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The Impact of Subtropical Indian Ocean Anticyclone over Tasmania Precipitation

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Authors' contributions

This work was carried out in collaboration among all authors. Author BAU designed the study and wrote the final manuscript. Author SUR supervised 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

Aims: To explore the association between observed frequency of anticyclones over subtropical Indian Ocean (10°S-50°S, 102.5°E-142.5°E) and average autumn rainfall over the districts of Tasmania.

Methodology: We have divided the rainfall amounts over nine districts of Tasmania into three categories (Above average, average and below average rainfall) by using z-scores technique for each autumn (March-May) month for the period of 1951-2016. We have also categorized the calculated frequency of anticyclone over the subtropical Indian Ocean in a similar fashion.

Results: Our analysis suggests inverse association between each category of average rainfall and

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the corresponding frequency of anticyclones for each month of autumn. This association revealed that during below average rainfall, the high frequencies of anticyclones were occupied over the most of the area of subtropical Indian Ocean that resulted less rainfall in the districts while during above average autumn rainfall, the high frequencies of anticyclones observed in the west of 110°E this enabled more autumn rainfall over the districts. We have also found the negative correlation coefficients between mean sea level pressure over the same domain of Indian Ocean and average rainfall over each district in each month of the autumn (March-May).

Conclusion: The slightly shift of Mean Central Pressure (MCP) to the north from the west coast of Tasmania from March-May enabled the extra-tropical activity of rainfall systems. This causes enhanced rainfall during average and above average rainfall conditions than March-April over nine districts of Tasmania.

Keywords: Anticyclones; Tasmania rainfall; subtropical Indian Ocean; extra-tropical cyclones; mean sea level pressure; z-scores; rainfall categories.

1. INTRODUCTION

Tasmania is the southernmost state of Australia. The topography of the state bears mountains in the west which extends to the midlands while the east coast consists of plains and agricultural regions. The landscape feature influences the spatial distribution of rainfall over the state as it receives more rainfall in the west while eastern region receives comparatively less rainfall annually. The earliest and perhaps most frequently cited map is that of [1]. Several Australian studies have encompassed rainfall variability in Tasmania, but most of them have selected fewer Tasmanian stations for their analyses. Selecting fewer station mostly results little emergence concerning areal differentiation, especially if the region has heterogeneities associated to their orography and land mass distribution.

Tasmania experienced the declined in precipitation since mid of the 1970s over its most parts and this decreased caused recession in the discharge of the state [2]. There may be several climate variables operating over the surrounding oceans that influenced the rainfall systems of the state. The decreasing trend in rainfall over Tasmania is greatest in autumn (March-May) than other austral seasons. Hope et al. [3] found that the winter rainfall is projected to increase in Tasmania while it decreased in most of the southeastern Australia. The low sea level pressure (SLP) patterns (cutoff lows) contribute morerainfall over the east coast of Tasmania from April-October and the high index of polarity of southern annular mode (SAM) associated with the decrease in daily summer rainfall over Tasmania [4]. The low SLP systems over the Pacific Ocean cause abrupt temporal rainfall distribution over the eastern Tasmania since these rainfall systems don't follow any seasonal cycle [4]. As described by Meneghini et al. [5] the decline in winter rainfall over southern South Australia, Victoria and Tasmania may be partly connected with SAM. Hill et al. [6] investigated the inter-annual rainfall variability over Tasmania and found its association with the variability in Pacific SAM, El-Nino southern oscillation (ENSO) and SAM.

The winter (May-August) Streamflow decline over the Arthur River Catchment of Tasmania is mainly associated with the increase of Indian Ocean Subtropical High Pressure (IOSHP) intensities and its zonal movements [7]. In [8] and [7] the authors have pointed out that Tasmania experiences the decline in rainfall in its most parts. This affects the streamflow from Tasmania to different parts of the Australia.

The reduction in rainfall and streamflow is caused by a North shift of pressure system, induced by an upward trend of the IOH forced by multi-decadal variability. We will show that as the Tamanian rainfall decline occurs in autumn, it is likely that it is driven by mechanisms of IOH pressure system. In this study, we have aimed to explore the association between average autumn (March-May) rainfall over the 9 districts of Tasmania for the period of 1951-2016 and the frequencies of anticyclones in the same temporal domain over the Subtropical Indian Ocean (10°S-50°S, 102.5°E-142.5°E).

2. MATERIALS AND METHODS

This analysis is based on the relationship between monthly average rainfall over the districts of Tasmania (Fig. 1(a)) and high pressure system over the Subtropical Indian Ocean defined by 102.5°E and 142.5°E meridians and, 10°S and 50°S parallels for the period of 1951-2016.Daily mean sea level pressure (MSLP) observations (with resolution 2.5° latitude by 2.5° longitude) data for the defined region over the Indian Ocean was obtained from the National Center for Environmental Prediction (NCEP) [9]. Monthly average rainfall data for the districts of Tasmania, for the austral autumn months (March-May), was obtained from the Bureau of Metrology (BOM), Australia. The average autumn (March-May) rainfall is showed in Fig. 1(b).

We have analyzed the below average, average and above average rainfall over the districts of Tasmania during autumn (March-May) months (1951-2016). We have applied z-score technique on each autumn (March-May) month of the average rainfall over the district of Tasmania for the period 1951-2016 and we defined rainfall intervals for below average, average and above average rainfall in the following manner:

$$Z = \frac{m_j - \bar{m}}{\sigma}$$

where, m_j is the monthly average rainfall in the year j, $\bar{m}$ is the mean of average monthly rainfall and σ is the standard deviation of the monthly average rainfall for the period of 1951-2016.

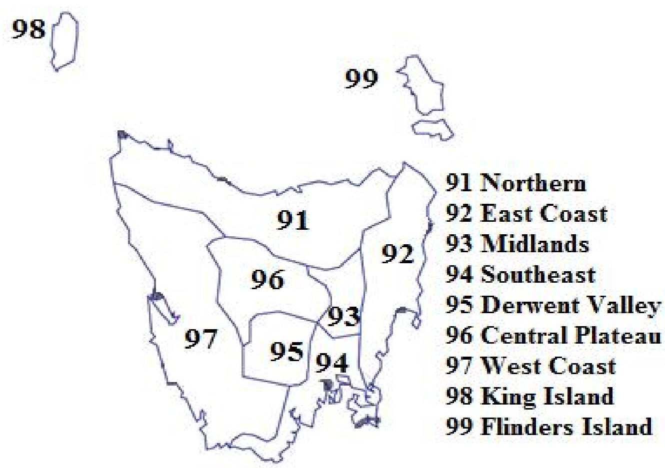


Fig. 1. (a) Tasmanian rainfall districts

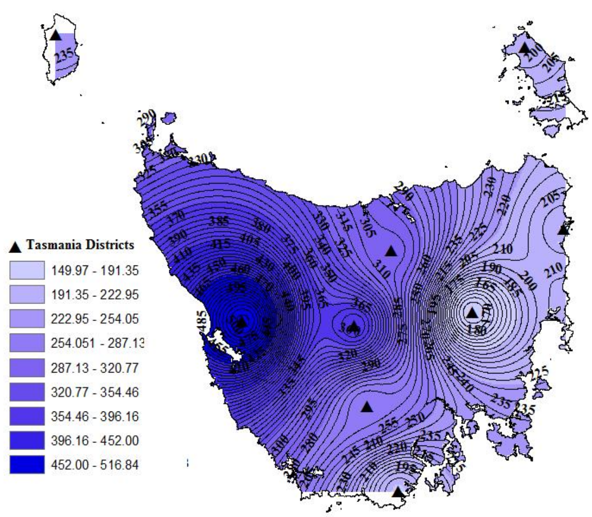


Fig. 1. (b) Mean autumn (March-May) rainfall (mm) over the districts of Tasmania for the period of 1951-2016

According to the method the intervals of rainfalls for each district and each month is defined below,

Extraordinarily dry when Z≤ -2.5
Extremely dry when -2.5<Z≤-1.5
Below average when -1.5<Z≤-0.5
Average when -0.5<Z≤0.5
Above average when 0.5<Z≤1.5
Extremely wet when 1.5<Z≤2.5
Extraordinarily wet when 2.5<Z

The rainfall for the month m_j in the jth year is characterized as below average (or above average) if in at least, it observed in five out of the 9 districts of the state, and it is defined as below average (or above average) and it has not observed in any of the rest of the stations. This quantitative approach was obtained from [10] and [11].

Rehman [12] investigated daily MSLP patterns for anticyclones analysis over the Indian Ocean domain (105-120°E, 10-50°S) and developed an algorithm for daily MSLP which reads a given threshold pressure ($p_t \geq 1020$ hpa) intensity and its geographical position at each grid point and temporal domain over Indian Ocean. We have also opted [12] method in this analysis to obtained the total frequency of anticyclones for each month of the autumn months over the Indian Ocean domain defined by 102.5°E and 142.5°E meridians and, 10°S and 50°S parallels for the period of 1951-2016. In order to find the relationship between monthly MSLP and average rainfall over each district of the state the correlation analysis between each of the average monthly rainfall for autumn season (March-May) over each districts (9 districts) and corresponding mean monthly sea level pressure field over defined region (102.5°E and 142.5°E meridians and, 10°S and 50°S parallels) of Indian Ocean were performed.

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.

The analysis of below average, average and above average rainfall over the districts of the Tasmania during autumn (March-May) months (1951-2016) shows 88 months which have the accumulation of below average (67) and above average (21) rainfall months, out of a total of 198 months for the autumn (March-May) over the state. The details for the months, below average (or above average) rainfall are presented in Table 1.

We have calculated the frequency of anticyclones from the daily MSLP data for the autumn months (March-May) and converted into the monthly frequencies by adding daily frequencies of the corresponding month and then we have constructed the three categories (below average, above average and average) of anticyclones frequency according to the obtained months of each category of rainfall (defined above). Three Composite maps for the anticyclones frequency corresponding to each category (below average, above average and average) for each month of the autumn season (March-May) were constructed. In this way, we have constructed 9 composite maps based on anticyclones frequency (Fig. 2(a)-Fig. 2(c), Fig. 3(a)-Fig. 3(c) and Fig. 4(a)-Fig. 4(c)). We have observed that the area of the center of high pressure and its frequencies gradually increased from March-May during the above normal conditions of MSLP (Fig. 2(a)-Fig. 4(a)). The normal conditions of MSLP (Fig. 2(b)-Fig. 4(b)) also showed the increased in the frequencies of anticyclones from March-May but comparatively lesser than during above normal conditions. It was observed during below normal conditions (Fig. 2(c)-Fig. 4(c)) of MSLP that the center of high pressure remained in the west of 110° (longitude) while in the east of 110° (longitude) the frequencies of anticyclones remains lesser than that of the above normal and normal conditions of MSLP composite fields from March-May.

In this study, we have obtained 27 correlation maps (9 districts and three months). The maps that showed similar correlations patterns in each month were averaged to obtain one correlation map which showed coherent districts relationship with MSLP and interpreted as the representative for all district in which average monthly rainfall responds as the MSLP departures. Hence, we obtained three average correlation maps (Fig. 2(c)-Fig. 4(c)) for coherent rainfall districts (Fig. 2(d)-Fig. 4(d)) for the autumn months. Three more maps (Fig. 2(e)-Fig. 4(e)) were added, each for each autumn month, for the comparative analysis of the observed rainfall measure during each category among the coherent districts. The average correlations coefficients maps (Fig. 2(d)-Fig. 4(d)) of coherent districts with MSLP showed not only that the area of negative correlations with MSLP increased but the magnitudes of negative correlations also increased from March-

May over period of 1951-2016. This showed that monthly average rainfall over the coherent districts was inversely associated with MSLP and this association has more increased from March-May while positive correlation has also observed but these were either zero or insignificant. In general, the negative association of rainfall with MSLP characterizes as less rainfall in the associated regions while positive association characterizes more rainfall in the associated regions. Rossby et al. [13] found not only the intensities but also the locations of the sea level pressure centers influence the associated regional climate. Hameed et al. [14] investigated the center of high pressure over the subtropical Indian Ocean and found its association with the winter (May-August) rainfall declined over Southwest Western Australia (SWWA) over the period from1951-2008. We have observed that during above average of MSLP categories (high anticyclones frequency composite maps) the average rainfall over the coherent districts was below average while during below average of MSLP categories (lowest anticyclones frequency composite maps) the average rainfall over the coherent districts (Fig. 2(f)-Fig. 4(f)) was above average from March-May.

This comparative analysis confirmed the inversely association between the MSLP over Indian Ocean Subtropical region and average autumn rainfall over the district of the state. Rehman [15] also observed the inverse associations between MSLP and streamflow. They investigated the winter (May-August) streamflow over SWWA and found the winter streamflow was inversely associated with high-pressure system and its geographical locations over the subtropical Indian Ocean. In another studies, [16] and [17] found that the declined in winter (May-August) streamflow over Tamar and Snug River Catchments of Tasmania associated with the increase of IOSHPS intensities and its zonal movements.

Table 1. The definition of the autumn (March-May) months as above average (A.A), below average (B. A) and average (A). Months without any definition were other than A. A. (B. A) or A

Time	Mar	Apr	May	Time	Mar	Apr	May
1951				1984			*B. A*
1952	*B.A*	*A. A*		1985			
1953	*B. A*		*B. A*	1986	*B. A*	*A. A*	
1954				1987		*B. A*	*A. A*
1955	*B. A*			1988	*B. A*	*B. A*	*A. A*
1956				1989			
1957		*A. A*		1990	*B. A*		*B. A*
1958				1991		*B. A*	*B. A*
1959	*B. A*		*B. A*	1992	*B. A*		
1960	*B. A*		*A. A*	1993		*B. A*	*B. A*
1961	*B. A*	*A. A*	*B. A*	1994			
1962		*B. A*	*A. A*	1995			*B. A*
1963		*B. A*	*B. A*	1996			*B. A*
1964		*B. A*		1997		*B. A*	
1965		*A. A*		1998	*B. A*		*B. A*
1966			*B. A*	1999		*B. A*	
1967	*B. A*	*B. A*	*B. A*	2000	*B. A*	*B. A*	
1968		*A. A*	*A. A*	2001	*A. A*		*B. A*
1969				2002	*B. A*	*B. A*	*B. A*
1970				2003			*B. A*
1971	*B. A*		*A. A*	2004	*B. A*		
1972	*B. A*		*B. A*	2005	*B. A*		*B. A*
1973	*A. A*	*A. A*		2006	*B. A*		
1974			*B. A*	2007		*B. A*	*A. A*
1975		*B. A*		2008		*B. A*	*B. A*
1976		*B. A*		2009	*A. A*		*B. A*
1977		*B. A*		2010			*B. A*
1978	*B. A*			2011			*B. A*
1979			*B. A*	2012	*A. A*		
1980				2013		*B. A*	
1981	*A. A*		*B. A*	2014			
1982	*A. A*	*B. A*		2015		*B. A*	*A. A*
1983				2016	*B. A*	*B. A*	

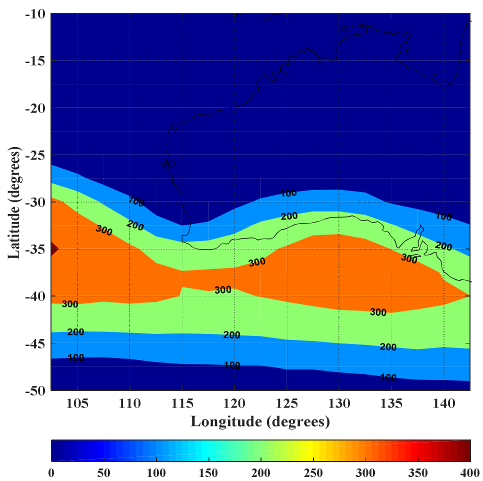


Fig. 2. (a)

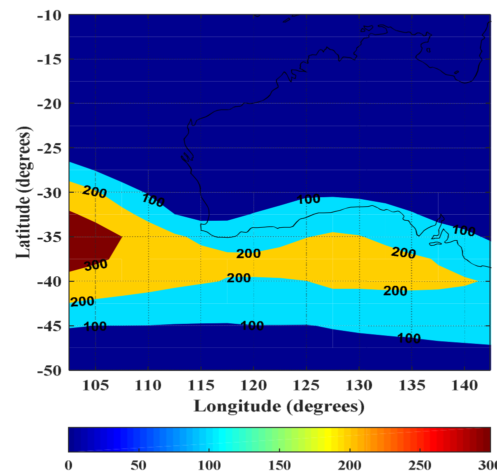
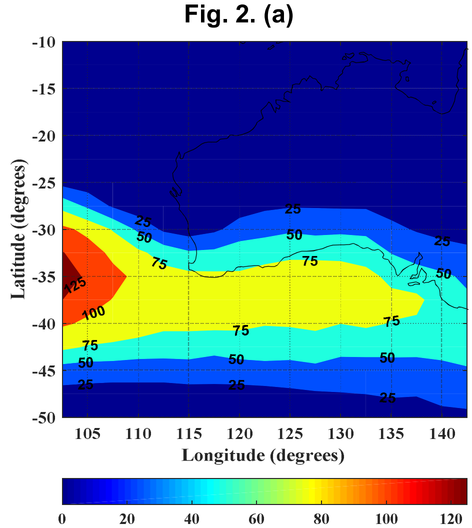


Fig. 2. (b)



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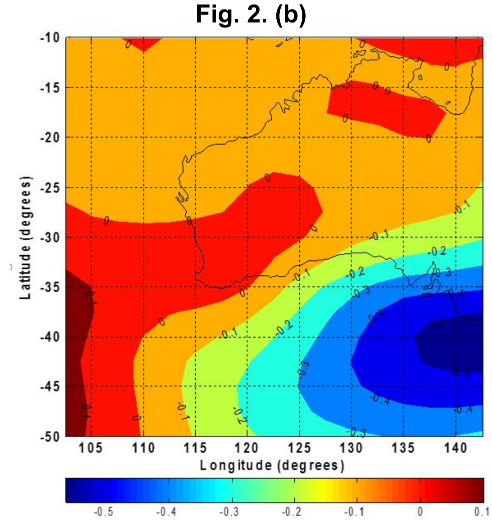


Fig. 2. (d)

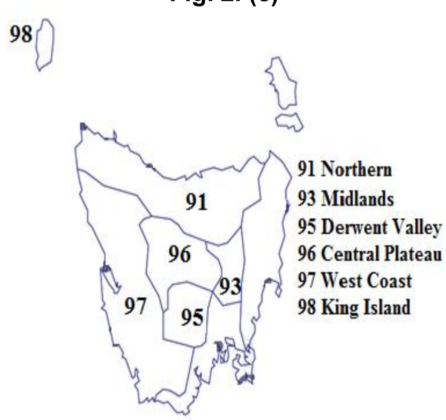


Fig. 2. (e)

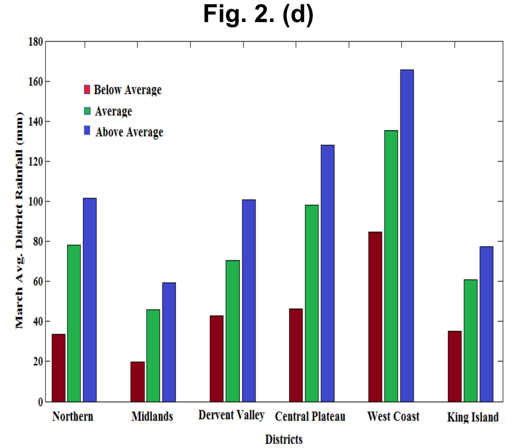


Fig. 2. (f)

Fig. 2. (a-c) Show the composites maps of observed anticyclones frequency in March for above average, average and below average respectively. Fig. 2 (d) shows map for average correlation coefficients between MSLP and average march rainfall over the districts. Fig. 2 (e) the districts whose rainfall correlations were averaged (coherent rainfall districts) and Fig. 2 (f) shows corresponding rainfall (mm) measures over the coherent districts

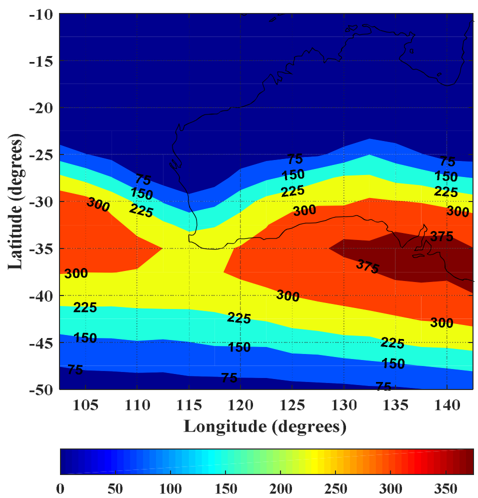
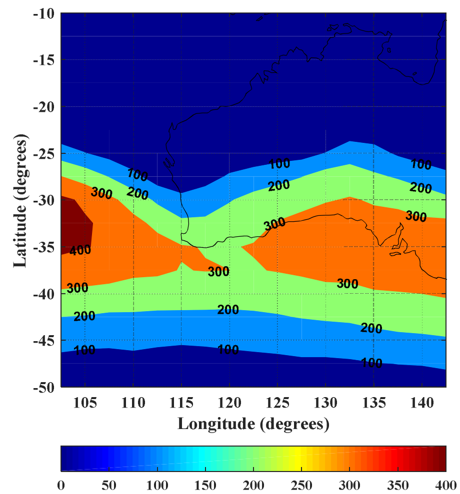


Fig. 3. (a)



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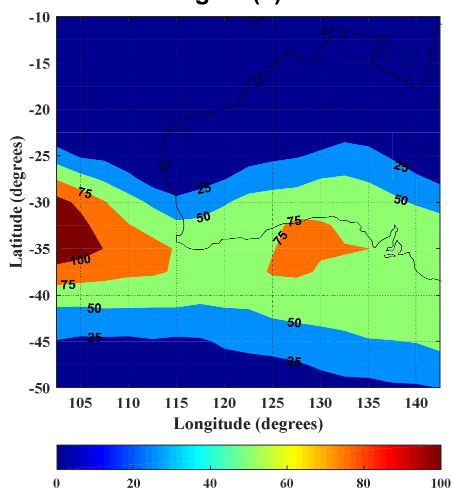

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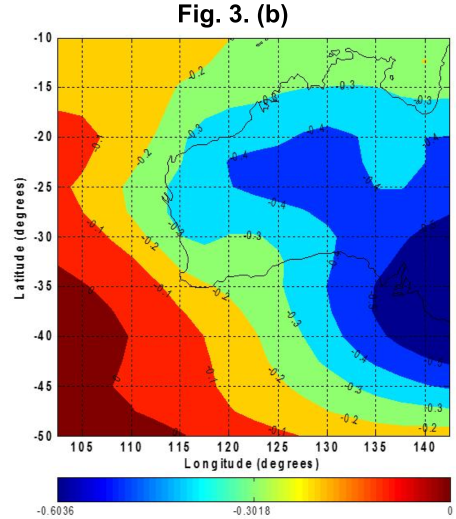

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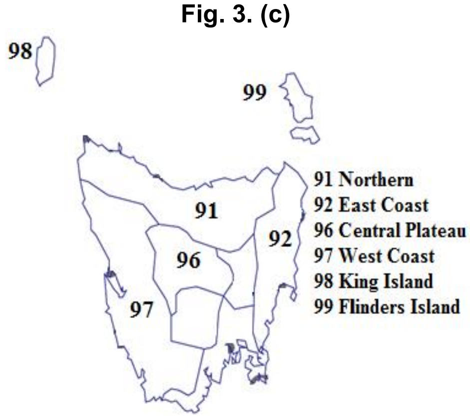

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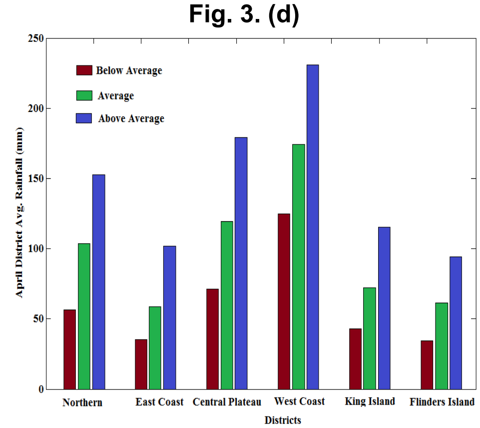
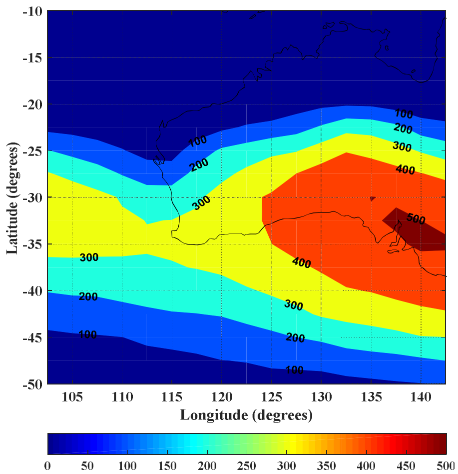


Fig. 3. (f)

Fig. 3. (a-c) Show the composites maps of observed anticyclones frequency in April in above average, average and below average respectively. Fig. 3 (d) shows the map for average correlation coefficients between MSLP and average march rainfall over the districts. Fig. 3 (e) highlights the districts whose rainfall correlations were averaged (coherent rainfall districts) and Fig. 3 (f) shows corresponding rainfall (mm) measures over the coherent districts



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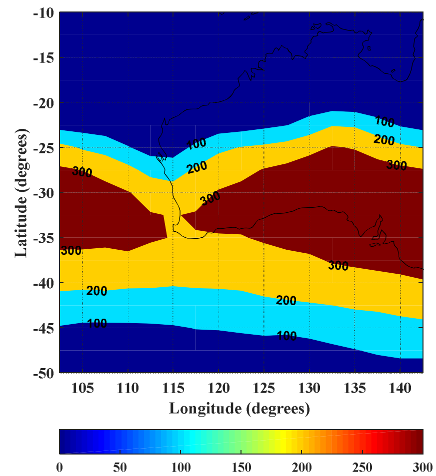

Fig. 4. (b)

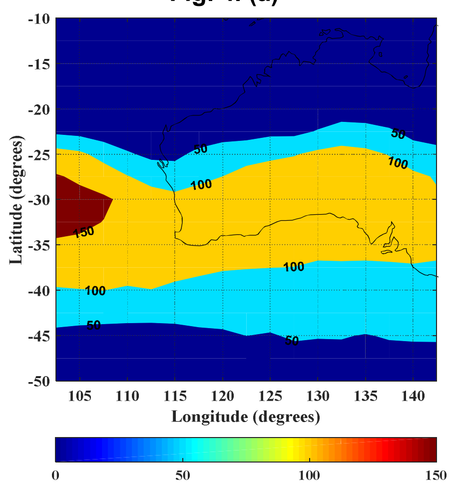

Fig. 4. (c)

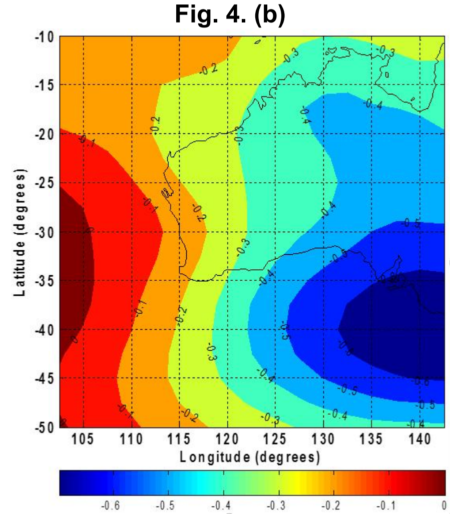

Fig. 4. (d)

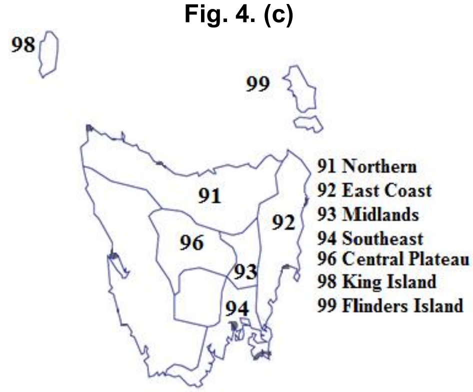

Fig. 4. (e)

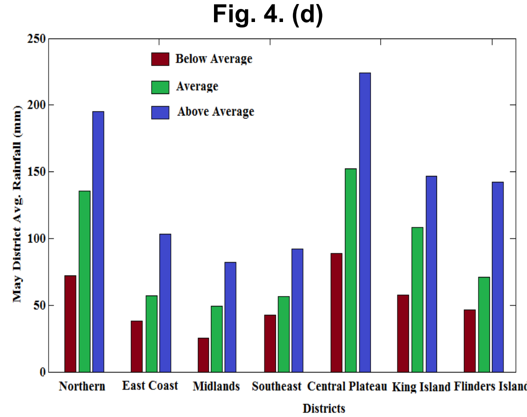

Fig. 4. (f)

Fig. 4. (a-c) Shows the composites maps of observed anticyclones frequency in May above average, average and below average respectively. Fig. 4 (d) shows the map for average correlation coefficients between MSLP and average march rainfall over the districts. Fig. 4 (e) the districts whose rainfall correlations were averaged (coherent rainfall districts) and Fig. 4 (f) shows corresponding rainfall measures over the coherent districts

4. CONCLUSION

The frequency of anticyclones has been found and its area from March-May has increased over the subtropical Indian Ocean (100-142.5°E, 10-50°S). Additionally, during above normal rainfall conditions MCP remained around the west of 110°E but in the opposite conditions MCP propagated near the west coast of the state with more intensity and prevent the rainfall systems over the districts, which caused more below average and average rainfall months over the districts of the state. Furthermore, it was observed that the MCP pressure slightly shifted to the north from the west coast of Tasmania from March-May which enabled the extra-tropical activity of rainfall systems which caused comparatively enhanced rainfall during average and above average rainfall conditions than March-April over the districts of Tasmania.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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