2B.5 SUBTROPICAL STORMS IN THE SOUTH ATLANTIC BASIN AND THEIR CORRELATION WITH AUSTRALIAN EAST-COAST CYCLONES

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1. INTRODUCTION

In March 2004, a subtropical storm formed off the coast of Brazil leading to the formation of Hurricane Catarina. This was the first documented hurricane to ever occur in the South Atlantic basin. It is also the storm that has made us reconsider why tropical storms (TS) have never been observed in this basin although they regularly form in every other tropical ocean basin. In fact, every other basin in the world regularly sees tropical storms except the South Atlantic. So why is the South Atlantic so different? The latitudes in which TS would normally form is subject to 850-200 hPa climatological shears that are far too strong for pure tropical storms (Pezza and Simmonds 2006). However, subtropical storms (ST), as defined by Guishard (2006), can form in such an environment.

Subtropical South Atlantic SST are typically much cooler than 26.5°C (Pezza and Simmonds 2006). The poleward migration of warm SST is governed by the strength of the Brazilian Current, the South Atlantic counterpart of the Gulf Stream. The striking difference, however, between the North and South Atlantic is the strength of the Malvinas Current (the South Atlantic counterpart of the Labrador Current), an equatorward branch of the Circumpolar Current encircling Antarctica. Usually, the strong Malvinas Current acts to suppress poleward migration of the Brazilian Current, effectively limiting subtropical SST. In March 2004, the Malvinas Current seems to have been weaker than normal and warm eddies in excess of 22º C migrated south of 30º S, providing oceanic forcing for the formation of Hurricane Catarina.

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With the exception of warmer SST in the Tasman Sea region (0°−60°S, 25°E−170°W), the climate associated with South Atlantic ST is very similar to that associated with Australian east-coast cyclones (ECC). A coastal mountain range lies along the east coast of each continent: the Great Dividing Range in Australia (Fig. 1) and the Serra da Mantiqueira in the Brazilian Highlands (Fig. 2). The East Australia Current transports warm, tropical water poleward in the Tasman Sea predominantly through transient warm eddies (Holland et al. 1987), providing a zonal temperature gradient important to creating a baroclinic environment essential for ST formation.

2. METHODOLOGY

a. Definition of a subtropical storm

Subtropical storms are defined as surface cyclones between 20°-40° latitude that have gale force winds (>17 ms^{-1}) and hybrid thermal structure: they are warm-cored in the lower-troposphere and cold-cored aloft. The core of the subtropical cyclone tilts westward with height (Guishard 2006; Guishard et al. 2007).

b. Data

ECMWF high-resolution spectral model reanalyses (ERA-40, Uppala et al. 2005) are utilized in our study for their temporal coverage (August 1957 to December 2002), and high spatial resolution (ranging from 1.2° x 1.2° to 1.4° x 1.4° and 14 vertical levels for the domain of interest).

NCEP Global Forecast System (GFS) operational analyses have 1° x 1° degree horizontal resolution and 26 vertical levels. GFS analyses from 2000-2007 are utilized to study the evolution of ST and their environments in both the South Atlantic and Tasman Sea regions. Combined with the ERA-40 study, this gives a 51-year total study period (1957-2007), with a three year (2000-

2002) overlap between the two databases.

c. Methods and diagnostics

The definition of ST from Guishard (2006) is applied to the ERA-40 and GFS analyses to identify and partition ST, although his CPS criteria have been relaxed for this study due to the findings of Manning and Hart (pers. comm. 2007).

An automated detection and tracking algorithm (Hart 2003) was implemented to compile a catalog of candidate ST. Any candidate storms that did not exhibit gale force winds were immediately deleted from this set (Guishard 2006; Arnott, pers. comm. 2005). Candidate systems were further culled based upon their Cyclone Phase Space (CPS, Hart 2003) characteristics and satellite signature. Synoptic analyses completed the filtering of candidate systems to derive the final ST database.

Three diagnostic tests remain to complete the fifty-one year climatology: (1) potential vorticity (PV) analysis (to identify development of a cut-off upper cyclone); (2) vertical wind shear (if the shear is too strong, the storm is more likely to develop into a baroclinic cyclone); and (3) genesis location relative to the local warm current (including the magnitude of warm-air advection into the ST).

3. Results

Subtropical storms in the South Atlantic develop under similar meteorological conditions as Tasman Sea region ST. Both South Atlantic and Tasman Sea region ST behave and appear similar to North Atlantic ST and so can be compared with the results of Guishard (2006) and Guishard et al. (2007). Indeed, we hypothesize that one genesis mechanism for the South Atlantic ST presented in this climatology is development due to wave interaction produced by the local topography with the warm SST just offshore (similar to ECC genesis in the Tasman Sea region).

ECC form in a trough in the subtropical easterly flow (Holland et al. 1987, Hopkins and Holland 1997). The trough typically develops downstream of a mid-tropospheric cold-core cyclone and lies equatorward of a strong subtropical ridge, between two diffluent jetstreams. This setup, referred to as a Rex block, provides a baroclinic environment in which ECC can form.

In the South Atlantic region, Zhou and Lau (1998) observe that in the austral summer months, the subtropical and polar jetstreams merge into a single jet, effectively reducing the amount of upper-level interaction between the two. They then split again in the late summer. Their study also notes that in the summer months, differential heating between the subtropical continent and the ocean becomes insignificant. Therefore, in the austral non-summer months, a baroclinic environment in which ST can form will be observed. It is these month which are comparable to the baroclinic environment which exists in the Tasman Sea region.

Ninety-two ST (1.8 per year) were identified along the east coast of South America (Fig. 3) compared to 185 ST in the Tasman Sea area (3.63 per year, Fig. 4) in the same fifty-one year time period. In most cases, the ST begins as a cut-off low with baroclinic origins that breaks away from a larger PV reservoir (e.g. a midlatitude trough) in a region of anomalously warm SST. This results in a near-neutral thermodynamic profile, favorable for formation of deep convection in the presence of forced ascent (Guishard 2006). The combination of these details with the storms' hybrid structure can amount to a lethal combination of damaging winds and high seas.

a. South Atlantic climatology

Surprisingly, the months which exhibited the largest amount of storms per month were in April, August, and September (austral autumn, winter, and spring, respectively, Fig. 5). As hypothesized, a significant fraction of South Atlantic ST originate east of the Serra da Mantiqueira mountain range due to heightened wave activity and track to the south and east following the warm water eddies. August is highlighted because it occurs in the annual upswing of ST numbers (Fig. 5). Genesis locations for August ST are over relatively cool SST (Fig. 2). Note that the SST (contours) are long-term monthly means for August, but genesis locations for the complete ST database for all months are plotted. This will be the same for the other three like plots.

To allow for a comparison between the South Atlantic and the North Atlantic basins, April has also been plotted in a similar fashion (Fig. 6). April, which falls into the austral early autumn, was identified as an active time of year in the North Atlantic by Guishard (2006). Genesis locations for April ST seem to be located over warmer SST and within a greater proximity to land. A heightened reliance on the local topography to produce upper-atmospheric disturbances has certainly led to this observation.

b. Tasman Sea region climatology

Australian ECC and the ST observed in the South Atlantic basin bear a striking resemblance to each other. Not only do ECC develop under similar meteorological conditions as South Atlantic ST, but their locations of origin relative to the coastal mountain range are similar, their tracks are similar, their satellite signature is similar, and their behavior as hybrid structures are similar. We can conclude with this comparison: that many ECC are in fact ST since these storms display all of the necessary characteristics of a ST.

As in the South Atlantic, July exhibited the largest amount of storms per month (Fig. 7). Again, as hypothesized, a significant fraction of Tasman Sea ST originate east of the Great Dividing Range. The ST then track to the south and east following warm water eddies. The July genesis points form over relatively warm SST, though are not nearly as warm as they get in the summer months (Fig. 1).

Mean April SST with respect to genesis location of April ST genesis points and all other ST in the database were plotted (Fig. 8). April ST genesis locations have a much larger spread than those of July. These ST genesis points seem to have migrated towards warmer SST as would be expected by traditional convention. There seems to be less baroclinic influence upon these ST formations. Perhaps this can account for the observed decrease in ST formations within this particular month.

4. Discussion/Conclusion

The conditions under which subtropical storms are able to develop in the South Atlantic basin and Tasman Sea region have been described using a fifty-one year climatology. Due to the subtropical storms' ability to form under the presence of vertical wind shear and cool SST, and their potential for transitioning into tropical cyclones in the North Atlantic, the possibility of tropical cyclones in the South Atlantic basin cannot be disregarded.

This study has shown numerous probable subtropical cyclone formations in both the South Atlantic and the Tasman Sea regions. We have also argued that subtropical cyclone development led to the formation of Hurricane Catarina. This is evidence of future viable tropical cyclogenesis in the South Atlantic basin, and provides some explanation for why tropical cyclogenesis was not previously suspected here: it is not the typical mechanism for genesis.

The resemblance between South Atlantic ST and Australian ECC helps to envision just how ST fit into the climate of the South Atlantic basin. Both regions have a similar topographic setup and similar SST gradients which, under the right meteorological conditions, create a baroclinic environment conducive to subtropical storm formation. The likelihood is that numerous occurrences of tropical development in the South Atlantic were overlooked not only because subtropical storms were not explicitly defined until Guishard (2006), but these formations occurred in an environment traditionally thought of as unfriendly to tropical storm formation. As we can see, however, this is not the case.

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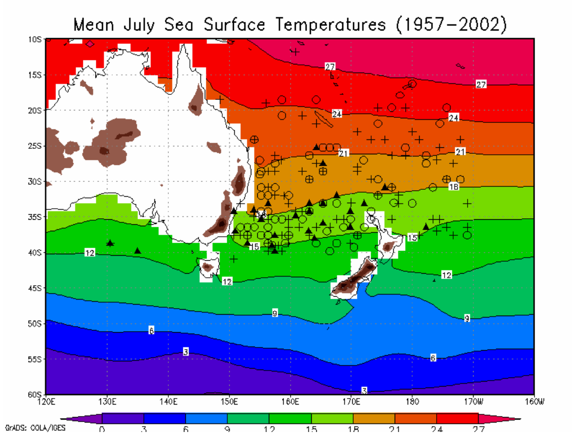

Figure 1. July is the peak genesis month in the Tasman Sea region. SST are in degrees C. The filled in triangles are ST that formed within July; the plus signs are ST that formed within the cold season (March-August); the open circles are ST that formed within the warm season (September-February). Note how the July ST genesis points are just downstream of the Great Dividing Range.

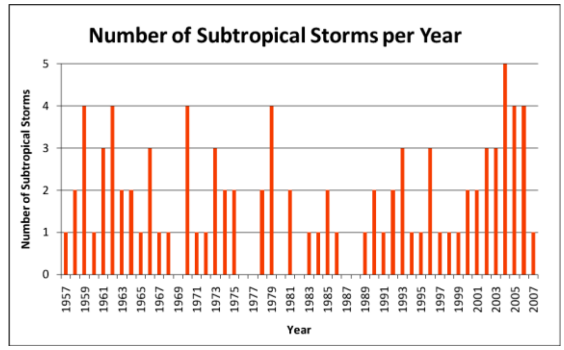

Figure 3. The South Atlantic has ninety-two confirmed ST storms within the fifty-one year climatology. The dates include September 1, 1957 through December 31, 2007.

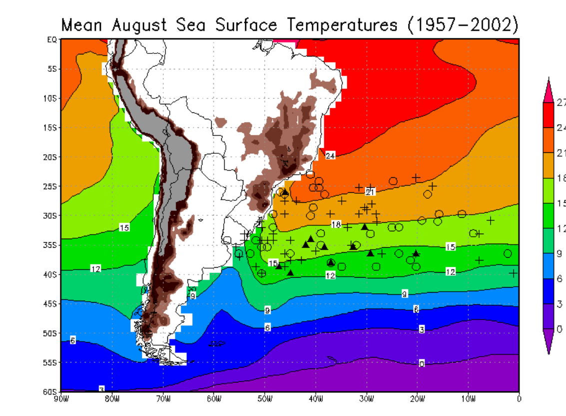

Figure 2. This plot shows one of the peak genesis months in the South Atlantic basin which was chosen due to its placement within the upswing of ST numbers. SST are in degrees C. The filled in triangles are ST that formed within August; the plus signs are ST that formed within the cold season (March-August); the open circles are ST that formed within the warm season (September-February). Note how the August ST genesis points are just downstream of the Serra da Mantiqueira mountain range.

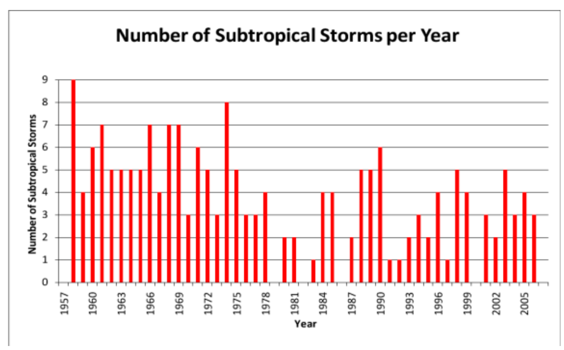

Figure 4. The Tasman Sea region has one-hundred and eighty-five confirmed ST storms within the fifty-one year climatology. The dates include September 1, 1957 through December 31, 2007.

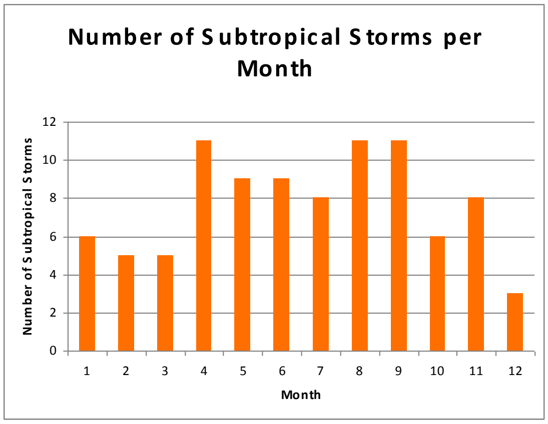

Figure 5. Number of storms per month within the fifty-one year climatology in the South Atlantic basin. April, August, and September all displayed a maximum in subtropical storm formation. December saw the least amount of ST formations overall.

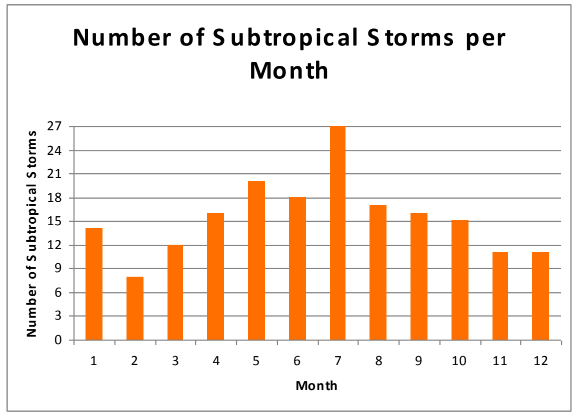

Figure 7. Number of storms per month within the fifty-one year climatology in the Tasman Sea region. July displayed a maximum in subtropical storm formation. February saw the least amount of ST formations overall.

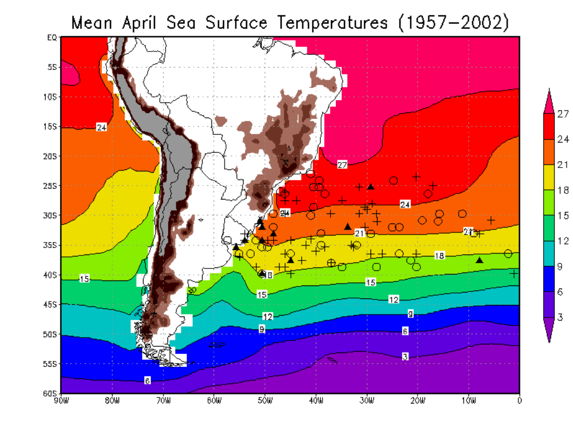

Figure 6. April demonstrated a peak in ST formation in the South Atlantic basin. SST are in degrees C. The filled in triangles are ST that formed within April; the plus signs are ST that formed within the cold season (March-August); the open circles are ST that formed within the warm season (September-February). Note the proximity between the April ST genesis points the Serra da Mantiqueira mountain range.

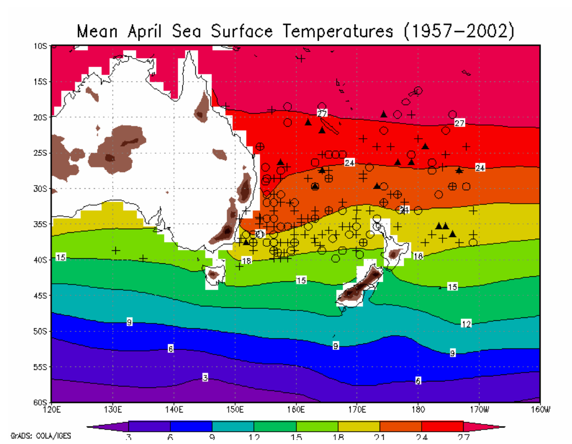

Figure 8. April is also a month which demonstrated a great amount of ST formation in the Tasman Sea region. Sea surface temperatures are in degrees C. The filled in triangles are ST that formed within April; the plus signs are ST that formed within the cold season (March-August); the open circles are ST that formed within the warm season (September-February). Note how the April ST genesis points have migrated north following the presence of warm SST.