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RESEARCH REPORT

An advanced process-oriented diagnostic for the representation of tropical convection

Smrutishree. L, Mohan T. S., Saji Mohandas and V. S. Prasad

December 2024

National Centre for Medium Range Weather Forecasting
Ministry of Earth Sciences, Government of India
A-50, Sector-62, NOIDA-201 309, INDIA

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9	Abstract	This study explores the moist convection processes for the representation of convection over tropical regions, especially over the Indian subcontinent. For this, six years (2015-2020) of NCMRWF's high-resolution regional reanalysis, known as IMDAA, is utilized. The analysis is carried out for the variables of rainfall, temperature and moisture profiles during the May to October season (rainy season). The focus of the study is to develop an advanced process-oriented diagnostic (POD) to enhance the understanding of the moist processes, which in turn leads to a pathway for model development. The Gálvez–Davison Index (GDI) is employed as a key tool to improve the representation of convection in tropical regions, addressing the limitations of traditional stability indices such as KI, LI, TTI, CAPE and CINE, which often exhibit discrepancies in accurately capturing the convective and cloud formation. The stability indices are applied to the reanalysis data focusing on Central India (CEN) and the Bay of Bengal (BEN) regions which were chosen based on the seasonal rainfall variance maps (also regarded as rainfall "hotspot" regions). Key results indicate that among all the stability indices, GDI exhibits a strong one-to-one correspondence with rainfall variability. Although the performance of CAPE and KI, also show reasonably good agreement with the rainfall evolution, the stability index GDI is more consistent and depicts a high correlation with rainfall variability than the other indices. The

		analysis demonstrates that GDI outperforms traditional stability indices in representing deep convection over both CEN and BEN. The study concludes that GDI provides a valuable tool for improving convective predictions, offering enhanced accuracy over traditional stability indices. The integration of GDI into forecasting models is recommended to better represent convective initiation and improve overall forecast accuracy.
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सारांश

यह अध्ययन उष्णकटिबंधीय क्षेत्रों, विशेष रूप से भारतीय उपमहाद्वीप पर संवहन की प्रक्रिया को समझने के लिए आर्द्र संवहन प्रक्रियाओं का विश्लेषण करता है। इसके लिए राष्ट्रीय मध्यम अवधि मौसम पूर्वानुमान केंद्र (रा.म.अ.मौ.पू.के) के उच्च संकल्प वाले क्षेत्रीय पुनर्विश्लेषण **(IMDAA)** के छह वर्षों (२०१ ५ - २०२०) के आंकड़ों का उपयोग किया गया है। इस विश्लेषण में मई से अक्टूबर के मौसम (बरसात के मौसम) के दौरान वर्षा, तापमान और विशिष्ट आर्द्रता के विभिन्न पहलुओं का अध्ययन मई से अक्टूबर (वर्षा का मौसम) तक किया गया है। अध्ययन का मुख्य उद्देश्य आर्द्र प्रक्रियाओं को समझने के लिए एक उन्नत प्रक्रिया-आधारित निदान **(POD)** विकसित करना है, जो मॉडल विकास के लिए एक मार्ग प्रदान करेगा।

गैल्वेज़-डेविसन इंडेक्स (**GDI**) को उष्णकटिबंधीय क्षेत्रों में संवहन के प्रतिनिधित्व को बेहतर बनाने के लिए एक महत्वपूर्ण उपकरण के रूप में उपयोग किया जाता है, जो **KI, LI, TTI, CAPE** और **CINE** जैसे पारंपरिक स्थिरता सूचकांकों की सीमाओं को संबोधित करता है, जो अक्सर संवहन और बादल निर्माण को सही तरीके से पकड़ने में विसंगतियां प्रदर्शित करते हैं। स्थिरता सूचकांक मध्य भारत (**CEN**) और बंगाल की खाड़ी (**BEN**) क्षेत्रों पर ध्यान केंद्रित करते हुए पुनर्विश्लेषण डेटा पर लागू होते हैं जिन्हें मौसमी वर्षा भिन्नता मानचित्रों (वर्षा "हॉटस्पॉट" क्षेत्रों के रूप में भी माना जाता है) के आधार पर चुना गया हैं।

मुख्य परिणाम दर्शाते हैं कि सभी स्थिरता सूचकांकों में, **GDI** वर्षा परिवर्तनशीलता के साथ एक मजबूत एक-से-एक मेल प्रदर्शित करता है। हालाँकि **CAPE** और **KI** का प्रदर्शन भी वर्षा विकास के साथ यथोचित रूप से अच्छा समझौता दर्शाता है, स्थिरता सूचकांक **GDI** अधिक सुसंगत है और अन्य सूचकांकों की तुलना में वर्षा परिवर्तनशीलता के साथ उच्च सहसंबंध दर्शाता है। यह विश्लेषण दर्शाता है कि **GDI, CEN** और **BEN** दोनों पर गहरे संवहन का प्रतिनिधित्व करने में पारंपरिक स्थिरता सूचकांकों से बेहतर प्रदर्शन करता है। अध्ययन का निष्कर्ष है कि **GDI** संवहन संबंधी पूर्वानुमानों को बेहतर बनाने के लिए एक मूल्यवान उपकरण प्रदान करता है, जो पारंपरिक स्थिरता सूचकांकों की तुलना में बेहतर सटीकता प्रदान करता है। **GDI** को पूर्वानुमान मॉडल्स में एकीकृत करने की सिफारिश की जाती है ताकि संवहन की शुरुआत को बेहतर तरीके से प्रस्तुत किया जा सके और समग्र पूर्वानुमान सटीकता में सुधार हो सके।

Abstract

This study explores the moist convection processes for the representation of convection over tropical regions, especially over the Indian subcontinent. For this, six years (2015-2020) of NCMRWF's high-resolution regional reanalysis, known as IMDAA, is utilized. The analysis is carried out for the variables of rainfall, temperature and moisture profiles during the May to October season (rainy season). The focus of the study is to develop an advanced process-oriented diagnostic (POD) to enhance the understanding of the moist processes, which in turn leads to a pathway for model development.

The Gálvez–Davison Index (GDI) is employed as a key tool to improve the representation of convection in tropical regions, addressing the limitations of traditional stability indices such as KI, LI, TTI, CAPE and CINE, which often exhibit discrepancies in accurately capturing the convective and cloud formation. The stability indices are applied to the reanalysis data focusing on Central India (CEN) and the Bay of Bengal (BEN) regions which were chosen based on the seasonal rainfall variance maps (also regarded as rainfall "hotspot" regions).

Key results indicate that among all the stability indices, GDI exhibits a strong one-to-one correspondence with rainfall variability. Although the performance of CAPE and KI, also show reasonably good agreement with the rainfall evolution, the stability index GDI is more consistent and depicts a high correlation with rainfall variability than the other indices. The analysis demonstrates that GDI outperforms traditional stability indices in representing deep convection over both CEN and BEN. The study concludes that GDI provides a valuable tool for improving convective predictions, offering enhanced accuracy over traditional stability indices. The integration of GDI into forecasting models is recommended to better represent convective initiation and improve overall forecast accuracy.

1. **Introduction:**

Deep convection in tropical regions is primarily driven by the combined influence of low-level convergence and latent heat release from the ensemble of cumulus clouds, which initiates and sustains the convective processes (Jakob and Schumacher, 2008). In addition, column instability serves as another dominant mechanism influencing convection (Tomassini, 2020). Conversely, mid-latitude convection is primarily driven by available potential energy from strong temperature gradients, often associated with frontal movements and boundaries between air masses. While large-scale circulations such as the Hadley cell, the Intertropical Convergence Zone (ITCZ), Madden-Julian Oscillation (MJO), the South Asian Monsoon and the Walker circulation play a major role in tropical convection frontal dynamics are the main drivers of convection in the mid-latitudes (Holton and Hakim, 2013).

An accurate representation of convection in deep tropical regions (-20S to 20N) is a very challenging task due to the presence of a small Coriolis force and a large Rossby radius of deformation near the Equator, as well as fast propagating gravity waves that export the convective heating (Bretherton and Smolarkiewicz, 1989). Further, tropical convection affects a wide spectrum of weather phenomena in space and time scales, from individual convective clouds to the large-scale convectively coupled waves (e.g. Simmons, 1982; Tomassini, 2018), the intraseasonal oscillations, and the Monsoon circulations. Thermodynamics is essential in the tropics, whereas dynamical processes are usually less pronounced (Tomassini, 2020). This influence is essential for understanding the behavior of convection, precipitation, and overall weather patterns in tropical regions. The precipitation occurrence, its rate and duration in the continental regions are a function of several of the atmosphere's favorable physical conditions and processes. In general, such conditions/processes include the presence of moisture/water vapor, and the troposphere's tendency to provide the vertical motion necessary to produce the required condensation (latent heating) rates. One critical condition is the troposphere's state of static stability. This stability is a steady state property of the atmospheric system such that any vertical disturbances introduced into the system will be either damped, enhanced, or remain unchanged.

Several studies have been undertaken to determine how to "best" characterize the tropospheric static stability to accumulated amounts of rainfall. During the past few decades, as aids for diagnosing or forecasting convective weather, numerous "indices" have been proposed for quantitatively estimating tropospheric static stability in research and weather forecasting schemes. These indices are developed to assess the degree of stability presence in the atmosphere in terms of conditional, absolute, latent, and potential/convective instabilities. There were based on the vertical displacement of a) a hypothetical air "parcel" of very small dimension, and/or b) an entire atmospheric layer of some prescribed isobaric thickness. Most of the stability indices combine measures of the thermal and moisture properties of the low- to mid-troposphere and are alleged to quantify the atmosphere's ability to produce convective phenomena. Many of the indices were developed to help in the forecasting of severe weather (e.g., Showalter, 1953; Galway, 1956; George, 1960; Miller, 1967; Miller et al., 1971). By evaluating the static stability of air columns, the stability indices are helpful in forecasting convection in a shorter time than numerical models (Glickman, 2000). For instance, thermodynamic diagrams (skewT-logP, T-phi etc.) obtained from observations provide a clearer representation of atmospheric stability. Further, indices play a significant role in enhancing the understanding of atmospheric stability by offering quantifiable measures that indicate the potential for convection and severe weather. As the skill of the present day numerical model forecasts for tropical convection is poor (Gálvez, 2016), weather forecasters must rely on quantities like stability indices to enhance the accuracy of their predictions for complex convective systems in the tropics. Particularly, in tropical regions, where convection is often driven by local heating rather than large-scale weather systems, the introduction of dry air can significantly influence the development and intensity of sever weather (Fritz and Wang, 2013; Wu et al, 2015).

In the present report, we employ a few traditional indices, namely the K Index (George, 1960), the Lifted Index (Galway, 1956), and the Total Totals Index (Miller, 1967), convective inhibition energy (CINE), convective available potential energy (CAPE) and Galvez-Davison Index (GDI) to compare their performance in representing the accurate representation of convection over tropical regions. More details about the GDI and other indices can be found in section 2 or Appendix. The present study emphasizes the performance of GDI, a relatively new convective index, and it is mainly based on the moisture-convection feedback mechanism, in capturing the development and evolution of tropical convection. As a preliminary assessment, we have performed a temporal analysis of the stability indices over the study region for six recent monsoon years during 2015-2020. The initial findings indicate that the GDI offers a valuable tool for enhancing convective predictions, demonstrating improved accuracy over traditional stability indices.

2. Data and Methodology:

a) *IMDAA rainfall and reanalysis data:*

In this work, we have extensively used the temperature and moisture profiles at five different standard pressure levels 950, 850, 700, 500, and 200 hPa; these levels are utilised to define three different layers. The thermodynamic conditions in the boundary layer are represented in Layer A, while Layer B captures variability associated with the trade wind inversion (TWI) through a simple average of the data from 850 and 700 hPa. Layer C represents the mid-troposphere by incorporating data from the 500 hPa level. For reference, the layers A, B and C are denoted in Fig 2. In addition, daily reanalysed rainfall data from IMDAA was also utilized to study the association with the stability indices.

b) *GDI computation methodology*

A crucial self-reinforcing process, known as a moisture-convection feedback mechanism, amplifies the convection in tropical environments and is a fundamental concept underlying the formulation of the new convective index, i.e. Gálvez–Davison Index (GDI). The index is mainly based on the moisture layers present in the atmosphere and equivalent potential temperature (EPT, θe) is regarded as the core concept underlying GDI calculation. When an air parcel is lifted dry adiabatically to its lifting condensation level (LCL), and then lifted moist adiabatically further, releasing latent heat as it ascends, it will eventually reach a specific temperature known as the EPT (Bolton, 1980). The release of latent heat during the lifting of an air parcel warms up the air and enhances its buoyancy, thereby influencing convection and storm development (Bolton, 1980; Davies-Jones, 2009). Since, EPT involves both the moisture content and thermal properties of an air column, making it useful for assessing stability, convection potential, and cloud formation in the atmosphere (Bolton, 1980; Holton, 1972). So, EPT can explain the detailed potential for further moistening of the air column. By considering the EPT profile, two separate studies have been conducted, focusing on tropical America (Gálvez, 2016) and Cuba (Fuentes-Alvarez et al., 2023), to evaluate the potential for convection. The formula used to calculate θe is provided below (Bolton, 1980).

The GDI is calculated as the algebraic sum of three sub-indices namely, CBI (Column Buoyancy Index), MWI (Mid-Tropospheric Warming Index), and II (Inversion Index) along with a terrain correction factor.

$$GDI = CBI+MWI+II+TC$$

The 950 hPa level is considered the mandatory surface level to incorporate boundary-layer information. This choice is crucial because, in some cases, TWIs can lie below the 850 hPa level. Figure 1 illustrates the observed EPT profiles across three different atmospheric layers (A, B, and C), defined using these pressure levels. Layer A represents the thermodynamic conditions in the boundary layer, while Layer B captures the variability of the TWI, using the simple average of data from the 850 and 700 hPa levels. Layer C represents the detailed mid-tropospheric conditions, based on data from 500 hPa. For more details and a detailed discussion, please refer (https://www.wpc.ncep.noaa.gov/international/gdi/, accessed on 13 October 2023).

Typical GDI values range from +05 to +60 during deep convection in the monsoon season, reflecting adequate atmospheric instability and moisture to sustain significant convective activity. Values above 45 indicate scattered to widespread thunderstorms with the potential for locally heavy rainfall, while values between 35 and 45 suggest scattered thunderstorms and widespread rain showers.

c) *Traditional stability indices (KI, LI, TTI, CAPE CINE):*

The K Index is an indicator of thunderstorm potential. A higher K Index value indicates a greater potential for heavy rainfall. It is determined by the vertical temperature lapse rate (from 850 to 500 hPa) and the vertical extent of low-level moisture (at 700 hPa) in the atmosphere, which enhances its effectiveness in the tropical environment. The K Index has limitations in its performance over elevated terrain and in areas with spatial homogeneity in the deep tropics.

Lifted index (LI) is used to assess the stability of the atmosphere and the potential for convection, whereas a lower Index value indicates an extremely unstable atmosphere. It is calculated by comparing the temperature of a lifted air parcel to the environmental temperature at a specified pressure level, typically around 500 hPa. The LI may not always accurately predict convection in certain environments, such as those influenced by strong winds or complex terrain, where other factors may play a more significant role.

The Total Totals Index (TTI) combines information about both temperature and moisture to provide more comprehensive view of atmospheric conditions. Higher TTI values (55 to 60) indicates greater instability and a higher likelihood of convective activity, including thunderstorms whereas the lower TTI values (less than 45) suggest more stable conditions, reducing the potential for significant convection. However, it may be unrepresentative in situations where low-level moisture is situated below the 850 hPa level. It also has limitations when analyzing conditions in other regions, as it was specifically designed for applications in the United States (Peppler and Lamb, 1989).

In addition to other indices, CAPE and CIN are two major parameters for forecasting convection and severe weather events (Glickman, 2000; Murugavel, 2012). CAPE indicates the potential for convection, CIN represents the "cap" that must be broken for convection to initiate. CAPE is the energy required to lift an air parcel from the surface to the level of free convection (LFC) where as CIN represents the amount of energy that inhibits convection (Riemann-Campe et al., 2009). A CAPE of around 1000–1500 J/kg is considered moderate, while values over 2500 J/kg are typically associated with strong to severe storms (Blanchard, 1998). At the same time CIN values are typically negative when convection is occurring (Alappattu & Kunhikrishnan, 2009).

3. Results

(a) *Rainfall variance:*

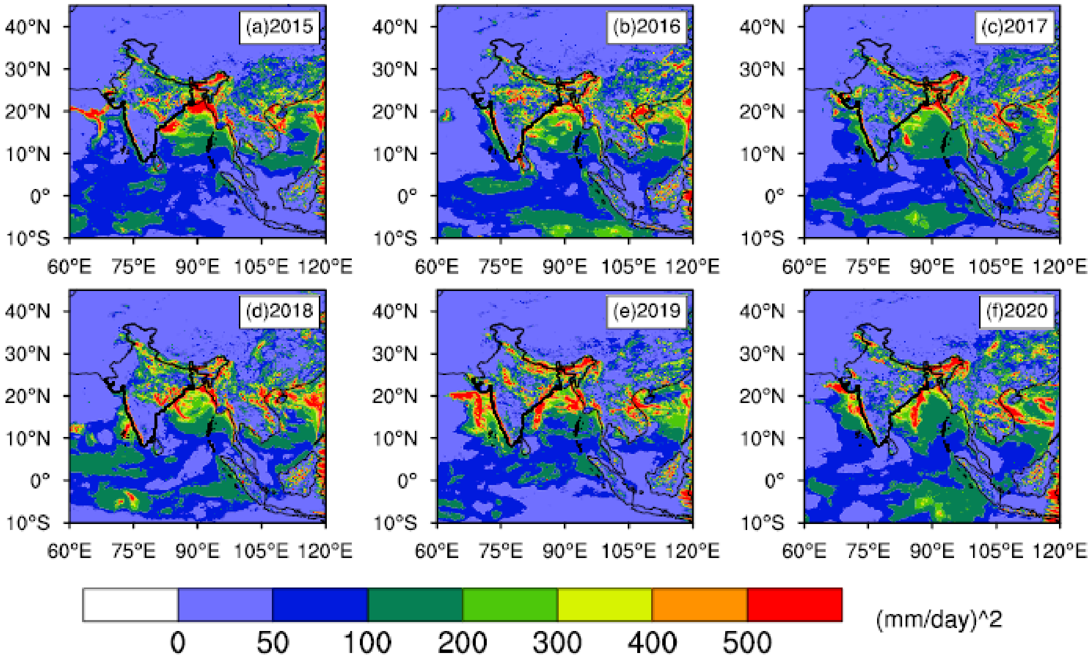

Figure 1*: Spatial distribution of daily rainfall variances computed from May through October from IMDAA data for 6 years (2015-2020).*

Note here that, while computing the daily variances, May to October rainfall data was considered. In the present context, we have focused on two key regions: Central India (regarded as the core monsoon zone, 15-25N,72-85E) and the Bay of Bengal (12-22N,87-97N), to examine the convection characteristics in the IMDAA data.

(b) *Vertical distribution of Equivalent potential temperature (EPT, θ_e)*

The existence of instability in the environment is the primary condition for the generation of convective systems, and the associated intensity depends on the magnitude of convective energy. The calculation of convective energy is closely linked with the selection of moist adiabatic process. For moist convection, generally, there are 4 methods available 1) Static energy conservation, 2) pseudo-equivalent potential temperature (θ_e); 3) Strict pseudo adiabatic equation; 4) reversable moist adiabatic process. In the present contest we have taken the second method as it serves as one of the key ingredients to address the moist thermodynamics of the atmosphere, especially over tropical regions. It is particularly useful to study the moist convection in both dry and moist atmosphere. It is conserved in moist adiabatic ascent and also in the presence of precipitation. This makes θ_e as an attractive variable for studying the moist convective modelling including saturation updrafts and down drafts (Bechtold, 2015).

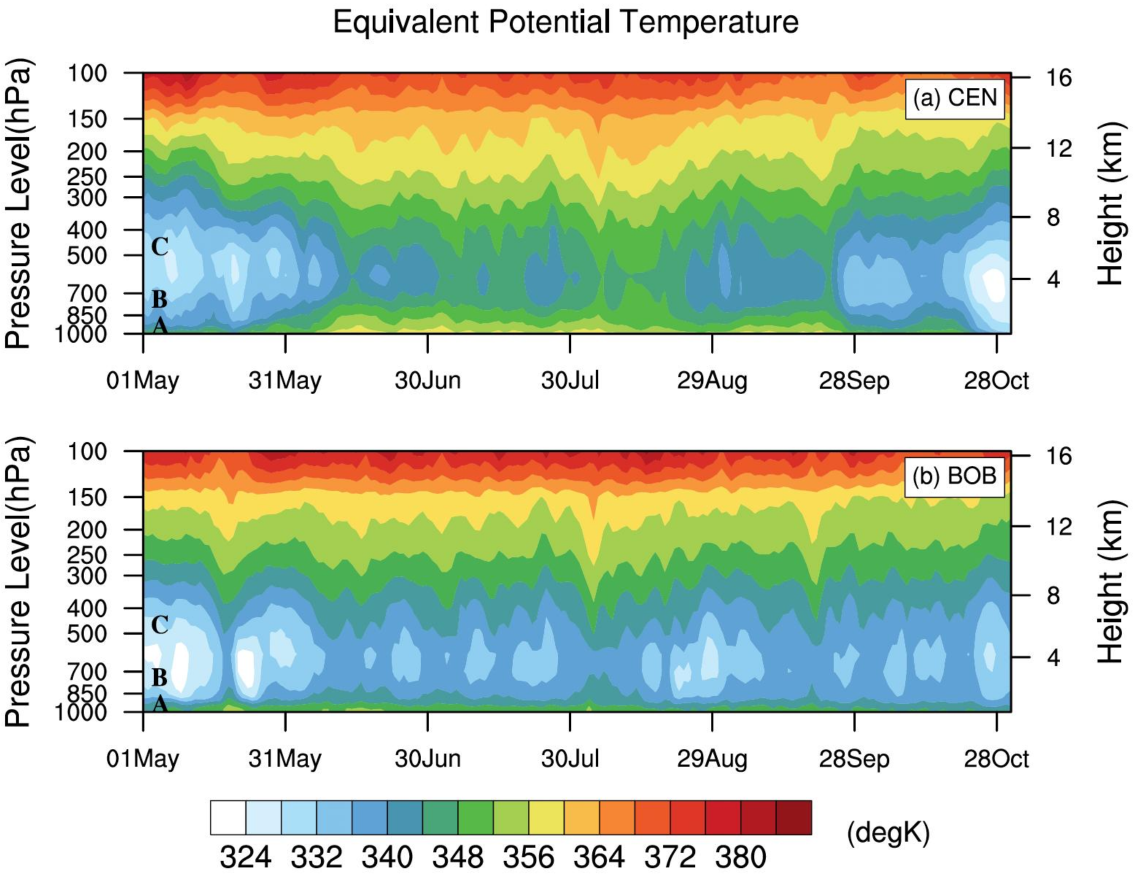

Figure 2: *Typical time-height cross-section of Equivalent potential temperature (EPT, θ_e) averaged over (a) central India CEN; and (b) the Bay of Bengal (BoB) during May to October. Units are in Kelvin (K). In the figure, the annotations A, B and C denote the layers between 950-850, 850-700 hPa and 500-200 hPa respectively.*

Before the discussion of the results based on instability indices, we show here the typical, vertical distribution of θ_e averaged over central India (CEN) and the Bay of Bengal (BOB). The regions are chosen based on the rainfall variance spatial maps. The vertical distribution of θ_e over both regions show a clear distinction as the season progresses. Over CEN the profiles are punctured by the low moist static energy (low θ_e) values around free tropospheric levels (700-500 hPa) in May. With the commencement of monsoon season and the availability of moisture in the atmosphere, the θ_e values raise above the boundary layer heights. On a similar note, the Bay of Bengal region also exhibits, relatively low moist static energy values before the monsoon and higher values during monsoon is noted. Interestingly, the magnitudes of EPT are relatively low (ranging from 330-340 K) during monsoon season compared to the values over CEN (ranging from 335-345K). The relatively large values of EPT over CEN compared to BOB are perhaps due to the enhanced air temperatures over land regions (Song et al., 2022).

(c) Stability indices - convection.

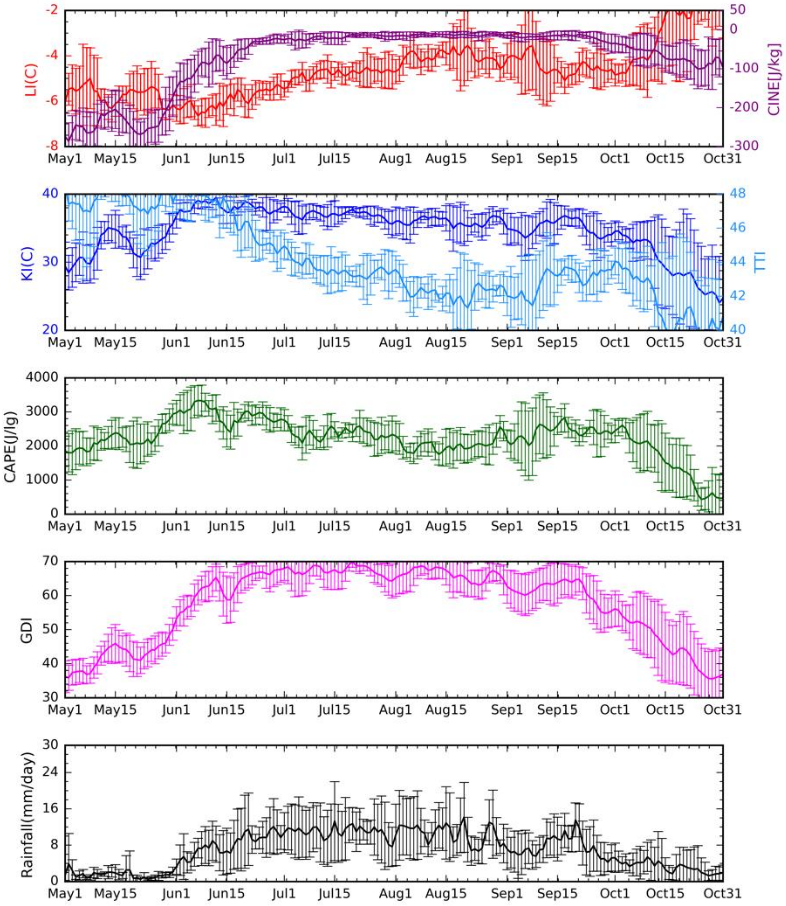

***Figure 3**: Temporal evolution of various stability indices (a) LI and CINE; (b) KI and TTI; (c) CAPE; (d) GDI and (e) Rainfall (mm/day) averaged over central Indian region (15-25N, 72-85E). The solid lines in the Figure indicate the mean and the standard deviation for all 6 years are given as vertical bars over the mean curve for the respective variable.*

Figure 3 and Figure 4 show the typical temporal evolution of the mean and standard deviation of the stability indices and rainfall averaged over CEN and BEN. Although we have examined all the indices for the individual years, to avoid redundancy, here we presented the typical temporal evolutions for the mean by combining all the years. We have combined LI and CINE; KI and TTI in one panel for better legibility. The figure also contains the rainfall along with the indices. The temporal evolution of the LI over CEN and BoB shows that the parcel inhibition energy (CINE) is largely negative (<-200J/kg), especially over CEN (Fig 3a) during May, which indicates the parcel is negatively buoyant and the atmosphere is statically stable (Fig 3a and 4a). With the commencement of the rainy season (i.e., during the monsoon onset) around the first of June, CINE becomes close to zero and continues exhibiting this feature until the end of September (the end of the monsoon season) indicating the parcel is positively buoyant. Later, during October the CINE values again started to exhibit large negative values depicting the absence of instability in the atmosphere. On the other hand, the CINE values over the BoB are almost equal to zero indicating the presence of instability throughout the period under consideration (Figure 4a). This could be due to the presence of abundant moisture in the surface layers and the SSTs (figure not shown). Another notable feature is that the seasonal changes in the inhibition are much more prominently seen over land regions than the ocean. The evolution of LI over both regions shows a gradual increase with the season irrespective of rainfall magnitudes and variability. Conversely, TTI values exhibit a decrease as the season progresses since the cloud cover increases over the period, leading to a cooling of the upper atmosphere. This diminishes the vertical temperature gradient, contributing to a more stable atmosphere and thus reducing the TTI.

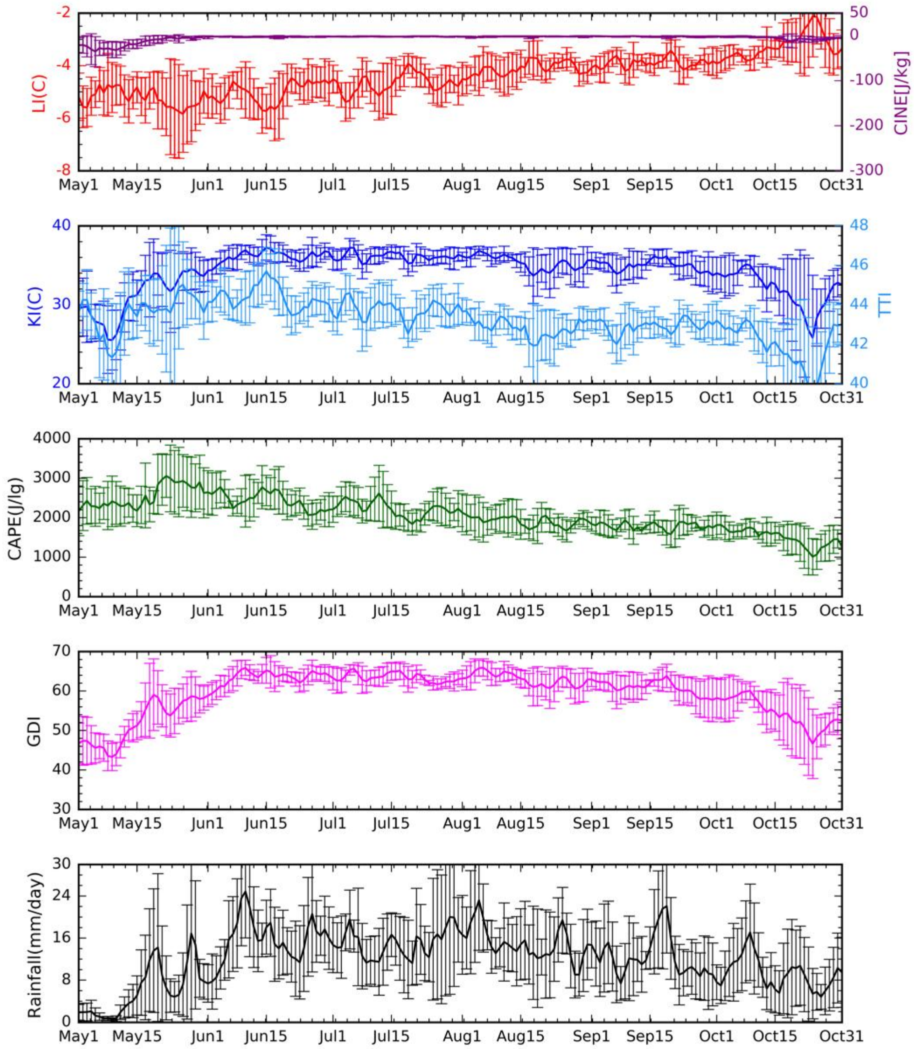

***Figure 4**: Temporal evolution of various stability indices (a) LI and CINE; (b) KI and TTI; (c) CAPE; (d) GDI and (e) Rainfall (mm/day) averaged over Bay of Bengal region (15-25N, 72-85E). The solid lines in the Figure indicate the mean and the standard deviation for all 6 years are given as vertical bars over the mean curve for the respective variable.*

On a similar note, it is seen that the temporal evolution of LI is showing a gradual increase and tending towards close to zero with time, indicating the decrease in the parcel temperature at 500 hPa level and reaching towards ambient air temperature values. Despite the presence of strong interannual variability in LI and TTI indices, the increasing (decreasing) trends of LI (TTI) are a consistent and robust feature in all years considered here.

All the other three indices, KI, CAPE, and GDI, exhibit a very nice one-to-one correspondence with the rainfall variability over both CEN and BoB regions. Careful examination of these three indices indicates that the variability of GDI is relatively more consistent with the rainfall variability compared to CAPE and KI. The relationship is very consistent throughout the seasons in all the years considered in the present study.

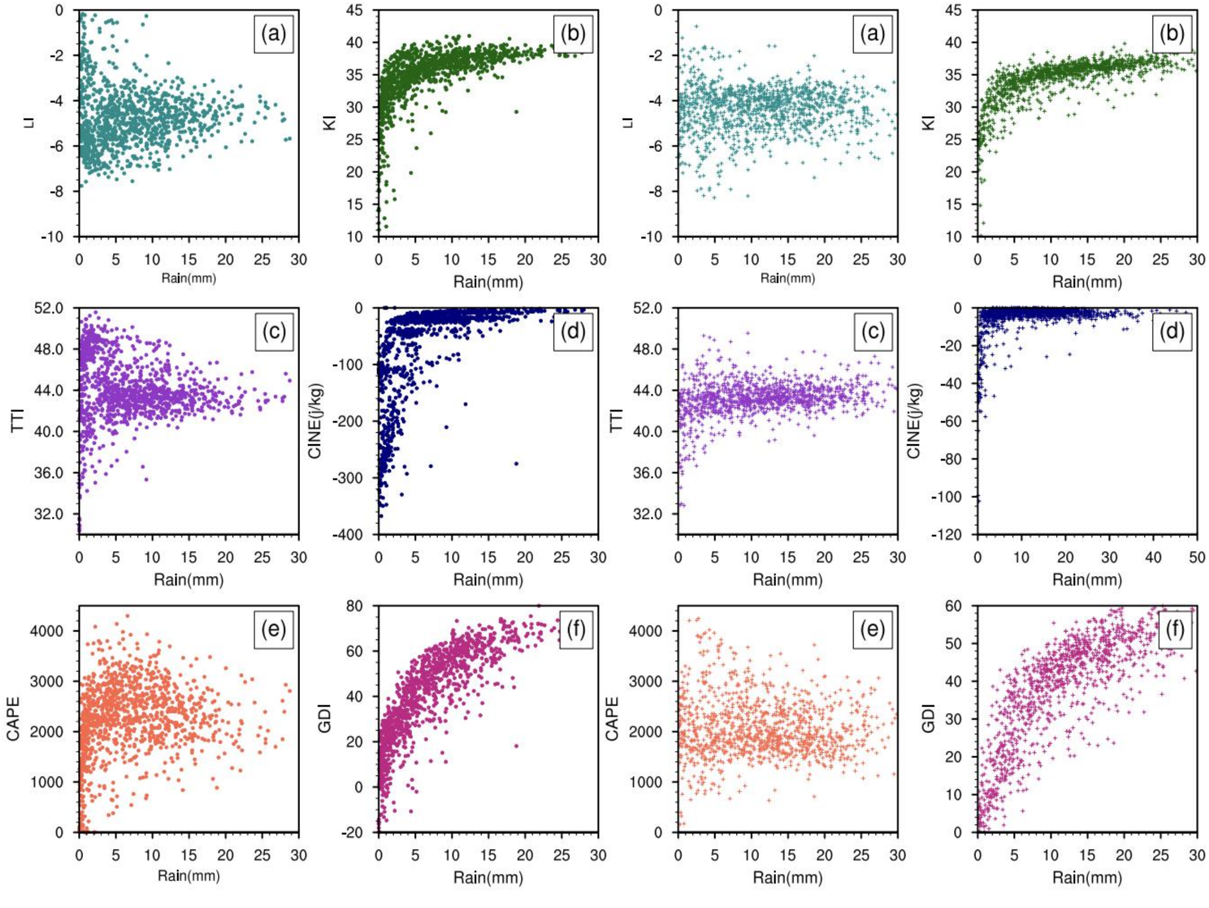

Figure 5: *Scatter plot between the rainfall on the x-axis and the various thermodynamic indices over central India and the Bay of Bengal regions. The scatter markers over central India is denoted with a solid "circle" whereas it was denoted by "+" over the Bay of Bengal region respectively.*

To further quantify the relationship between the thermodynamic indices and the convection (rainfall), we presented the indices' in a simple scatter plot. We have pooled all the 6 years of data to prepare the scatter diagram. The performance of each stability parameter was discussed separately. From Fig 5, it is clear that the scatter diagram relating the LI (which indicates the latent instability) vs rainfall indicates majority of the points are concentrated between -6 to -3 irrespective of the rainfall amounts. The orientation of the points are relatively more organized over Bay of Bengal (Fig 5a) compared to central India, where the LI magnitudes are relatively large. Interestingly these large LI values show exponential decrease over CEN with the increase in rainfall magnitudes. Similar orientation is also noticed over these two regions for TTI values. One of the major difference in the scatter diagram over these two regions is the orientation of CAPE vs rainfall. CAPE which is considered the vertical instability of the column indicates the magnitude increase very sharpy with the rainfall over CEN and after reaching maximum magnitudes between 3000-4000 J/kg. As the seasonal rainfall reaches more than 10-15 mm/day, CAPE starts decreasing and gradually reaches an equilibrium state, where the CAPE does not exceed despite the increments in rainfall amounts.

It is also noted from Figures 3 to 5, likewise GDI the KI outperforms LI and TTI and it’s association with rainfall variability is also better. This is due to KI and GDI both indices consider moisture at 700 hPa which is closely associated with the buoyancy and dry air entrainment in the mid-troposphere. However, KI has some limitations in the tropical environment as it overlooks the thermodynamic properties below 850 hPa, which are essential for assessing stability and moisture availability in the boundary layer. Another reason for GDI and its better representation of rainfall variability over KI is that GDI considers a layer instabilities rather than KI which is a single-level index.

4 Summary and Conclusions

In general, the traditional stability indices such as KI, LI, TTI, and CAPE often fail to accurately capture the formation of convective clouds and deep convection. Thus, to examine the fidelity of the stability indices in the representation of convection, this study examines the performance of various stability indices (KI, LI, TTI, CAPE, CINE and GDI; see section 2 for more details) for a more accurate representation of moist convection in tropical regions. For this study, we have used high-resolution regional reanalysis known as IMDAA for the recent 6 years of. (2015-2020) rainfall seasons (May-October).

Based on the rainfall variance, the study primarily focuses on Central India (CEN) and the Bay of Bengal (BEN) to examine convection characteristics. By focusing on these regions, the research aims to understand the differences in convection patterns and their relationship with atmospheric conditions. This approach allows for a detailed investigation of how convection evolves in these distinct areas, providing insights into the regional variability of moist convection. The BEN shows lower moist static energy values before the monsoon, which increase during the monsoon season. However, the EPT magnitudes are generally lower in the BEN during the monsoon compared to those in CEN.

The typical temporal evolution of all the traditional stability indices along with rainfall, CAPE, CINE and GDI over CEN and BOB is analyzed separately. The preliminary analysis indicates that, in May, the parcel inhibition energy (CINE) is largely negative (<-200 J/kg) over CEN, indicating a statically stable atmosphere. As the monsoon onset occurs in June, CINE approaches zero and remains positive until September, signifying a positively buoyant atmosphere. In contrast, CINE values over the BoB remain near zero, suggesting ongoing instability due to abundant moisture in the surface layers and sea surface temperatures. Seasonal changes in inhibition are more pronounced over land than over the ocean.

The evolution of LI shows a gradual increase throughout the season, irrespective of rainfall variability. Similarly, the TTI and KI decrease over time as cloud cover increases, leading to a cooling of the upper atmosphere and a reduced vertical temperature gradient. This contributes to a more stable atmosphere, lowering the KI and TTI. Over time, LI moves closer to zero, indicating a decrease in parcel temperature at the 500 hPa level toward ambient air temperature. Despite strong interannual variability, the increasing trend of LI and the decreasing trend of KI and TTI are consistent and robust features across all years analyzed.

A temporal composite analysis of all the indices with rainfall variability over both CEN and the BEN has been conducted, showing a strong one-to-one correspondence for CAPE, KI, and GDI. Among them, GDI exhibits a more consistent correlation with rainfall variability compared to CAPE and KI. The analysis indicates that the GDI outperforms traditional stability indices in representing deep convection over both BEN and CEN.

The analysis of six years of data set reveals that GDI consistently correlates with the magnitude of the correlation reaching as high as 0.9 (table not shown) over both land and oceanic regions and exhibits a very large one-to-one variability with rainfall variability. The findings suggest that GDI better captures the dynamics of deep convection, offering improved accuracy for convective predictions. Despite the analysis is carried out in a limited number of years the results are very encouraging and, the analysis is extended for other seasons and utilizing the NWP forecasts which are ongoing.

Author Contributions:

Smrutishree Lenka: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Original draft, review and editing.

Mohan T.S: Conceptualization, Investigation, Methodology, Supervision, Original draft, review and editing.

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