On the climatology and structure of tropical cyclones in the Australian/southwest Pacific region: II. Hurricanes

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(Manuscript received March 1983; revised October 1983)

A hurricane climatology is presented for the Australian/southwest Pacific region and compared to the tropical storm climatology in Holland (1983b). A description is then given of the structure and environmental interactions of intensifying and decaying hurricanes over the southwest Pacific Ocean, together with the continental influences on hurricanes just off the east and west Australian coasts. It is shown that upper-tropospheric interactions with the subtropical westerlies are important mechanisms in both the intensification and decay phases. Further, tropical cyclones off the west Australian coast are under a considerable continental influence.

Introduction

This is the second of three papers aimed at examining the climatological and structural features of tropical storms, hurricanes, and major hurricanes throughout the Australian/southwest Pacific region. In the two companion papers (Holland 1983b,c; hereafter referred to as H1 and H3) we discuss a number of aspects of tropical storms and major hurricanes. In this paper we examine various hurricane features. A hurricane climatology for the Australian/southwest Pacific region is presented first and compared to the tropical storm climatology in H1. We then describe and compare the structure of the intensification and decaying phases of oceanic hurricanes in the southwest Pacific region, and examine the continental influence on hurricanes just off the east and west Australian coasts.

Data and definitions

This study is based on the data and compositing methodology described in H1. We also adopt the special definitions in H1 of intensity, strength and size; of origin maximum intensity and decay points; and of tropical storm, hurricane and major hurricane. Specifically, recall that hurricanes are classified as:

(a) all cyclones in the Australian region (105-165°E) in which the minimum pressure was below 980 mb;
(b) all systems east of 165°E which were classified as hurricanes by Kerr (1976) or Revell (1981).

Note, however, that the climatology includes the entire life cycle of these cyclones, not just the hurricane phase.

The data problems and deficiencies described in H1 also apply to the observations presented here. In particular, we stress that the climatology is derived from a relatively short period (1959-1979) from which three hurricanes (Kerry, Hazel, Flores Sea; cf. H1) were inadvertently omitted. This was the maximum period for which we were confident of the observation quality. We are therefore confident of the general climatological features, but not the extrema (e.g. the Bathurst Bay hurricane example in H1).

Hurricane climatology

Spatial distribution

The spatial distribution of hurricanes throughout the Australian/southwest Pacific region is shown in Fig. 1. This distribution is qualitatively similar to that for tropical storms (Fig. 5 of H1) over the southwest Pacific. There are, however, marked differences in the Gulf of Carpentaria and off the northwest...
Fig. 1 Hurricane occurrence (days per 5° Marsden square for the 1959-1979 period) for the north/west Australian and southwest Pacific regions. Stippling indicates regions of no occurrence and dashed lines, indicating intermediate 5-day isochrones, are used for extra detail.

Fig. 2 Hurricane origin, maximum intensity and decay point distributions for the north/west Australian and southwest Pacific regions during the period 1959-1979. Tick marks indicate median latitudes and filled in symbols indicate multiple occurrences.

Australian coast. Intensifying tropical storms in the land-locked Gulf of Carpentaria tend to cross the coast before, or soon after, reaching hurricane intensity. Hence, we observe a much lower frequency of Gulf hurricanes compared to tropical storms. By comparison, there is a strong peak in hurricane occurrence off the northwest Australian coast. Hurricanes in this area typically track along and parallel to the coast and either continue to the southwest or suddenly recurve and make landfall anywhere between Broome and Geraldton (Fig. 1). Thus, a town such as Port Hedland is in the outer fringes of, and under direct threat from, a hurricane on an average of two to three days every year.

The hurricane origin, maximum intensity and decay point distributions are shown in Fig. 2. For the southwest Pacific region these are qualitatively similar to the tropical storm distributions in H1, except that the hurricanes display a trend towards lower-latitude origins and higher-latitude maximum intensity and decay points. By comparison, in the north/west Australian region the median storm and hurricane origin latitudes are similar, but most hurricanes originate in the Timor Sea, reach maximum intensity off the northwest Australian coast and decay by crossing that coast. As with the tropical storms in H1, the detrimental environmental winds and cold ocean poleward of 20°S has a strong limiting effect on the distribution of intensifying hurricanes; very few hurricanes reach maximum intensity poleward of 20 to 25 degrees.

Intra-seasonal distributions
The intra-seasonal distributions in Fig. 3 indicate that both regions have an early season hurricane maximum. This is due to a tendency for the early season
systems, which form along the fledgling monsoonal trough at low latitudes, to become hurricanes and also have longer lifetimes. Hurricanes in the north/west Australian region also exhibit a distinct mid-season minimum, which we believe is caused by the Australian continent. As we have discussed in Bureau of Meteorology (1978, Chapter 4; see also McBride and Keenan 1982), tropical cyclones typically originate along the monsoonal trough. During the mid-season this trough lies over northern Australia, and the oceanic area over which cyclones can form is considerably reduced. Further, those cyclones which form generally do so close to the coast and subsequently make landfall, or are otherwise adversely affected. Thus, while there is very little reduction in the frequency of tropical storms (H1), there is a distinct reduction in hurricane occurrence. As the monsoonal trough moves equatorwards off the continent in late February, the hurricane occurrence again increases sharply.

**Motion**
As we show in Fig. 4, westward moving systems comprise a much larger proportion of hurricanes than we observed for tropical storms in H1. A similar feature has been noted by Revell (1981) for the southwest Pacific region. However, the southwest Pacific hurricanes still have an eastward motion maximum and move faster on an average than those in the north/west Australian region.

The zonal motion distributions in Fig. 5 indicate that the major tropical storm to hurricane motion differences occur in the southwest Pacific region. There is a considerable increase in low-latitude westward motion of southwest Pacific hurricanes, or pre-hurricane systems, compared to the tropical storm observations in H1. By comparison, north/west Australian tropical storms and hurricanes have very similar zonal motion distributions. In this region there is a slight preference for eastward motion in the Gulf of Carpentaria, and systems off the northwest Australian coast generally track westward (actually west to southwestward, cf. Fig. 4). The lack of eastward movement, and slower average speed of north/west Australian compared to southwest Pacific hurricanes is largely the result of the removal of high latitude systems by the Australian continent.

**Oceanic hurricane structure**
We shall use the AUS06, developing oceanic hurricane, and the AUS07, decaying oceanic hurricane composites to describe the general structural features of deepening and decaying hurricanes in the southwest Pacific region. These stratifications are described completely in Holland (1983a). Briefly, both composites are comprised of the hurricane stage of the AUS09 pre-hurricane tropical storm described in H1. These hurricanes occurred in the southwest Pacific between 15° and 25° S and at least 1000 km from the Australian mainland.

**Dynamical structure**
As may be seen in the axisymmetric cross-section in Fig. 6, the oceanic hurricane is quite large. In both the developing and decaying phase it has a deep cyclonic circulation extending beyond 14 degrees latitude radius, and is overlain by an extensive an-
Fig. 5 Hurricane zonal motion distribution (averaged over 5° Marsden squares) for the north/west Australian and southwest Pacific regions. Stippling indicates regions of no occurrence and hatching indicates one standard deviation.

Fig. 6 Axisymmetric azimuthal wind (m s⁻¹) cross-section for the developing (AUS06), and the decaying (AUS07) oceanic hurricane. Hatching indicates anticyclonic circulation.

Fig. 7 Axisymmetric radial wind (m s⁻¹) cross-sections for the developing (AUS06), and the decaying (AUS07) oceanic hurricane. Outflow regions are hatched. Radial winds of less than 1 m s⁻¹ are not significantly different from zero.
Fig. 8(a) Plan view streamline/isotach (m s⁻¹) fields for the developing oceanic hurricane at 850 and 500 mb.

Fig. 8(b) Plan view streamline/isotach (m s⁻¹) fields for the developing oceanic hurricane at 250 and 150 mb.

tycyclone. In this regard, the oceanic hurricane is quite similar to the steady-state typhoon described by Frank (1977). However, the developing and decaying phases do have some interesting additional features.

The developing hurricane is similar to the pre-hurricane tropical storm in H1. It exhibits a strong, deep cyclonic circulation out to a radius of 8 degrees latitude (Fig. 6), with a weak vertical wind shear between 850 and 400 mb. A low-level wind maximum also extends beyond 10 degrees latitude radius, and is associated with a secondary maximum in radial inflow (Fig. 7); we shall presently see (Fig. 8) that this is a result of sustained northwesterly environmental winds equatorward, and southeasterly environmental winds poleward of the hurricane. Figure 7 further shows that the developing hurricane contains a deep low-level inflow, with the remnants of the secondary maximum near 400 mb which were noted in the pre-hurricane phase. This low-level inflow is overlain by an extensive upper tropospheric outflow, with a maximum between 2-6 degrees latitude radius, and a nearly constant radial wind from 6-14 degrees. This outflow is associated with an increasing anticyclonic circulation with radius and is overlain by a lower stratospheric inflow.

By comparison, the decaying hurricane has a stronger upper-level anticyclone, a weaker low-level cyclone, and more vertical wind shear between 700 and 400 mb. The radial flow is also quite different: the stratospheric inflow has ceased inside 6 degrees latitude radius; the upper tropospheric outflow and lower tropospheric inflow are weaker and cease at 12-14 degrees latitude radius; and a distant outflow has developed near 600 mb, though a residual inflow remains near 400 mb.
The plan view wind fields for the developing oceanic hurricane contained in Fig. 8, show a stronger, but otherwise similar structure to the tropical storm phase in H1. In the low to mid-levels, the composite hurricane has a large extent and is nearly symmetric. The strong, deep tropical inflow jet is still being maintained and the beta-effect distortion is clearly evident at 850 mb. At 250 mb, the upstream westerly trough now extends equatorward of the hurricane, but the confluence zone between the subtropical westerlies and the hurricane outflow has remained at least 6 degrees latitude from the centre. The subtropical outflow jet has also strengthened considerably with average radial winds exceeding 15 m s$^{-1}$.

The westerly winds have less effect at the 150 mb level. There is, however, still evidence of the strong outflow jet to the southeast. As with the tropical storm phase, this jet is complemented by a second equatorward jet to the northeast.

The streamline/isotach fields for the decaying hurricane are shown in Fig. 9. By comparison to the developing stage, the 850 mb circulation is less extensive and weaker and the deep tropical inflow has ceased. Indeed, the 500 mb flow contains a distinct subtropical inflow, and has become considerably distorted. The upper-level westerlies now extend well over the hurricane with only the remnants of an outflow regime at either 250 or 150 mb. The equatorward outflow has ceased entirely, and the southeastward 'outflow jet' is more a result of an imposition of baroclinic westerly flow than an actual cyclone outflow. In these regards the decaying oceanic hurricane is quite similar to the non-developing tropical storm in H1.

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Fig. 9(a) Plan view streamline/isotach (m s$^{-1}$) fields for the decaying oceanic hurricane at 850 and 500 mb.

Fig. 9(b) Plan view streamline/isotach (m s$^{-1}$) fields for the decaying oceanic hurricane at 250 and 150 mb.
Fig. 10 Axisymmetric cross-section of temperature anomaly (°C) (taken as the difference from the 14 degree latitude radius value at the same level) for the developing (AUS06) and the decaying (AUS07) oceanic hurricanes. Stippling indicates relatively cold regions.

Thermal structure
The axisymmetric cross-sections of temperature anomalies in the developing and decaying hurricanes are shown in Fig. 10. The well-documented mid to upper-tropospheric warm core (e.g. Shea and Gray 1973; Hawkins and Rubsam 1968; Frank 1977) may be clearly seen. In the developing hurricane the warm anomaly is quite strong and concentrated near 300 mb (the actual maximum anomaly in the eye cannot possibly be resolved by our larger-scale compositing procedure). In the decaying hurricane the warm anomaly is weaker and vertically more diffuse. These observations are consistent with our vertical wind shear observations in Fig. 6. Though not completely shown due to lack of resolution, a cold band of up to 5 °C is also present near the tropopause and in the lower stratosphere, surrounding an apparently warmer centre. In the developing phase the primary band extends from 1-3 degrees latitude radius with a secondary cold band 4-6 degrees latitude radius from the centre. In the decaying phase the primary cold band is further from the centre and covers 3-5 degrees latitude radius. Frank (1977) also observed a stratospheric cooling over his northwest Pacific typhoon, but this extended over the core region. Even though there are only a few observations, the lower stratosphere of both phases of the southwest Pacific hurricane is warmer in the core region than at 2-6 degrees latitude radius. We also note that the cool bands in Fig. 10 correspond closely to the outflow maxima in Fig. 7, which must be associated with sustained vertical motion. These observations support the speculation by Frank (1977) that the tropopause/lower stratospheric cooling results from overshooting cumulonimbus clouds.

A notable feature is the lower-level cool band at 2 degrees latitude radius in the developing phase and at 3 degrees latitude radius in the decaying phase. These cool bands are also quite dry and thus show distinctively in the equivalent potential temperature cross-sections of Fig. 11. These are an axisymmetric indication of the distinctive banded structure of all tropical storm and hurricane composites presented in this study. As we have discussed in H1, we believe that this banded structure arises from:
(a) an interaction between the cyclone and earth’s vorticity field; and

(b) differential advection of potentially warm tropical, and cold subtropical air.

The plan view equivalent potential temperature fields for the developing hurricane are shown in Fig. 12. The variations in equivalent potential temperature below 500 mb are largely due to moisture variations; at 250 mb they are entirely due to temperature variations. We can see that a deep tongue of warm, moist tropical air occurs on the northeast side. As with the pre-hurricane tropical storm (H1) this tropical air extends around and to the poleward side of the hurricane core. Cool, dry subtropical air is starting to flow equatorwards at large radii to the west of the hurricane; and a distinct low-level dry slot, corresponding to that in the axisymmetric cross-section of Fig. 11, extends from west through north and east of the core region.

Notice also the rapid fall in equivalent potential temperature to the southwest of the core at both 500 and 250 mb. This gradient lies along the confluence zone between the potentially warm hurricane outflow and cool upper-level environmental westerlies (Fig. 8). Unlike the pre-hurricane phase in H1, there is no evidence of strong upper-level subsidence along this confluence zone. This agrees with the qualitative wind field observations in Fig. 8(b) that there is also much weaker confluence, and less concentrated upper-level convergence in this region. However, the continued presence of a dry slot in the 500 mb moisture field of Fig. 13 indicates that some middle-level subsidence is being maintained in this confluence region.

The higher latitude, subtropical effects on the thermal structure of the decaying hurricane are clearly shown in Fig. 14. Only a residual of the warm moist tropical tongue (Fig. 12) remains to the northeast. This tongue is cut off from the core and no longer wraps around the poleward side. Rather, a strong equivalent potential temperature gradient has developed to the southwest as the hurricane comes under the influence of the west to southwesterly subtropical airstream.

Note, however, that the impinging westerly airstream has a less adverse effect on the stronger hurricane circulation than was evident in the non-developing tropical storm of H1.

The continental influence on hurricanes off the east and west Australian coast

As we have seen in this paper and H1, many tropical cyclones complete their entire life cycle within a few hundred kilometres of the Australian coast. They are thus affected in varying degrees by the close proximity of this large, dry land mass. In the extreme,
a number of these cyclones are destroyed in their formative or intensification stages by crossing the coast. But even those which remain out to sea have a substantial proportion of their circulation over land. Australian forecasters have long been aware of the debilitating effect of dry continental air being entrained into these coastal cyclones. Further, aside from those direct influences, the continent may indirectly affect coastal cyclones by the modifying effect that it has on the larger-scale flow fields.

In this section we shall discuss some of these influences by using the AUS04 and AUS10 composites. These are described fully in Holland (1983a), but briefly: AUS04, the east coast hurricane, contains all tropical cyclones within about 500 km of the east Australian coast between 15° and 25 °S, and with central pressures less than 990 mb; AUS10, the west coast hurricane, contains a similar cyclone set for the west Australian coast. In order to obtain sufficient observations for a detailed analysis, both deepening and decaying phases were included. However, the regional peculiarities resulted in the east coast hurricane being, on average, decaying, while the west coast hurricane is deepening.

The east coast hurricane

The 850 mb and 500 mb moisture fields for the east coast hurricane are shown in Fig. 15, together with the 850, 500, 250 and 150 mb wind fields in Fig. 16. At 850 mb the monsoonal trough extends west/northwest across Cape York Peninsula and a strong jet in the monsoonal westerlies provides the major influx of mass and moisture into the hurricane. The characteristic beta-effect distortion and elongation to the west, which we noted in our discussion of the oceanic cyclones, appears to be modified by the Great Dividing Range. Considerable orographic funnelling of these low-level winds is evident. Thus, even though a distinct moisture band ex-
Fig. 15 Plan view moisture mixing ratio (g/kg) fields for the east coast hurricane at 850 and 500 mb. Also shown in circles are mean January mixing ratios for a selection of stations from Maher and Lee (1977). No data were available for the hatched regions.

Fig. 16(a) Plan view streamline/isotach (m s⁻¹) fields for the east coast hurricane at 850 and 500 mb.

Fig. 16(b) Plan view streamline/isotach (m s⁻¹) fields for the east coast hurricane at 250 and 150 mb.
tends from the monsoonal westerlies around the hurricane, the inland regions are relatively unaffected (the encircled stations are not significantly different from their January mean from Maher and Lee 1977). Some advection of dry continental air is, however, evident from the west through north of the hurricane.

At 500 mb the coastal funnelling has disappeared. Instead, the hurricane appears to lie poleward of the subtropical ridge and is being influenced by a subtropical southwesterly flow. Thus, even though there is a deep monsoonal flow to the north, very dry continental air is being advected into the cyclone and is tending to cut off the tropical moisture supply. The poleward extent of tropical air around the hurricane, and the efflux of dry air from the continent, may be seen more clearly in the moisture cross-section of Fig. 17. This cross-section extends northwest and due south of the cyclone and approximately parallels the coastline. We see that moist tropical air extends polewards some 700 km at the surface and slightly less at higher levels. The low-level coastal funnelling also prevents the drier continental air below 850 mb from moving over the ocean within 600 km to the northwest. But this effect is lost above 800 mb, and dry air penetrates close to the centre under the influence of the impinging subtropical westerlies.

The associated characteristic convective signature for east coast hurricanes is illustrated by hurricanes Ada (1970) and Althea (1971) in Fig. 18. Note: (i) the large convective region to the south and southeast which ends along the coast and is curved anticyclonically by the interaction with the upper-level westerlies (cf. the 250 mb level in Fig. 16); (ii) the dry slot around the northern perimeter of the cloud mass; and (iii) the convective band lying along the approximate position of the low-level monsoonal jet and moist band in Figs 15 and 16. It is also now evident that the large 500 mb moist region encompassed by the 4 g/kg isohyet in Fig. 15 arises more from in situ convective activity than from horizontal advection. There is however, some advection of moisture out of this region over the continent.

The west coast hurricane

The 850 mb and 500 mb moisture fields for the west coast hurricane are shown in Fig. 19 together with the 850, 500, 250 and 150 mb flow fields in Fig. 20. At 850 mb the monsoonal trough extends northeastward over northern Australia. The now familiar jet from the monsoonal westerlies extends into the hurricane and there appears to be a secondary monsoonal surge equatorward of the Indonesian Islands (though this feature could be a result of data bias). Extensive trade wind easterlies lie poleward of the hurricane, and the super-positioning of the Western Australian Coastal Trough and the cyclone circulation is clearly evident at 850 mb. Unfortunately, we have no thermal data, and very little wind data, to
Fig. 19 Plan view moisture mixing ratio (g/kg) fields for the west coast hurricane at 850 and 500 mb. Also shown in circles are mean January mixing ratios for a selection of stations from Maher and Lee (1977). No data were available for the hatched region.

Fig. 20(a) Plan view streamline/isotach (m s⁻¹) fields for the west coast hurricane at 850 and 500 mb. No data were available for the hatched regions.

Fig. 20(b) Plan view streamline/isotach (m s⁻¹) fields for the west coast hurricane at 250 and 150 mb. No data were available for the hatched regions.
the west and northwest of the hurricane. However, to the east and southeast the hurricane circulation is advecting a considerable amount of tropical moisture over the normally dry northwestern deserts. This is in direct contrast to the east coast hurricane where orographic funnelling prevented an inland penetration of tropical air. This flux of moisture around the eastern side also protects the hurricane from incursions of dry continental air. Instead, mixing between the continental and maritime air produces a strong moisture gradient to the south. Any continental air reaching the core region will have been considerably modified by a long trajectory over warm tropical oceans.

A similar situation exists at 500 mb. This shows the depth of the monsoonal influx and the protection of the core region from dry continental air. The hurricane also lies just equatorward of the subtropical ridge at this level and is well removed from the subtropical westerlies. There is, however, evidence of the now familiar dry tongue extending around the northern perimeter; this is probably enhanced by dry continental air extending around the hurricane.

These features may be more completely seen in the moisture cross-section of Fig. 21 and the satellite mosaic of hurricane Joan (1975) in Fig. 22. The moisture cross-section runs northeast to southwest through the composite cyclone. However, it has been derived almost entirely from coastal stations and is thus representative of a mean coastal cross-section. On the poleward side, then, we see that the moist maritime air extends some 700 km near the surface and nearly 1000 km at higher levels. Presumably this increased extent with height is due to the stronger flux of drier continental air in the low-level trade winds. To the northeast lies an extensive region of tropical maritime air, interrupted only by the 400-600 km dry tongue above 750 mb. The cloud patterns for hurricane Joan further illustrate the flux of tropical moisture over the continent; the protected core region; the efflux of dry continental air off the southwest coast, and its advection around the western periphery of the storm; and the dry tongue to the north and northeast.

Some quite interesting examples of the continental effect on the west coast hurricane may be seen in Fig. 23. This figure gives a coastal cross-section of the temperature deviations from the Port Hedland January mean. We can see the usual mid-to-upper tropospheric warm core and the lower stratospheric cold band. The weakly sloping tropopause and absence of colder subtropical air within 1200 km also confirm that the cyclone is well within the tropics. Of most interest, however, is the reversal of the normal meridional temperature gradient, and the extremely cold core (by tropical standards) below 700 mb. The advection of hot tropical continental air around the poleward side of the hurricane, with colder tropical maritime air on the equatorward side, produces an equatorward directed temperature gradient. From thermal wind considerations this results in an easterly vertical wind shear over the hurricane (cf. the zonal wind observations in Fig. 23). These easterly winds, in turn, tend to advect the hurricane towards the west. As may be seen in Fig. 20, the deep

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**Fig. 21** Vertical moisture mixing ratio (g/kg) cross-section through the west coast hurricane and approximately along the Australian coastline.

**Fig. 22** ESSA 8 visible satellite imagery of hurricane Joan (from Director of Meteorology 1979) off the west Australian coast.

**Fig. 23** Vertical cross-section of temperature deviations from the Port Hedland January mean (Maher and Lee 1977) through the west coast hurricane and approximately parallel to the West Australian coastline. Also shown are the mean zonal wind components in the hurricane core.
subtropical ridge, which is anchored over the monsoon trough across northern Australia, also protects the west coast hurricane from the subtropical westerlies. Thus, the Australian continent appears to be largely responsible for the remarkably consistent southwestward trajectory, and peak occurrence frequency, of hurricanes just off the northwest coast (cf. Figs 1, 4 and 5).

The poleward advection of tropical maritime air around the cyclone further produces a considerable low-level cooling from the climatological norm; 900 mb temperatures within 600 km of the hurricane are 1 to 2 standard deviations below the January mean at Port Hedland. Combined with the hot tropical continental air at larger radii, this produces a strong cold core below 700 mb. (However, the unresolved eye region is almost certainly warm cored at these levels.) The resulting thermal wind effect on the azimuthal winds is shown in Fig. 24. Instead of the normally observed 850 mb wind maximum, the cyclonic winds increase in the vertical with a maximum near 700 mb. This cold-cored feature has also been observed by McBride and Keenan (1982).

In the upper levels (Fig. 20(b)) we find an anticyclone due east of the hurricane, which overlies, and is probably partially supported by, the deep overland convective activity in this region (cf. Fig. 23). The hurricane is still protected from the full impact of the subtropical westerlies, but is close enough to be able to maintain an outflow channel in the divergent flow to the southwest of the anticyclone. Following our conclusions in Holland and Merrill (1983), we believe that this arrangement is a major factor in the preponderance of hurricanes off the western Australian coast.

We have shown that hurricanes occur almost exclusively between November and May, with an early season peak occurrence in December. Hurricanes in the southwest Pacific region then reach a second peak in February. Those in the northwest Australian region occur most frequently in January and March and have a distinct minimum in February. The overwhelmingly preferred location is just off the northwestern Australian coast with a secondary maximum in the southeastern Coral Sea.

Hurricanes in the northwest Australian region mostly move exclusively westward. This is partially due to the general easterly environmental winds there, partially due to cyclone/continent interactions, and partially a result of higher latitude, eastward moving systems being removed by the Australian continent. Hurricanes in the southwest Pacific region have a slight preference for eastward movement, but the low-latitude, intensifying systems generally move westward.

We have separately examined the structure of intensifying and decaying oceanic hurricanes (at least 1000 km from the Australian coast), and of hurricanes just off the east and west Australian coasts. As with the tropical storms in H1, all composite hurricanes throughout the region are very large, have a deep equatorial inflow, and display a characteristic beta-effect distortion. This is, however, modified by coastal funnelling in the east coast hurricane.

A comparison of intensifying and decaying oceanic hurricanes also showed the dominating influence of the subtropical jet. In the intensifying hurricane, the upper westerlies impinge to within 6 degrees latitude of the centre. Thus, they do not affect the core region directly but provide an intense outflow channel to the southeast. When the westerlies move over the hurricane (or the hurricane moves under the westerlies) it is sheared off and rapidly decays. These composite conclusions are supported by case studies of hurricane Kerry (1979) in Holland and Merrill (1983). In addition, the composite intensifying hurricane is distinguished by a marked inflow near 400 mb, a stratospheric inflow and a very weak vertical wind shear in the lower troposphere. The importance of these features in the intensification process are also discussed by Holland and Merrill.

Hurricanes just off the east, and particularly the west, Australian coasts are affected considerably by the continent. Orographic funnelling along the Great Dividing Range effectively prevents an inland penetration of moisture from east coast cyclones. As a result, advection of dry continental air around the northern perimeter tends to cut off the tropical moisture supply to these systems. By comparison the dryness of the continental air generally has little, if any, direct effect on west coast hurricanes. Rather, these systems protect themselves by maintaining a strong influx of tropical moisture over much of northern Western Australia. It is the hot temperature of the air over the northwestern deserts that has the

Summary

In this paper we have described a number of climatological and structural features of hurricanes in the Australian/southwest Pacific region.

Fig. 24 Axisymmetric azimuthal wind cross-section for the west coast hurricane. Hatching indicates anticyclonic circulation.
major influence. We have shown that this produces a distinctly cold-core structure below 700 mb beyond the core region. Further, as west coast hurricanes advect the hot desert air off the coast, the normal meridional temperature gradient is reversed, and a deep easterly thermal flow is maintained across the hurricane core. Thus, the observed prevalent westward motion in this region is at least partially due to the cyclone/continent interaction.

In the next and last paper of this series (H3), we present an intensity change climatology for the Australian region and examine the structure of the major recurring hurricane.

Acknowledgments

I have enjoyed helpful conversations on this subject with Professor William M. Gray, Robert Merrill and Chen Lianshou. Grant Burton provided programming support, technical and typing support was provided by Barbara Brumit and Cindy Schrandt and the figures were drafted by Judy Sorbie. This research has been supported by the National Science Foundation Grant No. ATM-7923591 and the Australian Government.

References


Editor's Note: In this and the two other papers by Dr Holland published in this issue reference is made to 'hurricanes' in the context of severe tropical cyclones of hurricane force in the Australia/southwest Pacific region. The Australian Bureau of Meteorology has no official classification of tropical cyclones as 'hurricanes' and the use of that term in the Australian Meteorological Magazine is that of the author, and does not, in any way, imply a change by the Bureau in the terminology of the Australian region. In fact, the matter has been carefully examined in recent years and bureau policy is to continue the use of the term 'tropical cyclone'.