Computationally Efficient Parameterization of Turbulence and Clouds in Coarse-Grid CRMs

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Our Approach

- GOAL: Improve representation of unresolved processes (turbulence, shallow convection, etc.) in SAM
- METHOD (two additions to SAM):
  1. Assumed PDF to diagnose SGS cloud fraction, non-precipitating cloud condensate, liquid water flux
  2. Improved representation of the SGS turbulent length scale
- Can this be done without breaking the bank (computationally)?

Assumed PDF: Implementation into SAM

- Select the Analytic Double Gaussian I PDF
- Requires computation of several second order moments and one third order moment:

$$\overline{\theta_l'^2}, \overline{q_t'^2}, \overline{w'^2}, \overline{w'\theta_l'}, \overline{w'q_t'}, \overline{q_t'\theta_l'}, \overline{w'^3}$$

- The single column model of Golaz et al. (2002) used a predictive approach to find these moments
- To avoid substantial computational expense, can we avoid second/third order predictive closure?
- Moments diagnosed using modified expressions of Redelsperger (1986) and Canuto (2004)

Turbulent Length Scale

- Needed to parameterize:

$$\epsilon = \frac{\overline{e}^{3/2}}{L} \qquad K_H = 0.1L\overline{e}^{1/2}$$

- Currently SAM sets $L \propto \Delta z$
  - Typically results in a SGS model which is too dissipative for CRMs
- Cheng et al. (2010) suggests that eddy diffusivity schemes (K-theory) appear to function well given the correct amount of SGS TKE can be predicted
- We have formulated a new dissipation length scale that appears to partition SGS/Resolved TKE accurately

Standard SAM vs. PDF-SAM

- Standard SAM
  - 1.5 TKE closure
  - Length scale specified as dz (except in stable grid boxes)
  - "all-or-nothing" condensation
- PDF-SAM
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  - Length scale diagnosed
  - SGS condensation
  - No additional prognostic equations added to SAM code

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$$\overline{w'\theta_v'} = \overline{w'\theta_l'} + \frac{1-\epsilon_o}{\epsilon_o}\theta_o\overline{w'q_t'} + \left[\frac{L_v}{c_p}\left(\frac{p_o}{p}\right)^{R_d/c_p} - \frac{1}{\epsilon_o}\theta_o\right]\overline{w'q_l'}$$

LES Benchmarks

- The following LES cases have been used to test parameterization in 2D CRM configuration:
  - Clear Convective Boundary Layer (Wangara)
  - Trade-wind cumulus (BOMEX)
  - Precipitating cumulus (RICO)
  - Continental cumulus (ARM)
  - Stratocumulus to cumulus transition (OWN)
  - Deep convection (GATE) “Giga-LES”

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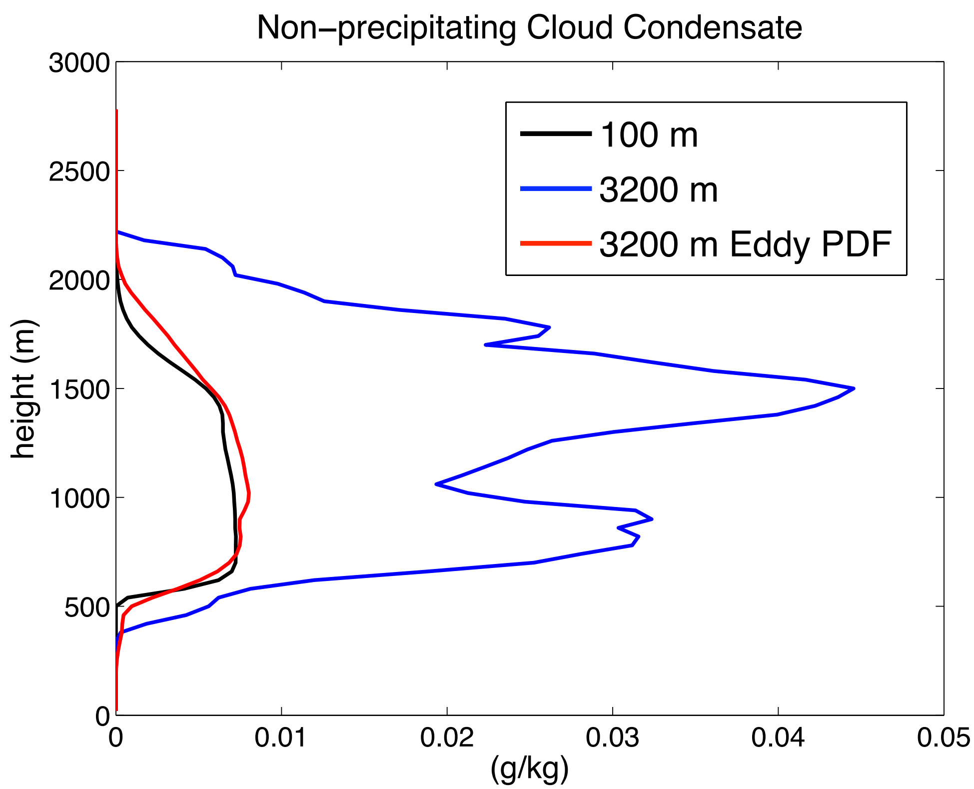
Selected Results

- Results from idealized cases (BOMEX, Transition, RICO)
- CRM Results presented for SAM run in 2D and for dx=3.2 km
  - Also present for dx=800 m to 25.6 km
- Results compared to predictive SCM of Golaz et al. 2002.

Non-Precipitating Shallow Convection (BOMEX)



LES: dx = dy = 100 m, dz = 40 m

CRM: dx = 3200 m, dz = 80 m

Results shown from last 3 hours

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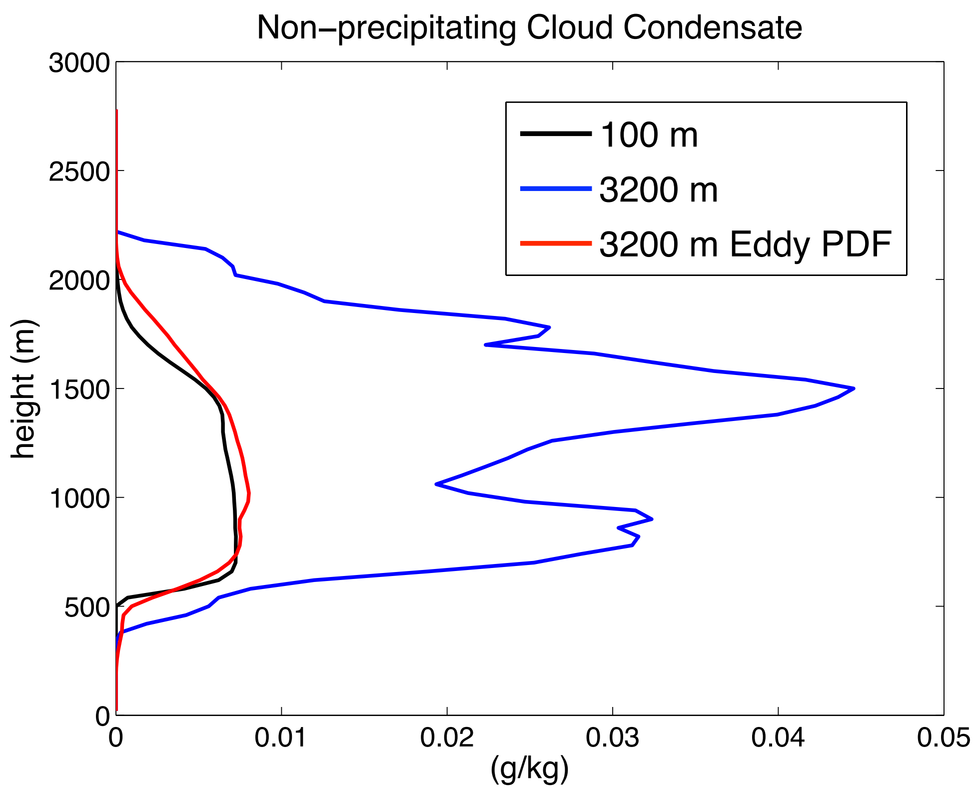

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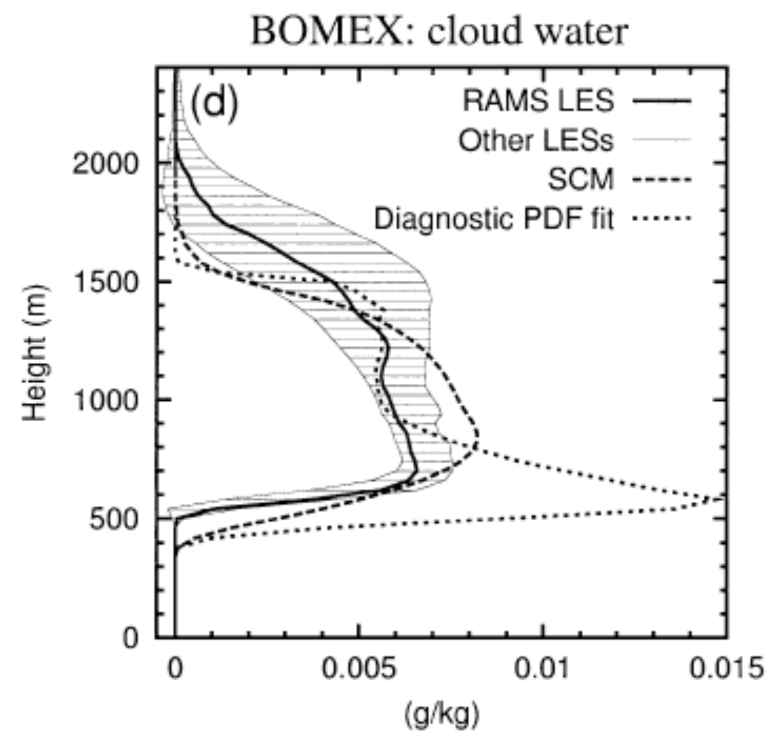

Golaz et al. 2002

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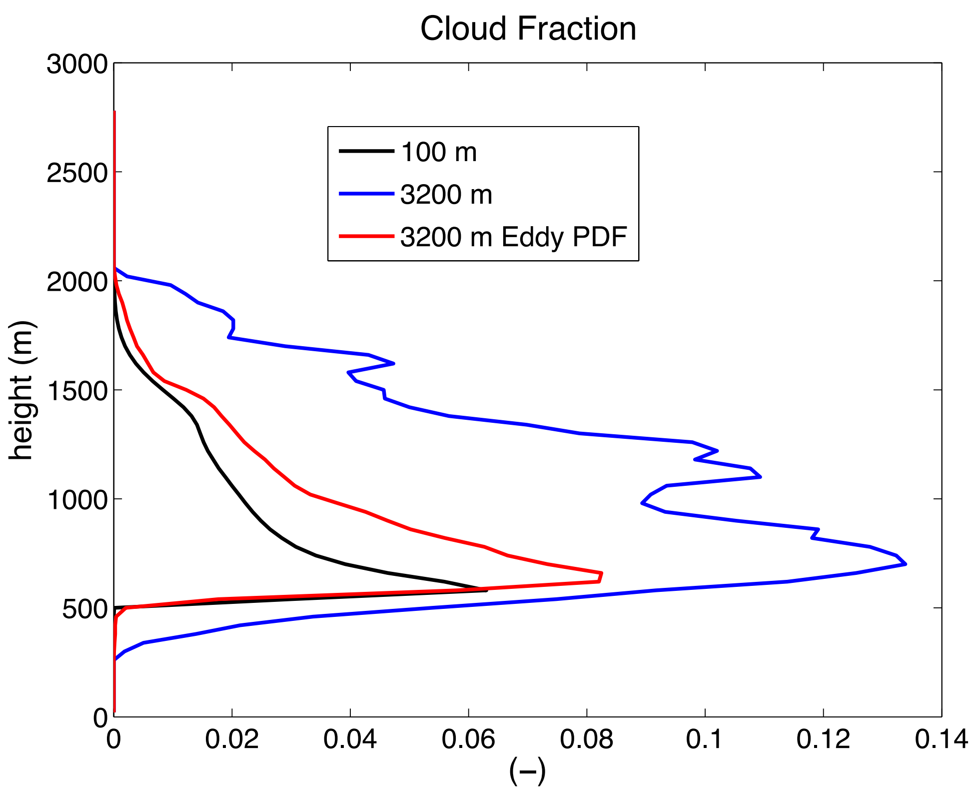

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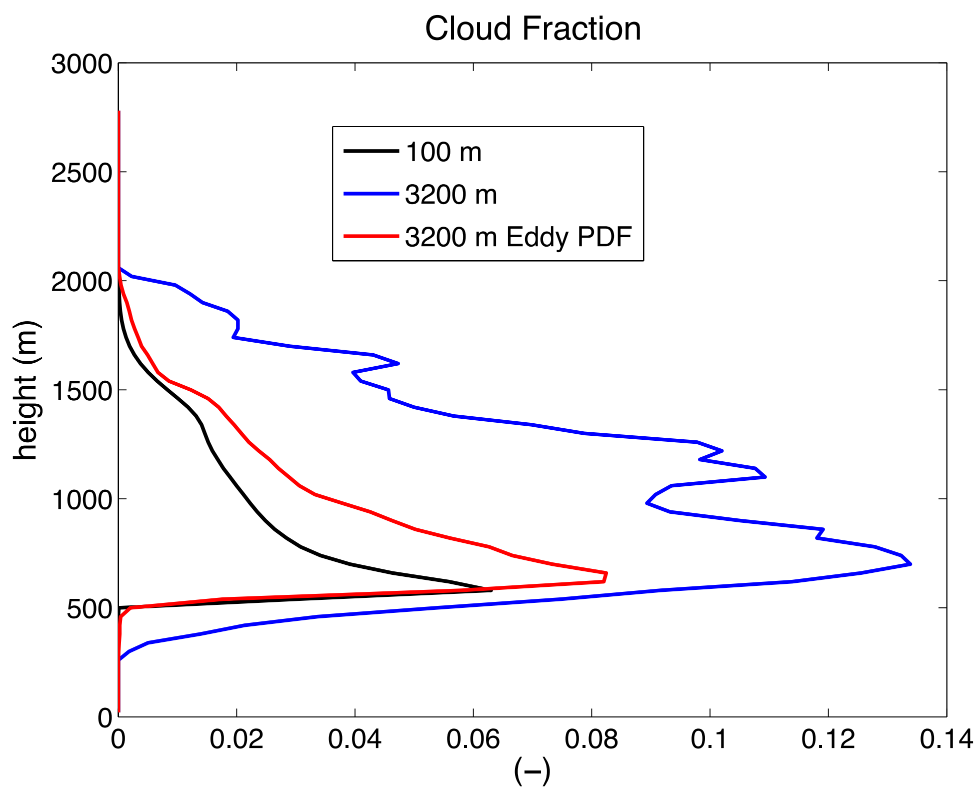

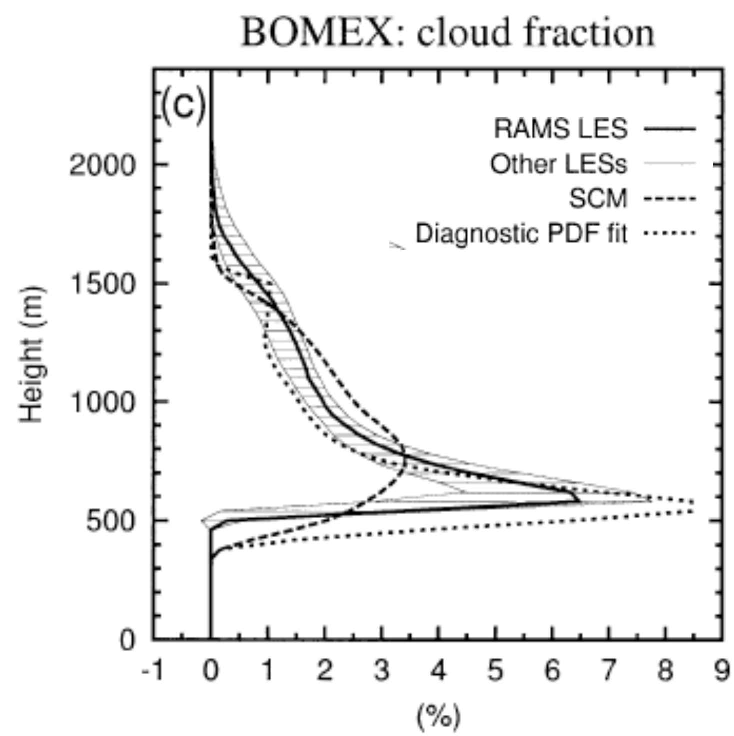

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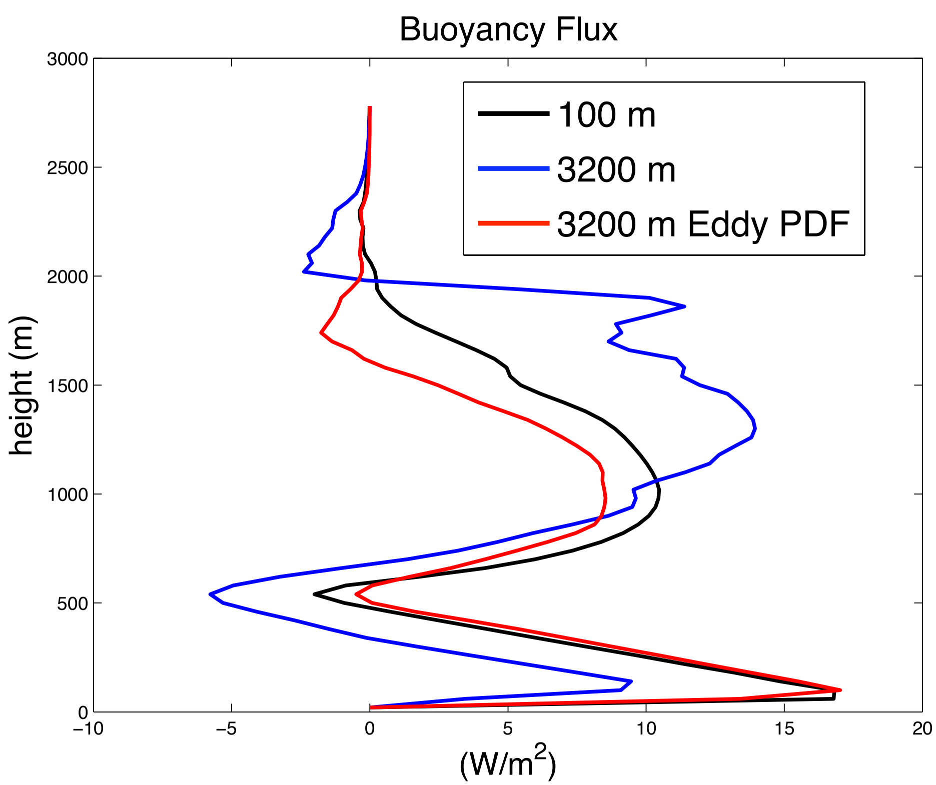

Standard SAM: Flux completely due to resolved scale
PDF-SAM: Flux driven by SGS model

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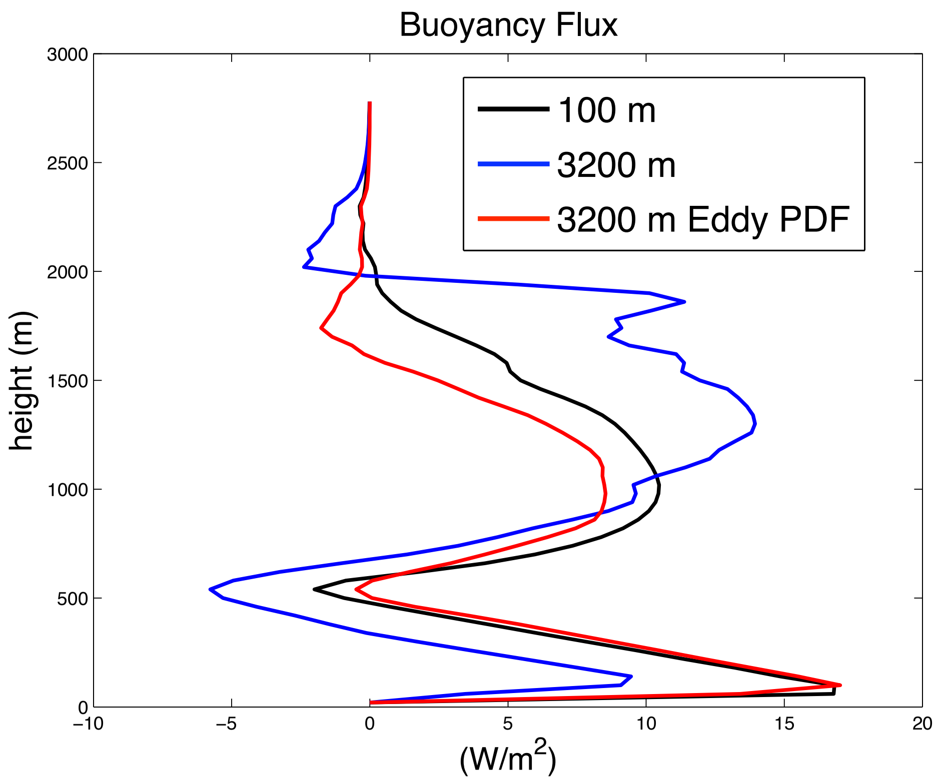

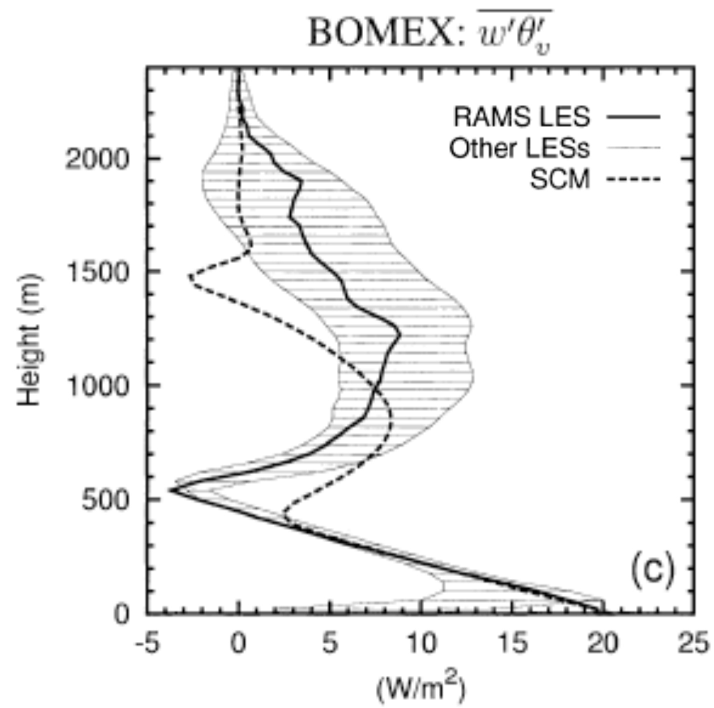

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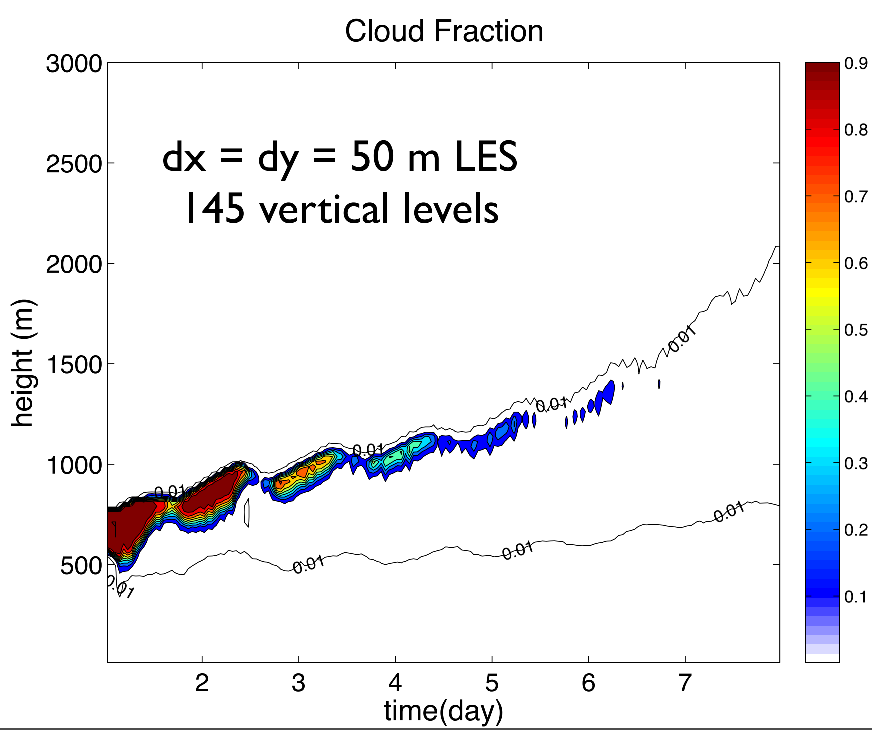
Lagrangian Transition Case

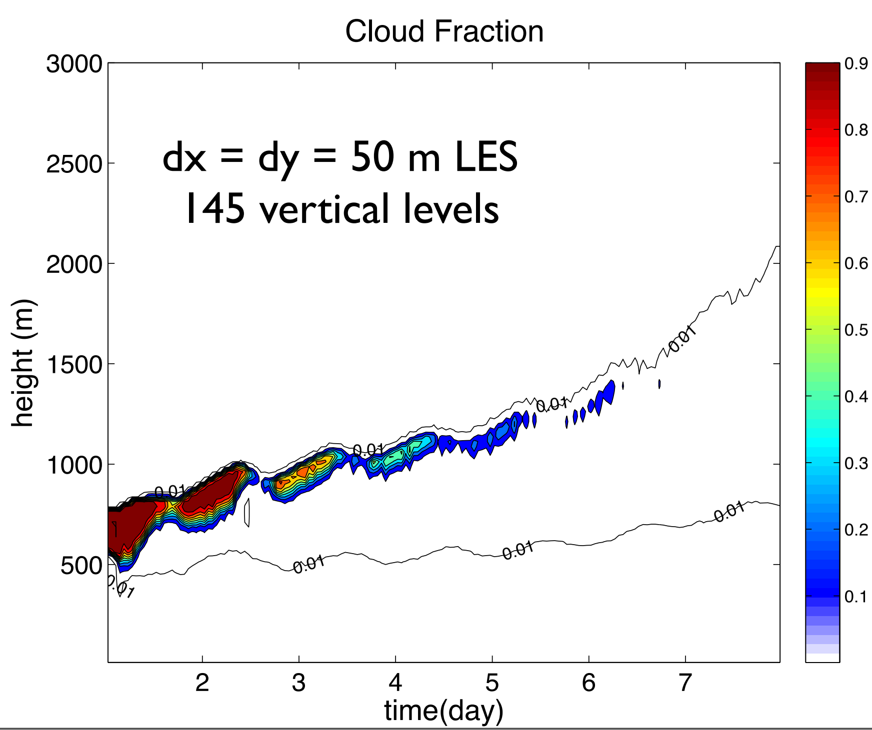
SST Warming Linearly



Lagrangian Transition Case

2D Standard SAM
dx = 3200 m
50 vertical levels

SST Warming Linearly



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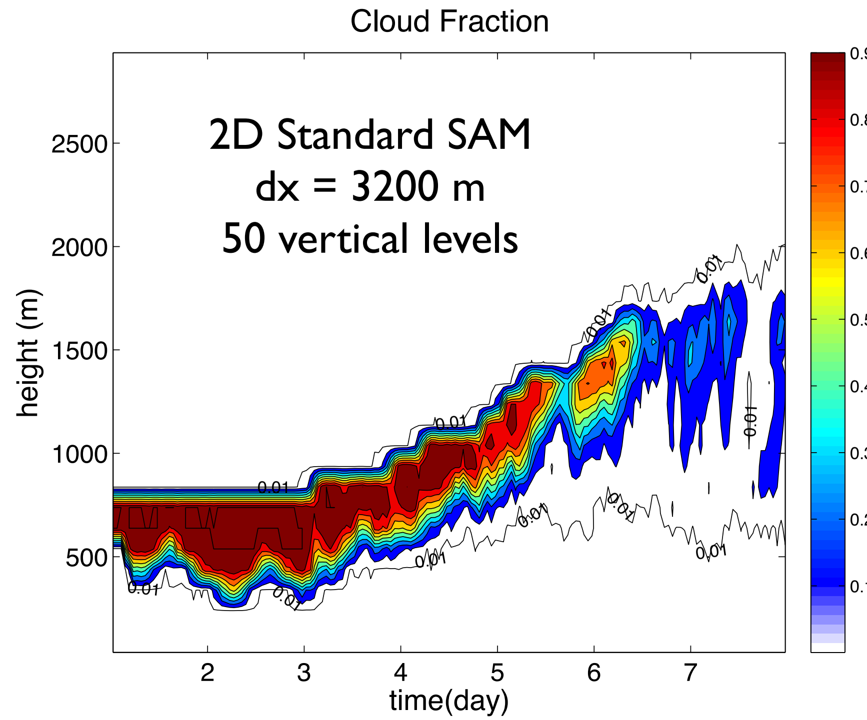

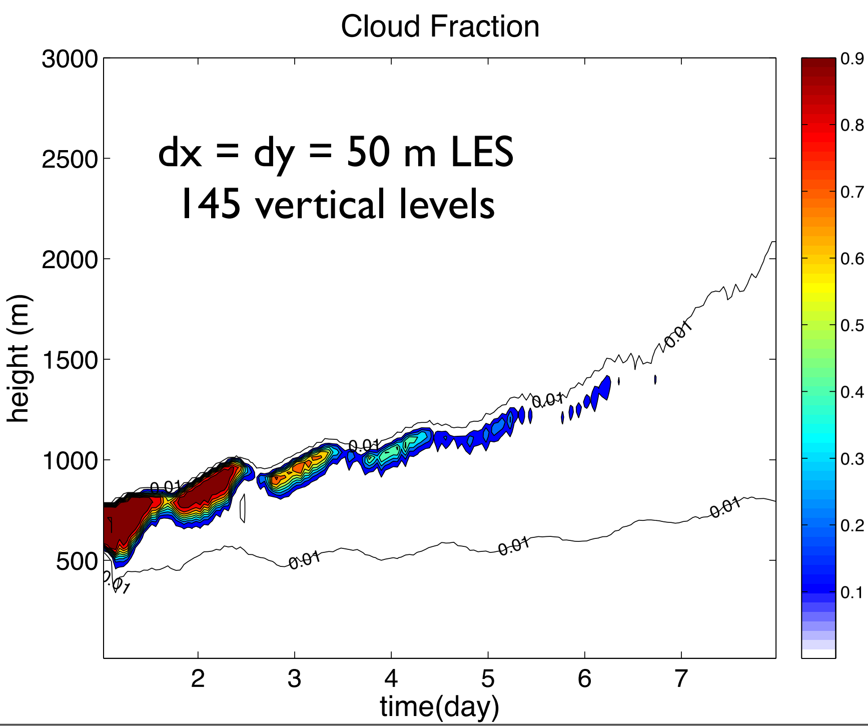

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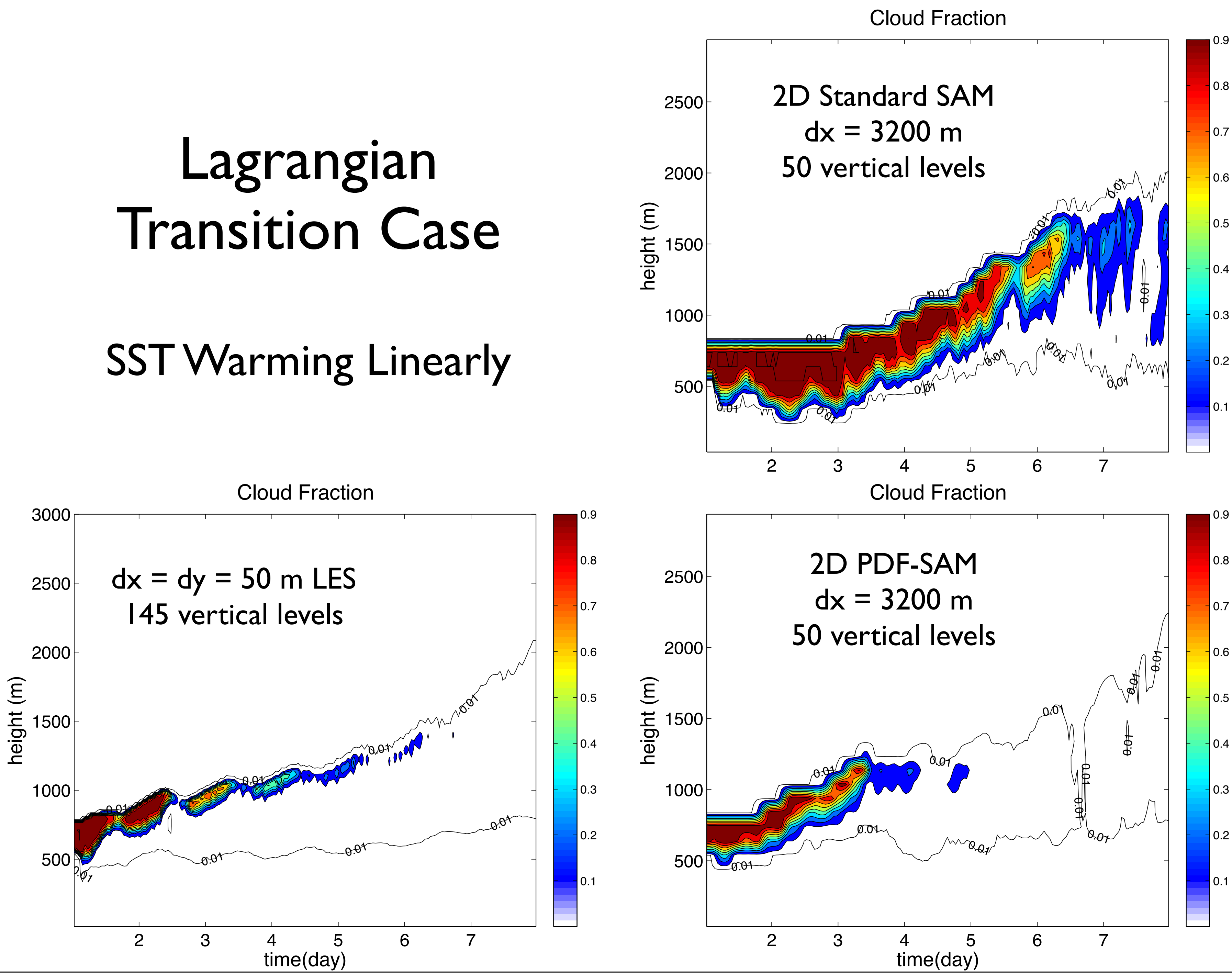

Sensitivity to Horizontal Grid Size Precipitating Cumulus (RICO)

LES: dx = dy = 100 m, dz = 40 m

2D CRMs: dx = 800 m to 25.6 km (102.4 km domain), dz = 100 m

Results shown from last 4 simulated hours

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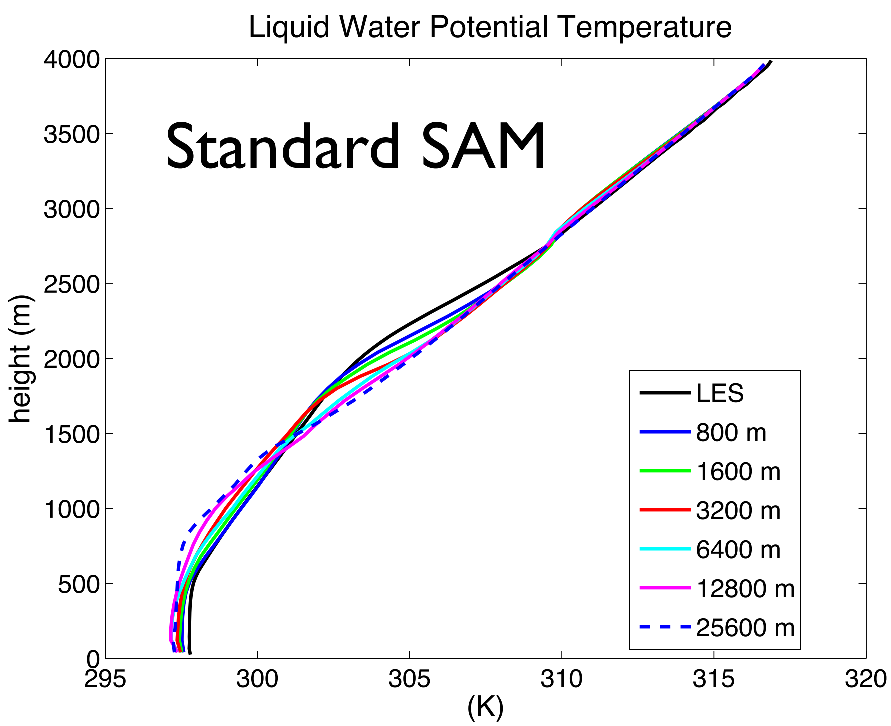

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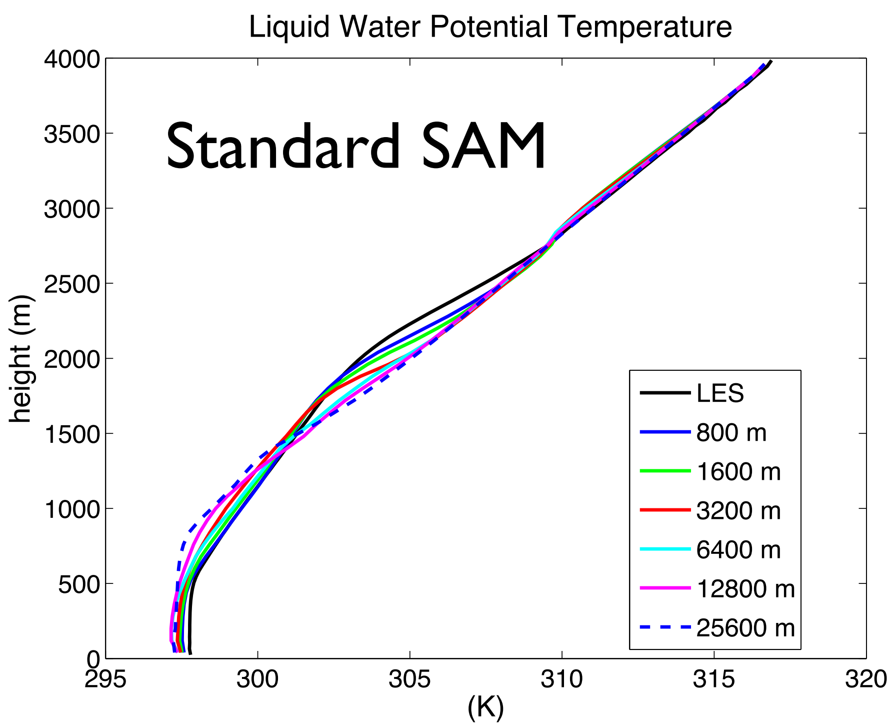

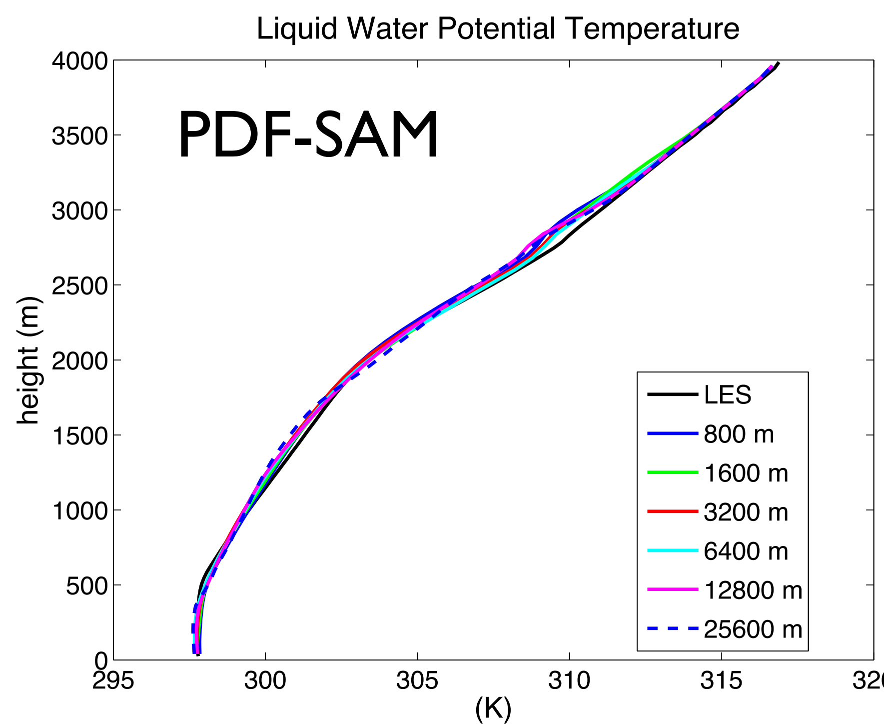

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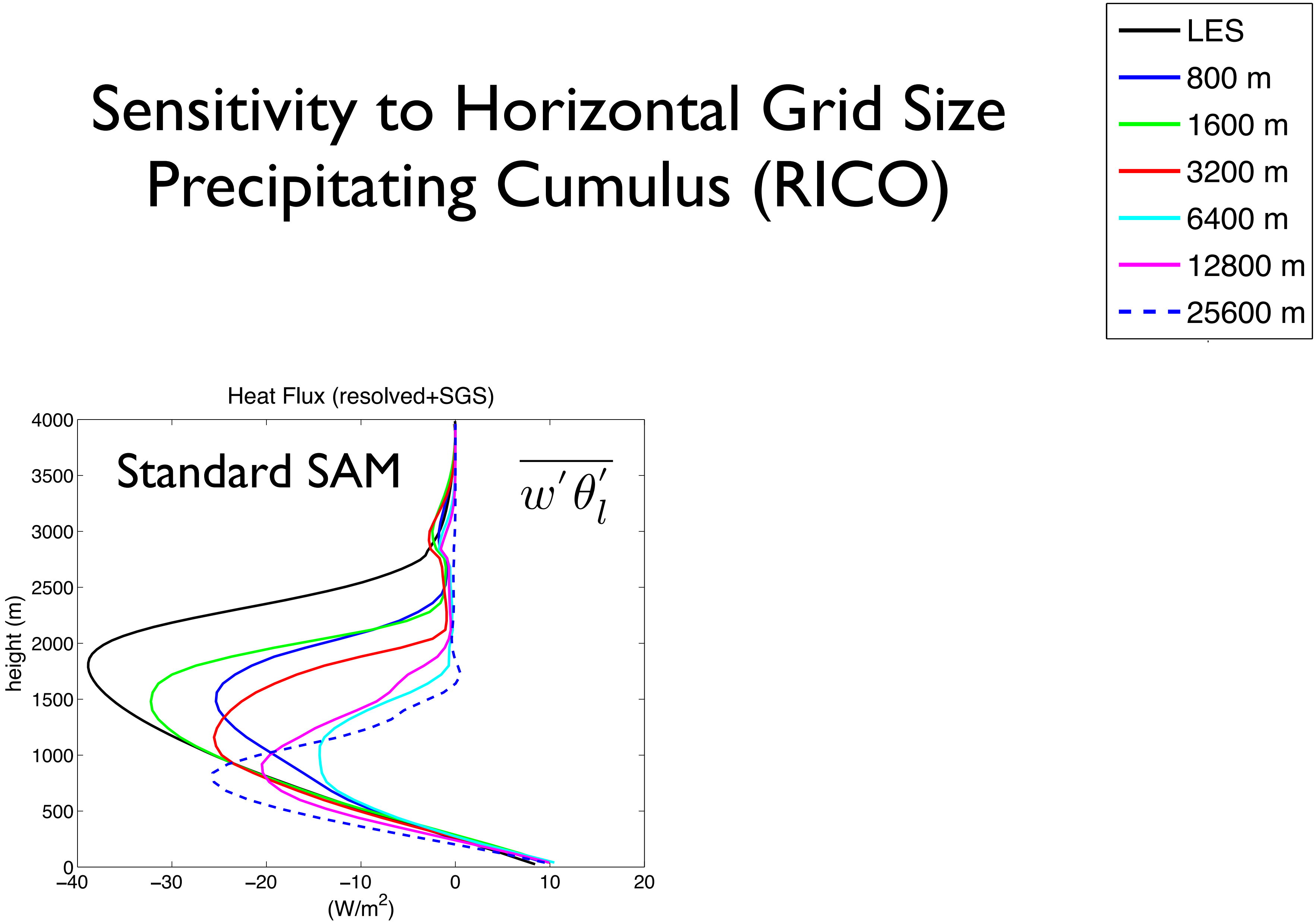

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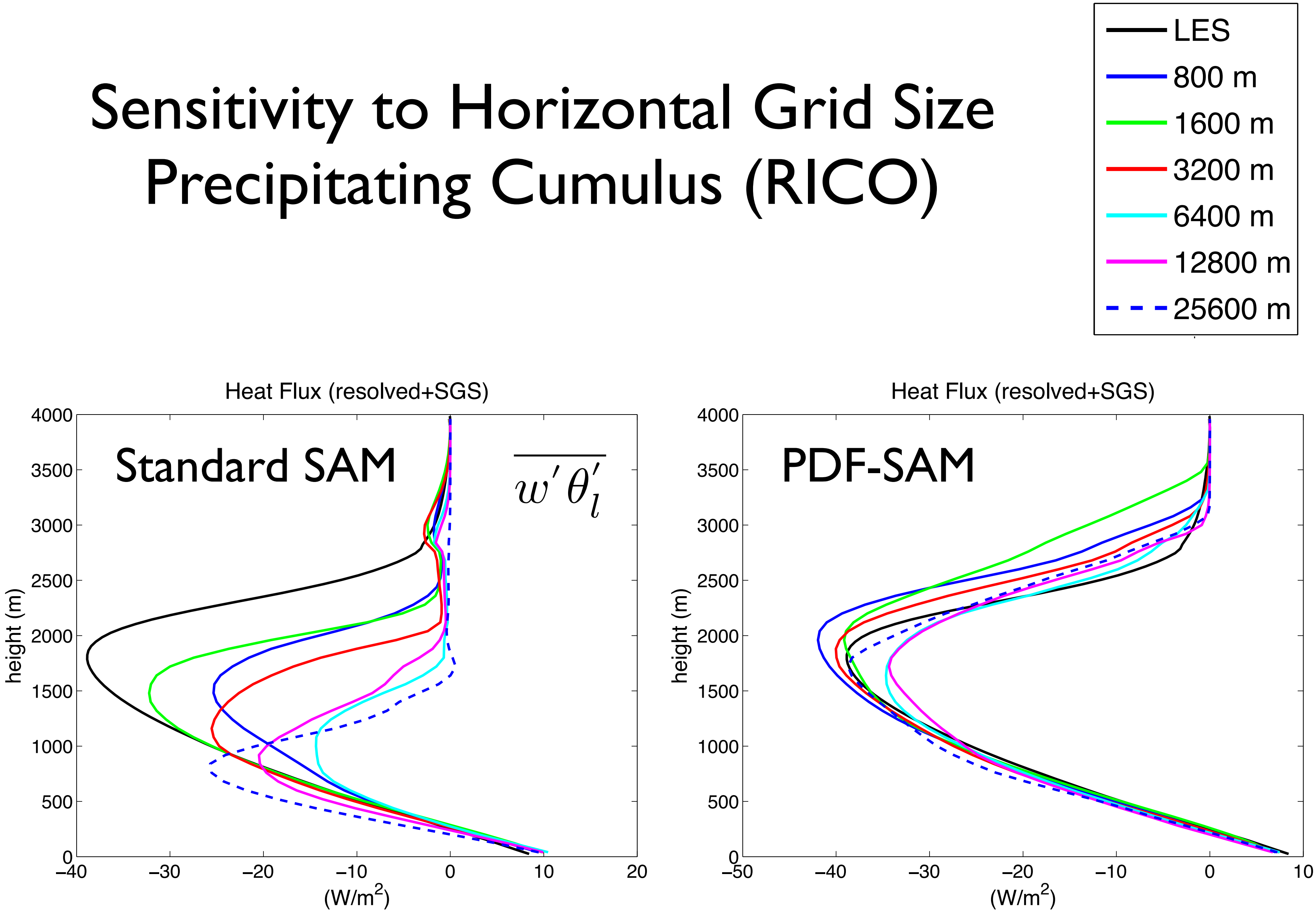

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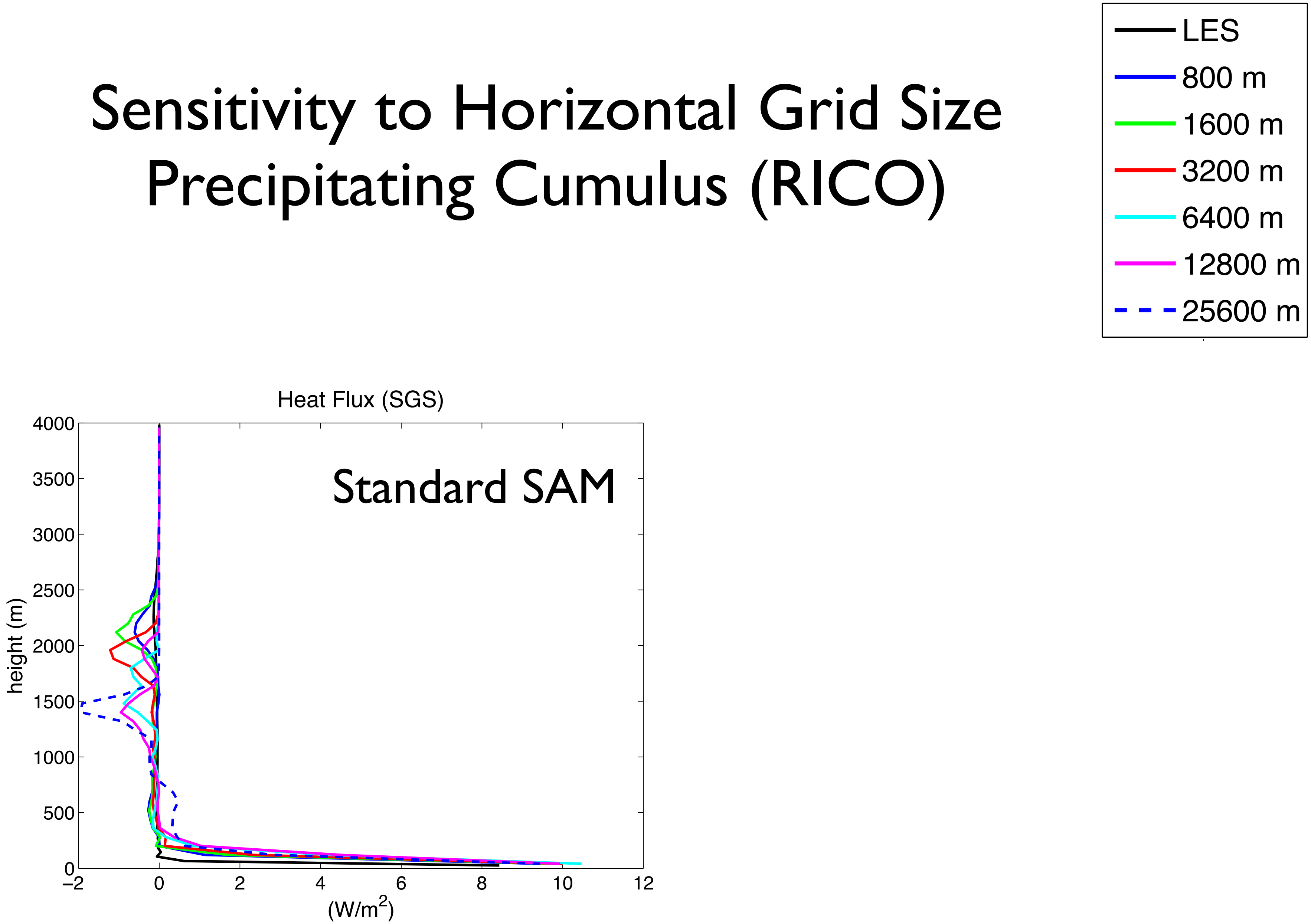

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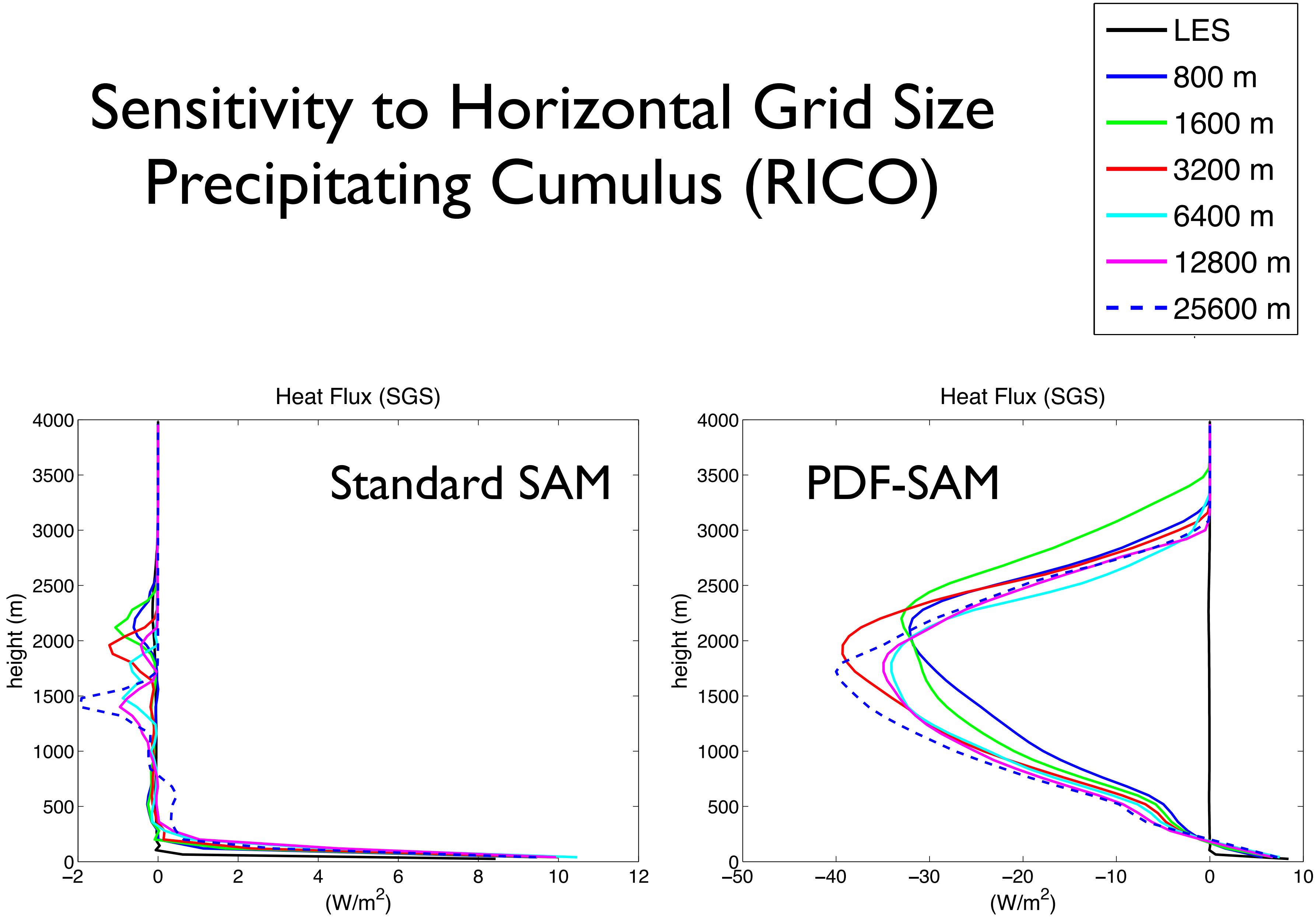

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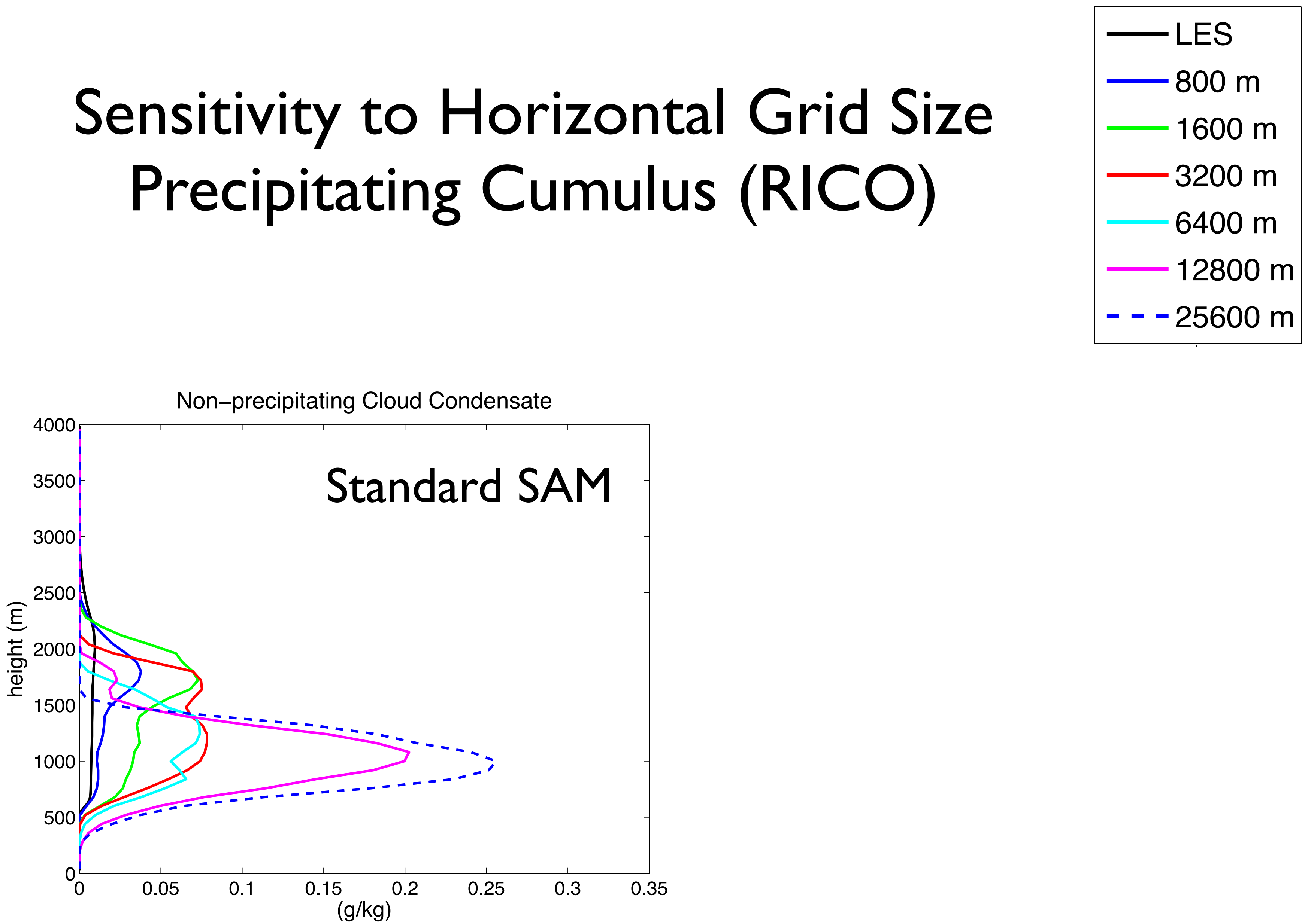

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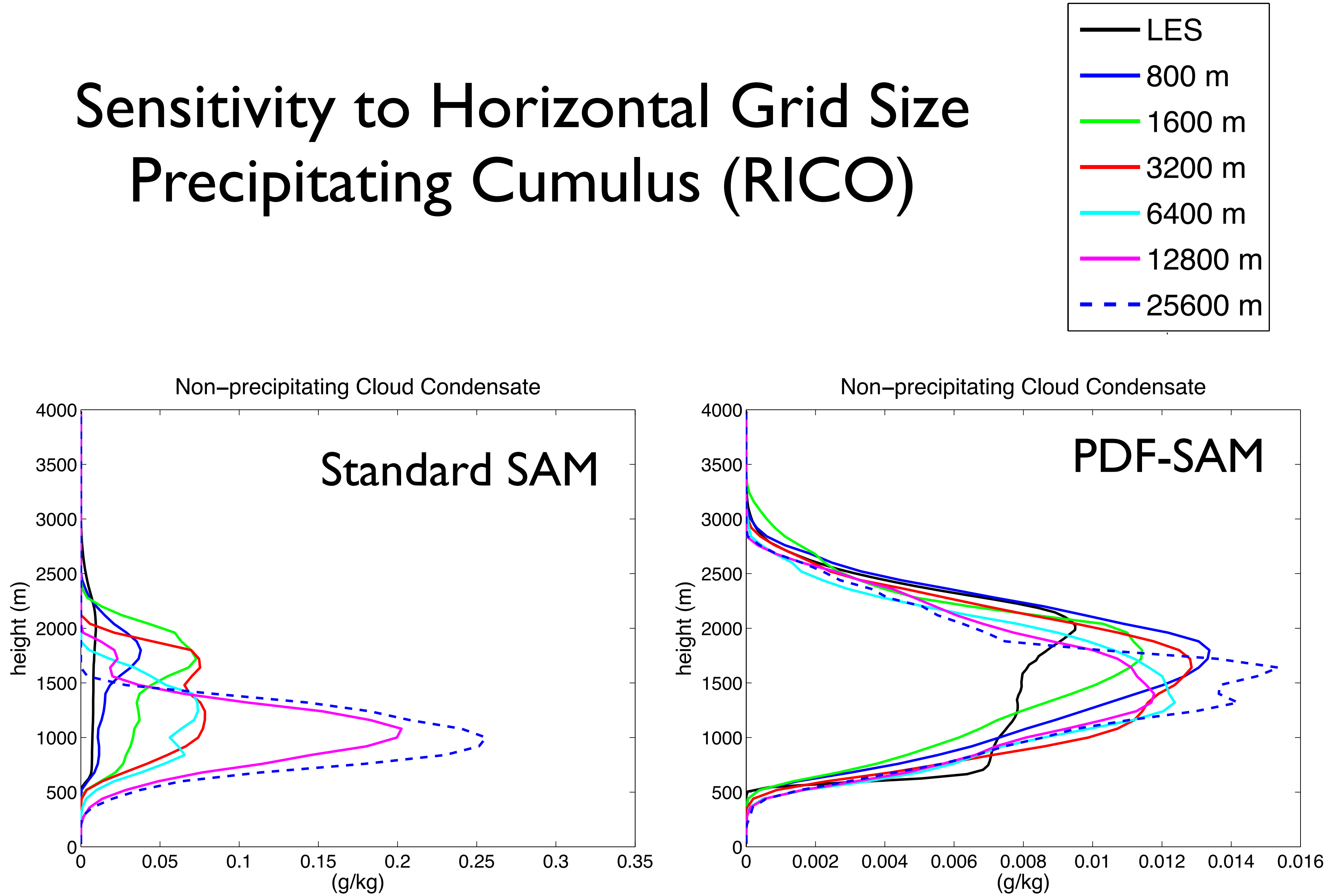

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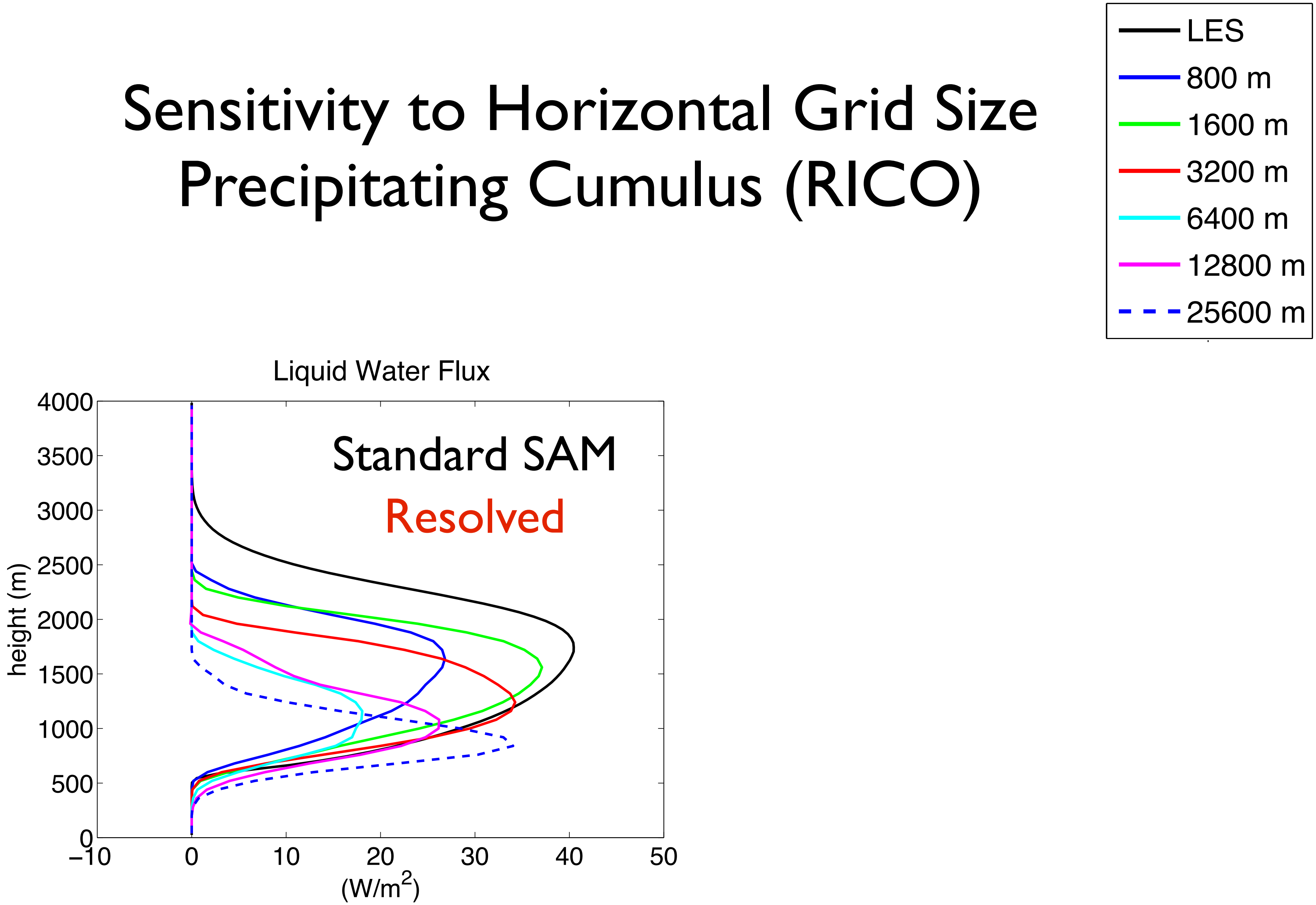

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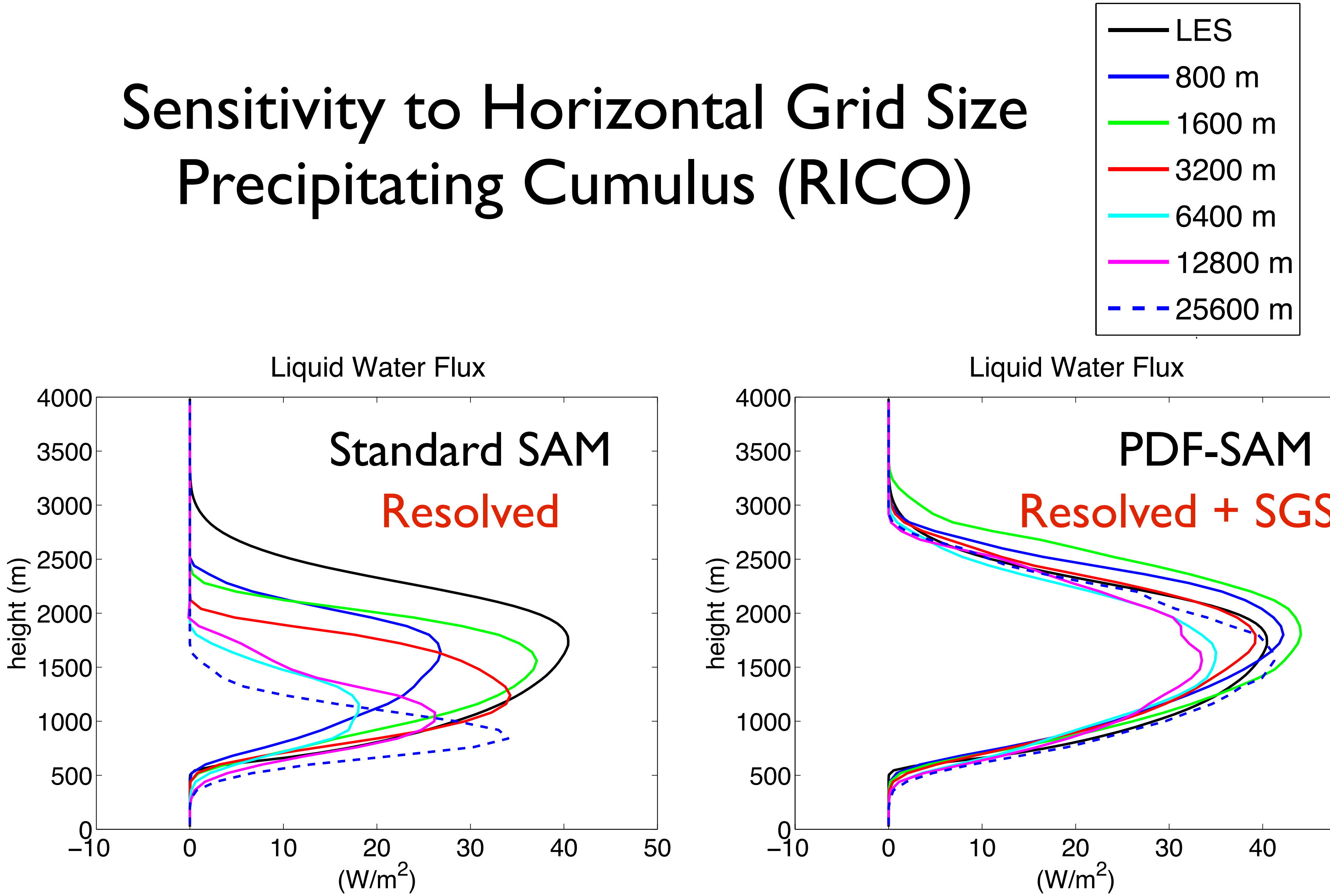

Summary

- It appears the simple diagnostic PDF-SAM closure can improve upon SAM
  - If appropriate amount of SGS TKE can be predicted, input moments can be realistically diagnosed
- PDF-SAM comparable results with Golaz et al. 2002
- Computational cost is kept comparable to standard SAM
- The real test: How does this scheme perform in the MMF (forthcoming)???
- Combine with other computationally cheap schemes that seek to improve SGS momentum fluxes etc.?