



Increasing pre-monsoon rain days over four stations of Kerala, India

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Abstract

The climate of India varies greatly by region, as seen by wind patterns, temperature and rainfall, seasonal rhythms and the degree of wetness or dryness. During the several seasons, the weather conditions change. Changes in meteorological factors (temperature, pressure, wind direction and velocity, humidity and precipitation, etc.) cause these changes. The pre-monsoon season (PRMS) comprises of March, April and May months. The precipitation patterns observed in PRMS are crucial because it affects a variety of crop-related operations across the country. The lifting index (LI), K index (KI), total totals index (TTI), humidity index (HI), improved k index, improved total totals index, total precipitable water (TPW) and convective available potential energy (CAPE) are studied at four locations in Kerala during PRMS. These variables were examined on rain day (RD)'s and no rain day (NRD)'s. The four stations we chose for our investigation were Thiruvananthapuram, Kochi, Alappuzha and Kannur. The GPM IMERG (Integrated Multi-satellite Retrievals for Global Precipitation Measurement) daily rainfall datasets have been utilized for this analysis. Fifth-generation ECMWF atmospheric reanalysis (ERA5) daily data for the PRMS of 2021 were used to measure all rainfall-related variables. During PRMS, all metrics clearly distinguished the RD and NRD. The rise in relative humidity and observations of dew point depression indicates that there is enough moisture for convective rain. In May, there were more negative VV values than in April.

Keywords Dew point depression · Precipitation · Convective system · Analysis

Introduction

Pre-monsoon season (PRMS) plays a crucial role in the cultivation of plantation crops across the country. During April–May, widespread pre-monsoon showers are seen assisting the growth of crops such as tea, coffee and cardamom in the Southern India. Sometimes, drought-like circumstances exist across Assam and West Bengal regions during PRMS that affects the growth of tea crops and its production. Over the last few years, PRMS rainfall has been increasing over Karnataka and Kerala regions that help in the growth of coffee plants. The PRMS is advantageous for mango, jute, rice and tea cultivation in West Bengal from an agricultural standpoint (Ranalkar and Chaudhari 2009). In few occasions, these crops are affected by few extreme events such as flooding, lightning, strong winds, hail, water logging and so on during PRMS. The pre-monsoon showers bring down the high temperatures that provide a big relief to the residents in metropolitan areas during the summer. Late rains can wreak havoc on standing crops, causing considerable crop loss and scarcity. Sometimes, the delay

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of rains leads to adverse effect on standing crops. Hence pre-monsoon rainfall is especially critical while harvesting Rabi crops. Pre-monsoon rainfall (PMF) is critical for the sowing of groundnut crop across different states. The number of PMF studies is limited, with the majority of them focusing on trends in specific places and historical periods (Kumar and Naidu 2020). Monthly or yearly rainfall analysis is frequently utilized in a variety of applications such as real-time flood monitoring, climate model diagnostics and verification (Janowiak and Arkin 1991; Subash and Ram Mohan 2011; Umakanth et al. 2021). Sadhukhan et al. (2000) examined PMF in Gangetic West Bengal region for the period 1901–1992. During the period 1901–1992, there was no long-term trend in pre-monsoon season rainfall over Gangetic West Bengal. However, there are short-term swings (Sadhukhan et al. 2000). During the period 1901–2003, the PRMS rainfall decreased in majority of the subdivisions (Guhathakurta and Rajeevan 2008). Kumar et al. (2010) conducted a 135-year trend study and observed a growing trend in PMF on a national scale from 1871 to 2005. Kothawale et al. (2010) examined the trends in daily temperature during extreme events throughout the PRMS. According to that study, the number of hot days and nights has increased, while the number of cold days has reduced. So, Nayak and Mandal (2014) investigated thunderstorms related to significant rainfall. They categorized pre-monsoon thunderstorms based on precipitation, which sparked our interest in doing this research. We have also classed thunderstorms based on rainfall as a result of this research.

In India, the PRMS is a time of transition between winter and monsoon circulation. The Kerala region experiences the arrival of monsoon winds in the last week of May or first week of June. The Kerala state is the first region in the Indian sub-continent to receive the monsoonal winds. The monsoon season typically begins in early June and lasts until September. The monsoonal winds usually arrive over Northeastern states of India during early June month (Pradhan et al. 2017). Usually by the first week of the July, the Southwest Monsoon normally covers the entire country (Kung and Sharif 1982; Koutavarapu et al. 2021a, b; Gogineni and Sangani 2021; Ranalkar and Chaudhari 2009). The geographical distribution of lightning flash density is particularly high over southern peninsular India, especially over Kerala during pre-monsoon season (Ranalkar and Chaudhari 2009). During different seasons, the spatial and temporal distribution of lightning incidence in Kerala varies. Based on a 17-year examination of lightning incidents in Kerala, it was discovered that 83 percent of all lightning incidents occur between 15:00 and 19:00 h. Varikoden et al. (2011) found that cloud frequency in the region during the pre-monsoon season is higher between 15:00 and 19:00 h (Murali Das et al. 2004). These findings are relevant since most of the clouds

that arise in the afternoon hours are convective clouds (Rakov and Uman 2003; Tyagi et al. 2013; Sangani et al. 2021a, b; Basu 2005; Mukhopadhyay et al. 2003; Uman and McLain 1969; Umakanth et al. 2020; Koutavarapu et al. 2021c). Kerala is 120 km wide at its widest point and runs northwest to southeast. The Arabian Sea borders it on the west and the Western Ghats mountain range borders it on the east. The state's southern border is the Indian Ocean. Lightning strikes more frequently in Kerala's midlands than in the mountain and coastal regions, according to Murali Das et al. 2004.

Kerala's driest months are January and February, with very little rain. Thunderstorm activity begins in March and gradually intensifies as the season progresses. This activity is particularly pronounced in the southern part of Kerala region. For the months of March and April, the long-term average daily rainfall in south Kerala is 1.9 and 4.8 mm, respectively, whereas the equivalent amounts in north Kerala are less than 1 mm. The rainfall associated with pre-monsoon thunderstorm activity is determined to be less than 10 mm per day on an area-averaged basis. The amounts are determined to be between 2 and 7 mm for south Kerala and less for north Kerala when averaged over distinct spells with different lengths. These are referred to as "light rain spells." Various factors connected with the start and advance of the southwest monsoon across India have been studied in Subramayya and Bhanu Kumar (1978) and Subbaramayya et al. (1984) research works. These authors have given a mean onset date on 20th May over Kerala for the 25-year period, i.e., 1956–1980. According to IMD records, the mean onset dates for the same time are completely different (30th May for Kerala region). It is commonly stated that the pre-monsoon thunderstorm rains in Kerala gradually intensify and mix with the monsoon rains, making it difficult to determine the monsoon onset date (IMD 1943). The pre-monsoon season rainfall is advanced by the occurrence of monsoon rainfall. The amount of daily rainfall in south Kerala prior to the onset of the monsoon is around 5–6 mm. This indicates the contribution of pre-monsoon thunderstorm activity. The pre-monsoon thunderstorm rain does not increase in intensity with time, but rather levels off by the middle of April. Rainfall begins abruptly at 17 mm on the onset date and continues to rise over the next 5 or 6 days, reaching a peak value of roughly 28 mm per day. After that, there is a slow oscillatory fall. The average pre-monsoon rainfall in north Kerala is around 4 to 5 mm per day, increasing to a little over 20 mm per day at the commencement and increasing further over the next 5 to 6 days. Pre-monsoon thunderstorms produce an average daily rainfall of about 5 mm. By the middle of April, this maximum has been achieved and there has been little increase than March month. Following the start of the monsoon, the average daily rainfall rises sharply to around 30 mm. The 10 mm threshold set for separating light and

heavy rain spells is nearly twice the normal pre-monsoon rainfall level (Vishnu et al. 2010; Chakraborty et al. 2021; Gogineni et al. 2020; Bondyopadhyay et al. 2021).

According to the India Meteorological Department's Meteorological Centre, Kerala's PRMS rainfall in 2021 was the greatest in 50 years and the fourth highest in the last 100 years. Over the three months, the state received 750.9 mm of rain, compared to 361.5 mm, the previous year. This year's significant rainfall is referred to as a "big excess" by the IMD because it represents a 108 percent deviation. There is a considerable excess in each of the 14 districts (a percentage departure of above 60 percent). From 1972 to 2021, pre-monsoon precipitation was the highest, and from 1922 to 2021, it was the fourth highest. The state experienced the most summer rainfall in the previous 100 years in 1933 (915.2 mm in length). The third-highest three-month rainfall total (788.1 mm) happened in 1932, while the second-highest total (791 mm) occurred in 1960. Kerala has received significant summer rains on multiple occasions over the last five decades. The previous high-water mark was 684.7 mm (2004). In 2006, the state received 577.6 mm of rain and 528.8 mm in 1999. In May, cyclonic storms erupted in the Arabian Sea and the Bay of Bengal, bringing further rain to Kerala. In 2021, the state saw a significant increase in winter rainfall, particularly in January and February. The state received an average of 114.1 mm, a 409 percent increase above the average of 22.4 mm (PREMONSOONRAINFALL.pdf (imd.gov.in)).

One of the properties of the large-scale atmospheric environment is rain-producing systems that lead to the static stability. Warm air mass attributes are key air mass features that contribute to such instability. At ground level, the air is humid, yet it is frigid and dry above (Beebe and Bates 1955; Gogineni and Chaturvedi 2019). To aid forecasters in this process, a number of indicators that define stability as a simple numerical field have been developed. The most basic indications are calculated using temperature and dew point. For example, Miller (1967) proposed a complete total index, George (1960) developed an enhanced K index, and more sophisticated indices are generated from the lifting of the air parcel. Examining the vertical levels in the atmosphere yielded a few instability parameters.

Umakanth et al. (2020) compared IMD thunderstorm occurrence days with NOAA CPC calculated rainfall days in the Anakapalle region during the pre-monsoon season for every year between 2001 and 2010. They discovered that the parameters of upward vertical velocity, convective available potential energy, K index (KI), humidity index and total totals index supported rainfall activity during the pre-monsoon season. They then used artificial neural networks (ANN) and auto-regressive moving average (ARMA) approaches to predict DCI and KI values in the Anakapalle region. During PRMS, we investigated the lifting index (LI), K index (KI), total totals index (TTI), humidity index (HI), improved

k index, improved total totals index, total precipitable water (TPW) and convective available potential energy (CAPE) characteristics at four locations in Kerala. On rainy days (RD) and non-rainy days (NRD), these variables were investigated. Thiruvananthapuram, Kochi, Alappuzha and Kannur were the four stations we investigated. This study used the GPM IMERG (Integrated Multi-satellite Retrievals for Global Precipitation Measurement) daily rainfall datasets. All rainfall-related indicators were measured using daily data from the fifth-generation ECMWF atmospheric reanalysis (ERA5) for the PRMS of 2021. In the present study, we have taken recent datasets such as GPM IMERG and ERA5 whose performance was better when compared to NOAA CPC and Era interim datasets (Umakanth et al. 2020). In this way, we have calculated MDI and other important parameters that highlighted the importance of GPM IMERG and ERA5 datasets in estimating PRMS convection activity. An attempt has been done to examine few indices in this research work. The purpose of this research is to investigate the performance in convective parameters on RD's and NRD's over four different stations located in Kerala during the PRMS of 2021. To begin, we have looked at daily gridded rainfall data from GPM IMERG (Integrated Multi-satellite Retrievals for Global Precipitation Measurement) dataset over Thiruvananthapuram, Kochi, Alappuzha and Kannur regions for the PRMS of 2021. Secondly, we have constructed the various stability indices using vertical temperature and humidity profiles from the ERA5 satellite reanalysis data and determine the usefulness of each index for evaluating RD's and NRD's. If the findings are favorable, the study can be considered as a pilot study with the technique being easily tested and deployed across the Indian subcontinent.

Data and methodology

Data

Only the PRMS was considered for this particular study over the four stations. The convection-related properties of four Kerala stations are investigated in this study. The GPM IMERG method (Integrated Multi-satellite Retrievals for Global Precipitation Measurement) is a standardized US approach to provide multi-satellite precipitation data to the GPM team in the USA. The Goddard Profiling Algorithm is used to grid the GPM constellation's various precipitation-relevant satellite passive microwave (PMW) sensor products, intercalibrate them to the GPM Combined Ku Radar-Radiometer Algorithm (CORRA) product and merge them into half-hourly $0.1^\circ \times 0.1^\circ$ (roughly 10×10 km) fields (GPROF 2017). These data can be accessed for any location on the globe. The webpage where GPM IMERG precipitation data collected is <https://gpm.nasa.gov/data/directory>. GPM IMERG products

have a high spatial resolution (0.1° latitude 85 0.1° longitude) as well as a range of time resolutions (ranging from half-hourly to monthly basis). These products aid in the detection of seasons with the highest precipitation values as well as seasons with the lowest precipitation values. The IMERG products are performing better in estimating rainfall intensities across the globe. Light rain with an intensity of 0 to 5 mm/day was accurately detected by the IMERG products. During spring and summer seasons, the IMERG products have shown better reliability in rainfall detection. Mohammed et al. (2020) research work also demonstrated that IMERG products can detect maximum daily rainfall and minimum daily rainfall. This research work has motivated us to carry out this research work. ERA5 is the fifth-generation ECMWF atmospheric reanalysis dataset. As a result, ERA5 is the fifth-generation of ECMWF global climate data atmospheric reanalyses. ERA5 surface level and pressure level reanalysis data with 0.25° precision were obtained for the year 2021 (Hersbach and Dee 2016). The URL where ERA5 data collected is <https://cds.climate.copernicus.eu#!/home>.

Methodology

First we retrieved temperature profiles and relative humidity profiles data which were obtained from the ERA5 reanalysis data. Later, we have calculated dew point temperature profiles from temperature profiles and relative humidity profiles data. These profiles were created using MATLAB software by the authors. The stability indices were calculated using temperature and dew point temperature profiles. The formulas used to calculate the various indices in this study are listed below.

(I) Deep Convective Index (DCI): The DCI tries to combine the features of equal potential temperature (Qe) with instability at 850 mb. This index is quite new. As a result, no firm critical values have been established. DCI values of 30 or above, on the other hand, indicate the possibility of intense thunderstorms. Given the existence of upward momentum, DCI ridge axis may be even more essential as a location for thunderstorm development (Barlow 1993).

$$DCI = at_{850} + dp_{850} - LI, \tag{1}$$

where *at* denotes ambient temperature and *dp* denotes dew point temperature. The pressure level is indicated by the suffix values.

(II) Lifted Index (LI).

The LI is mainly estimated to study the convective weather at lower tropospheric layers (Galway 1956).

$$Lifted\ Index\ (LI) = at_{500} - at_{parcel}, \tag{2}$$

where *at*₅₀₀ is temperature observed at 500 hPa; *at*_{parcel} is related to temperature of a parcel that has been lifted nearer to the earth’s surface to 500 hPa pressure level.

The critical values of LI parameter (Galway 1956).

LI (K)	Thunderstorm possibility
Higher than 2	No thunderstorm activity
From 0 to 2	Very less chance for thunderstorm activity
From – 2 to 0	Thunderstorms are possible
From – 4 to – 2	Chances for moderate thunderstorms
Below – 4	Chances for severe thunderstorms

(III) k index (KI)

When it comes to determining convective and heavy rain-producing situations, the K index (KI) is very important. Both moisture and temperature are taken into account in its calculations. Temperatures and dew points are computed without the need for a "skew-T" diagram. There is an increase in convection potential and KI as the moisture content and 850–500 temperature difference increase (George 1960).

$$KI = (at_{850} - at_{500}) + dp_{850} - (at_{700} - dp_{700}) \tag{3}$$

The pressure level is indicated by the suffix values.

The critical values of KI index indicating thunderstorm activity (Johnson 1982).

KI (K)	Thunderstorm chances
Under 288	0% Chance
In the middle of 288 and 293	20% chance
In the middle of 294 and 298	20–40% possibility for little thunderstorms
In the middle of 299 and 303	40–60% possibility for little to medium thunderstorms
In the middle of 304 and 308	60–80% possibility for heavy thunderstorms
In the middle of 309 and 313	80–90% possibility for severe thunderstorm event
Above 313	Over 90% possibility for thunderstorm event

(IV) Total totals index (TTI)

The total totals index is made up of the vertical totals (VT) and the cross totals (CT) (CT). The VT represents static stability or the lapse rate between 850 and 500 mb. The dew point of 850 mb is included in the CT. As a result, TT accounts for static stability and 850 mb moisture, but fails to account for low-level moisture below 850 mb. Furthermore, despite a high TT value, convection may be hampered if a big capping inversion exists (Miller 1967).

Cross totals, $CT = dp_{850} - at_{500}$; Vertical totals, $VT = at_{850} - at_{500}$

$$Total\ totals\ Index, TTI = CT + VT = at_{850} + dp_{850} - 2at_{500} \tag{4}$$

The pressure level is indicated by the suffix values. The critical threshold values of TTI parameter (Miller 1972).

TTI values (K)	Thunderstorm possibility
With thresholds ranging less than 44	Convection not likely
With thresholds ranging from 44 to 50	Likely thunderstorms
With thresholds ranging from 51 to 52	Isolated severe storms
With thresholds ranging from 53 to 56	Widely scattered severe thunderstorms
Above 56	Scattered severe storms

(V) Humidity Index (HI)

Litynska et al. (1976) established the humidity index (HI), which contains moisture depth at three standard levels: 850 hPa, 700 hPa and 500 hPa and is primarily used to forecast air mass thunderstorms.

$$HI = (at_{850} - dp_{850}) + (at_{700} - dp_{700}) + (at_{500} - dp_{500}), \tag{5}$$

where at denotes ambient temperature and dp denotes dew point temperature.

When HI readings reach 30 K or below, there is a strong chance of thunderstorms forming in that area.

(VI) Convective available potential energy (cape)

CAPE refers to the buoyant energy necessary to accelerate an air packet aloft. The entire positive buoyant energy from free convection to equilibrium can be determined by putting them together (Moncrieff and Miller 1976).

$$cape = \int_x^y g \left[\frac{TV_{parcel} - TV_{env}}{TV_{env}} \right] dz, \tag{6}$$

where TV_{parcel} and TV_{env} indicate the virtual temperature of the parcel and the virtual temperature of the environment, respectively. The levels of free convection and neutral buoyancy are represented by x and y .

The critical values of Cape parameter (Grieser 2012).

Cape (in J/kg)	Thunderstorm chances
Under 300	No energy for convection
From 300 to 1000	Poor potential for weak convection
From 1000 to 2500	Moderate potential for convection
Greater than 2500	Strong potential for convection

(VII) Improved total totals index & improved K index

Both improved total totals index & improved K index are calculated by the average of the temperatures at surface (at 2 m), the 925 hPa and the 850 hPa pressure levels (Miller 1967). These are obtained from the formulas shown below.

$$\begin{aligned} &\text{Improved total totals index} \\ &= (Temp2m + at925 + at850)/3 \\ &\quad + (Tempd2m + dp925 + dp850)/3 - 2at500 \end{aligned} \tag{7}$$

[Miller 1967]

$$\begin{aligned} &\text{Improved K-index} = ((Temp2m + at850)/2 - at500) \\ &\quad + (Tempd2m + dp850)/2 \\ &\quad - (at700 - dp700) \end{aligned} \tag{8}$$

[Charba 1977],

where at denotes temperature, dp denotes dew point temperature, Temp2m stands for surface temperature at 2 m, and Tempd2m stands for surface dew point temperature at 2 m.

The threshold for thunderstorm occurrence is usually seen at 57 K (Miller 1967).

The threshold for thunderstorm occurrence is usually seen at 300 K (Charba 1977).

(VIII) Total precipitable water (TPW)

The total precipitable water (TPW) product is calculated using the recovered atmospheric moisture profiles and represents the total integrated moisture in the atmosphere from the surface to the top. It is calculated using the formula:

$$TPW = \frac{1}{g} \int_{P_1}^{P_2} WdP. \tag{9}$$

W is the mixing ratio, and P_1 and P_2 are the two pressure levels (Carlson et al. 1990).

(IX). Mean daily intensity (MDI): The formula for this is given below (Nandargi and Mulye 2012).

$$MDI = (\text{Average seasonal Rainfall} / \text{Number of rainy days}) \tag{10}$$

Results and discussion

The current study looked at the factors connected with PRMS convective systems over the stations of Thiruvananthapuram, Kochi, Alappuzha and Kannur. First, we have collected the daily rainfall data from GPM IMERG rainfall product for the entire PRMS during 1981–2021. We computed the mean rainfall for the entire PRMS for that year, respectively. So, the yearly mean PRMS rainfall over all the four stations is shown in Fig. 1 during 1981–2021. During these 41 years, all the four stations indicated highest rainfall in 2021 PRMS. Thiruvananthapuram and Alappuzha stations showed almost 1000 mm rainfall in PRMS of 2021, i.e., highest over past 41 years, whereas Kochi and Kannur stations indicated nearly 974 and 689 mm rainfall. For

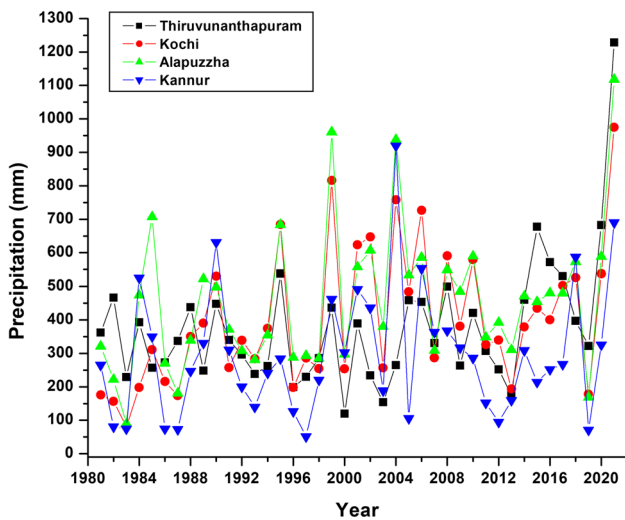


Fig. 1 Yearly variations for daily mean rainfall for the entire PRMS over Thiruvananthapuram, Kochi, Alappuzha and Kannur regions during 1981–2021

this reason, we have selected 2021 PRMS as our case study over the four stations. Initially, we have looked at the GPM IMERG daily gridded rainfall dataset for the PRMS in 2021. We have acquired ERA5 reanalysis data.

In Fig. 2, we show daily GPM IMERG rainfall for the full PRMS in 2021. Out of four stations, Thiruvananthapuram station received high rainfall (~1228 mm), whereas Kannur station received less rainfall (~689 mm) during PRMS. Alappuzha station also received nearly 1118 mm rainfall. The phrase "rain day (RD)" refers to a day when the station has recorded a detectable amount of rain, 0.1 mm or more

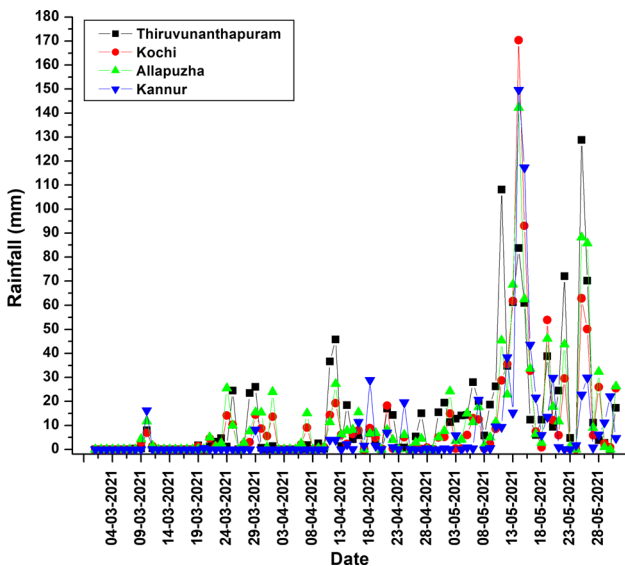


Fig. 2 Daily rainfall for the entire PRMS over Thiruvananthapuram, Kochi, Alappuzha and Kannur regions during 2021

(Nandargi and Mulye 2012). We can extrapolate from this that during the PRMS, more convective systems are reported across four places in Kerala. In this work, Box-and-Whisker plots are employed to investigate a variety of convective-related properties. A percentile plot, often known as a Box-and-Whisker plot, is a visual representation of percentiles.

Table 1 MDI values over all the four stations

Station name	Rain days	Rainfall (mm)	MDI
Thiruvananthapuram	65	363.9	5.59
Kochi	64	400.6	6.25
Alappuzha	62	451.7	7.28
Kannur	42	281.9	6.71

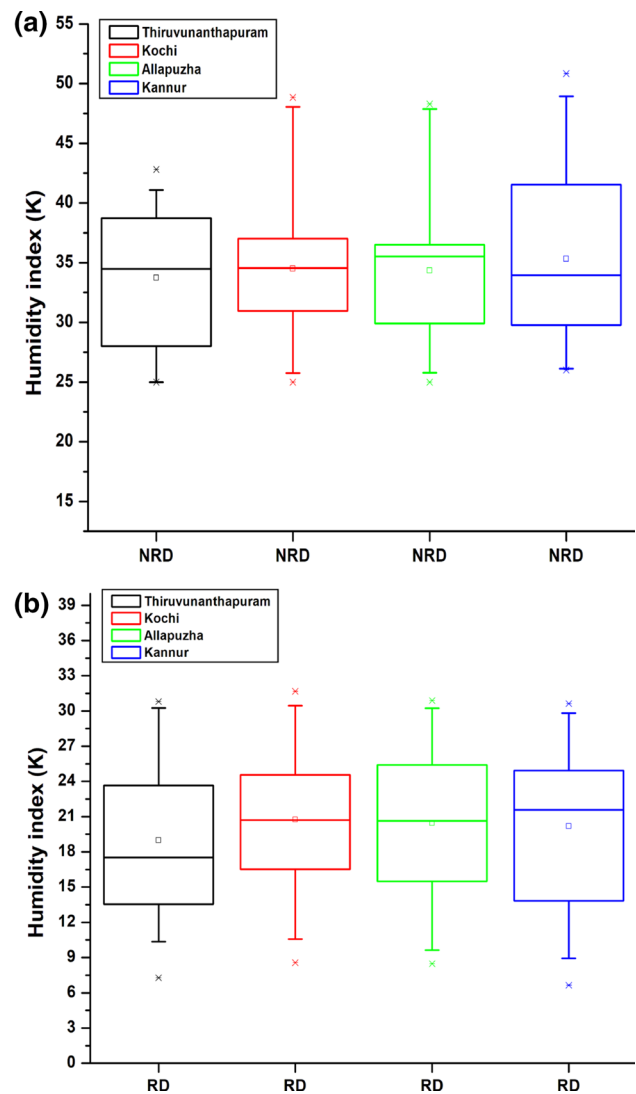


Fig. 3 Box-and-Whisker plot of humidity index for **a** NRD and **b** RD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations during PRMS of 2021

The Box represents the middle half of the sorted data and is drawn from the lower quartile value to the higher quartile value (i.e., 25th to 75th percentile). The interquartile range of the dataset, which extends from the 25th to the 75th percentile, determines the height of the box section. The small box below the 50 percent center horizontal bar within the box indicates the mean value. At the ends of the whiskers, the 5th and 95th percentile values are shown. Out of 92 days in PRMS, Thiruvananthapuram station recorded 65 rain days (RD), Kochi recorded 64 rain days, Alappuzha station recorded 62 rain days and Kannur recorded 42 rain days. Kannur has more NRD, i.e., 50 days when compared to other stations. On these RD and NRD, we have attempted to investigate changes in a few parameters. The formula for the calculation of MDI is given in Eq. 9. From Table 1, the average PRMS rainfall across Alappuzha station is high

among four stations. The rain days are also highest over Thiruvananthapuram station than other stations.

The Box-and-Whisker diagram of the HI parameter for the RD and NRD across the Thiruvananthapuram, Kochi, Alappuzha and Kannur stations in PRMS of 2021 is shown in Fig. 3. The range of HI values at four stations during NRD of PRMS is 26 to 55 K (Fig. 3a). HI values above 30 K indicate a lower risk of severe convection (Litynska et al. 1976). In Fig. 3b, the HI values that vary from 10 to 30 K are observed during RD. HI values less than 30 K suggest a high likelihood of severe convection (Litynska et al. 1976). Among all stations, Kannur station indicated better thresholds of HI parameter during RD and NRD. The Box-and-Whisker diagram of the DCI parameter for the RD and NRD across the Thiruvananthapuram, Kochi, Alappuzha and Kannur stations in the PRMS of 2021 can be shown in Fig. 4. During the NRD, DCI values range from 20 to 30 K at four locations during the PRMS as illustrated in Fig. 4a.

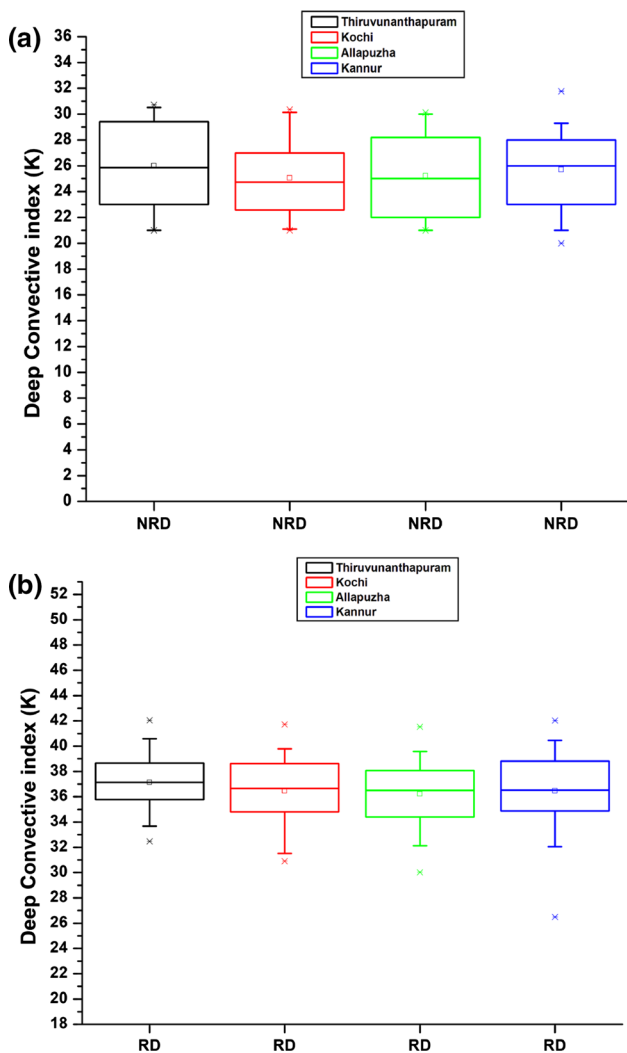


Fig. 4 Box-and-Whisker plot of deep convective index for a NRD and b RD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations during PRMS of 2021

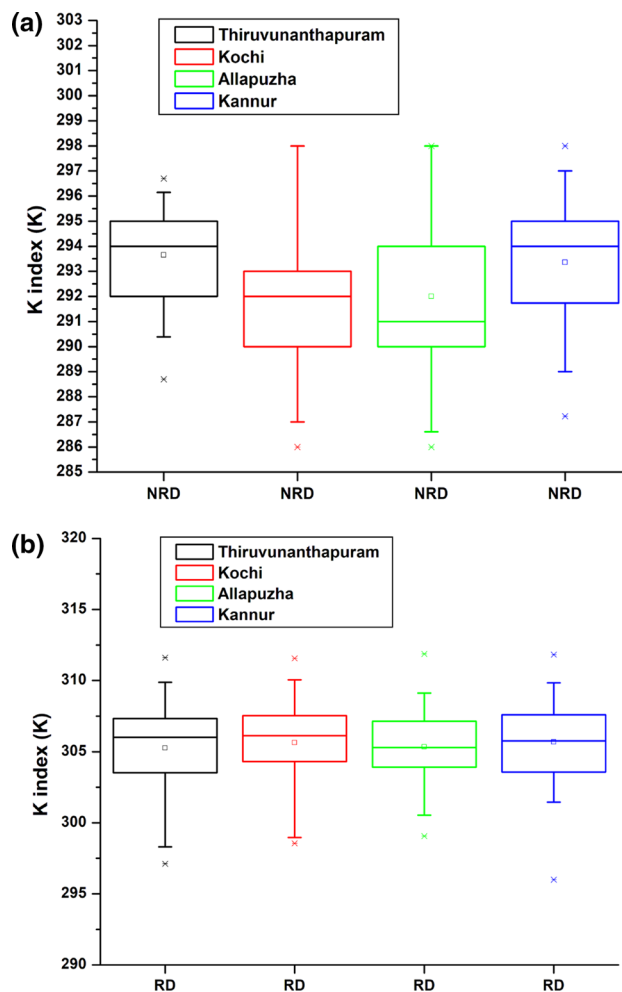


Fig. 5 Box-and-Whisker plot of K index for a NRD and b RD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations during PRMS of 2021

DCI values above 30 K suggest a less likelihood of severe convection (Barlow 1993). In Fig. 4b, the DCI values that vary from 31 to 43 K are observed during RD. DCI values above 30 K suggest a high likelihood of severe convection (Barlow 1993). Among all stations, Thiruvananthapuram station indicated better thresholds of DCI parameter during RD and NRD.

Figure 5 shows the Box-and-Whisker diagram of KI parameter for the RD and NRD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations in PRMS of 2021. During RD (Fig. 5b), the KI values fluctuate between 300 and 313 K, whereas during NRD (Fig. 5a), these values fluctuate from 285 to 298 K. KI values above 299 K indicate 40–60% chances for heavy to severe convection occurrences (Johnson 1982). Out of all stations, Kochi station is more sensitive to KI threshold values in displaying the severity of a convective system. Figure 6 shows the Box-and-Whisker diagram of TTI parameter for the RD and NRD over Thiruvananthapuram, Kochi, Alappuzha and

Kannur stations in PRMS of 2021. During RD (Fig. 6b), the TTI values fluctuate between 42 and 50 K, whereas during NRD (Fig. 6a), these values fluctuate from 36 to 46 K. TTI values above 46 K indicate high chances for heavy to severe convection occurrences (Miller 1972). Out of all stations, Thiruvananthapuram station is more sensitive to TTI threshold values in displaying the severity of a convective system.

In Fig. 7, a Box-and-Whisker diagram represents the improved KI parameter for the RD and NRD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations in PRMS of 2021. During RD (Fig. 7b), the improved KI values fluctuate between 305 and 320 K, whereas during NRD (Fig. 7a), these values fluctuate from 285 to 300 K. Improved KI values above 303 K indicate nearly 60–80%

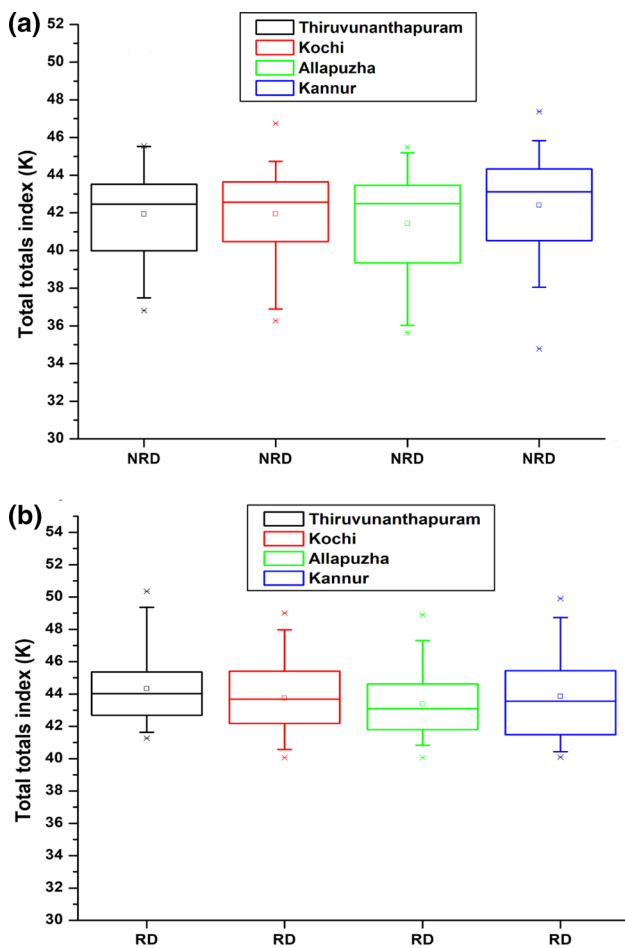


Fig. 6 Box-and-Whisker plot of total totals index for **a** NRD and **b** RD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations during PRMS of 2021

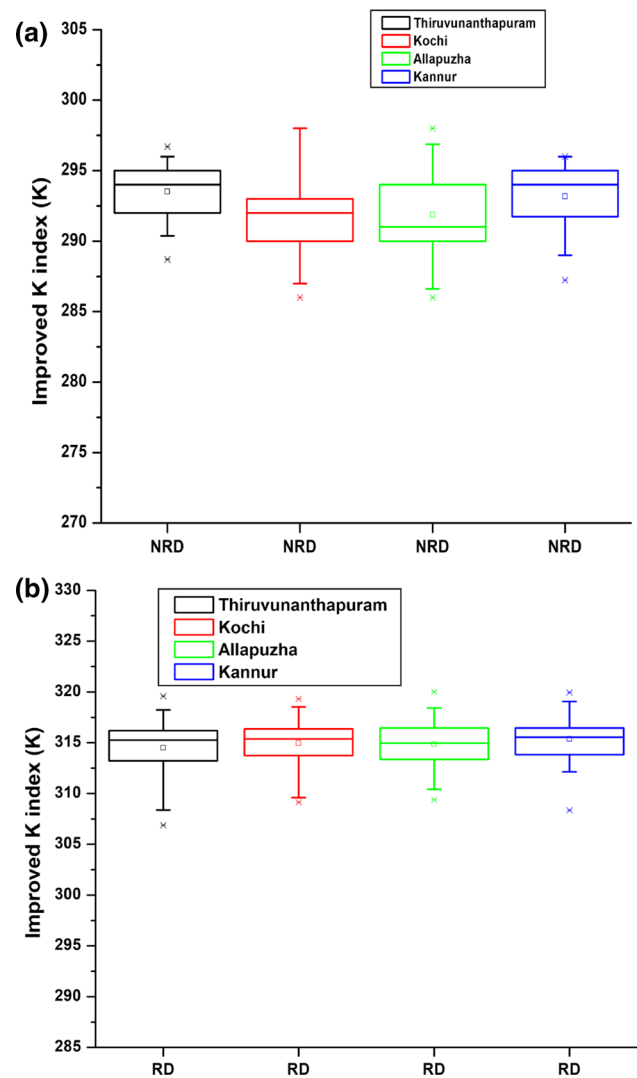


Fig. 7 Box-and-Whisker plot of improved K index for **a** NRD and **b** RD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations during PRMS of 2021

chances for heavy convection occurrences (Charba 1977). Figure 8 shows the Box-and-Whisker diagram of improved TTI parameter for the RD and NRD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations in PRMS of 2021. During RD (Fig. 8b), the improved TTI values fluctuate between 46 and 60 K, whereas during NRD (Fig. 8a), these values fluctuate from 36 to 48 K. Improved TTI values above 57 K suggest a strong likelihood of severe convection (Miller 1967).

In the PRMS of 2021, a Box-and-Whisker diagram of the LI parameter for the RD and NRD over the Thiruvananthapuram, Kochi, Alappuzha and Kannur stations is presented in Fig. 9. In PRMS, the LI values vary from -4 to 7 K at four stations during NRD shown in Fig. 9a. In Fig. 9b, the LI values that vary from -6 to -2 K are observed during RD. LI values less than -4 K suggest

a high likelihood of severe convection (Galway 1956). Kochi and Thiruvananthapuram stations have shown the best LI parameter thresholds for RD and NRD of all the stations. In Fig. 10, a Box-and-Whisker diagrams represent the TPW parameter for the RD and NRD over the Thiruvananthapuram, Kochi, Alappuzha and Kannur stations in PRMS of 2021. During RD (Fig. 10b), the TPW values fluctuate between 45 and 70 mm, whereas during NRD (Fig. 10a), these values fluctuate from 24 to 45 mm. TPW values above 45 mm indicate high availability of moisture accumulation which triggers the heavy convection occurrences. Kochi and Kannur stations have shown the best TPW parameter thresholds for RD and NRD of all the stations.

In the PRMS of 2021, the Box-and-Whisker diagram of the CAPE parameter for the RD and NRD across the Thiruvananthapuram, Kochi, Alappuzha and Kannur stations is presented in Fig. 11. The range of CAPE values

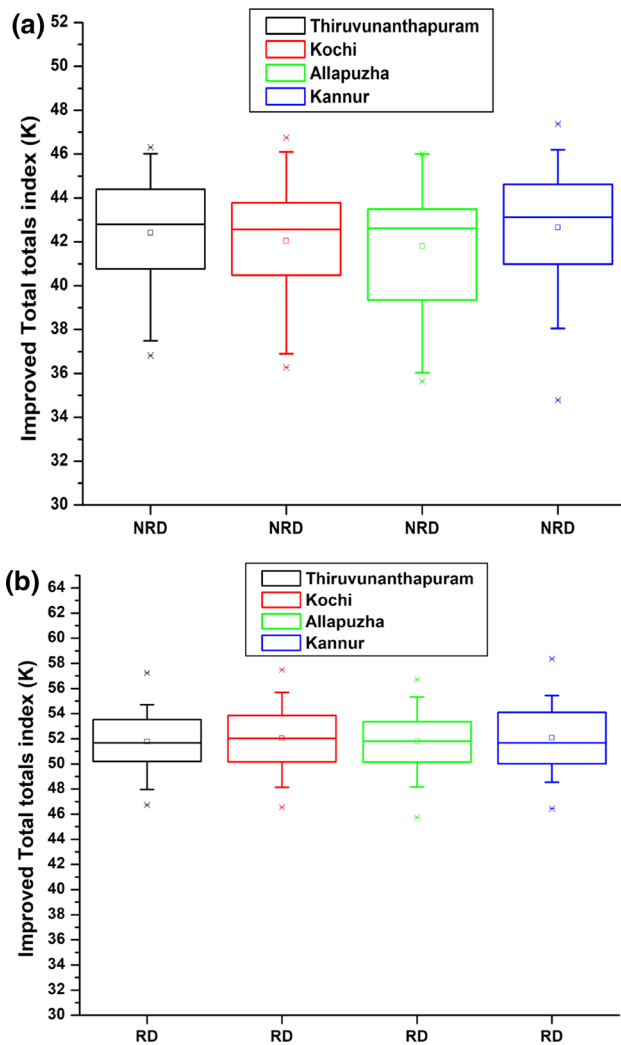


Fig. 8 Box-and-Whisker plot of improved total totals index for **a** NRD and **b** RD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations during PRMS of 2021

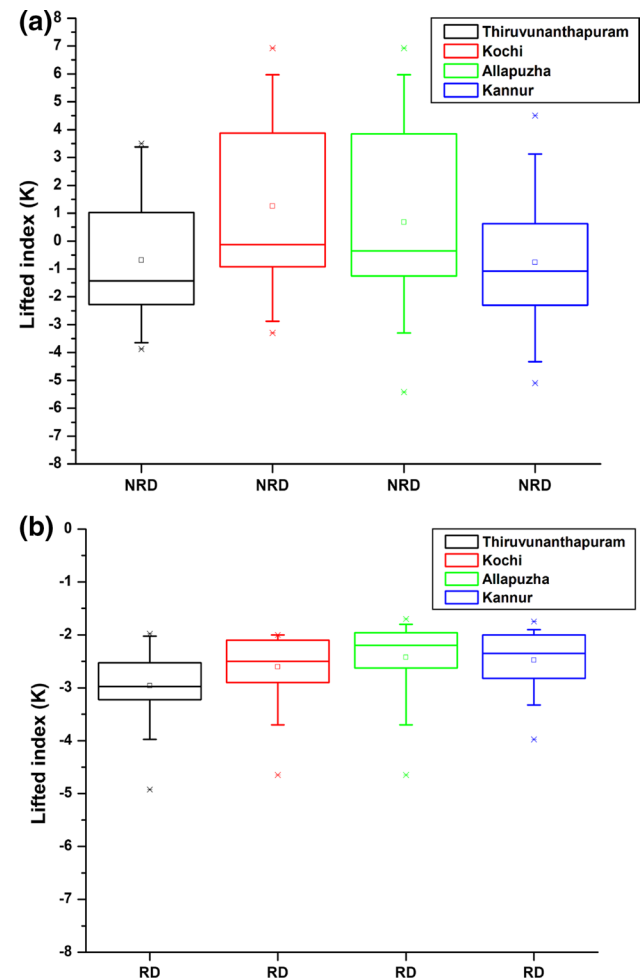


Fig. 9 Box-and-Whisker plot of lifted index for **a** NRD and **b** RD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations during PRMS of 2021

at four stations during NRD of PRMS is 100 to 1850 J/kg (Fig. 11a). CAPE values below 1500 J/kg suggest a less likelihood of severe convection (Moncrieff and Miller 1976). In Fig. 11b, the CAPE values that vary from 1500 J/kg to 3500 J/kg are observed during RD. CAPE values higher than 2000 J/kg suggest a high likelihood of severe convection (Moncrieff and Miller 1976). Kochi and Kannur stations have shown the best CAPE parameter thresholds for RD and NRD of all the stations. The amount of energy required to keep an air parcel from rising to the level of free convection from the surface is measured by convective inhibition (CIN). Convection in the atmosphere is prevented by CIN values larger than 200 J/kg. CIN is typically caused by a capping stable layer or inversion, with levels of > 200 J/kg reducing convective potential significantly. In the PRMS of 2021, we displayed the CIN parameter over the Thiruvananthapuram, Kochi, Alappuzha and Kannur stations in Fig. 12a–d. During the months of March and April, all stations reported high

values of > 500 J/kg. In March and April, the Thiruvananthapuram station recorded values of over 200 J/kg. In May, all stations had CIN values of less than 200 J/kg.

As shown in Fig. 13a–d, we reported relative humidity and divergence over the four sites for the PRMS in 2021. High relative humidity values are observed near the earth's surface. High moisture content is present nearer to the surface that triggers the occurrence of convection. This helps for the occurrence of heavy precipitation near the earth's surface. During PRMS, negative divergence values are observed indicating that dry air is present from the surface to the 600 hPa level. This dry air is lying above the moist air due to the high relative humidity values, encouraging convection activity over four stations. The dew point depression is minor around 1000 hPa and 950 hPa. It increased

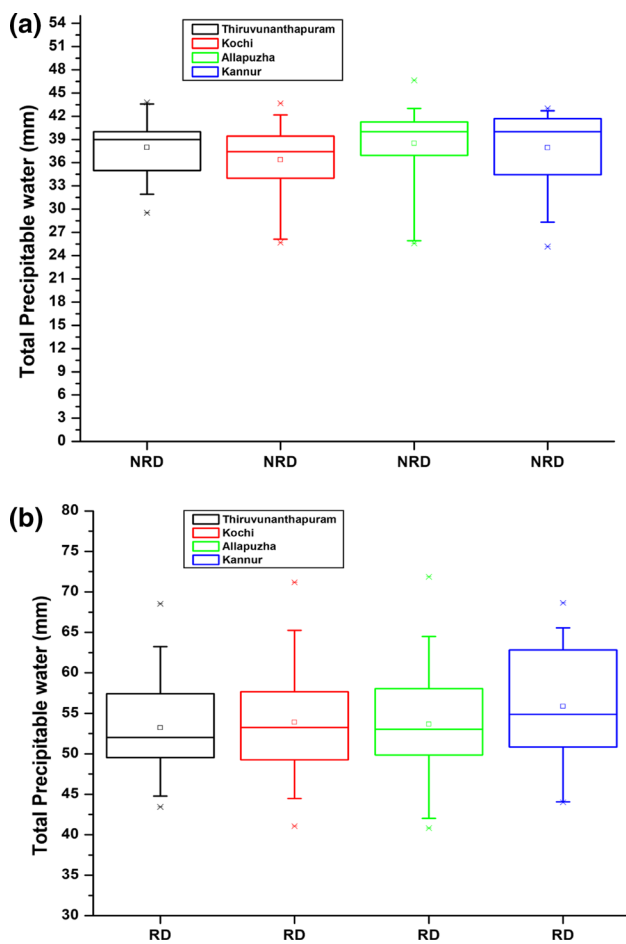


Fig. 10 Box-and-Whisker plot of total precipitable water for **a** NRD and **b** RD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations during PRMS of 2021

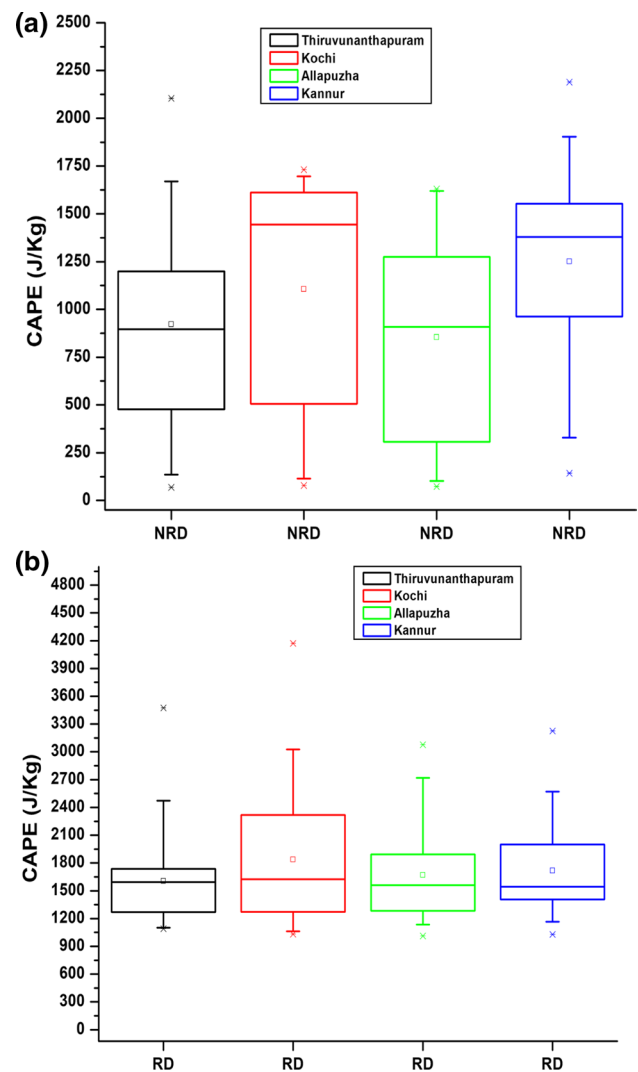


Fig. 11 Box-and-Whisker plot of convective available potential energy for **a** NRD and **b** RD over Thiruvananthapuram, Kochi, Alappuzha and Kannur stations during PRMS of 2021

to 5–12 K at 800 hPa and then began to rise to 18 K at 500 hPa. In March, it dropped to 15 K at 250 hPa. Even at 200 hPa, the readings climbed in April and May. This clearly demonstrates that moist air exists between 1000 and 800 hPa and dry air exists above this moist air from (800–500 hPa), and that moist air exists between 500 and 400 hPa and dry air exists in the upper layers of the atmosphere, indicating a very unstable environment at all stations (Fig. 14a–d).

In Fig. 15a–d, we have shown a plot of vertical velocity (VV) and temperature over four locations. On heavy convection days, we observed large negative vertical velocity values. This indicates an upward motion of air mass in the lower atmospheric levels. More negative VV values were observed in May month when compared to April month.

When negative VV values are seen, it is an indication of ascending air mass. When positive VV values are observed, it is an indication of sinking air mass. This scenario is due to the fact that pressure decreases with increase in height. On heavy precipitation days, these VV values are supported by the high moisture accumulation over the study region. Usually warm air is a combination of moisture and air content. This warm air carries the entire moisture to the upper levels of the atmosphere. Moisture cools quickly in the upper atmosphere, generating huge clouds that spread out due to the lower pressure. Moisture is the major ingredient for the rainfall occurrence. In the summer season, enough moisture content is available for the occurrence of convective systems across the study region. When moisture is added to or withdrawn from a body of air, its specific

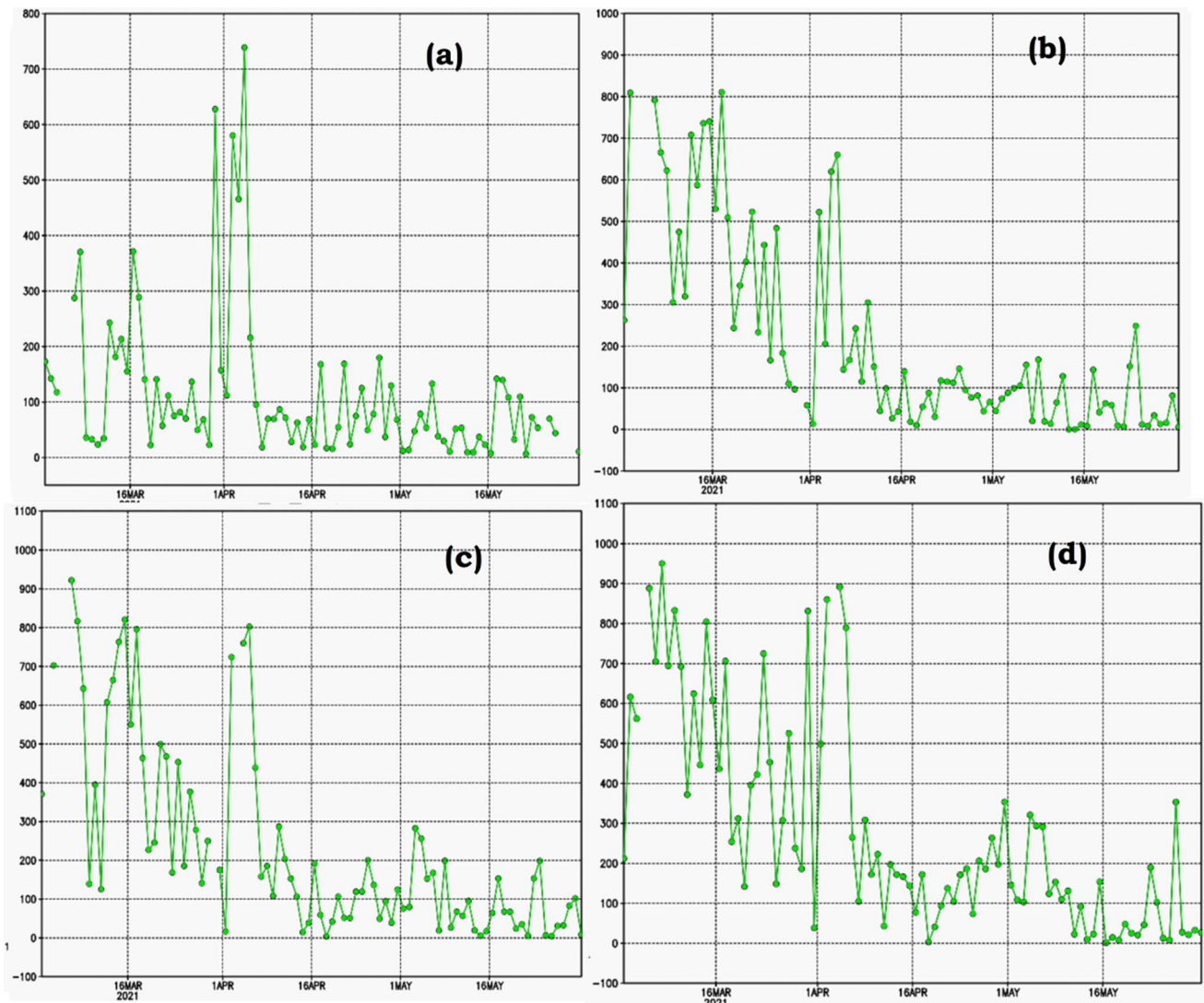


Fig. 12 Daily variations of convective inhibition over **a** Thiruvananthapuram, **b** Kochi, **c** Alappuzha and **d** Kannur stations during PRMS of 2021

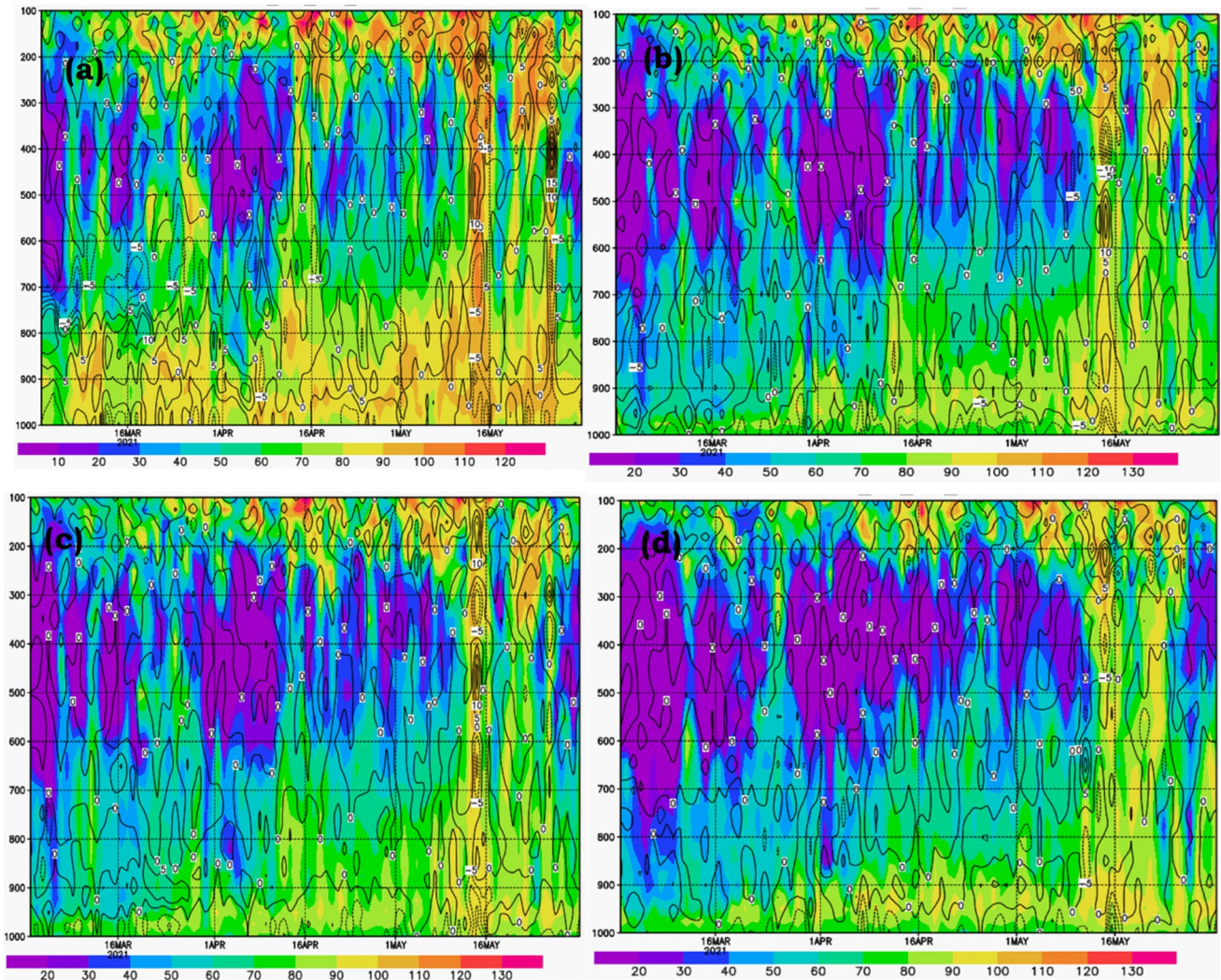


Fig. 13 Relative humidity (percentage, shaded) and divergence ($\times 10^{-5}$ /s, contour over time) are shown as time–height sections over **a** Thiruvananthapuram, **b** Kochi, **c** Alappuzha and **d** Kannur stations during PRMS of 2021

humidity does not change as the temperature or pressure of the air varies. Figure 16a–d shows the time–height segment of the specific humidity. At all four locations, the specific humidity parameter values at lower atmospheric pressure levels are higher. In May, the observed specific humidity values are higher in comparison with March and April months. This could be the reason for the higher rainfall in May compared to other months.

Conclusions

During the PRMS, the convection-related characteristics are researched at four stations: Thiruvananthapuram, Kochi, Alappuzha and Kannur. The current research is being conducted from March to May month of 2021.

During the PRMS, Thiruvananthapuram station received the most rainfall (1228 mm), while Kannur station received the least (689 mm). Rainfall totalled about 1118 mm at Alappuzha station.

In the PRMS, Thiruvananthapuram station reported 65 rain days, Kochi station reported 64 rain days, Alappuzha station reported 62 rain days and Kannur station reported 42 rain days. When compared to other stations, Kannur has a higher NRD of 50 days.

Kannur station has the best HI parameter thresholds for RD and NRD of all the stations.

During the RD and NRD, the Thiruvananthapuram station had the best DCI parameter thresholds of all the stations. Kochi station is the most sensitive to KI threshold levels in depicting the severity of a convective system of all the stations. Thiruvananthapuram station is the most

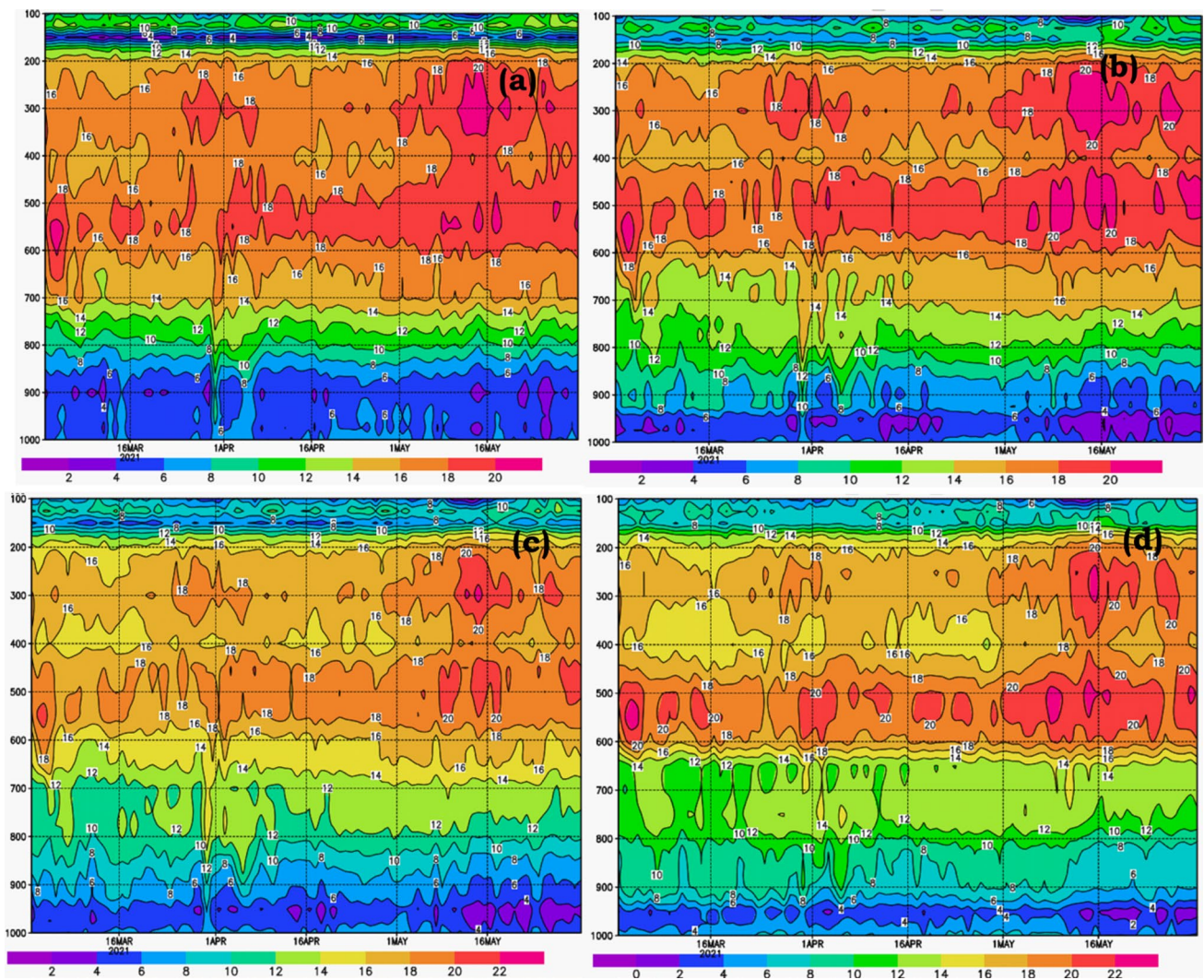


Fig. 14 Time–height sections of a dew point depression over **a** Thiruvananthapuram, **b** Kochi, **c** Alappuzha and **d** Kannur stations during PRMS of 2021

sensitive to TTI threshold values in depicting the severity of a convective system of all the stations. The best LI parameter levels for RD and NRD were found at the Kochi and Thiruvananthapuram stations. Of all the stations, Kochi and Kannur have the best TPW parameter thresholds for RD and NRD. Of all the stations, Kochi and Kannur have the best CAPE parameter thresholds for RD and NRD. CIN values greater than 200 J/kg hinder convection in the atmosphere. CIN is most commonly generated by a capping stable layer or inversion, with amounts of > 200 J/kg greatly lowering convective potential. The improved KI and improved TTI parameters are useful

predictors for distinguishing between rainy and non-rainy days. Higher KI and TTI values indicate favorable conditions for convection activity, implying that high instability and low atmospheric moisture content play a critical role in the occurrence of convective systems over Kerala's four stations.

During NRD, the threshold values are HI: 26–55 K; DCI: 20 K to 30 K; KI: 285–291 K; TTI: 36–46 K; improved KI: 285–300 K; improved TTI: 36–48 K; LI: –4 to 7 K; TPW: 24–45 mm; and CAPE: 100–1850 J/kg. During RD, the threshold values are HI: 10–30 K; DCI: 31–43 K; KI: 300–313 K; TTI: 42–50 K; improved KI:

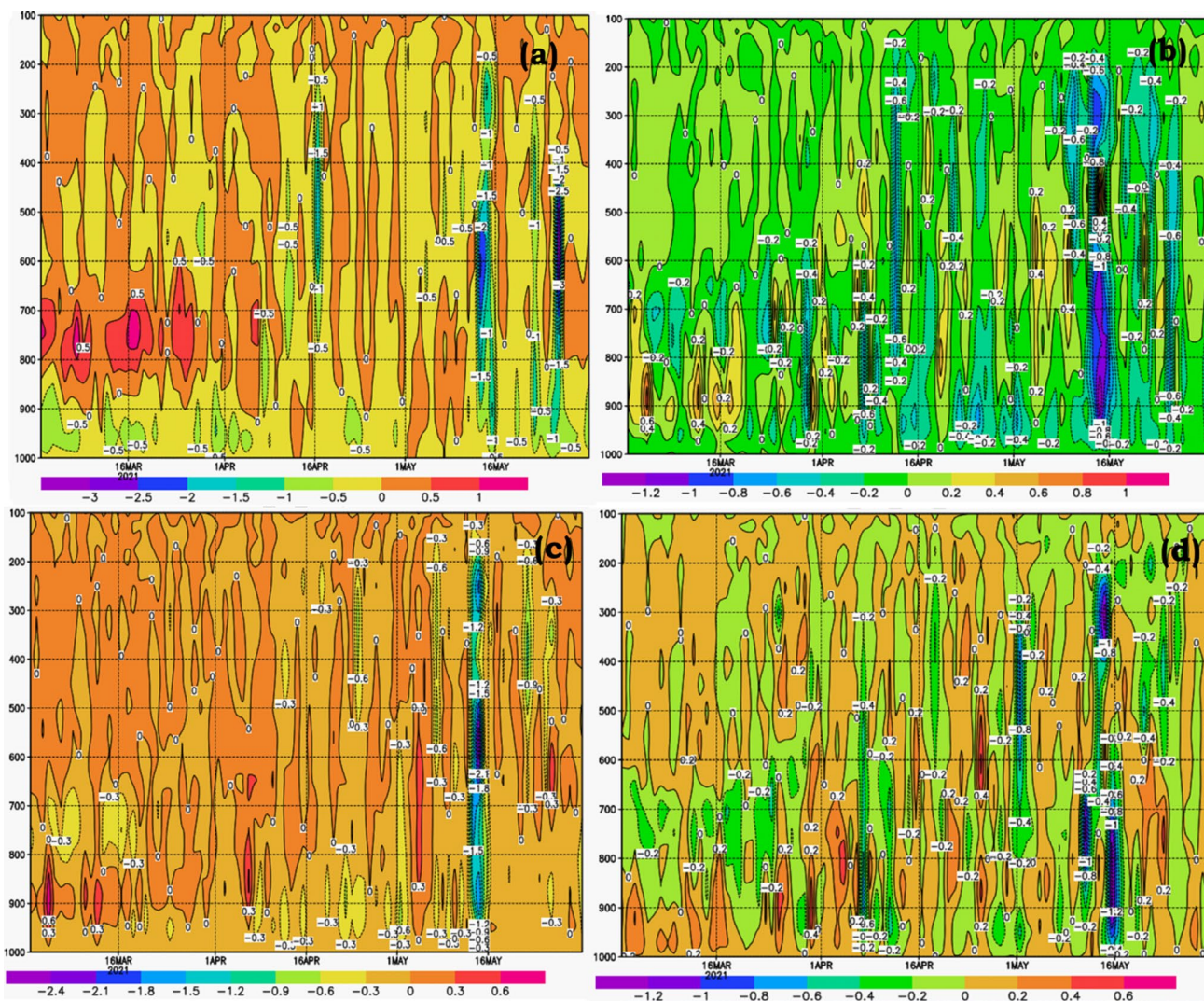


Fig. 15 Time–height sections of a vertical velocity over **a** Thiruvananthapuram, **b** Kochi, **c** Alappuzha and **d** Kannur stations during PRMS of 2021

305–320 K; improved TTI: 46–60 K; LI: -6 to -2 K; TPW: 45–70 mm; and CAPE: 1500–3500 J/kg.

Near the pressure levels closest to the earth's surface, high relative humidity values are observed. This means that the more moisture near the surface, the better the convection mechanism operates. At the surface pressure levels, heavy precipitation is needed. During the season, negative

divergence data show that dry air is present from the surface to the 600 hPa level. There were more negative VV values in May than there were in April. When substantial vertical velocity estimates are paired with high moisture content, heavy rain is forecast. Specific humidity rises dramatically at the surface, which can be used to detect a moving air mass. At all four locations, the specific humidity parameter values are higher at lower atmospheric pressure levels.

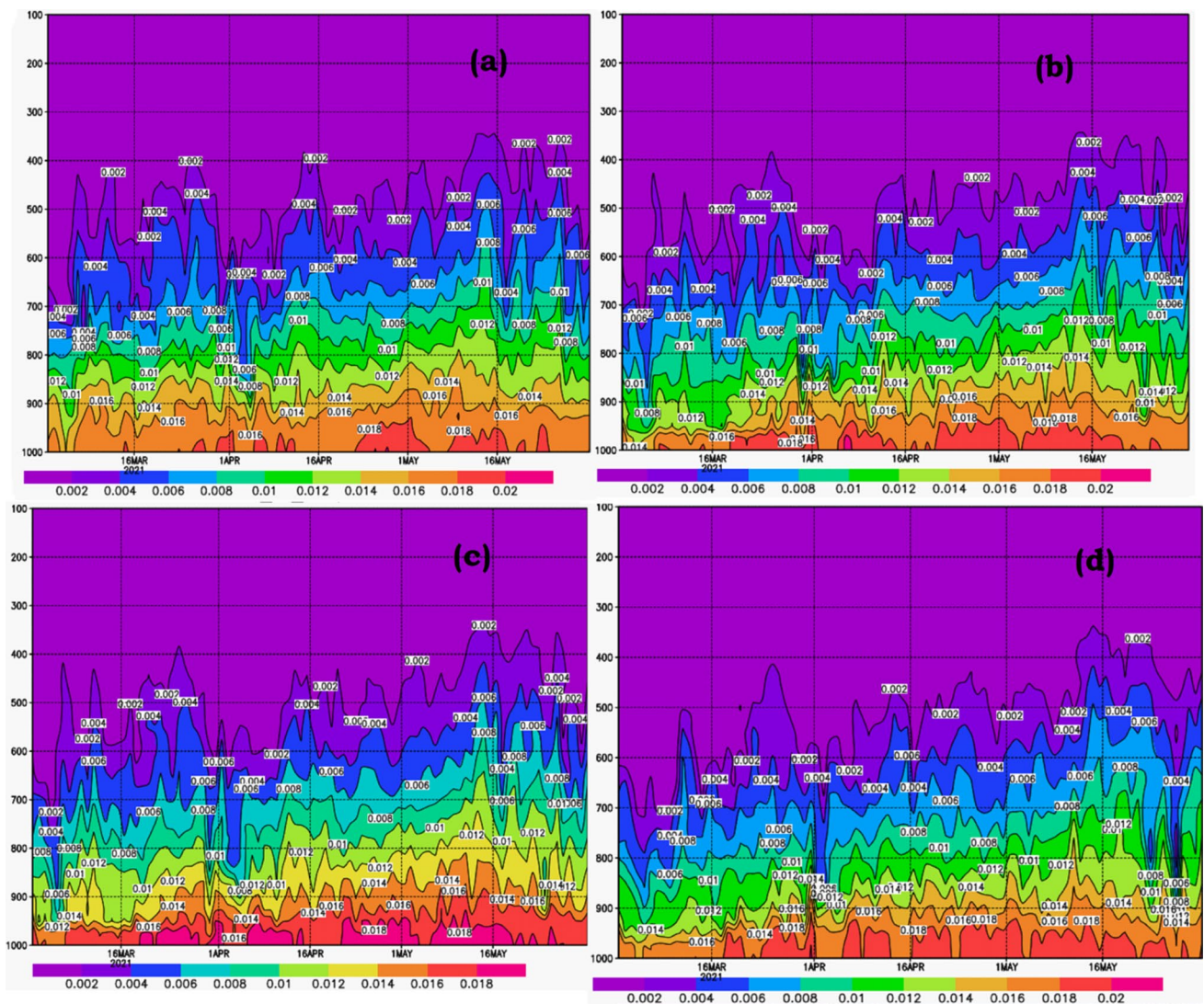


Fig. 16 Time–height sections of a specific humidity over **a** Thiruvananthapuram, **b** Kochi, **c** Alappuzha and **d** Kannur stations during PRMS of 2021

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Declarations

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