Analytical evidence for deep ocean warming trend in tropical Indian Ocean

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Abstract. The present climate change has a warming impact on the Earth’s climate system, hence called as global warming. Study about oceans is relevant to the current scenario of changing climate and many studies show significant warming trends in the Sea Surface Temperature (SST) in the ocean during the past several decades. Extensive warming is found in deeper layers of oceans too. In this study, the monthly mean deep ocean temperature data which was spatially averaged over the tropical Indian Ocean (IO) during the period 1950 to 2012 was subjected to a statistical EMD analysis to estimate the impact of warming to deeper IO. The temperature signal is decomposed into components called as Intrinsic Mode Functions (IMFs) along with a residual part. The IMFs represent the temperature fluctuations resulting from inter-annual oscillations such as ENSO (El-Nino Southern Oscillation) and the residual part can be considered as the long-term trend. The IMFs obtained at each depth showed variabilities in QBO, ENSO and tidal frequencies. Residual part of the signal too had significant magnitudes, indicating the impact of global warming signals at deeper oceans.

1. Introduction

Due to high heat capacity and vastness, oceans are huge reservoirs of heat and thereby play a crucial role in maintaining climate and life on Earth. However, gradual changes in ocean state can have a significant impact on the Earth’s climate. As an impact of global warming, the ocean temperature during the second half of the 20th century showed a gradual increasing trend, which is believed to be the reason for climate anomalies felt around the globe [1]. Levitus et al. [2] has shown that the world ocean is responsible for approximately 84% of the possible total increase of Earth’s heat content for the past 40 years. The studies conducted by Alory et al. [3] and Levitus et al. [2] on ocean warming have highlighted the warming in Indian Ocean(IO) particularly, and proposed a mechanism for the penetration of warming signals deeper into the oceans. They further demonstrated that the warming has unique vertical patterns in the Indian and Pacific Oceans, with increased warming rates at deeper ocean depths.

Unlike Pacific, IO is greatly influenced by seasonally reversing winds and associated oceanographic processes. Inter-annual processes such as Indian Ocean Dipole (IOD) [4] and El-Nino Southern Oscillation (ENSO) are the two prominent forms of inter-annual variability that introduce additional variabilities at lower frequencies. Evidence for inter-annual warming anomalies is identified
in the surface temperatures in IO [4][5]. Recent studies show that temperature variability is not restricted to upper surface layers alone, but penetrates to sub-surface layers too [5][6][7][8][9]. Processes such as solar heating, radiative heat loss, currents, wave breaking, convective mixing etc. decide the fate of the surface layer, called as Ocean Mixed Layer (OML) [7][10]. The increased surface layer turbulence is found to have a role in the increased deep ocean warming during the 21st century [11].

In this paper, temperature data for deeper layers of tropical Indian Ocean was analysed to identify the extent of warming signals at deeper oceanic depths. Advanced data analysis is a necessary part in research to unravel hidden signals from large data sets. Here, the data was subjected to Empirical Mode Decomposition (EMD) analysis [12], which is a statistical data analysis tool in which the signal is broken down into various components within the time domain, usually done for natural signals, such as meteorological and oceanographic data, that are non-linear and non-stationary. The decomposition method is adaptive and therefore highly efficient. The components of the EMD are called as Intrinsic Mode Functions (IMFs) and the remaining is considered as a residue. These IMFs produce instantaneous frequencies as functions of time when coupled with Hilbert transforms, which provide an identification of embedded structures [13] and hence represent physical processes that contribute to the observed variability in the data.

Natural processes mostly have multiple causes, and each one of these causes may happen at particular intervals. Thus obtaining IMFs which reveals the local character of the original data is useful. However the process of obtaining IMFs from data signals has following constraints:

- The number of extrema and the number of zero crossings must be equal or utmost one.
- The mean value of the extrema envelopes should be zero.

The EMD tool adopted in this study and its step-by-step process is explained in the next section. Assuming that any data may consist of different IMFs, every IMF component has a unique local frequency. Each mode function consists of information regarding how the frequency of the original signal varies with time. The implementation of EMD in this study hypothesize that the oceans are getting heated at the surface and the heat is being penetrated or transported down into the deeper oceans. EMD analysis thus helps to extract individual IMFs representing oceanic processes such as Quasi-biennial oscillations (QBO), ENSO (El-Nino Southern Oscillation) etc. QBO is the oscillation with a period of 2-4 years observed in the high level winds over the equator that are steered by atmospheric waves. ENSO describes fluctuations in the state of ocean and atmosphere (temperature, pressure, wind etc) in the east-central equatorial pacific region, comprising of two opposite phases known as El-Nino and La-Nina, with a periodicity of 4-10 years. Sunspots are temporary phenomena on the Sun’s photosphere that appear as spots darker than the surrounding areas and have a period of around eleven years. Tidal force is responsible for the fluctuations of sea level and currents in the ocean due to the gravitational pull among Earth, Sun and Moon. In addition to the variability at diurnal and semi-diurnal periods, tidal force also undergoes oscillations at higher periods of about 24 years [14][15], which is being studied here for its influence in the warming signals. EMD analysis has been applied in many areas and is found to be a valuable tool in data analysis [16, 17].

In this study, we perform the EMD analysis on ocean temperature data to confirm and elaborate the findings on global warming trend in the tropical IO. Previous studies produced only estimates of long term trends and did not attempt to separate the contributions from inter-annual forcing. The trends estimated in these studies were estimated from the raw data without any kind of filtering, so as to acquire all the available frequencies in the data for the decomposition process. Here we quantify the contribution of each inter-annual forcing to the total variability and its depth of influence. The residual part of the signal which represents the trend is free of high frequency oscillations and is therefore more realistic. Also, local regression is performed on the data, in order to substantiate the residue trend obtained in EMD.

2. Data and Methodology
The 1°x1° gridded monthly surface temperature data of IO (30° S to 30° N, 40° E to 120° E) is obtained from International Comprehensive Ocean-Atmosphere Data Set (ICOADS) for the years 1960-2011.
The 1×1 gridded monthly subsurface and deep ocean temperature data of IO (30° S to 30° N, 40° E to 120° E) for the period 1950-2012 is obtained from the version 4 of the Met Office Hadley Centre EN series of data sets of global quality controlled ocean temperature and monthly objective analyses [18]. The deep ocean temperature data was selected at depths 5m, 25m, 98m, 235m, 540m and 967m. The data was spatially averaged over each month, hence converted into a time series data. The EMD analysis is then implemented using the R package called EMD that performs the one and two dimensional EMD [19].

Figure 1 is a flowchart of the processes involved in EMD analysis. Since a signal may involve more than one oscillatory mode, and assuming that the data consists of different simple IMFs, EMD is developed to decompose the signal \( x(t) \) into IMF components as follows [12, 20]:

(i) Identify all the maxima and minima of \( x(t) \).
(ii) Generate its upper and lower envelopes, \( x_{up}(t) \) and \( x_{low}(t) \).
(iii) Compute the local mean: \( m(t) = (x_{up} + x_{low})/2 \).
(iv) Extract: \( g(t) = x(t) - m(t) \).
(v) Check whether \( g(t) \) is an IMF or not.
   (a) If \( g(t) \) is an IMF, extract IMF and replace \( x(t) \) with the residual \( r(t) = x(t) - g(t) \).
   (b) If \( g(t) \) is not an IMF, further sifting is done with \( x(t) = g(t) \).
(vi) Repeat steps i-v until the residue satisfies either of the following stopping criteria:
   (a) Exceeds the predefined maximum number.
   (b) \( |r(t)| < tol \), where \( tol \) is the tolerance level of sifting process.
   (c) \( \sum_t \left( \frac{r(t) - r_{t-1}(t)}{r_{t-1}(t)} \right)^2 < tol \)

This filtering process also known as sifting will continue until the sieved data shows no oscillations and no more IMFs can be derived. Final output of EMD as IMFs of the data is used to visualize, if any, variations in the deep ocean temperature of the mixed layers of IO at 7 depths. These IMFs are also representations of various oceanic processes which help in better interpretations of the graphs. For this purpose, the periodicity of each IMF is calculated by dividing the number of years by total number of peaks in the IMF.

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**Figure 1.** Flowchart of the proposed method (EMD). The initial signal \( x(t) \) undergoes the process and the IMF signal \( g(t) \) is obtained as output.
3. Results and Discussions

3.1. Spatial trend of deep ocean warming:

Figs.2(a-f) represent the trends of annual deep ocean temperatures of IO during 1950-2011 at selected depths. The long term variations of ocean temperature at 5m (Fig 2(a)) show both increasing and decreasing trends. Warming trends are found at coastal areas near to land masses (northern Arabian Sea, eastern Bay of Bengal (BoB) and west of Madagascar). Maximum warming trend of 0.16°C/decade is found at the eastern and south-western IO. Large areas of cooling trend with higher magnitudes were also noticed at western IO and also at south of equator. The Southern IO (SIO) shows a consistent warming trend in many depths.

At 25m (Fig.2(b)), the temperature trends have a close similarity with that at 5m. However magnitudes of positive trends at 25m were higher than that at 5m. High magnitudes are found at northern Arabian Sea and at eastern BoB. Three warming pockets are located close to the coastal areas of Somalia, eastern coast of India and Indonesia and parts of south-western IO regions. The positive and negative trends at South show consistency with 5m. This feature was found to be similar with the findings of Pai et al. [9], Rao et al. [21] and Roxy et al. [22].

![Figure 2](image-url)  
**Figure 2.** Spatial variation of temperatures (°C per decade) in the IO, at various depths ranging from 5m-967m, the red shades indicating warm regions and blue shades indicating cold regions.

At 98m (Fig.2(c)), vast areas of warming is found at SIO and a cooling trend at the western and equatorial IO. This cooling trend is not cogent with the trend at depths above and produce different sign of trends in the vertical [9]. In all the depths from 5m to 235m (Figs.2(a-d)), a consistent anomalous heating is observed in the northern waters of Madagascar, with a high warming rate.

At 235m (Fig.2(d)), areas along the eastern coast of Indian sub-continent and another at the farthest regions of western IO do reveal mild amounts of isolated cooling which is in agreement with the observations of Alory et al. [3]. At depth of 540m (Fig.2(e)), the warming is not so evident and do not advocates any considerable amount of warming or cooling. Hence it can be said that the warming trend do not penetrate deeper than 500m in IO. In Fig.2(f), the temperature trend is almost uniform in the whole of IO, though at 967m the waters of NIO show a moderate warming and a cooling trend over the SIO waters.
3.2. EMD analysis of monthly deep ocean temperature:
EMD analysis was performed on monthly mean temperature data averaged over 30° N – 30° S, 40° - 120° E at selected depths (0m, 5m, 25m, 98m, 235m, 540m, 967m). After the extraction of available IMFs, the remaining part is considered as residue that can be interpreted as long-term trend of the ocean temperature. The local regression trend of the data is also plotted along with the data signal in the EMD analysis figures.

3.2.1. At surface: Fig.3 depicts the original signal and IMFs corresponding to the surface temperature of IO. IMF1 has a time period of around 6 months which depicts the seasonal variations of temperature. The second IMF shows seasonal variations of around 1 year, possessing higher variance than the previous IMF. IMF3 and IMF4 project a time period of around 2-4 years, similar to that of a QBO cycle. IMF5 with an average period of 8.4 years depicts the presence of an ENSO cycle at the surface. From the residue plot, a long term trend in surface temperature is evident. The temperature has increased from about 27.53°C in 1960 to 28.24°C in 2011 with a rate of increase of 0.13°C per decade. This observation is in agreement with the warming rate obtained in previous studies [9, 21].

![Figure 3. IMFs obtained after EMD analysis of temperature data of IO at the surface. The final graph represents the residue temperature variation.](image-url)
3.2.2. At 5m depth: Fig.4 depicts the IMFs corresponding to the deep ocean temperature at 5m depth. IMF1 shows semi-annual seasonal variations at this depth. IMF2 and IMF3 show variations of lower frequencies with 1.06 and 1.84 time periods. IMF4 can be considered as a clear representation of QBO with period 3.68 years. IMF5 signal corresponds to ENSO signal with a period of 7.82 years. The residue plot of temperature at 5m depth reveals that the temperature trend has swept down to deeper layers also. An increase of 0.21°C was noticed in temperature for the period 1950-2011 at a rate of 0.03°C per decade which is less than that observed at surface.

**Figure 4.** IMFs obtained after EMD analysis of temperature data of IO at 5m depth. The final graph represents the residue temperature variation.
3.2.3. At 25m depth: In Fig. 5, QBO signal, as the highest frequency oscillation, is observed in IMF$_3$, followed by ENSO cycle in IMF$_4$, sunspot cycle in IMF$_5$ and tidal cycle in IMF$_6$. The residue plot dictates a positive temperature trend in the mixed layers of IO, in which a monotonic increase in the temperature was found until 1990s and followed by nearly constant temperature. The rate of temperature increase till 1990 is found to be 0.09°C per decade. But for the 62-year period under consideration, this depth has undergone a temperature increase of 0.05°C per decade. Hence the magnitude of warming rate is less than the surface warming.

Figure 5. IMFs obtained after EMD analysis of temperature data of IO at 25m depth. The final graph represents the residue temperature variation.
3.2.4. At 98m depth: At 98m depth, higher IMFs become prominent. IMF$_1$ to IMF$_3$ exhibit semi-annual seasonal variations. QBO signal is found with the largest variance in this depth observed in IMF$_4$. An ENSO cycle of 4.17 years is observed again in IMF$_5$ (Fig.6). Sunspot (8.94 years) and tidal force (20.86 years) variabilities are reflected in the IMFs 6 and 7 respectively. At 98m depth, the long term temperature trend showed an increase from 21.59°C to above 21.79°C. The warming rate is found to be 0.03°C per decade. Thus the warming signals extent to move further into deeper layers of ocean since 1960s, which supports the study of Krishna et al. [5], stating that there are warm pockets of temperature in the central Arabian Sea and Equatorial IO in this depth.

Figure 6. IMFs obtained after EMD analysis of temperature data of IO at 98m depth. The final graph represents the residue temperature variation.
3.2.5. At 235m depth: IMF₄ shows a QBO cycle of 2.5 years, IMF₅ shows an ENSO cycle (4.47 years) and IMF₆ can be a sunspot cycle (8.94 years) in Fig.7. However, these signals tend to have lesser magnitudes as we go deep down the ocean layers. The residual signal at 235m depth showed a different pattern as compared with other depths. Instead of having a long term trend, it has a cyclic variability with a period of 50-60 years.

Figure 7. IMFs obtained after EMD analysis of temperature data of IO at 235m depth. The final graph represents the residue temperature variation.
3.2.6. At 540m depth: QBO is represented in IMF_4 (2.41 years), ENSO in IMF_5 with a cycle period of 4.81 years and sunspot signal with a mean period of 8.94 years in IMF_6, shown in Fig 8. At this depth, there is a steady increasing temperature trend since the beginning of 1970s and this trend reached its maximum at 9.67°C in 2011. The rate of warming is found to be of magnitude 0.006°C per decade.

![Figure 8. IMFs obtained after EMD analysis of temperature data of IO at 540m depth. The final graph represents the residue temperature variation.](image-url)
3.2.7. At 967m depth: At this depth, the QBO, ENSO and sunspot variabilities are still visible in IMFs 4, 5 and 6 respectively. However, the EMD analysis suggests only a weak signal of warming trend at this depth (visible from the temperature range of IMFs), from which it can be concluded that the depth of global warming is limited to depths below 1000m for Indian Ocean. Moreover we observe a 0.01°C decrease in the long-term temperature trend.

![Figure 9. IMFs obtained after EMD analysis of temperature data of IO at 967m depth. The final graph represents the residue temperature variation.](image)

Hence comparing the IMFs at all depths, it can be said that the first and second IMFs for each depth represents the semi-annual seasonal variations. The third or fourth IMFs can be related to the QBO signal which has a cycle period of around 2.5 years. The fifth IMF, representing ENSO variability of 4-10 years cycle period is identified at all depths. Higher period of variabilities in the temperature data can be attributed to sunspot and tidal frequencies with periods 11 and 22 years respectively. Though all the four modes of variabilities are visible at each depth, there is a general decrease in their magnitudes with depth.

The residual part of the signal, representing the warming trend, showed an increasing trend in the deep ocean temperatures especially at surface, 5m, 25m, 98m and 235m. At higher depths, the temperature trend is weaker, indicating the absence of global warming impact. The high variabilities in some IMFs can be attributed to the corresponding anomalous temperature variations and changes occurring to the ocean circulations due to various anthropogenic as well as natural forcing.
3.3. IMF Statistics and Analysis:

Table 1. Time period T (in years) of IMFs and their variance (in percentage).

|       | IMF 1   | IMF 2   | IMF 3   | IMF 4   | IMF 5   | IMF 6   | IMF 7  |
|-------|---------|---------|---------|---------|---------|---------|--------|
| T     | T       | T       | T       | T       | T       | T       | T      |
| VAR%  | VAR%    | VAR%    | VAR%    | VAR%    | VAR%    | VAR%    | VAR%   |
| SURFACE | 0.49 | 52.12 | 0.99 | 41.14 | 2.1 | 1.89 | 3.89 | 1.92 | 8.42 | 1.51 | 16.83 | 0.35 | - | - |
| 5m     | 0.51 | 40.52 | 1.06 | 58.04 | 1.84 | 5.86 | 3.68 | 3.58 | 7.82 | 2.44 | 15.65 | 1.94 | 62.58 | 0.59 |
| 25m    | 0.49 | 43.52 | 1.12 | 53.31 | 2.16 | 5.78 | 4.47 | 1.89 | 12.52 | 1.34 | 20.86 | 0.6 | - | - |
| 98m    | 0.26 | 15.83 | 0.55 | 14.38 | 1.1 | 15.08 | 2.24 | 24.72 | 4.17 | 29.45 | 8.94 | 12.15 | 20.86 | 8.73 |
| 235m   | 0.27 | 14.55 | 0.65 | 23.44 | 1.2 | 12.75 | 2.5 | 16.88 | 4.47 | 8.59 | 8.94 | 11.07 | 20.86 | 2.04 |
| 540m   | 0.27 | 9.45 | 0.66 | 19.51 | 1.25 | 15.3 | 2.41 | 10.28 | 4.81 | 11.58 | 8.94 | 10.23 | 20.86 | 28.11 |
| 967m   | 0.28 | 8.5 | 0.75 | 28.54 | 1.36 | 10.24 | 2.72 | 10.95 | 4.81 | 17.08 | 8.94 | 24.69 | 15.65 | 3.46 |

The variance and time period of all IMFs were estimated at all depths (Table 1). It helps to quantify the contribution of each IMF to the observed variability in deep ocean temperatures. The depth-averaged time periods of the four IMFs are 0.37, 0.83, 1.57, 3.13, 6.72, 12.73 and 28.16 years that corresponds to semi-annual and seasonal variations, and also physical processes such as QBO, ENSO, Sunspot and tidal activities. IMFs showed a good consistency in their periodicities with depth. In general, in most of the depths, the first three IMFs depict signals of seasonal variations of high frequencies. Another observation is that IMFs 1&2 dominates (40-58%) to the total variability in temperature, up to 25m depth. But from 98m onwards, IMFs 4-7 are the dominating signals (10-30%). The sunspot (IMF 3) has a lesser contribution of 0.3-12% and the tidal forcing has the weakest contribution among the four IMFs. All IMFs are having slowly varying amplitudes and hence these are narrow-band processes [14]. This analysis only indicates the contribution of each IMF to the total variability at each depth independently but does not give a comparison between depths.

Table 2. Correlation of surface IMFs with other IMFs at each depth.

|       |       | IMF 1     | IMF 2     | IMF 3     | IMF 4     | IMF 5     | IMF 6   |
|-------|-------|-----------|-----------|-----------|-----------|-----------|--------|
| T     | T     | T         | T         | T         | T         | T        | T      |
| Data  | 5m    | -0.047499729 | 0.229672203 | -0.203009738 | 0.222939942 | -0.271261727 | -0.005233144 | 0.134505389 |
|       | 25m   | -0.048098981 | 0.21749811 | -0.222490192 | 0.106471633 | -0.162098662 | 0.124589887 | 0.339256346 |
|       | 98m   | 0.136833101 | -0.014683222 | 0.226357977 | 0.024027505 | -0.143196095 | 0.035856916 | 0.165377559 |
|       | 235m  | 0.069092892 | -0.030741272 | 0.027007978 | 0.002389308 | -0.000487016 | 0.144496852 | -0.034142666 |
|       | 540m  | -0.115711543 | -0.12098298 | -0.160018222 | -0.210420743 | -0.227243069 | 0.139555126 | 0.199940442 |
|       | 967m  | -0.320139859 | -0.1393127 | -0.559064537 | 0.02294529 | 0.008483613 | -0.124921155 | 0.23576486 |

In Table 2, the correlations of the data and IMFs of the surface ocean are compared with the data and IMFs of other depths. The correlation of each IMF is at each depth with the corresponding surface IMF is calculated. Correlation matrices are obtained for each IMF at other 6 depths and are compared with the surface (0m) IMFs. Comparing the values for IMF 1, the correlation with surface is high for 5m and 25m depth. Hence, it can be inferred that these seasonal oscillations are prominent only up to 25m. IMF 2 shows maximum value at 235m and IMF 1 only up to 5m. Whereas the QBO related mode IMF 4 shows the maximum relation with surface IMF at 967m depth. The value leads at 235m for IMF 5 with a correlation of 0.1444, showing the dominance of ENSO up to the respective depth. The tidal forcing is observed up to 25m in IMF 6.
3.4. Trend Analysis of deep ocean warming in the selected depths:

![Temperature trend plots](image)

**Figure 10:** Anomaly of residue temperatures (°C) obtained after retrieving all the IMFs in EMD are plotted against time (in months), in all 7 depths. These anomaly residue plots can be considered as the temperature trend.

As a supporting evidence for the spatial trend analysis in deep ocean temperatures (Figs 2(a-f)), the residue temperatures against time were combined for all depths (Fig.10) and studied. At 5m depth, the temperature trend is evidently showing a gradual increase of 0.2°C within the 62 year period. Further moving down to 25m depth, a similar increasing trend is seen till 1990, reaches a peak of 26.80°C, and thereafter shows a decline. In this depth, the temperature has risen by 0.39°C during the first 40 years (1950-90). Moving to 98m, the temperature remains steady at 21.59°C during 1950-60, rises afterwards and reaches 21.79°C by 2012.

At 235m, the trend has a cyclic nature with two peaks observed at years 1976 and 2012. The oscillation of temperature may indicate the presence of another IMF but has not been resolved by the EMD. The removal of this signal only can provide information on the temperature trend. At 540m, the amplitude of the trend is very less, though the trend is an increasing one from 9.63°C to 9.67°C. After reaching the maximum at 1996, the temperature shows a decrease till 2012. Just above 1000m, the temperature doesn’t show much change and remain steady at about 6.14°C.

For a comparison, the residue temperatures are plotted together against time (Fig.10). The figure shows an evident increase in the ocean temperature not only for the surface but for depths up to 98m.
also. It should be noted that the deep ocean temperatures below the depth of 98m are gradually moving towards a rising trend, which is to be investigated further for the causes and effects.

3.5. Discussions
Previous studies showed that the inter-annual temperature variability (especially in SST) in IO is contributed mainly by ENSO and IOD. In the present study, the deep ocean temperature data that was spatially averaged for the Indian Ocean was subjected to a statistical EMD analysis. Analytical results showed the presence of ENSO signals even up to 1000m. EMD analysis at 6 different depths within the 1000m water column resolved contributions from other oscillations such as seasonal, QBO, Sunspot and Tidal. Among the seven, IMFs corresponding to QBO and ENSO dominated in contribution to the total variability at all depths. The temperature trend (residual part) has a significant warming phase up to 300m, indicating the penetration of global warming signals. Thus, deeper layers of oceans are becoming exposed to the temperature variations and can start to affect the Earth’s ecosystem.

Ocean is always in a dynamic state. Surface and subsurface currents, eddies, convection, up-welling and downwelling, waves and several other forms of motion circulates the ocean water globally and thereby mixing up the heat into different layers of ocean waters. As the easterlies and westerlies blow above the ocean surface, the upper ocean moves as in the Ekman transport. This mechanism drives the water perpendicular to the wind to form upwelling and downwelling. Both anthropogenic and natural forcing result in wind anomalies over the equator, which reduce the wind speed, thereby lead to warmer SST in the equatorial western basin [23].

4. Conclusion
The statistical evidence procured through a thorough probing on deep ocean temperature data of Indian Ocean for the period 1950-2012, shows warming signal in deeper layers too. In addition to the existent concern of surface warming, the aforementioned issue also paves way to visible changes in Indian Monsoon patterns and climate anomalies on a global scale.

However the reasons behind the dominance of certain IMFs limiting to certain depths alone have to be looked into. The causes and effects of these observed patterns are still an open problem, providing a scope for further research in this area. Despite the fact that many explanations have been given for the specified areas of the study, a viable explanation has not yet been drawn.

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