The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2160-21

Conference on Decadal Predictability

16 - 20 August 2010

Impact of the Indian Ocean High Pressure System on Winter Precipitation over Western and Southwestern Australia

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IMPACT OF THE INDIAN OCEAN HIGH PRESSURE SYSTEM ON WINTER PRECIPITATION OVER WESTERN AND SOUTHWESTERN AUSTRALIA

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OUTLINE

Perth

- Introduction
- Data and Method
- Winter precipitation over Western Australia
- Winter precipitation Southwest Western Australia
- Prolonged Drought in Southwest Western Australia
- Mechanisms for the Relationships between the Indian Ocean High and the Variability of Precipitation in Western Australia and Southwest Western Australia

INTRODUCTION

The ongoing declining trend in winter precipitation in South Southwest Western Australia (SWWA) has been investigated in several observational and modeling studies and a review can be found in Nicholls (2006).

It has been recognized that interannual rainfall variations over SWWA are related to variations in atmospheric pressure over SWWA and over the surrounding region including the Indian Ocean (Allan and Haylock, 1993; Smith et. al., 2000).

Timball et. al. (2006) concluded that although anthropogenic influences seem to have contributed to the decline in rainfall but the evidence is ambiguous.

This study aims to investigate the variability of winter precipitation over Western Australia using the centers of action approach. The large-scale semi-permanent High and Low pressure centers which are prominent on a global map of monthly averaged sea level pressure were called the ‘‘centers of action’’ (COA) by Rossby et. al. (1939).

A key point noted by Rossby et. al. was that changes not only in the pressure, but also the position of a center of action influence regional circulation in the scheme used in this paper as COA is characterized by three indices representing its longitude, latitude, and pressure. icantly influence rainfall variations in Southeast Australia.

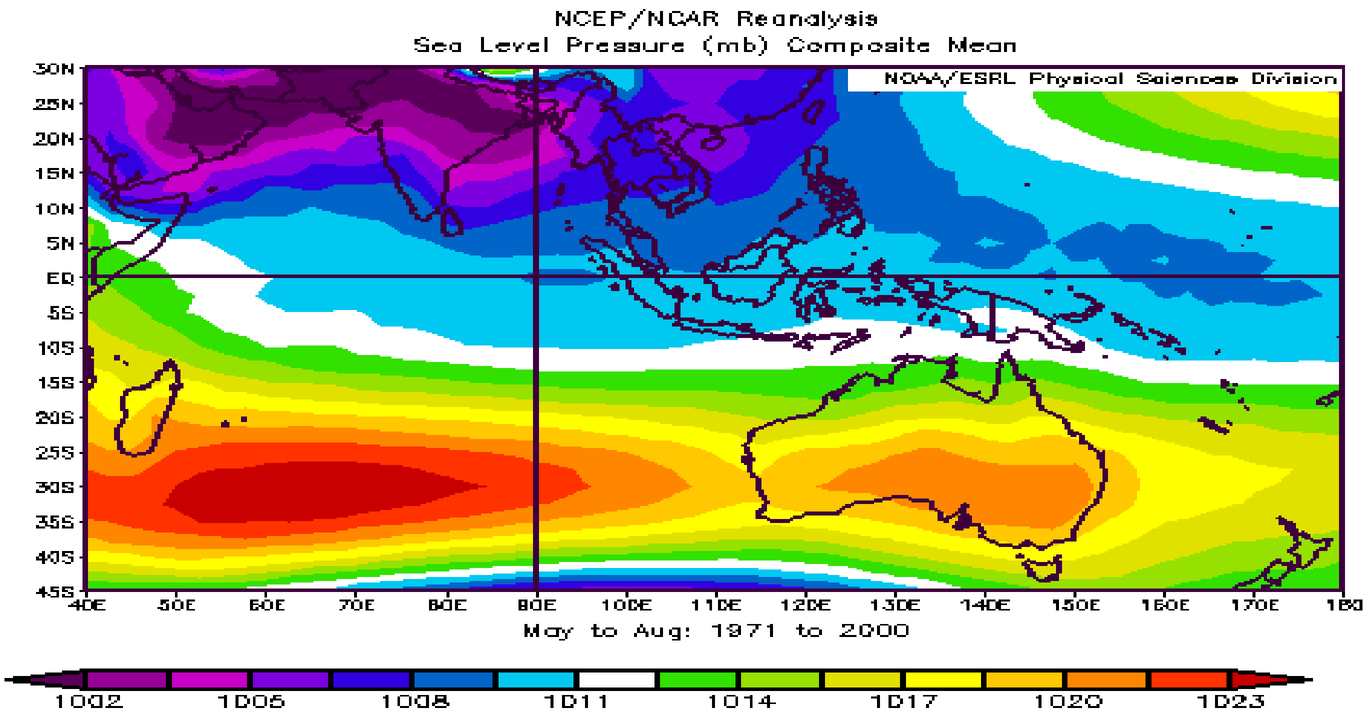


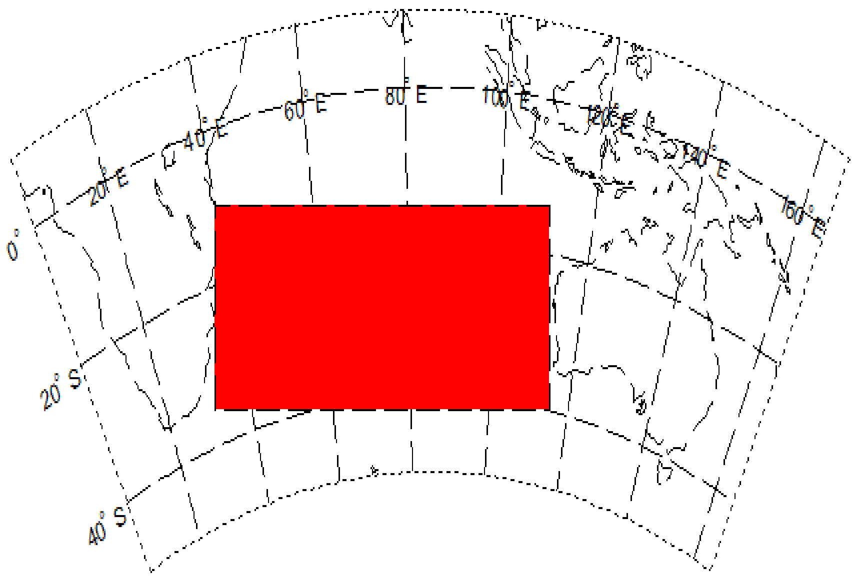
Figure 1 shows the distribution of sea level pressure in the southern subtropical Indian and Pacific Oceans during the southern winter (May to August) over 1971-2000. Australia is seen to be flanked by the Indian Ocean High to the west and the south Pacific High to the east. The Indian Ocean High (IOH) is seen to be stronger and situated closer to Western Australia. Our results indicate the South Pacific High does not influence winter rainfall in Western Australia. However, in a companion paper we present results that both of these centers significantly influence rainfall variations in Southeast Australia.

DATA

- The historical Australian rainfall data used in this study is based on a new high-resolution gridded dataset developed by the Australian Bureau of Meteorology (Jones et al. 2009).
- Monthly averaged gridded SLP data from NCEP reanalysis (Kalnay et. al, 1996) 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 (2004).
- The NCEP reanalysis was also used for constructing composite maps to understand meteorological changes that accompany different extreme conditions of the Indian Ocean High.

Centers of Action indices
of Pressure, Latitude, Longitude

- Characterize each Center of Action with three indices:
  - Pressure



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

- Measure of the anomaly of
- atmospheric mass over
- the area of interest.

- Position: Latitude.

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

  - Pressure-weighted mean latitudinal and longitudinal positions of the centers.

- Indices calculated using monthly sea level pressure data from NCEP (Kalnay et al., 1996; http://www.ncep.noaa.gov

The COA approach has been applied successfully to a wide range of regional climate problems such as:

- Regional cloud cover change associated over the western United States (Croke, Cess and Hameed, 1999, J. Climate)
- The Variations of zooplankton in the Gulf of Maine (Piontkovski and Hameed, 2002, Global Atmos. Ocean System)
- The dominant influence of Icelandic Low on the position of the Gulf Stream northwall (Hameed and Piontkovski, 2004, Geophysical Research Letters)
- On the variability of African dust transport across the Atlantic (Riemer et al., 2006, Geophys. Letters; Doherty et.al., 2008, Journal of Geophysical Research)
- Meteorologically driven trends in sea level rise (Kolker and Hameed, 2007, Geophysical Research Letters.)

Impact of Indian High Pressure

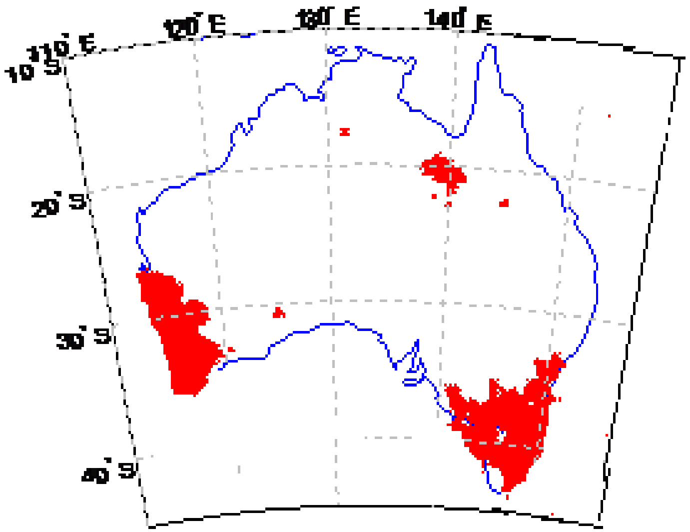


Figure 2. Correlation between MJJA precipitation and MJJA IOH pressure. Red: negative correlation with $p < 0.05$.

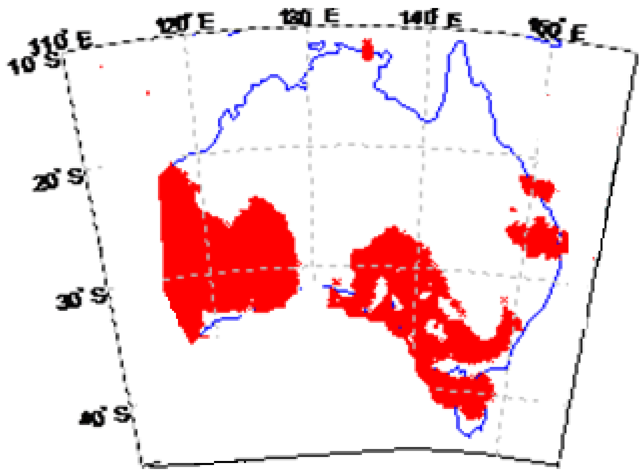


Figure 3. Correlation between MJJA precipitation and MJJA IOH Longitude. Red: negative correlation with $p<0.05$.

Based on these results we have selected two regions for further investigation:

(1)Western Australia (113-126°E, 20-35°S).

(2) Southwest Western Australia (115-118°E, 31-33.5°S).

Table 1: Correlation Matrix of MJJA Precipitation for Western Australia and Southwest Western Australia.

Parameters	Western Australia	Southwest Western Australia (SWWA)	SWWA (detrended)
Time	-0.24	**-0.35**	0
SOI	**0.26**	**0.39**	**0.33**
Indian Ocean Dipole	–0.2	–0.007	–0.037
Indian Ocean High Pressure	–0.19	–0.49	–0.36
Indian Ocean High Latitude	0.21	0.24	**0.32**
Indian Ocean High Longitude	–0.6	–0.58	–0.65
IOHPS & IOHLN		**0.72** **-52%**	**0.7** **-50%**

WINTER PRECIPITATION OVER WESTERN AUSTRALIA

WAprecip = 793.88 – 8.71* (IHLN)

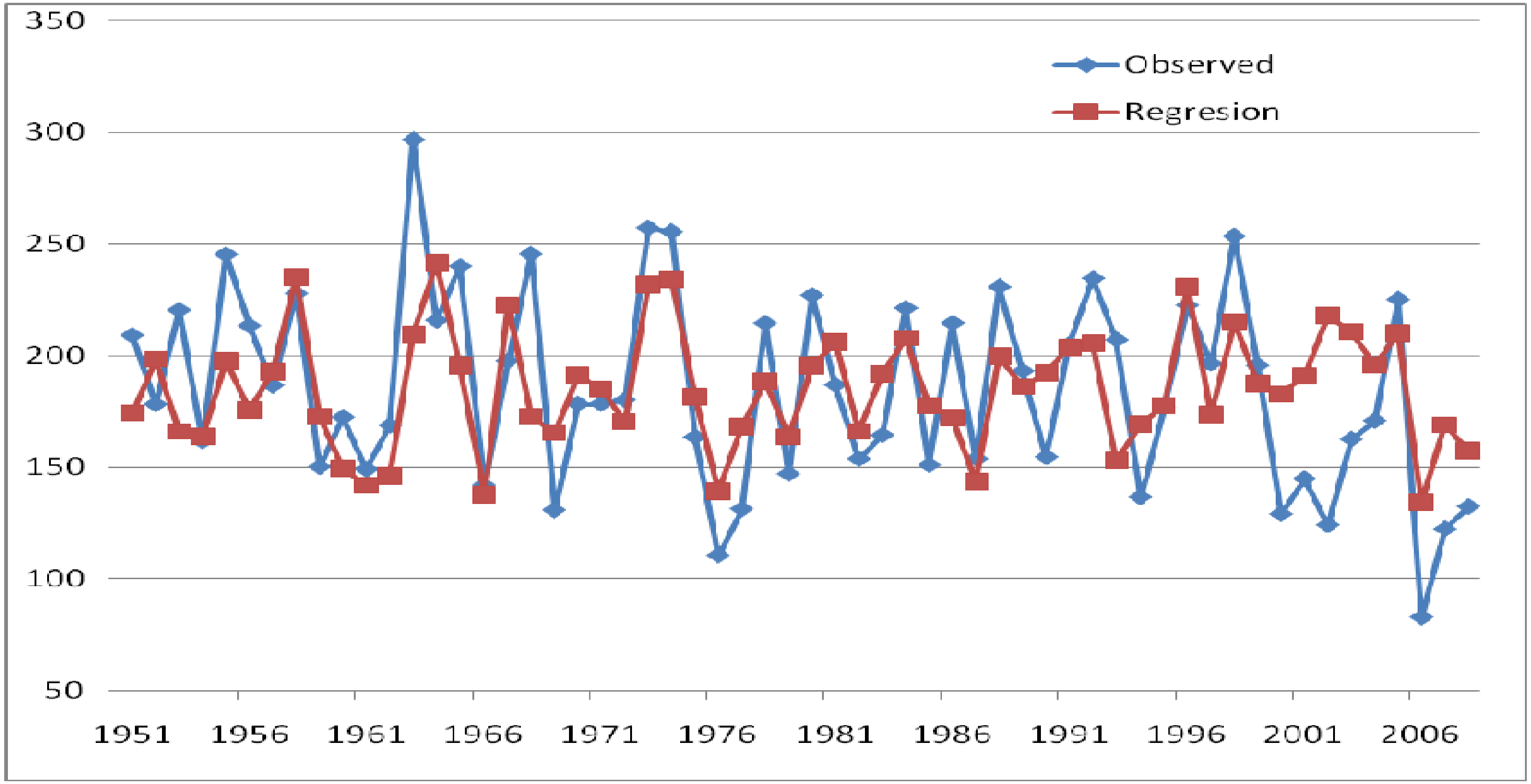


Figure 4. Western precipitation (MJJA) compared with regression with IOH longitude. Variance explained $R^2 = 0.36$, a significant enhancement over the SOI value of $R^2 = 0.10$

WINTER PRECIPITATION OVER SOUTHWEST WESTERN AUSTRALIA

$$SWWAprecip = 60229.83 - 12.56^{*} (IHLN) - 57.79^{*} (IHPS)$$

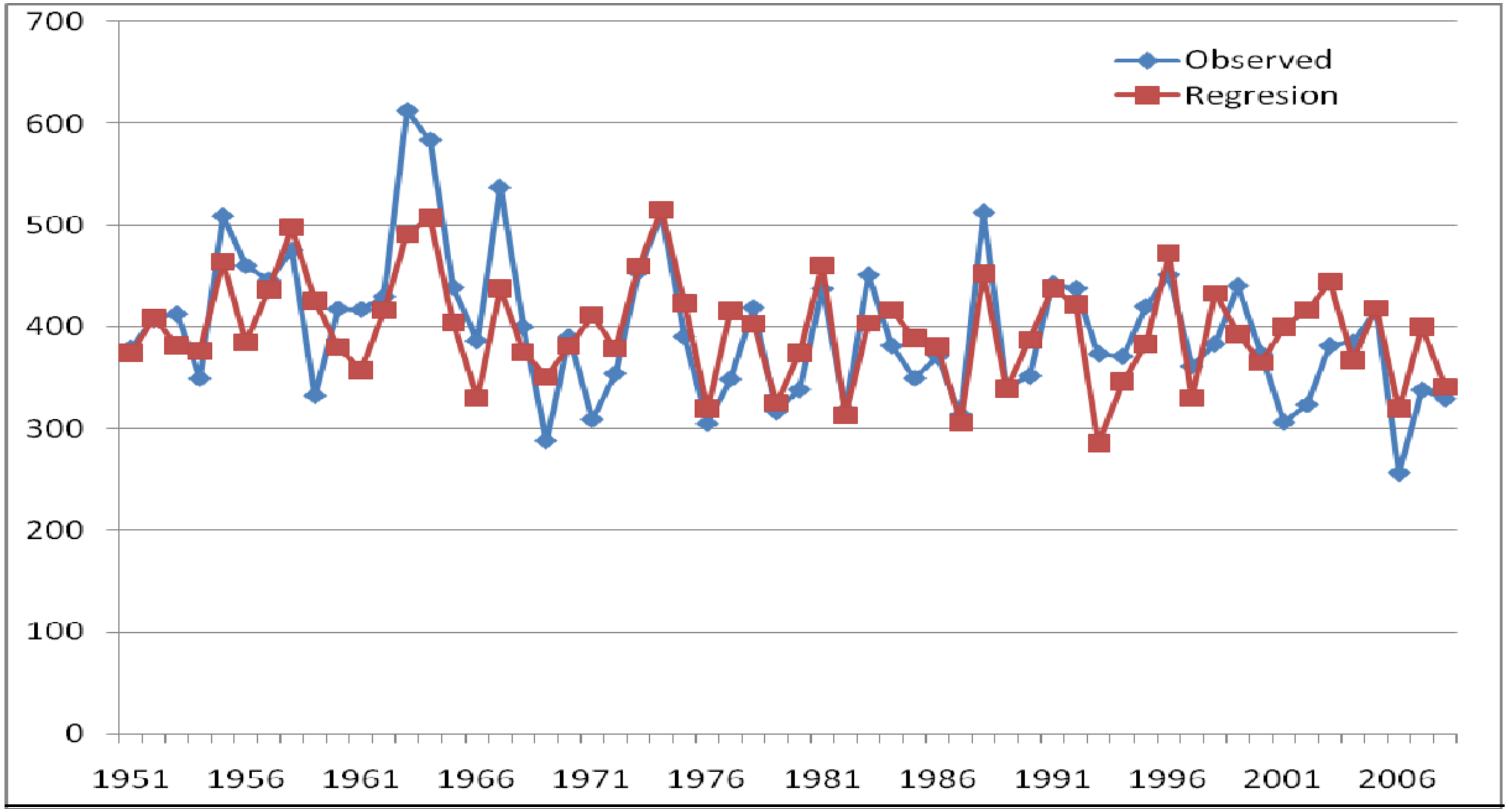
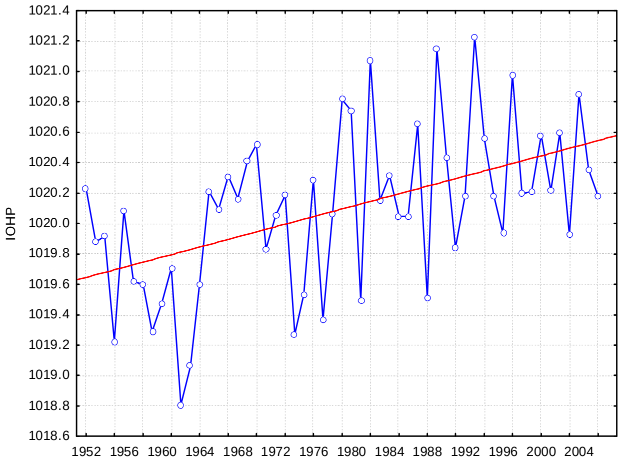
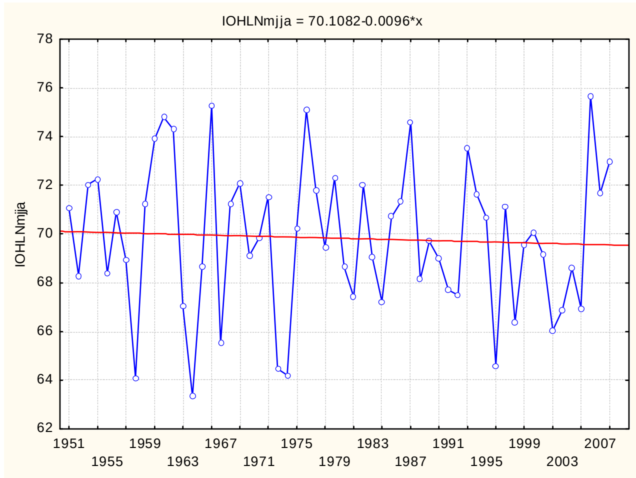


Figure 5. Southwest Western Australia precipitation (MJJA) for 1951-2008 compared with the regression model described above. Variance explained $R^2 = 0.52$, a significant enhancement over the SOI value of $R^2 = 0.10$

Prolonged Drought in Southwest Western Australia.





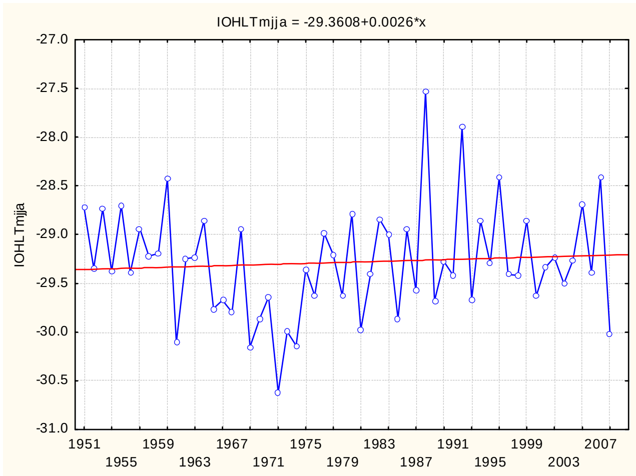


Figure 6**.** Time series of Indian Ocean High properties: (a) pressure (b) longitude (c) latitude

Mechanisms for the Relationships between the Indian Ocean High and the Variability of Precipitation in Western Australia

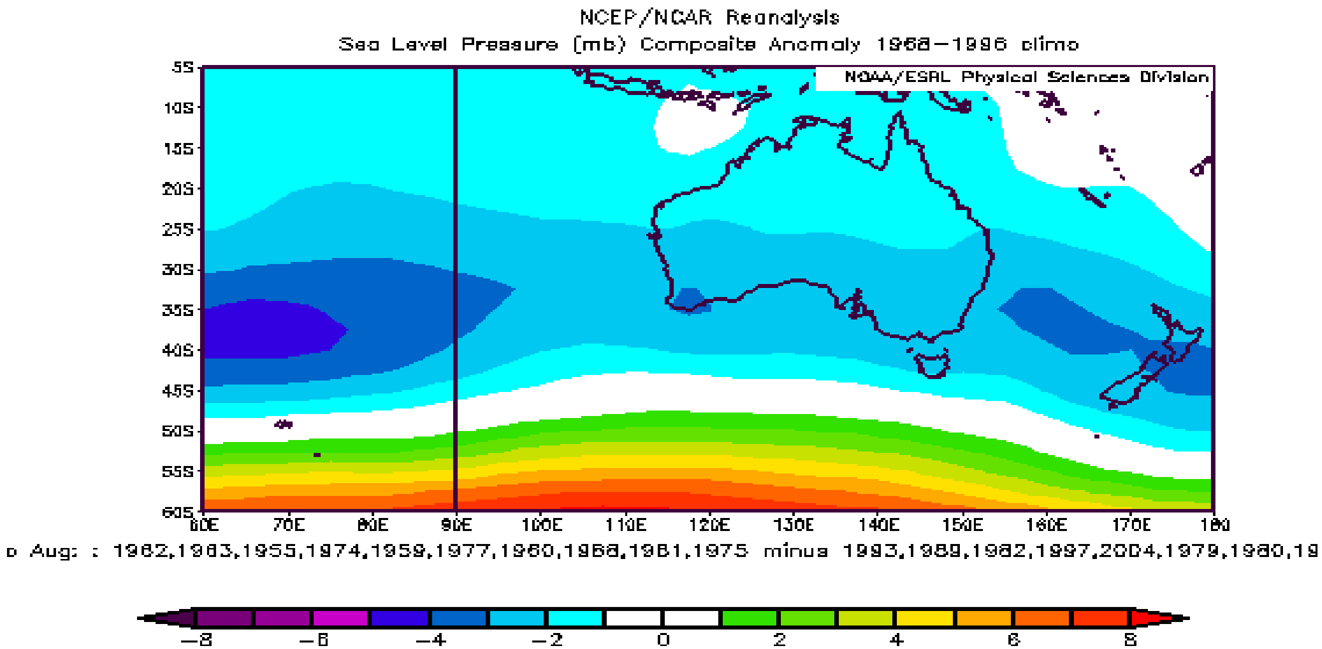


Figure 8. Composite differences of sea level pressure between the 10 winters when Indian High Pressure was minimum (more rain in SWWA) and the 10 years when the Indian High Pressure was maximum (less rain in SWWA).

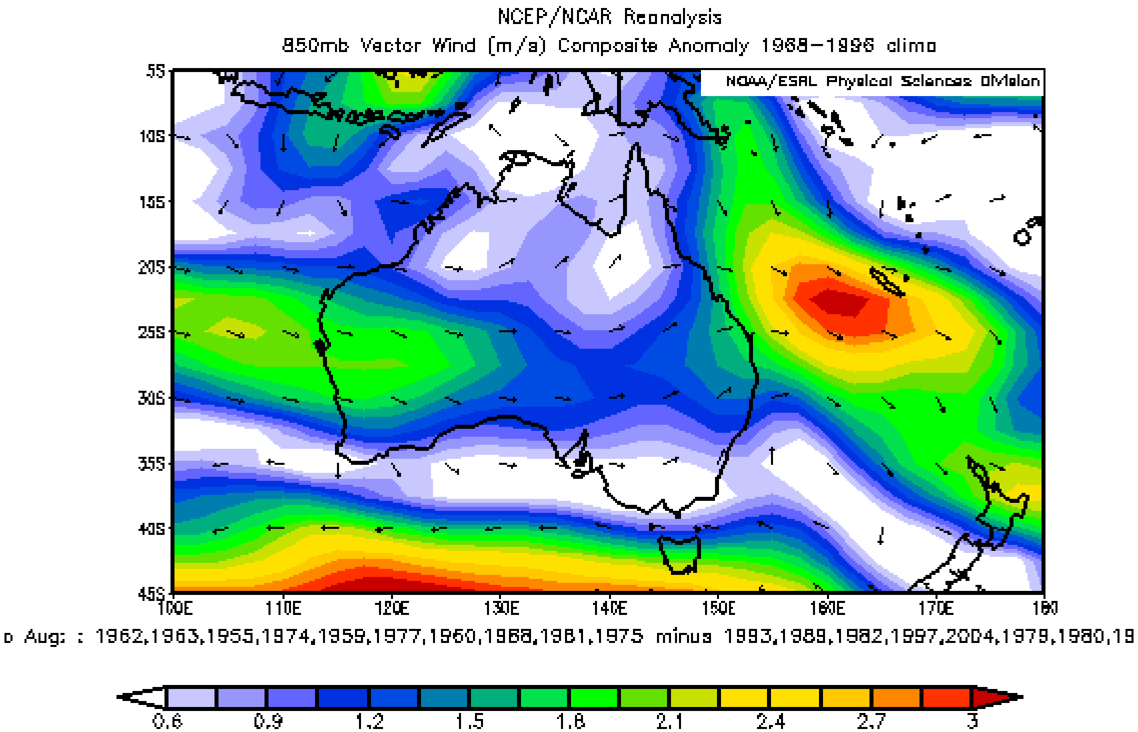


Figure 9. The 850 hPa vector wind composite anomalies between the 10 winters when Indian High Pressure was minimum (more rain in SWWA) and the 10 winters when the Indian High Pressure was maximum (less rain in SWWA).

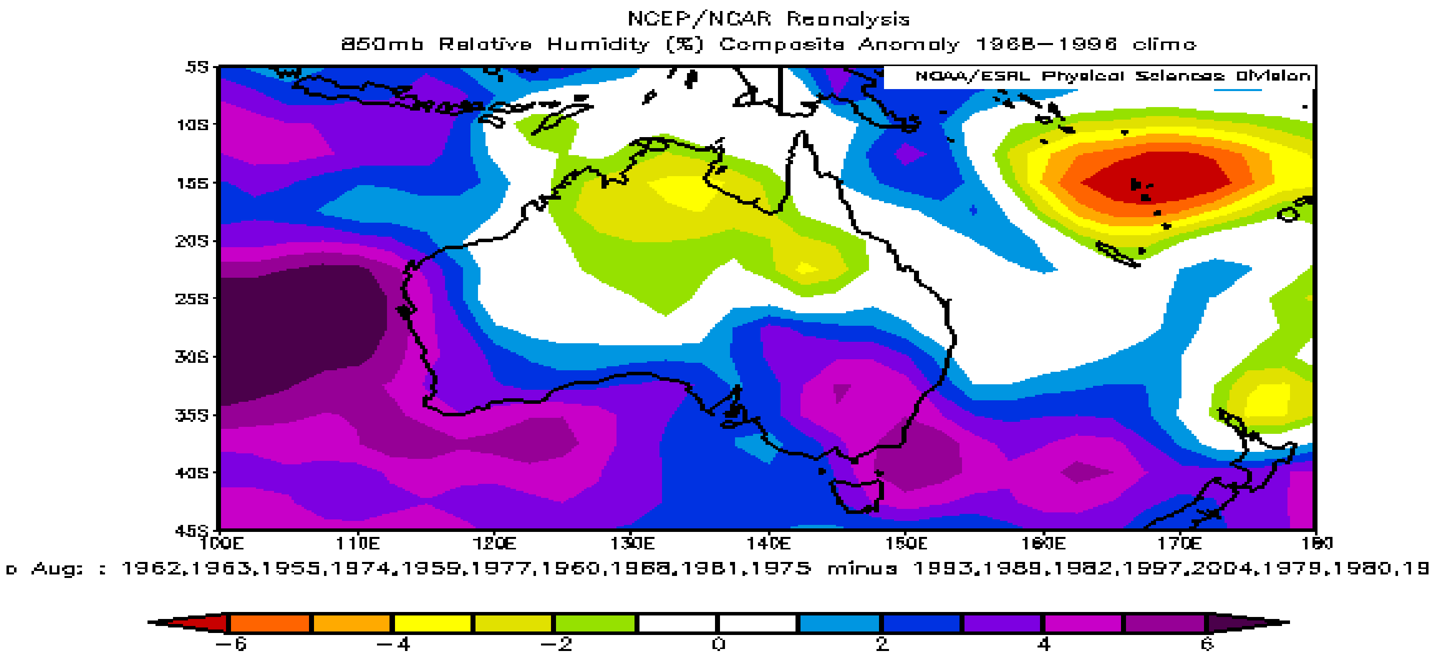


Figure 10. The 850 hPa relative humidity composite anomalies between the 10 winters when Indian High Pressure was minimum (more rain in SWWA) and the 10 winters when the Indian High Pressure was maximum (less rain in SWWA). We see 2 to 5 percent increases over Southwest Western Australia

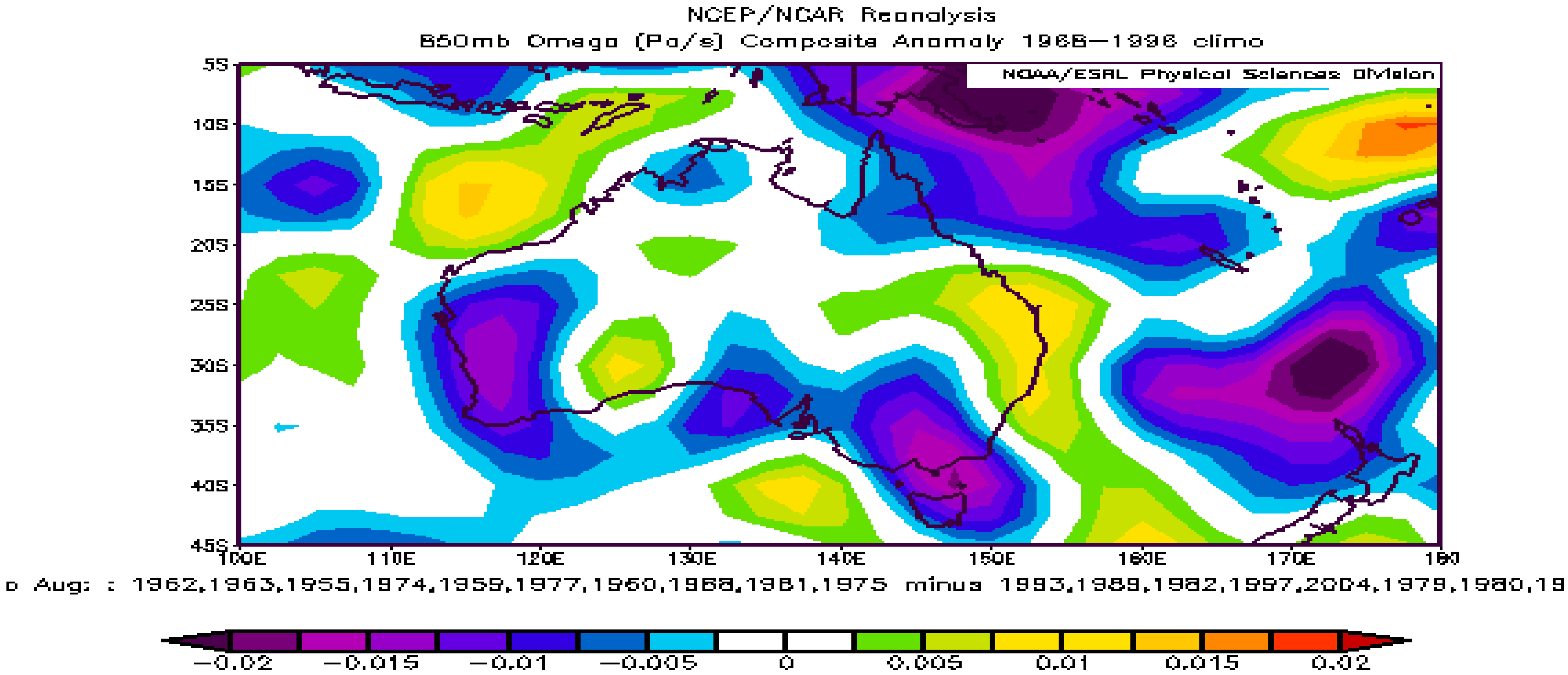


Figure 11. Composites of 850 hPa vertical wind velocity differences between the 10 winters when Indian High Pressure was minimum (more rain in SWWA) and the 10 winters when the Indian High Pressure was maximum (less rain in SWWA. There is predominant ascending velocity over Southwest Western Australia.

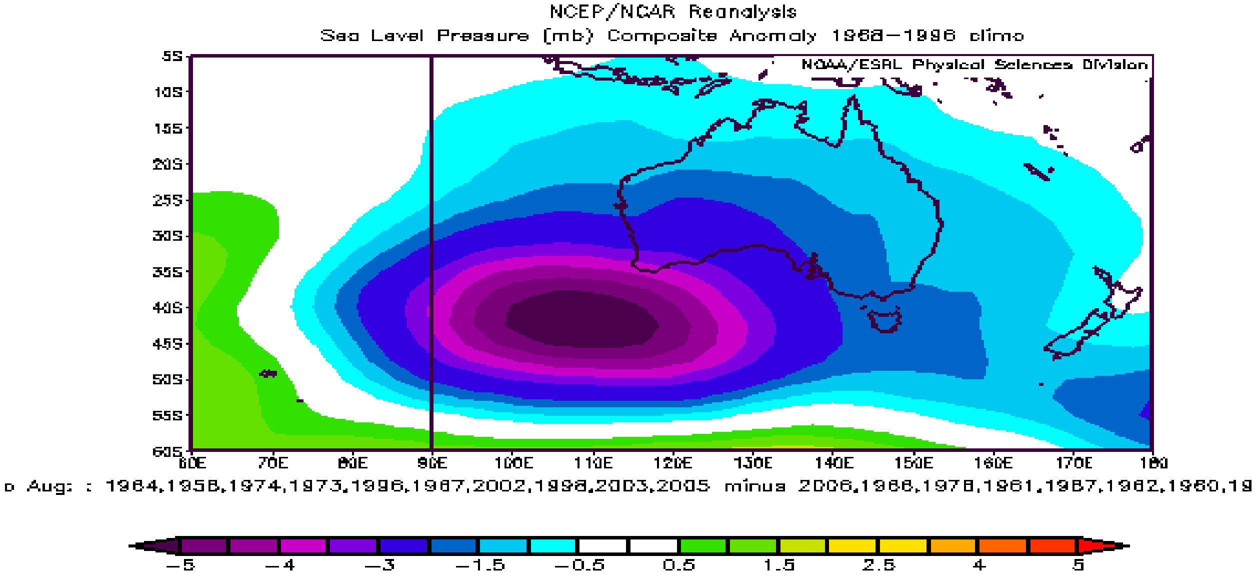


Figure 13. Composite of differences in sea level pressure between winters when Indian High was located to west (more rain in WA) and the 10 winters when the Indian High was located to east (less rain in WA). An anomalous low pressure pattern centered over the ocean extends low into Western Australia.

CONCLUSIONS

- While previous researchers have identified increasing trends in sea level pressres in Southwest Australia as the immediate cause of the ongoing droug/ht in this region, the present paper has examined this relationship in terms of the dynamics of the Indian Ocean High pressure system. Specifically, it was found that th east-west shifts in the position of this subtopical high is a significant deteminant of winter rainfall in Western Australia and Souhwest Australia.

- **It is noteworthy that winter rainfall in Western and Southwestern Australia are much more sensitive to changes in the pressure and the longitudinal position of the Indian Ocan High than it is to fluctuations of sea surface temperatures as represented by the Indian Ocean Dipole in sea surface temperatures**.

- The results presented in this paper offer an alternate pathway to diagnosing the role of global climate change in the progression of drought in western and southwestern Australia.

- The results presented in this paper would suggest examination of the Indian Ocean High in the GCMs. The Indian Ocean High , like other subtropical highs, is a coherent permanent feature of the climate system. Its genesis is in the subsidence of air in the local downward arm of Hadley circulation. Hope (2006) has discussed some aspects of the Indian Ocean High in several coupled GCMs used in the IPCC AR4. A more quantitative comparison of the area weighted pressure and position of the High with those in Reanalysis data can shed light on model skill in calculating regional rainfall in Western and Southwestern Australia, and projecting these quantities into the future.

Thank You