A "Ray" Pattern of Clouds and Precipitation in a Super Cloud Cluster Observed and Simulated during the CINDY2011/DYNAMO Field Campaign

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1. INTRODUCTION

The slow eastward propagation (4-8 ms^{-1}) is one of the most fundamental features that distinguishes Madden-Julian Oscillation (MJO) from other tropical waves/disturbances (e.g., Zhang 2005). Understanding of dynamical mechanisms governing the slow propagation of MJO remains as one of the greatest challenges in the study of tropical meteorology. In the present study, we focus on the multiscale structure of a super cloud cluster (SCC), accompanied by eastward-propagating precipitating systems and westward-moving cloud shields, during a MJO wet phase (see Fig. 1). Such a "ray" pattern of clouds and precipitation was revealed by Yamada et al. (2010) during the MISMO field campaign in 2006 (Yoneyama et al. 2008), and was observed again during the Cooperative Indian Ocean experiment on intraseasonal variability in the Year 2011 (CINDY2011) / the Dynamics of the Madden-Julian Oscillation (DYNAMO). Moreover, this pattern was captured by a week-long near real-time simulation in some degree. Based on both the observational data and simulation results, we provide a description on the evolution and structure of these precipitating systems during the experiment.

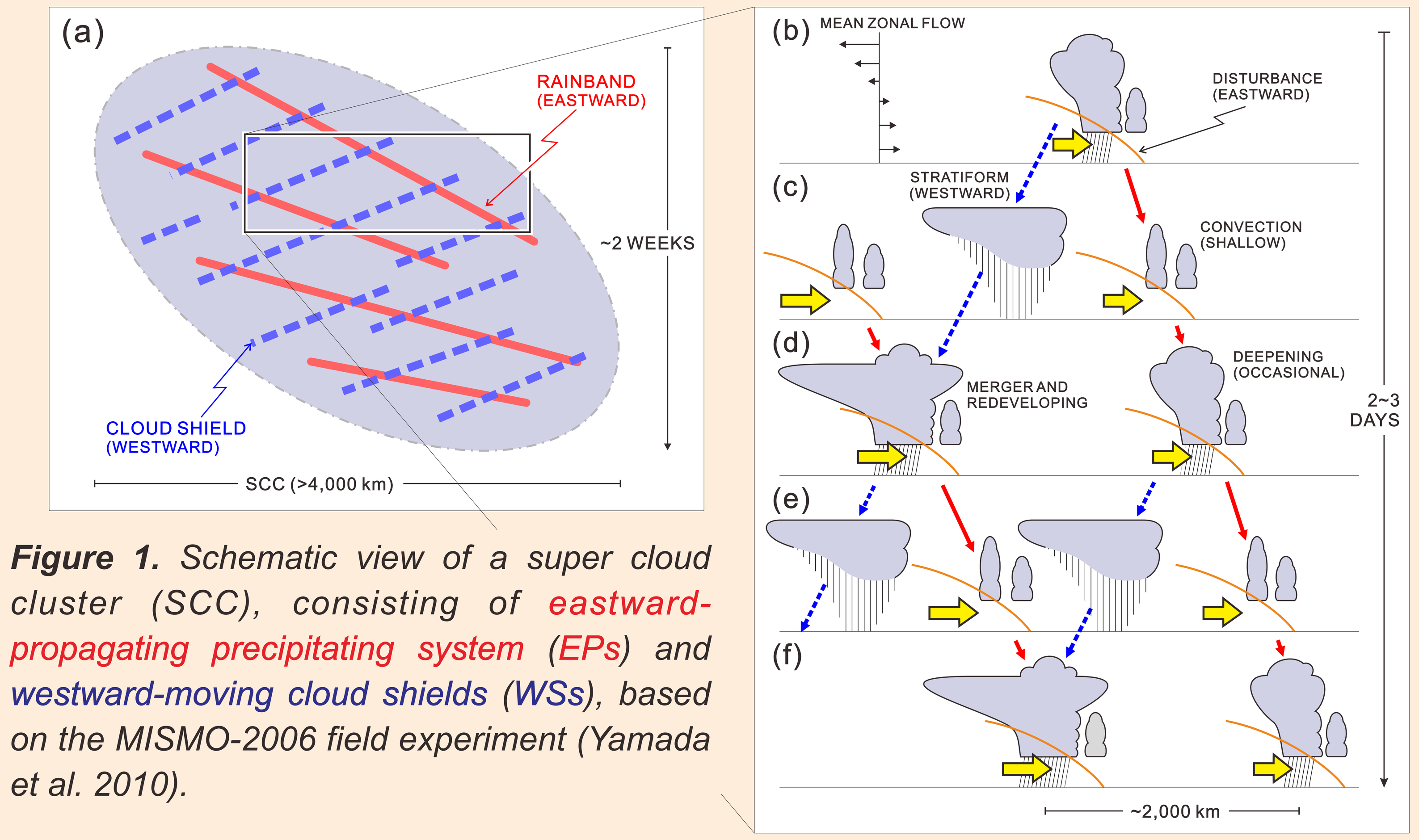

Figure 1. *Schematic view of a super cloud cluster (SCC), consisting of eastward-propagating precipitating system (EPs) and westward-moving cloud shields (WSs), based on the MISMO-2006 field experiment (Yamada et al. 2010).*

2. OBSERVED FEATURES

The time-height plots of infrared brightness temperature (Fig. 2) show the slow eastward propagation of SCCs (< 8 ms^{-1}) during the periods in both 2006 and 2011.In an enlarged plot in the Indian Ocean (Fig. 3a), a SCC envelope is characterized by a ray pattern of cloud streaks. The satellite-derived rain rate (Fig. 3c) indicates a predominance of eastward propagation of rainfall areas. These rain areas developed in a moist environment with precipitable water higher than 50 mm (Fig. 3d) The SMART radar at Gan succeeded to capture the structure of the eastward-propagating precipitating systems, consisting of leading/trailing lines of convection extending to south-north direction in the lower troposphere (< 5 km). These features are consistent with those observed in 2006 and described by Yamada et al. (2010).

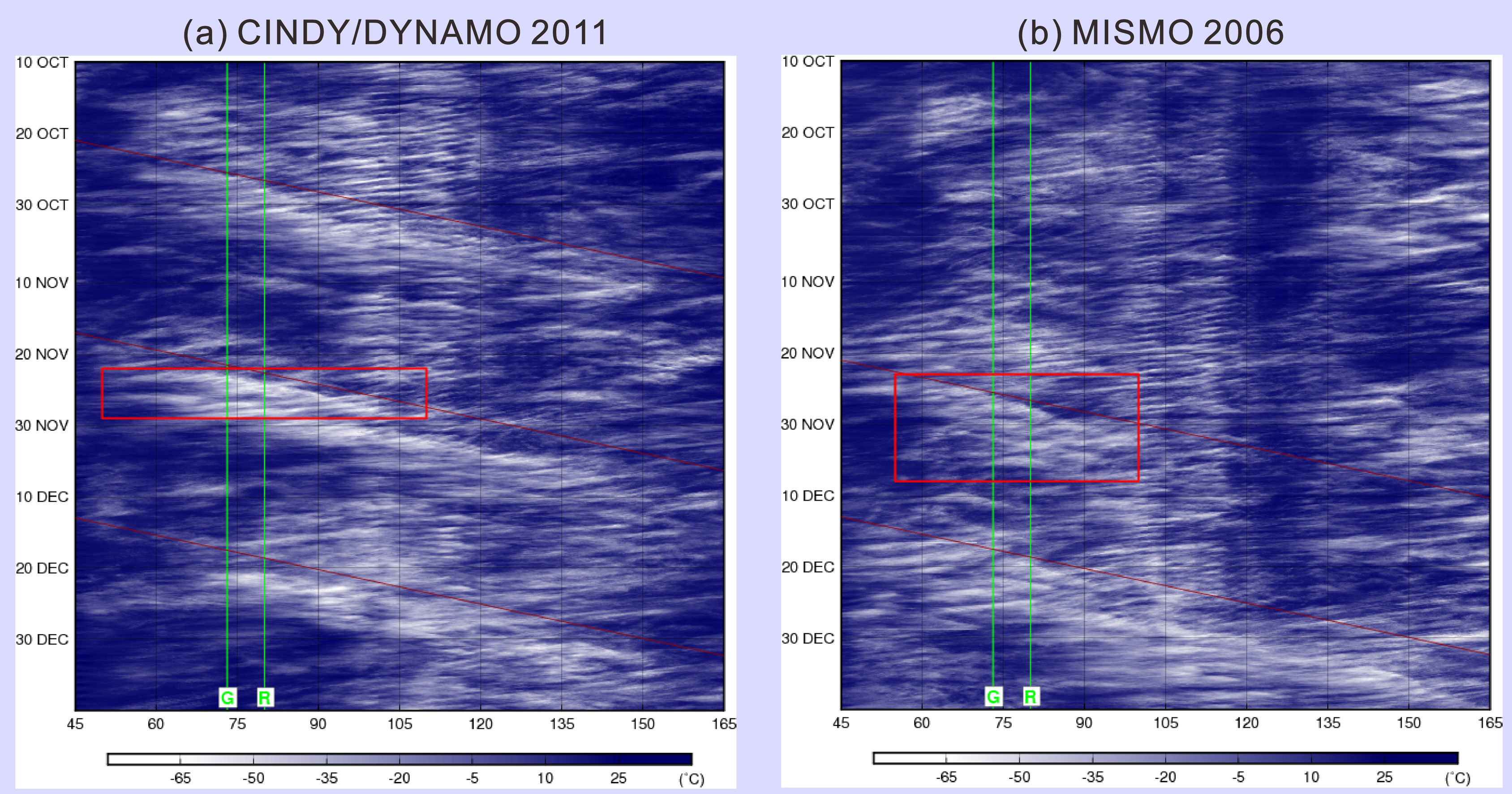

Figure 2. *Longitude-time plots of satellite-derived infrared brightness temperature (T_{BB}) along the equator (averaged in 5°S-5°N) during (a) CINDY/DYNAMO in 2011 and (b) MISMO 2006. Brown bold lines indicate 8 ms^{-1} of reference speed.*

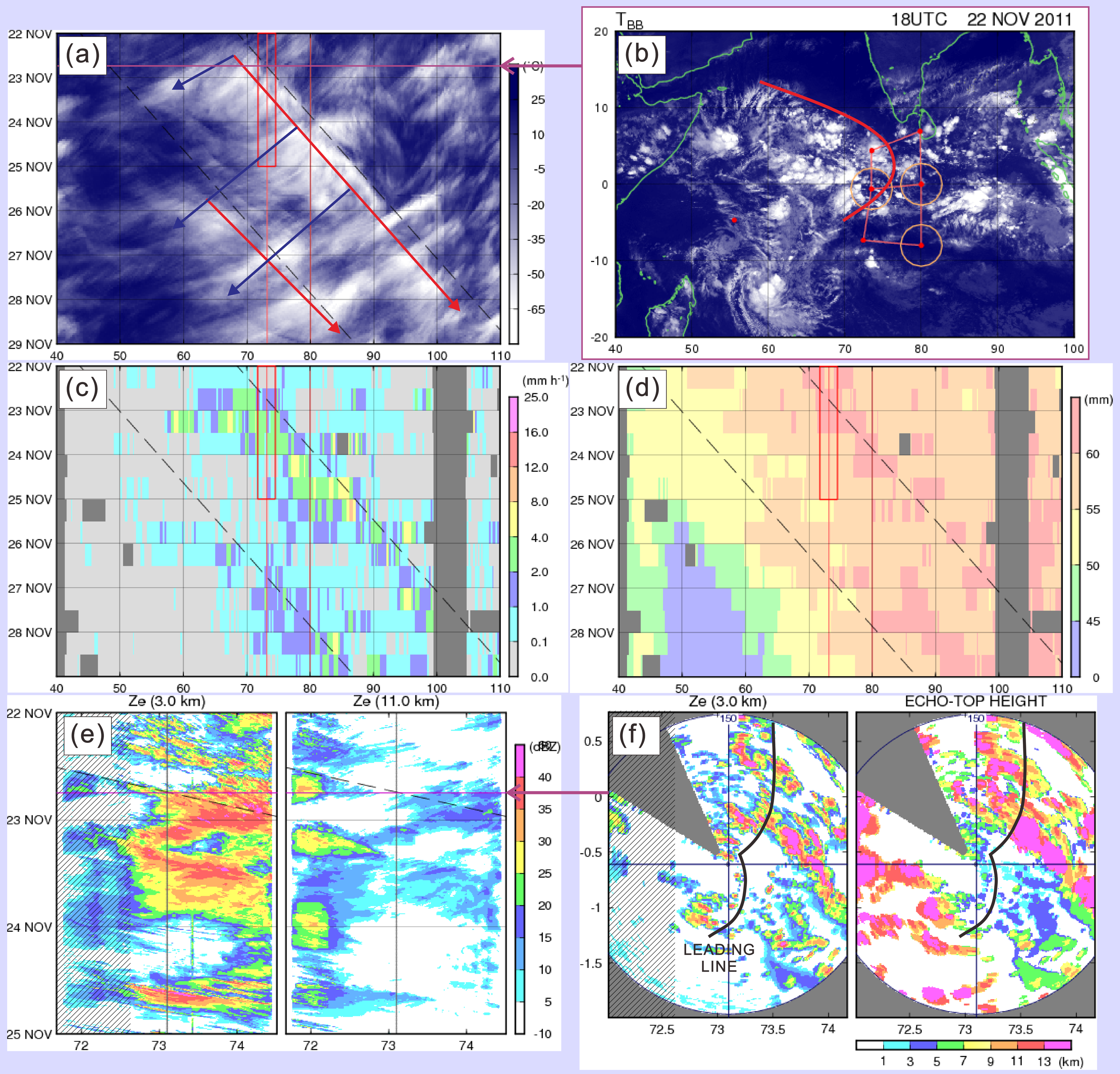

Figure 3. *(a) Longitude-time and (b) horizontal plots of T_{BB} in the Indian Ocean. Longitude-time plots of (c) satellite-derived rain rate and (d) precipitable water. (e) Longitude-time plots of radar reflectivity observed by the SMART radar at Gan. (f) Horizontal plots of reflectivity and echo-top height at 1801 UTC 22 November 2011.Broken lines in the longitude-time plots indicate 8 m s^{-1} of reference speed.*

3. RAY PATTERN SIMULATED BY NICAM

During the CINDY/DYNAMO experiment, week-long near real-time simulation have been carried out using a regionally stretched version of Nonhydrostatic Icosahedral Atmospheric Model (NICAM) with a horizontal grid size of 14-30 km (Nasuno et al. 2012). Although the resolution is too coarse to resolve individual convective elements, this simulation succeeded in some degree in reproducing the ray pattern during MJO convectively active phases. The simulated eastward-propagating systems are marked by the slow propagation speed (< 10 ms^{-1}), repetition cycle of 2-3 days, leading/trailing lines of convection, the vertical structure tilting westward with height, and easterly vertical shear of environmental flow, which are consistent with the observed characteristics. The simulation also showed that the eastward-propagating systems can sustain in a moist environment with the precipitable water greater than 50 mm, suggesting their sensitivity to the horizontal/vertical moisture distribution. Dynamical process of the slow eastward propagation will be examined using on-going NICAM simulations with finer resolution (3.5~7 km).

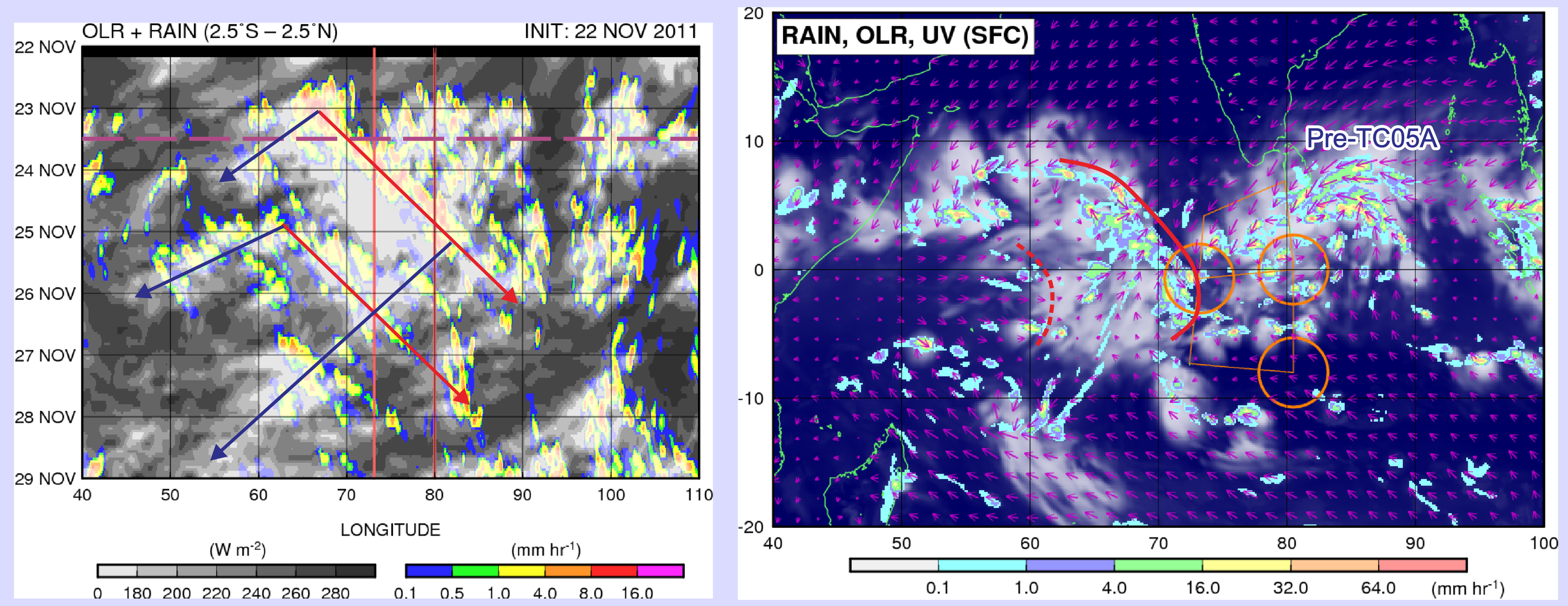

Figure 4. *(left panel) Longitude-time plots of the rain rate and OLR. Initial time of the simulation is 0000 UTC 22 November. (right panel) Horizontal distributions of the rain rate, surface winds, and OLR at 1200UTC 23 November.*

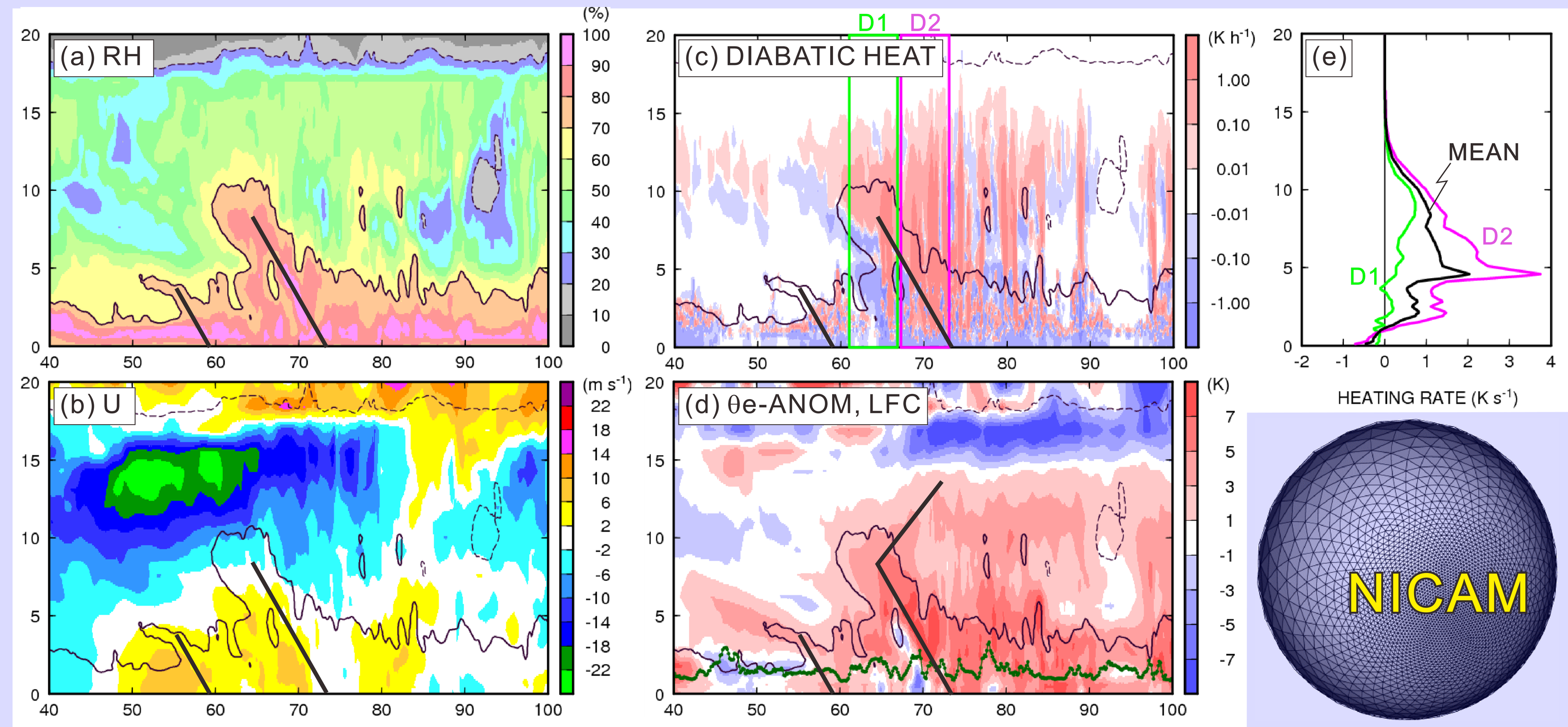

Figure 5. *Longitude-height plots of (a) relative humidity, (b) zonal winds, (c) diabatic heating rate, (d) equivalent potential temperature anomaly and the level of free convection (LFC) at 1200UTC 23 November, averaged between 2.5°S and 2.5°N. (e) Vertical profiles of diabatic heating rate, averaged in the domains shown in (c).*

4. SUMMARY AND FUTURE WORK

The super cloud clusters during CINDY/DYNAMO experiment were characterized by the coexistence of eastward-propagating precipitation systems (EPs) with westward-moving cloud shields (WSs), which are recognized as a ray pattern in longitude-time Hovmöller plots. The characteristics of EPs are quite similar to those observed during the MISMO-2006 experiment. Both the observation and NICAM simulation showed that EPs developed in an environment with precipitable water greater than 50 mm. These results suggest that EPs are convective systems unique to a wet phase of MJO. Future work will be directed to understanding of the mechanisms governing the slow eastward propagation of EPs and the relevance to the overall eastward propagation of MJO, using NICAM simulations with finer horizontal spacing (3.5~7 km).

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