Improvement of Downdrafts in Convective Parameterizations:

Examining Assumptions With High Resolution CRM Data

Katherine Thayer-Calder and David A. Randall
Dept. of Atmospheric Science, Colorado State University

Introduction

Cloud parameterizations that include simple downdrafts have been around for many years [Johnson (1976), Tiedke (1989), Sud and Walker (1993), Cheng and Arakawa (1997), and others], but many parameterizations in use today either neglect downdrafts entirely, or base their representations on a several dangerous assumptions. The worst is assuming that we are able to neglect the influence of downdrafts all together (Section 1), but others include neglecting downdraft and surface flux interactions (Section 2), neglecting the impact of the boundary layer variability on convection (Section 3) and simplifying precipitation evaporation unrealistically (Section 4). In the past, the accuracy of these assumptions has been difficult to test with observations. This study uses two high resolution Cloud-Resolving Model (CRM) runs to examine them in detail.

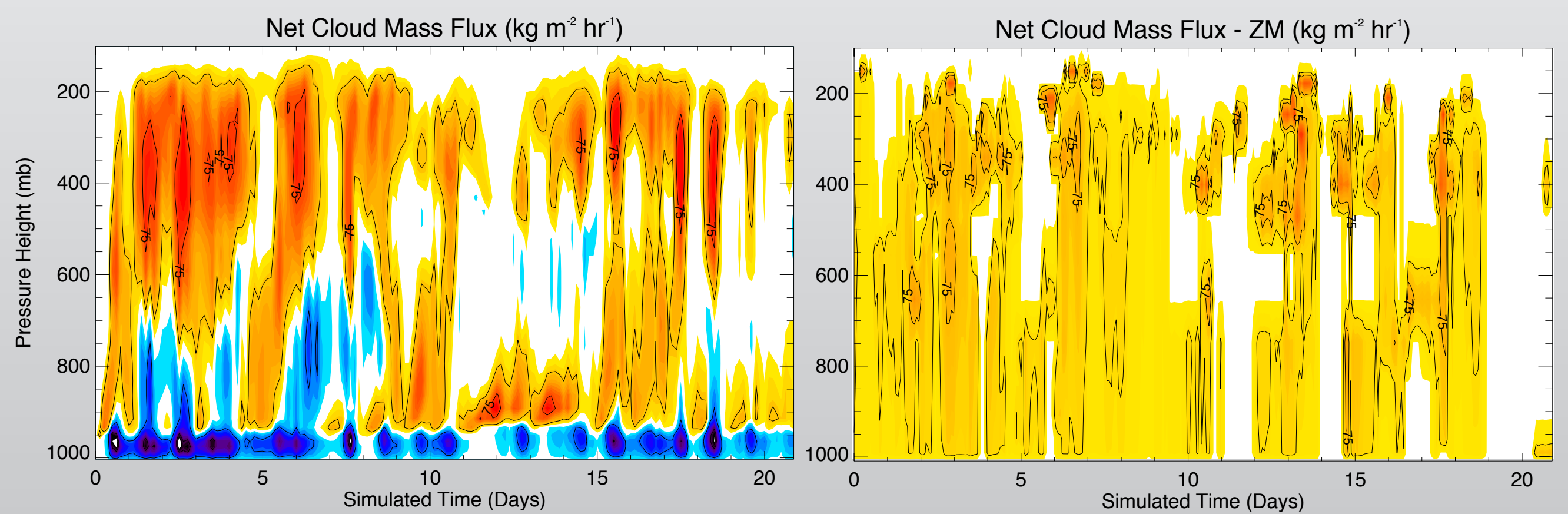

Fig.1 Total vertical mass flux by clouds in the TOGA-COARE SAM simulation (left) and the single-column version of CAM 3.5 (right). The cloud parameterization in CAM has simple downdrafts that are constrained to evaporation of less than 20% of precip.

Using **System for Atmospheric Modeling (SAM)**:

1. Simple Radiative-Convective balance (RC)
   - No large scale forcing
   - 1km horz res with 64 vert levs up to 5hPa
   - 128x128 km domain and 10 second time step
2. TOGA-COARE run (TC)
   - Large-scale forcing from TOGA-COARE data
   - Same resolution, domain and time step

Assumption 1. Downdrafts do not move as much mass as updrafts and the subsiding environment.

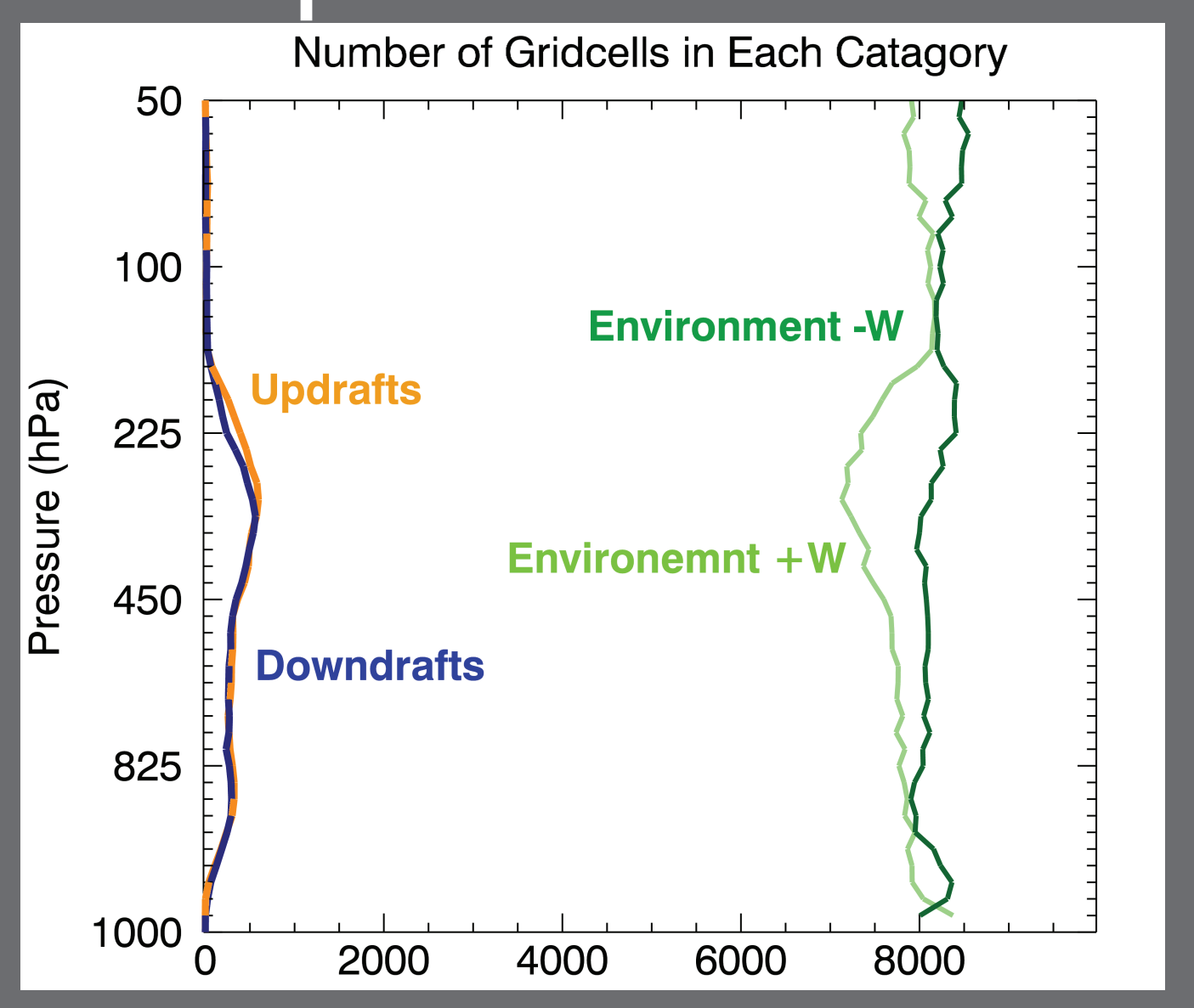

Fig.2 We categorized 3D data points by the vertical velocity in each cell. W>1.0 = updraft, W< 1.0 = downdraft

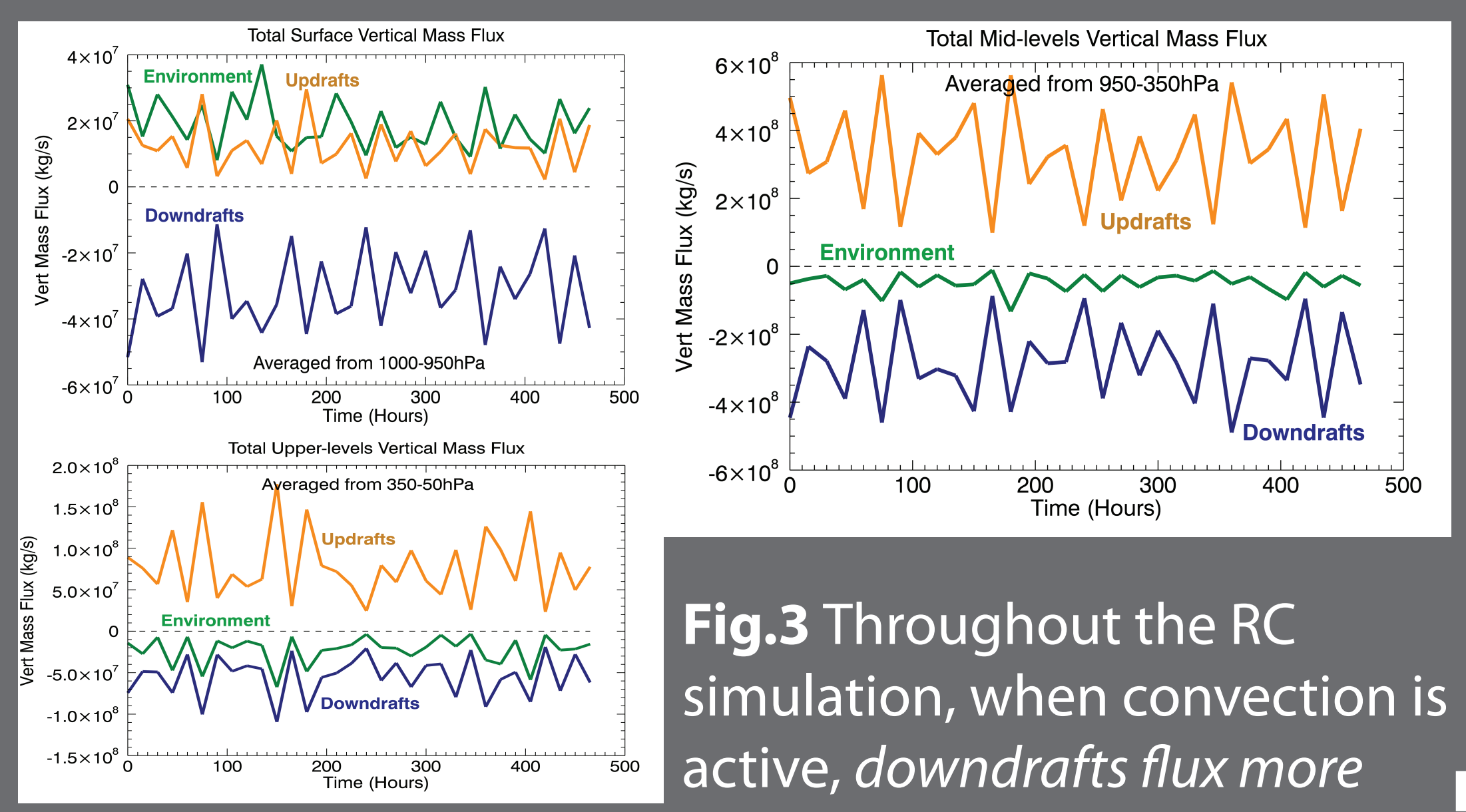

Fig.3 Throughout the RC simulation, when convection is active, *downdrafts flux more mass downward than the environment.*

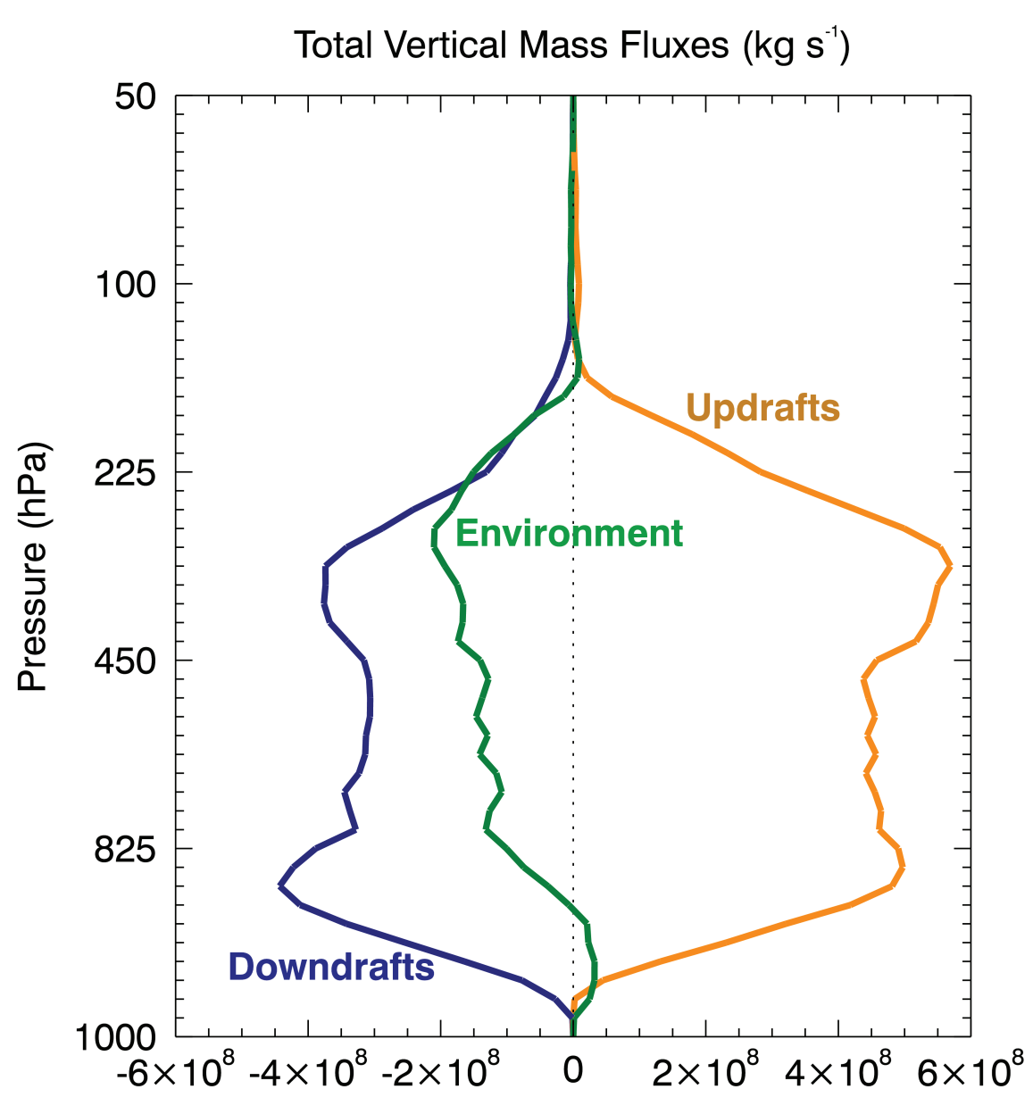

Fig.4 Updraft mass lifting is balanced first by downdrafts and second by the environment.

Assumption 2. Downdrafts only increase surface fluxes.

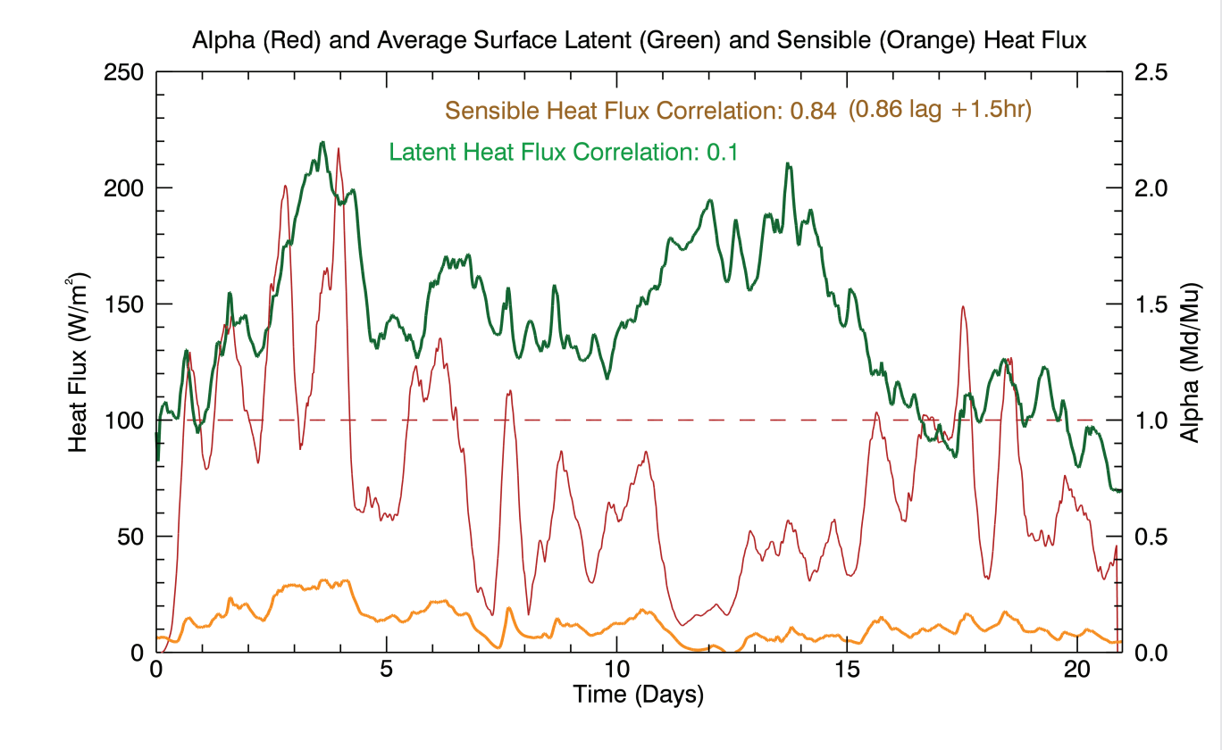

Fig.5 We use the ratio Alpha (downdraft mass flux divided by updraft mass flux) from Raymond (1995) as a guage of downdraft activity. In theory, as gustiness due to downdrafts increases near the surface, the fluxes of heat and moisture from the surface should increase as well. *Sensible heat fluxes are somewhat correlated to alpha (0.85) but latent heat fluxes are not well correlated (0.1).*

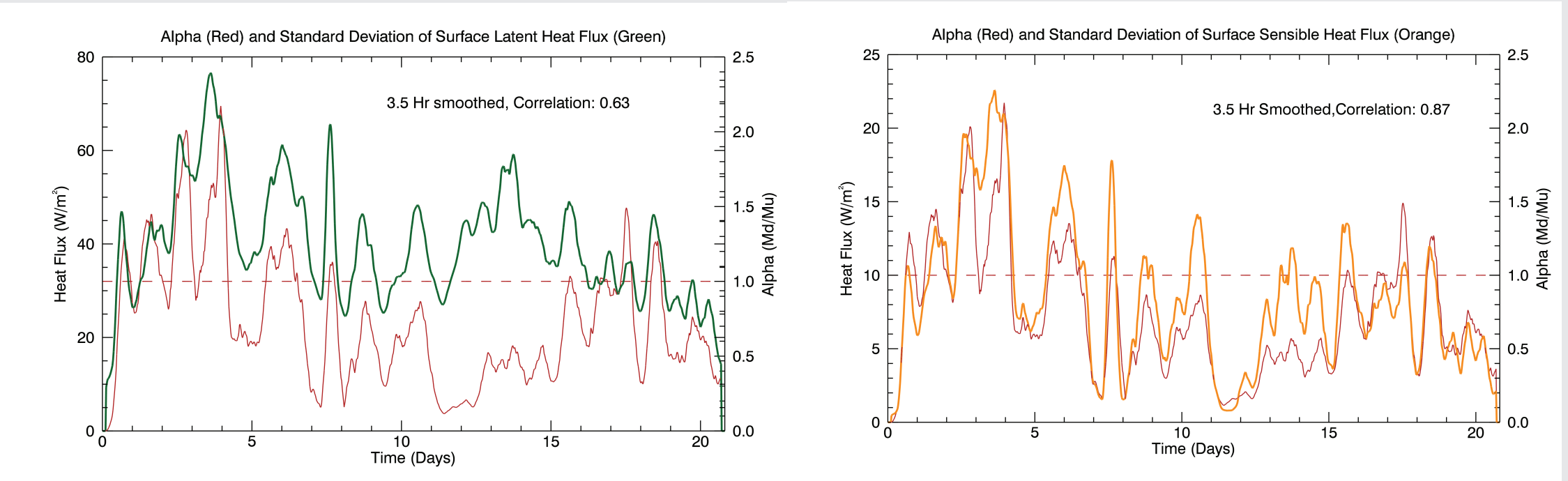

Fig.6 However, the standard deviation of the surface distribution of these fluxes is much more correlated with downdraft activity.

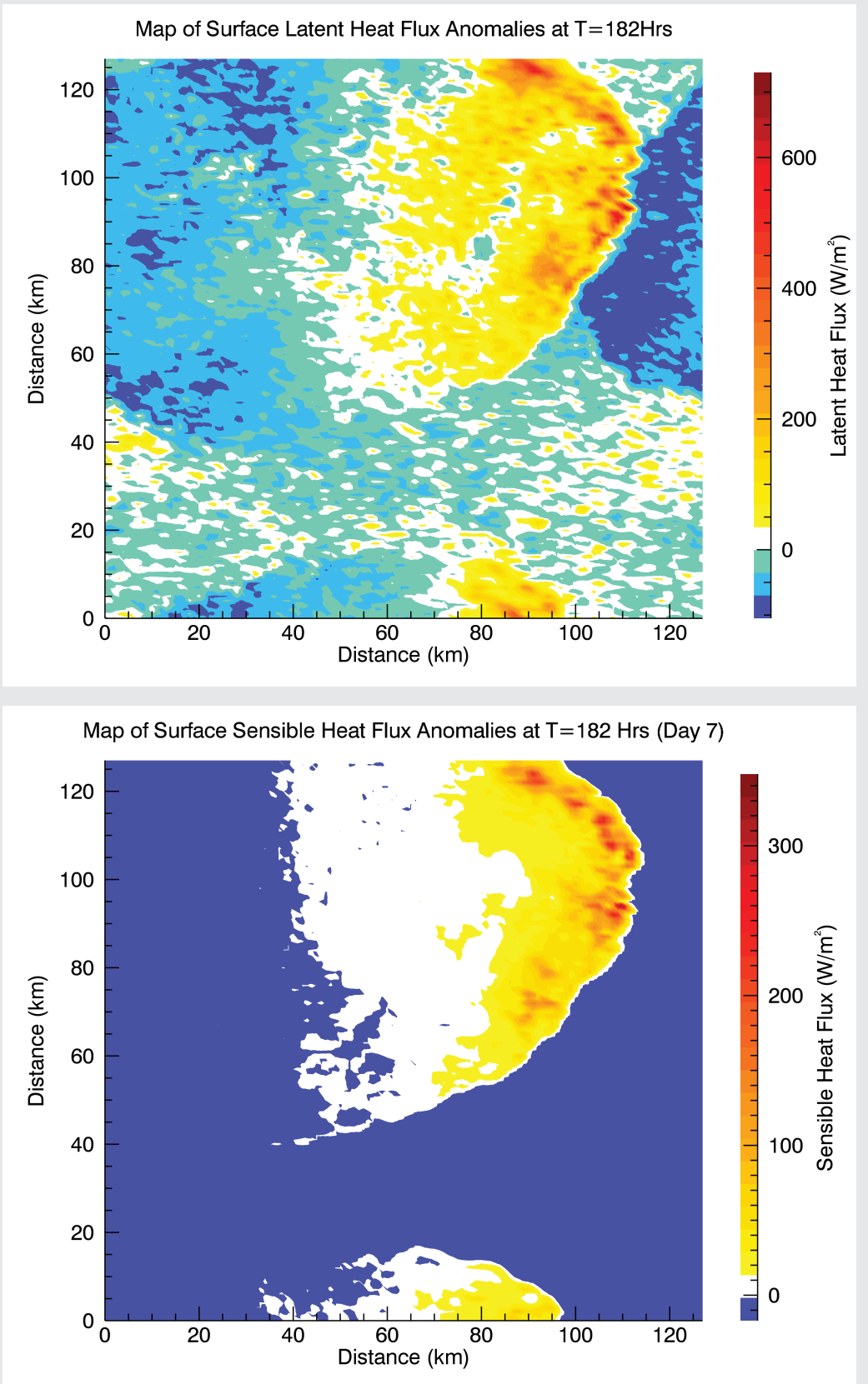

Fig.7 The cold gusty air in a coldpool greatly increases the variance of the latent heat flux (top) but cool saturated air cancels the effects of gustiness in the mean. Senible heat fluxes (bottom) are better correlated as the cold air in the cold pool has a dominant effect over warm boundary layer air.

Assumption 3. BL Forcing is simple in the mean.

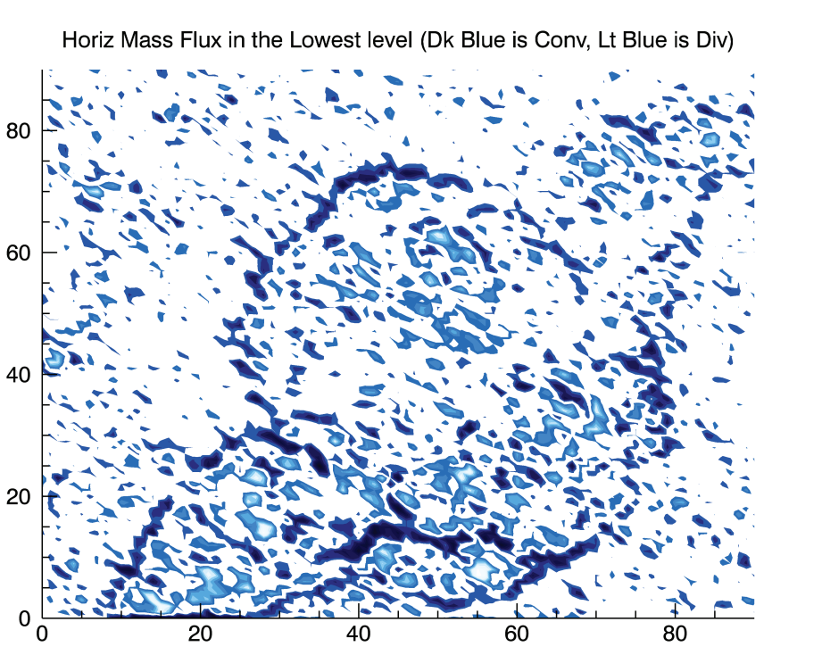

Fig.8 (left) A map of boundary layer mass convergence (dark blue) around divergence (light blue) caused by a cold pool during RadConv.

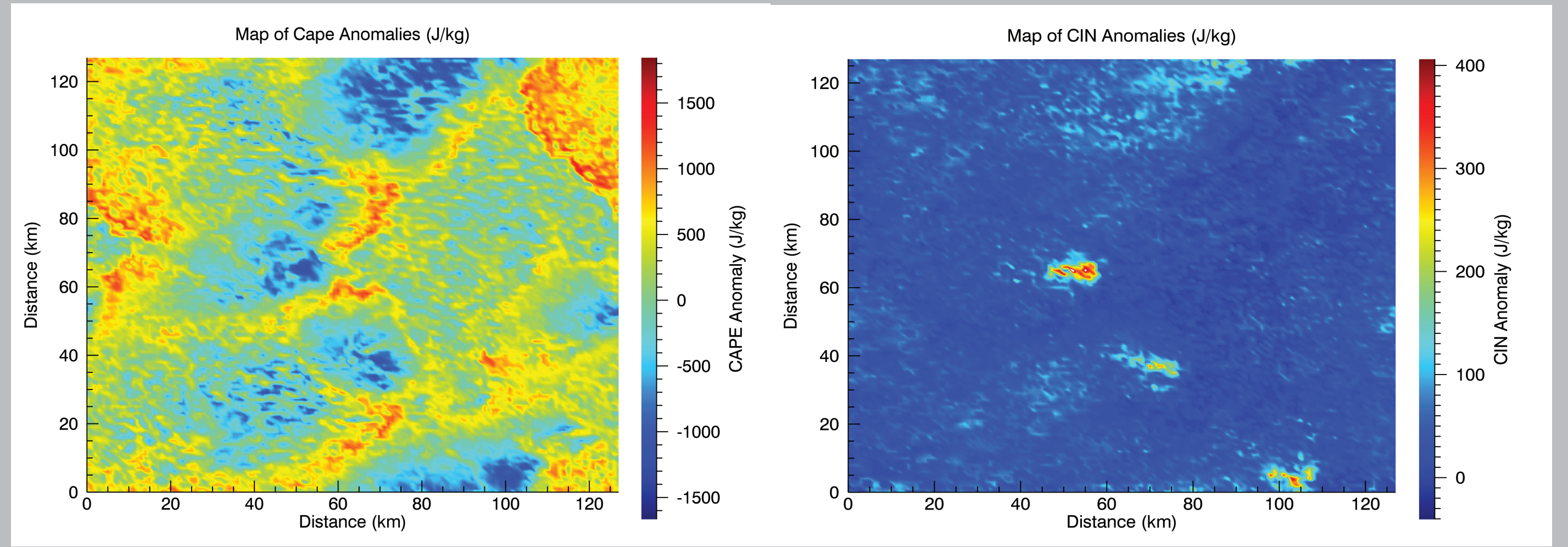

Fig.10 We calculated CAPE (left) and CIN (right) for each three dimensional column during TOGA. For the timestep in Fig. 9, the regions of warm air convergence between coldpools have enhanced CAPE. These regions have lower CIN as well, and areas of cold, diverging air have very high CIN.

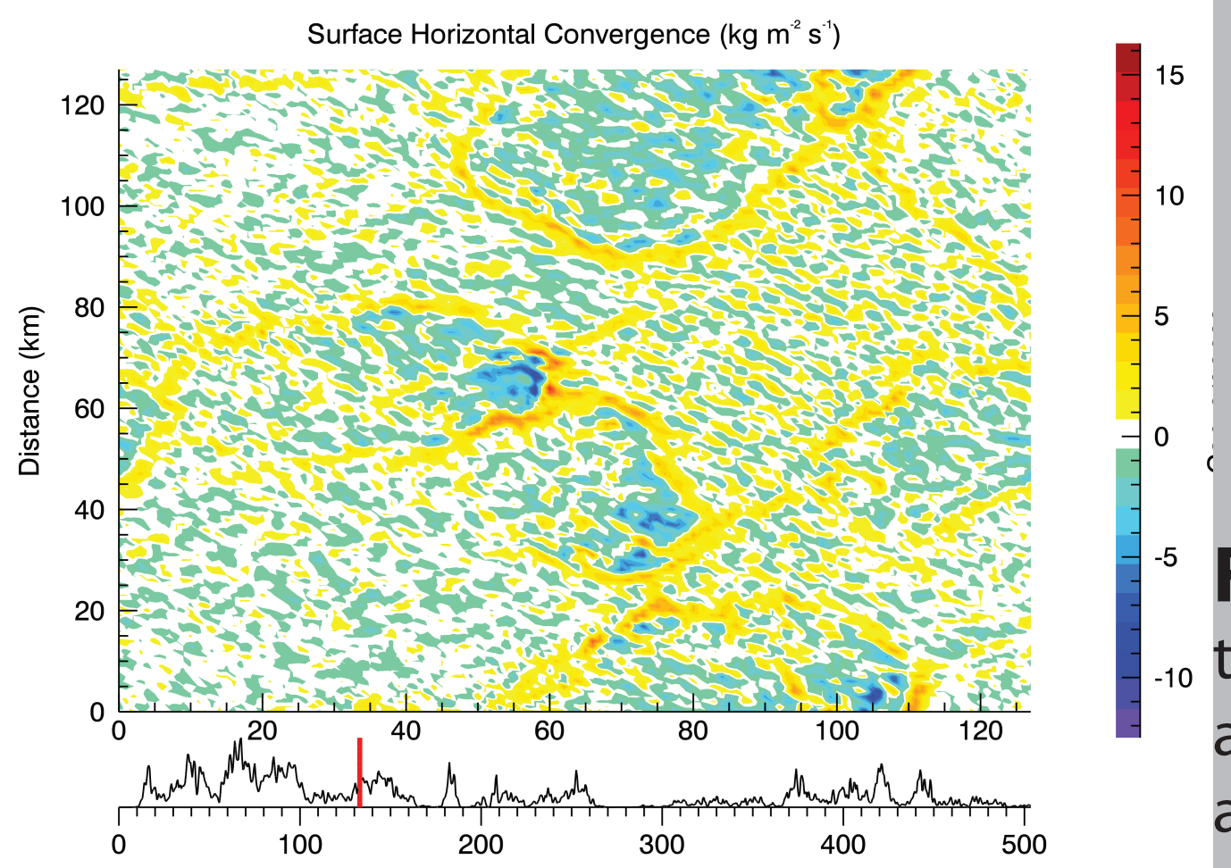

Fig.9 (left) This map of horizontal mass convergence shows cold pools forming and interacting during a convectively active period of TOGA. Cool air flows out of downdrafts and spreads out as it hits the surface (blue and green), and warm, moist, boundary layer air is squeezed into the peripheries (yellow and red).

Assumption 4. Rain evaporation simplifications.

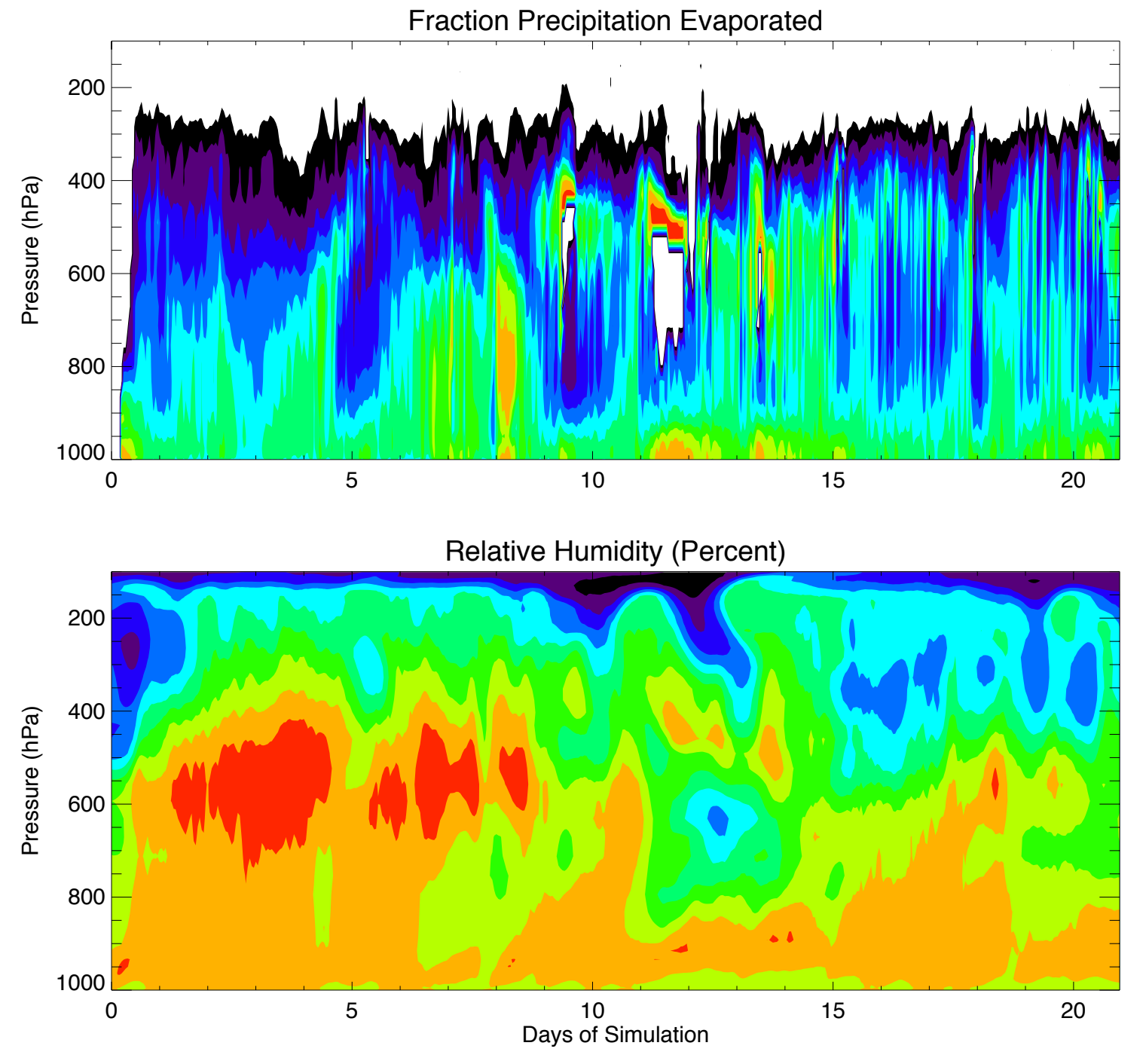

Fig.11 The fraction of precipitation evaporated is not a single number, and during TC, it varies between 30 -100%.

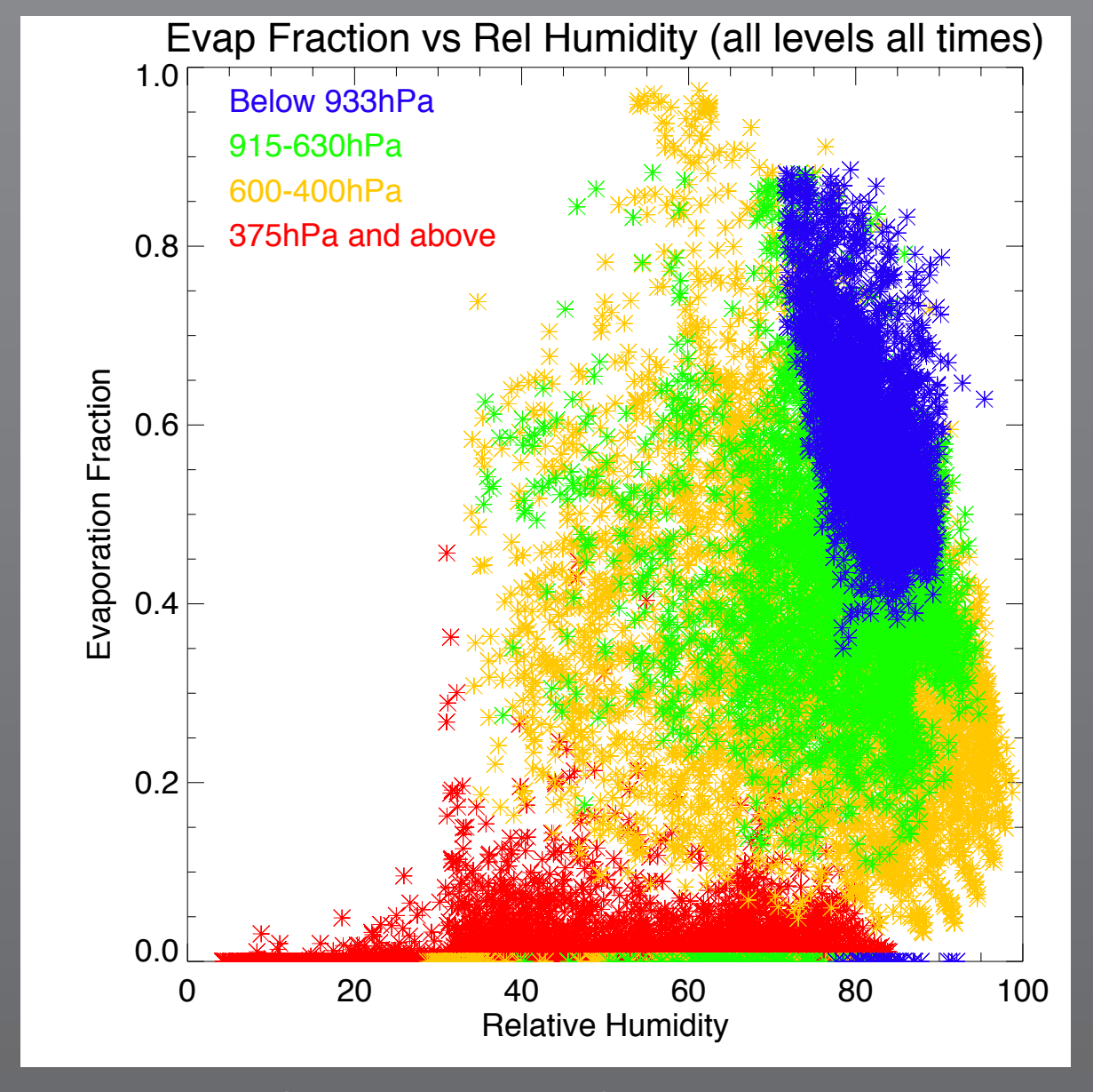

Fig.12 The fraction of precipitation evaporated is sensitive to the environmental relative humidity in the lowest levels, and *not related to relative humidity at all in the upper reaches of convective cells.*

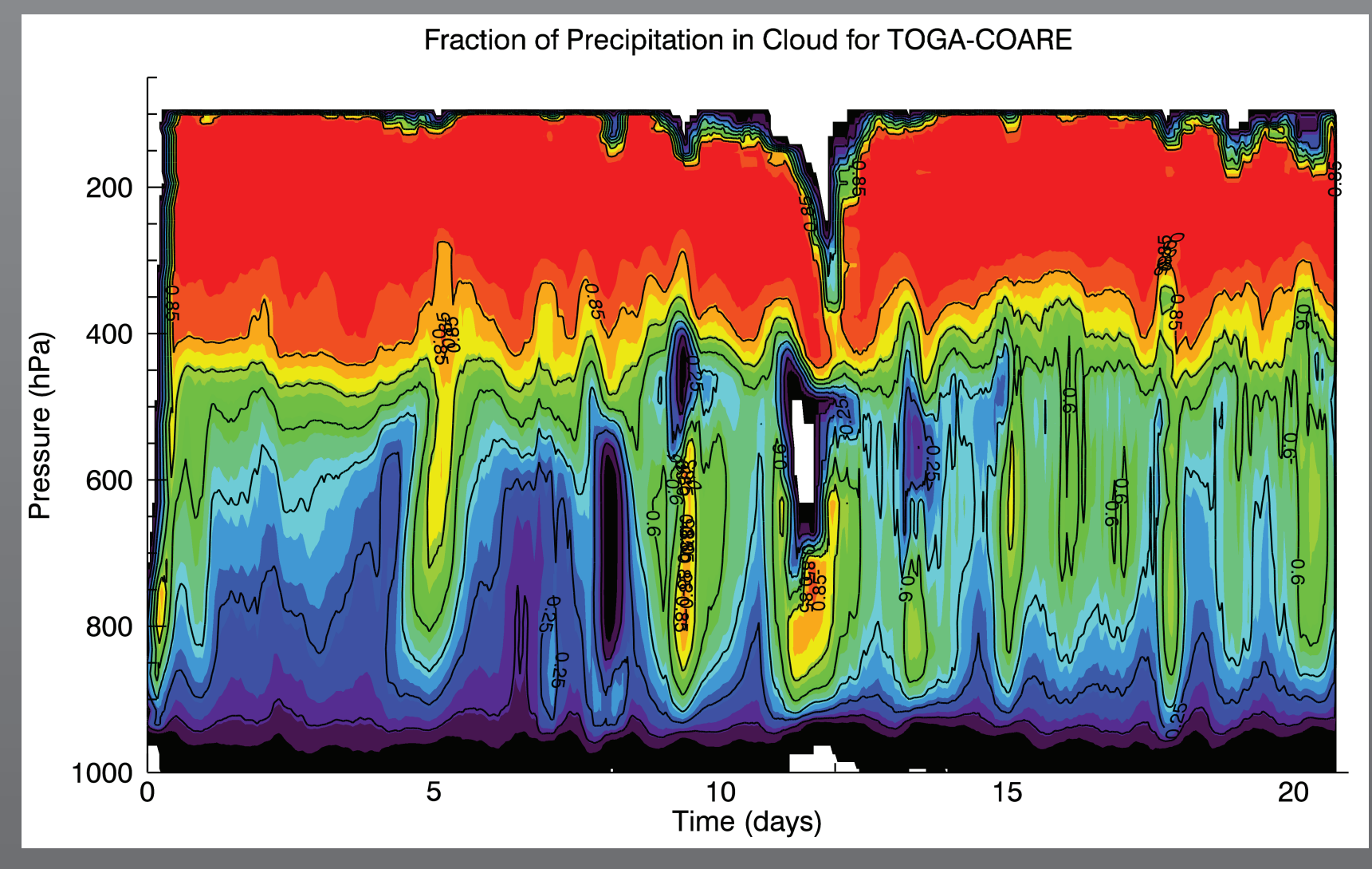

Fig.13 *The amount of precipitation evaporated will be most sensitive to environmental relative humidity outside of clouds.*
In upper levels, precip forms in clouds and very little evaporates. In the boundary layer, it falls out of clouds and evaporates quickly, with some dependence on the average relative humidity.

Parameterization Improvement

Design of parameterizations is always a balance between speed and simplicity, and the accurate representation of a very complex system. While most already agree that the above assumptions are generally inaccurate, they persist because a simple scheme is quick to run, easy to tune, and easy to understand. We believe that modern model and observational data should be employed to create parameterizations that are still relatively simple, but based on more realistic interpretations of key processes. For example, modern parameterizations should:

- ***Include the mass, moisture, and temperature flux processes of downdrafts.***
- ***Improve the interactions of downdrafts and surface fluxes.***
- ***Drive downdrafts by buoyancy calculations related to realistic precipitation formation and evaporation.***
- ***Explicitly include boundary layer variability and its influences on the regulation of convection.***

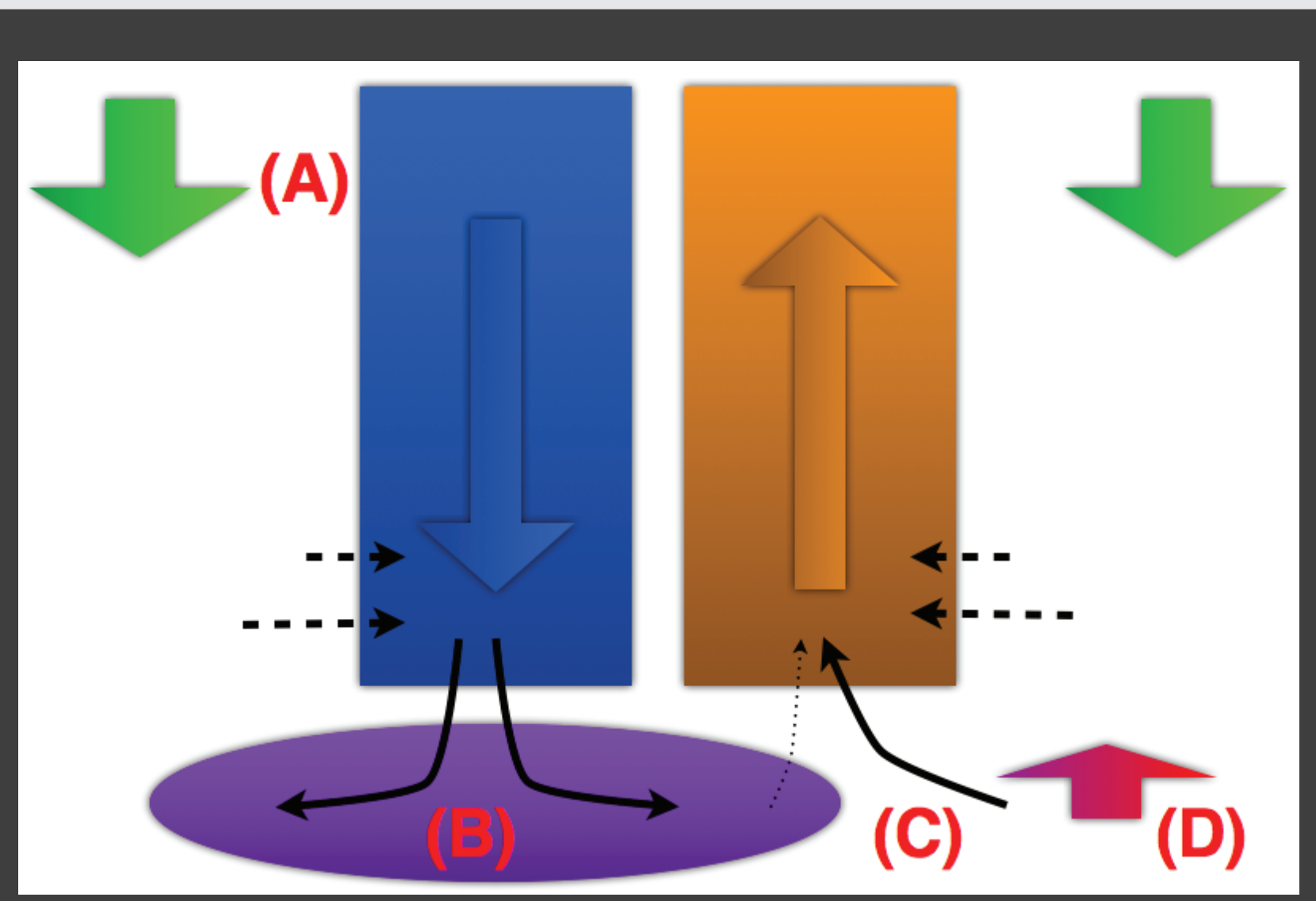

Fig.14 Cartoon showing the primary mass fluxes and interactions resulting from convection.

References

Cheng, M-D. and A. Arakawa, 1997: Inclusion of Rainwater Budget and Convective Downdrafts in the Arakawa-Schubert Cumulus Parameterization. *J. Atmos. Sci.*, **54**, 1359-1378.

Johnson, R., 1976: The Role of Convective-Scale Downdrafts in Cumulus and Synoptic-Scale Interactions. *J. Atmos. Sci.*, **33**, 1890-1910.

Khairoutdinov, M. and D. A. Randall, 2003: Cloud Resolving Modeling of the ARM Summer 1997 IOP: Model Formulation, Results, Uncertainties, and Sensitivities. *J. Atmos. Sci.*, **60**, 607-625.

Raymond, D. J., 1995: Regulation of Moist Convection over the West Pacific Warm Pool. *J. Atmos. Sci.*, **52**, 3945-3959.

Sud, Y. C. and G. K. Walker, 1993: A Rain Evaporation and Downdraft Parameterization to Complement a Cumulus Updraft Scheme and Its Evaluation Using GATE Data. *Mon. Wea. Rev.*, **121**, 3019-3039.

Tiedke, M. 1989: A Comprehensive Mass Flux Scheme for Cumulus Parameterization in Large-Scale Models. *Mon. Wea. Rev.*, **117**, 1779-1800.

Zhang, G. J. and N. A. McFarlane, 1995: Sensitivity of climate simulations to the parameterization of cumulus convection in the CCC-GCM. *Atmos.-Ocean*, **3**, 407-446.

This work has been supported by the National Science and Technology Center for Multi-Scale Modeling of Atmospheric Processes, managed by Colorado State University under Cooperative agreement No. ATM-0425247. To contact us, email: KateTC@atmos.colostate.edu .