Spatio-Temporal Variations of Thermodynamic Indices during Pre-Monsoon Season Thunderstorms over Eastern India

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Abstract

Thunderstorms are very violent and short-lived weather phenomena associated with thunder, rain, heavy wind, lightning and dense clouds. These storms are persistent and intense during the pre-monsoon (March-May) season over Eastern and North-eastern India, leading to catastrophic destruction over the regions. These thunderstorms are locally known as Kal-Baishakhi, Bordoichila or Nor'westers, which are short-lived events able to make changes in the thermodynamic properties of the environment. In this work, thermodynamic indices were calculated and analysed to evaluate the spatial and temporal variations of thunderstorms over Eastern India (Odisha, Jharkhand and West Bengal). The present study also investigated the influence of climate change on thermodynamic indices thresholds over Eastern India by using radiosonde data and ERA-5. The thermodynamic indices considered in the study are Boyden index, bulk Richardson's number, convective available potential energy, convective inhibition, cross totals index, dew point temperature at 850hPa, humidity Index, K index, lifted index, relative humidity at 700hPa, Showalter index, severe weather threat index, total totals index, vertical totals index. After calculating these indices, with the information of thunderstorm occurrence over the region, skill score analysis has been accomplished based on the contingency table. The work discussed the change in the thermodynamic indices pattern with every 5-year interval time for temporal variations and the climatological variation of thermodynamic indices by using spatial plots to differentiate the thunderstorm and non-thunderstorm days for spatial variations. In the temporal variation, some thermodynamic indices show a noticeable shift of threshold values over time, while some indices do not exhibit any apparent change in the pattern. The trend analysis of these thermodynamic indices shows evident changes in trends over the different regions of Eastern India for thunderstorm and non-thunderstorm days. Keywords: Thunderstorm, Climate Change, Thermodynamic indices, Radiosonde data, Skill score

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Introduction

- Thunderstorms are characterised by lightning, thunder, rain showers, prevailing gusts, and hail, resulting in severe weather and the loss of lives, property, and farmland. Thunderstorms are the most destructive occurrence across eastern India during the pre-monsoon season (March-May) and are often pushed from the north-west to the south-east (Yamane and Hayashi, 2006; Tyagi, 2011; Das et al., 2014). Thunderstorm forecasting is required to avoid such problems.
- Several research have been conducted over the last century to better understand the various thunderstorm characteristics (Mukhopadhyay et al., 2005; Ghosh et al. 2008). Many studies have been published in which thunderstorm stability properties and associated thermodynamic indices have been studied (Schultz 1989; Kunz 2007; Tyagi et al. 2011; Sahu et al., 2020a; Sahu et al., 2020b). Many academics have investigated the operational effectiveness of various stability indices for thunderstorm prediction (Jacovides and Yonetani 1990; Lee and Passner 1993).
- The atmospheric static stability is measured via stability indices (Peppier 1988). The indices were computed using changes in dew-point temperature, air temperature at various levels, moisture, and dynamic driving forces in terms of wind shear. To predict the occurrence of thunderstorms, weather scientists employ thermodynamic characteristics and skill score analysis.
- The current research work employs different thermodynamic indices for spatial and temporal variations : the Boyden index (BOYD), Convective available potential energy (CAPE), Convective inhibition (CIN), Cross Totals index (CTI), Humidity index (HI), K index (KI), Lifted index (LI), Severe weather threat index (SWEAT), Total totals index (TTI), and Vertical totals index (VTI) over the eastern India.
- For temporal variations, we proposed suitable threshold values of these indices, and to identified some indices which performs best in predicting thunderstorm activity across the eastern India during the Pre-monsoon season for the study period.
- For Spatial variation we prepared composite maps to see the variations of these thermodynamic indices region wise for both thunderstorm and non-thunderstorm days and also predicted their trend. Here we shown the CAPE and CIN fluctuations and their trends to understand influence of climate change in changing the thunderstorm frequency and intensity.

Data and Methodology

- In this work we utilized radiosonde observations which is obtained from the University of Wyoming for temporal variation and ERA5 reanalysis datasets produced from European Centre for Medium-Range Weather Forecast (ECMWF) for spatial variation of these thermodynamic indices. Both 00 UTC and 12 UTC data was analyzed over the eastern Indian regions.
- The thunderstorm information used in this study was obtained from the India Meteorological Department (IMD), Pune.
- Thermodynamic indices was computed which is based on a formulation described in the form of a contingency table by Kunz (2007) and Tyagi et al. (2011).
- The Mann-Kendall test which is a non-parametric statistical test is used with 95% confidence level to comprehend the trends of these thermodynamic indices.

Results

Table 1: Threshold values of Indices according to maximum skill scores of Kolkata

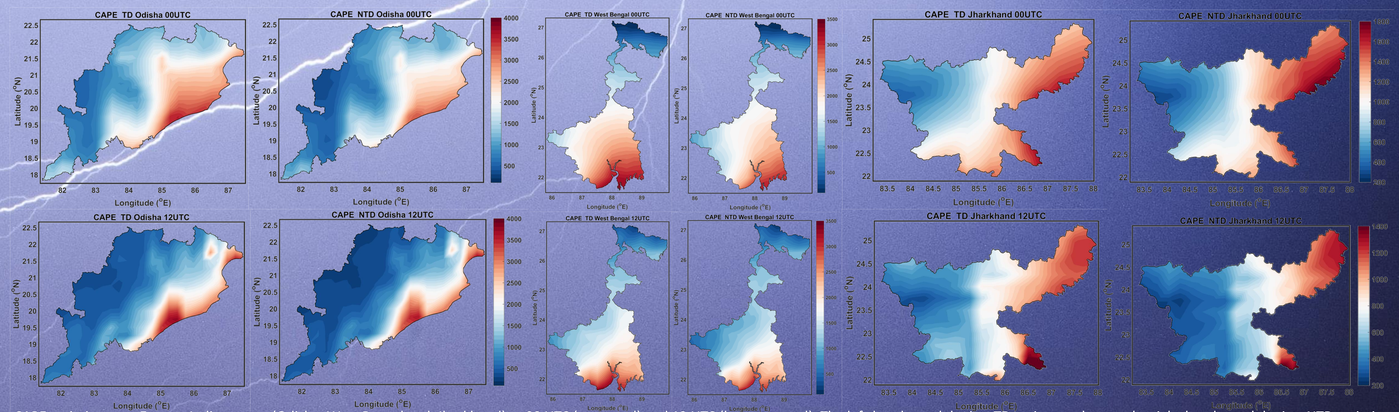
Index	Threshold Values for 00 UTC					Threshold Values for 12 UTC				
	1987-1991	1992-1996	1997-2001	2002-2006	RSS	1987-1991	1992-1996	1997-2001	2002-2006	RSS
LI	≤ -1	≤ -3	≤ -3	≤ -3	0.216	≤ -3	≤ -4	≤ -5	≤ -4	0.250
SHOW	≤ 3	≤ 2	≤ 1	≤ 2	0.293	≤ 4	≤ 2	≤ 3	≤ 4	0.218
CAPE	≥ 762	≥ 558	≥ 791	≥ 1012	0.221	≥ 665	≥ 1248	≥ 1597	≥ 1474	0.249
CIN	≥ -267	≥ -195	≥ -272	≥ -272	0.056	≥ -227	≥ -247	≥ -122	≥ -179	0.028
VTI	≥ 22	≥ 22	≥ 24	≥ 29	0.013	≥ 24	≥ 23	≥ 21	≥ 21	-0.019
BOYD	≥ 93	≥ 96	≥ 97	≥ 95	0.009	≥ 94	≥ 96	≥ 97	≥ 96	-0.046
KI	≥ 24	≥ 29	≥ 27	≥ 20	0.231	≥ 15	≥ 26	≥ 25	≥ 23	0.095
TTI	≥ 44	≥ 43	≥ 44	≥ 44	0.220	≥ 41	≥ 46	≥ 44	≥ 39	0.144
CTI	≥ 15	≥ 15	≥ 17	≥ 18	0.270	≥ 10	≥ 19	≥ 17	≥ 12	0.179
SWEAT	≥ 234	≥ 219	≥ 169	≥ 163	0.257	≥ 87	≥ 215	≥ 198	≥ 167	0.163
BRN	≥ 21	≥ 22	≥ 20	≥ 21	0.184	≥ 18	≥ 28	≥ 26	≥ 24	0.189
HI	≤ 30	≤ 40	≤ 40	≤ 27	0.202	≤ 53	≤ 38	≤ 44	≤ 47	0.136
DPT	≥ 4	≥ 10	≥ 8	≥ 12	0.242	≥ 5	≥ 9	≥ 7	≥ 8	0.176
RH	≥ 47	≥ 55	≥ 47	≥ 36	0.170	≥ 35	≥ 32	≥ 35	≥ 30	0.037

Table 2: Threshold values of Indices according to maximum skill scores of Bhubaneswar

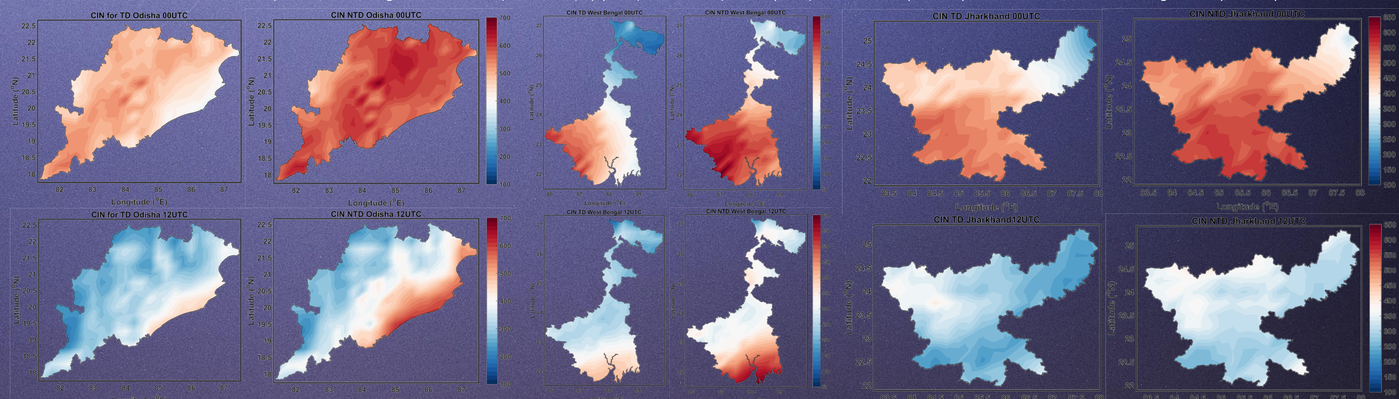
Index	Threshold Values for 00 UTC					Threshold Values for 12 UTC				
	1987-1991	1992-1996	1997-2001	2002-2006	RSS	1987-1991	1992-1996	1997-2001	2002-2006	RSS
LI	≤ -3	≤ -1	≤ -2	≤ -3	0.223	≤ -1	≤ -3	≤ -4	≤ -5	0.257
SHOW	≤ 3	≤ 10	≤ 3	≤ 0	0.256	≤ 6	≤ 3	≤ 1	≤ 2	0.196
CAPE	≥ 184	≥ 244	≥ 558	≥ 628	0.175	≥ 400	≥ 1594	≥ 975	≥ 1790	0.249
CIN	≥ -303	≥ -347	≥ -242	≥ -188	0.095	≥ -174	≥ -216	≥ -199	≥ -188	0.149
VTI	≥ 23	≥ 32	≥ 28	≥ 30	0.054	≥ 19	≥ 20	≥ 26	≥ 22	-0.029
BOYD	≥ 94	≥ 94	≥ 97	≥ 94	-0.032	≥ 96	≥ 95	≥ 97	≥ 94	-0.063
KI	≥ 23	≥ 16	≥ 18	≥ 28	0.189	≥ 21	≥ 26	≥ 30	≥ 28	0.103
TTI	≥ 42	≥ 33	≥ 42	≥ 49	0.207	≥ 38	≥ 41	≥ 49	≥ 41	0.143
CTI	≥ 16	≥ 13	≥ 11	≥ 15	0.246	≥ 11	≥ 18	≥ 17	≥ 19	0.185
SWEAT	≥ 139	≥ 228	≥ 131	≥ 200	0.181	≥ 100	≥ 108	≥ 168	≥ 119	0.140
BRN	≥ 3	≥ 34	≥ 28	≥ 15	0.124	≥ 11	≥ 11	≥ 28	≥ 50	0.167
HI	≤ 30	≤ 35	≤ 42	≤ 37	0.224	≤ 50	≤ 47	≤ 46	≤ 38	0.144
DPT	≥ 9	≥ 10	≥ 7	≥ 9	0.174	≥ 7	≥ 5	≥ 6	≥ 5	0.142
RH	≥ 41	≥ 44	≥ 40	≥ 43	0.125	≥ 47	≥ 41	≥ 36	≥ 40	0.050

Table 3: Threshold values of Indices according to maximum skill scores of Ranchi

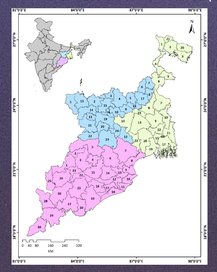
Index	Threshold Values for 00 UTC				Threshold Values for 12 UTC			
	1996-2000	2001-2005	2006-2010	RSS	1996-2000	2001-2005	2006-2010	RSS
LI	≤ -3	≤ -2	≤ -2	0.403	≤ -2	≤ -2	≤ -3	0.374
SHOW	≤ 0	≤ 0	≤ -1	0.350	≤ 1	≤ 0	≤ 0	0.320
CAPE	≥ 494	≥ 682	≥ 692	0.407	≥ 486	≥ 604	≥ 730	0.423
CIN	≥ -290	≥ -258	≥ -427	-0.151	≥ -156	≥ -228	≥ -120	-0.060
VTI	≥ 29	≥ 25	≥ 21	0.068	≥ 27	≥ 26	≥ 24	-0.096
BOYD	≥ 96	≥ 96	≥ 95	0.013	≥ 97	≥ 96	≥ 95	-0.098
KI	≥ 27	≥ 29	≥ 26	0.248	≥ 29	≥ 32	≥ 33	0.205
TTI	≥ 49	≥ 48	≥ 43	0.317	≥ 46	≥ 48	≥ 47	0.241
CTI	≥ 29	≥ 25	≥ 21	0.348	≥ 27	≥ 26	≥ 24	0.328
SWEAT	≥ 141	≥ 194	≥ 157	0.319	≥ 153	≥ 186	≥ 160	0.274
BRN	≥ 8	≥ 5	≥ 10	0.348	≥ 12	≥ 8	≥ 18	0.306
DPT	≥ 5	≥ 8	≥ 11	0.158	≥ 2	≥ 7	≥ 10	0.261
RH	≥ 47	≥ 40	≥ 41	0.132	≥ 43	≥ 34	≥ 58	0.149



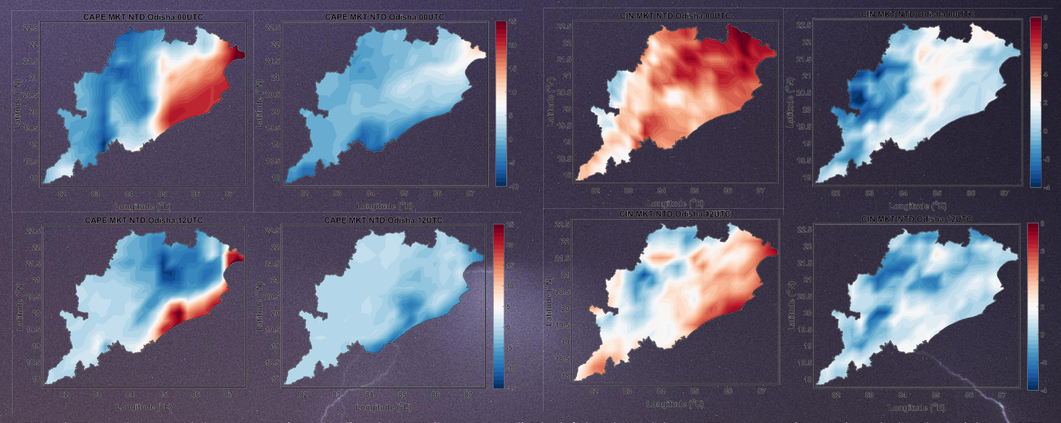
CAPE variation over Eastern Indian states (Odisha, West Bengal and Jharkhand) at 00 UTC (top panel) and 12 UTC (bottom panel). The left-hand panel depicts TD variants, whereas the right-hand panel depicts NTD variations.



CIN variation over Eastern Indian states (Odisha, West Bengal and Jharkhand) at 00 UTC (top panel) and 12 UTC (bottom panel). The left-hand panel depicts TD variants, whereas the right-hand panel depicts NTD variations.



Study area, The eastern Indian states (Odisha, West Bengal, and Jharkhand) are color-coded on the India map inset.



CAPE and CIN trend across Odisha at 00 UTC (top panel) and 12 UTC (bottom panel). The left-hand panel depicts TD variants, whereas the right-hand panel depicts NTD variations.

Summary

- The results for Bhubaneswar reveal that the daytime atmosphere during the pre-monsoon season had enhanced latent instability for thunderstorm days throughout the research. The findings suggest an increase in the extreme severity of severe weather occurrences over the site.
- For Kolkata, The threshold values for both 00 and 12 UTC are fluctuating. CAPE (increasing) and CIN (decreasing) threshold values are contrasting to each other.
- For Ranchi, the environment is favorable to thunderstorm occurrence all of the time, the threshold values reveal that the 12 UTC observations show larger possibilities of thunderstorm occurrence than the 00 UTC observations.
- The findings of temporal variations reveal that the threshold values of thermodynamic indices change in every 5-year interval at all three sites, but not in the same proportion.
- For spatial variation, the findings are important for comprehending long-term climatological changes in the convective environment across eastern and north-eastern India during the pre-monsoon season. From 1987 through 2016.
- In Odisha, the CAPE values show a considerable gradient between coastal and interior locations. The values are greater for coastal sites and gradually decrease as we move inland. Whereas the TD CIN values are lower over coastal regions than NTD instances, allowing for thunderstorm activity on TD days. Similarly, the trend is positive over coastal regions then negative in the inland regions of Odisha.
- For West Bengal, the findings suggest a favorable environment for thunderstorm occurrence over West Bengal's coastal area, elucidating the cause for the region's increased frequency of thunderstorm occurrence. The trend data suggest an increase in thunderstorm potential over West Bengal during night/early morning compared to daylight.
- CAPE values in Jharkhand are lower than in West Bengal and Odisha, although they follow a gradient pattern from one half of the state to the other. Higher CIN readings during NTD instances approve thunderstorm occurrences over Jharkhand. The trend data indicate that more violent thunderstorms may develop across the state in the future.

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