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Research Article

# Impact of Zonal Movement of Indian Ocean High Pressure on Winter Precipitation over South East Australia

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**Abstract:** Southeastern Australia (SEA) has suffered from 10 years of low rainfall from 1997 to 2006. A protracted dry spell of this severity has been recorded once before during the 20th century, but current drought conditions are exacerbated by increasing temperatures. Impacts of this dry decade are wide-ranging, so a major research effort is being directed to better understand the region's recent climate, its variability and climate change. Large-scale factors that influence the climate of southeastern part of Australia include the El Niño – Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM). This paper explores rainfall variability and trends within the State of South East Australia over the past century. For much of the State experiences large variations in rainfall over space as well as over time. We use the centre of action approach for the study of wintertime rainfall variability over the mentioned region, taking into account variations in Indian Ocean High pressure system. It is also found that east-west shifts in the position of this subtropical Indian Ocean high significantly influence winter rainfall in South East Australia. The negative correlation implies that when the Indian High shifted to the east there is less rainfall over south east Australia. Similarly when the Indian Ocean High Pressure maximum there is less rainfall observed and vice versa. It indicates that the Indian High pressure in the winter has steadily increased and expanded since the 1950s which is the most direct explanation of the drying trend over the South East Australia. (IOHP and IOHLN) explain 22% variability of rainfall over SEA. Our calculations suggest the variability of winter precipitation over South East Australia is not only influenced by the intensity of Indian Ocean High pressure system but it also depends on its zonal movement.

**Keywords:** Indian Ocean High Pressure, Precipitation, Teleconnection

## 1. INTRODUCTION

Australia is the driest inhabited continent on earth; its climate is harsh and extreme. Its interior has one of the lowest rainfalls in the world, and about three-quarters of the land are arid or semi-arid. Rainfall records reveal regular drought cycles, sometimes persisting for a decade and beyond, interspersed with years of above-average rain. Rainfall trends are important from an environmental and an economic perspective. For thousands of years, Australia has experienced strong year-to-year variations in rainfall. These natural variations and any more extreme variations or changes in the normal scope of variation that may result from anthropogenic climate change are important indicators for the condition of the atmosphere.

Particularly, in south-east Australia, since 1950, rainfall has decreased and droughts have become hotter and the number of extremely hot days has risen [1]. Climate change projections indicate that the south-east is likely to become hotter and drier in future. Most of South-Eastern Australia (SEA) has seen reduced rainfall since the late 1990s (National Climate Centre – NCC-, 2008). Rainfall across south-eastern Australia is highly variable on inter-annual and decadal time-scales (Fig. 1).

The first half of the 20th century was markedly drier than the second half, with a significant increase

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in the late 1940s [2]. In the late 1990s, most of the region entered an extended dry spell. From 1997 to 2009, virtually the entire area experienced rainfall below the long-term average, with some places recording the lowest totals on record. Most of the rainfall decline up to 2006 occurred in autumn, with 2006 through 2008 also experiencing relatively poor rainfall in winter and spring. The rainfall decline affected the southern area of the Murray-Darling Basin and the whole of Victoria, with impacts on the environment, irrigation industries and the cities of Adelaide, Melbourne and Canberra. It has been shown that a 13% reduction in rainfall in the southern Murray-Darling Basin from 1997-2006 led to a stream flow decrease of 44% [3].

Large-scale factors that influence the climate of southeastern part of Australia include the El Niño – Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM). The ENSO represents the effects of the Pacific Ocean, the IOD represents the Indian Ocean impacts, and the SAM represents the effects of the atmospheric circulation at high latitudes. These factors have been shown to have varying influences on seasonal rainfall patterns.

This study aimed at investigating the variability of rainfall over South East Australia (south of 33.5ºS and east of 135.5ºE) using the Center of Action (COA) approach. In the scheme used in this paper a COA is characterized by three indices representing its area-averaged longitude, latitude and pressure. The atmospheric centers of action are the large scale semi-permanent features of high and low pressure that are prominent in seasonal maps of global sea level pressure. Several recent studies have illustrated these advantages of the COA approach, such as the variations of zooplankton in the Gulf of Maine [4], the position of the Gulf stream north wall [5], the inter annual variability of Saharan mineral dust transport over the Atlantic [6], and the variability of wintertime Greenland tip jet [7]. These studies have demonstrated that not only changes in pressure but also changes in the latitude and longitude positions of the COA are in impact regional climates.

A recent study demonstrates the impact of the Indian Ocean high pressure system on winter precipitation over western and southwestern Australia [8]. In fact, the Indian Ocean High and South Pacific High are the centers of action that dominates atmospheric circulations that bring moisture to regions of SEA. Thus, this study proposes to investigate the impact of changes in pressures and positions of the Indian Ocean High on seasonal rainfall.

## 2. DATA

This study employed the Australian Bureau of Meteorology (BOM) gridded monthly rainfall datasets from 1950 to 2008. The datasets were developed using topography-resolving analysis methods applied to all available rainfall station data passed by a series of internal quality tests (see, http://www.bom.gov.au) It is the best available dataset for the analysis of variability in Australian rainfall.

Monthly averaged gridded mean sea-level pressure (MSLP) data from the National Center for Environmental Prediction (NCEP) reanalysis [9] for 1950–2008 were used for calculating objective COA indices for the monthly averaged pressure, latitude and longitude of the Indian Ocean High and the South Pacific High systems, as described by Hameed and Piontkovski [5]. The NCEP reanalysis was also used for constructing composite maps to understand meteorological changes that accompany different extreme conditions.

Southern Oscillation Index (SOI) is available at the Climate Data Centre, National Centers for Environmental Prediction. Indices for SAM prior to 1979 are based on very limited observations because there are only a small number of stations over the high latitudes of the southern hemisphere. The data of Indian Ocean Dipole (IOD) was used from 1958 to 2008, provided by Japan Agency for Marine-Earth Science and Technology (JAMSTEC). All calculations in this paper are for the season from June to August (JJA).

## 3. METHODOLOGY

The relationship between the atmospheric pressure fluctuation and rainfall variability over Australia, can be obtained through a quantitative assessment of the fluctuation in the pressure and location of the Indian Ocean High and South Pacific High, the two atmospheric centers of action that flank Australia. The pressure index $I_P$ of a High pressure system can be defined as an area-weighted pressure departure from a threshold value over the domain (*I, J*) as suggested by Hameed et al [10] and Santer [11].

$$I_{p,\Delta t} = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J}\left(P_{ij,\Delta t}-P_t\right)\cos\emptyset_{ij}\ \delta_{ij,\Delta t}}{\sum_{i=1}^{I}\sum_{j=1}^{J} cos\emptyset_{ij}\ \delta_{ij,\Delta t}}$$

Where $P_{ij,\Delta t}$ is the MSLP value at grid point $(i\ ,\ j)$ averaged over a time interval $\Delta t$, in this case monthly MSLP values are taken from NCEP reanalysis, $P_t$ is the threshold MSLP value ( $P_t$ = 1016 hPa for both the Indian Ocean High and the South Pacific High), $\varphi_{ij}$ is the latitude of the grid point *(i, j)*. $\delta = 1$ if $(P_{ij,\Delta t} - P_t) > 0$ and $\delta = 0$ if $\left(P_{ij,\Delta t} - P_t\right) < 0$. This ensures that the pressure difference is due to the High pressure system. The intensity is thus a measure of the anomaly of the atmospheric mass over the section *(I, J*). The domain of the Indian Ocean High was chosen as 10°S to 45°S and 40°E to 120°E and that of the South Pacific High as 10°S to 45°S and 160°E to 70°W.The domains of the two Highs and their threshold values were chosen by examining their geographical ranges in NCEP reanalysis data over the period 1948–2006. Similarly, the latitudinal index is defined as:

$$I_{\varphi,\Delta t} = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J}\left(P_{ij,\Delta t}-P_t\right)\varphi_{ij}\ \cos\emptyset_{ij}\ \delta_{ij,\Delta t}}{\sum_{i=1}^{I}\sum_{j=1}^{J}\left(P_{ij,\Delta t}-P_t\right)cos\,\emptyset_{ij}\ \delta_{ij,\Delta t}}$$

and the longitudinal index $I_{\lambda,\Delta t}$ is defined in an analogous manner.

## 4. RESULTS AND DISSCUSSION

We first assessed the dominance of the key drivers (COA indices, including pressure, latitude and longitude of the Indian Ocean High (IOH), of rainfall variability in south east Australia (SEA) by computing the correlation of these indices with the rainfall at each grid point across SEA. We do this in a moving 3 month window and then find the driver that accounts for the most variability (strongest correlation) in each 3 month season. The results are shown in Table1.

**Table 1**. Correlation Matrix of JJA Precipitation for South East Australia and Center of Action Variables, SOI, SAM and IOD during 1951– 2008. Values significant at the 0.05 statistical level are shown in bold.

| COA Variables | SEA Rainfall |
|---|---|
| Indian Ocean High Pressure (IOHPS) | **-0.263** |
| Indian Ocean High Longitude (IOHLN) | **-0.409** |
| Indian Ocean High Latitude (IOHLT) | 0.075 |
| SOI | **0.584** |
| Southern Annular Mode (SAM) | **-0.295** |
| Indian Ocean Dipole (IOD) | **-0.397** |

The two variables Indian Ocean High Pressure and Indian Ocean High Longitude are significantly correlated with South-East Australia (SEA)

**Table 2.** Correlation Matrix for Indian Ocean High Pressure, Indian Ocean High Longitude, SOI, SAM and IOD for JJA Season during 1951–2008. Values significant at 0.05 statistical level are shown in bold.

| | Indian Ocean High Pressure (IOHPS) | Indian Ocean High Longitude (IOHLN) | SOI | SAM | IOD |
|---|---|---|---|---|---|
| Indian Ocean High Pressure(IOHPS) | 1.00 | 0.086 | **-0.365** | **0.714** | 0.139 |
| Indian Ocean High Longitude(IOHLN) | 0.086 | 1.00 | **-0.327** | **0.315** | **0.374** |
| Southern Oscillation index (SOI) | **-0.365** | **-0.327** | 1.00 | -0.187 | **-0.547** |
| Southern Annual Mode(SAM) | **0.714** | **0.315** | -0.187 | 1.00 | 0.267 |
| Indian Ocean Dipole (IOD) | 0.139 | **0.374** | **-0.547** | 0.267 | 1.00 |

precipitation. In order to evaluate interdependencies among these variables we calculated their correlation matrix shown in Table 2. The Indian Ocean High Pressure is not correlated with the other variable i.e. Indian Ocean High Longitude. As Indian Ocean High longitude and Indian Ocean High Pressure are mutually independent; we construct a linear model of winter rainfall over SEA which yields:

$$SEAprecip = 5673.230 - 2.031(IOHLN) - 5.360(IOHPS)$$

$R^2$ for this regression is 0.220. It reveals that the variability of winter precipitation over South East Australia is influenced by the intensity of Indian Ocean High pressure system but it also depends on its zonal movement.

A drying trend in South East Australian rainfall since 1990 is apparent in Fig. 1. However, the intensity of Indian Ocean High pressure has been increasing trend. The negative correlation between rainfall over SEA and IOHP shows that the Indian High pressure in the winter has steadily increased and expanded since the 1950s which is the most direct explanation of the drying trend over the South East Australia. This result is consistent with that of Mitas and Clement [12] who showed a statistically significant intensification of their Hadley circulation indices throughout the second part of the 20th century.

### 4.1. Physical Mechanism for the Relationship between Indian Ocean High and Rainfall

The data in Table 1 revealed that the rainfall is negatively correlated with the Indian Ocean high pressure consequently there is more rainfall in winter when Indian ocean high pressure was the lowest is constructed and compared with composites obtained for the 10 winters in which Indian ocean high pressure was highest .Using NCEP/NCAR reanalysis monthly averaged fields, the composite mean of vector wind at 500 mb between the winters in which the Indian Ocean High was low is plotted in Fig. 2.

We can see the wind flow from the Indian Ocean brings moisture eastwards and its influence reaches in the region of South east Australia. Also, Fig. 3 shows that relative humidity was high when Indian ocean high was minimum and the weather is less humid when Indian ocean high is maximum so that the composite difference is positive i.e. 6% in SEA.

Fig. 4 shows composite difference of 500 mb vector wind velocities between the ten winters when the IOH was located most to the west (more rain in SEA) and the ten winters when the High was located most to the east (less rain in SEA). It shows

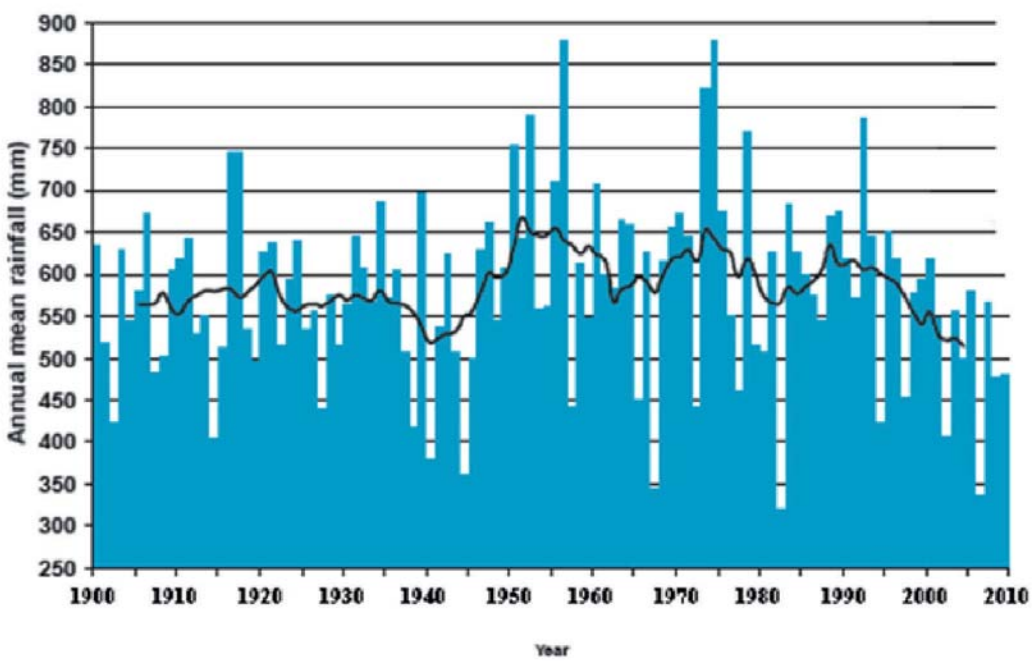


**Fig. 1.** Mean annual **rainfall** over mainland southeast australia from 1990 to 2009.Also shown is the 11th year running mean (solid black).

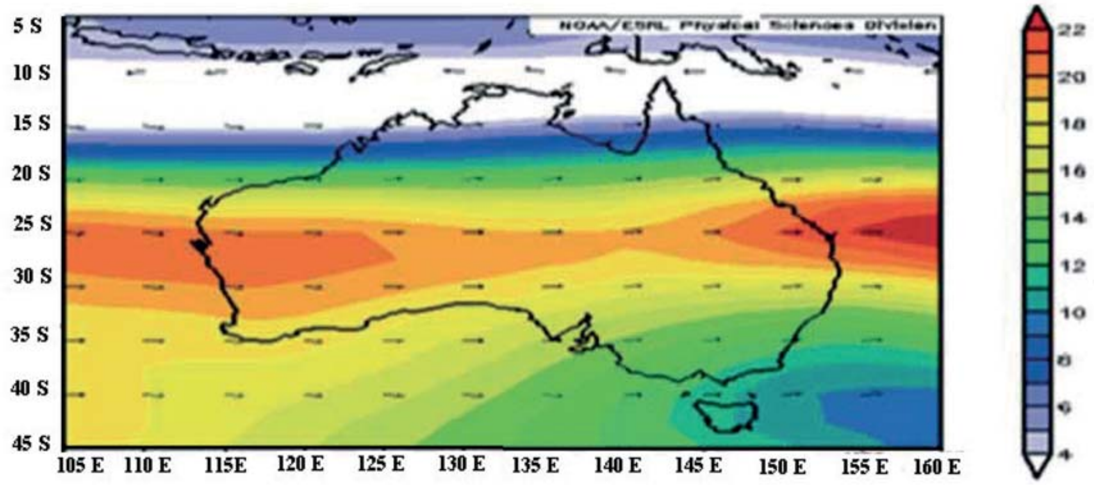


**Fig. 2**: Composite mean of **vector wind (500mb)** over the 10 winters when Indian Ocean High pressure was minimum.

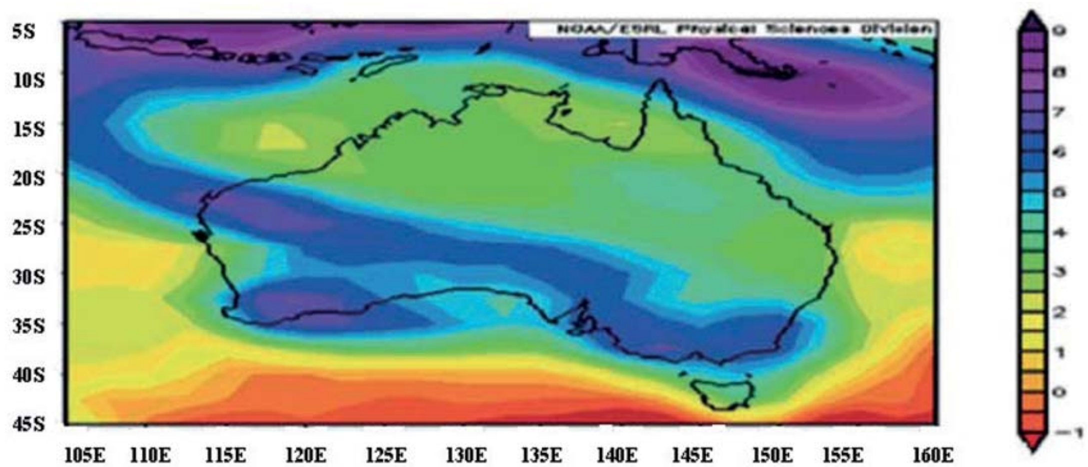


**Fig. 3:** Composite difference of **Relative Humidity (850mb)** during 1951–2008, between the ten winters when Indian High Pressure was minimum (more rain in SEA) and the ten winter when the Indian High Pressure was maximum (less rain in SEA).

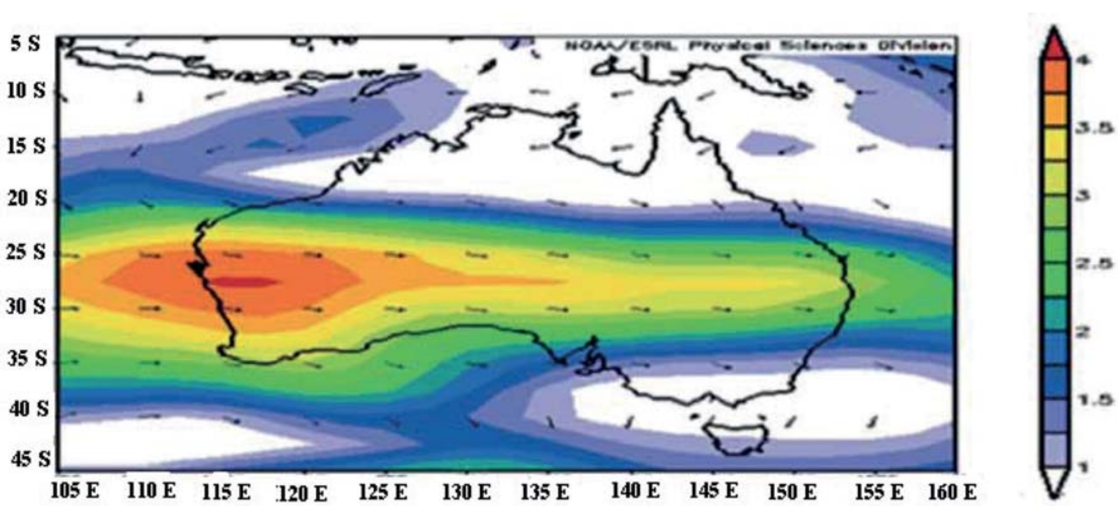


**Fig. 4:** Composite difference of **Vector Wind (500mb)** during 1951–2008, between the ten winters when Indian High Longitude was minimum (more rain in SEA) and the ten winters when the Indian High Longitude was maximum (less rain in SEA).

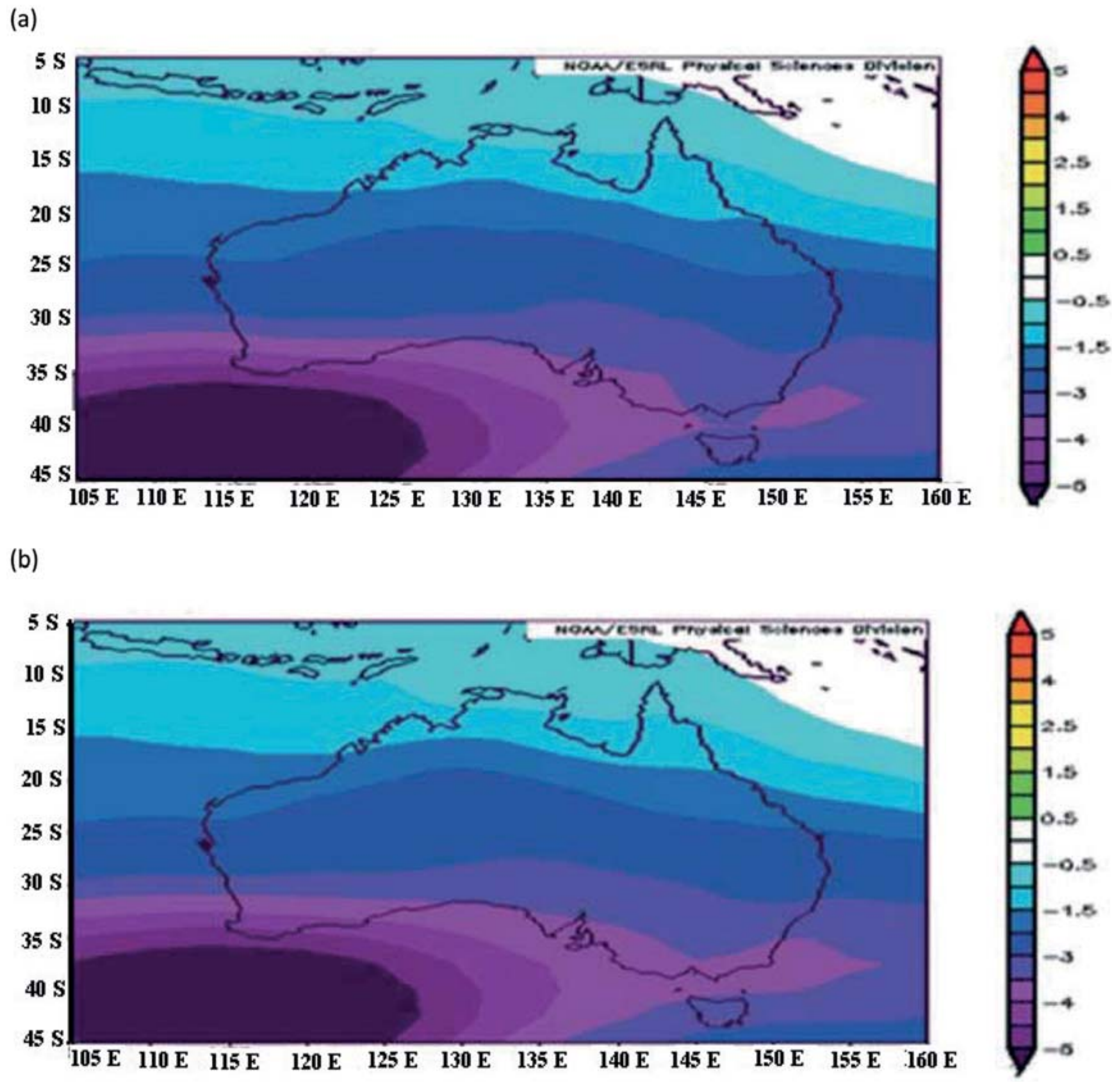


**Fig. 5:** Composite difference during 1951–2008, between the ten winters when Indian High Longitude was minimum (more rain in SEA) and the ten winters when the Indian High Longitude was maximum (less rain in SEA) (a) **Pressure (surface) (b) Sea level pressure(surface).**

anomalous flow from the ocean into west Australia with magnitude 4 m/s and in south east Australia it was reduced to 1 m/s to 1.5 m/s. Also we can see in Figs. 5 (a-b), which are the composite differences of Surface Pressure and Sea level pressure during 1951–2008, between the ten winters when Indian High Longitude was minimum (more rain in SEA) and the ten winters when the Indian High Longitude was maximum (less rain in SEA), these figures reveal that the low pressure was developed which was extended to the region of SEA.

Fig. 6 shows that weather was more humid when the IOH was located most to the west (more rain in SEA) as was located most to the east (less rain in SEA). Finally, it is noted that the impacts of Zonal Movement of Indian Ocean High Pressure on SEA rainfall exhibit important seasonal variations. NCEP reanalysis data show that atmospheric circulation is consistent with our empirical results.

## 5. CONCLUSIONS

Previous studies have identified large-scale factors that influence the climate of southeastern Australia includes the El Niño – Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the

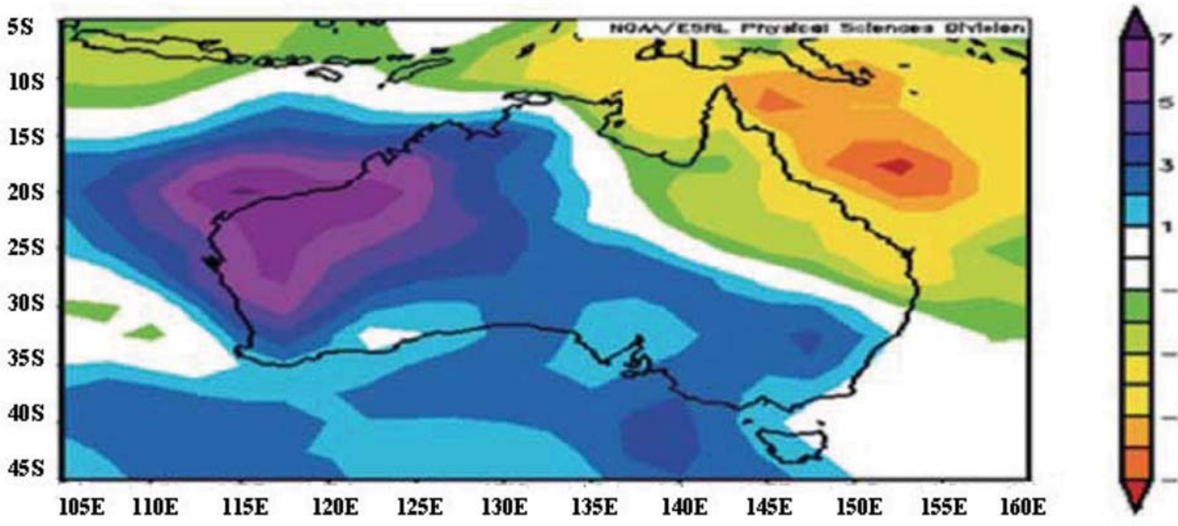


**Fig. 6:** Composite difference of **Relative Humidity (850mb)** during 1951–2008, between the ten winters when Indian High Longitude was minimum (more rain in SEA) and the ten winters when the Indian High Longitude was maximum (less rain in SEA).

Southern Annular Mode (SAM).These factors have been shown to have varying influences on seasonal rainfall patterns. The present paper has examined this relationship in terms of the dynamics of the Indian Ocean High pressure system which dominates atmospheric circulations that bring moistures to regions of South East Australia. Specifically, it was found that east-west shifts in the position of this subtropical Indian Ocean high significantly influence winter rainfall in South East Australia. The negative correlation implies that when the Indian High shifted to the east there is less rainfall over south east Australia. Similarly when the Indian Ocean High Pressure maximum there is less rainfall observed and vice versa. It shows that the Indian High pressure in the winter has steadily increased and expanded since the 1950s which is the most direct explanation of the drying trend over the South East Australia. The pressure and the longitude position of the IOH are not significantly correlated with each other. A statistical model of JJA rainfall in South East Australia using the IOH pressure and longitude as independent variables is presented. It explains 22 per cent of the observed rainfall variance. Our calculations suggest that the variability of winter precipitation over South East Australia is not only influenced by the intensity of Indian Ocean High pressure system but it also depends on its zonal movement.

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