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CHANGES IN DUST STORM OCCURRENCE OVER CENTRAL EASTERN AUSTRALIA: 1950 TO 2004

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ABSTRACT

A sudden decrease in dust storm frequency began in the mid-1970s over central eastern Australia. This decrease is linked to changes in the synoptic circulation during that period. NCEP/NCAR reanalysis data shows a change from anomalous low level south to southeast winds, to anomalous northwesterly winds over central eastern Australia during 1950-1974 and 1975-2004, respectively. Consequently, postfrontal south to southeast winds have decreased and fewer dust storms have occurred. Results from climate model simulations exhibit similar changes in wind anomalies. There appears to be a strong link between these circulation changes and the phases of the Pacific Decadal Oscillation (PDO).

Key Words: Dust Storms; Central Eastern Australia; Anomalies; Circulation; Climate; SST

1. INTRODUCTION

The major dust source regions over inland Australia lie mostly between 25 deg. and 35 deg. S, particularly over the 1.3 million km ^{2} Lake Eyre drainage basin in central eastern Australia (Washington et al. 2003). This is an area devoid of vegetation especially during prolonged dry periods that often halt or restrict the flow in the rivers and tributaries that drain into the basin. When the dry crusty surface comprising mainly of fine drainage basin sediment becomes broken through erosion processes, strong winds can cause the underlying fine dust particles to become airborne. At those Australian Bureau of Meteorology (BoM) synoptic stations where dust is reported, new World Meteorological Organization (WMO) guidelines were introduced from 1957. They consisted of several visibility categories, including: a dust storm/sand storm; well-developed dust devils; raised dust/sand; widespread dust in suspension; or a thunderstorm with dust or sand storm. Prior to 1957, reports of dust in Australia were recorded under just one dust storm category (Bureau of Meteorology 1925).

According to Sprigg (1982) and Ekström et al. (2004), dust storms and raised dust in central, northeastern and eastern Australia occur mainly in spring and summer as a result of strong low level south or southeasterly winds, following mid-latitude frontal systems. The southeasterly winds can extend north as far as 15-20 deg. S. For frontal related dust reports between 1995 and February 2005, Speer and Leslie (2005) found that there were two distinct synoptic types. One type occurs with frontal systems embedded in the zonal westerlies or low pressure systems that sweep across southeast

Australia and the east coast. The other synoptic type occurs with high pressure systems in the Great Australian Bight (GAB), following frontal systems that weaken or at least slow down over southeast Australia, particularly through central Queensland (QLD).

The aims of this study are to analyze the trends in duststorm frequency over the period 1950 to 2004 by investigating their relation first to synoptic scale circulation features over eastern Australia and, second, to large scale circulation features affecting the same region. Finally, the implications for possible changes in dust storm frequency under enhanced greenhouse warming conditions will be discussed for east central Australia.

2. DATA

The dust source region that affects central eastern Australia is the Lake Eyre drainage basin (Speer and Leslie 2005). Dust has been reported along with reductions in visibility for various categories defined by the Australian Bureau of Meteorology synoptic stations since 1957, using WMO standard criteria. Prior to 1957, dust was reported in Australia simply as a single category consisting of a dust storm. Clearly, with the change in reporting practice in 1957 the number of days on which dust was reported will have increased due to that change alone. Concentrating on central eastern Australia, 24 representative synoptic stations were selected and all days on which dust storm criteria were reported from at least at one of the 24 stations were calculated. This calculation produced a total of 2,669 dust storm days (see Fig.1). The key feature in Fig. 1 is the sudden and significant decrease in reported dust days in the early to mid-1970s, a result found earlier by Ekström et al. (2004). Twenty-one of the 24 stations have been operational throughout the entire period and reporting practices have not changed since 1957.

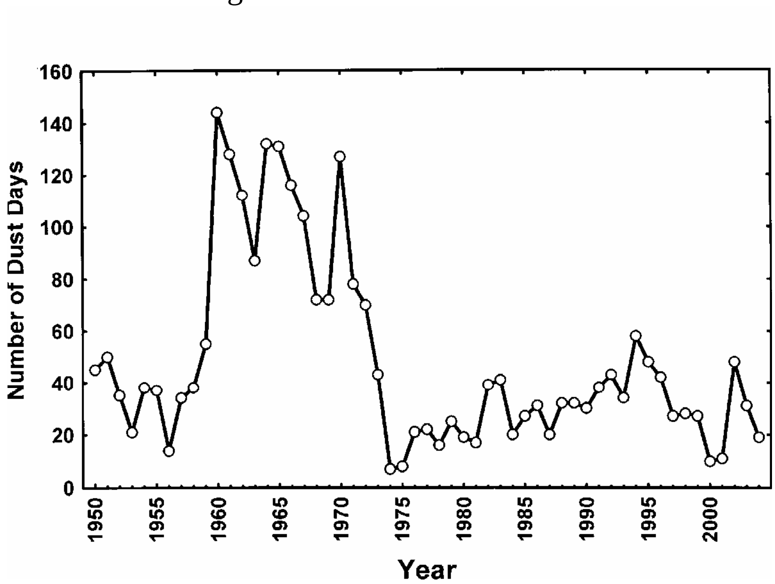
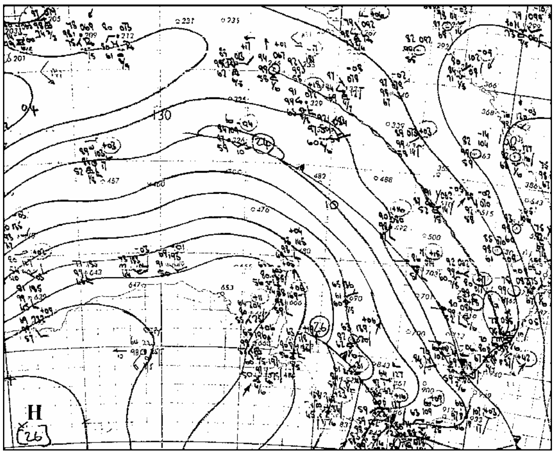


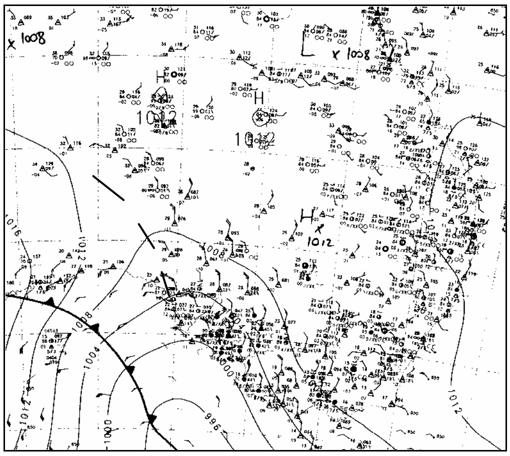
Figure 1. The number of dust days recorded in central eastern Australia during the period 1950 to 2004 from 24 synoptic stations.

A rise or fall in the number of dust reports is expected to coincide with a rise or fall in the number of synoptic scale frontal wind events. Several studies have indicated that the major synoptic influence responsible for dust storms are postfrontal south to southeast winds over eastern Australia resulting from high pressure systems in the GAB following the passage of cold frontal systems (see, e.g., Sprigg 1982; Ekström et al. 2004). However, during the most recent ten-year period, namely 1995 to 2004, Speer and Leslie (2005) have noted that frontal-related dust events accounted for just 18 out of a total of 43 (i.e. 42%), while the remaining 24 out of 43 (i.e. 58%) resulted from the influence of zonal westerlies or low pressure systems in the GAB. Figures 2a and 2b show examples of each of these two synoptic types, Figure 2a being an example of a dust storm produced by a high pressure system in the GAB, and Figure 2b, a dust storm event resulting from a low pressure system in the GAB.



(a)

Figure 2(a). MSLP chart valid at 11 UTC 8 Feb. 1962. Dust was reported over central eastern Australia, from a high pressure system in the GAB and associated postfrontal S/SE winds



(b)

Figure 2(b). MSLP chart valid at 00 UTC 19 Oct. 2002. In this case dust was reported over central eastern Australia, generated by a cold front located in the GAB

The following question immediately arises from the above analysis: “Is the reduction in the number of dust reporting days since the early to mid-1970s due to a corresponding decrease in the influence from high pressure in the GAB, because of fewer postfrontal south to southeast wind events?” In attempting to answer this question the approach adopted in the next Section focuses on a comparison of climate anomalies computed from the NCEP/NCAR re-analysis data. First, the climate reference anomalies for the tropospheric wind vector circulation over the period from 1950 to 2004 are analysed. The climate anomalies are calculated for the time intervals 1950-1974 and 1975-2004, measured relative to the climate mean over the entire time period 1950-2004. Next, a comparison is made of these reanalysis based synoptic circulation anomalies with those of a fully coupled climate model for the same period, based on the recently developed OU-CGCM climate model located at The University of Oklahoma (Karoly and Leslie, 2005). Finally, the possible role of the Pacific Interdecadal Oscillation (PDO) over central east Australia and the adjacent Tasman Sea will be discussed and changes in the tropospheric circulation over eastern Australia during the period 1950-2004 are related to the changes in observed duststorm frequencies.

3. TROPOSPHERIC CIRCULATION AND SST ANOMALIES 1950 TO 2004

Reference climatology

From the analyses of spring and summer 925 hPa vector wind anomalies derived from the NCEP/NCAR reanalyses for the period 1950 to 1974, anomalous south to southeasterly winds were found to be present in Spring (SON) and Summer (DJF) over the dust reporting locations (Figs. 3(a), 4(a)). This is consistent with the strong ridging that occurred south of the continent in that period, following cold frontal system passages. The results are confirmed by the 850 hPa geopotential height anomalies which show anomalous high pressures in the GAB for the same period (not shown). Conversely, the observed anomalous north to northwesterly winds in both spring and summer for the period 1975 to 2004 (Figs. 3(b), 4(b)) are consistent with reduced postfrontal south to southeasterly winds and anomalous negative pressure anomalies in the GAB for the same period (not shown). As a result, the 24 synoptic stations and particularly those nearest to the strongest anomalies have been much less affected by dust from the Lake Eyre basin source region for the period 1975 to 2004 than for 1950-1974.

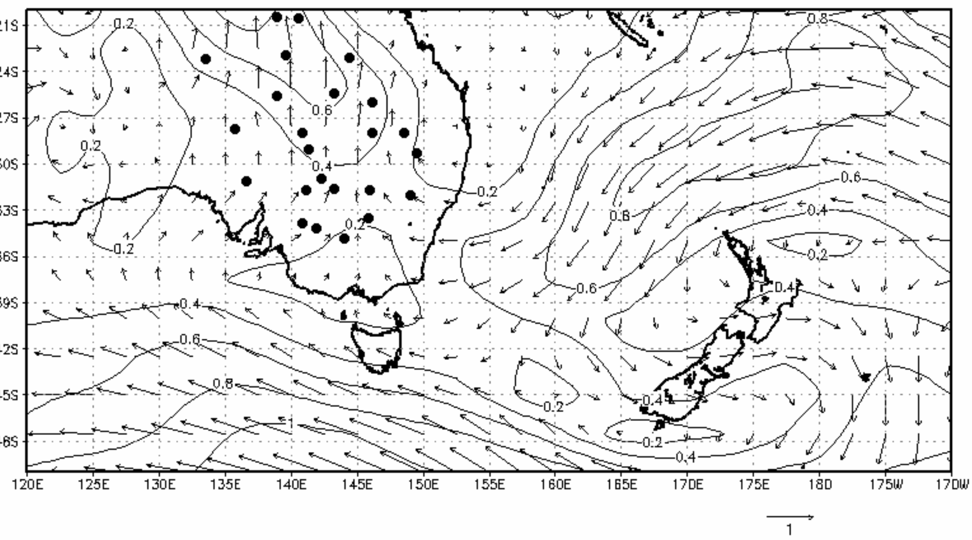


Figure 3(a). The September-November 1950-1974 NCEP 925 hPa vector wind anomaly field (m/s). Dust reporting stations indicated by bullet point symbols (•).

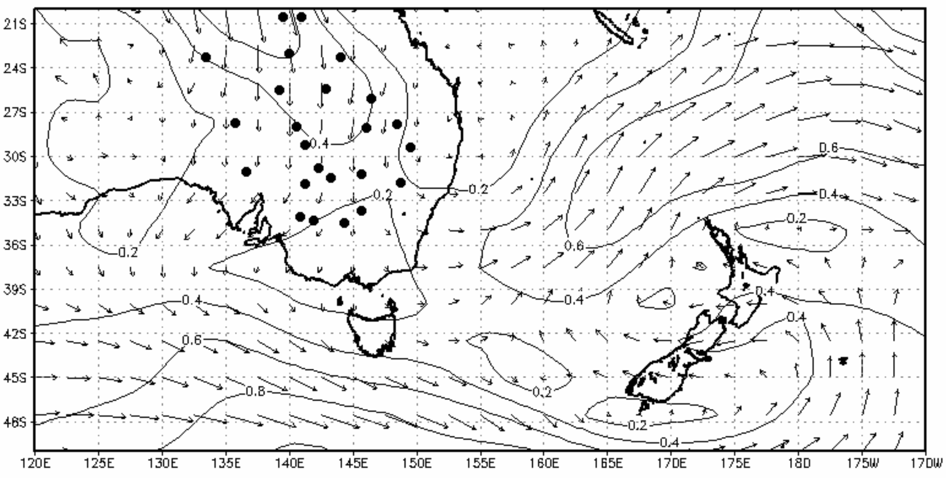


Figure 3(b). Same as in Fig. 3(a), except for 1975-2004

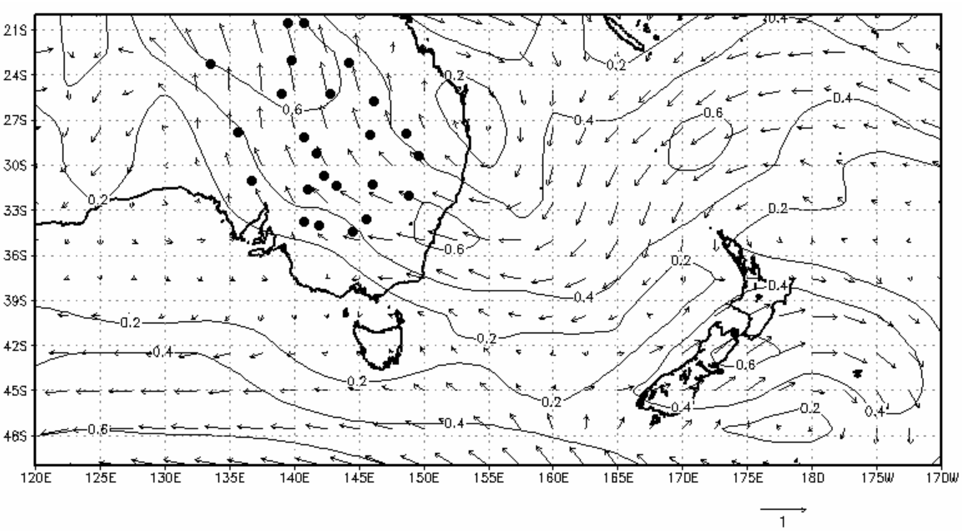


Figure 4(a). The December–February 1950 – 1974 NCEP 925-hPa vector wind anomaly (m/s). Dust reporting stations again are indicated by the bullet point symbol (•).

Climate model anomalies

In this section and thereafter we concentrate on the Southern Hemisphere (SH) summer season (DJF) only. Figures 5(a) and 5(b) show the model 925 hPa December to February wind anomalies over eastern Australia for the two periods 1950 to 1974 and 1975 to 2004, respectively. They should be compared directly with Figs. 4(a) and 4(b), respectively, because the anomalies in both periods are calculated with reference to the same climatological period 1950-2004. There is a striking similarity in the anomaly patterns from the NCEP/NCAR reanalysis data and the OU-CGCM climate model for both periods. In Figure 5(a) the key features are the moderate to strong anomalous south to southeast winds that affect the same area as in Figure 4(a).

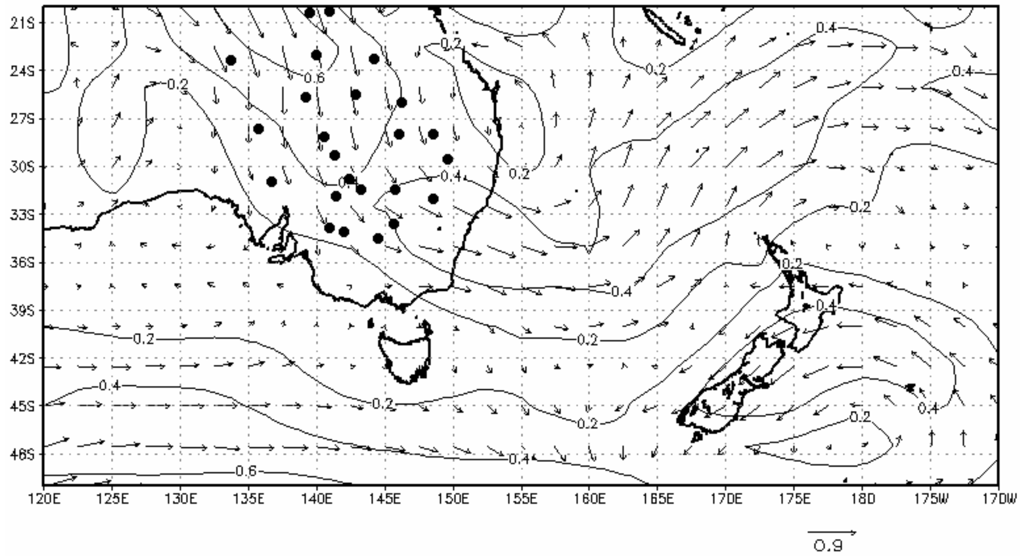


Figure 4(b). Same as in Figure 4(a) except for 1975–2004

Moreover, anomalously weak northerly winds over central eastern Australia in Figure 5(b) closely match the patterns shown by the NCEP/NCAR reanalysis data (Figure 4(b)).

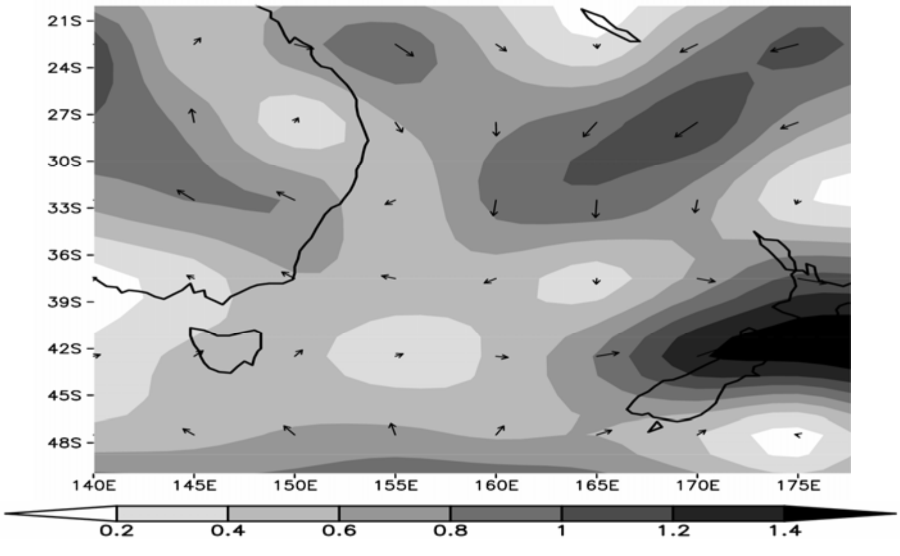


Figure 5(a). Model derived Dec. to Feb. wind anomalies (m/s) at 925hPa for the period 1950-1974 (the model climate reference period is 1950-2004)

Links to the Pacific Decadal Oscillation (PDO)

The PDO is a long-lived, El Niño-like, ocean-atmosphere pattern of Pacific climate variability (Zhang et al. 1997; Mantua et al. 1997). As far as the authors are aware there have been no climate impacts in the SH that have been linked to the PDO thus far. In its last cool phase (includes the period 1950 to mid-1970s) NH SST and

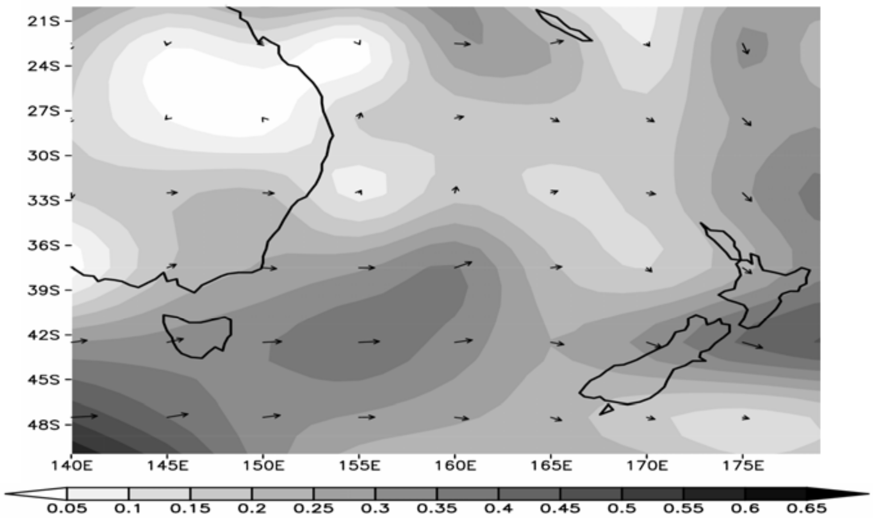


Figure 5(b). As in 5(a), except for 1975 to 2004.

atmospheric anomalies contrast with its warm phase (after 1976) when the PDO exhibits El Nino like characteristics in the NH (Zhang et al. 1997). This contrast in anomalies for the two phases is also the case for the SH to the extent that NCEP DJF climate wind anomalies in Figs. 4(a) and 4(b) show anomalous south to southeasterly winds and north to northwesterly winds, respectively, over southeastern Australia which are consistent with NCEP anomalous positive and negative precipitable water anomalies, respectively, over southeastern Australia for the same periods (see Figs. 6(a) and (b), respectively).

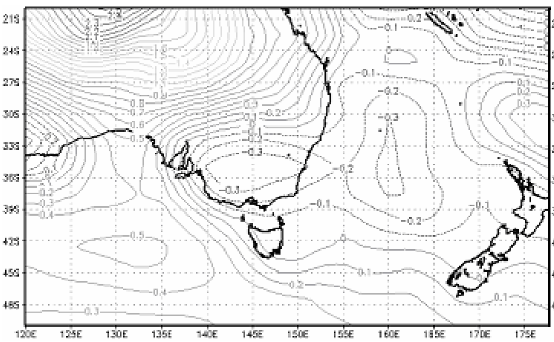


Figure 6(a). NCEP derived DJF precipitable water anomalies for the period 1950-1974

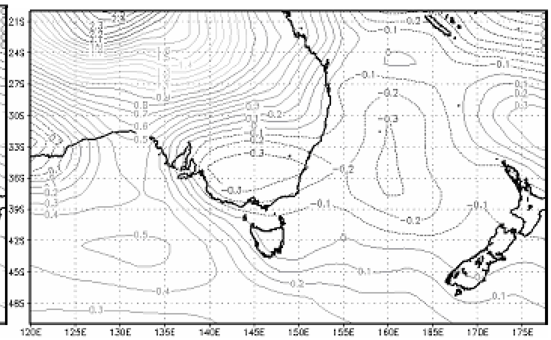


Figure 6(b). NCEP derived DJF precipitable water anomalies for the period 1975-2004

In terms of the SST distribution both the summertime (SH) warm phase and cool phase patterns are consistent with those of Mantua et al. (1997) covering the period 1900 to 1993. The cool phase DJF OU-CGCM pattern in Figure 7(a), that is from 1950 to 1974, closely matches the local NCEP reanalysis SST anomaly pattern for the same period shown in Figure 8(a). Similarly, the current warm phase DJF OU-CGCM pattern in Figure 7(b) matches the local NCEP reanalysis SST anomaly pattern from 1975 to 2004 in Figure 8(b). A key point to note in the figures is the change from anomalously strong positive SST values between New Zealand and Australia in the cool phase of the PDO (1950-1974) to the weak negative SST values between New Zealand and Australia in the warm phase of the PDO which began from about 1975.

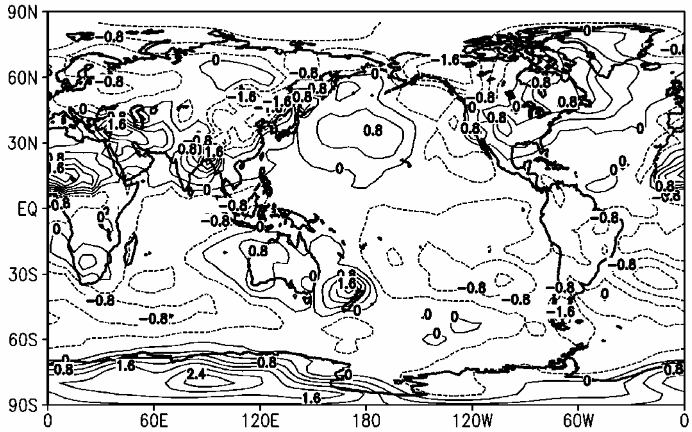


Figure 7(a). DJF model calculated SST (C^{0}) anomaly for the period 1950 – 1974.

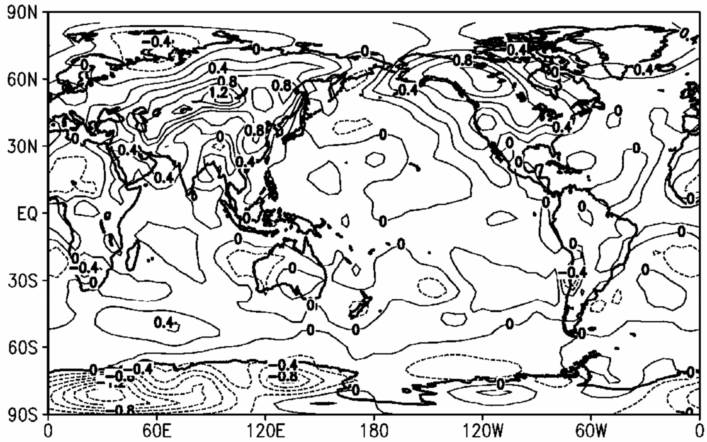


Figure 7(b). As in 7(a) except for the period 1975 – 2004.

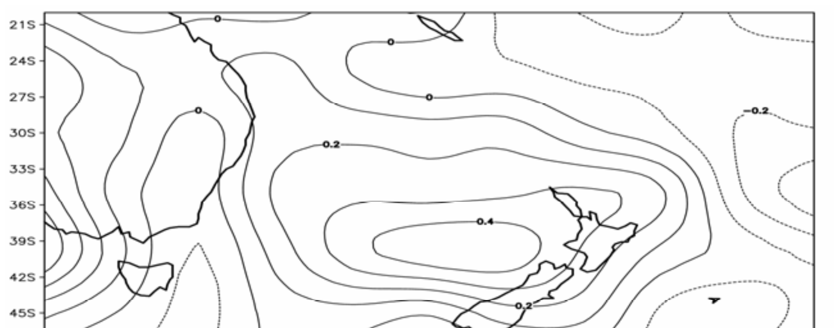


Figure 8(a). NCEP reanalysis SST anomaly (C^{0}) DJF 1950 – 1974

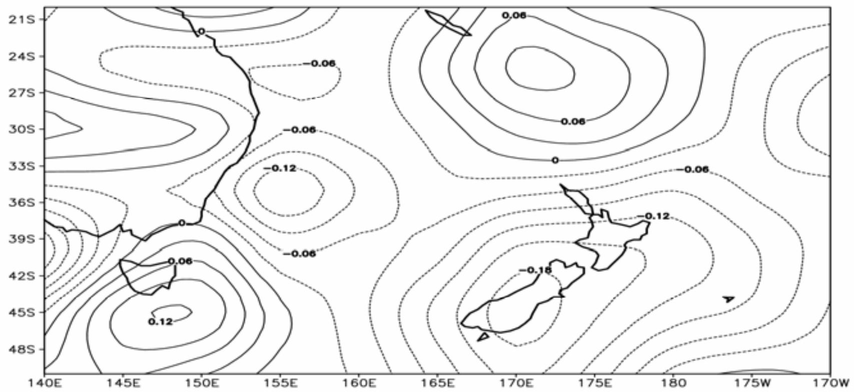


Figure 8(b). as in (a) except for 1975 - 2004

4. FUTURE PLANS TO STUDY THE IMPACTS OF FUTURE CLIMATE CHANGE UNDER ENHANCED CO2 CONDITIONS

The next stage of this study is to assess the impact on future climate of enhanced CO2 concentrations on the multi-decadal oscillation that we have identified here. Before this can be attempted, we must examine how well the OU-CGCM climate model performs under current climate conditions. In particular, can the climate model reproduce the main features observed in the period 1950-2004. We carried out this experiment by spinning up the climate model over 30 years from 1920 and then integrating it for a further 55 years, from Jan 1 1950 to the end of 2004. We then compared the wind vector anomalies and the SST distributions over the region of interest with the NCEP reanalyses, for the two periods 1950-1974 and 1975-2004. The results of this comparison are shown in the previous section. They are sufficiently encouraging that we have decided to analyse the OU_CGCM model run out to 2100 in a future study that will be reported on when it is completed.

5. CONCLUSIONS

In this study we identified a multi-decadal oscillation in the large scale circulation of the east central Australian region and the Tasman Sea that covered the periods 1950-1974 and 1975-2004 approximately. The impacts of this oscillation, which almost certainly is part of the larger Pacific Decadal Oscillation, are numerous and include the following. In the earlier period there are anomalous low level easterly winds over the near coastal region and east Australian coast accompanied by anomalously high precipitable water values. Further inland over central eastern Australia the anomalous southeast winds are linked to increased dust storm activity over the same area. In contrast, for the latter period there are anomalous low level northwest to westerly winds over the near coastal region and east Australian coast accompanied by anomalously low precipitable water values. This means that fronts with postfrontal south to southeasterly winds and dust storms sourced from the Lake Eyre region have affected the area much less in this period than the first period.

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