm prediction in Gangetic West Bengal (India) using Doppler Weather Radar and upper air data", *MAUSAM*, **63**, 2, 299-318.

Showalter, A., 1953, "A stability index for thunderstorm forecasting", *Bulletin American Meteorological Society*, **34**, 250-252

Singh, C., Yadav, B. P., Das, S. and Saha, D., 2014, "Thunderstorm accompanied with squalls over Agartala for consecutive two days on 30 April and 1 May, 2012", *MAUSAM*, **65**, 4, 539-552

Srinivasan, V., Ramamurthy, K. and Nene, Y. R., 1973, "Forecasting Manual, Part III, Summer-Nor'westers and Andhis and largescale convective activity over peninsula and central parts of the country", FMU Report No. III-2.2, India Meteorological Department, Delhi, India.

Tyagi, B., Krishna, V. N. and Satyanarayana, A. N. V., 2011, "Study of thermodynamic indices in forecasting pre-monsoon thunderstorms over Kolkata during STORM pilot phase 2006-2008", *Natural Hazards*, **56**, 681-698.

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