Development of a Scale-Aware Cumulus Parameterization Part II: Analysis of Cloud-Resolving Model Simulations

Yi-Chin Liu[1], Jiwen Fan[1], Guang Zhang[2], Kuan-man Xu[3], and Steven J. Ghan[1]

[1] Pacific Northwest National Laboratory, [2] Scripps Institution of Oceanography, [3] NASA Langley Research Center

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

Introduction

Atmospheric numerical models are running at higher and higher resolution. Existing cumulus parameterization have relied upon a number of inherent assumptions which are not valid anymore with grid spacing from 4 to 50 km, so-called gray zone scale.

Objectives

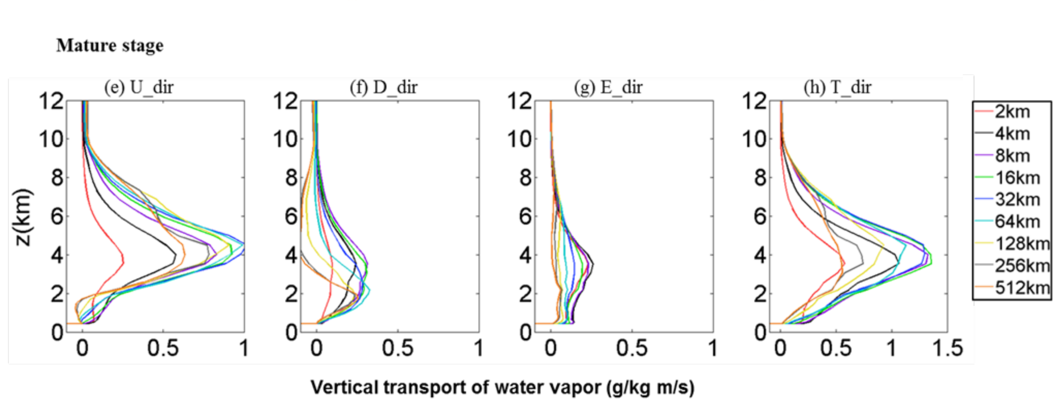
Develop a scale-aware cumulus parameterization based on the Zhang-McFarlane cumulus parameterization.

Methodology

- Employ cloud resolving model (CRM) simulations using the WRF model coupled with spectral-bin cloud microphysics (SBM)
- Simulate multiple convection systems at tropics (TWP-ICE) and the mid-latitude from the Midlatitude Continental Convective Clouds Experiment (MC3E).
- Examine both updraft and downdraft at convection developing and mature stages.

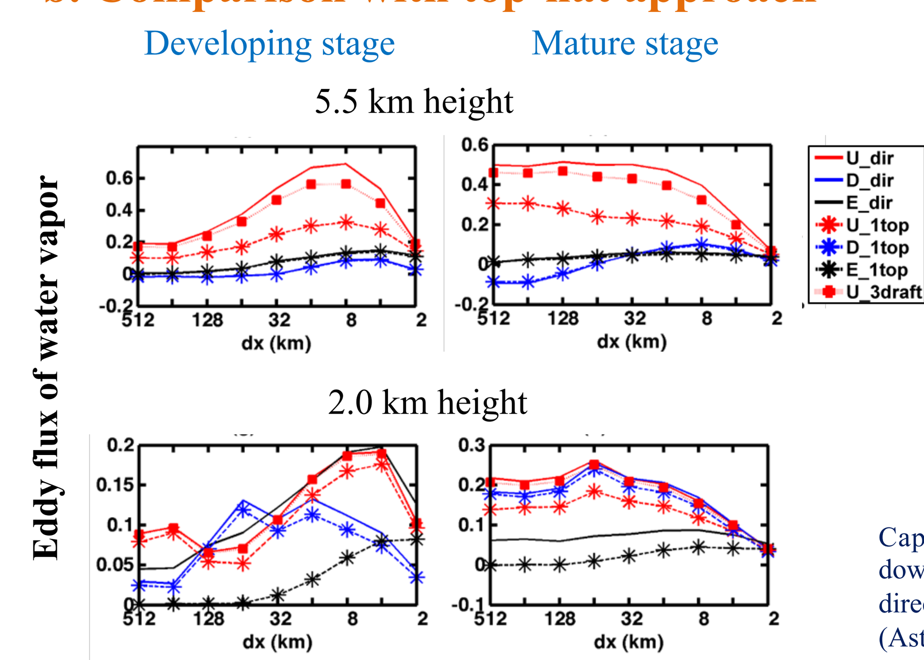
4. Results

a. Grid-spacing dependence of eddy transport



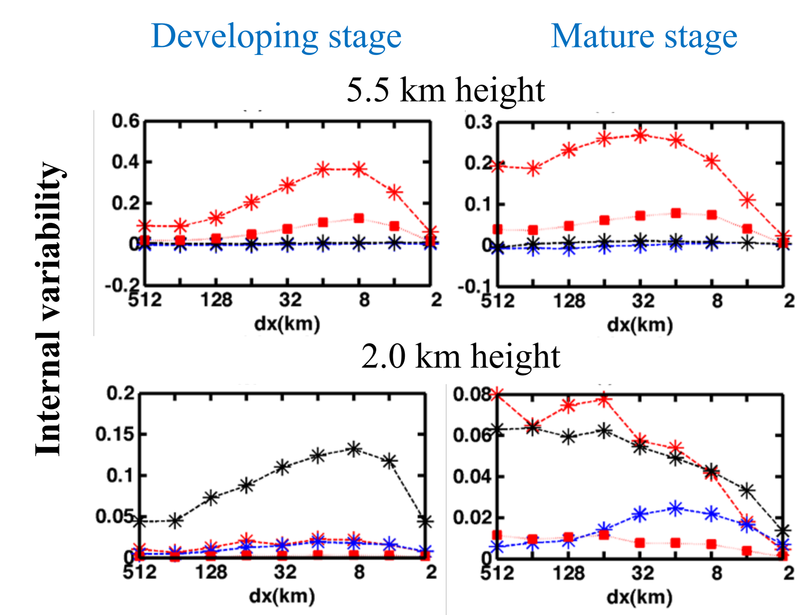
- ❑ **Downdrafts at low level can contribute as much as updrafts**

b. Comparison with top-hat approach



- ❑ **1-updraft underestimates updraft eddy transport while 1-downdraft can well represent the downdraft eddy transport.**
- ❑ **3-updraft can provide a better parameterized updraft eddy transport.**

Caption:: Grid-spacing dependency of updraft (U), downdraft (D), and environment (E) of eddy flux from direct calculation (solid line, dir), top-hat assumption (Asterisk, top1), and 3-draft assumption (square, top3).

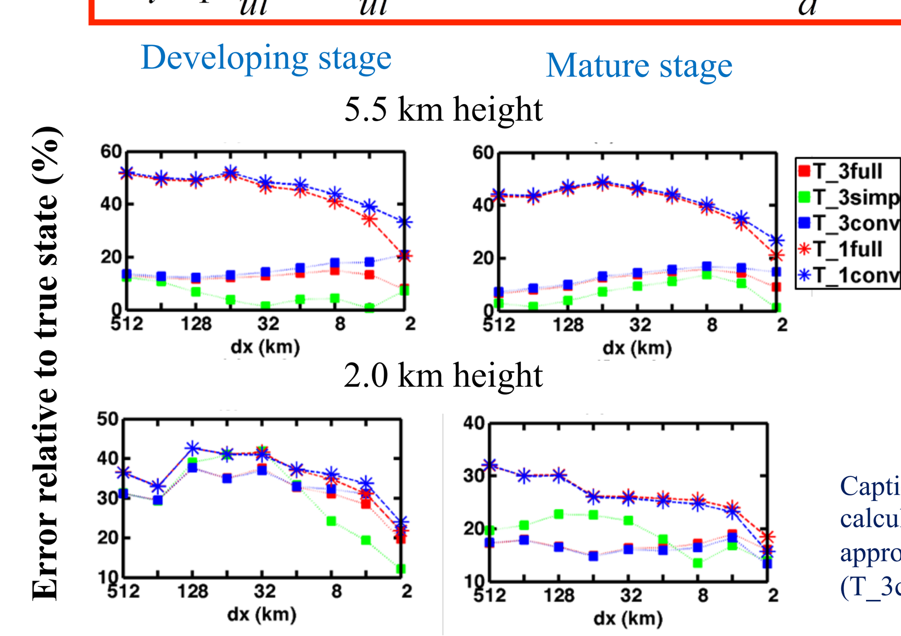


- ❑ **Updrafts have much larger internal variability than downdrafts**
- ❑ **3-updraft approach can significantly reduce the internal variability inside updrafts.**

c. 3-updraft approximation for total eddy transport

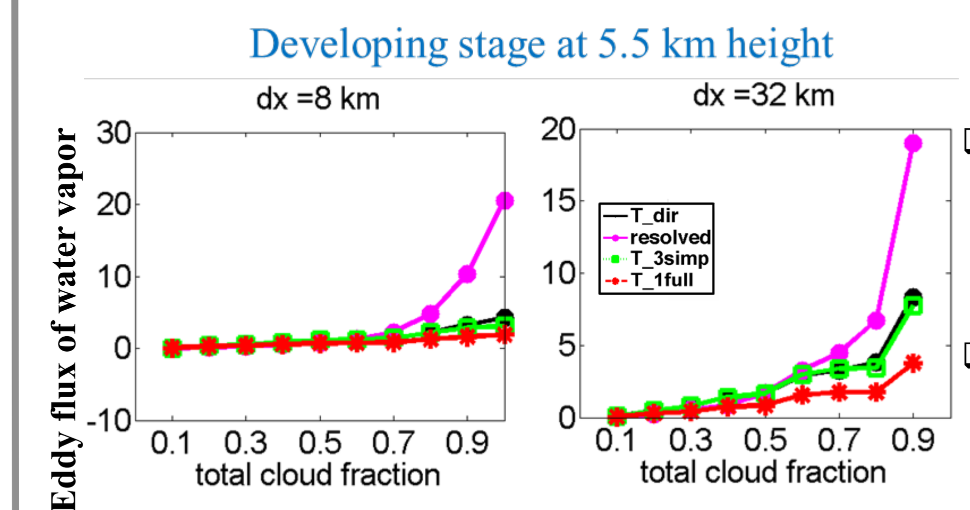
T_3simp: 3-updraft and one downdraft with simplified form

$$\sum_{i=1}^{i=3}\sigma_{ui}(1-\sigma_{ui})(w_{ui}-w_e)(q_{ui}-q_e)+\sigma_d(1-\sigma_d)(w_d-w_e)(q_d-q_e)$$

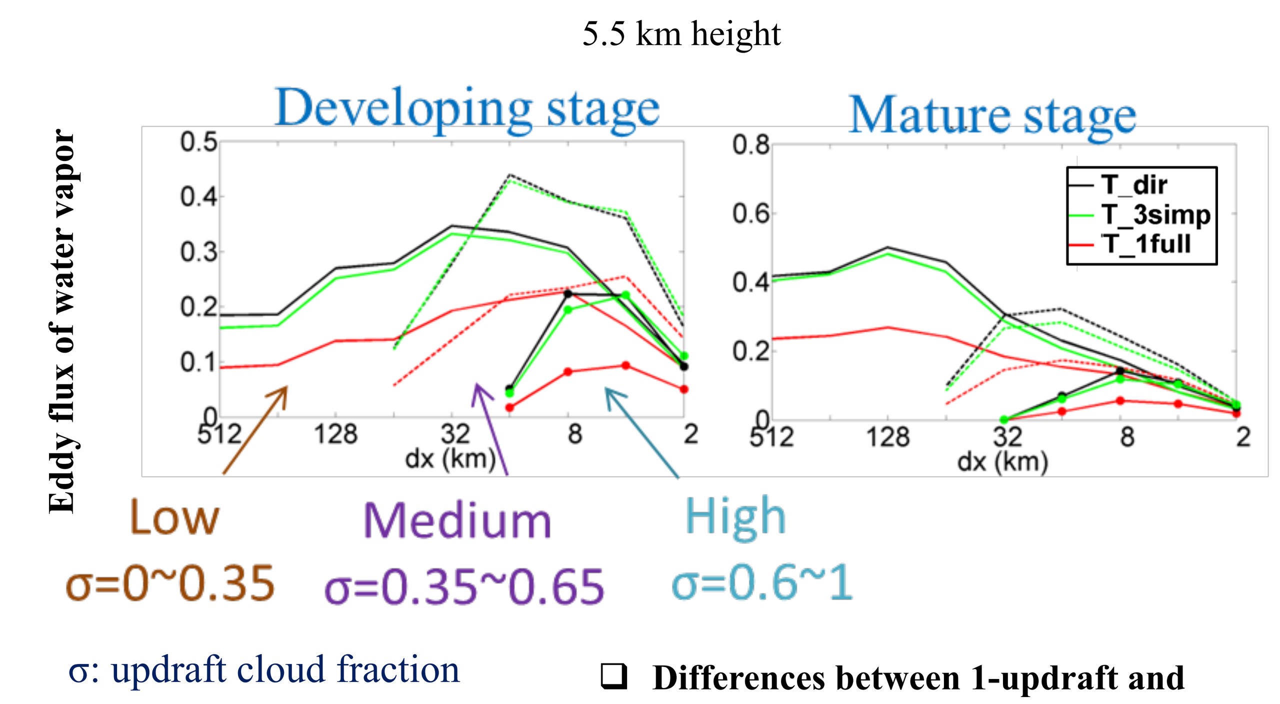


- ❑ **T_3simp has the smallest error.**
- ❑ **Consideration of non-smallness of cloud fraction does not improve parameterized eddy flux at any grid-spacing. Only accounting for the internal variability of updraft can improve it.**

Caption: Relative error (%) of total eddy fluxes relative to direct calculation from 1-updraft approximation (T_1full), 3-updraft approximation with original form (T_3full), conventional form (T_3conv), and simplified form (T_3simp).



- ❑ **Eddy and resolved fluxes can be of similar significance at gray-zone scales.**
- ❑ **Resolved flux is dominate term dx < 8 km.**



- ❑ **Differences between 1-updraft and direction calculation exist across all cloud fractions**

5. Conclusion

- ❑ **The 1-updraft approach significantly underestimates updraft eddy transport while the 1-downdraft approach can well represent the downdraft eddy transport.**
- ❑ **The 3-updraft approach can produce a much better parameterized updraft eddy transport due to a reduction of the internal variability inside updrafts by up to 60 %.**
- ❑ **Simplified 3-plume parameterization is proposed:**
  (1) no assumption of cloud fraction far less than 1,
  (2) simple formulations
  (3) accurate representation of eddy flux across scales.

U.S. DEPARTMENT OF ENERGY

Acknowledgment

Support for this work was provided through Scientific Discovery through Advanced Computing (SciDAC) program funded by U.S. Department of Energy Office of Advanced Scientific Computing Research and Office of Biological and Environmental Research.

Reference:

Arakawa, A., C.-M. Wu, 2013: A unified representation of deep moist convection in numerical modeling of the atmosphere. Part I. *J. Atmos. Sci.*, **70**, 1977–1992.

www.pnnl.gov