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
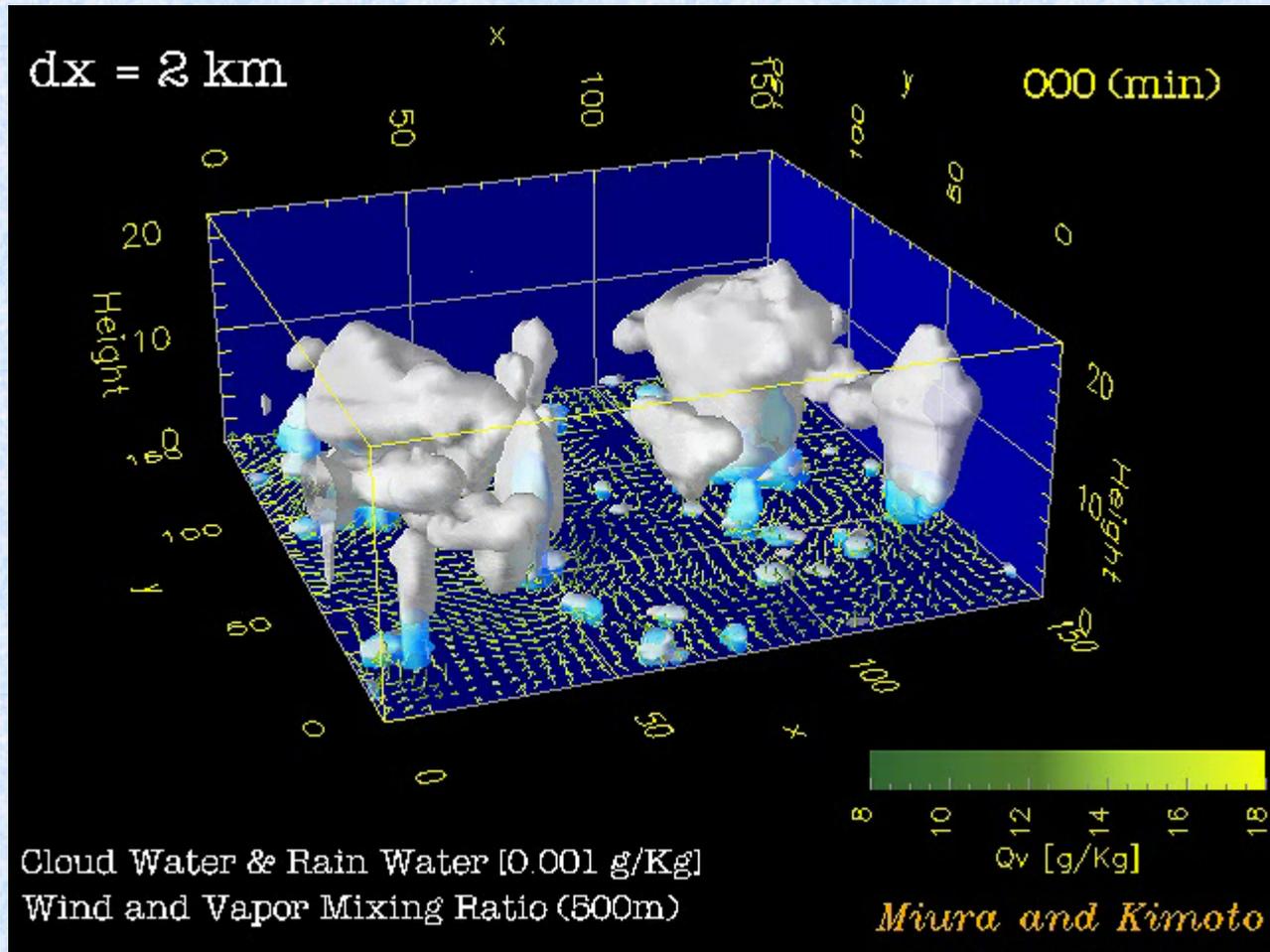
- Feedback to large-scale environment

?

2-D or 3-D
Horizontal & vertical resolution
Parameterizations in CRM

dx = 2 km & dx = 5 km

(Radiative-convective equilibrium simulation)

dx = 2 km & dx = 5 km

5km Cloud: Bigger in size & Smaller in number

Motivation

dx = 5 km

Systematic difference ? (in a statistical sense)

dx = 2 km

Process ?

Convergence ?

Experimental design

- Model: MRI-NPD NHM

- Resolution: dx = 5 km (dt = 20 s) & 2 km (dt = 6 s)

  dz = 40 − 1120 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)

  Reference: Tompkins and Craig, 1999

- SST = 300 K

- Without large scale flow

- With radiation

- output interval = 5 min

LSF obscures Q1 and Q2 dependencies on resolution

Cloud lifetime

Precipitation (Time Series); 2 km

Precipitation (Time Series); 5 km

Precipitation (Time Series); Composite
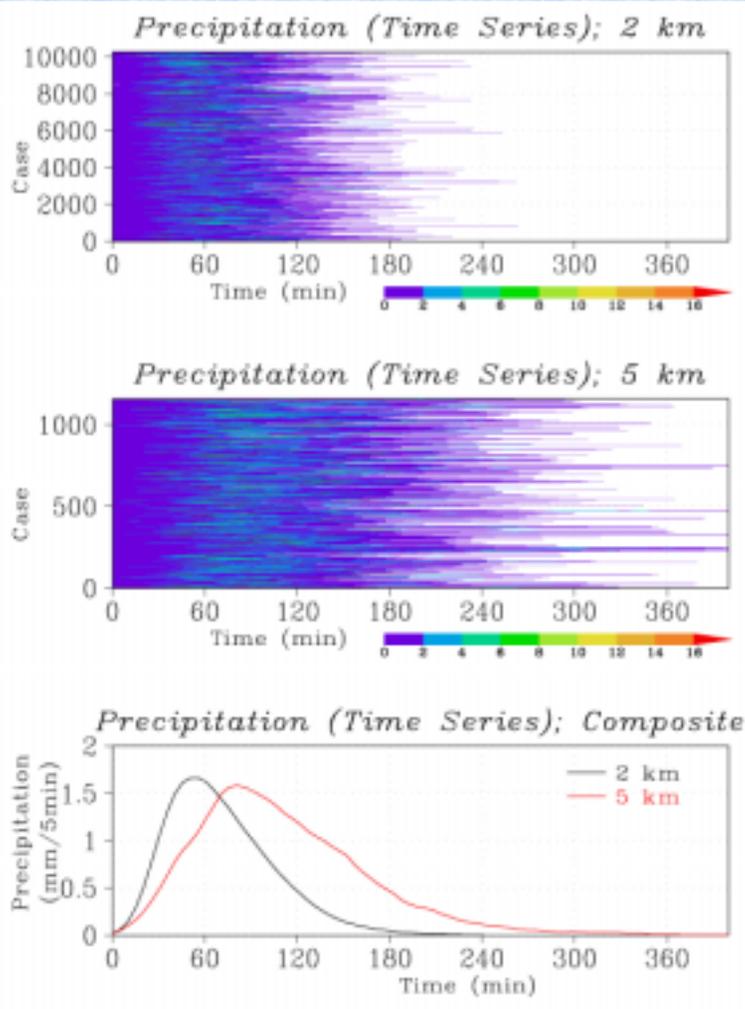
Clouds (dx = 5 km): Longer lifetime

Bigger in size

Smaller in number

2km
5km
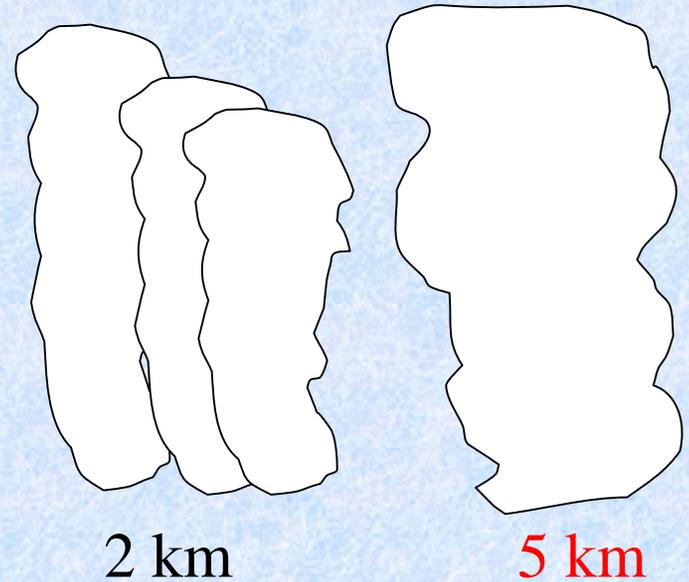
2 km   5 km

Precipitation lifetime (case: max > 1.0 mm/5min)

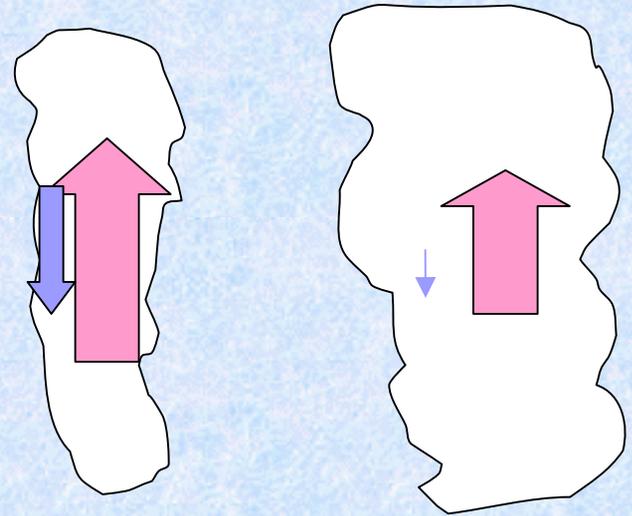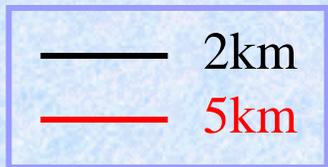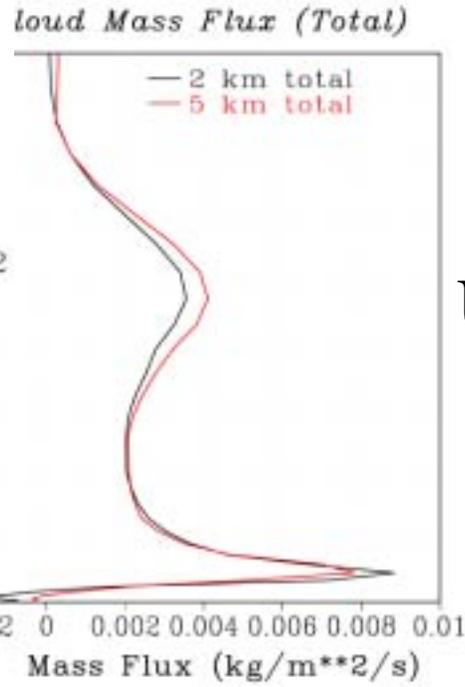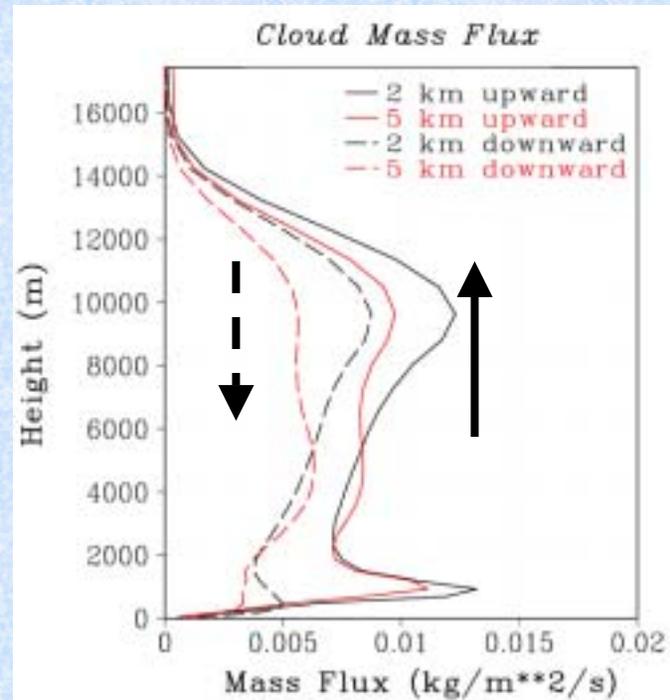# Impact on larger-scale

Time- and domain-averaged "relative humidity"
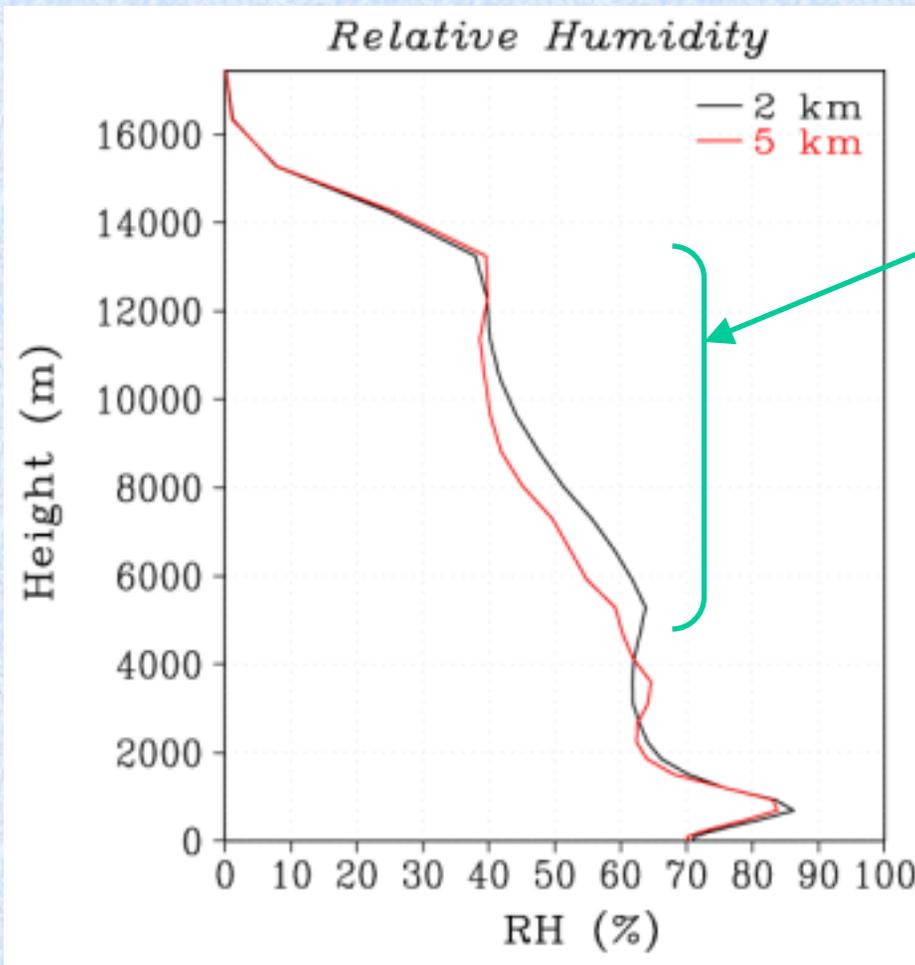
dx = 5km:
Drier in the middle to the upper troposphere

Cloud mass flux

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

Up & down: 2km > 5 km
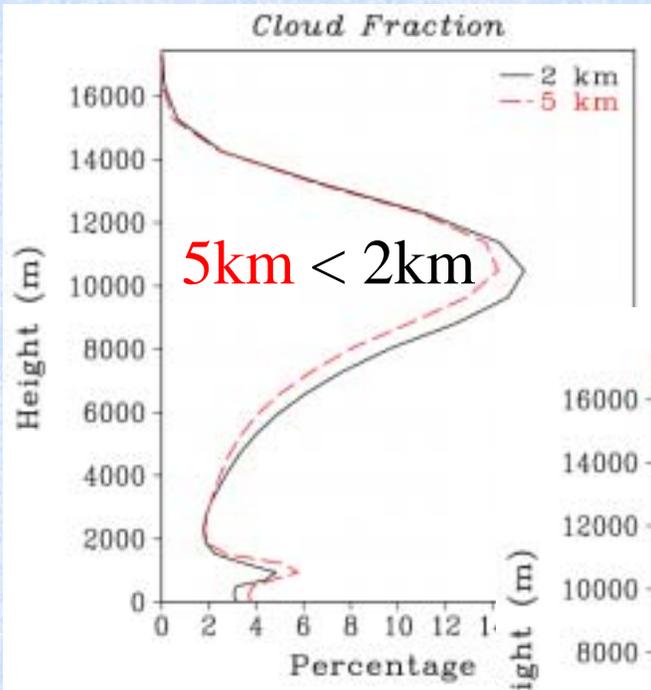
Total upward:
2km < 5km

Cloud dilution
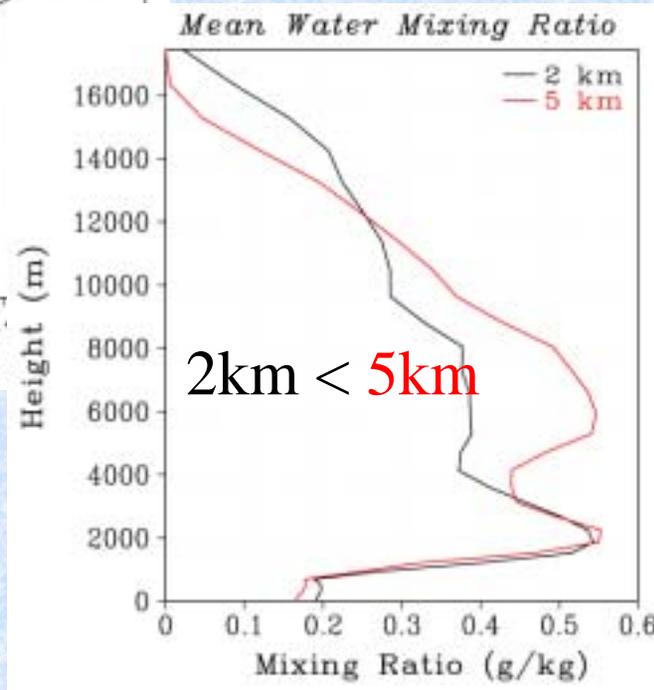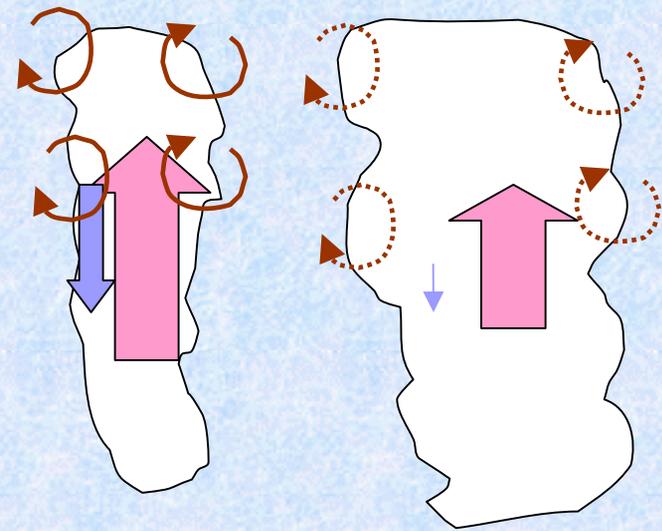
Time-averaged "cloud fraction"

Entrainment: 2km > 5km

5km < 2km

2km < 5km
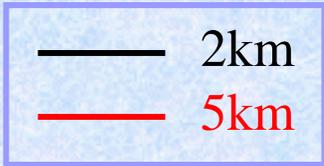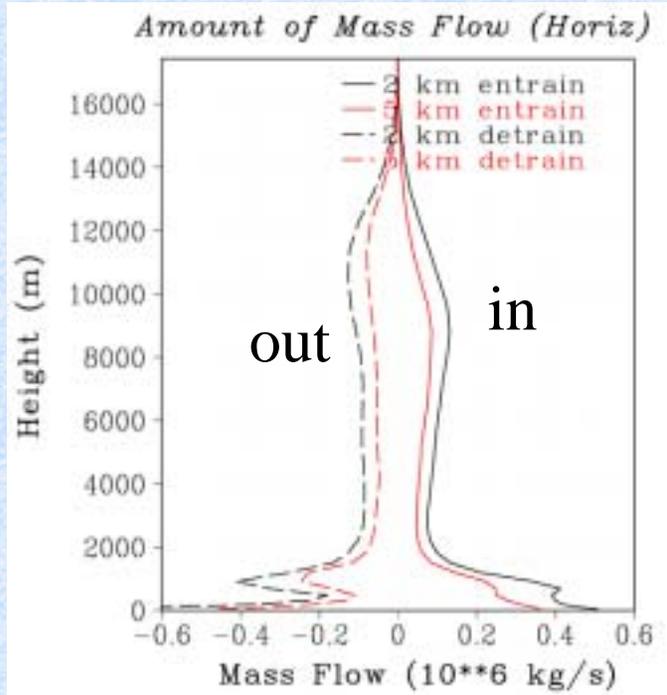
2km
5km

Horizontal or Vertical ?

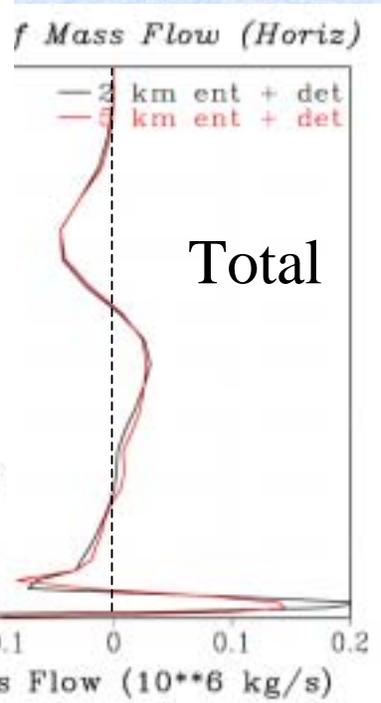Time- and domain-averaged "water mixing ratio" (in cloudy grid)

Horizontal inflow & outflow

Amount of Mass Flow (Horiz)

— 2 km entrain
— 5 km entrain
-- 2 km detrain
-- 5 km detrain

out   in

Height (m)

Mass Flow (10**6 kg/s)

2km
5km

— 2 km ent + det
— 5 km ent + det

Total

Mass Flow (10**6 kg/s)

In & out: 2km > 5km

Total: 5km ~ 2km

Horizontal convergence

Cloud fraction

Cloud dilution
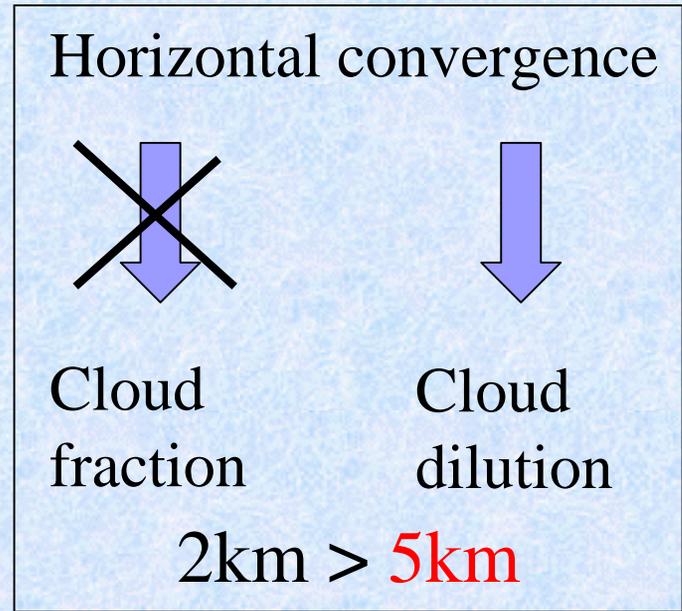
2km > 5km

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

NB: cloud expansion effect ignored

Vertical velocity

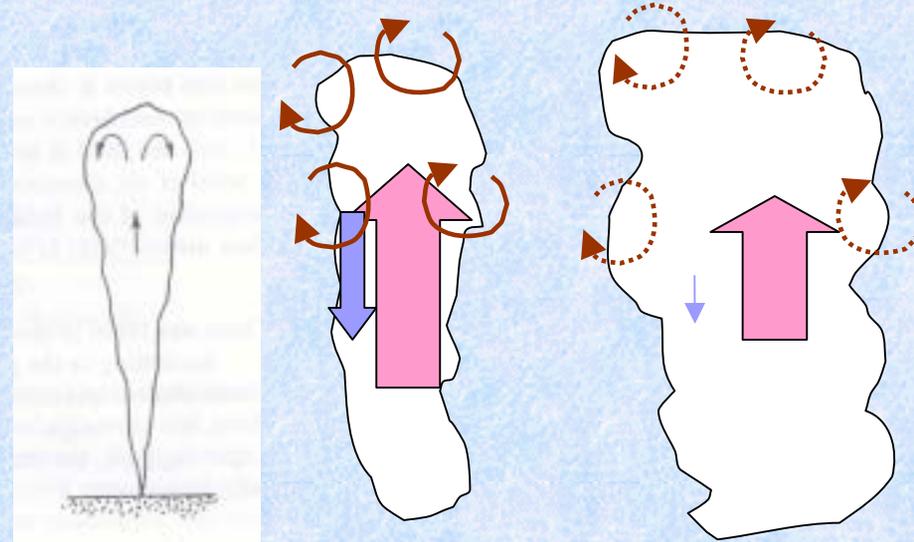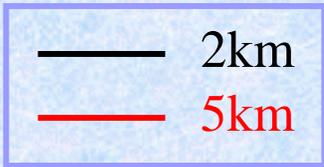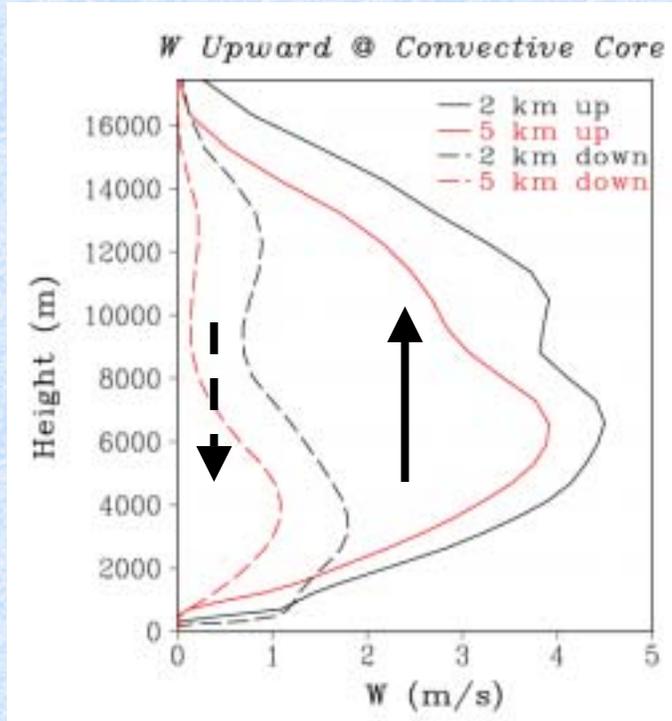W Upward @ Convective Core

Time-averaged "w" in convective core

(|w| > 1m/s)

Upward, downward w: 2km > 5km

? → Entrainment (<u>cloud top</u>):

2km > 5km

Legend:
2km
5km

Cloud fraction:
Cloud dilution:

2km > 5km

Emannuel (1994)

Heating in clear grids

Heating Rate: Clear

— 2 km adv
— 5 km adv

Height (m)

2km < 5km

Heating (K/Day)

Cloud mass flux

2km < 5km

Downward
mass flux

2km < 5km

2km
5km
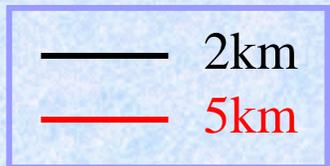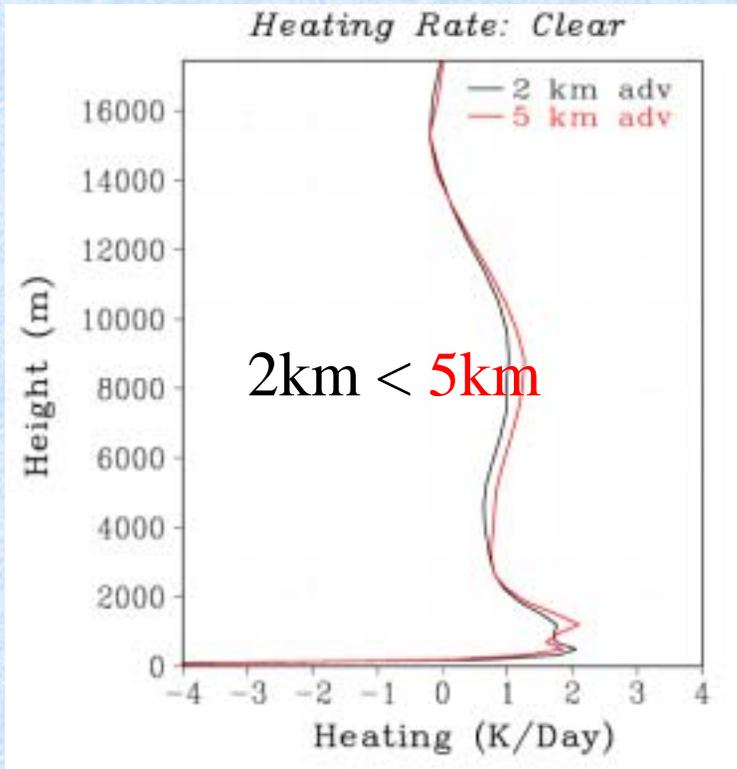
Time- and domain-averaged
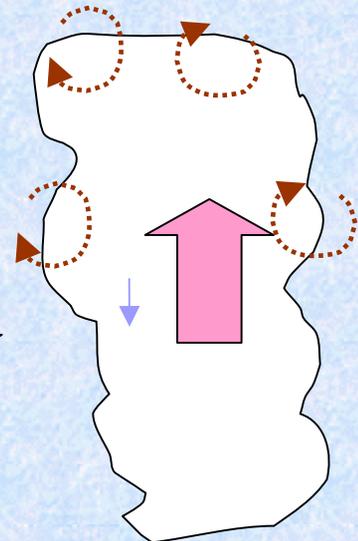"heating rate by advection"

(cloud free grids)

Summary

- RH (domain average): 2km > 5km (middle to upper troposphere)

- Systematic difference:

Coarser resolution ⟶ Weaker entrainment

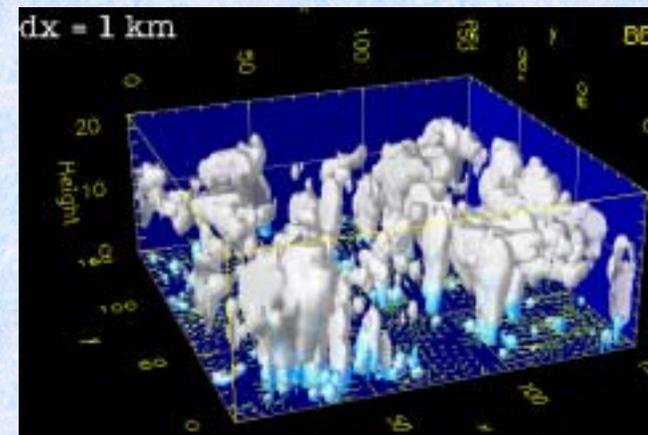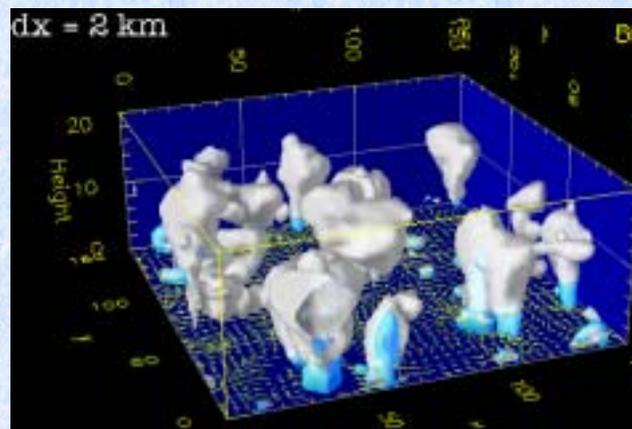Larger cloud mass flux (Weaker downdraft in cloudy grids) ⟶ Larger downward mass flux (cloud free grids)
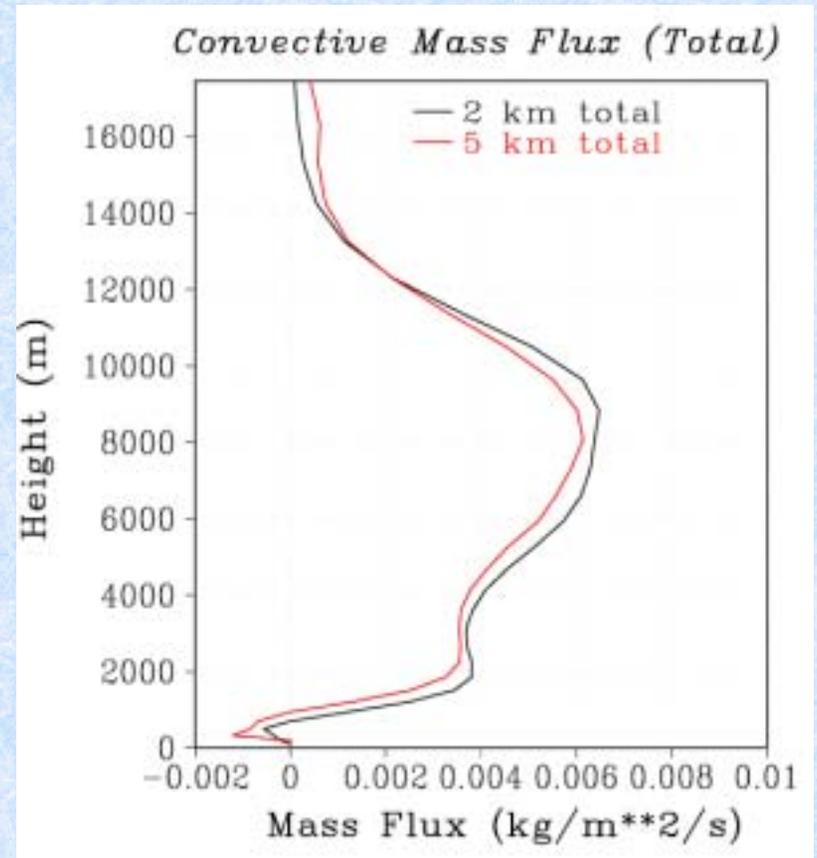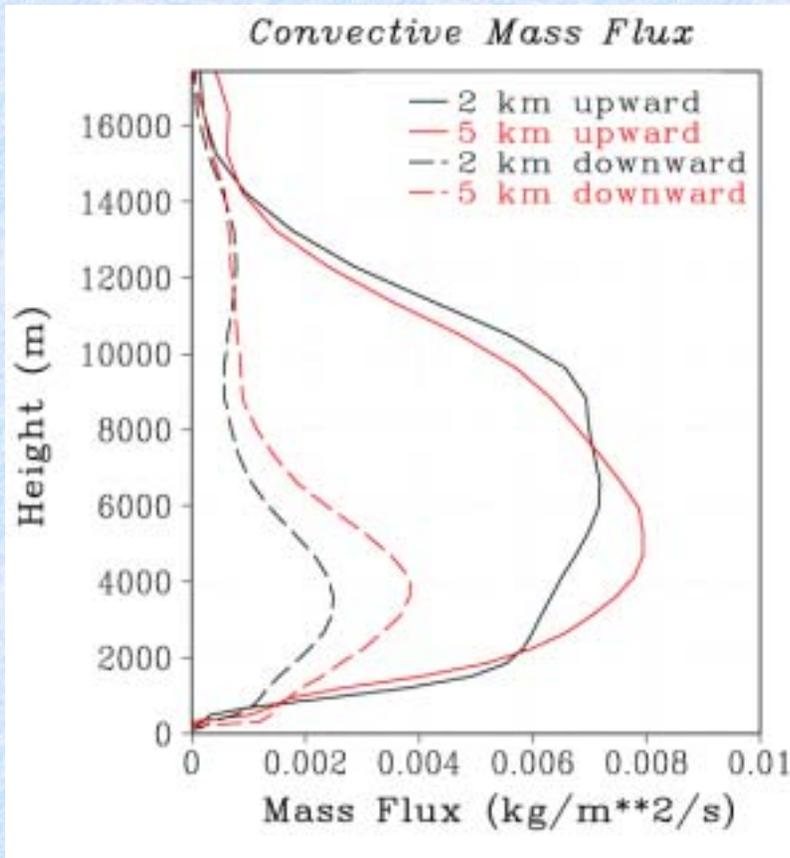
Lower RH

- Convergence ?
  dx = 2km ?
  dx = 1km ?
  ………

Appendix

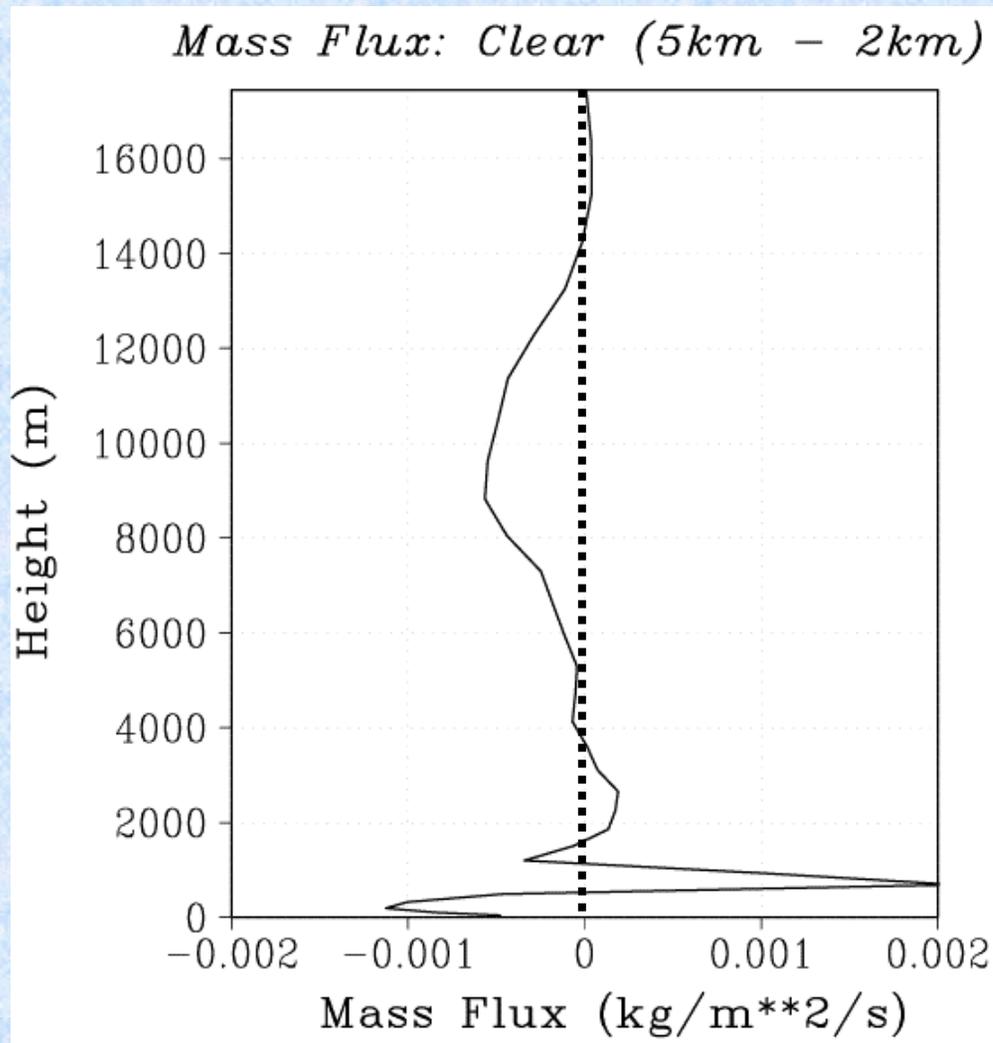# Convective mass flux

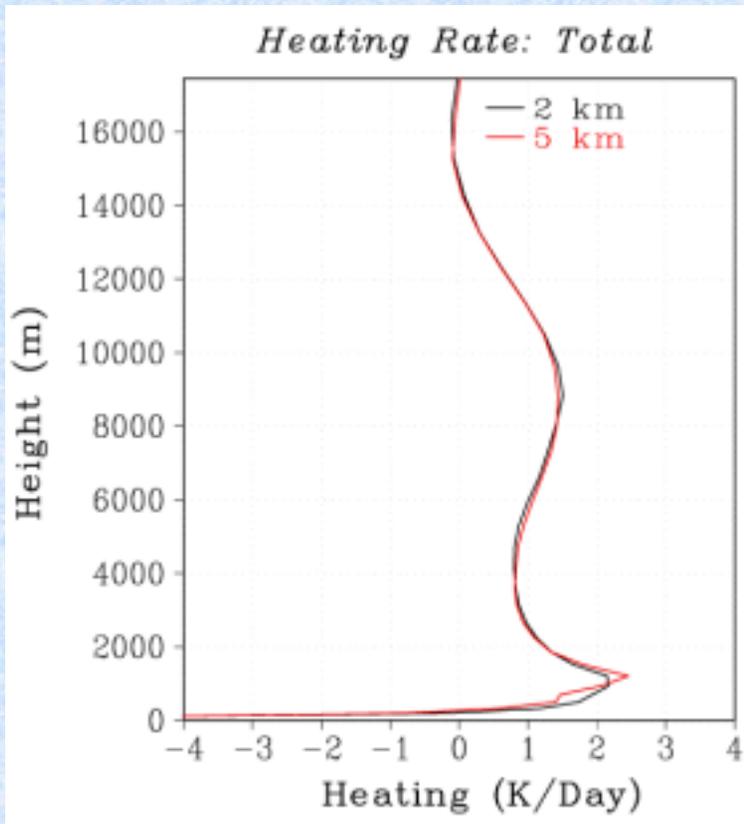Convective: q > 1.e-5 g/kg & |w| > 1 m/s
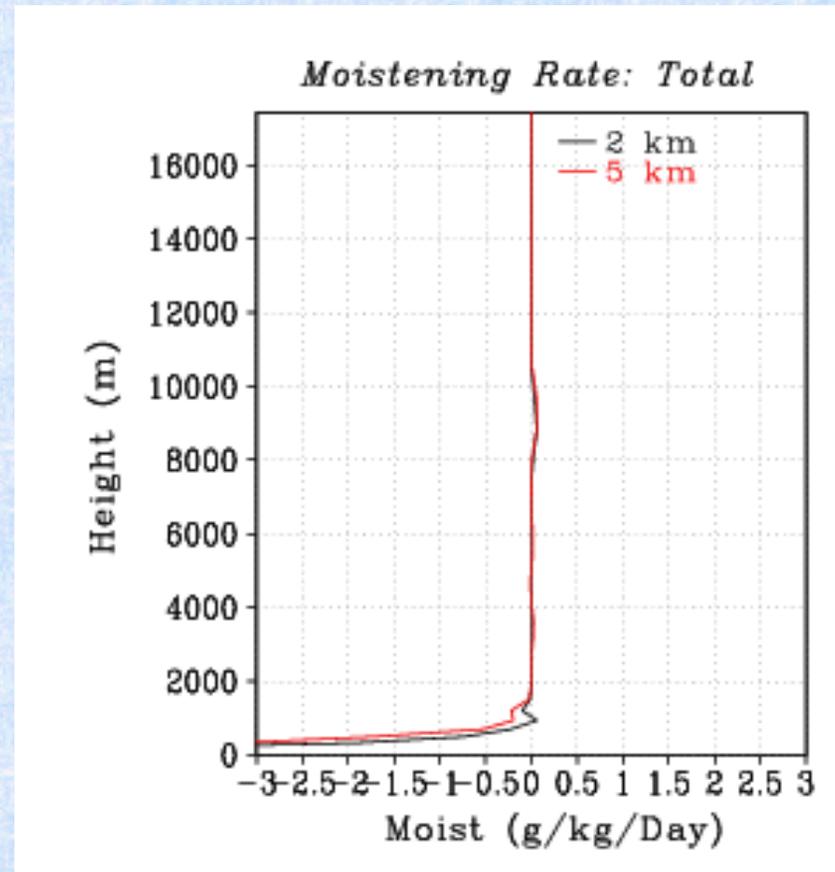

Core area: 2 km < 5 km ?

Difference of mass flux

Equilibrium ?

Heating rate
(adv + microphysics)

moistening rate
(adv + microphysics)