# Impact of Turbulence in Free Troposphere on Cloud System Simulation of MC3E

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## 1. Introduction

Clouds and precipitation remain one of the fundamental challenges in numerical simulation of mesoscale convective systems such as those observed in MC3E. Representation of turbulence in numerical models is believed to be more important in the simulation of shallow cumulus and stratocumulus clouds than that of deep convection. However, turbulence has a direct influence on the initiation and perhaps the decay of deep convection. The scale interactions between subgrid-scale and resolved scale are rarely understood because latent heat release is dominant in convective dynamics. This study will examine the importance of turbulence in free troposphere in simulation of deep convection using a pair of cloud resolving models (CRMs) with a low-order and third-order turbulence closures. The MC3E observations are used in the evaluation of these simulations.

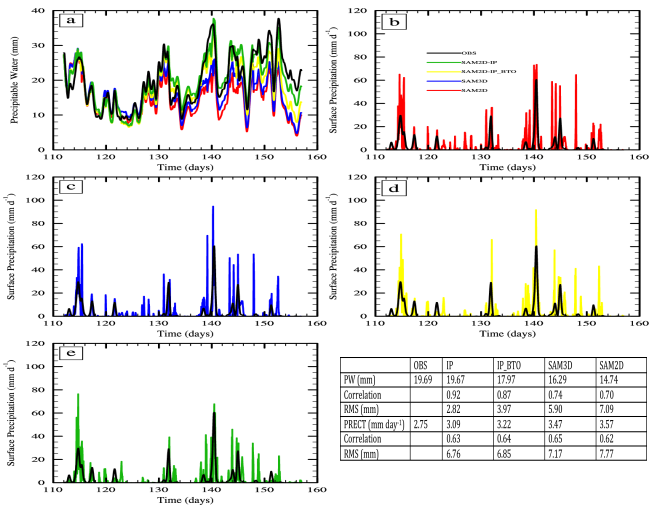
## 2. Model, data and analysis methods

The CRM used in this study is the System for Atmospheric Modeling (SAM) CRM version 6.10.3. The standard SAM has a 1.5-order turbulence closure with prognostic turbulence kinetic energy (TKE). In order to study the influence of turbulence on the simulation of mesoscale systems during MC3E, an intermediately-prognostic higher-order turbulence closure (IPHOC; Cheng and Xu 2006) scheme is implemented in SAM, which is called SAM2D-IPHOC.

Both SAM and SAM2D-IPHOC were run as 2-D CRMs for 45 days starting from day 112 to cover the entire MC3E period, which are labeled as SAM2D and SAM2D-iphoc experiments, respectively. The horizontal domain size used is 256 km while the horizontal grid-size is 1 km. The vertical grid-spacings are 50 m near the surface and stretch to 1 km at the model top (27 km). In order to explore the influence of the dimensionality, a 3D SAM (labeled as SAM3D) is run for 45 days with a horizontal domain of 64 km x 64 km and a grid-size of 4 km. In order to investigate the influence of the turbulence in the free troposphere on the simulations, another sensitivity experiment was performed with SAM2D and IPHOC, but with the higher-order turbulence closure limited to the boundary-layer only (SAM2D-IP_BTO).

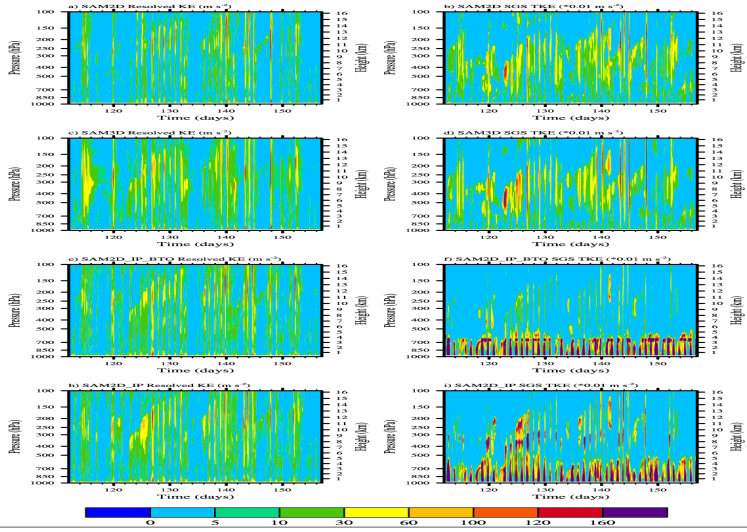
## 3. Results

### Time Evolution of Precipitable Water and Precipitation

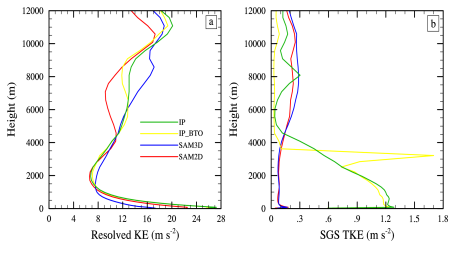



| | OBS | IP | IP_BTO | SAM3D | SAM2D |
|---|---|---|---|---|---|
| PW (mm) | 19.69 | 19.67 | 17.97 | 16.29 | 14.74 |
| Correlation | | 0.92 | 0.87 | 0.74 | 0.70 |
| RMS (mm) | | 2.82 | 3.97 | 5.90 | 7.09 |
| PRECT (mm day$^{-1}$) | 2.75 | 3.09 | 3.22 | 3.47 | 3.57 |
| Correlation | | 0.63 | 0.64 | 0.65 | 0.62 |
| RMS (mm) | | 6.76 | 6.85 | 7.17 | 7.77 |

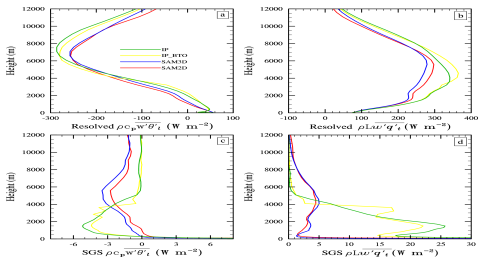
### Resolved (left) and Subgrid-Scale (right) KE



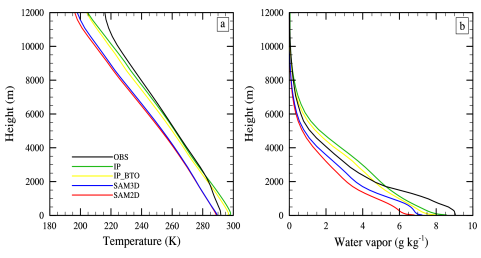

### Profiles of Resolved and SGS KE (day135-145)




### Resolved and SGS Transports (day135-145)




### Temperature and Moisture (day135-145)




## 4. Conclusion

The effects of turbulence in the free troposphere on the simulation of a series of mesoscale convective systems occurred during MC3E are studied with a set of experiments by turning on and off an advanced turbulence closure (IPHOC) in the free troposphere and boundary-layer, respectively. The SGS turbulence represented by kinetic energy from IPHOC is overall larger below 6 km, but smaller above than that of the default 1.5-order turbulence closure. This causes the resolved moisture and temperature transport to increase in the free troposphere, producing a warmer and moister free troposphere, which compares better with observations.