12.1 EVALUATING MULTI-DECADAL TRENDS IN TROPICAL CAPE

Charlotte A. DeMott and David A. Randall
Colorado State University, Fort Collins, CO 80523

1. INTRODUCTION

Previous studies have inferred changes to the thermodynamic structure of the tropical troposphere through the use of sounding data. Based on data from 1979-1997, Gaffen et al (2000) found that tropical surface temperatures have increased faster than mid-tropospheric temperatures, resulting in decreased atmospheric stability (increasing lapse rates). Ross and Elliott (2001) found that Northern Hemisphere water vapor mixing ratios have increased at most stations, especially over the Pacific Ocean and North America.

The frequency and intensity of convection in the tropics is sensitive the geographic and vertical distribution of water vapor, temperature lapse rates, and triggering mechanisms. Because tropical convection is the energy source for large-scale circulations such as the Hadley cell and Walker circulation, understanding the factors that influence its geographic and temporal variability are crucial to understanding larger-scale atmospheric variability. The influence of the large-scale temperature and moisture field on convective activity may be quantified by computing convective available potential energy (CAPE, Emanuel, 1994), which is a measure of thermodynamic energy available for the production of convective updrafts. CAPE is essentially a function of a lifted parcel's moisture content and the lapse rate of the atmosphere through which is ascends. Since trends have been detected in each of these variables, it is of interest to determine if changes in CAPE have also taken place.

In this study, we use radiosonde data to compute trends in tropical CAPE and analyze the leading factors causing such trends.

2. DATA AND ANALYSIS METHODS

Soundings used in this study are taken from the National Climatic Data Center (NCDC) Global Upper Air Network (GUAN) data set, a subset of the NCDC Comprehensive Aerological Reference Data Sets (CARDS) selected based on length and quality of temporal record and geographic location. All soundings in this dataset have been subjected to the Complex Quality Control procedures described by Eskridge et al. (1995). From this dataset, individual soundings located within +/- 25^o of the equator were selected for consideration and were tested on a sounding-by-sounding basis for inclusion or elimination from the sample. Criteria for retaining a sounding for study were 1) the first data level must be less than 50 m above the surface, 2) the sounding must extend to at least 200 mb, 3) at least 80% of mandatory levels below 200 mb must be present, 4) the two lowest sounding levels must have valid temperature and humidity data, and 5) the balloon must not descend prior to reaching 200 mb. Once a time series of usable soundings was constructed, details of the time series (based on the number of soundings available per month, consistency of station location and sonde type) for each sounding station were determined. Only those stations with records extending back to at least 1979 and free of detectable changes associated with instrumentation changes were included in the analysis. Soundings were virtically interpolated to 10 mb resolution. CAPE was computed by retaining the positive-only area for parcels that were lifted from the level nearest to 15 mb above the surface.

3. RESULTS

Results of the CAPE analysis are presented in Fig. 1. Upward- (downward-) pointing triangles indicate positive (negative) trends. Solid (open) symbols indicate trends that are (are not) significant at the 95% confidence levels as measured by a two-tailed Student's t-distribution test. Trends are expressed as a percentage of the long-term mean per decade. Positive trend counts slightly exceed negative trend counts, but a large fraction of negative trends do not pass the significance test. There is a general clustering of positive trends in the West Pacific and Caribbean, but there is no convincing case for widespread increases in tropical CAPE. Incidentally, the same conclusion might not be drawn from Gettleman et al (2002, hereafter G02) who performed a similar analysis, despite very good station-to-station agreement between their results and ours (9 of 10 stations common to our studies have same-signed CAPE trends). This apparent discrepancy is simply a difference of impression one is left with when viewing maps of the trends. The larger number of stations analyzed in our study resulted in the larger fraction of negative CAPE trends.

We next turn our attention to the question of how atmospheric lapse rates and moisture content influence CAPE. To answer this question, precipitable water (PW) and low-level (surface-700 mb) and mid-level (700-300 mb) temperature lapse rates are computed from the sounding data. Monthly anomalies of CAPE, PW, and lapse rate are then computed by subtracting the monthly values for each variable. On monthly timescales (not shown), CAPE is positively correlated with precipitable water (PW) at every station analyzed. Most stations are positively correlated with low-level lapse rate, but a few are anticorrelated. For mid-level lapse rates, roughly half the stations are positively correlated with CAPE, and half negatively correlated. Therefore, on monthly time scales, PW is the best predictor for CAPE, with low-level lapse rates being a secondary effect.

How these two variables may effect CAPE over multi-decadal periods is not completely obvious, however. We measure the effect of lapse rate and PW trends on CAPE trends by regressing monthly CAPE anomalies onto monthly lapse rate or PW anomalies and then constructing a lapse rate-fitted or PW-fitted CAPE time series. The ratio of the fitted CAPE trend to the raw CAPE trend provides a measure of the importance of each variable's influence on the CAPE trend. Results of this analysis are presented in Fig. 2. Positive CAPE trends are indicated by yellow-to-red symbols while negative CAPE trends are indicated by aquamarine-type colors. Filled (open) symbols indicate trends that are (are not) statistically significant. Circles indicate stations where both lapse rate *and* PW trends are significant whereas diamonds identify stations where lapse rate and/or PW trends are not significant.

Several conclusions may be drawn from these scatter plots. First, significant CAPE trends are always accompanied by significant lapse rate and PW trends (i.e., there are no filled diamond symbols). At all but two stations (Jamaica and Nairobi), positive CAPE trends are accompanied by positive PW trends. For most of these stations, the trend is dominated by the PW trend (since most of the points lie within the 1:1 and 1:-1 lines). There is no clear cut effect of lapse rate on CAPE trends. For about half of the stations within the 1:1 and 1:-1 lines, lapse rate trends offset CAPE trends, and enhance CAPE trends for the remaining half.

4. DISCUSSION AND FUTURE WORK

The analysis presented above suggests that significant CAPE increases over the past 20-40 years are more common than CAPE decreases, but this may be due in part to the inhomogeneous geographical distribution of analyzed stations. More conclusively, we can say that CAPE trends are largely determined by trends in PW. Lapse rate trends tend to modify the effects of PW trends by either enhancing or reducing CAPE trends.

Current efforts are focused on 1) examining the effects of observation practice changes (instrumentation and/or station location changes) on CAPE trends, 2) computing lapse rate and precipitable water trends from global independent data sets such as MSU temperatures and SSM/I precipitable water, and 3) studying the response of precipitation to CAPE trends.

5. REFERENCES

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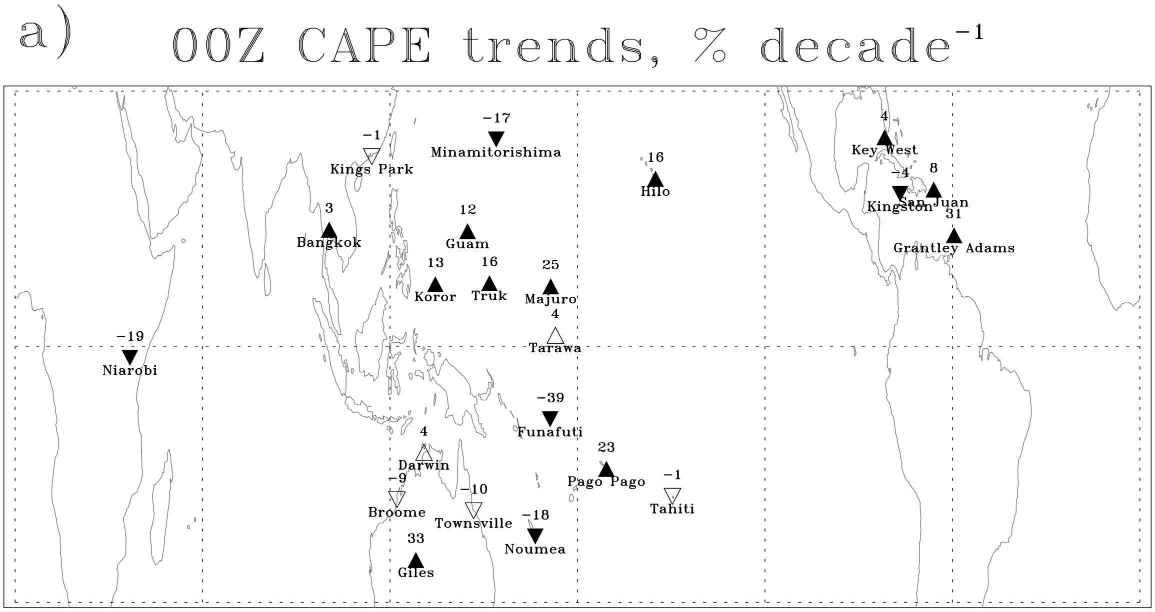

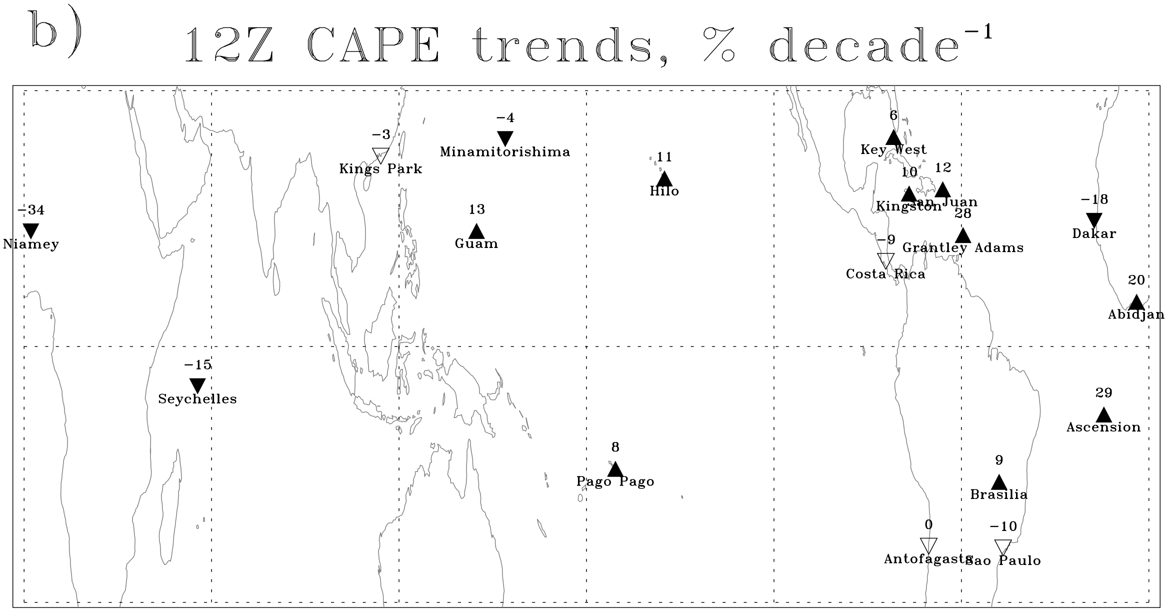

Fig. 1. CAPE trends for 00Z and 12Z sounding launch times. Filled (open) symbols denote trends that are (are not) significant at the 95% confidence level. Upward- (downward-) pointing triangles denote positive (negative trends). Trends are computed through 1999 for most stations based on time series extending back at least 20 years prior to that date.

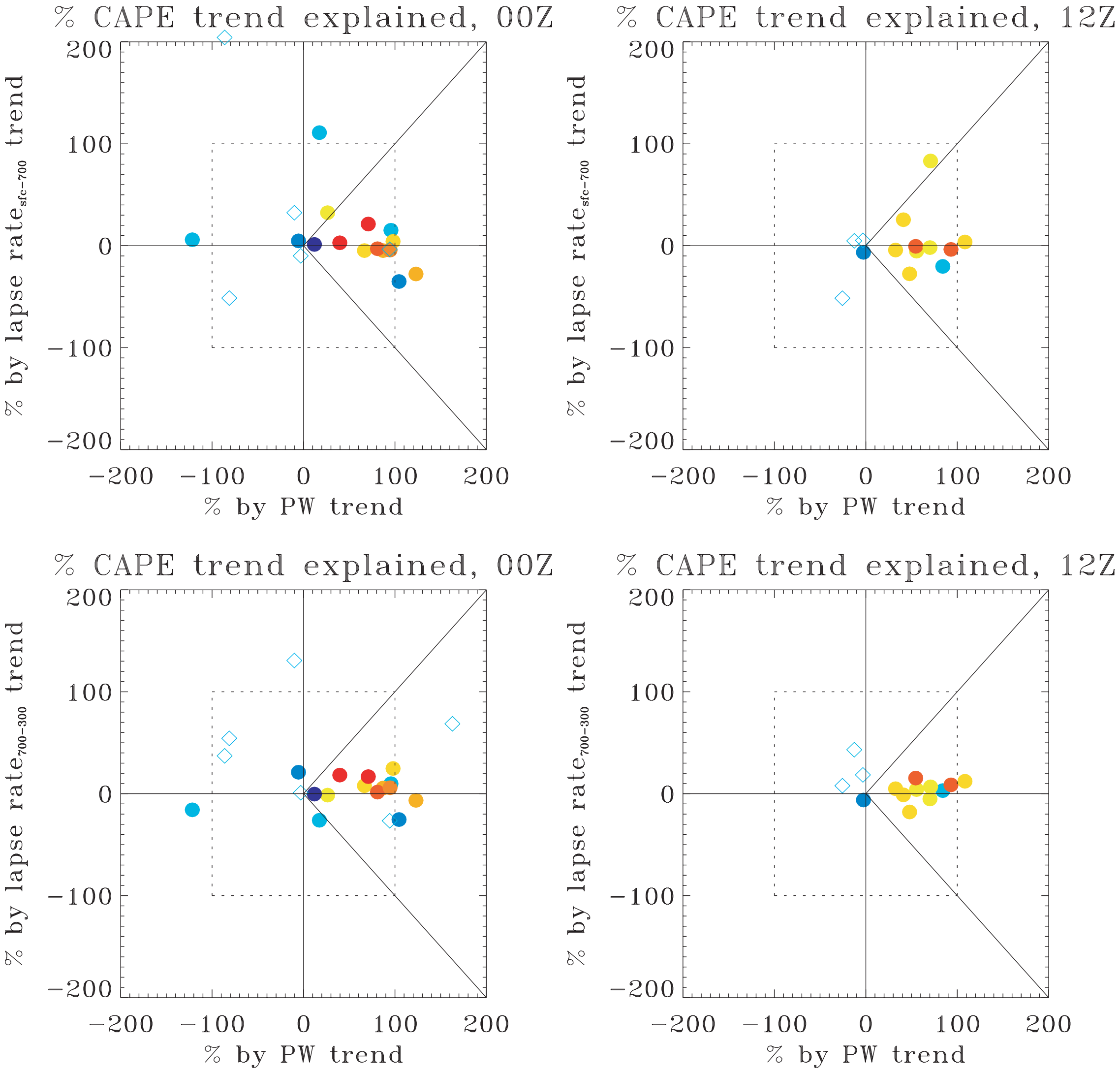

Fig. 2. Percentage of CAPE trend explained by trends in precipitable water (PW) and temperature lapse rate (top panels: low-level lapse rate; bottom panels: mid-level lapse rate). Filled (open) symbols denote CAPE trends that are (are not) significant at the 95% confidence level. Circles (diamonds) indicate that PW and lapse rate are (are not) significant as well. Yellow- to orange-colored symbols denote the positive CAPE trends (warmer colors=greater + trend) while aquamarine colors indicate negative CAPE trends (darker blues=larger - trend).