Estimation of subgrid scale processes using a cloud-resolving model

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Introduction

At Frontier Research System for Global Change, we are now developing

A new Nonhydrostatic Global Circulation Model

(Dr. Satoh's talk, on Friday)

aiming a breaking through of the cloud parameterization problem by

- **Resolving Clouds**
  - horizontal resolution _1 km (in future)
- **Resolve Mesoscale Convective Systems**
  - horizontal resolution 5_30 km (at present)

search for proper cloud parameterization

Motivation

horizontal resolution: 5_30 km

- **Scale-sparation : unclear**
- **Quasi-equilibrium, Small cloud fraction : not proper**
- **Problem of Grid-resolved-condensation**

- **Re-examination of subgrid-scale effects**

---- especially, to resolve mesoscale systems ----

using an established nonhydrostatic model.

the Meteorological Research Institute/Numerical Prediction Division Unified Nonhydrostatic Model (MRI/NPD-NHM)

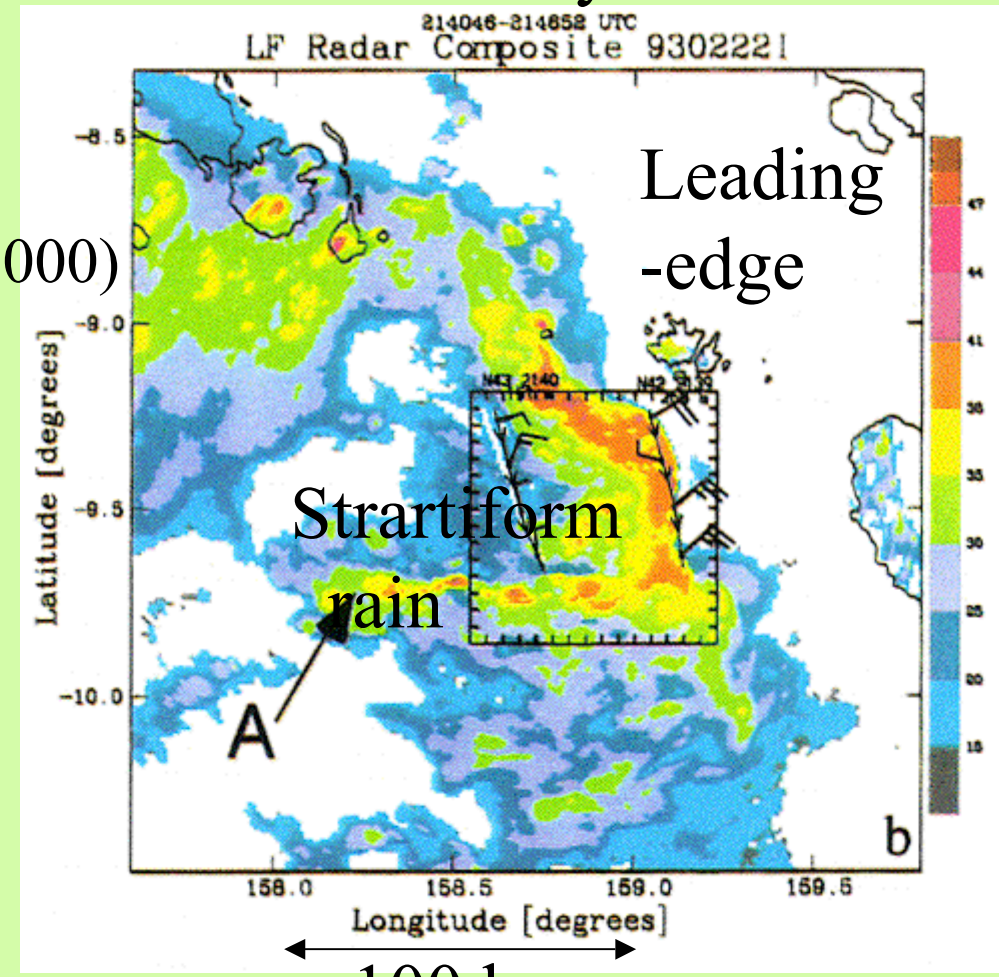
- Fully compressible
- Ice microphysics; Ikawa et al. (1991)
- Turbulence; Deardorff (1980)
- Surface Flux; Kondo (1975)
- Cloud interactive Radiation; Sugi et al. (1990)

(Dr. Saito's and Mr.Miura's talks on Wednesday)

Tropical Squall Line
--- GCSS WG4 Case1
Redelsperger et al.(2000)
TOGA COARE (1993/2/22)
Horizontal Resolution:
1.5, 2.5, 3.75, **5**, 7.5 km

Comparison of Convective Behavior to estimate Subgrid-scale Effects
(Nasuno and Saito, 2003 Submitted to Mon.Wea.Rev.)

Radar Reflectivity



Jorgensen et al. (1997)

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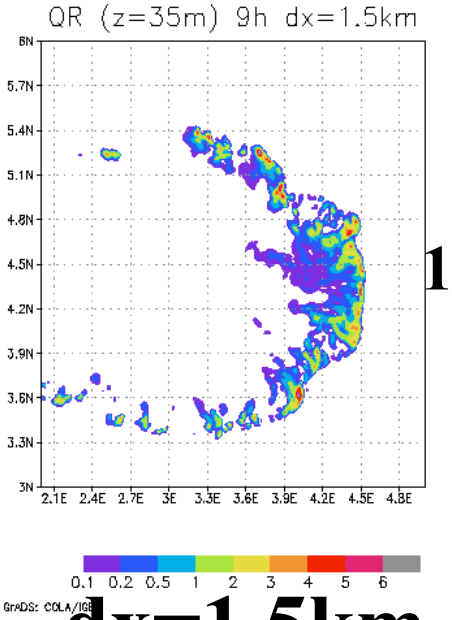
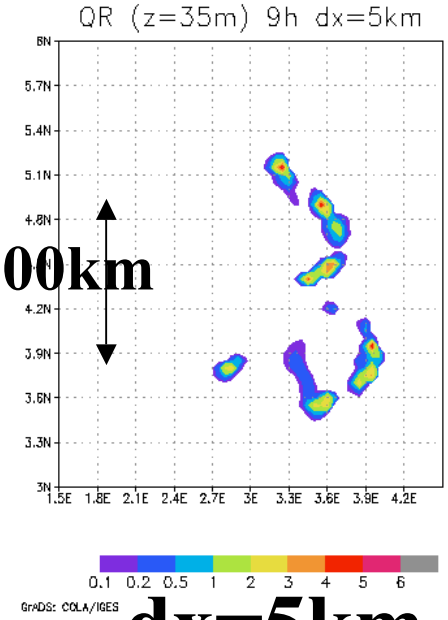
Rainwater (z=35m)

9h





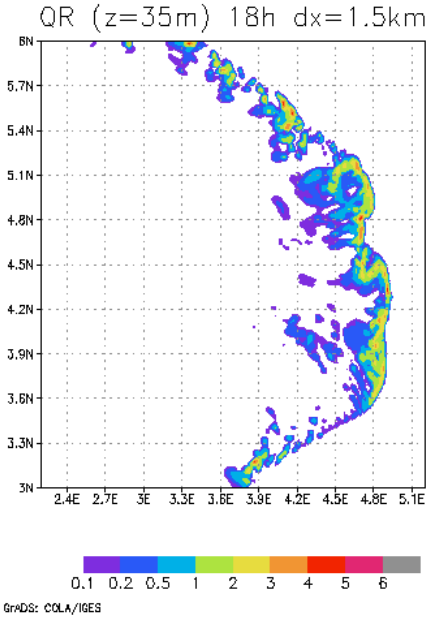
100km

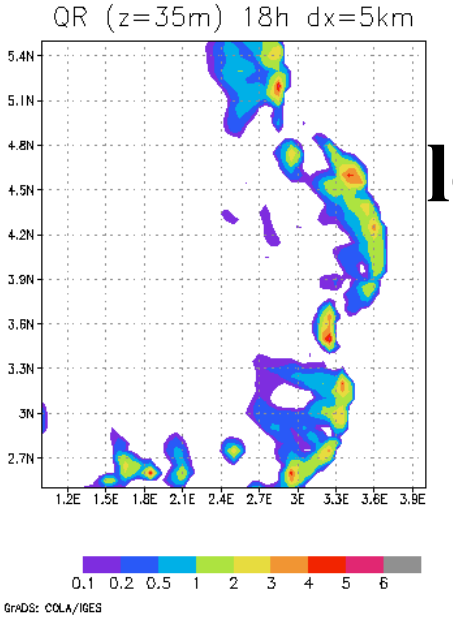
discrete cell

dx=1.5km

dx=5km

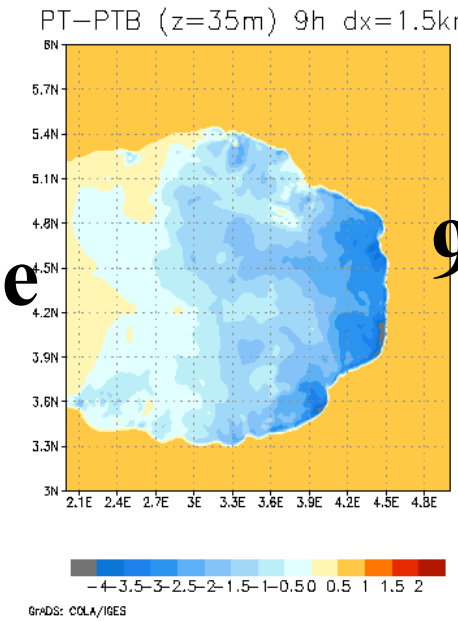
18h



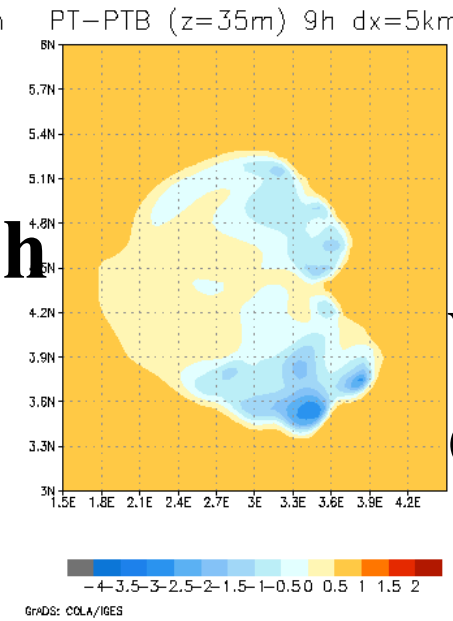


local peak

Potential temperature deviation (z=35m)

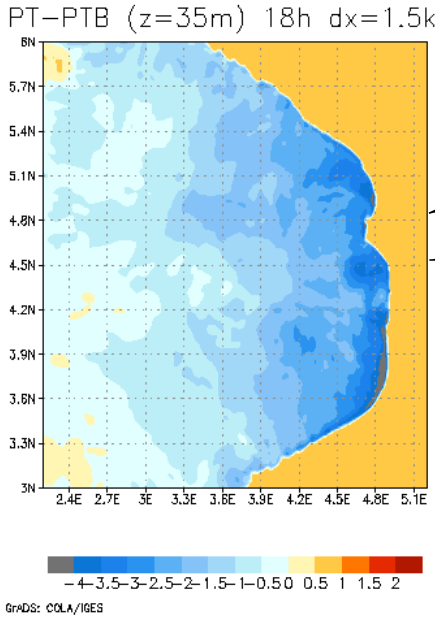


9h

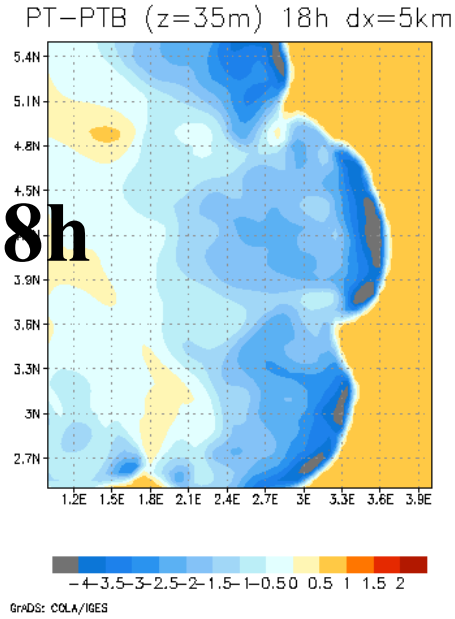


Weak Cold Pool

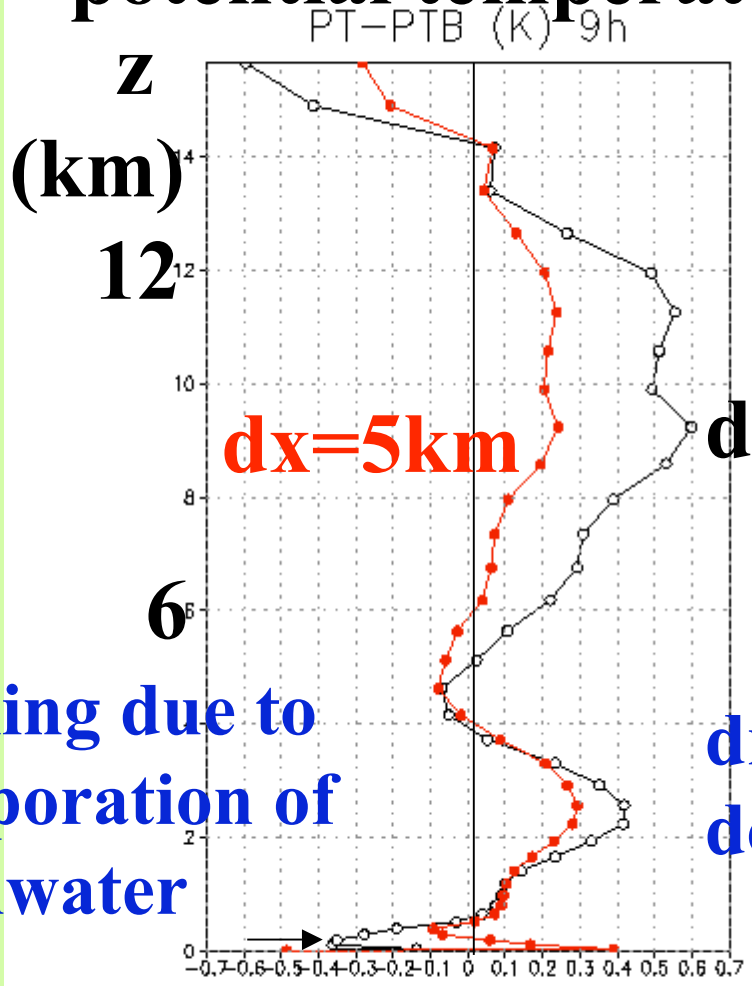
dx=1.5km **dx=5km**



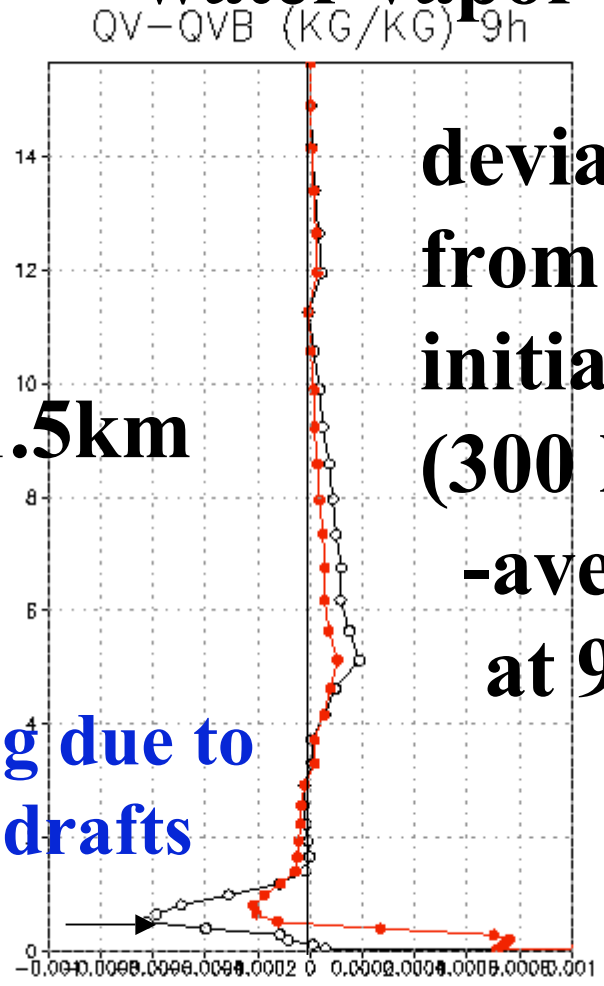
18h



potential temperature



water vapor



dx=5km

dx=1.5km

deviations from the initial state (300 km2 -average) at 9h

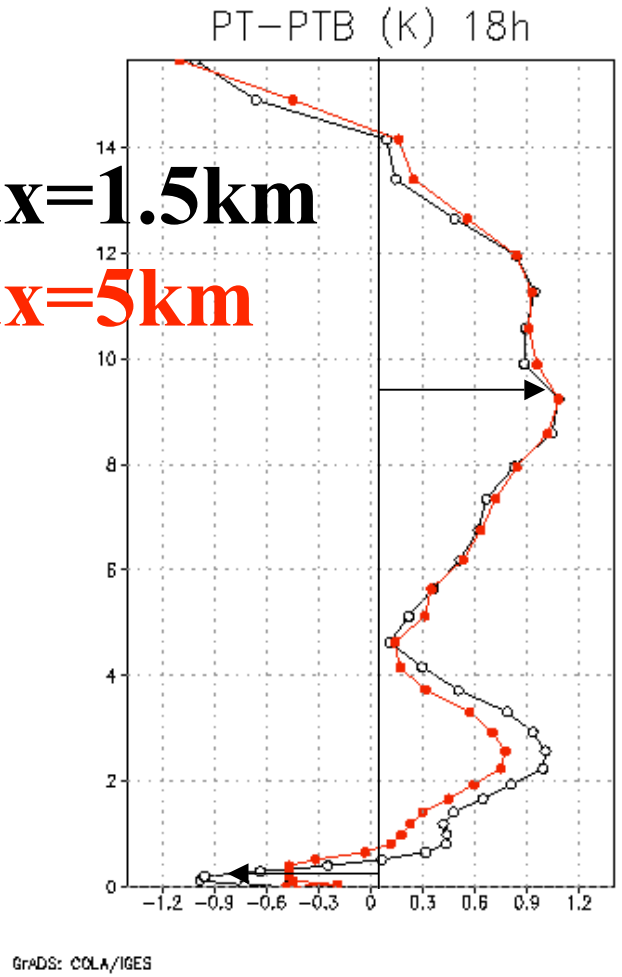
cooling due to evaporation of rainwater

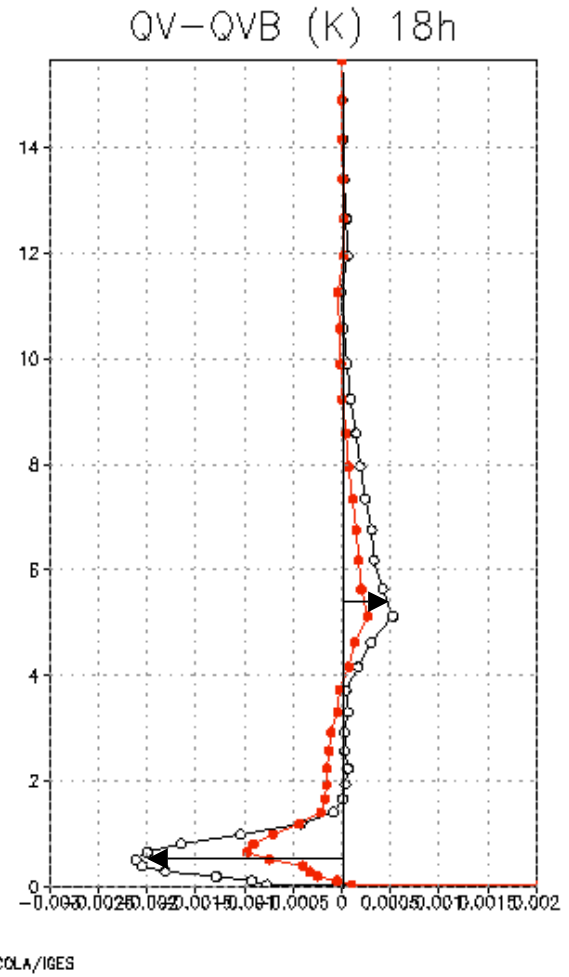
drying due to downdrafts

Stabilization by convection

dx=1.5km

dx=5km





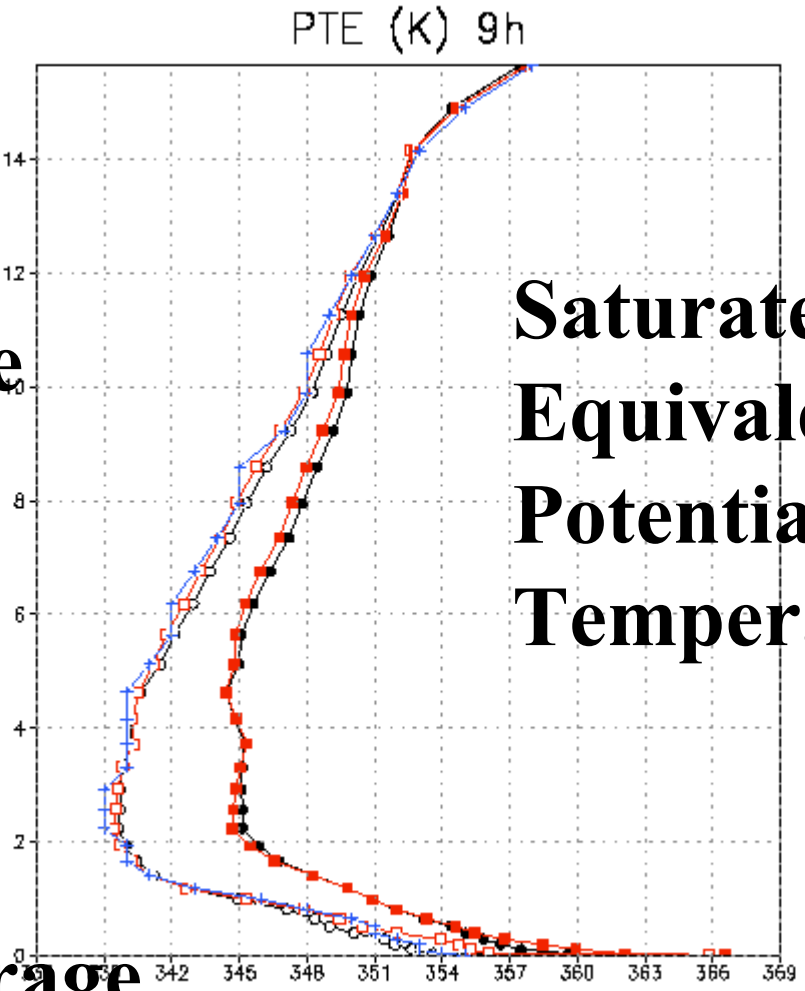
Equivalent Potential Temperature

Initial

dx=1.5km

dx=5km

300km2-average



Saturated Equivalent Potential Temperature

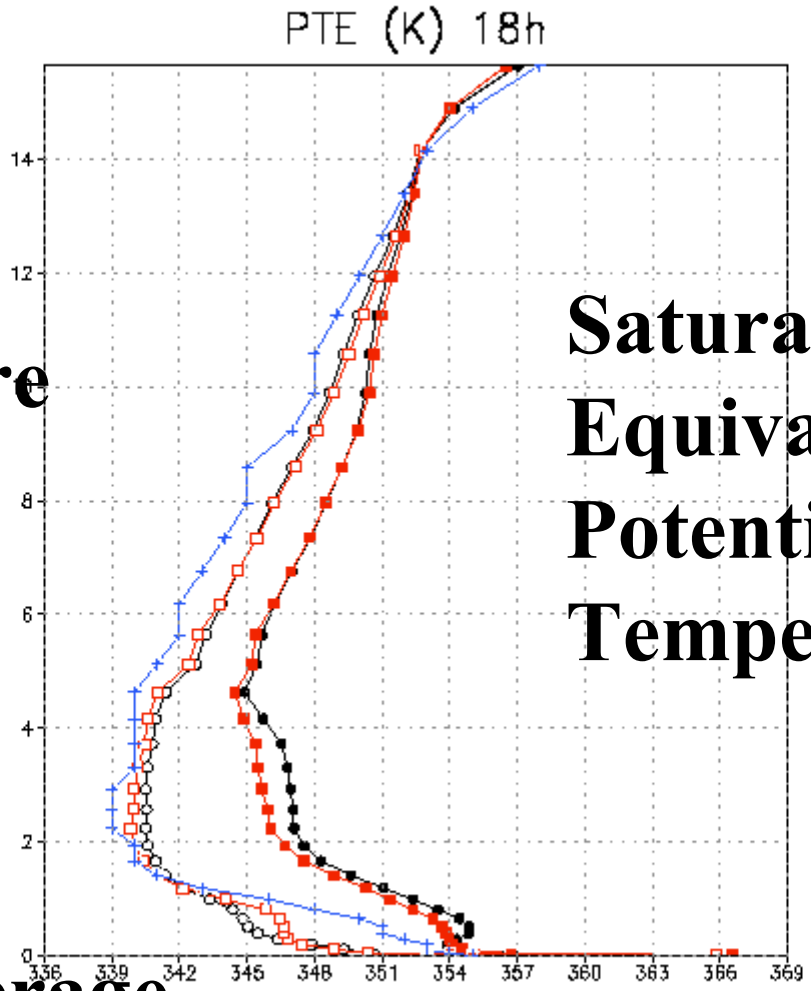
Equivalent Potential Temperature

Initial

dx=1.5km

dx=5km

300km2-average



Saturated Equivalent Potential Temperature

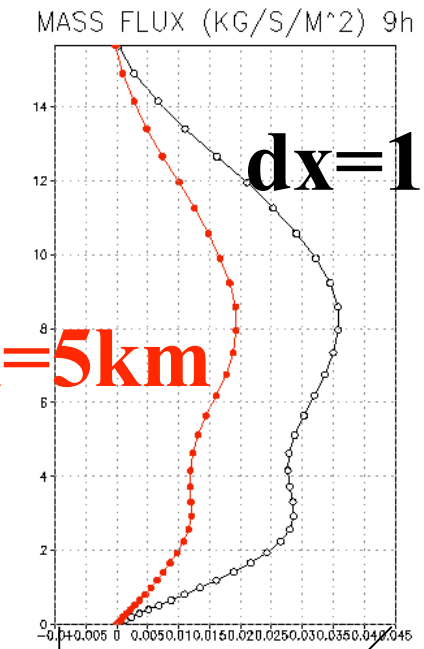
Mass flux

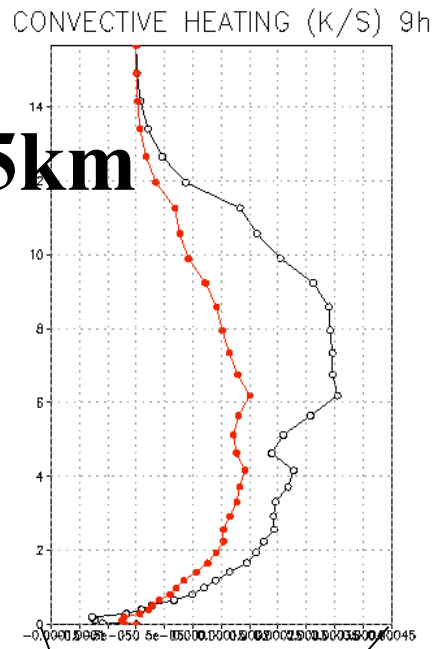
Convective heating

dx=1.5km

dx=5km

9h



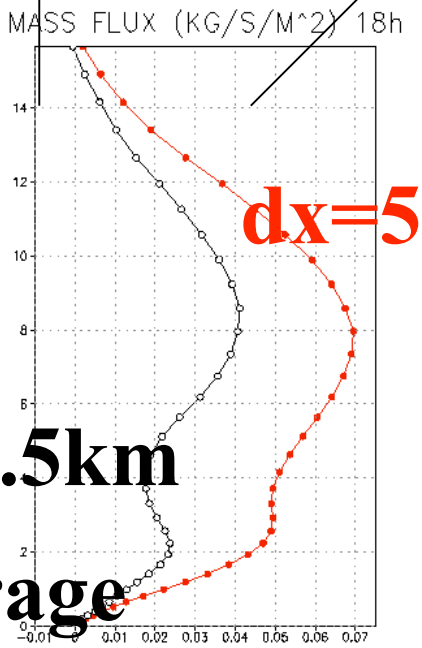


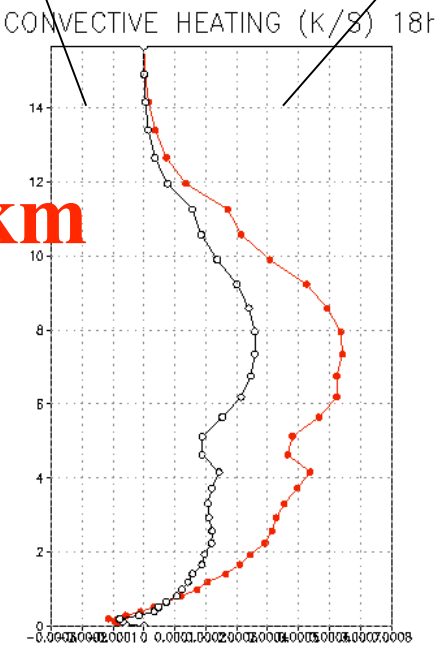
18h

dx=5km

dx=1.5km

300km2-average





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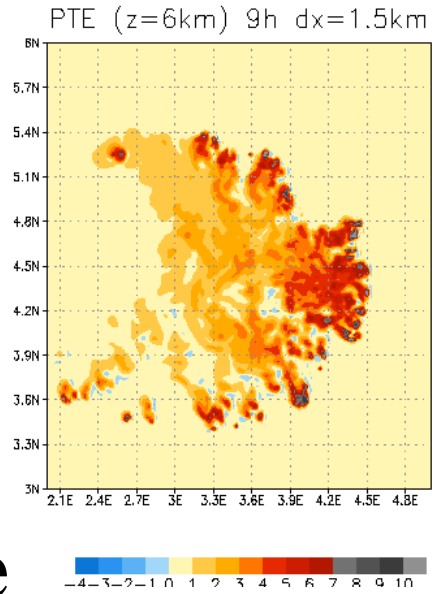
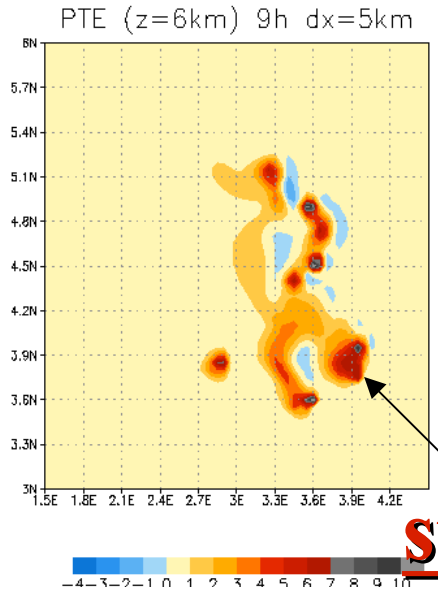
Equivalent potential temperature deviation

z=6km

9h





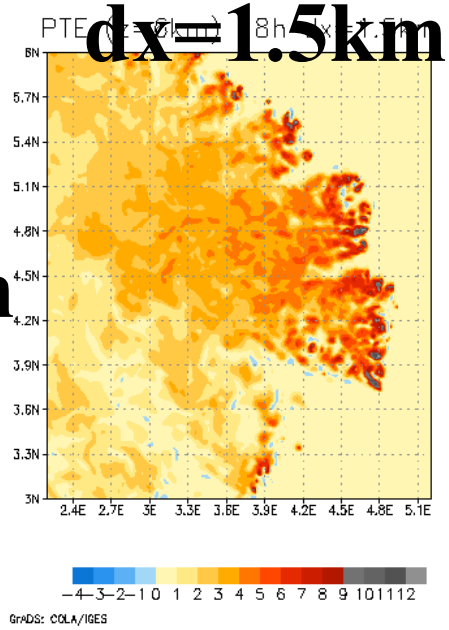
fewer clouds

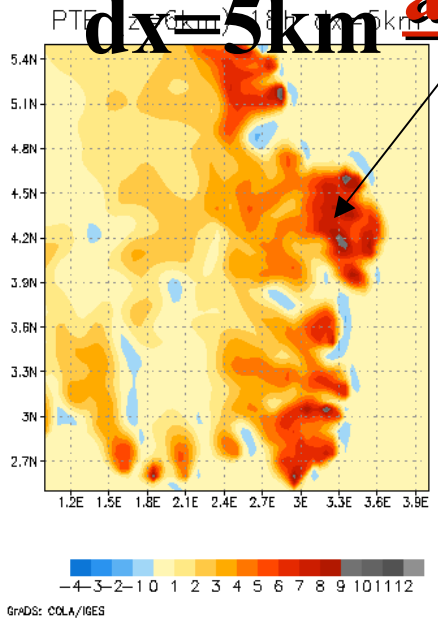
stabilization at a local area

dx=1.5km

dx=5km

18h





over-stabilization

Climate Model

At a coarse resolution

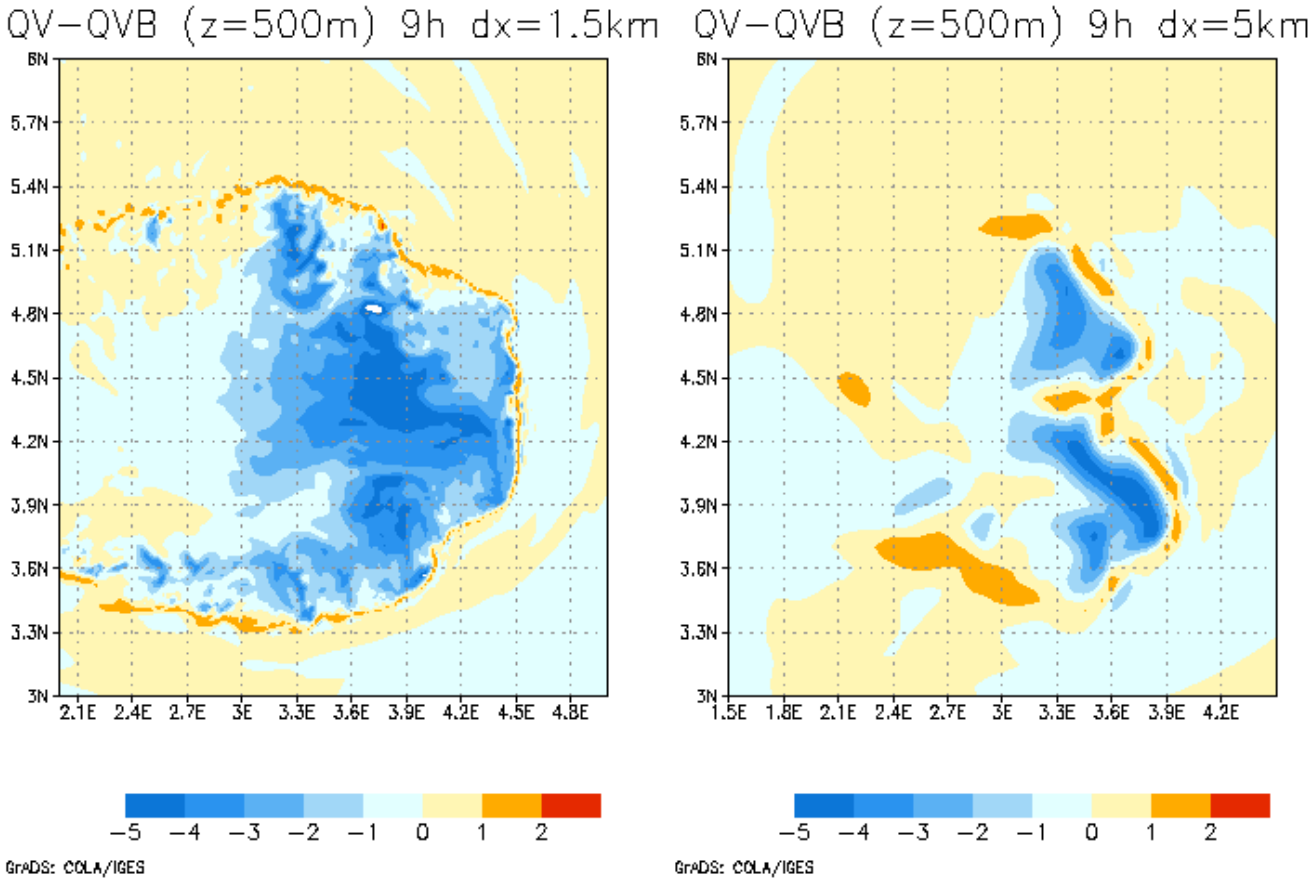
- **Fewer clouds causes**
  - **weak cold pool → less organization**
  - **less heat release**

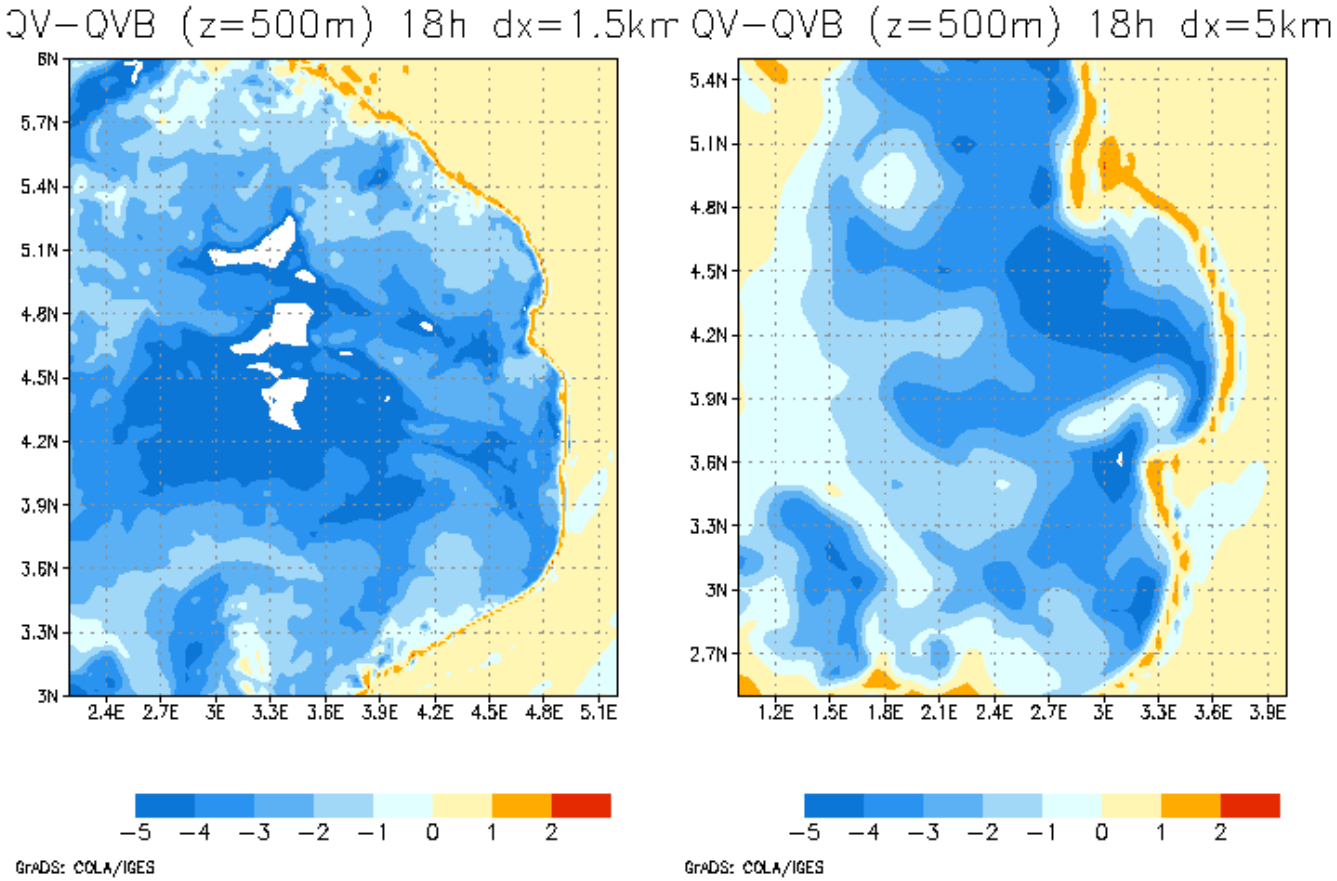
→ instability remains in a vast domain

→ accumulation of moisture in the boundary layer

→ when heat release begins, vigorous convection abruptly removes the instability (huge mass flux, convective heating)

➢ **the range of the variation in stability is larger**


QV−QVB (z=500m) 9h dx=1.5km
6N
5.7N
5.4N
5.1N
4.8N
4.5N
4.2N
3.9N
3.6N
3.3N
3N
2.1E 2.4E 2.7E 3E 3.3E 3.6E 3.9E 4.2E 4.5E 4.8E
−5 −4 −3 −2 −1 0 1 2
GrADS: COLA/IGES
QV−QVB (z=500m) 9h dx=5km
6N
5.7N
5.4N
5.1N
4.8N
4.5N
4.2N
3.9N
3.6N
3.3N
3N
1.5E 1.8E 2.1E 2.4E 2.7E 3E 3.3E 3.6E 3.9E 4.2E
−5 −4 −3 −2 −1 0 1 2
GrADS: COLA/IGES


QV−QVB (z=500m) 18h dx=1.5km
6N
5.7N
5.4N
5.1N
4.8N
4.5N
4.2N
3.9N
3.6N
3.3N
3N
2.4E 2.7E 3E 3.3E 3.6E 3.9E 4.2E 4.5E 4.8E 5.1E
−5 −4 −3 −2 −1 0 1 2
GrADS: COLA/IGES
QV−QVB (z=500m) 18h dx=5km
5.4N
5.1N
4.8N
4.5N
4.2N
3.9N
3.6N
3.3N
3N
2.7N
1.2E 1.5E 1.8E 2.1E 2.4E 2.7E 3E 3.3E 3.6E 3.9E
−5 −4 −3 −2 −1 0 1 2
GrADS: COLA/IGES

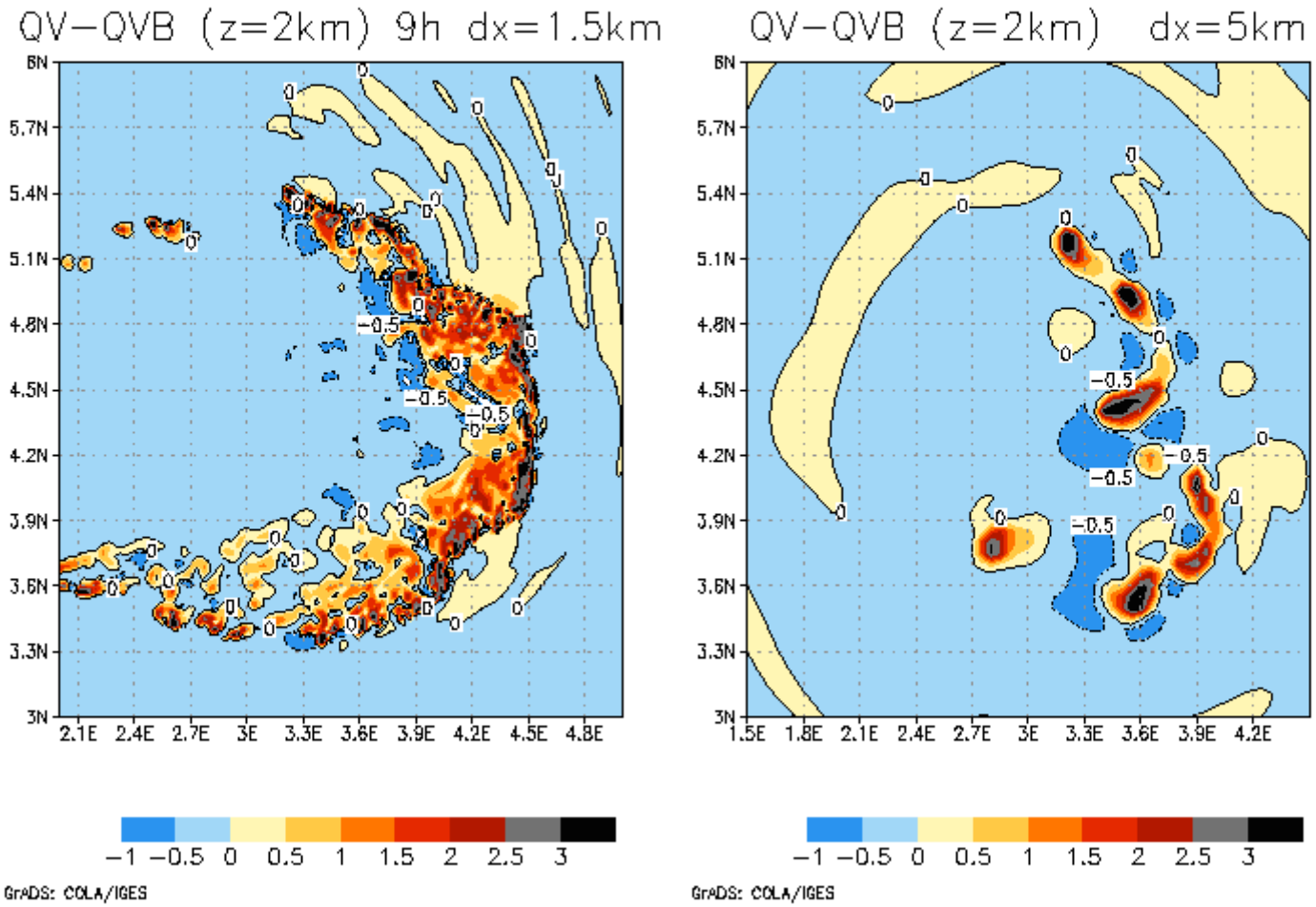
■ Why fewer clouds at a coarse resolution?

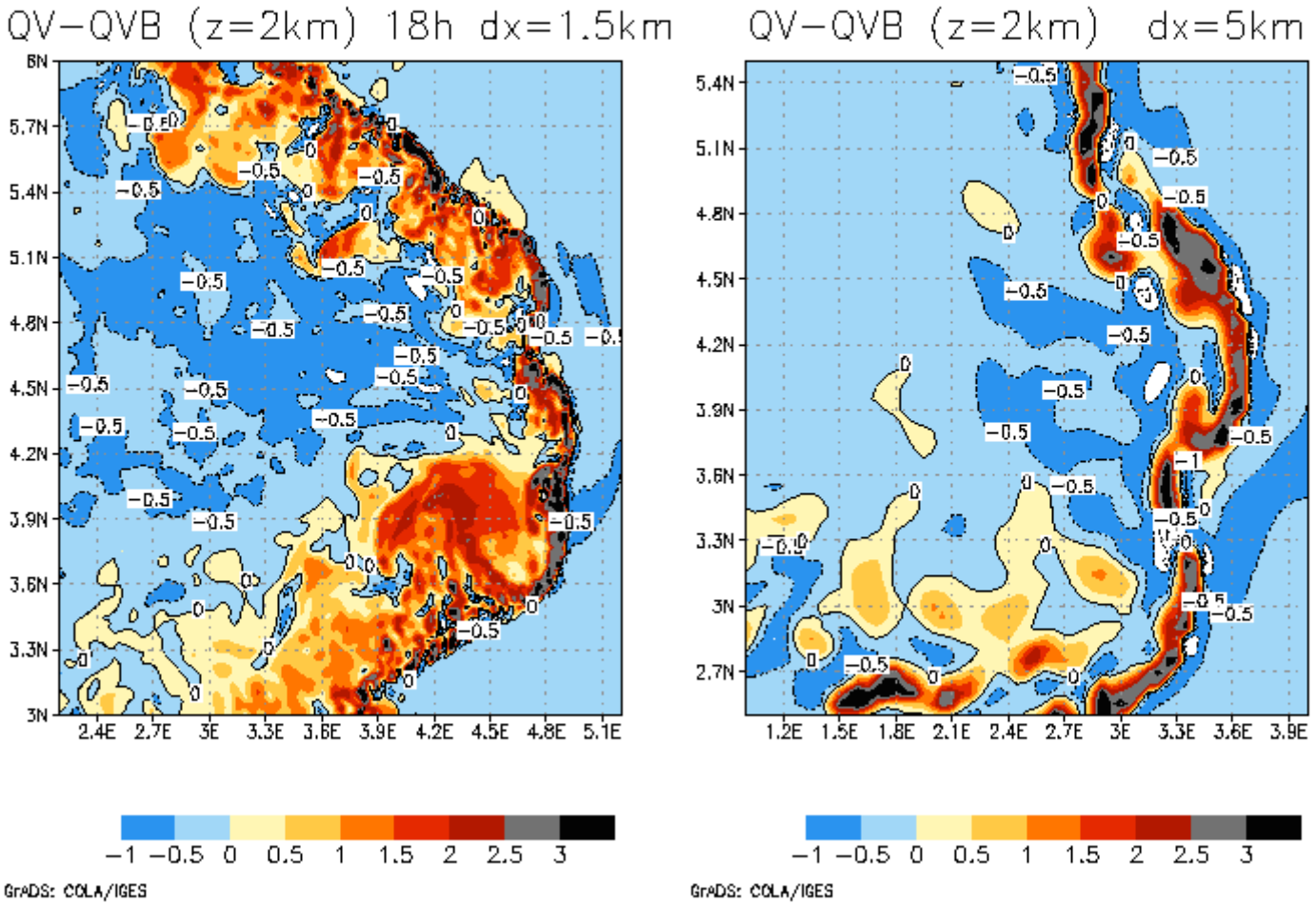
- **No heat release until grid-saturation**
- **Difficulty to get a positive buoyancy (updraft, heating) in the boundary layer to Break CIN**

➢ **Adiabatic cooling vs. Convective heating**

- **Inhibition by strong local drying by subsidence**

➢ **Cloud formation processes at a finer resolution (observation)**


QV−QVB (z=2km) 9h dx=1.5km
QV−QVB (z=2km) dx=5km
6N
5.7N
5.4N
5.1N
4.8N
4.5N
4.2N
3.9N
3.6N
3.3N
3N
2.1E 2.4E 2.7E 3E 3.3E 3.6E 3.9E 4.2E 4.5E 4.8E
1.5E 1.8E 2.1E 2.4E 2.7E 3E 3.3E 3.6E 3.9E 4.2E
−1 −0.5 0 0.5 1 1.5 2 2.5 3
GrADS: COLA/IGES


QV−QVB (z=2km) 18h dx=1.5km
QV−QVB (z=2km) dx=5km
−1 −0.5 0 0.5 1 1.5 2 2.5 3
GrADS: COLA/IGES

Suggestion to Future Parameterization

- **Proper representation of**
  - **subgrid-scale precipitation**
  - **the speed and range of stabilization**
  - **the initiation of convection (Dr.Suzuki's talk)**

  will surely improve current schemes.

cf. Yamasaki (1986, 2001)

→ **prediction of cloud water and rainwater**

→ **control heating rate and vertical profile as a function of low-level instability**

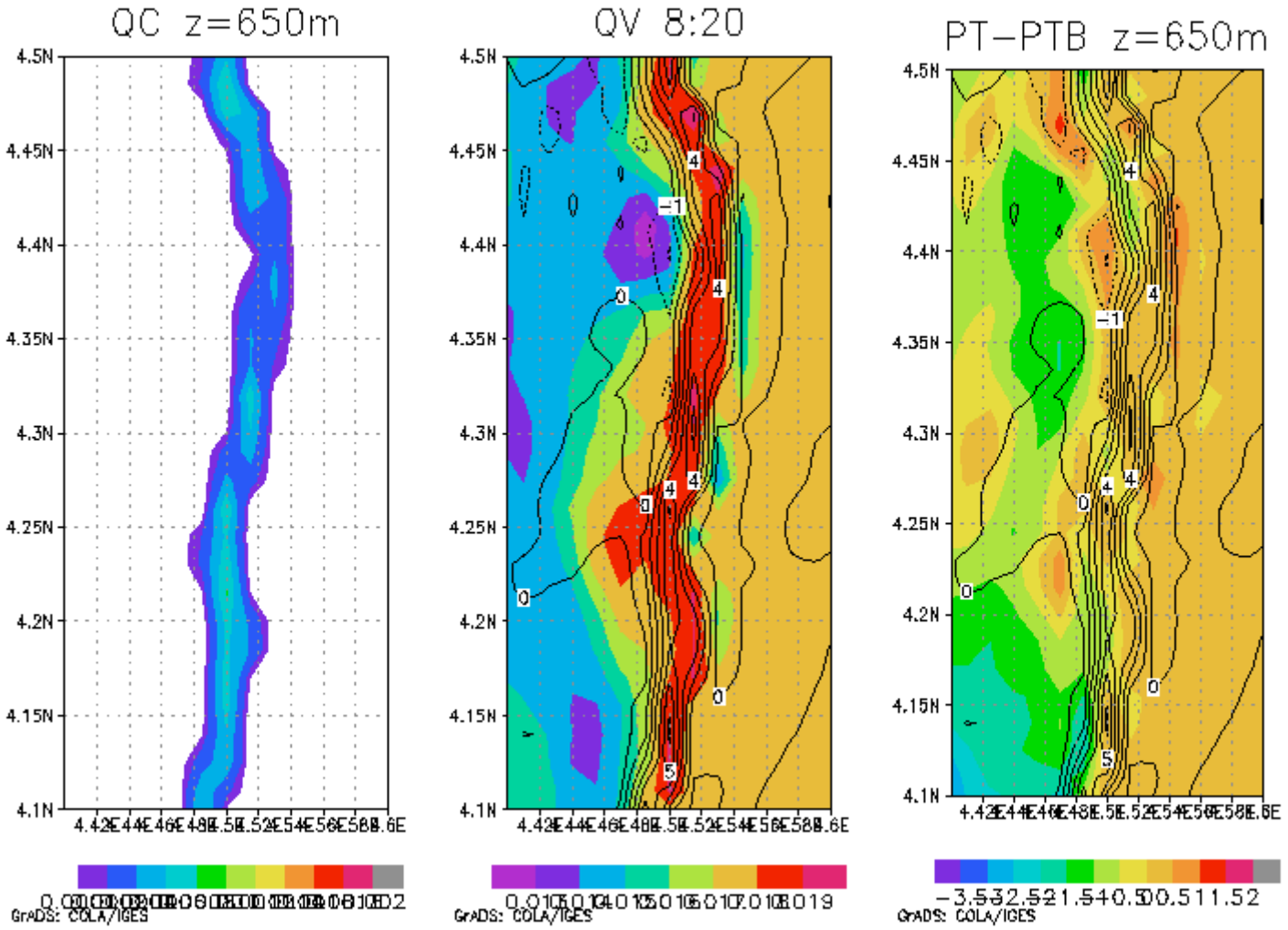
- **How the current cloud schemes represent the effects of subgrid-scale clouds ?**

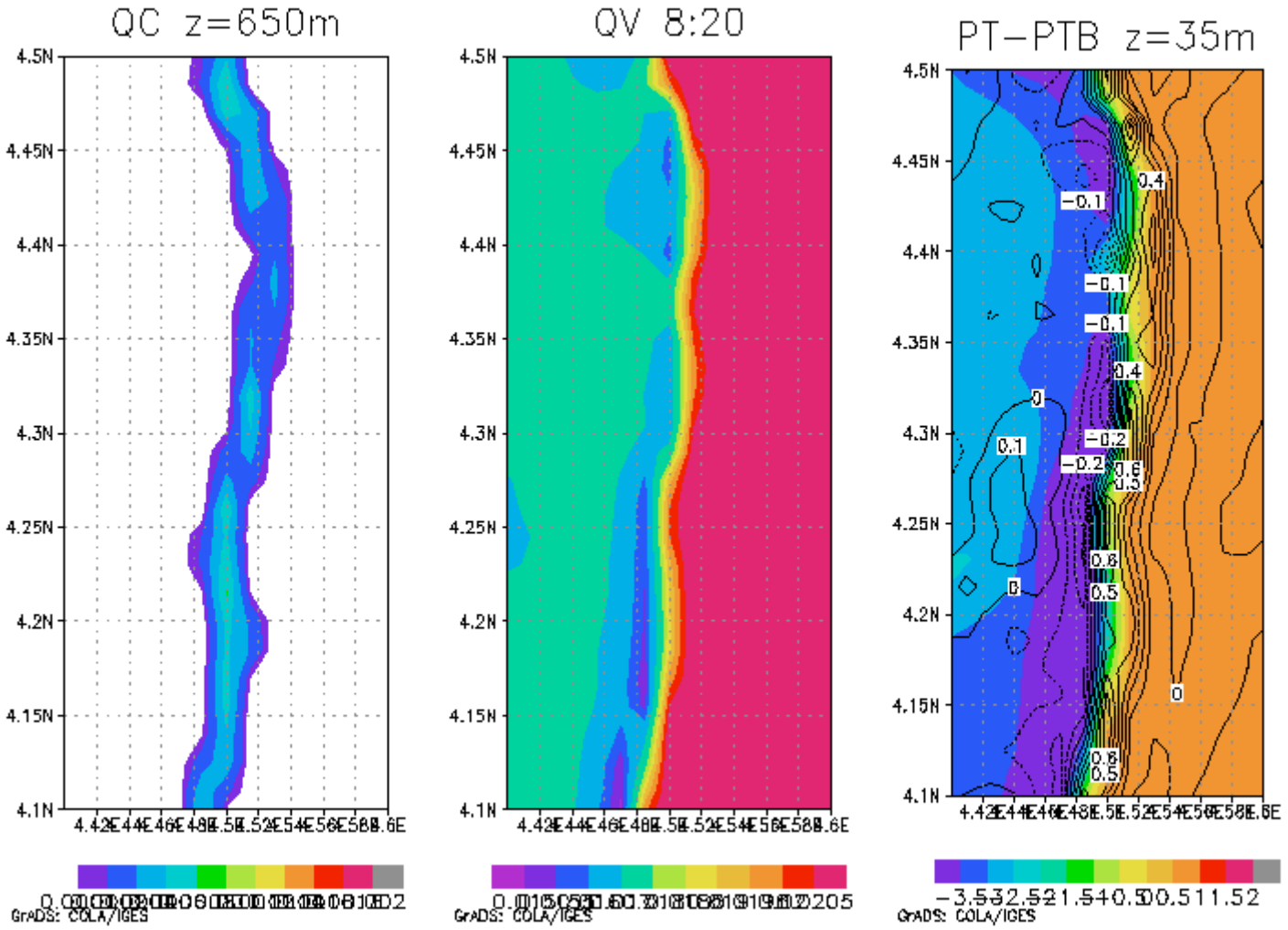
  ---- more proper assumption/concepts ?----

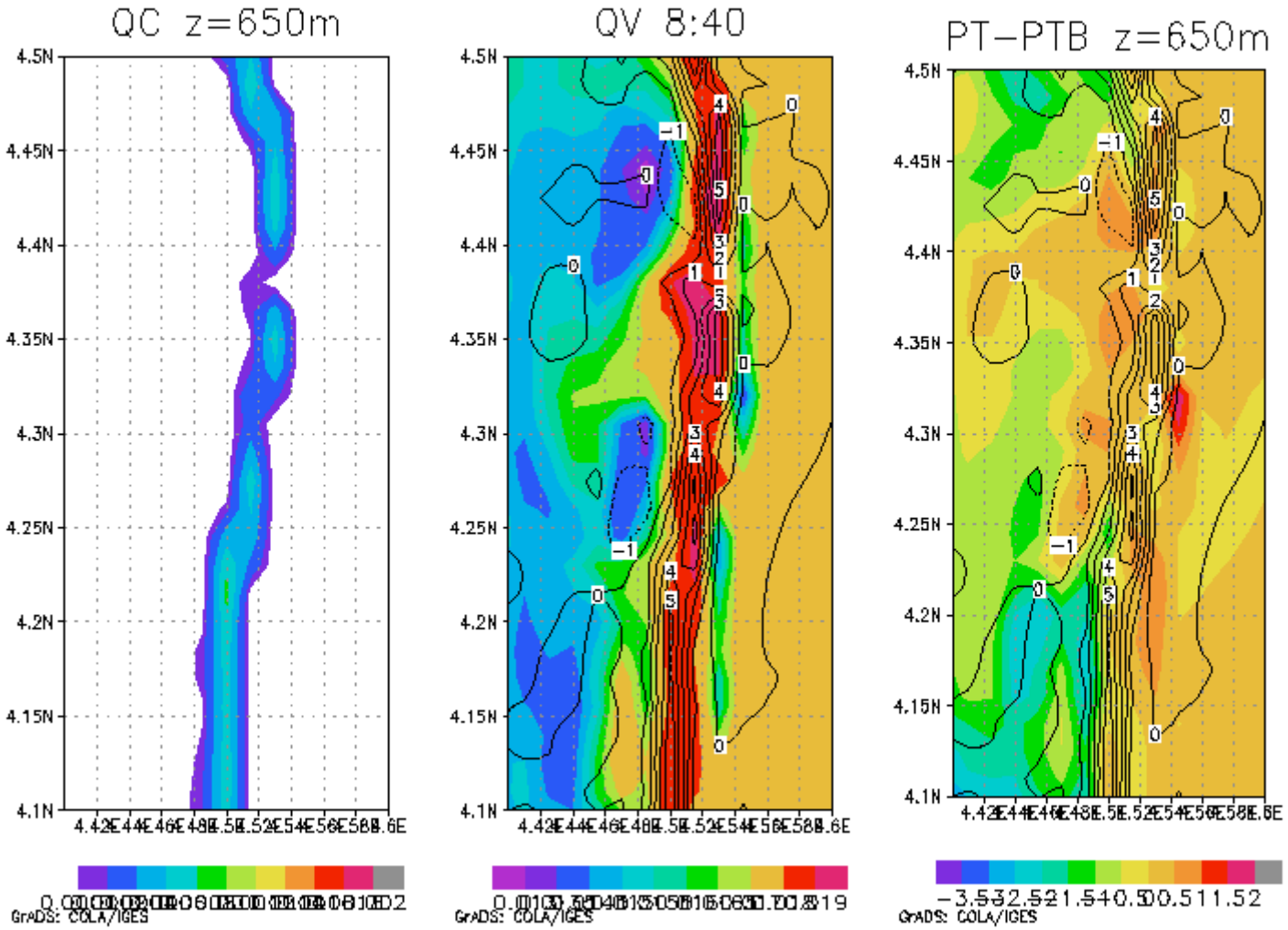
  - **Kain-Fritsch, Yamasaki, etc. : mesoscale model**
  - **Arakawa-Schubert, Emanuel, etc.: large-scale model**

- **Concerns on the use of CRM to this problem**
  - **Dependence on numerical diffusion**
  - **Sensitivity to physical schemes**

    (cloud microphysics, surface fluxes, etc)


QC z=650m
QV 8:20
PT−PTB z=650m
4.5N
4.45N
4.4N
4.35N
4.3N
4.25N
4.2N
4.15N
4.1N
GrADS: COLA/IGES
GrADS: COLA/IGES
GrADS: COLA/IGES


QC z=650m
QV 8:20
PT−PTB z=35m
4.5N
4.45N
4.4N
4.35N
4.3N
4.25N
4.2N
4.15N
4.1N
4.42E 4.44E 4.46E 4.48E 4.5E 4.52E 4.54E 4.56E 4.58E 4.6E
−3.5 −2.5 −1.5 −0.5 0.5 1.5 2
GrADS: COLA/IGES
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0 5.2 5.4 5.6 5.8 6.0 6.2 6.4 6.6 6.8 7.0 7.2 7.4 7.6 7.8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QV 8:40
PT−PTB z=650m
4.5N
4.45N
4.4N
4.35N
4.3N
4.25N
4.2N
4.15N
4.1N
4.42E 4.44E 4.46E 4.48E 4.5E 4.52E 4.54E 4.56E 4.58E 4.6E
−3.5 −2.5 −1.5 −0.5 0.5 1.5 2
GrADS: COLA/IGES

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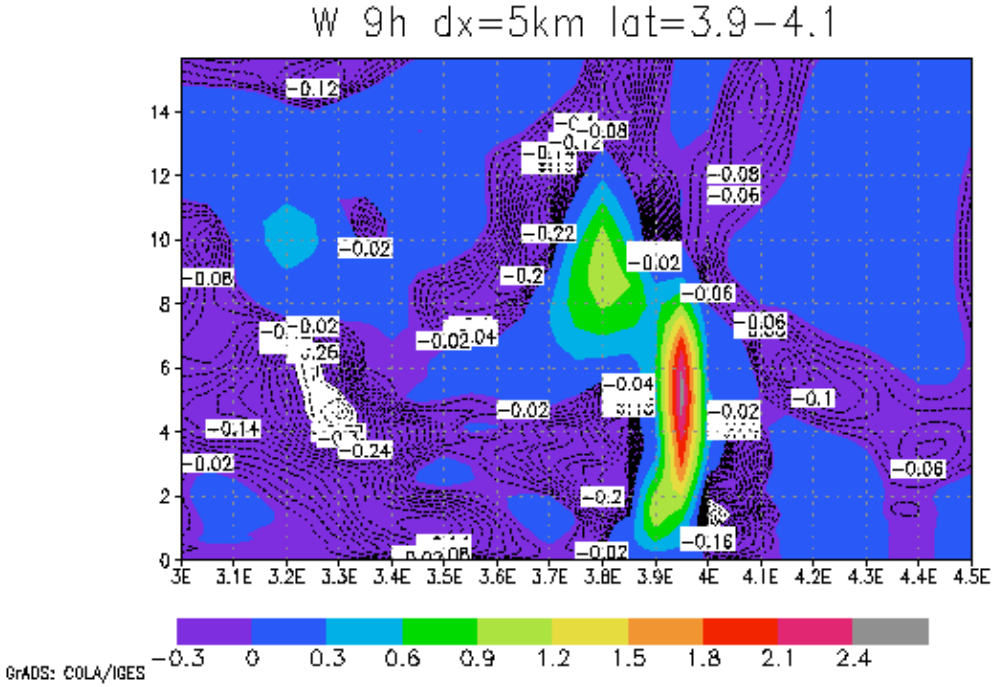

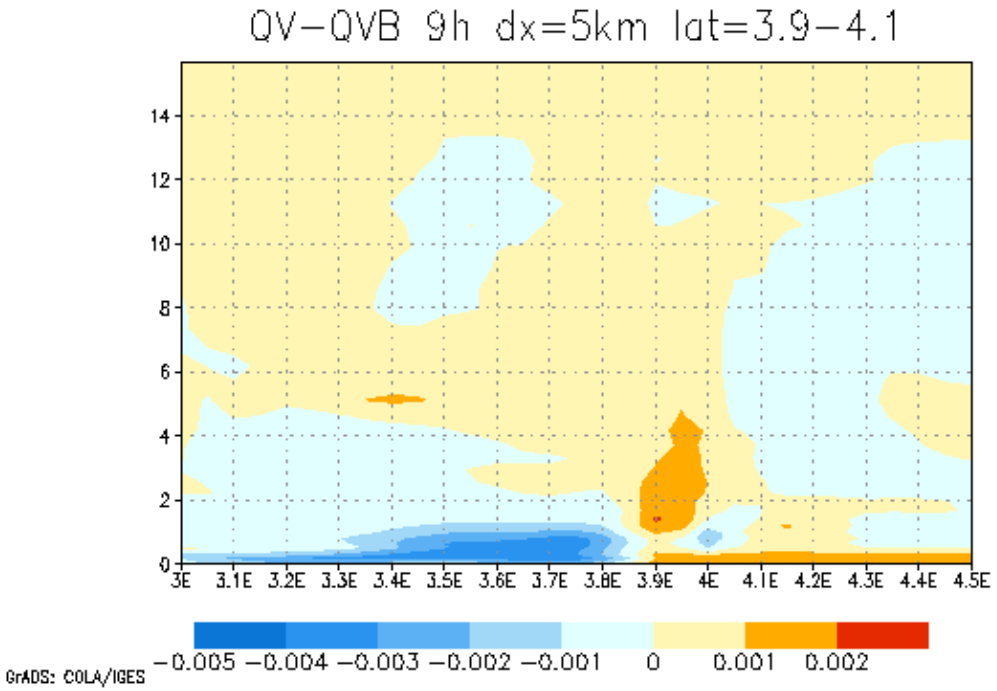

ate Model

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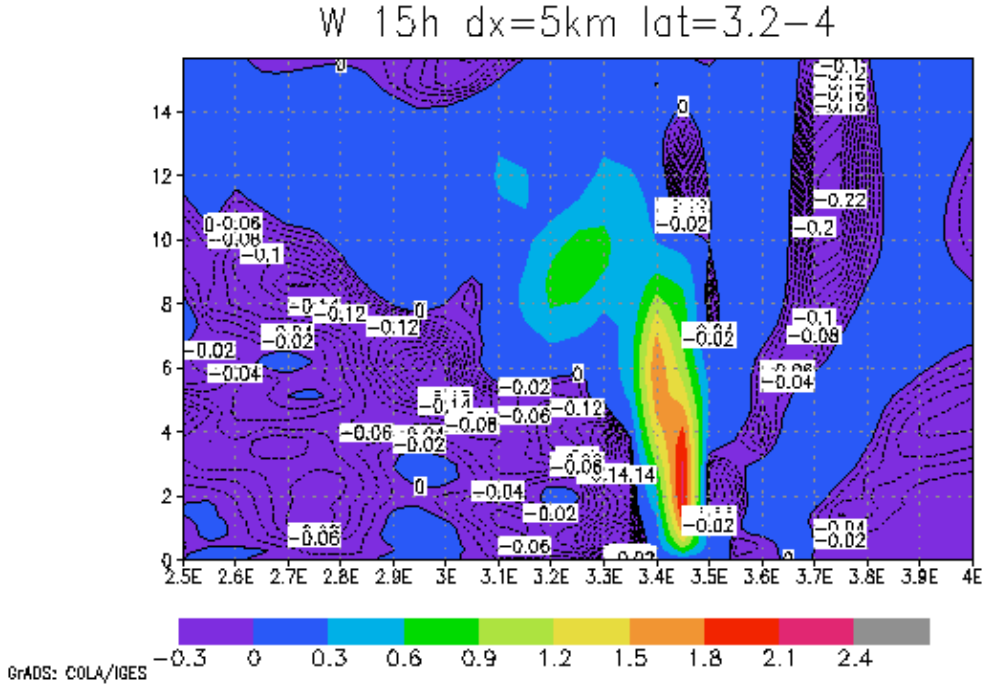

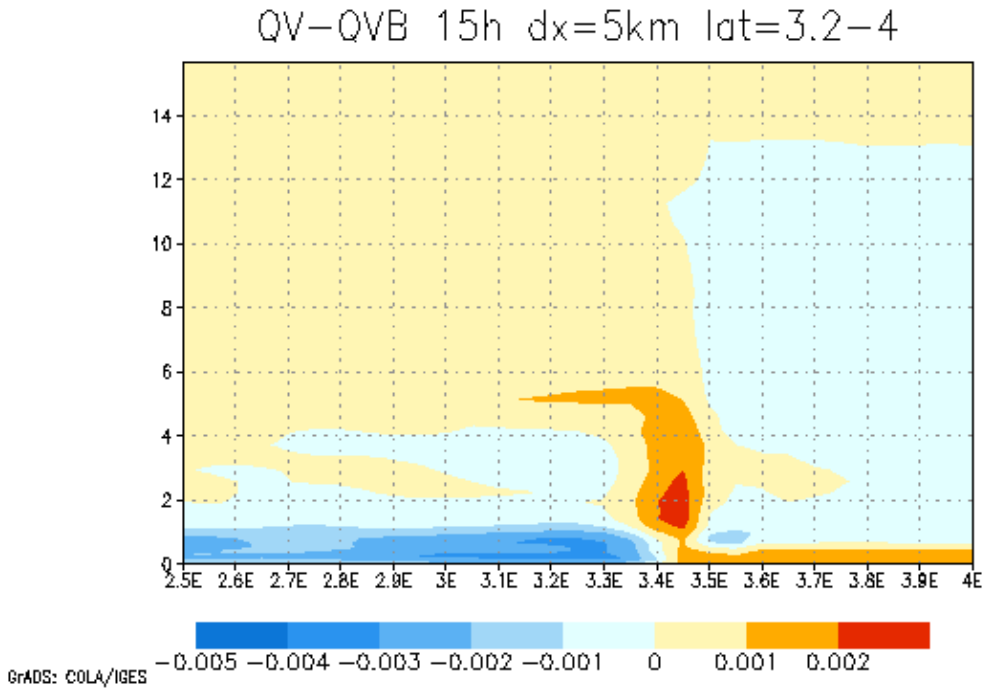

nate Model

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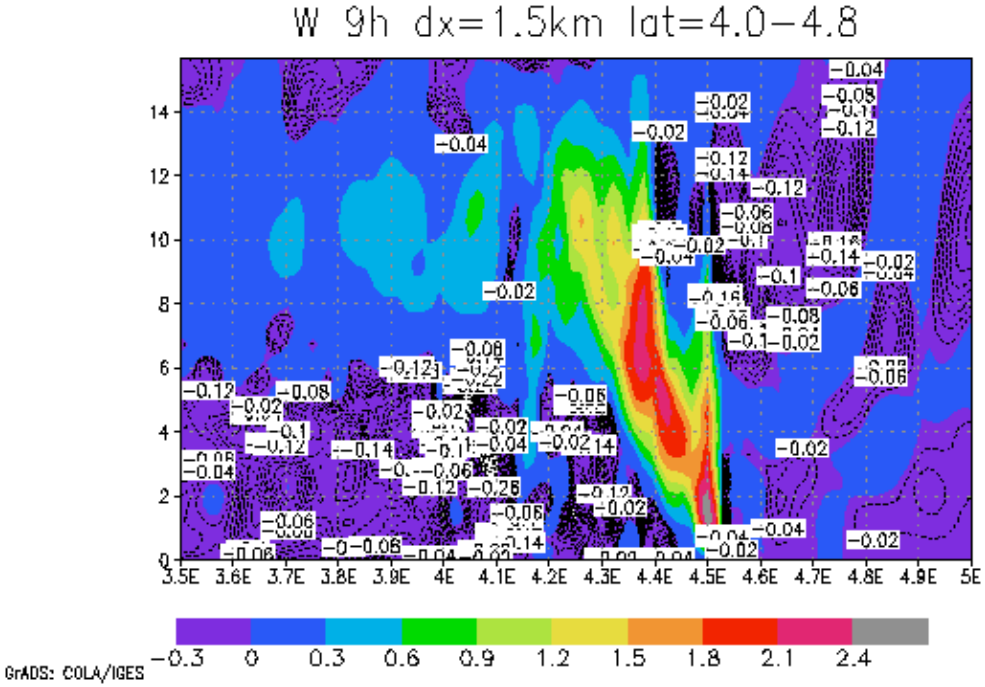
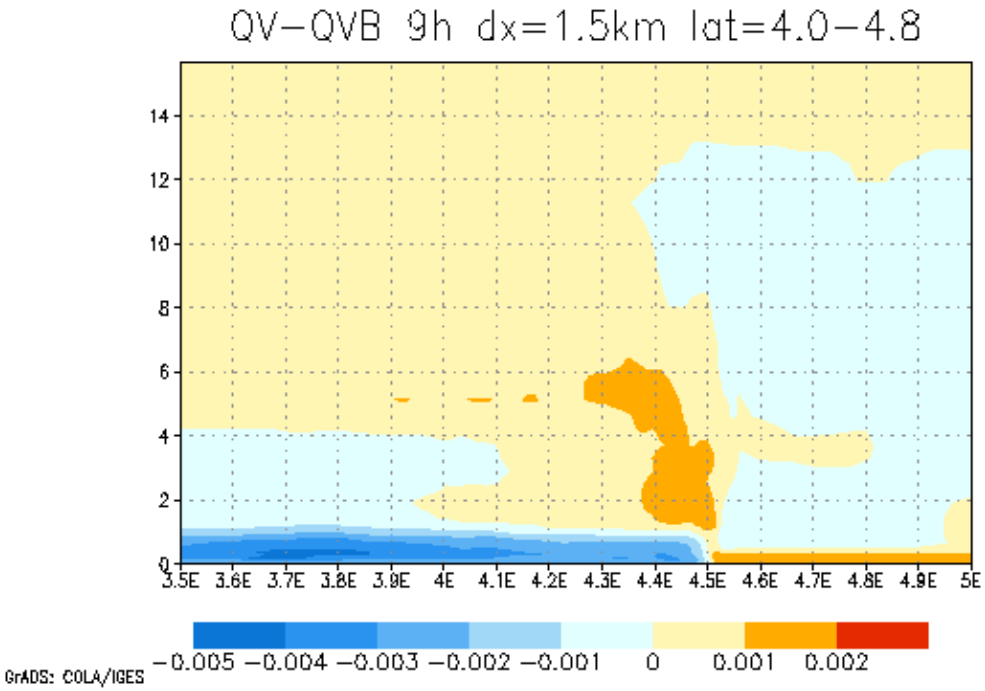
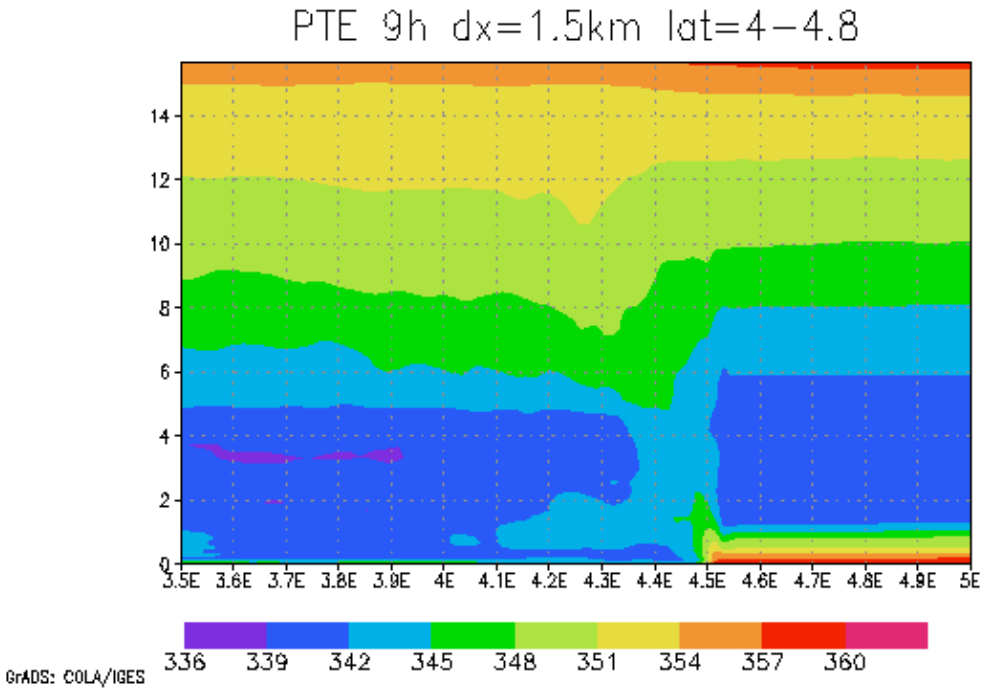
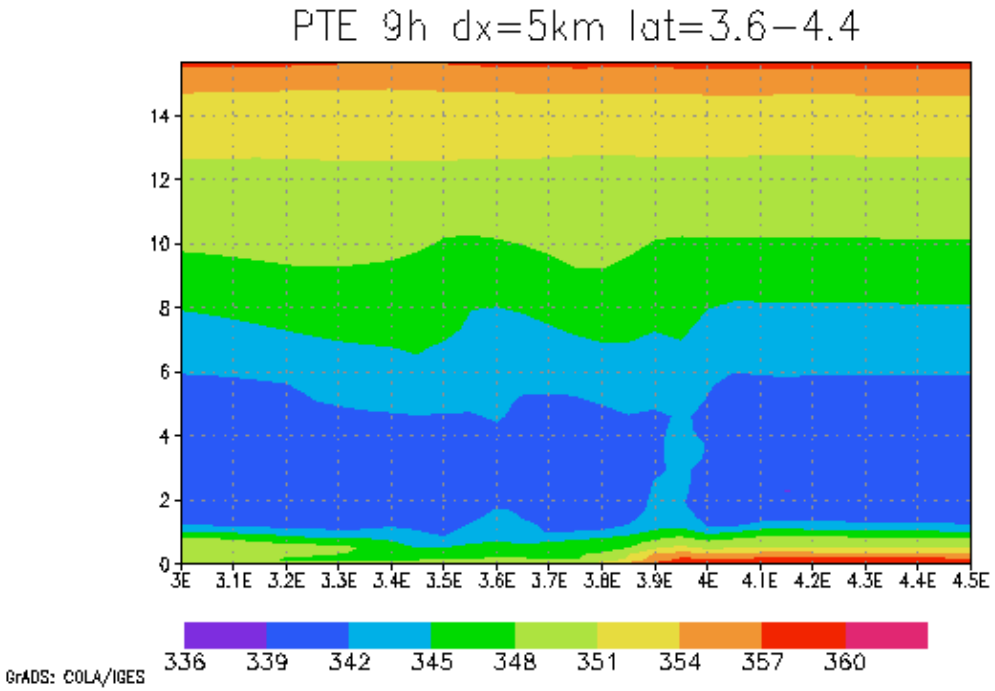




limate Model


PTE 9h dx=1.5km lat=4-4.8
14
12
10
8
6
4
2
0
3.5E 3.6E 3.7E 3.8E 3.9E 4E 4.1E 4.2E 4.3E 4.4E 4.5E 4.6E 4.7E 4.8E 4.9E 5E
336 339 342 345 348 351 354 357 360
GrADS: COLA/IGES


PTE 9h dx=5km lat=3.6-4.4
14
12
10
8
6
4
2
0
3E 3.1E 3.2E 3.3E 3.4E 3.5E 3.6E 3.7E 3.8E 3.9E 4E 4.1E 4.2E 4.3E 4.4E 4.5E
336 339 342 345 348 351 354 357 360
GrADS: COLA/IGES