Seasonal climate summary
southern hemisphere (spring 2001):
persistence of near-normal conditions
in the tropical Pacific

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Southern hemisphere circulation patterns and associated anomalies for the austral spring 2001 are reviewed, with emphasis given to the Pacific Basin climate indicators and Australian rainfall and temperature patterns. Spring 2000 and summer 2000/01 saw the development of a positive phase of the Southern Oscillation. By autumn 2001, the Southern Oscillation had returned to a neutral state, which persisted through to spring 2001.

Spring rainfall was above to very much above average across most of Tasmania, central and western Australia, and central Queensland. For most of the rest of the country, spring rainfall was near average. Spring was cooler than average across most of the continent with respect to both maximum and minimum temperatures. Tasmania on the other hand recorded a warmer than average spring.

Introduction

The positive phase of the Southern Oscillation which developed during spring 2000 (Watkins 2001) and persisted through summer 2000/01 (Fawcett 2002), returned to a neutral phase by autumn 2001 (Pahalad 2002). The neutral conditions which became established during autumn 2001 persisted through winter (Fawcett and Watkins 2002) into spring.

This summary reviews the southern hemisphere and equatorial climate patterns for spring 2001, with particular attention given to the Australasian and Pacific regions. The main sources of information for this report are the Climate Monitoring Bulletin (Bureau of Meteorology, Australia) and the Climate Diagnostics Bulletin (Climate Prediction Center, Washington). Further details regarding sources of data are given in the Appendix.

Pacific Basin climate indices

The Troup Southern Oscillation Index*
The set of largely neutral monthly values (+1.8, −3.0, −8.9) for winter 2001 (Fawcett and Watkins 2002) of the Troup Southern Oscillation Index (SOI) was followed by +1.4 (September), −1.9 (October) and +7.2 (November), indicating the continuation of a neutral state of the Southern Oscillation. Supporting this view, the 30-day values of the un-normalised Tahiti-Darwin pressure difference (not shown) stayed mostly within one standard deviation of their estimated climatological values.

The September/October and October/November values of the Climate Diagnostics Centre (CDC) Multivariate El Niño-Southern Oscillation (ENSO) Index (MEI) covering the season were both weakly

*The Troup Southern Oscillation Index (SOI) used in this article is ten times the standardised monthly anomaly of the difference in mean sea-level pressure between Tahiti and Darwin. The calculation is based on a sixty-year climatology (1933-1992).
negative (thereby indicating conditions slightly more like a La Niña than an El Niño). As the MEI is derived from a number of atmospheric and oceanic indicators, it reinforces the truly neutral state suggested by the winter values of the SOI.

The rise in the SOI towards the end of the season was due more to the accumulation of positive anomalies at Tahiti than negative anomalies at Darwin. Negative anomalies at both stations in October largely offset each other.

Figure 1 shows the monthly SOI values from January 1997 to November 2001. A curve of five-month moving averages has been superimposed on the graph.

**Outgoing long wave radiation**

Figure 2, adapted from the Climate Prediction Center (CPC), Washington (CPC 2001), shows the monthly standardised anomaly of outgoing long wave radiation (OLR) from January 1997 to November 2001, together with a three-month moving average. These data, compiled by the CPC, are a measure of the amount of long-wave radiation emitted from an equatorial region centred about the date-line (5°S to 5°N and 160°E to 160°W). Tropical deep convection in this region is particularly sensitive to changes in the phase of the Southern Oscillation. During warm (El Niño) ENSO events, convection is generally more prevalent resulting in a reduction in OLR. This reduction is due to the lower effective black-body temperature and is associated with increased high cloud and deep convection. The reverse applies in cold (La Niña) events, with less convection in the region expected.

The monthly values +0.6 (September), +0.2 (October) and +0.1 (November) of this index were consistent with a neutral state of the Southern Oscillation. The September value was the highest value since March 2001, at the end of the third successive positive phase of the Southern Oscillation seen in recent years.

In the Pacific, increased OLR (not shown) was experienced in an area centred east of the Solomon Islands, whilst decreased OLR occurred across scattered regions through the central South Pacific. OLR anomalies over the Australian continent and to its north were generally negative, reflecting the above-average rainfall that much of the continent experienced during the season.

**Oceanic patterns**

**Sea-surface temperatures**

Figure 3 shows the spring 2001 sea-surface temperature (SST) anomaly in degrees Celsius (°C). The contour interval is 0.5°C. Positive anomalies are shown in orange and red shades, while negative anomalies are shown in blue shades.

Spring 2001 sea surface temperatures were generally above average in the western equatorial Pacific, with a band of anomalies along the equator in the +0.5 to +1.0°C range between 160°E and 150°W. This was reflected in the monthly values of the NINO4 SST index, as calculated by the National Meteorological and Oceanographic Centre (NMOC), Melbourne, which were +0.739°C (September), +0.472°C
Fig. 3  Anomalies of sea-surface temperature for spring (September, October, November) 2001 (°C). The contour interval is 0.5°C.

(October) and +0.481°C (November). Weekly values of this index (not shown), also as calculated by NMOC, showed generally rising values from February 2001 through to September, followed by generally declining values for the remainder of the year. This generally downward trend in NINO4 in the latter part of the year was temporarily interrupted in November, as can be inferred from November’s value being slightly higher than October’s.

In the eastern equatorial Pacific, the anomalies on and south of the equator were generally negative, although just north of the equator, some positive anomalies were observed. NMOC’s monthly values of the NINO3 SST index were weakly negative for each of the spring months.

Much of the Indian Ocean north of 40°S was warmer than usual in spring, although anomalies were generally smaller than those which occurred in winter, with only small areas having anomalies exceeding 0.5°C. Except in the south Tasman Sea, sea-surface temperatures around the Australian coastline were mostly near normal.

The band of negative SST anomalies around Antarctica in the latitudes between 40°S and 60°S, which has been present for most of the past year (Fawcett 2002; Pahalad 2002; Fawcett and Watkins 2002), remained during spring, although the strength of the anomalies was reduced, with only small areas below -1.0°C.

Subsurface patterns
Figure 4 shows a time-longitude diagram of the anomaly in metres of the depth of the 20°C isotherm along the equatorial Pacific Ocean between January 1996 and November 2001, as calculated by the Bureau of Meteorology Research Centre (BMRC). This isotherm is generally situated very close to the equatorial ocean thermocline, the region of greatest temperature gradient with respect to depth. The thermocline can also be regarded as the boundary between the upper ocean warm water and the deeper ocean cold water. An abnormally shallow thermocline in the eastern Pacific Ocean is characteristic of La Niña events. Positive anomalies correspond to the 20°C isotherm being deeper than average, and negative anomalies to it being shallower than average.

Winter 2001 had been characterised by a slightly deeper than normal 20°C isotherm (implying slightly warmer than average subsurface temperatures) across most of the equatorial Pacific. This state of affairs largely continued into spring, although there was some cooling in the eastern Pacific (east of 120°W). As in 2000, though, the relatively large anomalies which occurred in the western Pacific during the first half of the year were not sustained into the late winter or spring.

In the first half of 2001, there had been speculation about a transition to El Niño conditions. As previously reported (Fawcett and Watkins 2002), nothing in this regard had eventuated by the end of winter.
Atmospheric patterns

Surface analyses
The spring 2001 mean sea-level pressure (MSLP) across the southern hemisphere is shown in Fig. 6, with the associated anomalies shown in Fig. 7. These anomalies are the departures from an eleven-year (1979-1989) climatology obtained from the European Centre for Medium-range Weather Forecasts (ECMWF). The MSLP analysis itself has been computed using data obtained from the Bureau of Meteorology’s Global Assimilation and Prediction (GASP) model daily 2300 UTC analyses.

The low pressure anomaly over high elevation parts of South America and the high pressure anomaly over the Antarctic plateau are persistent features, and appear to be the result of a systematic difference between the GASP and ECMWF models and the way they extrapolate down to mean sea level. Therefore, the indicated low pressure over parts of South America should not be treated as a meteorological consequence of the current state of the El Niño-Southern Oscillation.

The Antarctic circumpolar trough showed three substantial minima, located at 75°E, 130°W and 30°W. The minimum at 30°W was some 10 hPa stronger than normal, while the minimum at 130°W was some 6 to 7 hPa stronger than normal. In the lat-
Fig. 6  Spring 2001 mean sea-level pressure (hPa). The contours are spaced at 4 hPa intervals between 972 hPa and 1024 hPa.

Fig. 7  Spring 2001 mean sea-level pressure anomaly (hPa). The contours are spaced at 2 hPa intervals between -14 hPa and +20 hPa.

The point of strongest anomaly was displaced somewhat from the point of lowest pressure. The minimum near 75°E was of near-normal intensity.

MSLP values for the season were below average across most of the equatorial Pacific, the major exception being in the far west. A region of slightly below average pressure was present, however, over the island of New Guinea.

MSLP values over Australia were generally slightly above average north of 30°S, and slightly below average to the south. Anomalies were below 2 hPa throughout the continent. A substantial area of anomalously high pressure was located to the south of the continent over the Southern Ocean, indicating a southward displacement of the circumpolar trough.

Mid-tropospheric analyses
The mean 500 hPa geopotential height patterns for spring 2001 are shown in Fig. 8, with anomalies shown in Fig. 9. The pattern to the anomalies around Antarctica (Fig. 9) broadly followed a two-wave pattern, with negative anomalies located near 45°E and 125°W. Around 50°S however, the anomalous flow characteristics were closer to a three-wave pattern, with positive anomalies to the southeast and southwest of Australia and a third positive anomaly almost diametrically opposite. In some contrast to the MSLP pattern (Fig. 7), more than half of the Australian continent recorded negative anomalies, consistent with the cool conditions experienced over much of the continent during spring.

A subtle splitting of the flow was present over the Tasman Sea (Fig. 8) for the season. Something of this kind was also observed in winter (Fawcett and Watkins 2002).

Blocking
Figure 10 is a time-longitude section of the daily southern hemisphere mid-level Blocking Index,

\[ BI = 1/2[(u_{25} + u_{30}) - (u_{40} + 2u_{45} + u_{50}) + (u_{55} + u_{60})] \]

Here, \( u_\lambda \) indicates the 500 hPa level zonal wind component at \( \lambda \) degrees of southern hemisphere latitude ranging from 0° at the equator to +90° at the South Pole. The blocking index measures the strength of the 500 hPa flow at the mid-latitudes (40°S to 50°S) relative to that at subtropical (25°S to 30°S) and high (55°S to 60°S) latitudes.

Taken across the entire season in the form of a seasonal mean (Fig. 11), southern hemisphere blocking was above average in Australian longitudes, the disposition of positive and negative anomalies referred to above (Fig. 9) contributing to this. Blocking was also higher than average in the southern Atlantic Ocean.

Winds
Low-level (850 hPa) and upper-level (200 hPa) wind anomalies for spring 2001 are shown in Figs 12 and 13 respectively.
The low-level spring wind anomalies (Fig. 12) were southerly to south-easterly across the eastern half of the equatorial Pacific, similar to those for winter (Fawcett and Watkins 2002). In the western equatorial Pacific, the anomalies were much weaker and more variable in direction, although easterly on the equator itself. The upper-level flow (Fig. 13) had westerly anomalous characteristics just south of the equator, suggesting a slightly enhanced Walker circulation for the season. This would be consistent with the slightly positive average SOI for the season.

For the tropical Indian Ocean, while there was some anomalous cross-equatorial (monsoonal) flow in the low levels for spring, it was weaker than the corresponding winter anomalous flow, was mainly confined to the far east, and had little signature in the upper-level anomalies. In fact, the equatorial anomalies across the Indian Ocean were mostly westerly in the low levels, with upper-level easterly anomalous return flow. This upper-level flow showed a strongly diffuent pattern over the western tropical Indian Ocean.

Low-level wind anomalies over Australia were mostly north-westerly, with the strongest anomalies occurring through the centre of the continent. There were strong westerly anomalies at upper levels over northern Australia, and easterly anomalies south of the continent, consistent with a cyclonic anomaly at upper levels over south-western Australia. This may, in turn, be consistent with the high spring rainfalls observed over much of western and central Australia.
Fig. 11  Mean southern hemisphere blocking index for spring 2001 (bold line). The dashed line shows the corresponding long-term average. The horizontal axis shows degrees east of the Greenwich meridian.

Ozone

As described in the previous spring seasonal summary (Watkins 2001), the Austral spring is typically the time of the maximum extent of the Antarctic ozone hole, as well as the time of lowest annual ozone levels. In the absence of sunlight, the wintertime polar vortex in the lower stratosphere cools to below -80°C, and ice clouds form. Chlorine and bromine compounds react in the ice clouds to produce chemical species that, when combined with the incoming UV radiation as the sunlight returns in spring, destroy ozone (WMO 1998). As the stratosphere warms in spring (and hence ice clouds can no longer form) this process weakens. Ozone levels then return to near normal by early summer. The compounds that lead to the ozone breakdown are largely anthropogenic, but now appear to be in decline (WMO 1998).

Figure 14 shows the mean ozone measurements for spring 2001 from the Total Ozone Mapping Spectrometer (TOMS) instruments. Typically, the ozone hole is taken as the area of total column ozone with a value of less than 220 Dobson Units.

The ozone hole in 2001 peaked in size at around 25-26 million km². This was smaller than the record values reached in 2000, when a peak near 28.5 million km² occurred in early September. However, the early dissipation of the ozone hole that occurred in 2000,
when it had declined substantially in size by late October, was not repeated in 2001. In 2001, the hole remained largely intact through the end of October, before declining through November and disappearing altogether by mid-December, a pattern consistent with most other years in the past decade. (WMO 2001).

The minimum ozone values recorded over the Antarctic continent in 2001 were near 100 Dobson Units (DU). These were similar to values in 2000 and somewhat above the record lows of 88 DU which occurred in 1993 (NOAA 2000).

The ozone hole in 2001 was largely consistent in size, duration and depth with the climatological mean over the last decade.

**Australian region**

**Rainfall**

Figure 15 shows the spring rainfall totals for Australia, while Fig. 16 shows the spring rainfall deciles, where the deciles are calculated with respect to gridded rainfall data for all springs from 1900 to 2001.

Spring rainfall was above to very much above average across most of the western two-thirds of the country. Also similarly affected were Tasmania, parts of western and southern Victoria and scattered areas across Queensland. Near-average totals predominated in remaining parts of the country, with few substantial areas of below-average rainfall.

All three months were wetter than normal over extensive areas of Australia, especially October, in which extensive regions in western and central Australia had rainfalls in the top 10% of recorded falls. This marked a continuation of the abnormally wet conditions which have persisted in the central and western interior since the beginning of 1999.
The main features of the season were the development of active low-pressure troughs in the tropics, particularly in October and November, and a series of significant disturbances in the westerlies across the south of the continent. Interactions between these two zones of activity were common.

**Temperatures**

Figures 17 and 18 show the maximum and minimum temperature anomalies respectively for spring 2001. The anomalies have been calculated with respect to the 1961-1990 period.

Spring maximum temperatures were below average across most of the continent, the major exceptions being northern and coastal areas (Fig. 17). A large area extending from the centre of the continent into inland Western Australia and down into coastal South Australia recorded anomalies between -1 and -2°C, with peak anomalies between -2 and -3°C around the WA/NT/SA border. Part of the northwest coast of Western Australia also recorded anomalies between -1 and -2°C, with peak anomalies between -2 and -3°C.

Around the northern and coastal fringes of the continent, the anomalies were generally positive, exceeding +1°C in a number of Queensland and New South Wales locations. Tasmania also recorded positive anomalies for the season.

The seasonal averages masked considerable differences between the three months. September was mostly warmer than usual, with anomalies near 3°C in western New South Wales. In contrast, October was very cool, with widespread anomalies below -3°C (up to 5°C in northern South Australia), and November was also cooler than normal in most of the country. In some locations, particularly in Tasmania, September was the warmest month of the spring, and November the coolest, a reversal of the normal seasonal pattern.
The pattern of spring minimum temperature anomalies (Fig. 18) showed similarities to the maximum temperature pattern, although with generally reduced amplitude and spatial coherence. Most of the country experienced negative anomalies for the season, but only in scattered places (mostly in the interior) did the anomalies reach the −1 to −2°C range. As with the maximum temperatures, coastal parts of the Northern Territory and Queensland mostly recorded positive anomalies, but only reaching the +1 to +2°C range in a few places. Tasmania also recorded positive anomalies for the season. As for maximum temperatures, September was generally warmer than usual, and October and November cooler.

References


Appendix

Data sources used for this review were:

- National Climate Centre, *Climate Monitoring Bulletin - Australia*. Obtainable from the National Climate Centre, Bureau of Meteorology, GPO Box 1289K, Melbourne, Vic. 3001, Australia.

- Climate Prediction Center (CPC), *Climate Diagnostics Bulletin*. Obtainable from the Climate Prediction Center (CPC), National Weather Service, Washington D.C., 20233, USA.