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COMPARISON OF CONVECTIVE ENVIRONMENTS IN DEEP TROPICAL AND EXTRATROPICAL ATMOSPHERES WITH 1989-2002 RADIOSONDE DATA

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1. INTRODUCTION

Description of tropical convection is still a weak link in the present mesoscale and global models. The tropical regions generally have a low predictability (Krishnamurti 1999). Knowledge about tropical convection organization below the synoptic scale is elusive, albeit there has been much progress in understanding the larger scale dynamics of the tropical atmosphere on intraseasonal and longer time scales. The morphology and dynamics of tropical weather systems that is important in day-to-day weather forecasting are much less understood, perhaps with the exception of tropical cyclones, but including monsoonal weather (Smith et al. 2001).

In comparison, knowledge about storm dynamics in mid-latitudes such as US has improved substantially. Relatively mature theories and tested conceptual models have been established and utilized extensively in the storm weather practice, such as the one based on the theory of shear-cold pool interaction proposed by Rotunno, Klemp and Weisman (Rotunno et al. 1988). Significant supportive parameters have been identified to guide the convective weather forecast in these regions. Are the theories and conceptual models readily applicable to tropical convective weather forecast?

Solution to the above question necessitates a close examination of the similarities and differences of the convective environments between the tropical and extra-tropical atmospheres.

2. DATA

In this study, a quantitative evaluation of convective environments in tropical and extratropical atmospheres is performed by using twice daily radiosonde data at three stations for a 14 year period from 1989 to 2002. The data is offered by the Department of Atmospheric Sciences, University of Wyoming at their website. The three stations are (1) Singapore Changi airport (SIN) at 1.36ºN, 103.98ºE, (2) Little Rock of Arkansas US (LR) at 34.73ºN, 92.23ºW, and (3) Beijing China (BJ) at 39.93ºN, 116.28ºE. The elevations of the three stations are 16 m, 78 m, and 55 m, respectively, which may warrant negligible topographic influence. Approximately 30,000 soundings are inspected.

Atmospheric state variables (p, t, q, and **v**) on non-mandatory levels are interpolated to mandatory levels using a weighting function related to distance. Generally used instability indices are provided in the dataset. The mean air of the lowest 500 m of the atmosphere is used as the initial parcel in the calculation of Convective Available Potential Energy (CAPE). A common approach, the irreversible pseudoadiabatic process, which assumes all condensate precipitates instantaneously, is applied. This eliminates the effects of liquid water and ice loading and the heat capacity change. Virtual temperature is used to accommodate the effect of moisture on air density (buoyancy). Strict data quality control is conducted prior to data analysis.

Although there is yet controversy regarding the Lifted Parcel Theory and the calculation of CAPE depending on the choice of the initial parcel (Roff and Yano 2002), the calculation of CAPE throughout the dataset is consistent and unified. The convective properties are investigated in the context of relative rather than absolute significance.

3. RESULTS

Low-level wind shear is one of the most important parameters that affect convective storm development. Monthly mean zonal wind profiles at the three stations are thus first checked in Fig. 1. The most significant variation of zonal winds below 500 hPa occurs at LR. It is less considerable at BJ, and rather insignificant at SIN.

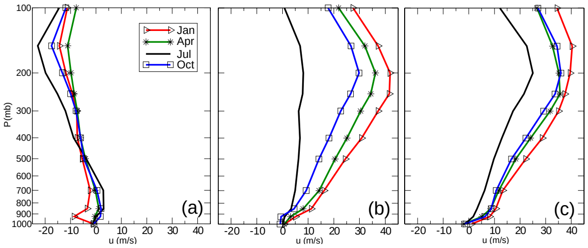

Fig. 1 Mean (1989-2002) vertical profiles of zonal wind in Jan., Apr., Jul., and Oct. at (a) SIN, (b) LR, and (c) BJ.

Fig. 2 shows the frequency distribution of wind shear, which is herein defined as the difference between the wind vectors at the surface and 6 km above ground level. In SIN, wind shear less than 5 m/s occurs 80% of time, and 5-10 m/s shear occurs 19% of time. The shear of 10-15 m/s occurs only 1% of time.

Stronger wind shear (10-15 m/s) appears about 10 times more frequently (10%) in LR, while each of the 0-5 m/s and 5-10 m/s shears accounts for 40% of the total frequency distribution (see also Fig. 2). The frequency distribution of various wind shears in BJ is somewhat in the range between SIN and LR.

Fig. 3 illustrates the frequency distribution of CAPE. SIN has about 1000-2000 J/kg 60% of time, while it is 10% less in LR, and there is a further 10% decrease in BJ. There are more spreads of higher (>3000 J/kg) and lower CAPE (0~250 J/kg) values in the midlatitude stations than in the tropical station.

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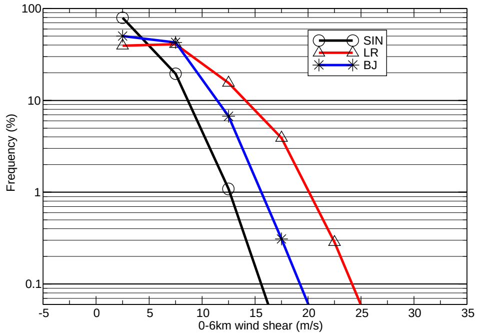

Fig. 2 Frequency distribution of 0-6km wind shear at SIN, LR, and BJ. Only data from Apr. to Oct. is used.

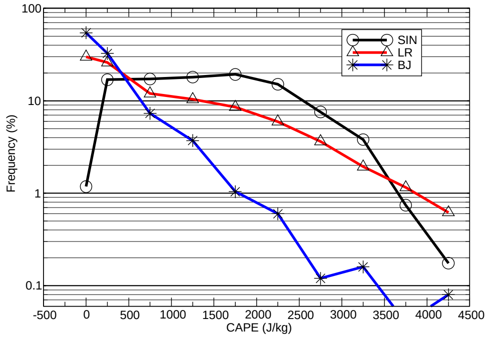

Fig. 3 Frequency distribution of CAPE at SIN, LR, and BJ. Only data from Apr. to Oct. is used.

For the convective inhibition (CIN) (figure omitted), BJ has more frequencies of large CIN values (>100 J/kg) than LR and SIN. Cases with CIN = 340 ± 20 J/kg occur 9% of time in BJ, but only 1.5% in LR and 0.2% in SIN. For CIN = 20 ± 10 J/kg, it occurs 75% of time in SIN, 45% of time in LR, and 10% in BJ.

Comparison of the lifting condensation level (LCL), level of free convection (LFC), and equilibrium level (EL) at the three stations discloses (figures not shown) that the LCL and LFC in the tropical atmosphere are lower than those in the extratropical atmosphere by about 100 hPa, and the EL is approximately 40–400 hPa higher depending on the season. Therefore, tropical convection is generally lower and deeper.

The atmospheric lapse rate, static stability, and potential (convective) stability are examined in Fig. 4. The lapse rate in SIN is smaller than in LR and a bit larger than in BJ in July as seen in Fig. 4a. Convective storms grow vigorously in steep lapse rate which favors cold pool and cell regeneration (Brooks et al. 2003). Fig. 4b implies that the atmosphere at SIN is less stable statically with a slightly reduced buoyancy frequency than at LR and BJ. Fig. 4c denotes that the potential instability is quite high in SIN than in LR and BJ, consistent with the high frequency of large CAPE at SIN, but not necessarily meaning stronger storms.

Another striking difference between tropical and extra-tropical atmospheres lies in the moisture content and the associated boundary layer thermodynamic status that primarily decides the CAPE value. Fairly humid condition with RH>85% exists close to surface in SIN throughout the year in contrast to 50-60% in LR and 50-80% in BJ (figure not shown). Time height evolution of θ_e exhibits much smaller seasonal change of the thermodynamic conditions in the lower troposphere in SIN than in LR and BJ. Well mixed boundary layers appear in SIN at all times, although the boundary layer height fluctuates with season (figure not shown). It reaches the highest in May, matching the fact that this is the hottest time in SIN.

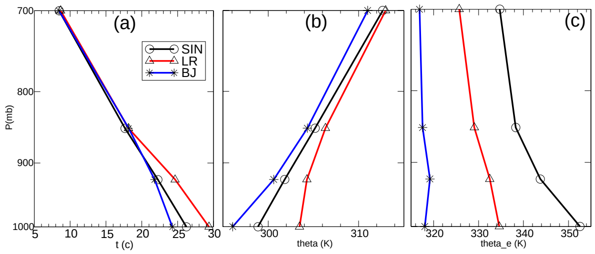

Fig. 4 Mean (1989-2002) vertical profiles of (a) temperature in Jul.; (b) potential temperature θ in Aug.; and (c) equivalent potential temperature θ_e in Sept. at SIN, LR and BJ.

4. CONCLUDING AND DISCUSSION

Deep tropical atmosphere is characterized by weak low-level wind shear. It is statically less stable with a slightly smaller buoyancy frequency than that in midlatitudes, implying slow system propagation in tropics if the organized convection is considered to be a gravity wave (Raymond 1976). It is also potentially more unstable with large CAPE and low CIN, which is, however, not necessarily signifying more vigorous convection. Gentle lapse rate due to intense solar radiation and low base of free convection induced by abundant near-surface moisture lead to unfavorable cold pool development. The balance between wind shear and cold pool is realized while both variables bearing small values, thus is delicately maintained. These may explain why deep tropical maritime convection tends to be fragile, though more populous, and short lived, compared to midlatitude storms. Our work suggests that the wind shear and cold pool interaction theory might need a refinement when applied in deep tropics.

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