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Intrinsic Frequency Components Observed in CAPE over India using EMD and Lomb-Scargle periodogram

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Abstract

Convective available potential energy (CAPE) is one of the indicators of instability of atmospheric convection which develops due to lapse rate and environmental conditions. Convection takes place before monsoon starts and as it is measured in CAPE reaches to maximum value at a place and after monsoon ends CAPE takes minimum value. In this way we have a cycle of convection over the year. In this study we have inspected intrinsic oscillatory frequency components by applying EMD and Lomb-Scargle periodogram (LSP) algorithm in CAPE over Karaikal, Cochin, Mangalore, Chennai, Vishakhapatnam and Mumbai regions in India for a period of 37 years (1980-2016) using radiosonde data. We have observed significant variation of convective activity from one station to another in India. Maximum convection takes place in Karaikal. On applying EMD analysis and LSP algorithm, it is observed that there were two convective activities first activity occurs in the month of April-May and second in the month of Oct-Sep for all stations but for Cochin there were 3 to 4 convective activities. It is also observed that early convection takes place in Cochin starting from March onwards.

1. Introduction

The convective available potential energy (CAPE) is one of the instability indices in the measurement of atmospheric convection. Deep convection in the tropical atmosphere occurs due to the unstable lapse rate can be studied by CAPE. Environmental conditions also plays crucial role in the development of deep convention. Convection feed on the potential energy inherent in the temperature and moisture stratification, the so called CAPE resulting from lifting of the air mass due to thermal instability or some kind of dynamical mechanism. Apart from this there were several complex atmospheric and oceanic process evolving at different time scales might be involved. Globally there is indication of low frequency variability in CAPE reported by Riemann-Campe et al.(2009). Masatsuga and Youshiko (2007) shown that the influence of seasonal auto correlation can not be neglected in their analysis of seasonality of air temperature. Zhang and Chou (1999) studied variability of water vapor, infrared radiative cooling and atmospheric instability for deep convection in the equatorial western pacific. Several studies have been carried out on atmospheric stability indices using radiosonde data sets (Gettlemann et al., 2002). Using high resolution radiosonde data Alappattu and Kunhikrishnan (2009) estimated the CAPE and convective inhibition (CIN) during spring season over the oceanic region surrounding the Indian sub continent. Y.D.Shanti et al., (2014) reported diurnal variation in CAPE using cosmic GPS RO data over Gadanki. Till now there is no clear information of periodicity in convective activity in a year and intrinsic frequency components. In this study we have implemented an adaptive and effective method to process and analyze nonlinear and non stationary data, called empirical mode decomposition (EMD) and found intrinsic mode function (IMF). For each IMF Lomb-Scargle periodogram algorithm is applied to find the periodicity in a signal.

2. Data

The data for this study utilizes CAPE values provided by the radiosonde observations from upper air soundings from the website of university of Wyoming, Department of Atmospheric science (http://weather.uwyo.edu/upperair/sounding.html). This site provides text data for all stations over India for 37 years (1980-2016). The benefit of this approach is that it is based on direct observations of the atmosphere.

3. Methodology

CAPE is the positive buoyancy of an air parcel and is an indicator of atmospheric instability which is useful in predicting severe weather. CAPE is expressed in J/kg and it provides energy to lift the parcel from level of free convection (LFC) to environmental level (EL). CAPE is given by the equation 1,

$$\mathrm{CAPE} = \int_{E}^{L} g\left(\frac{T_p - T_e}{T_e}\right) ------(1)$$

Where Tp is parcel temperature and Te is environmental temperature, g is acceleration due to gravity. As the CAPE data is directly available every day at 00z and 12z UTC in the above mentioned site, the data is collected, daily mean is calculated and missing data is interpolated linearly. Yearly and monthly mean is calculated for the duration. Monthly and yearly mean is calculated for the duration and then subjected to EMD and LSP algorithm.

Empirical mode decomposition (EMD) is an adaptive and data driven multi resolution technique in which multi component wave form is resolved into several components without leaving the time domain. These components referred to as intrinsic mode function (IMF) are expected to be single component in nature. The function IMF is therefore sufficient to describe the signal even though they are not necessarily orthogonal. The reasons are given in Huang et al. for some special data the neighboring components could certainly have sections of data carrying same frequency at different time durations but locally any two components should be orthogonal for all practical purposes.

The EMD steps are:

1. Identify local maxima and minima of a signal S (t).
2. Perform cubic spline interpolation between maximum and minimum to obtain envelops emax(t) and emin(t) and find mean m(t)= (emax(t) + emin(t))/2.
3. Extract intrinsic mode function (IMF), C1 (t) = S (t) – m (t).
4. If the number of local extrema of C1 is equal to or differs from the number of zero crossing by one, and the local average is zero, implies that envelop mean of upper and lower envelop is zero then C1 is the IMF. If C1 does not meet the above condition then repeat steps 1 to 3 on C1 instead of S (t) until C1 obtained satisfies the condition of an IMF.
5. Compute the residue r1= S(t) – C(t), if the residue is above a threshold value of error tolerance then repeat steps 1 to 4 on r1 to obtain IMF and a new residue.

The first IMF consists of highest frequency components of information. The subsequent IMFs contain lower frequencies. If n orthogonal IMFs are obtained in this iterative process the original may be reconstructed as $S(t) = \sum_{i=1}^{N} \mathrm{Ci}(t) + r(t)$

The final residue exhibits any general trends followed by the original. For each IMF obtained LSP algorithm is applied to find the frequency components.

Generally periodograms identify periodicity of a time series signal applying Fourier or least square fitting method. The Lomb-Scargle periodogram is a mathematical tool to find spectral analysis of a time series of unknown periodicities. It is based on least squares technique developed by Lomb and Scargle. In this study we have applied LSP as it has more advantages than other. It is faster as it will not depend on NFFT algorithm and weights unevenly sampled data. LSP provides optimal statistics and detects false alarm probability to asses the significance of a signal with noise

Power spectral Density (PSD) of LSP

Let us consider N data points Xi= Xi (t) collected at times ti where i=1,2,…N, and its mean is Xm. PSD of LSP is given as

$$\mathrm{PN}(\omega) = \frac{1}{2\sigma^2}\left\{\frac{[\sum_i (X_i - X_m)\cos\omega(t_i - \tau)]^2}{\sum_i c\quad {}^2\omega(t_i - \tau)} + \frac{[\sum_i (X_i - X_m)\sin\omega(t_i - \tau)]^2}{\sum_i s\quad {}^2\omega(t_i - \tau)}\right\} ---2$$

Where tau τ is defined as

$$\tau = \left(\frac{1}{2\omega}\right)\tan^{-1}\left[\frac{\sum_i \sin 2\omega(t_i)}{\sum_i \cos 2\omega(t_i)}\right]$$

PN gives the normalized power as a function of angular frequency (ω=2π/P) for all periods (P) tested (Lomb, 1976; Scargle, 1982). The periods were restricted to T= tmax –tmin.

The false alarm probability (p) in LSP is given by $p(P_{max}) = 1 - (1 - e^{-P_{max}})^M$ − − − − 3
Where the variable M depends on the number of data points, their spacing and on the number of independent frequencies tested (Scargle, 1982). In general M can be set equal to N provided that only periods longer than twice the average sampling interval are investigated.

4. Results and discussions

From yearly mean of CAPE of six regions as shown in Fig 1, it is observed that the CAPE values reaches maximum in the month of April for all regions but for Cochin maximum occurs in March. There were two maximums for all regions but there are three maximum for Cochin. The second maximum occurs in Sep to Oct. Maximum convection occurs in Karaikal.

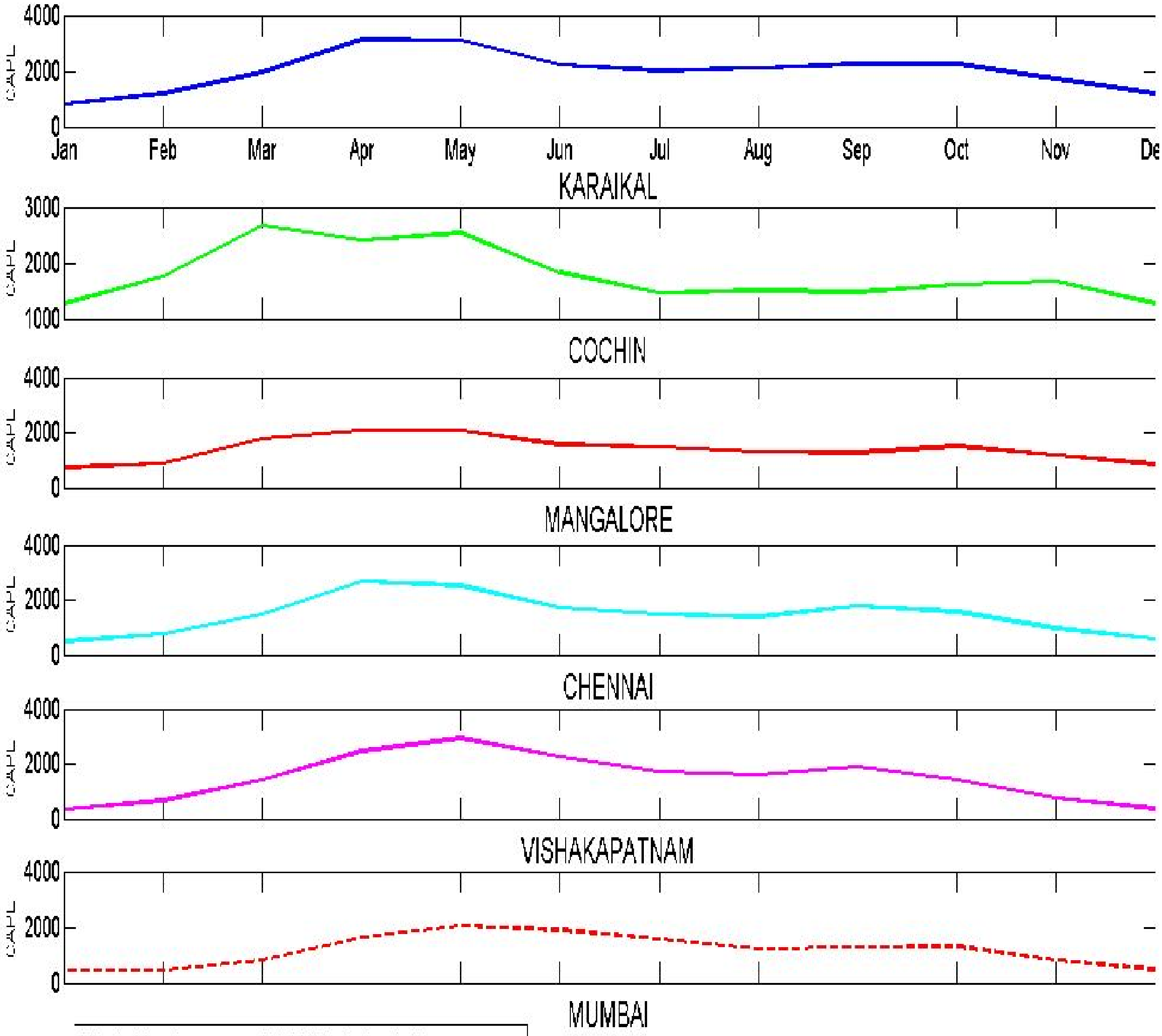

Fig 1: Yearly mean of CAPE of six stations

CAPE data of all the six regions over India during 1980-2016, monthly and yearly mean is calculated and then EMD analysis have been applied and found IMFs of corresponding stations. Here we have considered only two IMFs and their corresponding LSPs. As the first IMF consists of highest frequency components of information along with few lower components and second IMF consists of lower components mixed in the complete signal which are significant at 0.5% confidence level.

The yearly means CAPE are subjected to EMD analysis from which we get first IMFs of six regions Karaikal (A), Cochin (B), Mangalore (C), Chennai (D), Vishakhapatnam (E) and Mumbai(F) and their corresponding power spectral density (a, b, c, d, e and f) on applying LSP are shown in Fig 2. It is observed that all the 5 stations show similar variation in first IMF but Cochin show significant difference from other stations. Even in PSD of LSP of all stations show dominant periodicity of 2 convective cycles per year but for Cochin there were 4 to 5 convective cycles per year at 0.5% significant level.

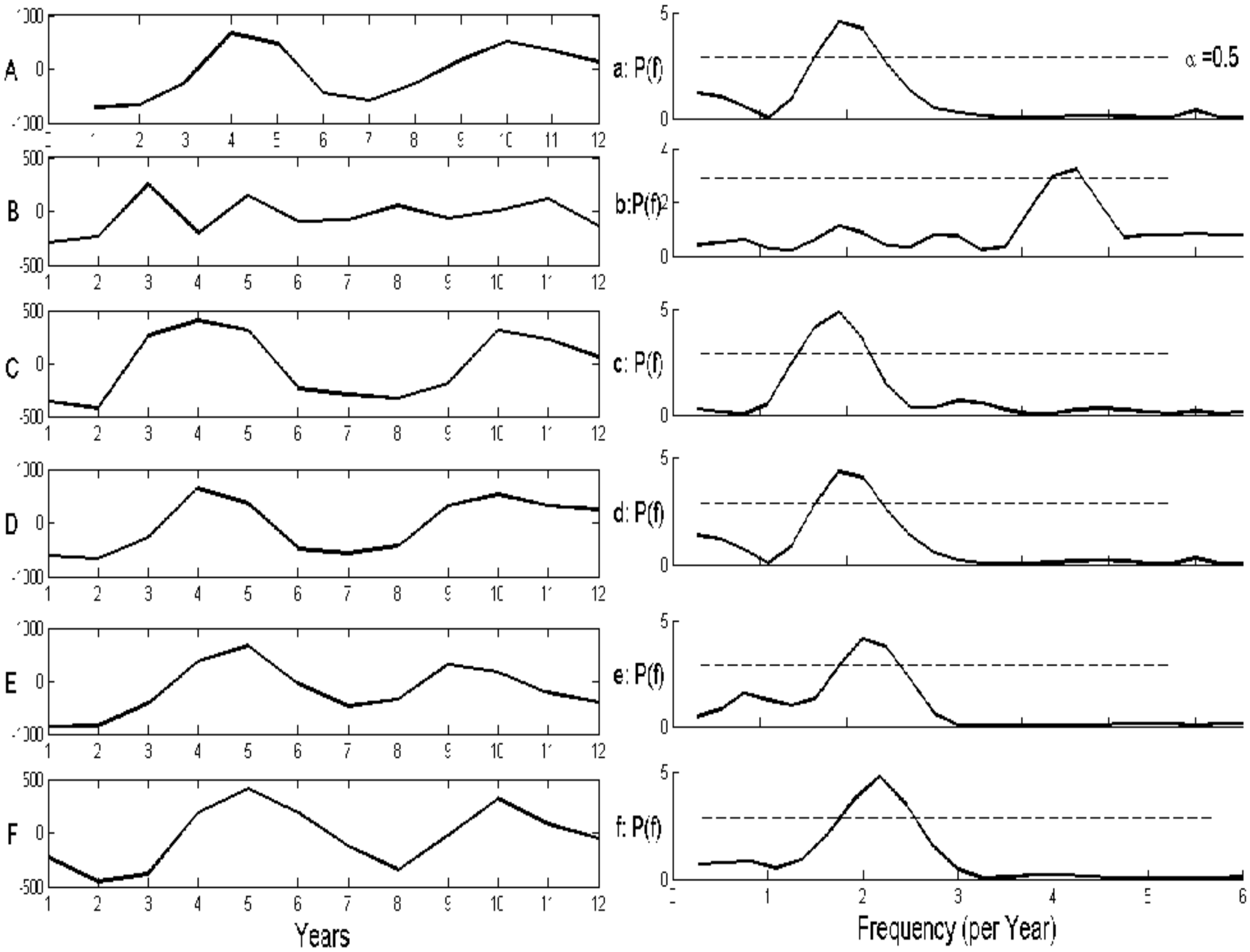

Fig2: A,B,C,D,E,F are First IMFs and a,b,c,d,e,f are corresponding Lomb-Scargle Periodogram

There are intrinsic frequency components were present in CAPE which can be observed in second IMFs of all the stations and their PSDs of LSP as shown in Fig 3. Here we have taken monthly mean for all 37 years (1980-2016) and subjected to EMD and LSP. The first IMF (1A), second IMF (2A) is taken into consideration and their corresponding PSD. Here it clearly shows dominant period in first and second IMFs of all stations except Cochin and Mumbai. Because of decomposition in EMD algorithm it could clearly show the second dominant periodicity after application of LSP and significant difference from one station to another. Cochin show dominant periodicity in both IMFs at the same periods and Mumbai and Mangalore show a broader variation in periodicity. It means that convection occurs for long duration in Mumbai and Mangalore than other stations.

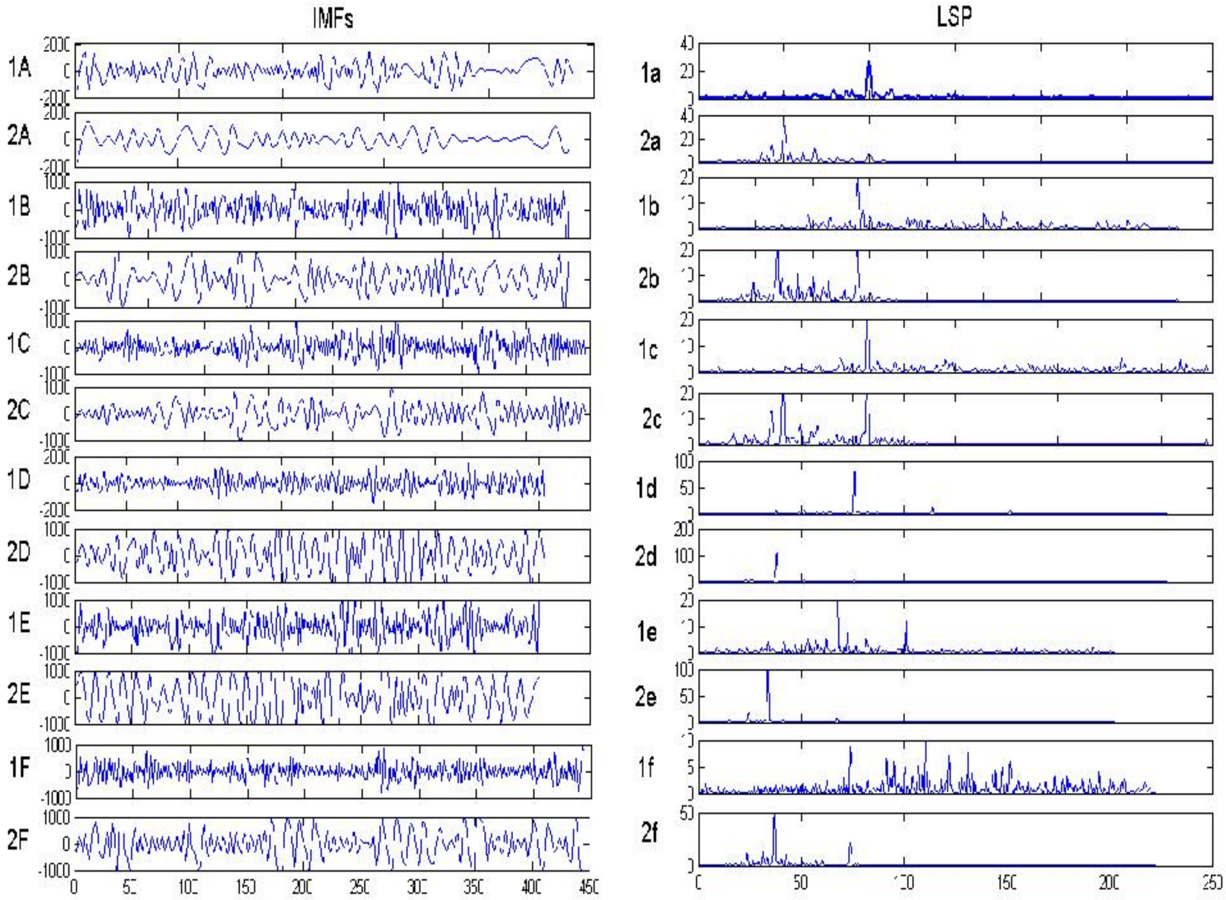

Fig 3: 1,2 with cap case letters corresponds to IMF1 and IMF2 and 1,2 with small case letter corresponds to LSP of their corresponding IMFs, letters corresponds to different Stations

5. Conclusions

There are two convective activities occurs in all regions and Cochin shows more than two. On applying EMD analysis and LSP algorithm, it is observed that there were two convective activities, first occurs in the month of April-May and second in the month of Sep-Oct for all stations but for Cochin there were 3 to 4 convective activities. It is also observed that early convection takes place in Cochin starting from March onwards. The long periodicity is observed in Mumbai and Mangalore regions from PSD of first IMFs. Because of EMD and LSP algorithm it clearly shows dominant periodicity in first and second IMFs. This mean there are intrinsic frequency components present in CAPE.

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