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Wavelet Analysis of Winter Rainfall Variability over Victoria

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Authors' contributions

This work was carried out in collaboration between all authors. Author BAU designed the study and wrote the final manuscript. Author SUR supervise the study. Authors AJK and SAH reviewed the literature. Author KK performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SSZ and TAS performed the literature review and assisted to wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This study employ Wavelet analysis to investigate the winter (May-Aug) rainfall variability with respect to the intensity of Indian Ocean Subtropical High Pressure (IOSHPS) System and its longitude, Indian Ocean Subtropical High Longitudes (IOSHLN), positions. The physical relationship among these predictors and winter rainfall were analyzed using composites of atmospheric circulation patterns. We have found inverse association between IOSH indices and winter rainfall. We have observed that maximum rainfall variability occurred in 1-3 years periodicity during 1951-1979 when IOSHPS was located around Southern Australia. This caused moisture onshore and Victoria received more rainfall. We have also observed that highest variability from 1980-2016 with

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similar periodicity in IOSHPS. The shifting of IOSHPS from Southern to Southeastern Australia and increase in its intensity from the post 1979 period of the analysis era (1951-2016) cause further declined in winter rainfall over Victoria.

Keywords: Periodicity; Indian Ocean subtropical high pressure; atmospheric circulations; moisture and variability; wavelet analysis.

1. INTRODUCTION

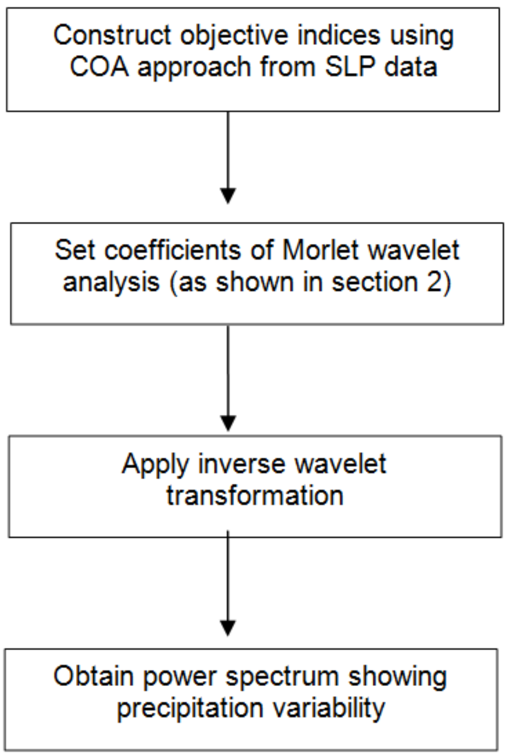
Victoria ($141^{\circ}E\ to\ 150^{\circ}E, 36^{\circ}S\ to\ 40^{\circ}S$) is a densely populated and second-most populous state situated in southeast of Australia. It receives most of its rainfall during the winter (May-August) season which is also known as the cool season. Rainfall remains highly variable, and a declining trend in rainfall is observed in this season, while summer remains warm and dry. Due to dry weather in summer, bushfires events are common in the state [1]. There are many large scale climate drivers associated with this decline. Ummenhofer et al. [2] found the severe dry conditions over Victoria associated with Indian Ocean Dipole (IOD). (Cai et al. [3] analyzed the recession in autumn rainfall over Victoria and found about 40 percent recession in the long term average rainfall (1956-2006). Further investigations revealed ENSO events also contributed to this recession phenomenon. (Chiew et al. [4] investigated the average streamflow over southeast Australia and found that the reduction is associated with El-Nino southern oscillation (ENSO). Doe et al. [5] suggests that the forecasting of Standardized Precipitation Index (SPI) which is an acceptable statistical metric for drought assessment can support in decision-making for agriculture, water demand and management, pricing and policy for handling the risks connected with the evolution of a current drought in the future. Hope et al. [6] investigated the drought conditions over South Australia and found the drought would continue over Tasmania. Pepler et al. [7] examined severe low sea level pressure patterns (1950-2008) and revealed the Eastern Seaboard of Australia may influence extreme climate situations and coastal erosion. Landvogt et al. [8] investigated the trends in rainfall (2000 to 2005) over the northeastern Alps of Victoria and found rainfall increases with terrain elevation. They further revealed that the fronts contribute to most of the winter rainfall while cold lows are responsible for summer rainfall in the region. Kiem et al. [9] analyzed the pattern of rainfall and found that the increase in subtropical ridge intensity and its southward propagation during post-1993 caused decline in winter rainfall over Victoria. Further analysis revealed that the effect of southern annular mode (SAM) is dominated than ENSO with this decline. Poleward movements of subtropical ridge over the Australia during winter caused rainfalls over Western Australia (WA), South Australia (SA) and most parts of the Victoria [10]. Hameed et al. [11] applied COA and found associations between IOSH and the decline in Southwest Western Australia winter (May-August) rainfall. Rehman et al. [12] also used this method and found relationship between IOSH and winter (May-August) streamflow over Southwest Western Australia. Rehman et al. [13] further improved the method and found more improved results than previous studies over COA. They showed winter (May-August) streamflow over Snug River catchment, Tasmania and Acheron River catchment, Victoria association with IOSH indices respectively.

The review of literature presented above suggests designing a study to investigate the decline in winter rainfall over Victoria region and the impact of dominant predictors that are causing the decline. The objective of this work is to find periodicities in winter rainfall over Victoria, Australia on the basis of wavelet transform analysis and to explore the association of these periodicities with the indices of Indian Ocean Subtropical High Pressure (IOSHPS).

2. DATA DESCRIPTION AND METHODOLOGY

The monthly total rainfall and gridded monthly rainfall data set (0.05 by 0.05) over Victoria was obtained from the Bureau of Metrology of Australia. The monthly mean sea level pressure (MSLP) data set (2.5 by 2.5) for winter (MJJA) was used to calculate IOSH indices (IOSHPS and IOSHLN) and then the obtained indices were used for wavelet analysis and to construct MSLP composite fields. The mathematical form of this concept is deduced by [11] which is known as center of action approach (COA).

We have adapted the method used by Rehman, et al. [14] to MSLP data over the domain ($82.5^{\circ}to137.5^{\circ}E, 10^{\circ}to50^{\circ}S$) of Indian Ocean and obtained the two objective indices of IOSH (IOSHPS and IOSHLN). We have used wavelet analysis method to both winter (May-August) rainfall over Victoria and obtained IOSH indices respectively. Wavelet transform is useful technique to analyze time series with variable variance (non-stationary) and provide output in both frequency and time domains. It also provides information about the amplitude of periodicity according to the time domain within time series. We have used morlet as mother wavelet (n = 6) and scale $s_0 = \frac{1}{3}$, sampling time $dt = 0.25$, discrete scale $dj = 0.05$ and lag 1 = 0.72 for red noise. The flowchart of methodology is shown in the pictorial representation below.



Pictorial representation of methodology used in the study

3. RESULTS AND DISCUSSION

In this section, we have discussed the observed relationship between Indian Ocean Subtropical High Pressure (IOSHPS) and average rainfall over the districts of the state.

This section of the study provides discussion and the justification of the relationship between winter rainfall over Victoria and IOSH indices. The arrangement of the figs. in this study listed as Figs. 1(a)-3(a) show the time series of winter rainfall anomalies over Victoria and IOSH indices (IOSHPS and IOSHLN) respectively.

Black contour lines in wavelet power spectrums show 95% significant area which enclosed red region. Figs. 1(c)-3(c) show the average variance (1-3 years) in the time series and blue dashed line characterize the 95% significance level.

We have observed 1-3 years periodicity in winter rainfall over Victoria from 1978 to 1983 and 1993 to 1998 at 95% level of significance (Fig.1. (b) and Fig. 1. (c). The Global Wavelet Spectrum (GWS) showed that the power of these periodicities at 95% significance level (Fig. 1 (c). We have also noticed two more periodicities in winter rainfall before 1970s but these were just approached the significance level (Fig. 1(d). We have observed two main periodicities in IOSHLN (Figs. 2(b)-2(d) from 1952 to 1958 and 1972 to 1988 which were significant. The frequency of these periodicities caused winter rainfall to decrease before 1970s (Fig. 1(c). There were two periodicities (1-3 years) from 1992 to 1998 and 2006 to 2010 observed in IOSHPS (Figs. 3(b)-3(d). These periodicities also caused winter rainfall to decrease (Fig. 1(c). The inverse association between IOSH indices and winter rainfall was evident as whenever IOSH indices showed significant periodicities then winter rainfall became non-significant or vice versa. The Inverse association between sea level pressure over Indian Ocean and winter (May-August) rainfall over Victoria also found by [15]. On the basis of the observations we divided the time series into two parts one before 1979 and another post 1979 of the analysis era (1951-2016). The composite map for sea level pressure (Fig. 4(b) over the period of 1951-1979 showed that when IOSHLN experienced periodicities before 1970s that characterized as the IOSHPS was located around $130^{\circ} to 140^{\circ} E, 25^{\circ} to 35^{\circ} S$ (covered less area) with peak intensity around 1020 hpa over the South Australia and the composite map for winter rainfall over that period showed in Fig. 4(a).

The composite map for sea level pressure (Fig. 5(b) over the period of 1980-2016 when IOSHPS experienced its periodicities that characterized as less winter rainfall over Victoria as the IOSHPS was located around 130° to 150°E, 25° to 40°S (covered more area) over Southern and Southeastern Australia with peak intensity around 1021 hPa caused less winter rainfall over Victoria (Fig. 5(a).This explained the inverse association between IOSH indices and winter rainfall over Victoria, Australia.

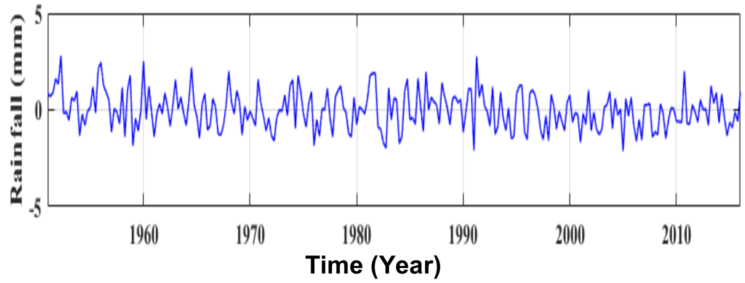


Fig. 1(a). Winter (May-August) rainfall anomalies over Victoria (1951-2016)

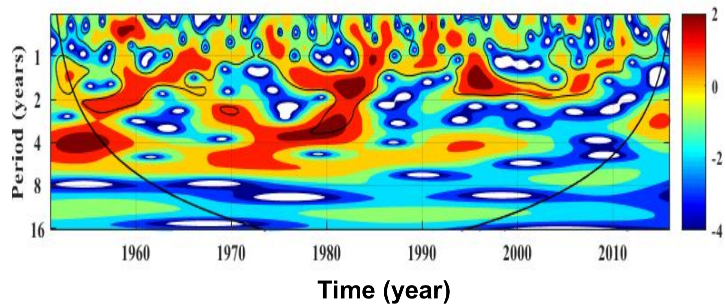


Fig. 1(b). Wavelet Power Spectrum (WPS) shows periodicity from minimum (dark blue) to maximum (red) precipitation variability

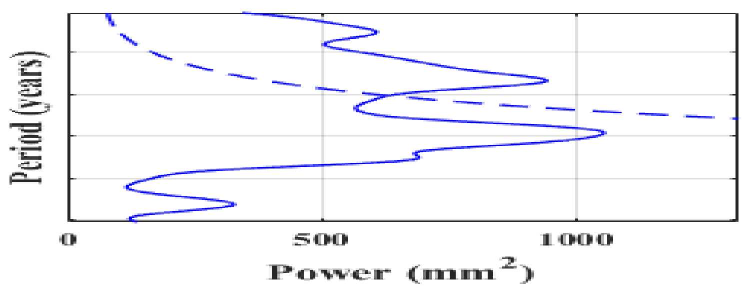


Fig. 1(c). Global Wavelet Spectrum (GWS) shows the strength (intensity) of winter precipitation variability

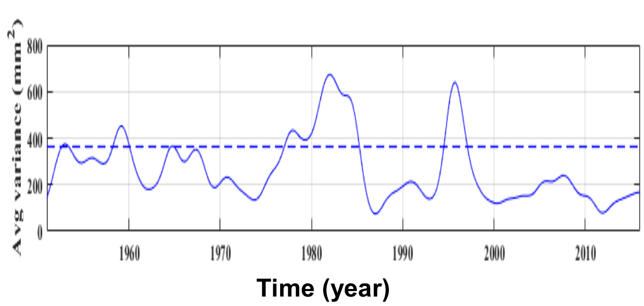


Fig. 1(d). Shows the average variance in winter rainfall (1-3 years). The 5% significance level in variance shows areas enclosed within the black contour lines, and as the dashed line in the GWS in the bottom

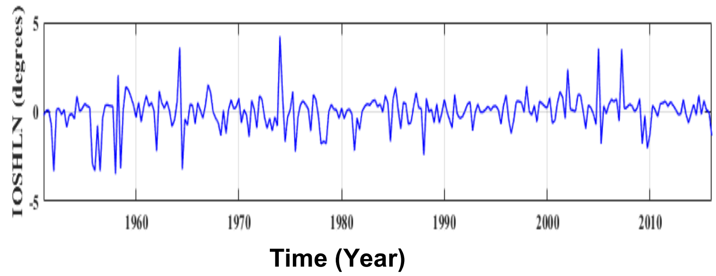


Fig. 2 (a). Winter (May-August) IOSHLN over Indian Ocean (1951-2016)

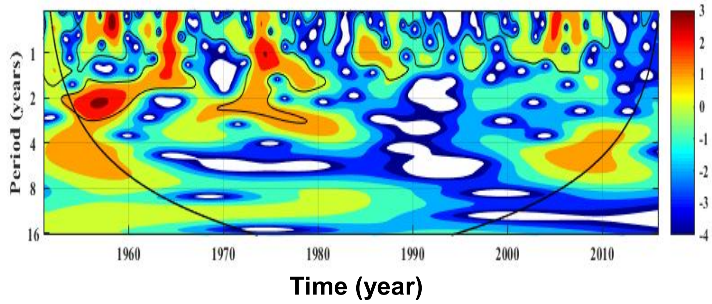


Fig. 2(b). WPS shows periodicity from minimum (dark blue) to maximum (red) IOSHLN variability

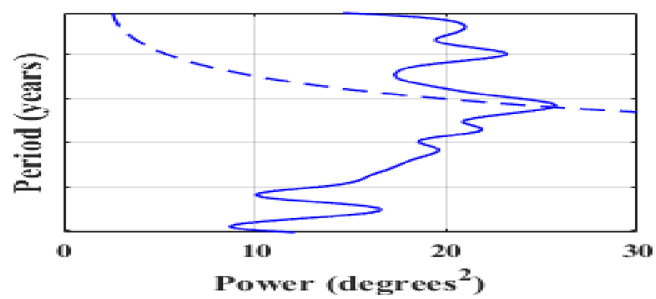
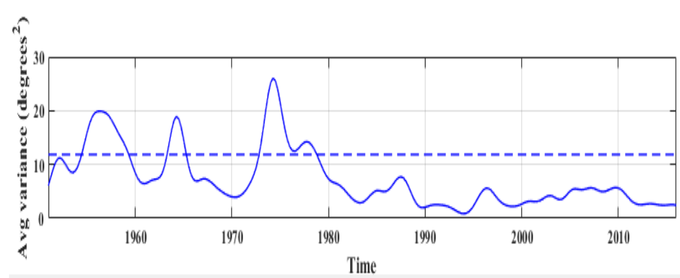


Fig. 2(c). GWS shows the strength (intensity) of winter IOSHLN variability



Time (year)

Fig. 2(d). Shows the average variance in winter IOSHLN (1-3 years). The 5% significance level in variance shows areas enclosed within the black contour lines, and as the dashed line in the GWS in the bottom

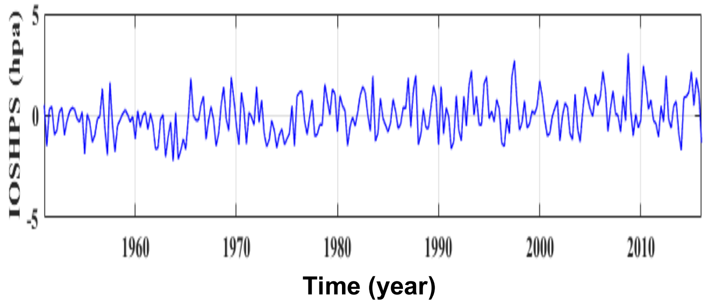


Fig. 3(a). Winter (May-August) IOSHPS over Indian Ocean (1951-2016)

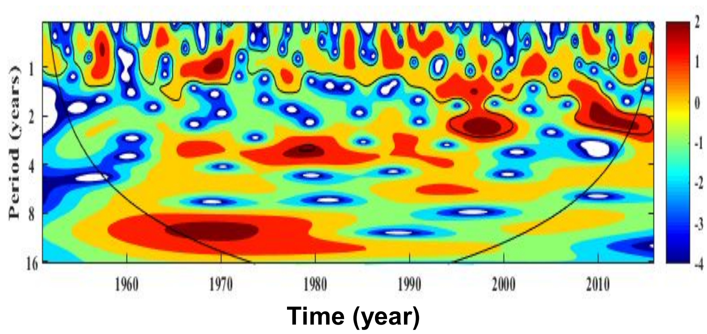


Fig. 3(b). WPS shows periodicity from minimum (dark blue) to maximum (red) IOSHPS variability

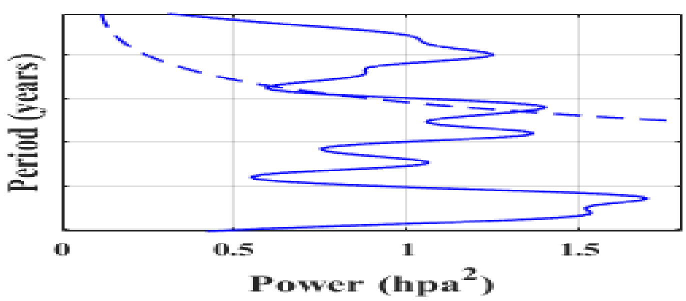


Fig. 3(c). GWS shows the strength (intensity) of winter IOSHPS variability

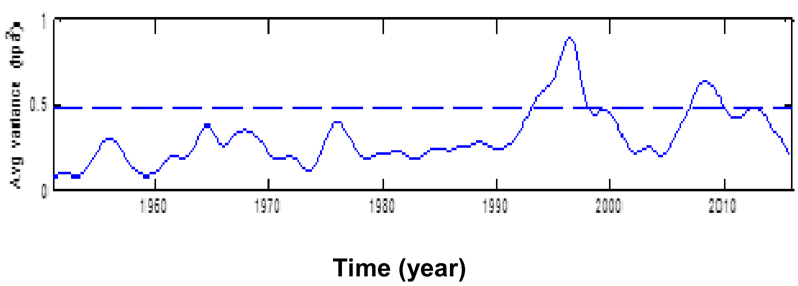


Fig. 3(d). Shows the average variance in winter IOSHPS (1-3 years). The 5% significance level in variance shows areas enclosed within the black contour lines, and as the dashed blue line in the GWS in the bottom

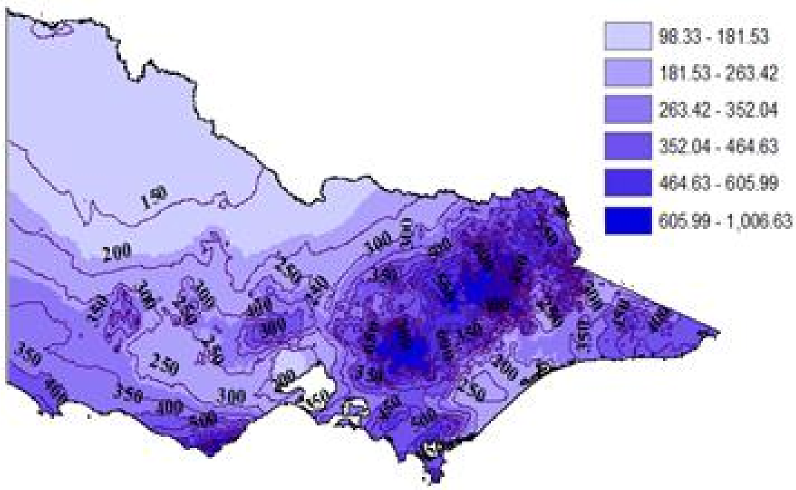


Fig. 4(a). Shows the composite map for winter (May-August) rainfall over Victoria (1951-1979)

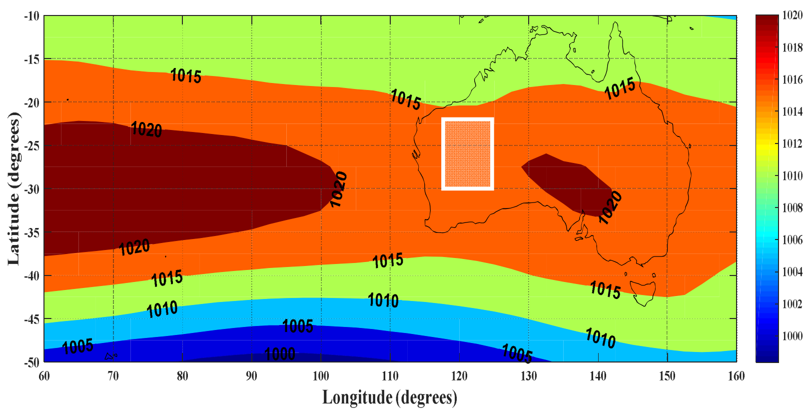


Fig. 4(b). Shows the composite map for winter (May-August) sea level pressure over Indian Ocean and the continent (1951-1979)

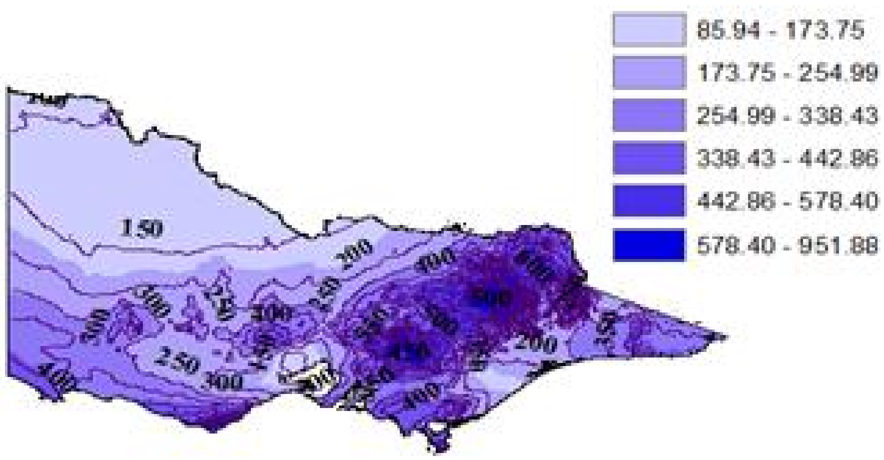


Fig. 5(a). Shows the composite map for winter (May-August) rainfall over Victoria (1980-2016)

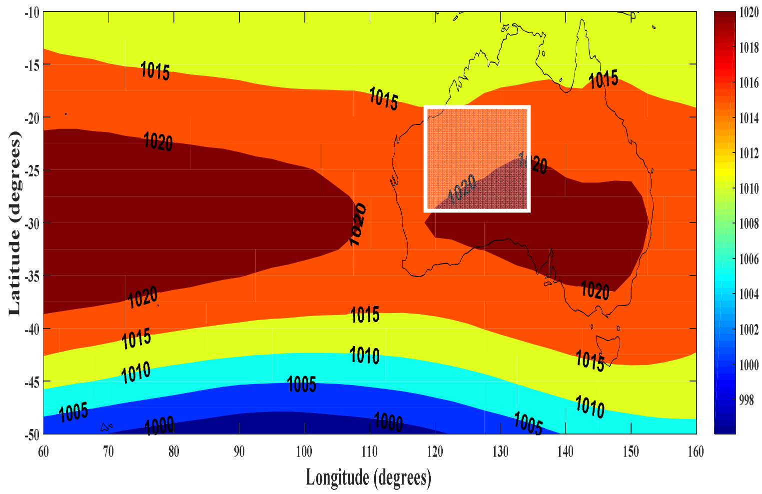


Fig. 5(b). Shows the composite map for winter (May-August) sea level pressure over Indian Ocean and the continent (1980-2016)

4. CONCLUSION

It can be inferred from the results presented in this study that both the IOSH intensity and its longitude positions are inversely associated with winter (May-August) rainfall over Victoria (1951-2016). The IOSHLN has influenced the rainfall from pre-1979 of the analysis era (1951-2016). The IOSHPS has not only propagated from southern to Southeastern Australia but has also enhanced its intensity from the post 1979 period. This has caused a further decline in winter rainfall over Victoria. The periodicities of 1-3 years showed IOSH indices and winter rainfall over Victoria is highly variable. The variability in IOSH indices account for the 43 percent variability in winter (May-August) rainfall over Victoria, Australia for the period of 1951 to 2016.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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