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Kinematics, cloud microphysics and spatial structures of tropical cloud clusters: A two-dimensional cloud-resolving modeling study

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Abstract

Kinematics, cloud microphysics and spatial structures of tropical cloud clusters are investigated using hourly outputs from a two-dimensional cloud-resolving model simulation. The model is forced by the large-scale vertical velocity, zonal wind and horizontal advections obtained from Tropical Ocean Global Atmosphere Coupled Ocean–Atmosphere Response Experiment (TOGA COARE). A period of 1600–2300 LST 21 December 1992 is selected for this study when the zonal-mean westerly winds in the lower troposphere intensify while the zonal-mean easterly winds above weaken. Under the vertical-shear environment, there are a westward-propagating cloud cluster, a newly-formed cloud cluster, and four eastward-moving cloud clusters. Two weak eastward-moving cloud clusters merge into strong westward-moving cloud clusters. Merged clouds display notable growth in the eastern edge, indicating that merging processes enhance convection. The development of the new cloud at the western edge of the existing cloud cluster before merging may account for the westward propagation of cloud cluster group, while the advection of the maximum total hydrometeor mixing ratio by the westerly winds after merging may cause the eastward propagation of individual cloud clusters.

Keywords: Cloud-resolving model; Cloud microphysics; Cloud merger

1. Introduction

Observational analysis has revealed that cloud cluster groups (super cloud clusters) and individual cloud clusters embedded within them propagate in different directions and have different evolution and spatial distributions (e.g., Nakazawa, 1988; Lau et al., 1991; Mapes and, Houze 1993). The meteorological research community for recent decades has paid much attention to focus on the hierarchical cloud structures and behaviors (e.g., Lau et al., 1989; Numaguti and Hayashi, 1991; Chao and Lin, 1994; Yano et al., 1995). Chao and Lin (1994) simulated hierarchical cloud patterns with a two-dimensional hydrostatic model and found that the downdraft associated with the existing cloud cluster forces boundary layer convergence and the formation of a new cloud cluster at the

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eastern edge that leads to the eastward propagation. Wu and LeMone (1999) carried out cloud-resolving model simulations and observational satellite and radar analysis and showed that the westward movement of cloud patterns is mainly caused by the horizontal advection of the anvil clouds by the mean flow and the creation of new convective cells to the west of the old convective clouds. Peng et al. (2001) used a two-dimensional cloud-resolving model to simulate tropical cloud clusters over the large-scale warm pool and found that the new cloud cell forms in the leading edge of the propagating surface cold-air pool due to the combined effects of the overall wave and gravity waves.

Gao et al. (2005b) derived a surface rainfall equation and analyzed a COARE-forced cloud-resolving model simulation and found that water and ice cloud sources/sinks make significant contributions to the variation of surface rain rate while water vapor sink variation is mainly responsible for the variation of surface rain rate. Gao et al. (2004, 2005a) introduced the convective (CVV), moist (MVV), and dynamic (DVV) vorticity vectors to analyze two-dimensional tropical convection. The analysis of zonally-averaged and mass-integrated vectors showed that the vertical component of the CVV is highly correlated with the total hydrometeor mixing ratio (sum of the mixing ratios of cloud water, raindrops, cloud ice, snow, and graupel). The MVV and CVV are interchangeable over tropical deep convective regime where atmospheric moisture plays a key role in convective development. The tendency of the vertical component of the MVV is determined by the interaction between the vorticity and the zonal gradient of condensational/depositional heating. The vertical and zonal components of the DVV are in phase and out of phase with the sum of the mixing ratios, respectively. The tendency of the vertical component of the DVV is controlled by the interaction between the vorticity, buoyancy, and vertical pressure gradient, whereas the tendency of the zonal component is determined by the interaction between the vorticity and zonal pressure gradient.

In this study, hourly outputs from the two-dimensional cloud-resolving model simulation by Li et al. (2002a) are analyzed to study tropical cloud clusters.

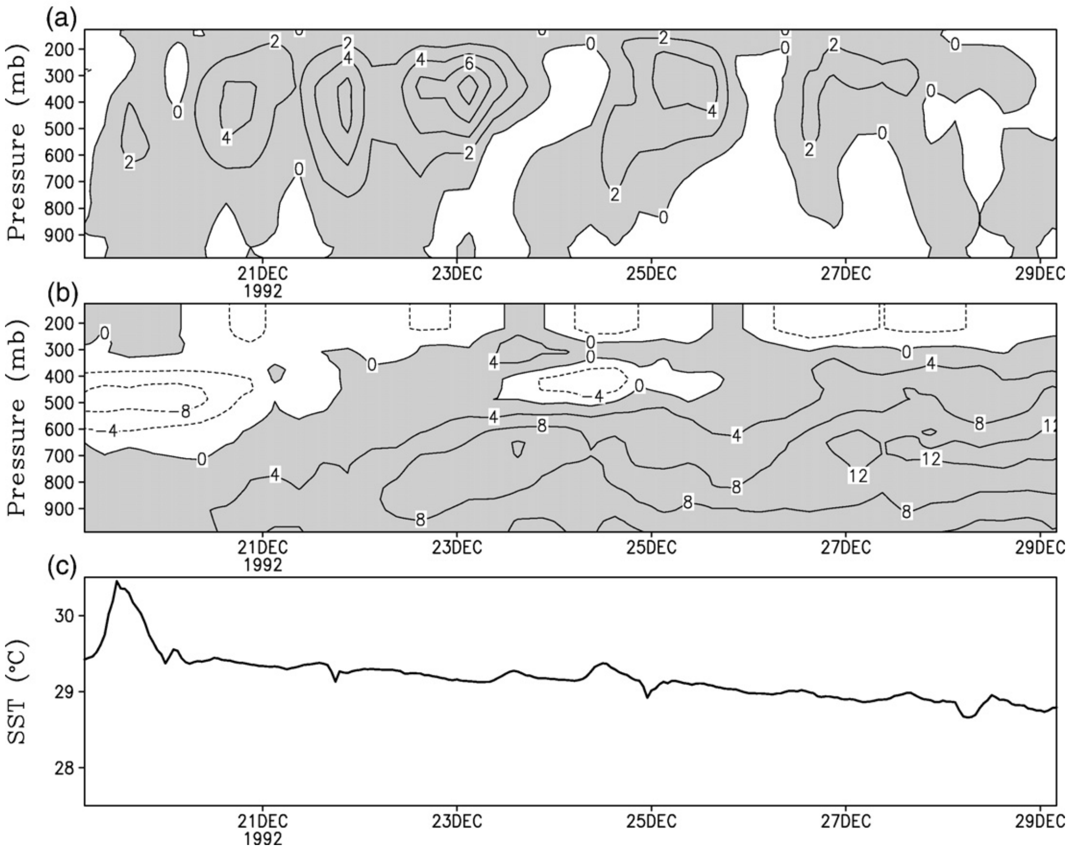

Fig. 1. Temporal and vertical distribution of vertical velocity (a), zonal wind (b), and time series of sea surface temperature (c) observed and derived from TOGA COARE for the 10-day period. Upward motion in (a) and westerly wind in (b) are shaded. Units of vertical velocity, zonal wind, and sea surface temperature are cm s^{-1}, m s^{-1}, and °C, respectively.