The tropical circulation in the Australian/Asian region - May to October 2002

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A summary of the broadscale tropical circulation from 70°E to 180°, for the six months May to October 2002, is presented. Starting from the neutral conditions at the beginning of the period, a weak to moderate El Niño evolved through the season. El Niño conditions were endorsed by positive pressure anomalies over most of the equatorial latitude belt, negative values of the Southern Oscillation Index, warm sea-surface temperature anomalies in the northwestern Pacific and westerly wind anomalies at lower levels in the equatorial Pacific close to the dateline supported by an eastward shift in the weather patterns. Though a few major active convective events occurred during the season, only three could be attributed to the 30 to 60-day intraseasonal oscillation with periodicity around 35 days at the beginning and end of the season; with a gap of 50 to 60 days in the middle. However, several convective periods enhanced by the passage of waves such as equatorial Rossby waves and gravity waves made it difficult to estimate the Madden-Julian Oscillation (MJO) west to east propagation and the periodicity accurately. A total of 23 tropical cyclones (10 typhoons) developed during the period, less than the mean (26) for the RSMC area, which is consistent with the moderate El Niño conditions.

Introduction

This summary reviews the broadscale tropical circulation in the Australian/Asian region during the period May to October 2002. The area covered is the Darwin Regional Specialised Meteorological Centre (RSMC) analysis domain, that is, 70°E to 180°, 40°N to 40°S. Seasons such as those of 2000 and 2001 were described in previous summaries in this series by Shaik and Bate (2001 and 2002b). The first section of this summary uses mostly six-month average charts to describe the overall seasonal circulation and anomalies. The second section uses time series to portray variations of the tropical circulation within the season. Intra-seasonal variability of various elements, such as outgoing long-wave radiation (OLR), 200 hPa velocity potential and mean sea-level pressure (MSLP) anomaly, are analysed in this section. The third section briefly describes the occurrence of tropical cyclones in the six-month period. Data sources used in this study are detailed in the Appendix.

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Broadscale seasonal features

Southern Oscillation

Figure 1 shows the ten-year behaviour of Troup's Southern Oscillation Index (SOI) from November

Fig. 1 **SOI time series for ten years to October 2002: monthly values (bars); five-month centred mean values (black line).**

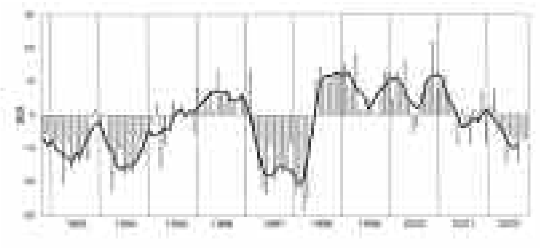
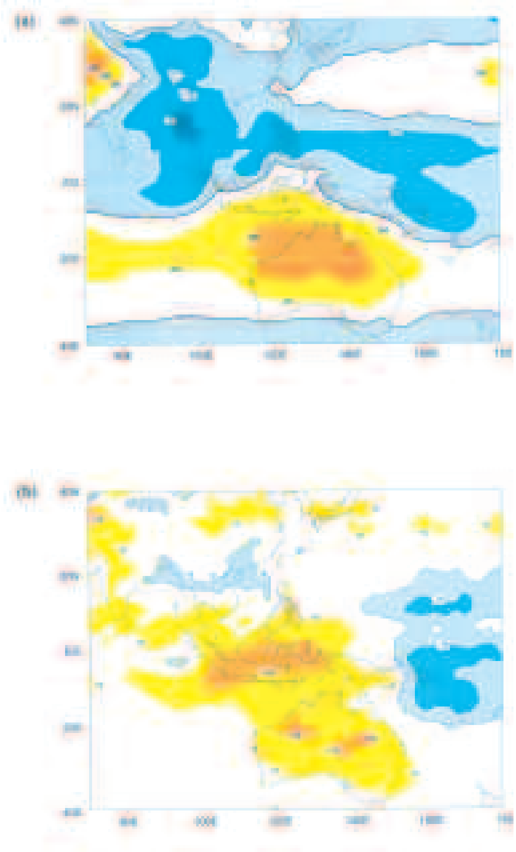


Fig.2 **Six-month (May to October 2002) (a) mean OLR (W m^{-2}), heavy line 240 W m^{-2}, 260 W m^{-2} and above yellow shading, 240 W m^{-2} and below blue shading: (b) OLR anomaly (W m^{-2}), > +5 W m^{-2} yellow shading, < -5 W m^{-2} blue shading.**



1992 and its symmetrical five-month running mean. Monthly values of the SOI from January 2000 are given in Table 1. During the season, the five-month running mean of the SOI reached its lowest value since April 1998, dropping to -10 in July 2002 (centred upon July), with the mean SOI for the season at –9.7, much lower than the previous two seasons (-0.1 and –3.3 during November 2001 to April 2002 season and May to October 2002 season respectively). Persistent negative monthly SOI values around one standard deviation support the establishment of moderate El Niño conditions.

Convection and tropospheric circulation

The OLR mean and anomaly – used as a proxy for convection – for the six-month period are shown in Fig. 2(a) and 2(b) and for each individual month are shown in Figs. 3(a) to (f) and 4(a) to (f) respectively. Areas of above average convection during the season in the RSMC area were confined between 150°E and the date-line in the tropical Pacific, a feature associated with El Niño conditions. Positive OLR anomalies over the Indian subcontinent during July indicate below average convection associated with the monsoon over the region and are consistent with the correlation studies relating it to the El Niño events. Monthly OLR anomaly figures indicate that the above average convection in the northern hemisphere during June and August was confined to the equatorial western Pacific. Below average convection was recorded for the season over Indochina, Indonesia, Philippines and Papua New Guinea. High positive anomalies over India are in line with

Table 1. Monthly values of Troup's SOI for the period January 2000 to October 2002.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
2000	+5	+13	+9	+17	+4	-5	-4	+5	+10	+10	+22	+8
2001	+9	+12	+7	0	-9	+2	-3	-9	+1	-2	+7	-9
2002	+3	+8	-5	-4	-14	-6	-8	-15	-8	-7		

a restrained monsoon over India. In the southern hemisphere, most of the Australian continent was drier than normal, typical of an El Niño-related weather pattern.

The axes of low level convergence and upper level divergence as indicated in the velocity potential analyses at 850 hPa and 200 hPa levels respectively (Fig. 5) remained close to their respective climatological mean positions, similar to the May – October 2001 season (Shaik and Bate 2002b). However, the centres of strong low level convergence and upper level divergence were positioned east of their respective mean location (means not shown). Overall, the upper level divergence was weaker than normal indicating weaker than normal Hadley circulation associated with the monsoon. The good vertical alignment of the centres of low level convergence and upper level divergence in the western Pacific indicate well organised upmotion of a vigorous Hadley circulation in the area.

Seasonally averaged mean sea-level pressure (MSLP) and anomalies are shown in Fig. 6. Pressures were slightly higher than normal over most of the tropics west of 150°E. The weak negative anomalies in the central western Pacific coincided with the area of cyclone formation during the season. Except for a few patches of negative pressure anomalies over Indochina, most of the monsoon trough areas in the northern hemisphere recorded higher than normal pressures. Higher than normal pressures in the west and negative pressure anomalies in the eastern tropics are consistent with El Niño conditions. Pressures over Australia remained slightly higher than normal.

Vector wind analyses and anomalies at 850 hPa and 200 hPa are shown in Figs 7 and 8 respectively. Moderate westerly anomalies implying weak easterlies persisted at the lower levels over most of the tropical western Pacific, typical of El Niño conditions. The upper-level easterlies over the western Pacific were close to climatology but the anomalies over the southern hemisphere indicate a strong meridional component in the westerly flow. Despite the weak monsoon in the northern hemisphere, cross equatorial flow at lower levels was stronger than climatology. However, the cross equatorial flow over the Indian Ocean turning more towards the southern Bay of Bengal rather than the Indian Peninsula and a strong low-level speed convergence over the Andaman Sea, contributed to a subdued performance of the monsoon over the Indian region. Though the onset of the monsoon over India took place on 29 May, three days ahead of the average date, below average rainfall was recorded for the season, related to the restrained monsoon conditions during July (IMD 2002). A cyclonic gyre appeared at low levels in the equatorial southern Pacific northeast of Papua New Guinea, indicating a stronger than normal South Pacific Convergence Zone (SPCZ) in the area.

The cross-equatorial components of the wind flow and anomalies are shown in Fig. 9. These diagrams indicate that the flow pattern is somewhat different from the previous seasons in 2002, 2001, 2000 and 1999 where weak La Niña to neutral conditions persisted (Shaik and Bate 2003, 2002b, 2002a, 2001, 2000 respectively). There is a clear eastward shift in the low-level southerlies and upper-level northerlies from the previous years as well as from the climatological location. Low-level and upper-level winds associated with the Hadley cell over the Indian Ocean were out of phase, consistent with the weak monsoon conditions over the region. The upper-level northerlies extended over most of the RSMC area with the cell of maximum intensity shifting gradually from its mean location between 95°E and 105°E to around 135°E during the current season. The low-level southerlies also followed a similar trend of eastward shift indicating the gradual shift of the ENSO pattern from weak La Niña in 2001 to moderate El Niño. However, less than normal convection as suggested by the pressure and OLR pattern between 120°E and 130°E longitude range did not match with the active Hadley circulation inferred by the cross-equatorial flow over the same longitude range but the flow appears to have enhanced the convection to the east of it. The cross equatorial flow over the western equatorial Pacific near the date-line was close to normal.

Sea-surface temperature

Six-month mean and anomalous sea-surface temperatures (SST) are shown in Fig. 10. The SST configuration in the tropics reflects a more mature El Niño type sea surface pattern than seen in the November 2001 – April 2002 season (Shaik and Bate 2003). Changes include, warmer anomalies in the northwest Pacific, strengthened warm anomalies in the equatorial Pacific near the date-line, and strengthened warm anomalies in the equatorial Indian Ocean. However, the warmest waters in the equatorial Pacific remained close to the date-line rather than close to the South American coast as in a typical El Niño pattern (not shown). A few patches of cooler anomalies persisted near the north Australian coast, Indonesia and Papua New Guinea.

Intraseasonal variability

Figures 11 to 13 show time/longitude plots of (a) 200hPa velocity potential, (b) OLR and (c) MSLP anomaly, averaged over 10° latitude bands, across the Darwin RSMC longitude range. The southern and

Fig. 3 **Monthly mean OLR (W m^{-2}), heavy line 240 W m^{-2}, 260 W m^{-2} and above yellow-red shading, 240 W m^{-2} and below blue shading: (a) May 2002; (b) June 2002; (c) July 2002; (d) August 2002; (e) September 2002; (f) October 2002.**

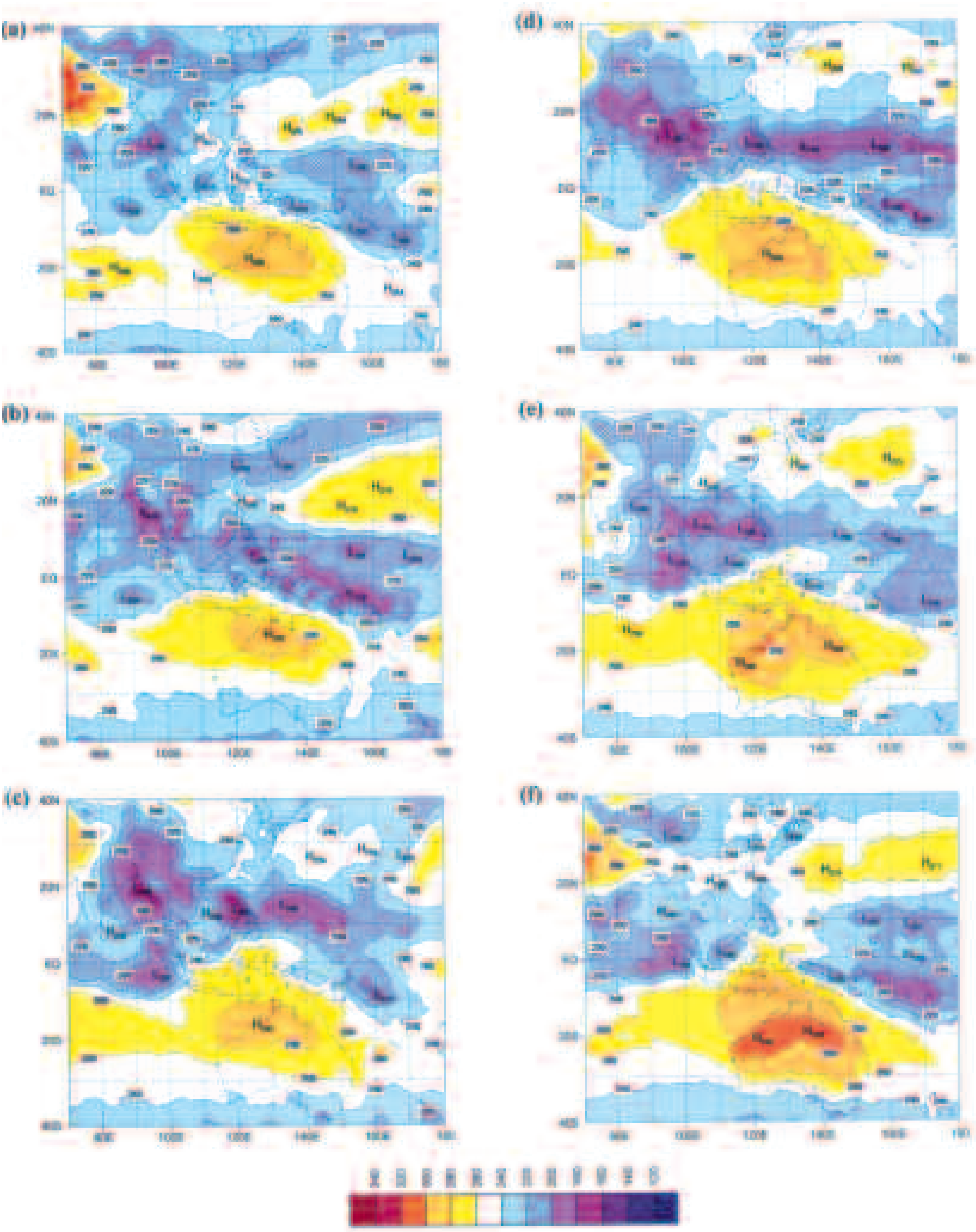


Fig. 4 **Monthly OLR anomaly (W m^{-2}), heavy line zero, > +5 W m^{-2} yellow-red shading, < -5 W m^{-2} blue-purple shading: (a) May 2002; (b) June 2002; (c) July 2002; (d) August 2002; (e) September 2002; (f) October 2002.**

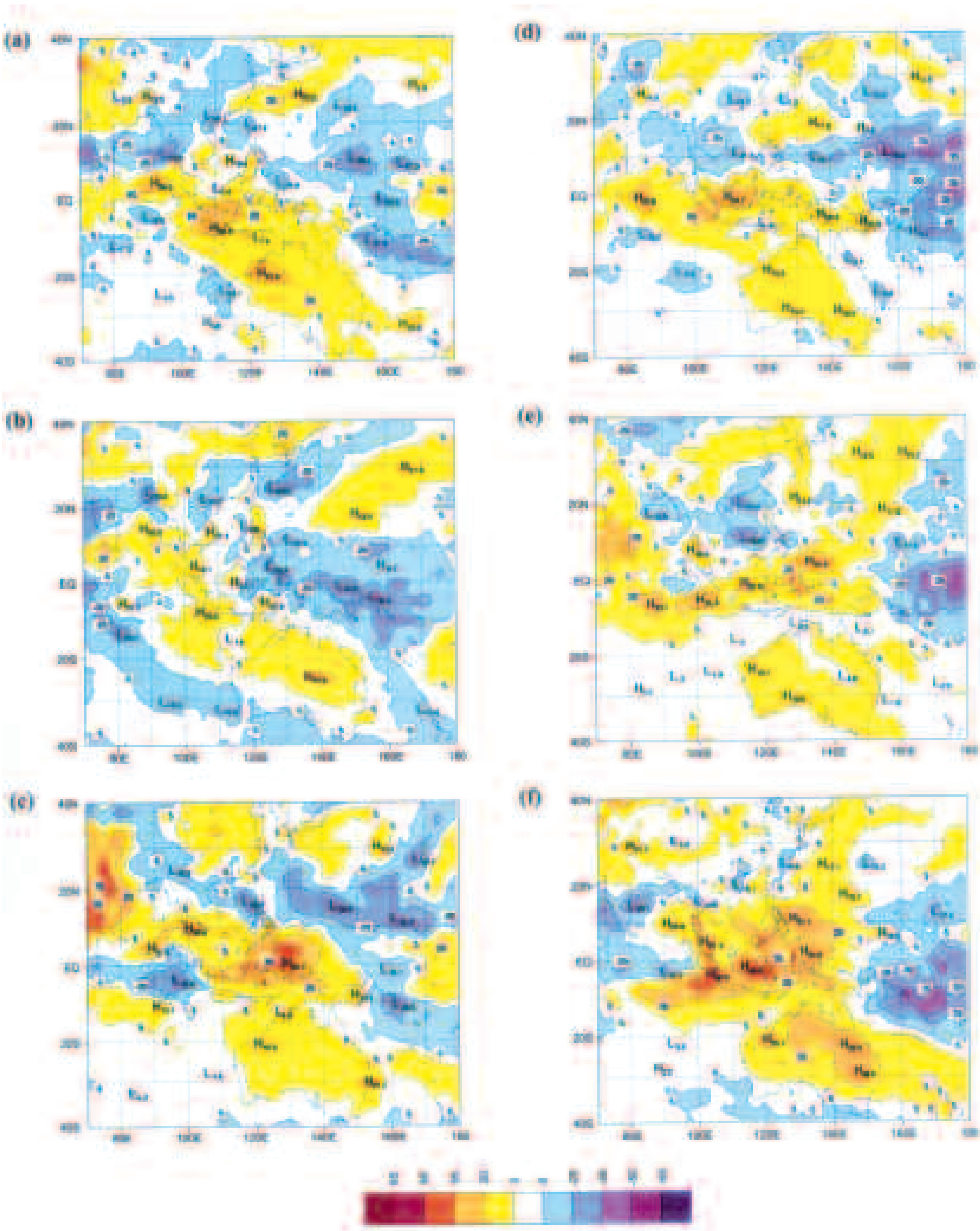


Fig. 5 **Six-month mean velocity potential (10^6 m^2 s^{-1}), May to October 2002, negative contours dashed: (a) 850 hPa; (b) 200 hPa.**

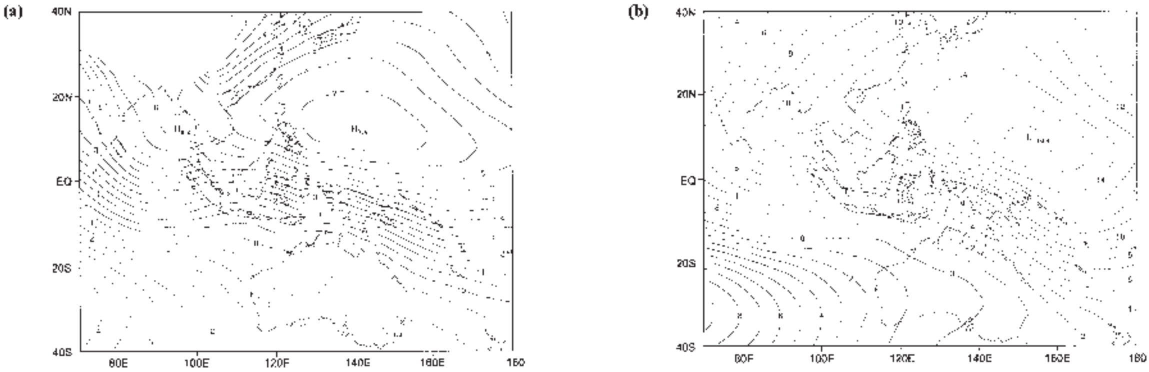


Fig. 6 **Six-month MSL pressure (hPa), May to October 2002: (a) mean, isobar interval 2 hPa; (b) anomaly, contour interval 1 hPa, shaded areas negative.**

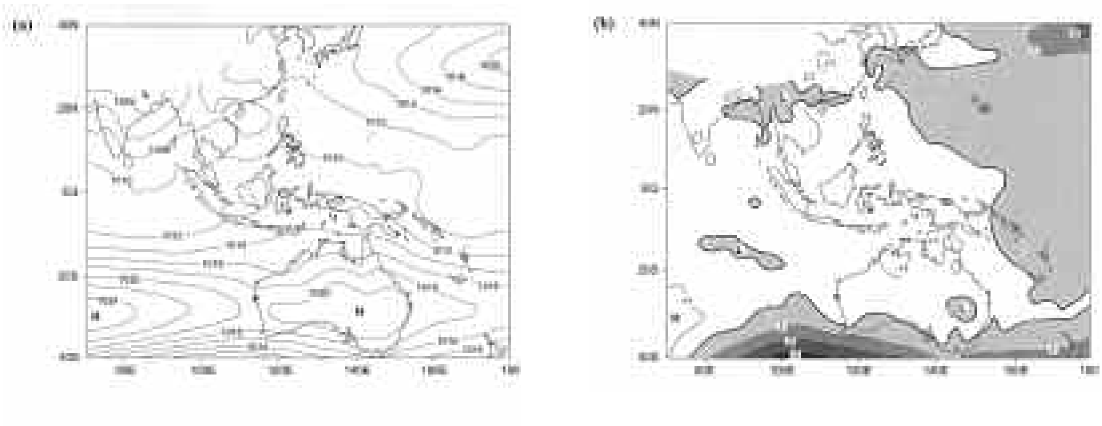


Fig. 7 **Six-month 850 hPa vector wind field, May to October 2002, isotach (dashed) interval 5 m s^{-1}: (a) mean; (b) anomaly.**

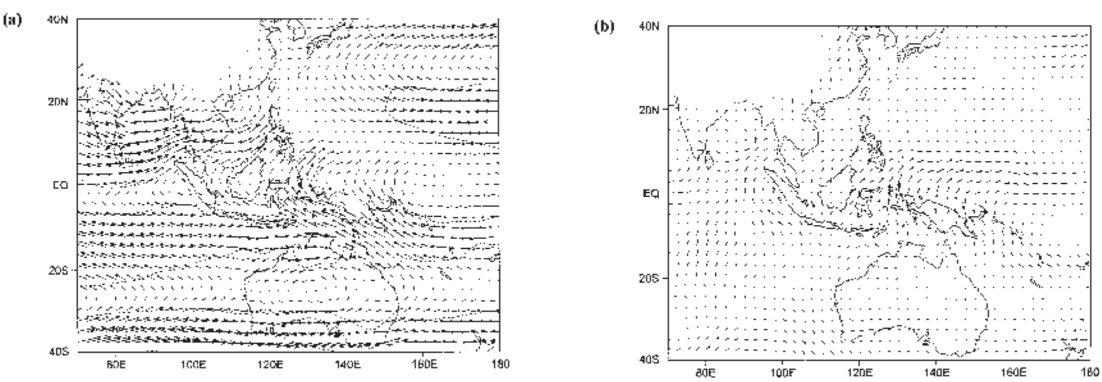


Fig. 8 Six-month 200 hPa vector wind field, May to October 2002: (a) mean, isotach (dashed) interval 20 m s^{-1}; (b) anomaly, isotach (dashed) interval 5 m s^{-1}.

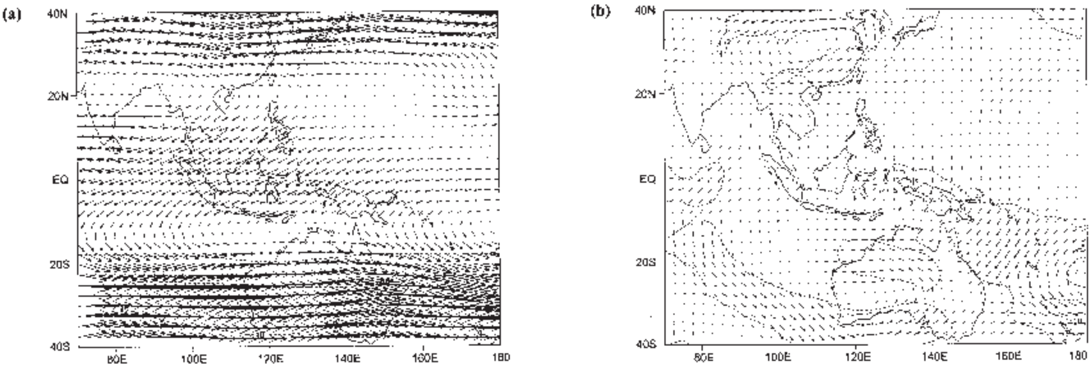


Fig. 9 Equatorial cross-section of six-month meridional wind, May to October 2002; contour interval 2 m s^{-1}, negative (northerly) contours dashed, positive (southerly) shaded: (a) mean; (b) anomaly.

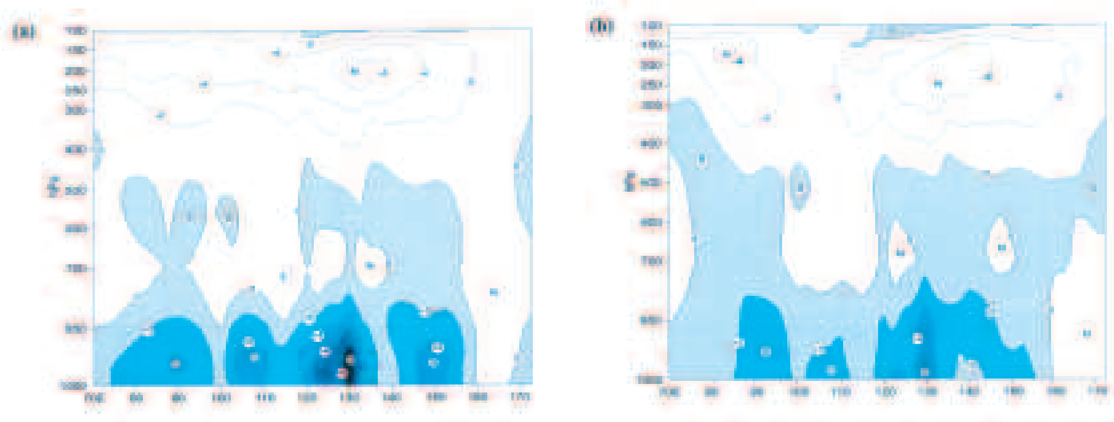


Fig. 10 Six-month SST (°C), May to October 2002: (a) mean, isotherm interval 1°C, >29 °C pink shading; (b) anomaly, contour interval 0.5°C, < zero °C blue shading, > +0.5°C, pink shading.

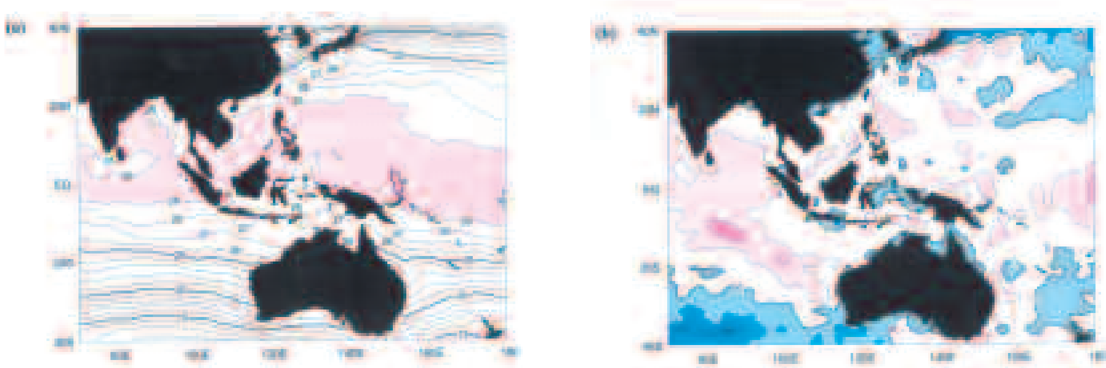


Fig. 11 **Time-longitude sections, latitude band 5°S-15°S, 1 May to 31 October 2002 of five-day backward running mean: (a) 200 hPa velocity potential (10^5 m^2 s^{-1}); (b) OLR (W m^{-2}). White crosses denote time and longitude of TC genesis events; dots denote events poleward of the latitude band; (c) MSLP anomaly (hPa).**

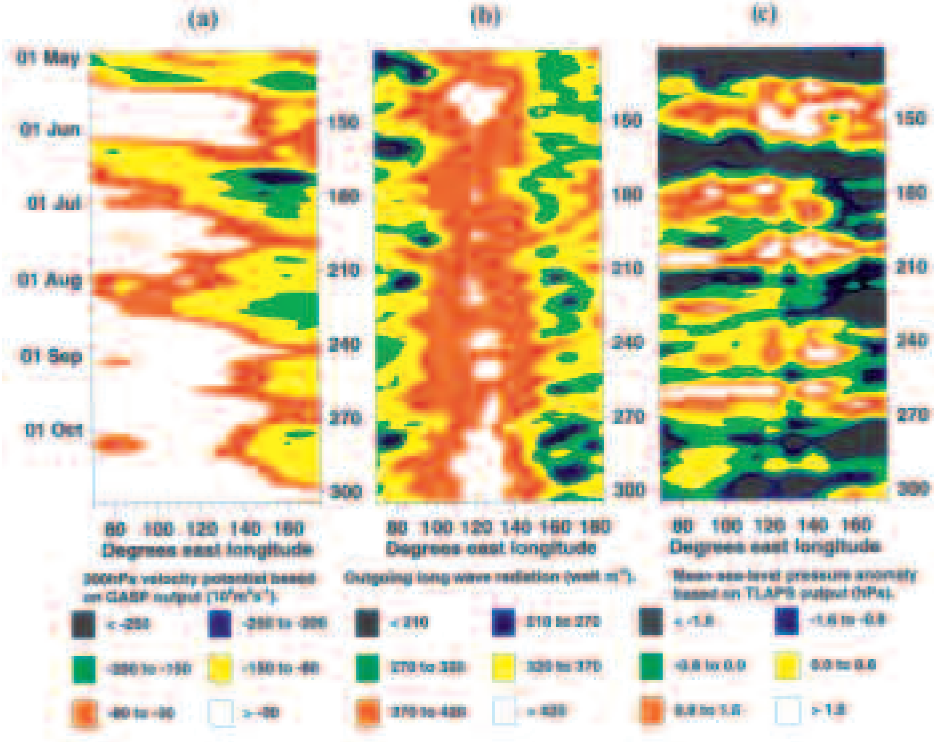


Fig. 12 **Time-longitude sections, latitude band 5°N-5°S, 1 May to 31 October 2002 of five-day backward running mean: (a) 200 hPa velocity potential (10^5 m^{2}s^{-1}); (b) OLR (W m^{-2}); (c) MSLP anomaly (hPa).**

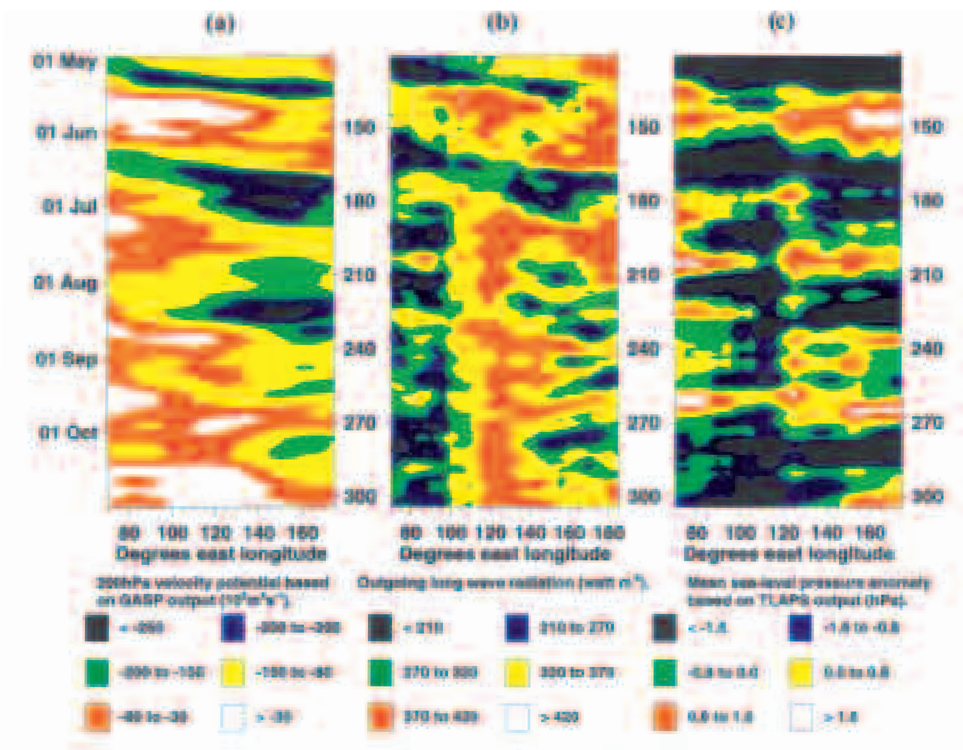
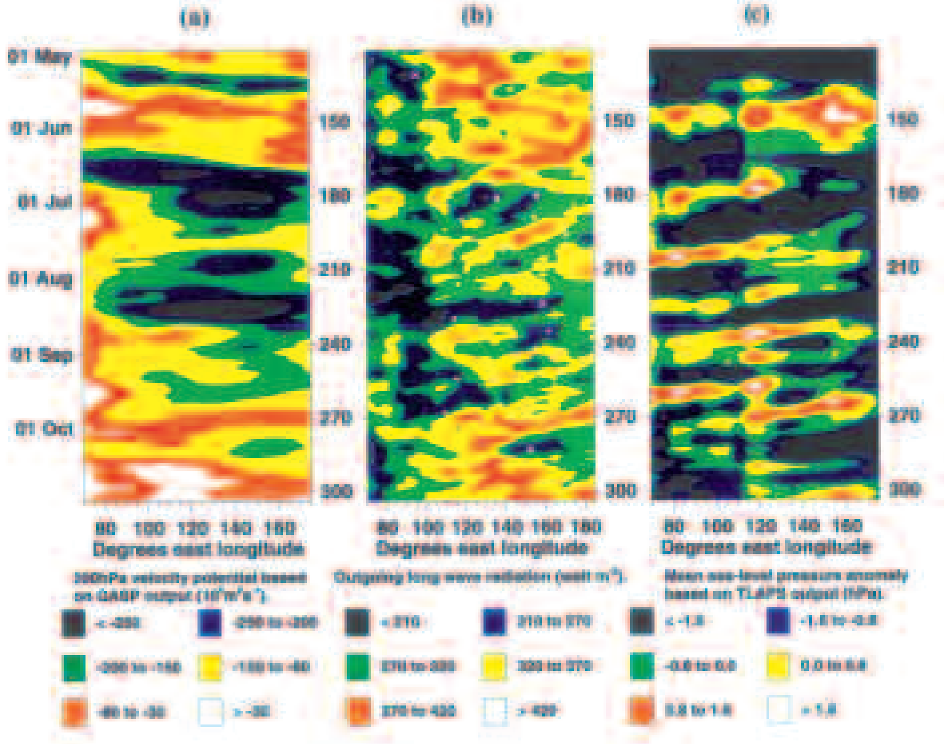


Fig. 13 As for Fig. 11, except latitude band 5°N-15°N.



northern OLR plots (Figs 11(b) and 13(b)) also indicate the date and longitude of tropical cyclone genesis events.

The 200 hPa velocity potential series generally indicate weaker than normal divergence west of 140°E in the southern and equatorial belts. The OLR series for the same latitude belts indicate weaker than normal convection between 100°E and 140°E, consistent with the weather pattern over the region. These time series indicate enhanced convection, west of 100°E, though weak, in every month except June where it was strong and extended across the whole RSMC longitude range. Only the northern hemisphere convective pulses in May, June and October were related to the 30 to 60 day Madden-Julian Oscillation (MJO). Even in these cases, although the convection was attributed to the MJO signal, except for the June event, the classical west to east propagation was not evident. The other convection periods appeared more strongly associated with higher frequency modes such as easterly waves. Overall the periodicity of the pulses of the 30 to 60 day MJO across the longitude range remained close to 35 days during the beginning and the end of the season with a quiet period of 50 to 60 days in between.

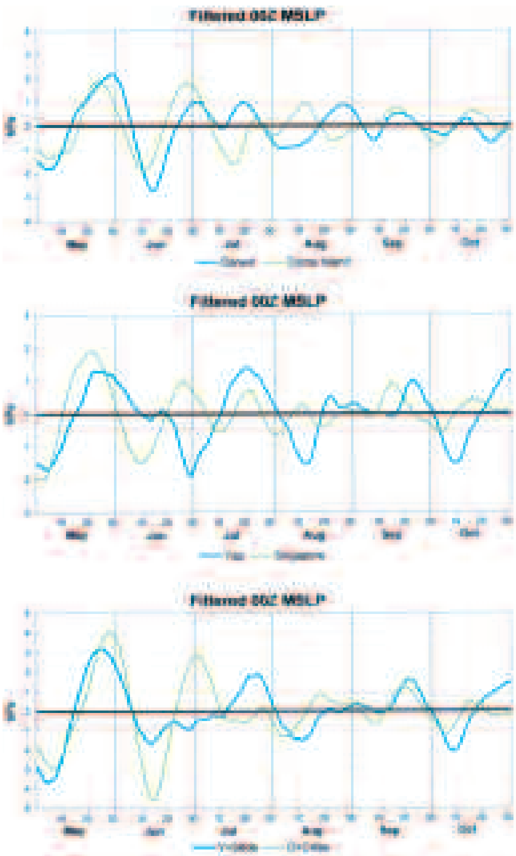
Figure 14 shows filtered station pressure anomaly series for four stations, two in each hemisphere. In Fig. 14(c) the signal for the eastern station in each hemisphere has been added to that for the western station four days earlier. A four-day period was chosen, as this is approximately the time that an eastward-moving global wave with a period of 45 days will take to travel over this longitude range.

Darwin and Cocos Island pressures were in phase with the MJO during the entire period except in August where they were out of phase. A similar trend could be seen with Yap and Singapore pressure series though the Singapore pressure wave appears to be faster than the Yap pressure wave. The combined pressure series (Fig. 14 (c)) show good phase agreement except during the end of June/beginning of July, indicating broadscale eastward-moving global wave patterns are in phase in both the hemispheres.

Tropical cyclones

Tropical cyclones (TCs) are defined as having maximum ten-minute mean winds greater than 17 m s^{-1}, or named systems. Operational tracks are shown in Fig.

Fig. 14 MSLP anomalies for two tropical stations in each hemisphere, normalised then passed through a 40-day Butterworth filter, 50% response at 23 and 70 days: (a) southern hemisphere, green line Cocos Island (12.2°S, 96.8°E) blue line Darwin (12.4°S, 130.9°E); (b) northern hemisphere, green line Singapore (1.4°N, 104.0°E), blue line Yap (9.5°N, 138.1°E); (c) Darwin plus Cocos Is. 4 days earlier (green line) and Yap plus Singapore 4 days earlier (blue line).



15, while Table 2 lists TCs in order of occurrence within the various basins, showing duration and estimated maximum intensity details. Tracks are from the near real-time publication Darwin Tropical Diagnostic Statement (DTDS), and are based on Darwin RSMC operational manual analyses, with limited post-analysis in a few cases. A brief discussion and more information on each cyclone can be found in the DTDS for the relevant month. Other details about the cyclone data analysis are presented in the Appendix.

A total of 23 TCs were analysed in the Darwin RSMC area during the summary period. Of these, ten reached severe tropical cyclone or typhoon intensity. Out of the 23 TCs, one formed in the north Indian Ocean, one developed in the south Indian Ocean and a rare one in the southwest Pacific close to the equator; the remainder formed in the northwest Pacific. An additional TC, *Ele*, formed east of the date-line and moved into the Darwin RSMC area with hurricane intensity. On average 26 TCs form in the RSMC region between May and October with the average numbers for the respective basins being 21.9 (14.5 typhoons) for the northwestern Pacific, 2.8 for the north Indian Ocean and 2.6 for the south Indian and Southern Pacific Oceans combined. The fact that the total number of cyclones formed in the region is below normal but above average in the northwest Pacific Ocean reflects the continuing El Niño conditions.

Acknowledgments

The authors would like to express their sincere thanks to Rob Porteous for his drafting of various figures. Sincere thanks also to Dr Andrew Watkins of the National Climate Centre, Commonwealth Bureau of Meteorology, for generating OLR six-monthly and monthly maps, using data collected from the NOAA-16 satellite through the Climate Prediction Center, Maryland, USA. Thanks are also due to other National Climate Centre staff, for their generous help in archiving and providing numerical weather prediction data used in producing various maps. Thanks are also expressed to the Climate Prediction Center, Camp Springs, Maryland, USA and BMRC for the permission to use their OLR figures.

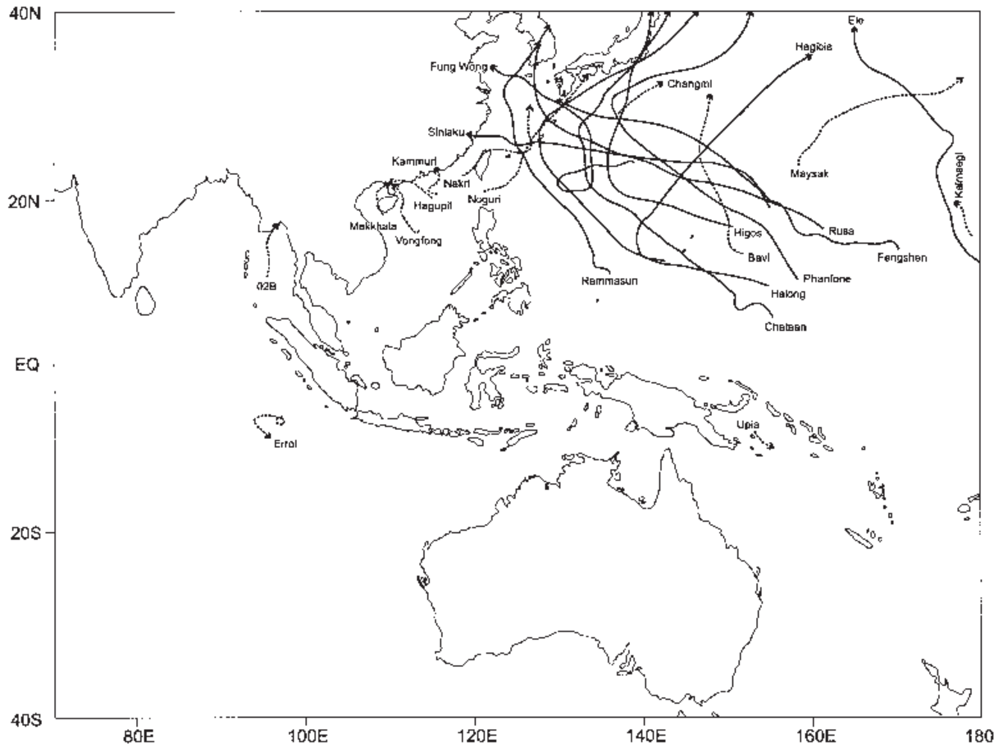
Appendix

Data sources

Six-month seasonal charts were constructed using the Australian Bureau of Meteorology global model (GASP). Anomalies are derived from the European Centre for Medium-range Weather Forecasts (ECMWF) climatology. Sea-surface temperature (SST) anomalies were calculated relative to the 1°x1° global SST climatology from the US National Centers for Environmental Prediction (Reynolds and Smith 1995). Further data source details are listed below.

Darwin Tropical Diagnostic Statement (DTDS), May to October 2002 (issued monthly), and *Weekly Tropical Climate Note*, for the period 1 May 2002 to 30 October 2002. Commonwealth Bureau of Meteorology, PO Box 40050, Casuarina, NT 0811, Australia.

Fig. 15 Tropical cyclone tracks, May to October 2002. Solid line denotes system reached severe tropical cyclone (typhoon/hurricane) intensity; dashed line denotes system reached only tropical cyclone/storm intensity.



MSLP, upper wind and velocity potential map fields from the Commonwealth Bureau of Meteorology's Global Assimilation and Prediction system (GASP – Bourke et al. 1990; Bur. Met. 1998); anomalies derived from the ECMWF 11-year climatology. MSLP and velocity potential data for Hovmoeller series from the Limited Area Prediction System (LAPS – Puri et al. 1998), nested within GASP.

OLR six-monthly and monthly map figures for the period May to October 2002 are derived from the data generated by Climate Prediction Center, W/NP52, Room 605, WWBG, 5200 Auth Road, Camp Springs, Maryland, 20746-4304 USA. OLR anomalies are derived using 1979-95 climatology data set. OLR data for Hovmoeller diagrams are from Japan Meteorological Agency's GMS-5 geostationary satellite.

Sea-surface temperature analysis derived from the operational global analysis of National Meteorological and Oceanographic Centre, Commonwealth Bureau of Meteorology, Melbourne. Includes blended in situ and satellite data, 1°C resolution. The 1°x1° global SST climatology from the US National Centers for Environment Prediction (Reynolds and Smith 1995) was used to calculate anomalies.

Tropical cyclone climatology for the northwest Pacific Ocean calculated from figures given in Grandau and Engel (2002). For the north Indian Ocean the climatology is from Mandal (1991).

Tropical cyclones

Following WMO guidelines (Neumann, 1993), winds were assumed to be averaged over ten minutes except those from JTWC, which uses one-minute means. A conversion factor of 0.88 to relate one-minute to ten-minute means was applied to warnings issued from JTWC. Minimum pressures were also obtained from the warnings, except for those issued by JTWC and PAGASA Manila. In these cases minimum pressures were estimated using the relationship of Atkinson and Holliday (1977). Since most agencies use the unit of knots (kn) in warnings, wind speeds are shown in

Table 2. Tropical cyclones within the Darwin RSMC area, May – October 2002. TC = tropical cyclone, TS = tropical storm, Ty = typhoon, H = Hurricane.

Name	*Dates (UTC) at TC intensity in Darwin RSMC area*	*Maximum 10-min. mean wind (while in Darwin RSMC area) m s^{-1} (knots)*	*Estimated minimum MSLP (hPa)*	*Warning Agency**
Bay of Bengal /North Indian Ocean				
Unnamed 02B (TC)	10 May – 12 May	18 (35)	997	JTWC
South Indian Ocean				
Errol (TC)	9 May – 13 May	18 (35)	995	BoM, Perth
South Pacific				
Upia (TC)	25 May – 28 May	21 (40)	995	PNG
Northwest Pacific/South China Sea				
Hagibis (Ty)	16 May – 21 May	46 (90)	935	JMA
Noguri (TS)	7 June – 11 June	31 (60)	975	PAGASA
Rammasun (Ty)	29 June – 6 July	46 (90)	945	PAGASA
Chataan (Ty)[1]	29 June – 11 July	49 (95)	930	JMA
Halong (Ty)[2]	8 July – 16 July	44 (85)	945	JMA
Nakri (TS)	8 July – 13 July	23 (45)	990	Hong Kong
Fengshen (Ty)	15 July – 27 July	52 (100)	920	JMA
Kalmaegi (TS)	20 July – 21 July	21 (40)	1000	JMA
Fung-Wong (Ty)	21 July – 27 July	39 (75)	960	JMA
Kammuri (TS)	3 Aug – 5 Aug	26 (50)	980	Hong Kong
Phanfone (Ty)[3]	12 Aug – 20 Aug	44 (85)	945	JMA
Vongfong (TS)	17 Aug – 19 Aug	26 (50)	978	Hong Kong
Rusa (Ty)	23 Aug – 1 Sept	41 (80)	950	JMA
Ele (H)	29 Aug – 4 Sept	46 (90)	940	JMA
Sinlaku (Ty)	29 Aug – 4 Sept	41 (80)	950	JMA
Hagupit (TS)	11 Sept – 12 Sept	31 (60)	975	Hong Kong
Changmi (TS)	21 Sept – 23 Sept	23 (45)	985	JMA
Mekkhala (TS)	25 Sept – 28 Sept	21 (40)	992	Hong Kong
Higos (Ty)[4]	27 Sept – 1 Oct	46 (90)	935	JMA
Bavi (TS)	9 Oct – 13 Oct	26 (50)	985	JMA
Maysak (TS)	27 Oct – 30 Oct	28 (55)	985	JMA

* PAGASA = Philippine Atmospheric, Geophysical and Astronomical Services Administration, Manila; BoM = Commonwealth Bureau of Meteorology, Australia; JTWC = Joint Typhoon Warning Center, Pearl Harbor, Hawaii; JMA= Japan Meteorological Agency, Tokyo; PNG = Papua New Guinea National Weather Service, Port Moresby; Hong Kong = Hong Kong Observatory, Hong Kong.

Notes:

1 *Chataan* weakened and moved northward out of the RSMC area (40°N) and merged in the extratropical flow.
2 *Halong* moved northward out of the RSMC area (40°N) and merged in the extratropical flow.
3 *Phanfone* weakened and moved northeastward out of the RSMC area (40°N) and merged in the extratropical flow.
4 *Higos* moved northward out of the RSMC area (40°N) while still intensifying.

Note also that central pressures are not available from PAGASA Manila and JTWC warnings; in these cases only the wind has been obtained from the warnings and pressures are estimated from the relationship of Atkinson and Holliday (1977).

Table 2 in knots as well as m s^{-1}. Climatological numbers are from Grandau and Engel (2002) for the northwest Pacific and southern hemisphere and Mandal (1991) for the north Indian Ocean.

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