OBSERVATIONAL AND MODELING STUDIES IN SUPPORT OF THE ATLANTIC STRATOCUMULUS TRANSITION EXPERIMENT (ASTEX)

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LONG TERM GOALS

Our long-term goal is to learn how to predict the cloudiness, entrainment rate, and turbulent fluxes in the marine boundary layer under any and all large-scale conditions. In particular the effects of varying sea surface temperature, varying inversion strength, and varying mean winds must be included. The cloudiness types encompassed include fog, stratus, stratocumulus, and shallow cumulus clouds, with or without mesoscale organization.

OBJECTIVES

We are focusing on the effects of cloud-top cooling due to radiation and/or evaporation, both of which can drive downdrafts in the cloudy marine layer. We are trying to understand how such cooling affects the turbulence in the cloudy boundary layer below. Specific questions are: How does the cooling affect the time change of the cloudiness and the entrainment rate? How does the cooling affect mesoscale organization?

This work is supported by ONR Marine Meteorology program.

APPROACH

Our approach is primarily theoretical, but we are making use of data from FIRE, ASTEX, and BOMEX to test our theories. We are using numerical models to make connections between the theory and the data. We are also testing our ideas using the results of large eddy simulations (LES) performed by our colleague Dr. Chin-Hoh Moeng, of NCAR.

WORK COMPLETED

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(1) During the past year we have made major progress in formulating a new entrainment parameterization in which the effects of cloud-top cooling are included in a very simple and physically consistent way. The basic idea is that the cloud-top cooling affects the turbulence only through its effects on the buoyancy of the air sinking in downdrafts at the top of the boundary layer. This leads us to define an "effective inversion strength," as the inversion strength that would yield the same downdraft properties if no cloud-top cooling were occurring. The entrainment rate is then equal to the value that would occur with the effective inversion strength in place of the true inversion strength, and no cloud-top cooling.

(2) Mass, heat and moisture budget computations for the ASTEX region were completed.

RESULTS

(1) The entrainment formula developed through the approach described above has been incorporated into a numerical model and tested against LES data, with good results.

(2) Budget computations were carried out for each 3 hr observational time from 12 UTC 1 June to 21 UTC 15 June for ASTEX. Mean profiles of horizontal divergence, relative vorticity, vertical motion and the apparent heat source Q_1 and moisture sink Q_2 are shown in Fig. 1. Also denoted in Fig. 1 is the level of trade inversion base (I_b) which for the 1-15 June period over ASTEX averaged 1470 m. Over the ASTEX region we note that strong divergence occurs at lower levels. For BOMEX the divergence abruptly changes to convergence near inversion base (1.5 km), while for ASTEX this changeover is much more gradual, occurring near 2.5 km. While the relative vorticity is negative and nearly constant below the trade stable layer, above this layer anticylonic vorticity decreases. The nearly constant values of divergence and relative vorticity below inversion base and the rapid changes above this level suggest that the horizontal flow below the trade inversion layer is well-mixed and decoupled from the flow above. Results from ASTEX and BOMEX show that subsidence maximizes near the inversion base with rates of 2.6 mb hr^{-1} and 2.0 mb hr^{-1}, respectively. The vertical velocity profile from ASTEX (Fig. 1c) exhibits sinking motion throughout the entire trade inversion layer with subsidence rates of 2.0 mb hr^{-1} at the inversion base.

Vertical profiles of Q_1 and Q_2 from ASTEX (Fig. 1d) are similar to BOMEX in many respects. Both regions show a large apparent heat sink and apparent moisture source near the inversion base which result from evaporation of cloud droplets which detrain near this level. We note here that a Q_2 of -10 K day^{-1} is equivalent to a moistening rate of 4 g kg^{-1} day^{-1}. While the moistening rates near the inversion are smaller for ASTEX (-9 K day^{-1} compared to -14 K day^{-1} for BOMEX), one must consider that the ASTEX averaged profiles in Fig.1 are for a significantly longer period (15 days compared to 5 days for BOMEX). During the 1-15 June period, daily averaged Q_2 rates near I_b for ASTEX varied from +5 K day^{-1} and -20 K day^{-1} . The displacement of the moistening peak slightly above the inversion base for BOMEX and slightly below it for ASTEX may reflect stability differences between the two regions. For example, summertime inversion strengths over the Caribbean are typically less than 3 K km^{-1}
while the average inversion strength for 1-15 June 1992 over the ASTEX region was 12.2 K km^{-1}. The weaker stability of the trade stable layer over the BOMEX region may allow clouds to penetrate further into the inversion layer before they detrain their mass and moisture. Above the trade inversion layer, as convective effects diminish, the Q_2 profile decreases to zero. In contrast, the Q_1 profile for ASTEX decreases to a reasonable cooling rate of -1 to -2 $Kday^{-1}$, consistent with clear-sky radiational cooling rates. At levels below cloud base, the positive Q_1 and negative Q_2 values are due to convergence of vertical eddy fluxes of heat and moisture.

IMPACT

The impact of these results is that for the first time the effects of cloud-top cooling can be computed in a physically based way.

TRANSITIONS

(1) We are currently writing a paper describing our new entrainment parameterization. We have also presented our results at two workshops, and we have discussed them with colleagues at various meetings.

(2) We are also currently writing a paper describing the mass, heat, and moisture budgets of the ASTEX triangle.

RELATED PROJECTS

As mentioned above, we are collaborating with Dr. Chin-Hoh Moeng of NCAR. We are also interacting closely with Prof. Steve Krueger of the University of Utah and Prof. Chris Bretherton of the University of Washington.

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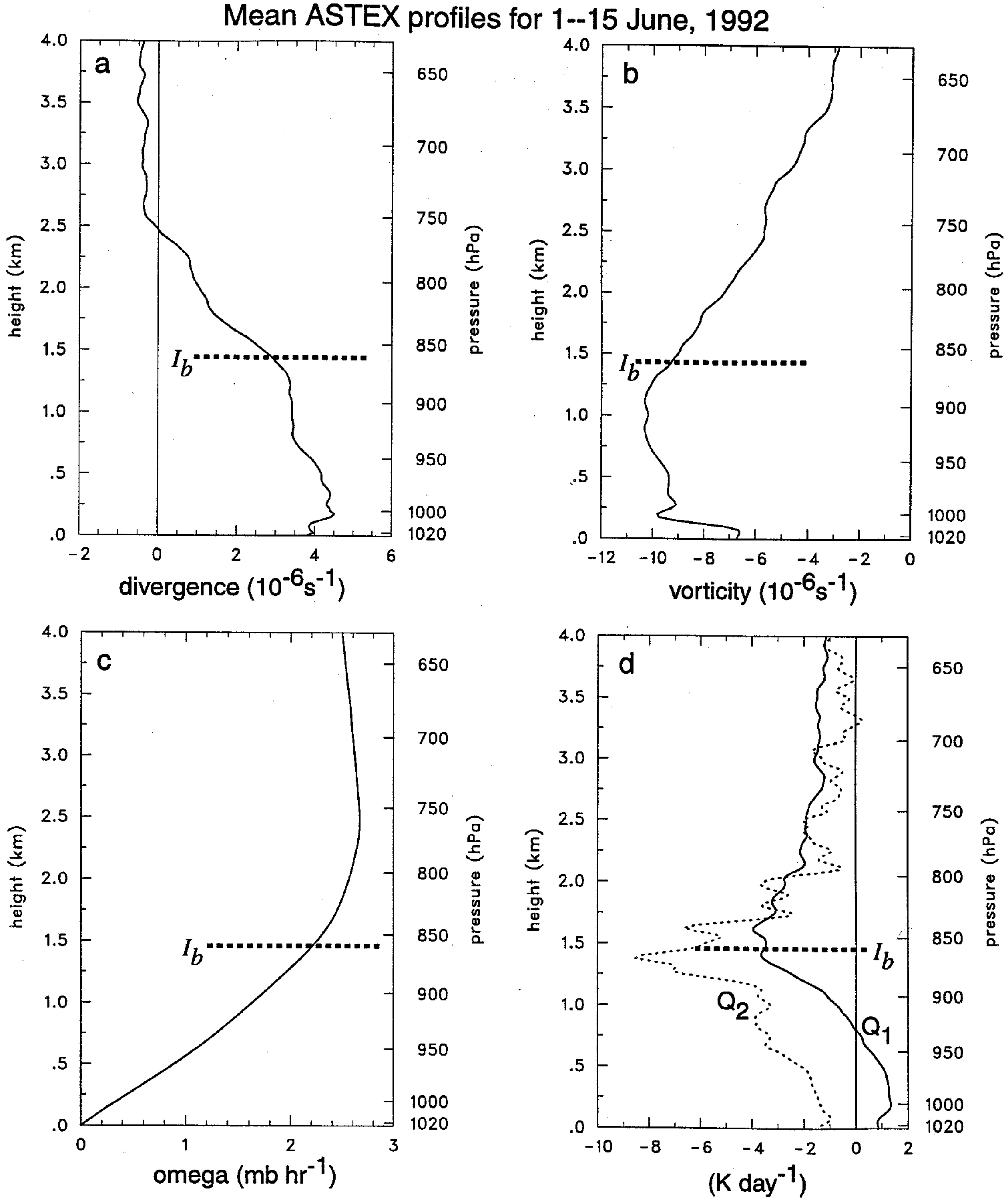

Figure 1: Mean vertical profiles of (a) divergence, (b) relative vorticity, (c) omega, and (d) apparent heat source Q_1 (solid) and apparent moisture sink Q_2 (dashed) for 1–15 June 1992 over the ASTEX triangle. Heavy dashed line at 1470 m indicates the average level of the inversion base (I_b) for this period.