13B.7 THE TRADE WIND REGIME OF EASTERN AUSTRALIA

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1 INTRODUCTION

The northeastern coast of Australia, being a relatively data rich region of the tropics, is well suited for studies of tropical weather and climate phenomena. Previous research in this region has largely been focused on the westerly monsoon circulation of austral summer. A basic understanding of the easterly trade wind regime is lacking, despite it's prevalence along much of the coast.

This region exemplifies conditions at the western flanks of the subtropical high pressure systems, where the trade winds are known to vary considerably from classic models developed from observations in the eastern North Pacific and Atlantic oceans (Hastenrath, 1966). The coastline extends from the deep tropics into the middle latitudes and has relatively homogeneous topography, providing an excellent opportunity to investigate latitudinal variation in the trade wind regime. A climatology of the trade wind regime across eastern Australia is presented in this study. The spatial and temporal variability of the trade winds themselves, and also their associated temperature inversion are described. The drivers of this variability are also examined.

2 DATA

Numerous upper-air observing stations are spread along the coast of eastern Australia (Fig. 1). These stations are divided into two groups: 1) those that only launch rawinsondes, which measure wind speed and direction, and 2) those that also launch radiosondes, which also measure thermodynamic variables. The stations in the first group include Carins, Mackay, and Coffs Harbour, and generally launch rawinsondes four times a day at the hours of 2300, 0500, 1100, and 1700 UTC. The stations in the second group include Weipa, Townsville, Rockhampton, and Brisbane and generally launch radiosondes at 2300 UTC with rawinsonde launches at 0500, 1100, and 1700 UTC. The exception is Weipa, which generally only launches one rawinsonde at 1100 UTC along with the standard 2300 UTC radiosonde launch.

Quality controlled wind observations from rawinsonde and radiosonde launches at each station were obtained from the Integrated Global Radiosonde Archive (IGRA, Durre et al., 2006) which is maintained by the National Climatic Data Center (NCDC). Atmospheric sounding data from the 0000 UTC radiosonde launches (often launched

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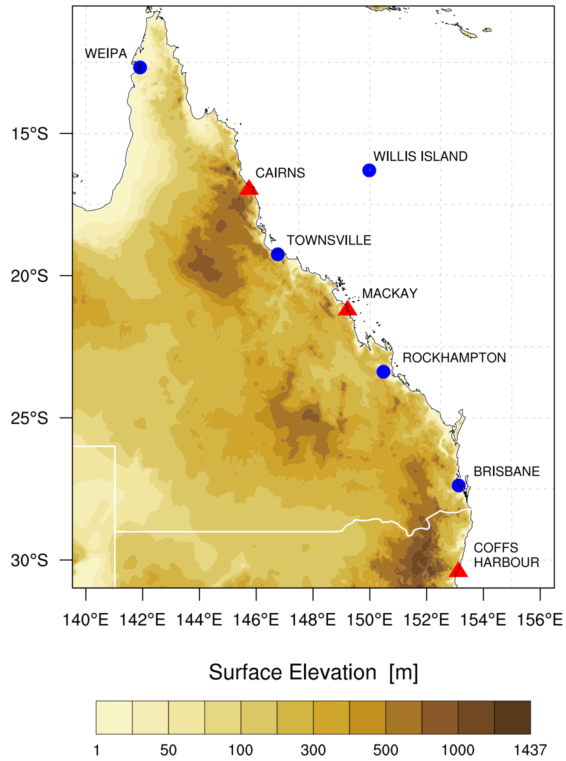

Figure 1: Overview of the study region in eastern Australia. Radiosonde (blue circles) and rawinsonde (red triangles) stations are plotted over surface elevation (shaded, m).

at ±2 hours from 0000 UTC) from the stations listed previously were obtained from an archive maintained by the University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html). The 35 year period 1976–2010 was chosen for analysis of both datasets as vertical and temporal coverage of upper-air observations had become consistent by the beginning of this period. Nevertheless, several large gaps in the observational record exist: a lack of both radiosonde and rawinsonde launches from Willis Island for the period from July 2004 through September 2006, and rawinsonde (radiosonde) observations start at Weipa in July 1990 (October 1998).

The state of El Niño–Southern Oscillation is represented by the Southern Oscillation Index (SOI). Monthly values of the SOI were obtained from the Australian Bureau of Meteorology, National Climate Centre, which derives the index using the method of Troup (1965).

A ridge of high-pressure is detectable in MSLP observations from stations in eastern Australia. An index of the latitude (°S) and intensity (hPa) of this subtropical ridge is derived from monthly mean MSLP patterns obtained by interpolating monthly mean (land-based) station data onto a 1° x 1° latitude–longitude grid (Drosdowsky, 2005). Monthly values of this subtropical ridge (STR) index were obtained from the Centre for Australian Weather and Climate Research.

Monthly SST were drawn from the National Oceanic and Atmospheric Administration (NOAA) Extended Reconstructed Sea Surface Temperature (ERSST) analysis version 3b (Smith et al., 2008). These data are on a fixed 2.0° x 2.0° latitude–longitude grid.

The European Centre for Medium Range Weather Forecasts (ECMWF) Interim Reanalysis (ERAI, see Dee et al., 2011) was used for climatological analyses, for the period 1979-2010. These 6 hourly data were average to daily fields.

3 METHODOLOGY

3.1 Defining the Low-level Wind

The low-level winds are approximated by the vertical mean of the u & v components of the wind from all observations between the surface and 800 hPa. A minimum threshold of at least 3 wind observations was used in this calculation. This method was applied to each rawinsonde and radiosonde launch at each station over the study period (1976–2010).

3.2 Identifying the Trade Wind Inversion

An algorithm was developed to identify the trade wind inversion (TWI) in each radiosonde observation. The algorithm follows the method used in Cao et al. (2007):

(i) The inversion is restricted to the 950-600 hPa layer. A lower limit on environmental temperature is set to 273 K.

(ii) The base of the TWI starts with a vertical temperature increase accompanied by RH decrease with height.

(iii) Top of the TWI defined as the level where temperature begins to decrease with height.

(iv) The higher of the two points defining any super adiabatic layer is ignored in this analysis.

(v) When multiple inversions are detected, the layer with the greatest relative humidity drop within the inversion is selected as the TWI.

After identifying the trade wind inversion several important variables describing the inversion are recorded for detailed examination. The base height of the inversion is the level (m above sea level) where the environmental temperature begins to increase with height. The thickness (m) of the inversion is the difference in height between the base and top of the inversion and the strength or magnitude of the inversion is the difference in temperature across the inversion. The relative humidity decrease from the base to the top of the inversion is also examined.

4 THE TRADE WINDS

4.1 Frequency of winds

In general the frequency of low-level wind directions associated with the trade winds (east to southeast) steadily decreases poleward along the coast of eastern Australia. All of the stations equatorward of the Tropic of Capricorn are dominated by low-level winds from the directions associated with the trades, with these wind directions occurring in more than 57% of rawinsonde launches with a maximum of 79% at Weipa. Of the two stations poleward of the Tropic of Capricorn only Brisbane has a significant occurrence of winds from the trade wind directions (just over 40%).

4.2 Annual cycle of winds

The annual cycle of low-level winds were examined by grouping the observations for each station by month. The monthly frequency of occurrence of winds from directions between east and southeast (67.5° to 157.5°) and the monthly steadiness of the winds were calculated (Fig. 2). The steadiness (or persistence) of the wind is defined as the ratio of the mean vector velocity to the mean scalar speed of the wind in a timeseries.

The prevalence of the trade wind regime during a given month is indicated by the combination of steadiness of the wind (Fig. 2d–f) along with high frequency of winds from directions associated with the trades (Fig. 2a–c). The study area can be divided into 3 regions based on these wind data: the deep tropics (Weipa, Willis Island, and Cairns), the mid-tropics (Townsville, Mackay, and Rockhampton), and the subtropics (Brisbane and Coffs Harbour). In the deep tropics the steadiness and frequency of winds indicate the dominance of the trades in all except the summer months of December–March. On the contrary, in the mid-tropics the trades dominate the first 5 months of the year at all stations. There is also indication of intermittent trades through the winter and spring in the mid-tropics, with decreasing frequency poleward. In the subtropics a period of the year dominated by the trades is not present, as is seen at stations at lower latitudes. Only Brisbane shows a combination of steadiness and frequency of winds indicative of trades, but only during the late summer months (February–April), and only at moderate values suggesting intermittent trades.

The annual cycle of the trade winds is largely driven by the subtropical ridge (STR) over eastern Australia. The monthly timeseries of frequency of winds from the trade

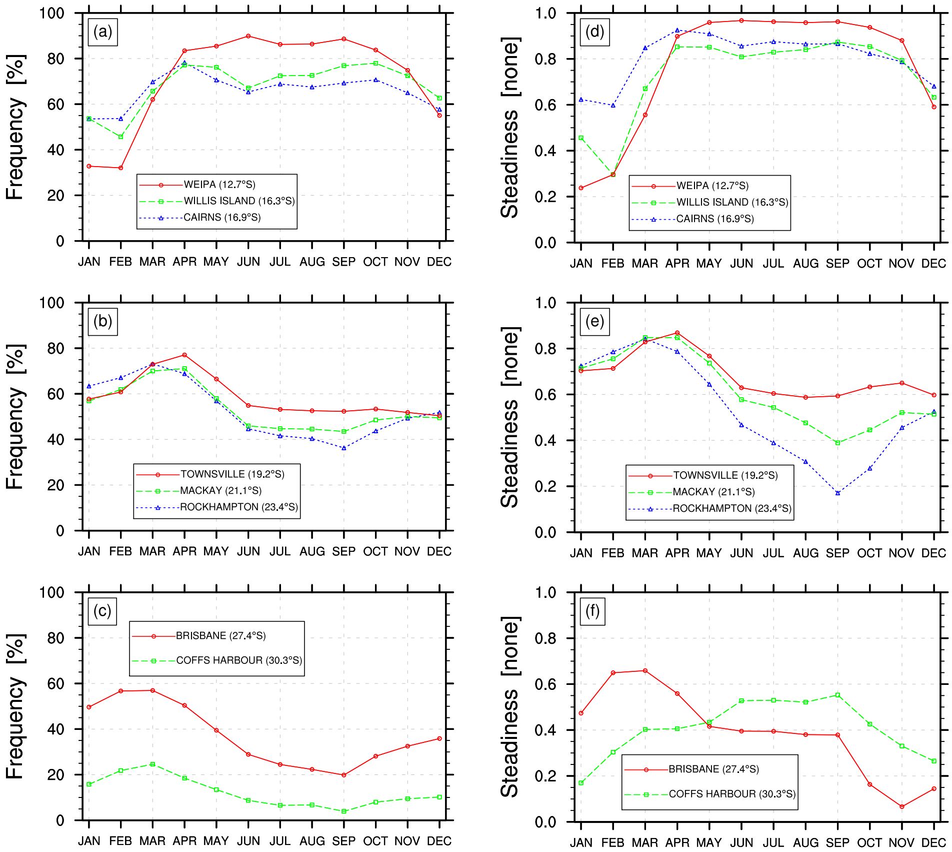

Figure 2: (a–c) Frequency (%) of low-level wind observations from directions between east and southeast and (d–f) steadiness (dimensionless) of the low-level wind for each month at each station. Stations have been grouped by latitude from data over the period 1976–2010

directions are strongly cross correlated with the intensity of the STR at stations in the deep tropics (Weipa, Willis Island, & Cairns) with correlations of 0.54-0.66. In the subtropics correlations with the intensity of the STR are weak but are strong with the latitude of the STR with values greater than 0.60 at Brisbane & Rockhampton.

4.3 Interannual variability and climate drivers

Interannual variations in trade wind frequency are examined by comparing the monthly timeseries of frequency of low-level winds from directions associated with the trades (east and southeast) at each station with various climatic indices relevant to eastern Australia. These climatic indices are monthly local SST, monthly intensity and latitude of the STR, monthly SOI, and monthly mean omega on the 850, 700, & 500 hPa pressure surfaces over eastern Australia. The station at Weipa was excluded from this analysis due to its relatively short temporal record (1990–2010).

Trade wind frequency is found to be most closely related to the STR over eastern Australia ((Fig. 3). Correlations with STR intensity are very high throughout the winter at all stations except Coffs Harbour, with the highest correlations (approximately 0.9) found at stations in the mid-tropics (Fig. 3a–c). The latitude of the subtropical ridge is only moderately correlated to the frequency of winds from the trade directions (Fig. 3d–f). The correlations at most stations only reach statistically significant levels (above the 99 % confidence interval of 0.43) only in the mid to late winter months of July–September. The magnitude of these correlations are highest in the mid and subtropics (reaching 0.7 to 0.8).

5 THE TRADE WIND INVERSION

5.1 Frequency of the inversion

An inversion is a common feature over the coast of eastern Australia, occurring in more than 68% of soundings in the tropics and in 59% of soundings at the subtropical station at Brisbane. Frequency of inversion occurrence

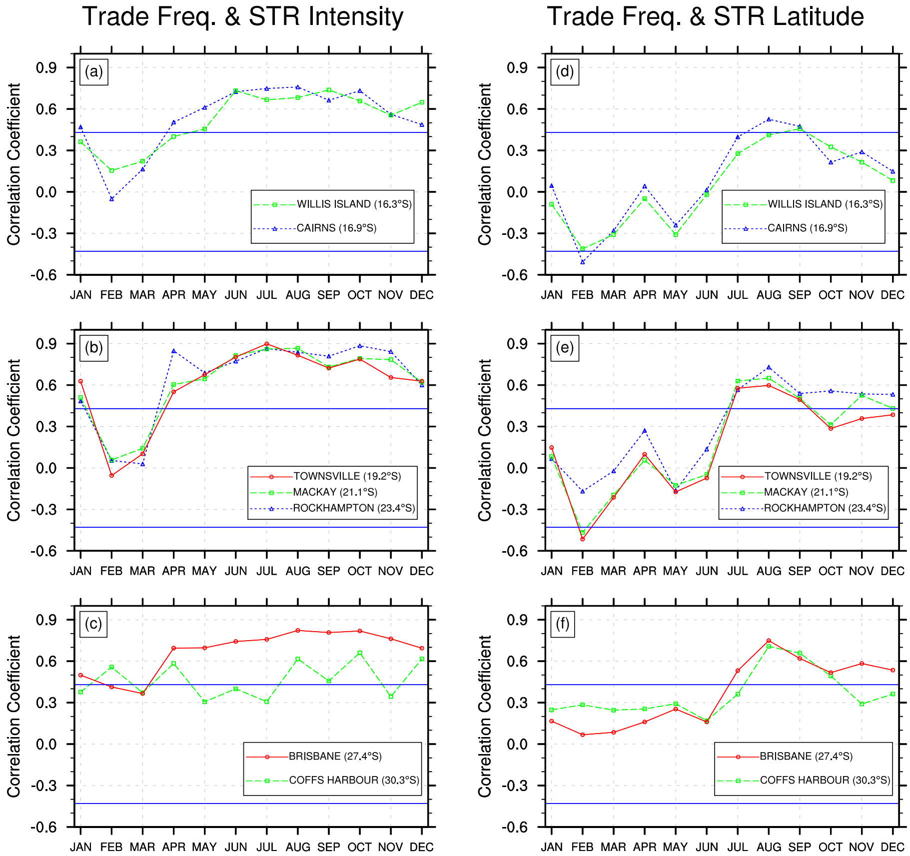

Figure 3: Cross correlation (Pearson product moment) between monthly frequency (%) of winds from directions between east and southeast and an index of subtropical intensity (a–c) and latitude (d-f). The 99% confidence interval (approximately ± 0.43) is indicated by the solid horizontal lines. All correlations are for the period 1976–2010.

generally decreases poleward along the coast with the exception of Townsville where it reaches its maximum value of 77%.

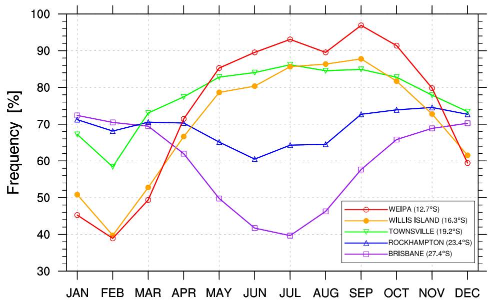

Figure 4: Frequency of occurrence (%) of a trade wind inversion for each month of the year at each of the 5 stations that launch radiosondes, based on data from 1976–2010.

5.2 Annual cycle of the inversion

The monthly frequency of occurrence of the inversion is plotted for each station (Fig. 4). In general, an inversion is most frequent in those months dominated by the trade winds. Stations in the deep tropics have inversion frequencies greater than 80% throughout the winter, while the station in the subtropics (Brisbane) has the highest frequency in the summer months (70%). The station at Rockhampton, which lies near the Tropic of Capricorn, has a much weaker annual cycle of inversion occurrence, with frequencies between 60-75% throughout the year.

The basic properties of the inversion have a distinct annual cycle (Fig. 5). The median value of each property was calculated for each month in the radiosonde time-series (minimum threshold of 5 observations), then the mean of these monthly values was calculated for each month. The annual cycle of inversion base height (Fig. 5a) follows a similar pattern at most stations with a maximum in March/April and minimum in September/October. The magnitude of the annual cycle in base height is also

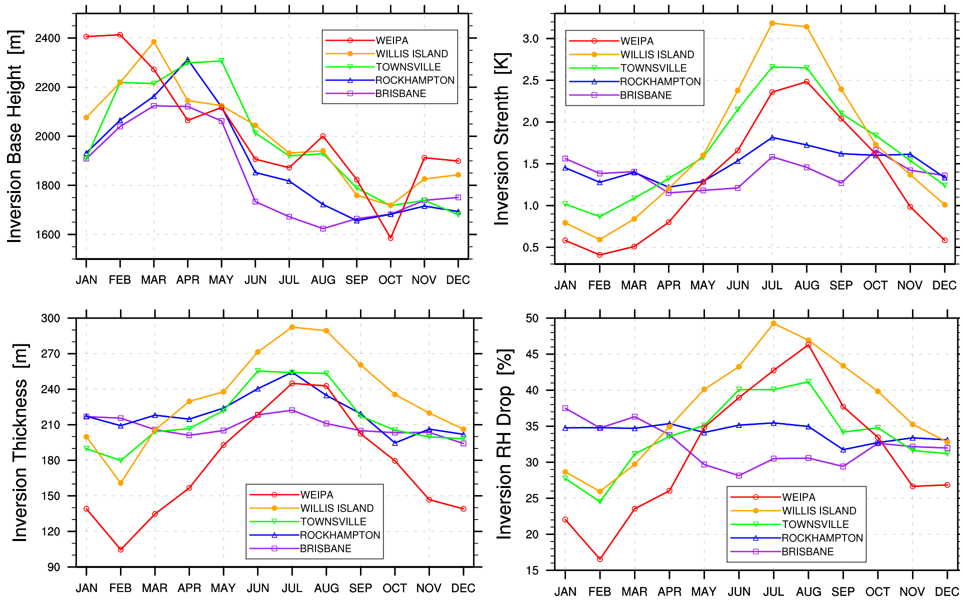

Figure 5: Annual cycles of (a) inversion base height, (b) inversion strength, (c) inversion thickness, and (d) inversion relative humidity drop at each of the 5 stations that launch radiosondes, based on data from 1976–2010.

similar across the stations with peak-to-peak amplitudes of 500-800 m, with the highest (lowest) amplitudes at the equatorward-most (poleward-most) station.

The thermodynamic properties of the inversion (thickness, strength, & relative humidity drop) all have similar annual cycles (Fig. 5b-d). These properties all have maxima in July/August and peak-to-peak amplitudes which decrease poleward to the point that the stations at Rockhampton and Brisbane have little to no discernible annual cycles. The Pearson product-moment correlation between the entire monthly timeseries of the thermodynamic properties of the inversion gives high correlation coefficients of 0.7–0.8 at stations in the deep tropics (Weipa & Willis Island). While thermodynamic properties of the inversion do covary with each other, they are largely independent of the inversion base height, with which they are very weakly correlated (< 0.26) at all stations. The intensity and also latitude of the STR has a moderate correlation with thermodynamic properties of the inversion (0.4–0.6 in the tropics) but very weak correlations with inversion base height.

5.3 Interannual variability and climate drivers

Interannual variations in inversion properties are examined by comparing the timeseries of monthly median values of each variable at each station with the selected climatic indices mentioned previously. Again, the station at Weipa was excluded from this analysis due to its relatively short temporal record (1998–2010).

Inversion base height is most strongly correlated with the intensity of the STR, primarily during the winter months (June–October) where correlations reach up to 0.6 (Fig. 6a). However, inversion strength (as well as the other thermodynamic properties of the inversion) is only weakly correlated to the intensity of the STR (Fig. 6b) as well as the other climate indices examined (not shown). The frequency of occurrence of the inversion is most strongly correlated with the local SSTs, again primarily during the winter months (June–September) where correlations reach up to 0.6 (Fig. 6c).

6 CONCLUSIONS

Based on the analyses presented the following conclusions are made about the trade winds and their associated temperature inversion over eastern Australia:

6.1 The trade winds

1. The trade wind regime dominates the deep tropics (roughly 12–18°S) throughout austral winter (April–November), and the mid-tropics (roughly 18–25°S) from late summer to early Autumn (January–May).

2. The poleward fringe of the trade wind regime is found near Brisbane (27.4°S), where the trades are common primarily during the months of February and March.

3. The annual cycle of trade wind frequency is related to the subtropical ridge over eastern Australia. The annual cycle in the subtropics (deep tropics) is most

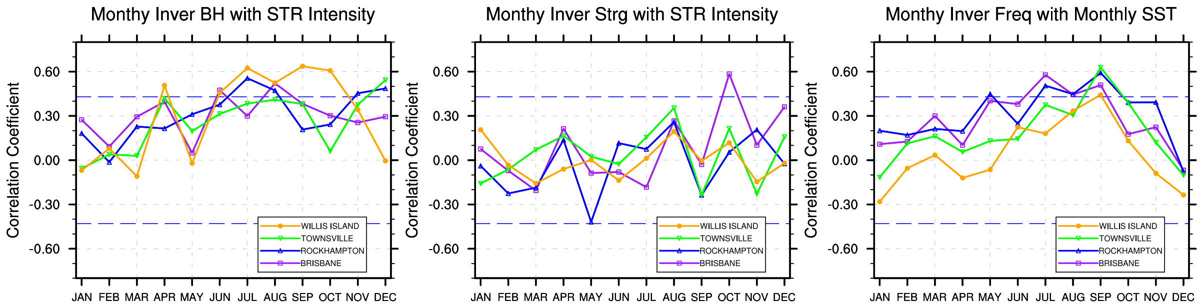

Figure 6: Cross correlation (Pearson product moment) between monthly median (a) inversion base height and intensity of the subtropical ridge (b) inversion strength and latitude of the subtropical ridge, (c) inversion frequency and local SST. The 99% confidence interval (approximately ± 0.43) is indicated by the dashed horizontal lines. All correlations are for the period 1976–2010.

closely related to the intensity (latitude) of the subtropical ridge.

4. Interannual variability in the occurrence of the trade winds is largely driven by variability in intensity of the subtropical ridge during austral winter at all stations except Coffs Harbour.

6.2 The trade wind inversion

1. A low-level temperature inversion is a common feature over the coast of eastern Australia, and monthly occurrence at a given location is highest during it's respective trade wind season

2. A strong annual cycle is found in inversion base height with a pattern that is independent of latitude. Maxima (Minima) are found in austral autumn (spring)

3. The annual cycles in thermodynamic properties of the inversion are strong near the equator and become very weak in the subtropics. These properties all have very similar annual cycles and covary with one another, with maxima in austral winter.

4. Inversion base height and thermodynamic variables are found to vary independently of one another (on monthly timescales).

5. Interannual variability in inversion frequency (base height) has a moderate relationship with the local SSTs (intensity of the subtropical ridge) during austral winter and spring.

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