Final Report to the National Aeronautics and Space Administration for

Studies of

Trade-Wind Cloudiness and Climate

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Accomplishments

1. Closed mesoscale cellular convection (MCC) consists of mesoscale cloud patches separated by narrow clear regions. Strong radiative cooling occurs at the cloud top. Shao and Randall (1996) used a dry two-dimensional Bousinesq model is used to study the effects of cloud-top cooling on convection. Wide updrafts and narrow downdrafts are used to indicate the asymmetric circulations associated with the mesoscale cloud patches. Linear analysis of the model indicates only that the longest waves are most unstable, and gives no indication of asymmetric convection cells in the linear convective regime. A weakly nonlinear analysis suggests the presence of downdrafts that are narrower than the updrafts, but this effect is not very pronounced for reasonable values of parameters. Fully nonlinear numerical simulations show that strong cloud-top cooling can generate highly asymmetric mesoscale cells corresponding to closed MCC. Nonlinear processes play essential roles in generating and maintaining closed MCC. Based on the numerical results, a conceptual model was constructed to suggest a mechanism for the formation of closed MCC over cool ocean surfaces.

2. A new method to estimate the radiative and evaporative cooling in the entrainment layer of a stratocumulus-topped boundary layer has been developed by Shao et al. (1997). The mixing process was represented by the concentrations of a conserved tracer, rather than by the mixing fraction $\chi$ used in previous studies. This approach avoids the uncertainty inherent in calculating $\chi$. The new method explains why the evaporative cooling estimated from data is sensitive to the values of jumps of temperature and moisture across the inversion as determined from data, while the radiative cooling is not. The sensitivity of the evaporative cooling to the jumps makes its comparison with the radiative cooling inconclusive, and so only the maximum possible evaporative cooling (MPEC) was considered. The method was applied to a set of large-eddy simulation (LES) results and to a set of tethered-balloon data obtained during FIRE. It was shown that for the LES results the average MPEC is larger than the average radiative cooling, while for the FIRE data the average radiative cooling and MPEC are about the same. The evaporative cooling depends more strongly on the extent of mixing than does the radiative
cooling. The two important parameters in the method (i.e., the saturation mixing ratio and the probability density function of the mixed parcels) are used to parameterize the fractional cloudiness.

3. Chen et al. (1996, 1998) developed a stratocumulus-capped marine mixed layer model which includes a parameterization of drizzle based on the use of a predicted cloud condensation nuclei (CCN) number concentration. The autoconversion process is parameterized in terms of an assumed droplet size distribution. The accretion and sub-cloud evaporation processes are parameterized following Redelsperger and Sommeria. Aerosol particles are divided into two modes, representing the small nucleation mode and the CCN mode, respectively. Both number and mass balances are considered. Two steady states were obtained, as in the model of Baker and Charlson. The lower steady state CCN number concentration corresponds to the typical marine time boundary layer. The higher steady state CCN number concentration is regarded as the continental air mass case. A difference between the results of Chen et al. (1996, 1998) and those reported by Baker and Charlson is that the former obtain a smoother transition between these two states. This result supports some observations that suggest there is no sharp transition between the drizzling and non-drizzling steady states of CCN number concentration in the marine boundary layer. The model was tested using ASTEX data, and the results show that the boundary layer’s macroscopic structure is sensitive to the CCN number concentration. When the CCN number concentration increases, the drizzle rate decreases, so that the boundary-layer cloud remains thick. When the CCN number concentration decreases, the drizzle rate increases and as a result the boundary-layer cloud becomes thinner.

4. We have developed, implemented, and tested a very elaborate new stratiform cloudiness parameterization for use in GCMs (Fowler et al. 1996; Fowler and Randall 1996 a, b). The parameterization was initially incorporated into the CSU (Colorado State University) GCM, and is now being ported to the CSM (Climate System Model) which has been developed at the National Center for Atmospheric Research (NCAR).
5. Xu and Randall (1996a) demonstrated that probability density function (PDF)-based cloudiness parameterizations and large-scale relative humidity (RH)-based cloudiness parameterizations are regime-dependent when applied to large-scale models. As an alternative to these conventional RH- and PDF-based approaches, Xu and Randall (1996b) proposed a very simple cloudiness parameterization, and tested it using simulations of observed tropical cloud systems and subtropical stratocumuli with the UCLA cloud ensemble model. The parameterization uses the large-scale average condensate (cloud water and cloud ice) mixing ratio, \( \bar{q}_l \), as the primary predictor, and the large-scale relative humidity, \( \bar{RH} \), as a secondary predictor. The cloud amount, \( C_s \), is assumed to satisfy

\[
C_s = \frac{1}{\bar{RH}^p} \left[ 1 - \exp\left( -\alpha \frac{\bar{q}_l}{[(1 - \bar{RH})q^*]^{\gamma}} \right) \right],
\]

where \( q^* \) is the saturation water vapor mixing ratio, and coefficients \( \alpha, p, \) and \( \gamma \) are semi-empirical constants which were statistically determined from simulations of tropical cloud systems. An evaluation of the parameterization was performed using independent simulations of subtropical stratocumuli (Xu and Randall, 1996b), and this evaluation has now been repeated using ARM data. The validity of the approach and the sensitivity to cloud regime and horizontal-averaging distance was investigated by Xu and Randall (1996b).

6. Finally, we have developed a new, mechanistic parameterization of the effects of cloud-top cooling on the entrainment rate (Randall et al. 1998). The theory is formulated in terms of an "effective inversion strength," which is the true inversion strength minus a correction for cloud-top cooling. The predictions of the theory agree well with large-eddy simulation results. The parameterization has been implemented in the CSU GCM, with good results.
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Refereed Publications


Fowler, L. D., and D. A. Randall, 1996 b: Liquid and Ice Cloud Microphysics in the CSU General


Non-Refereed Publications

Randall, D. A., 1995: Parameterization of Subgrid-Scale Stratiform Cloudiness Associated with


