Cumulus ensemble simulation using a cloud resolving model: Impact of horizontal resolution

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Application of cloud resolving models

Cloud Resolving Model (CRM)

for improvement of existing parameterization?
for super-parameterization?
for global simulation?

Some questions:
• Cloud properties
• Feedback to large-scale environment

2-D or 3-D
Horizontal & vertical resolution
Parameterizations in CRM
\[ dx = 2 \text{ km} \& dx = 5 \text{ km} \]

(Radiative-convective equilibrium simulation)

Cloud Water & Rain Water [0.001 g/Kg]
Wind and Vapor Mixing Ratio (500m)

Miura and Kimoto
dx = 2 km & dx = 5 km

5km Cloud: Bigger in size & Smaller in number
Motivation

$dx = 5 \text{ km}$

Systematic difference? (in a statistical sense)

$dx = 2 \text{ km}$

Process?

Convergence?
Experimental design

• Model: MRI-NPD NHM

• Resolution: \( dx = 5 \text{ km} \) (\( dt = 20 \text{ s} \)) & \( 2 \text{ km} \) (\( dt = 6 \text{ s} \))

\[ dz = 40 - 1120 \text{ m} \]

• Domain Size: 150 km x 150 km x 26400 m (3-D)

• Span: 45 days (30 days to attain equilibrium & 15 days to analyze)

• SST = 300 K

• Without large scale flow

• With radiation

• output interval = 5 min

Reference: Tompkins and Craig, 1999

LSF obscures Q1 and Q2 dependencies on resolution
Cloud lifetime

Clouds ($dx = 5\ km$): Longer lifetime
Bigger in size
Smaller in number

Precipitation lifetime (case: max $> 1.0\ mm/5\ min$)
Impact on larger-scale

Time- and domain-averaged “relative humidity”

\[ dx = 5\text{km}: \]

Drier in the middle to the upper troposphere
Cloud mass flux

Time-averaged “cloud mass flux”  (Cloudy grid: $q_{\text{water or ice}} > 5.\text{e-3 g/kg}$)

Up & down: 2km > 5 km

Total upward:
2km < 5km
Cloud dilution

Time-averaged “cloud fraction”

Entrainment: 2km > 5km

5km < 2km

2km < 5km

Time- and domain-averaged “water mixing ratio” (in cloudy grid)

Horizontal or Vertical?
Horizontal inflow & outflow

In & out: 2km > 5km

Total: 5km ~ 2km

Horizontal convergence

Cloud fraction

Cloud dilution

2km > 5km

Time-averaged “inflow & outflow” (in: clear grids → cloudy grids)

NB: cloud expansion effect ignored
Vertical velocity

Time-averaged \( \mathbf{w} \) in convective core
\( (|\mathbf{w}| > 1 \text{m/s}) \)

Upward, downward \( \mathbf{w} \): 2km > 5km

Entrainment (cloud top):
2km > 5km

Cloud fraction:

Cloud dilution:
2km > 5km

Emannuel (1994)
Heating in clear grids

Time- and domain-averaged “heating rate by advection”
(cloud free grids)
Summary

- RH (domain average): 2km > 5km (middle to upper troposphere)
- Systematic difference:
  - Coarser resolution → Weaker entrainment
  - Larger cloud mass flux (Weaker downdraft in cloudy grids)
  - Larger downward mass flux (cloud free grids)
  - Lower RH
- Convergence?
  - $dx = 2\text{km}$?
  - $dx = 1\text{km}$?
  .........
Appendix
Convective mass flux

Convective: $q > 1.0 \times 10^{-5} \ \text{g/kg} \ & \ |w| > 1 \ \text{m/s}$

Core area: $2 \ \text{km} < 5 \ \text{km}$ ?
Difference of mass flux

Mass Flux: Clear (5km – 2km)

Height (m)

Mass Flux (kg/m**2/s)
Equilibrium?  

Heating rate  
(adv + microphysics)  

Moistening rate  
(adv + microphysics)