Convective Available Potential Energy in the Environment of Oceanic and Continental Clouds: Correction and Comments

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1. Introduction

The purpose of this note is twofold: 1) to report and correct a significant error in the estimate of the convective available potential energy (CAPE) reported by Zipser and LeMone (1980) for the Thunderstorm Project cumulonimbus environment, and 2) to suggest that this error, together with the new oceanic results from the western Pacific warm pool (Lucas et al. 1994), actually sharpens the question asked in Zipser and LeMone, but not yet answered: Why are the vertical velocities in convective updrafts so low over the tropical oceans?

2. The corrected CAPE

Zipser and LeMone (1980) estimated CAPE for the Thunderstorm Project to be about 3000 J kg^{-1}. They obtained this value by integrating the "positive area" or integrated thermal buoyancy from the level of free convection to the parcel equilibrium level from the sounding given on p. 20 of Byers and Braham (1949). The error resulted from the authors assuming that the moist adiabat in the figure was the moist adiabat of the undilute parcel. It is, instead, a *reference* moist adiabat with an equivalent wet-bulb potential temperature of 26°C. Our best estimate of the *actual* moist adiabat for the parcel representing the lowest 50 hPa of the sounding is 24.2°C. Unfortunately one can only make an estimate from the plotted sounding; the original data are not included in the report. Thus, we now estimate a Thunderstorm Project CAPE of 1950 ± 500 J kg^{-1}, much less than the reported value of 3000. As noted in Zipser and LeMone, Braham (1993 personal communication) confirmed that the sounding in question is essentially a mean proximity sounding for the combined Florida and Ohio storms. The corrected CAPE for the Thunderstorm Project is more consistent with the 1300–1500 J kg^{-1} values reported by Bluestein et al. (1987) for nonsevere squall lines over Oklahoma and the 1600–2700 range reported by Barnes et al. (1992) for "high-CAPE" cumulus congestus in the Convection and Precipitation/Electrification Experiment conducted in Florida in 1991.

3. The implications

The vertical velocity within cumulonimbus clouds over tropical oceans is observed to be much lower than that within cumulonimbus over land (LeMone and Zipser 1980; Zipser and LeMone 1980; Jorgensen et al. 1985; Jorgensen and LeMone 1989; Lucas et al. 1994). In the above papers, data from the Thunderstorm Project were used as the reference set for storms over land, although other less comprehensive datasets, and ample anecdotal evidence, confirm beyond a reasonable doubt that continental storms have stronger updrafts. The reason for this difference has not been explained quantitatively, and the lower CAPE estimates shed doubt on any explanations that depend on larger CAPEs over land.

CAPE is often used as a measure of the degree of convective instability. The vertical velocity, which could be attained by perfect conversion of the CAPE into vertical kinetic energy is a kind of scaling velocity, is obviously a gross overestimate of the true vertical velocity for most conditions. That CAPE is an overly simplistic measure of convective instability is well known. Zipser and LeMone (1980) noted that the CAPE for their tropical Atlantic soundings was near 1500 J kg^{-1}, compared to 3000 J kg^{-1} for the Thunderstorm Project soundings. They did not use this "fact" to explain the difference in vertical velocities but rather stated that while both land and ocean cumulonimbus velocities were low compared to their (theoretically) available potential buoyant energy, the

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oceanic clouds achieved a smaller fraction of that energy. In a discussion of several of the above studies, Jorgensen and LeMone (1989), stated (p. 630): "Clearly the continental environment is much more potentially unstable than the nearly moist-adiabatic marine environment. Furthermore, the vertical velocities in the stronger continental cores achieve a greater fraction of the vertical velocity predicted from the CAPE."

The most recent statistics for vertical velocities in cumulonimbus clouds in mesoscale systems to the north of Australia (Lucas et al. 1994) are similar to those from the other marine experiments and have similar CAPEs to the other marine locations, in spite of sea surface temperature averaging over 30°C. The soundings, deemed representative of air entering those specific convective systems, were constructed independently by Alexander and Young (1992) and Griffith (1992), the latter data summarized in Griffith and Zipser (1993). The average CAPE determined by Alexander and Young was 1780 J kg^{-1} for six squall cases and 1694 J kg^{-1} for four nonsquall cases, and by Griffith was 1770 J kg^{-1} for eight cases. The standard deviations for the Alexander and Young data are about 500 J kg^{-1}, while the CAPEs for the Griffith soundings range from 800 to 2500 J kg^{-1}. Therefore, we may conclude that these warm pool oceanic CAPEs, like those elsewhere over the ocean, are not significantly different from the corrected CAPE for the Thunderstorm Project.

The oceanic vertical velocity statistics derived from four independent datasets are closely comparable (Lucas et al. 1994). Only the strongest 10% of convective updraft cores have average vertical velocities exceeding 4–5 m s^{-1}. Comparable values for the Thunderstorm Project are 12–13 m s^{-1}. *There is (now!) no basis at all for attributing the difference to differences in CAPE over land and water.* Rather, the paradox of such weak convective updrafts over tropical oceans is deepened. The question is now focused upon why the oceanic updrafts achieve such a low fraction of their potentially available updraft velocities compared with land updrafts. The answer seems associated mainly with water loading, less low-level buoyancy, and entrainment being more effective in reducing the actual buoyancy of oceanic clouds. We believe that it is time to focus on this issue with the aid of cloud models that are capable of simulating the growth of clouds from realistic initial conditions and realistic forcing. However, it will be challenging to obtain sufficiently accurate observational data for initialization and verification of models.

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