The sensitivity of cloud dynamics and boundary layer structure to 3-D radiative heating effects*

I3RC **Workshop**

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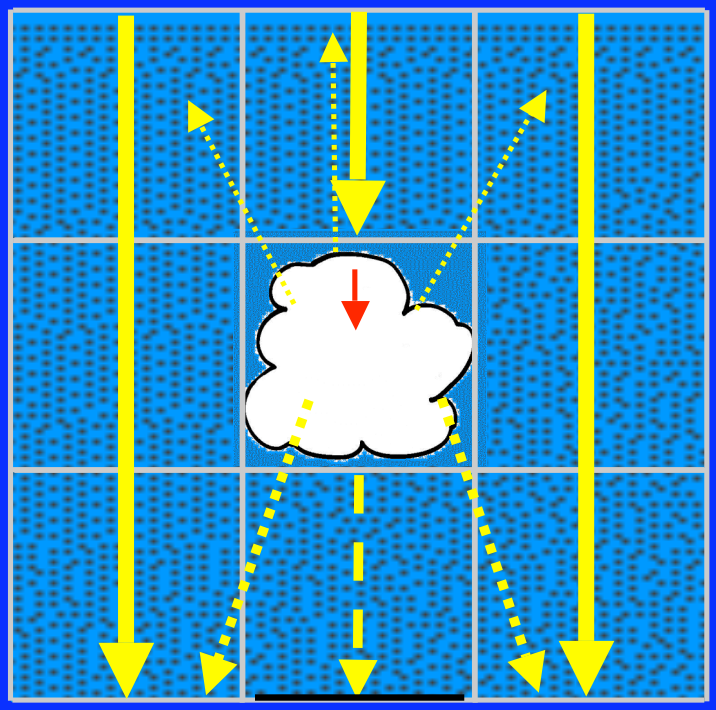
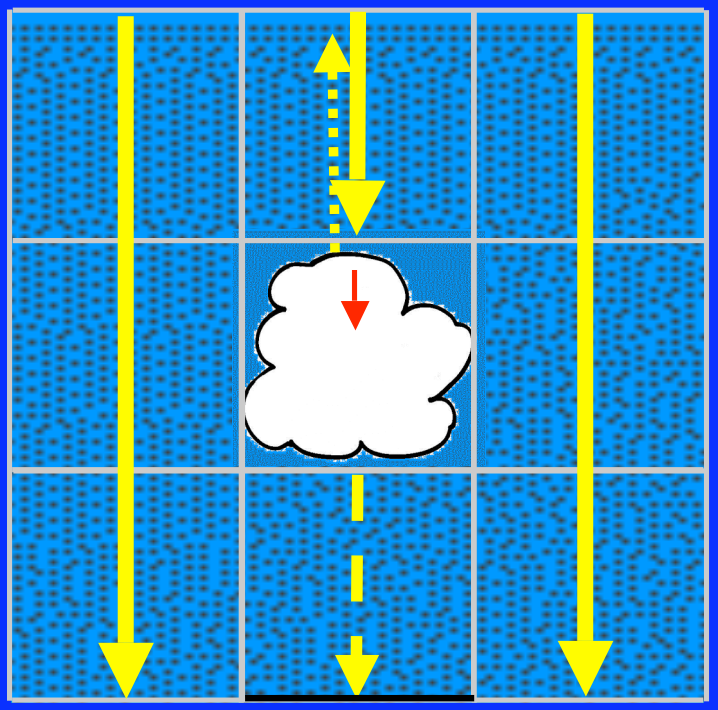
*a radiative narrative

SZA = 0

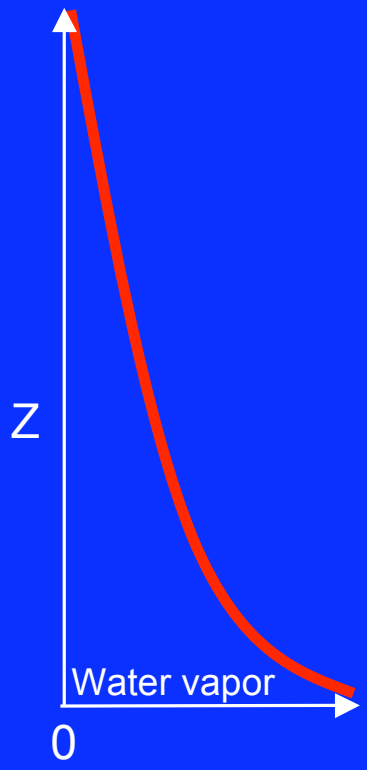
Surf ↓ 3D > ICA
TOA ↑ 3D < ICA
ABS 3D > ICA



3D
(horizontal transport)

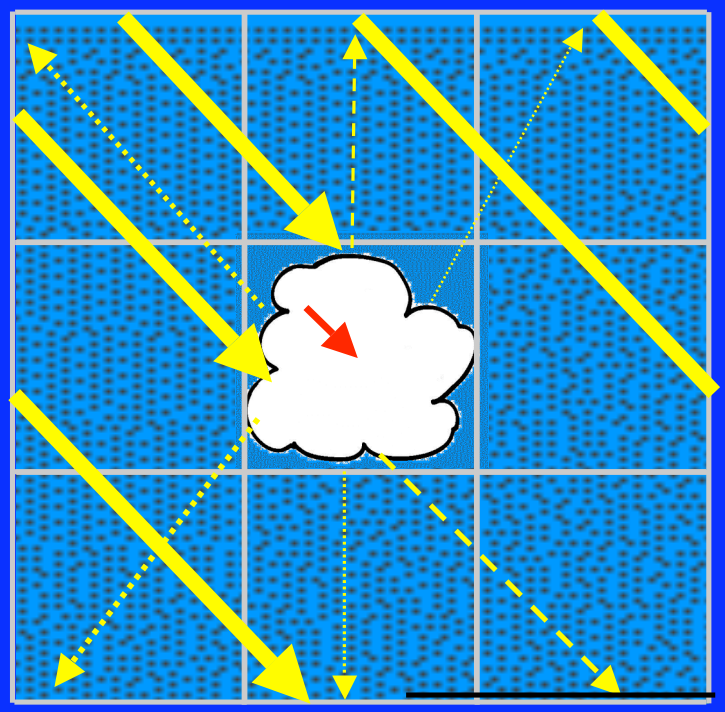


ICA

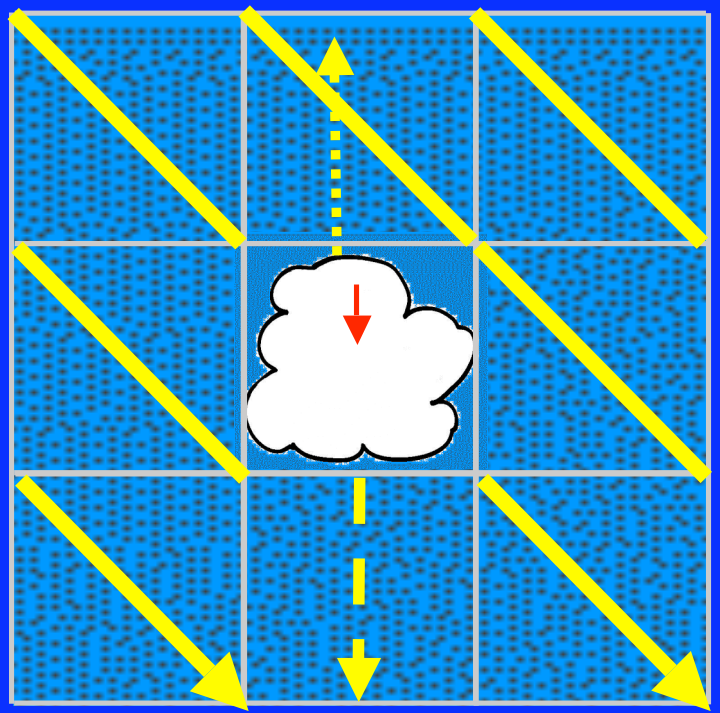


SZA = 45

Surf ↓ 3D < ICA
TOA ↑ 3D > ICA
ABS 3D > ICA



3D



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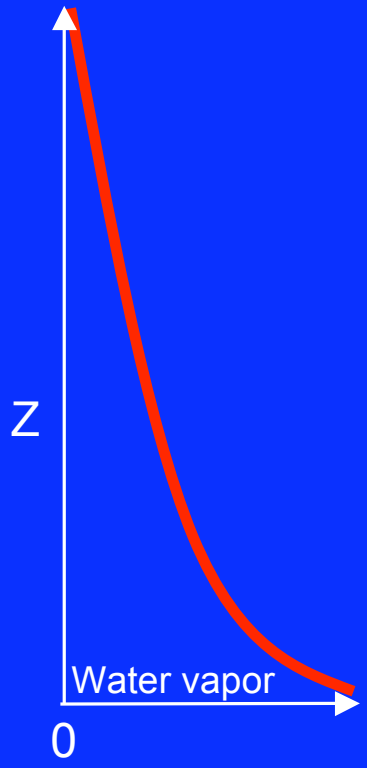
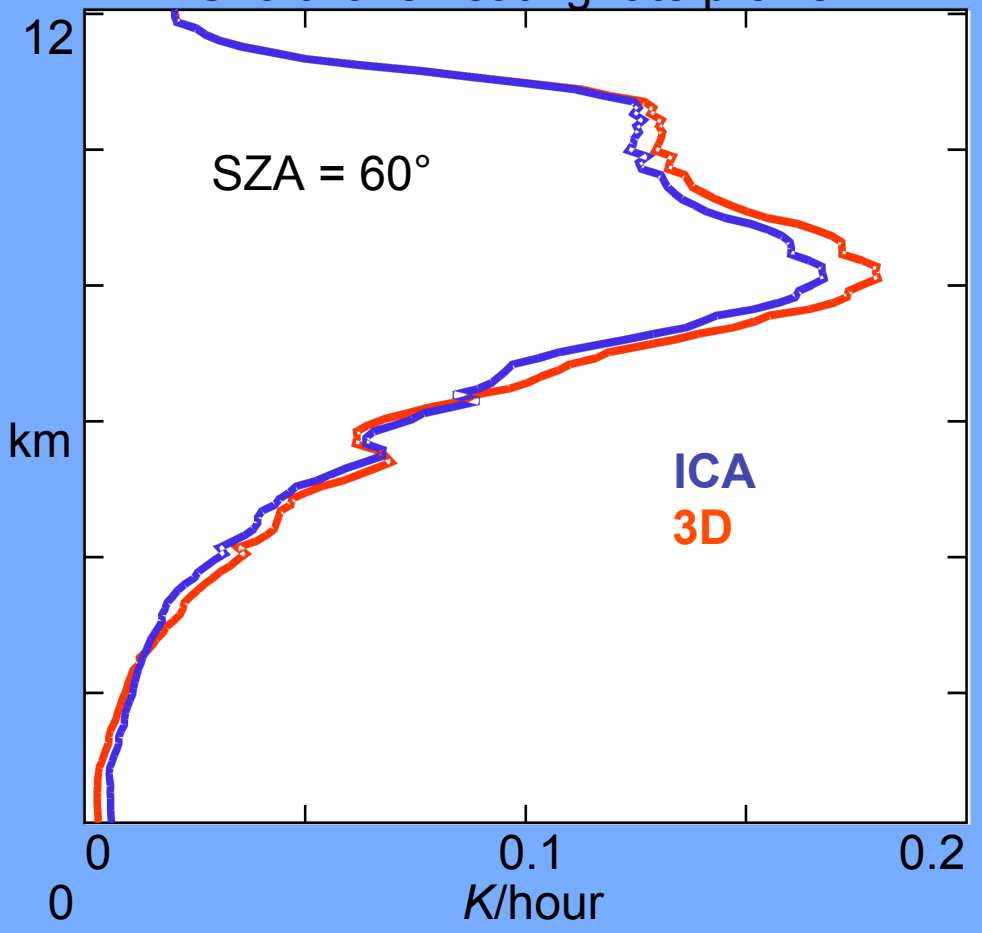
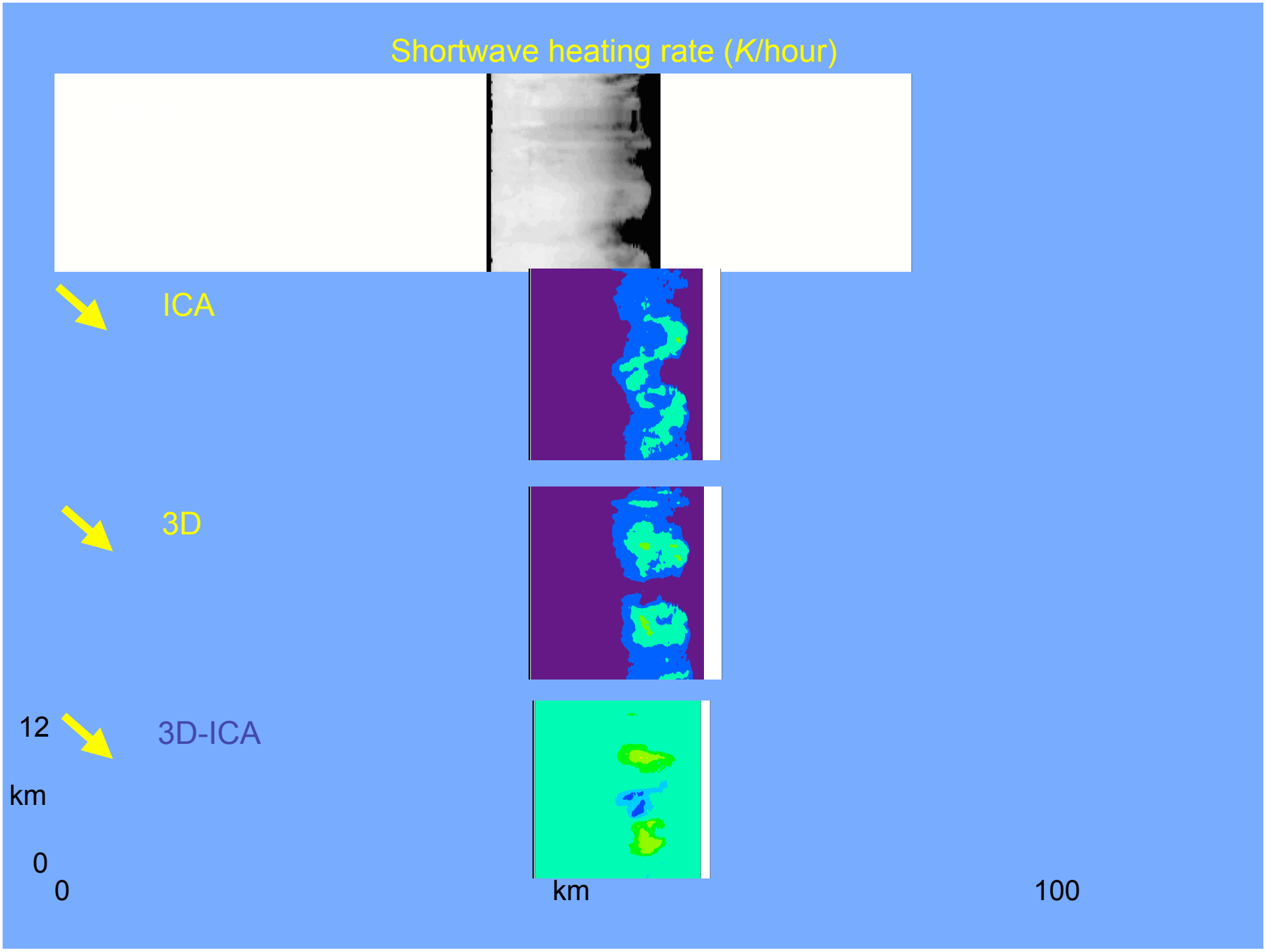


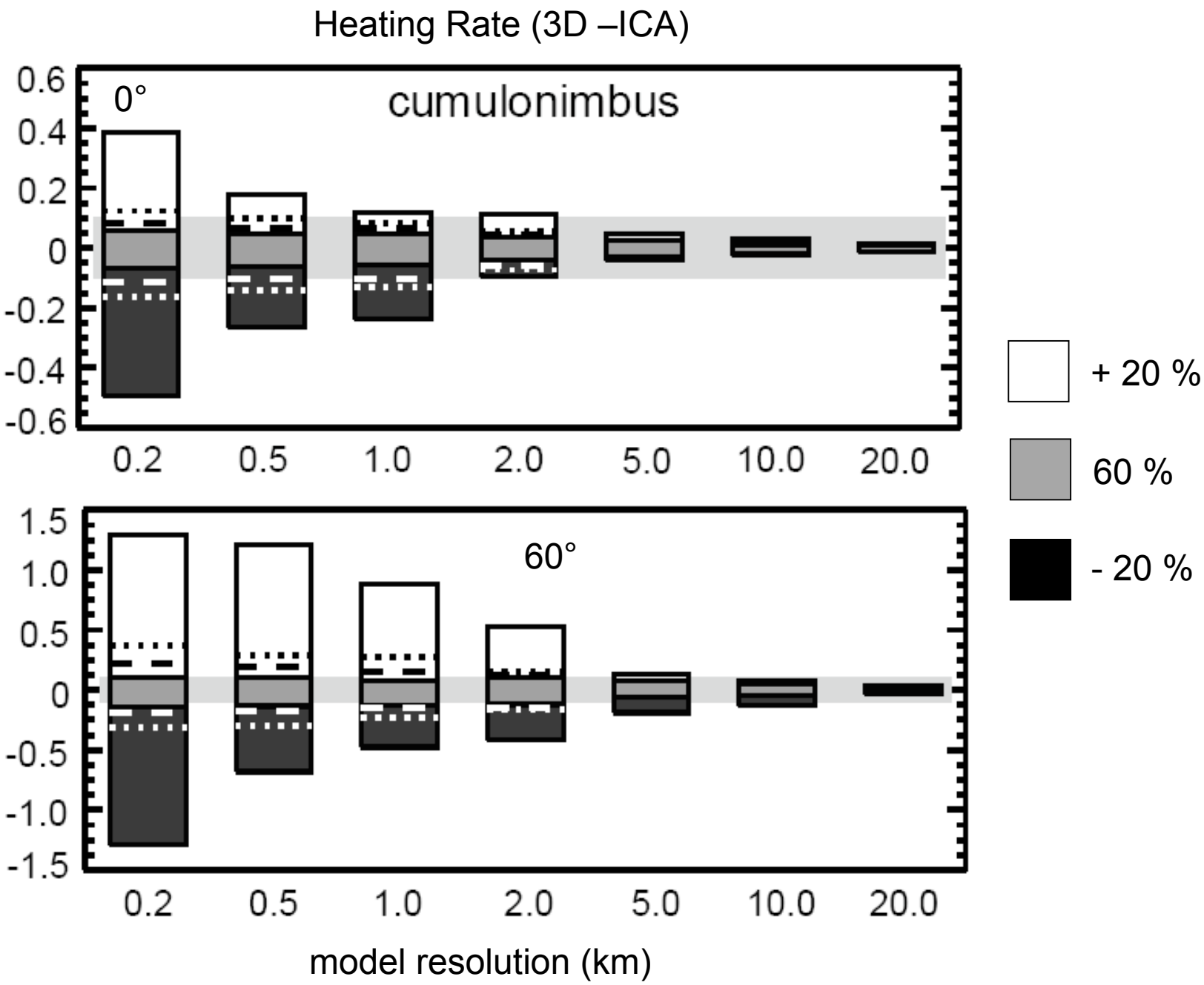
MMCR derived cloud field

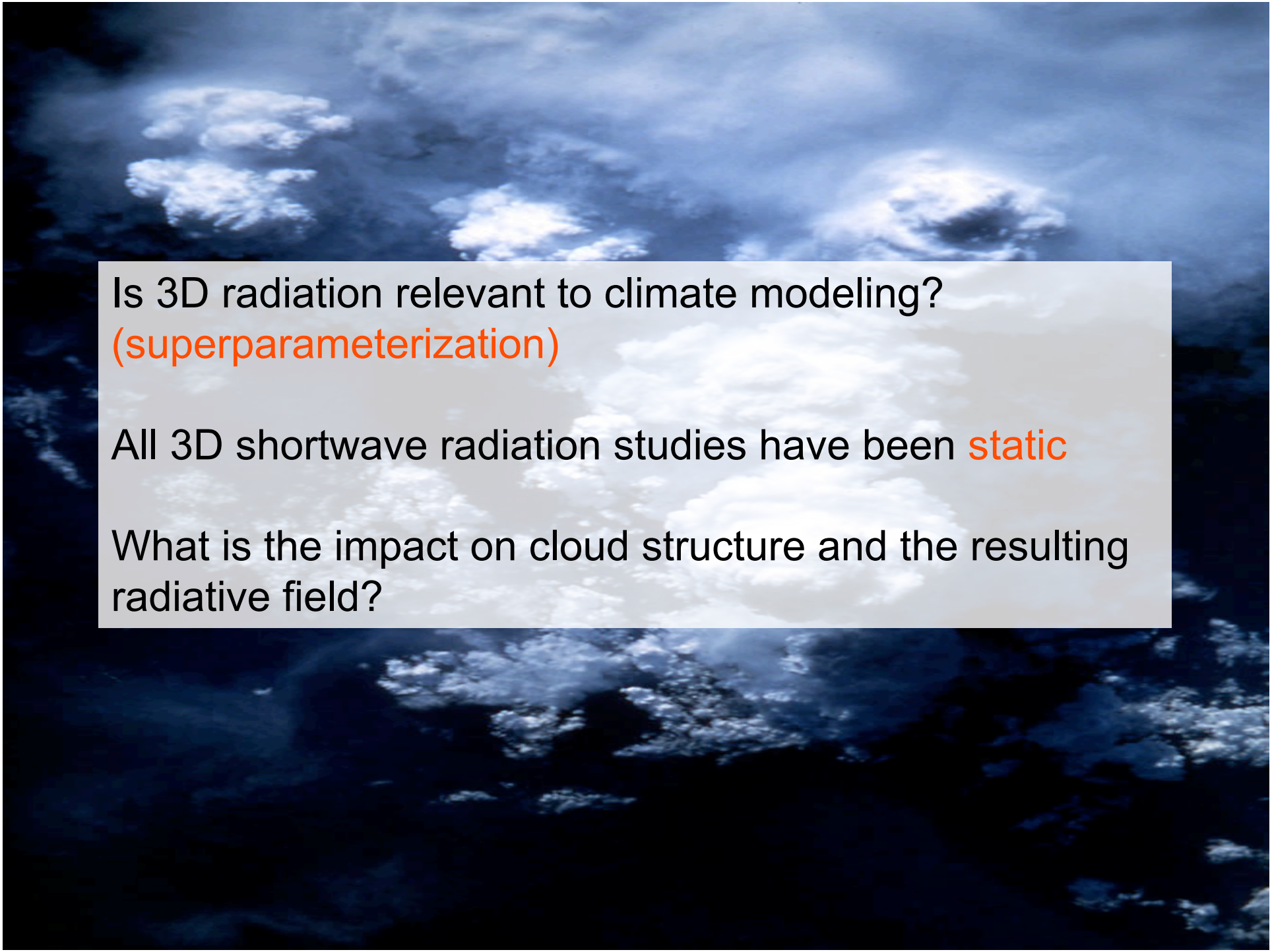
3D shortwave radiative effects tend to cancel on the scale of GCMs

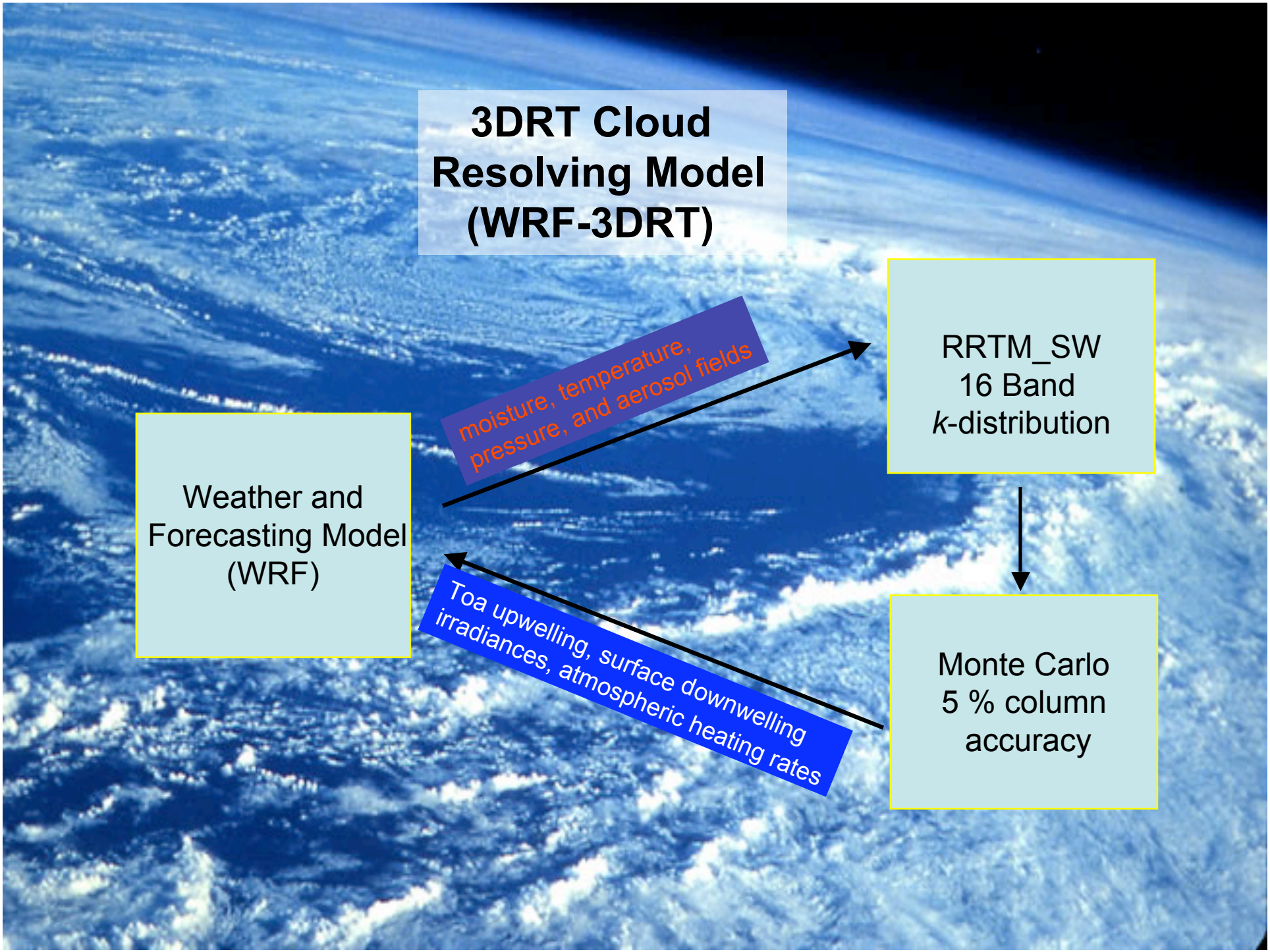
Shortwave heating rate profile

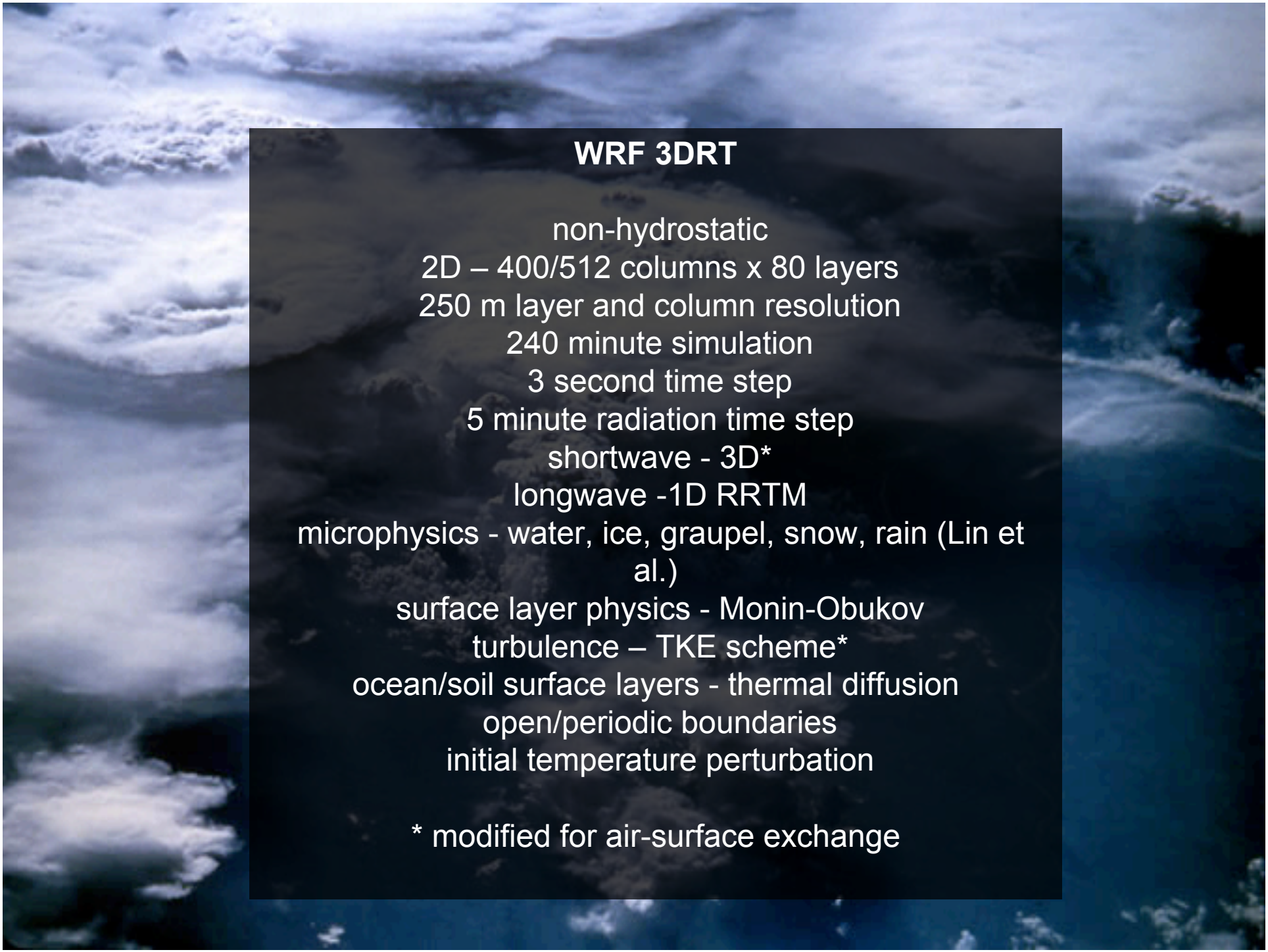



Shortwave heating rate (*K*/hour)
ICA
3D
3D-ICA
12
km
0
0
km
100


Heating Rate (3D –ICA)
0°
cumulonimbus
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0.2
0.5
1.0
2.0
5.0
10.0
20.0
60°
1.5
1.0
0.5
0
-0.5
-1.0
-1.5
+ 20 %
60 %
- 20 %
model resolution (km)


Is 3D radiation relevant to climate modeling?
(superparameterization)
All 3D shortwave radiation studies have been static
What is the impact on cloud structure and the resulting radiative field?

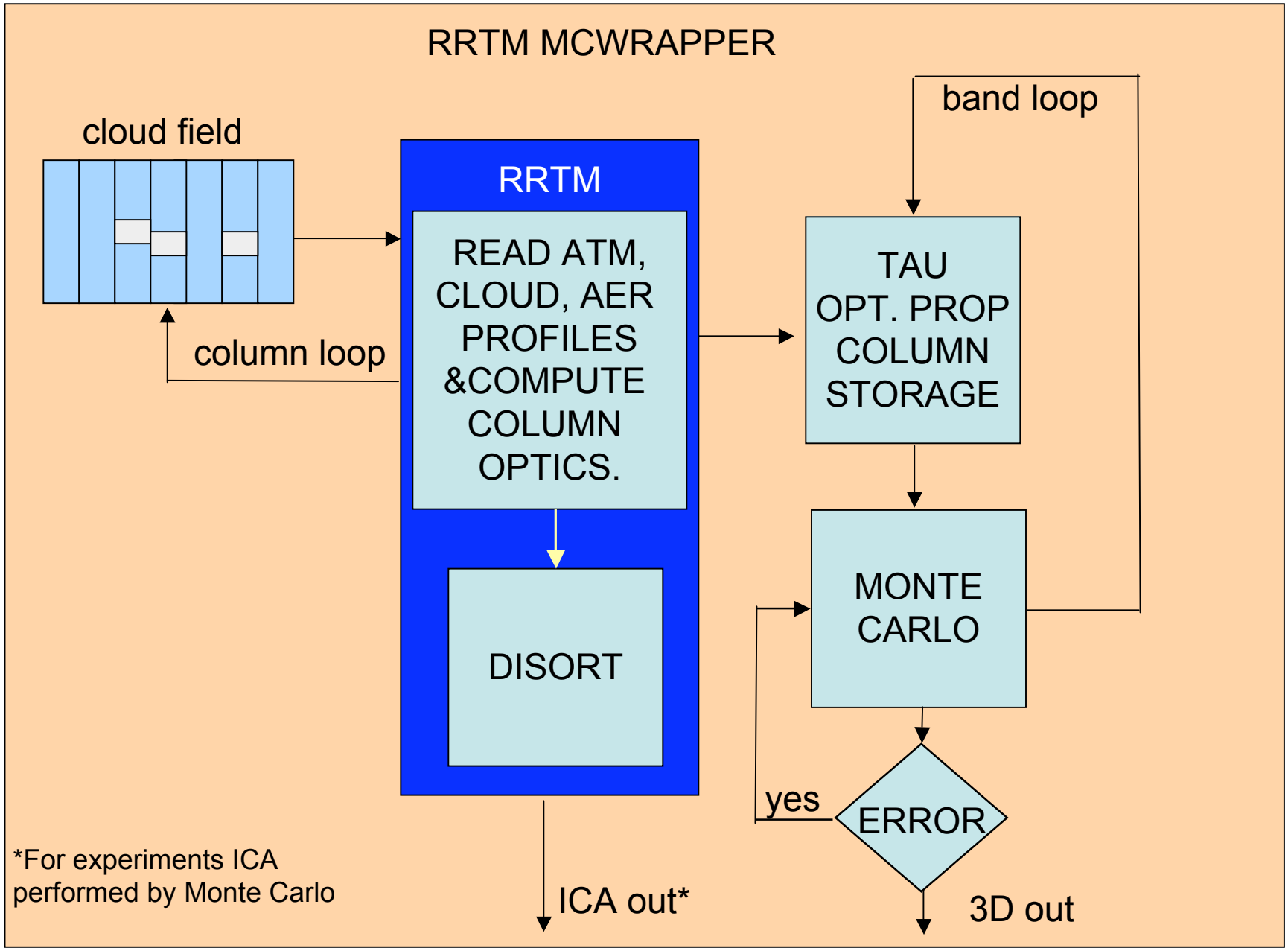

3DRT Cloud Resolving Model (WRF-3DRT)
Weather and Forecasting Model (WRF)
moisture, temperature, pressure, and aerosol fields
RRTM_SW 16 Band k-distribution
Monte Carlo 5 % column accuracy
Toa upwelling, surface downwelling irradiances, atmospheric heating rates

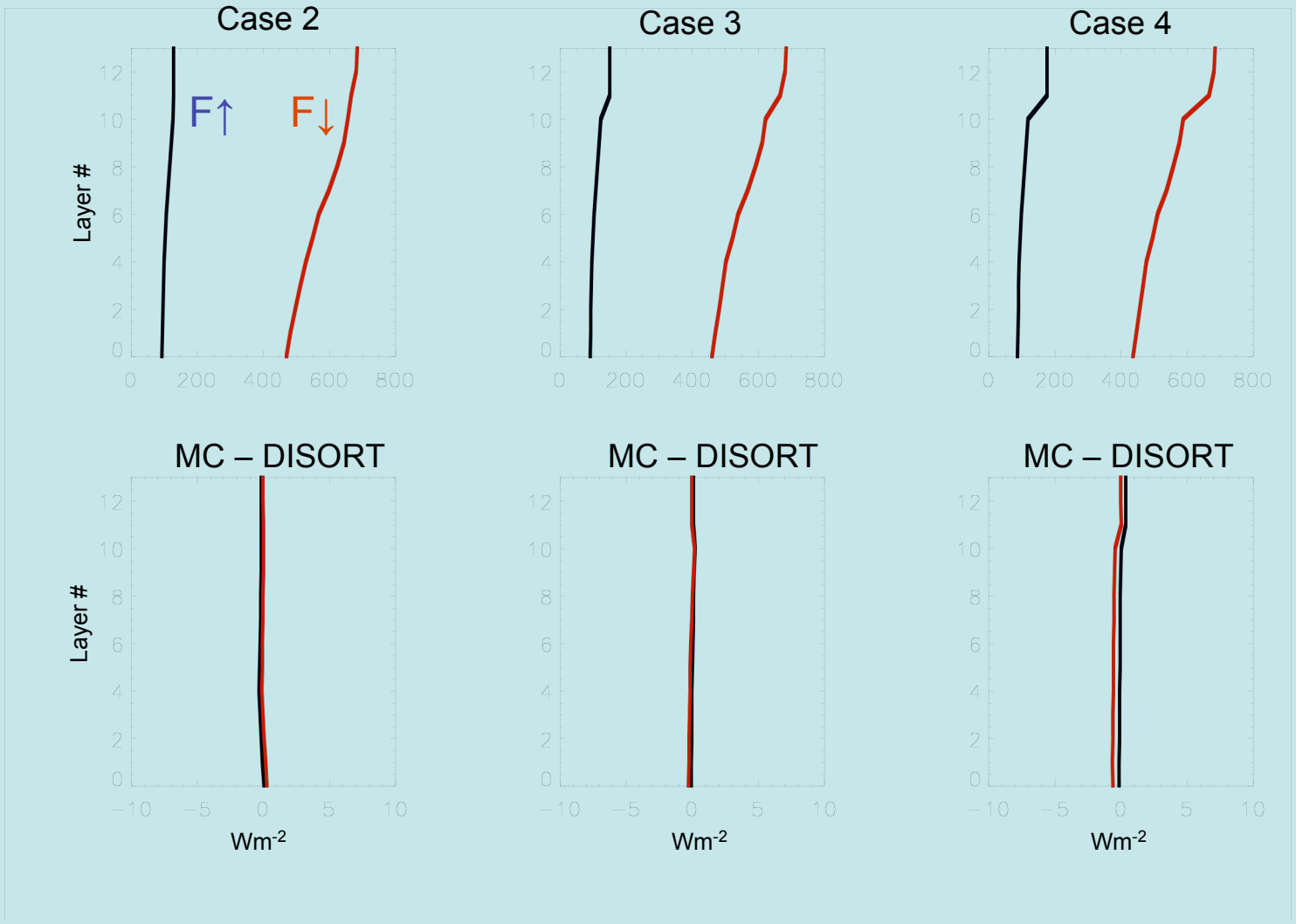


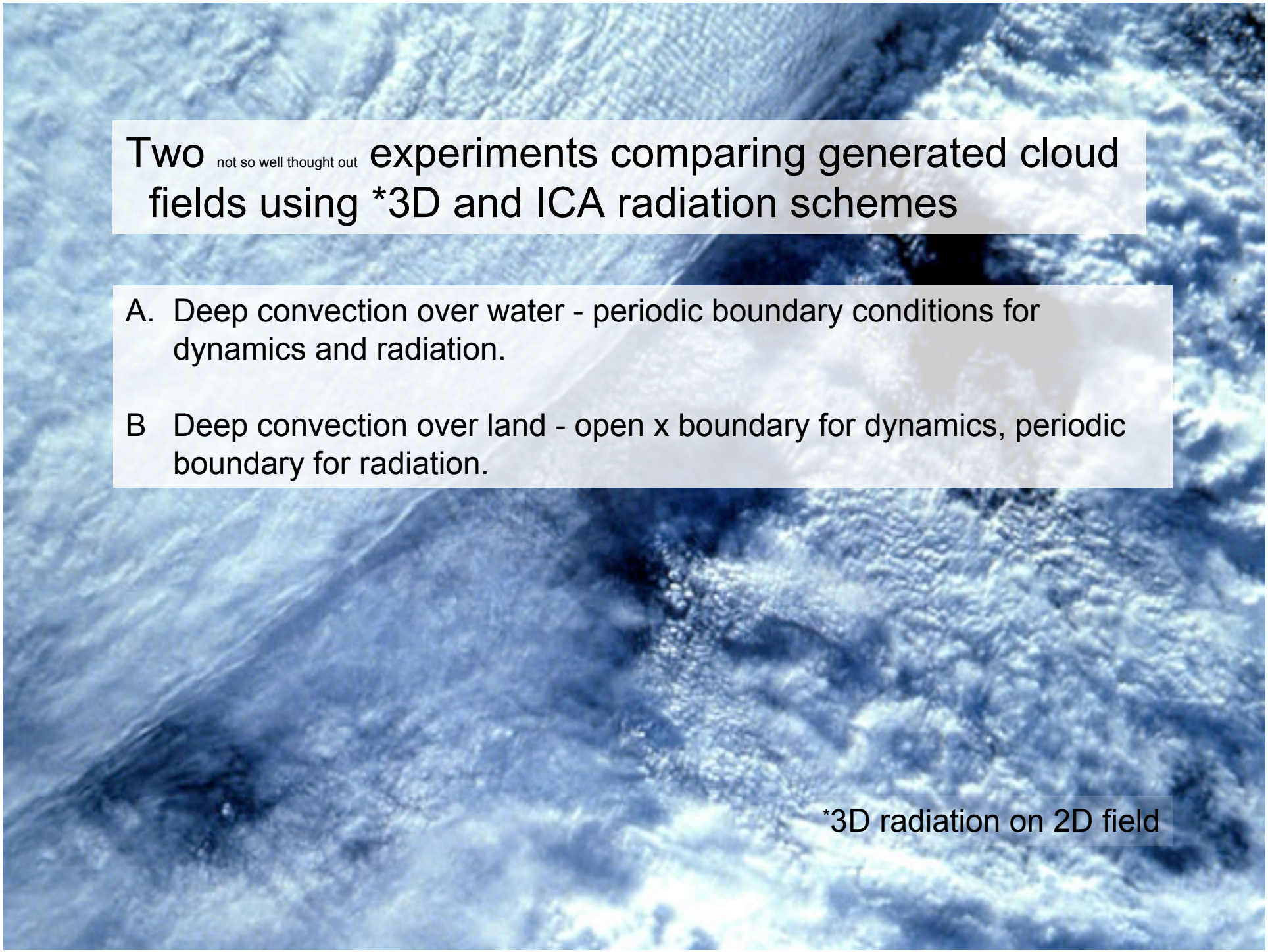
WRF 3DRT

non-hydrostatic
2D – 400/512 columns x 80 layers
250 m layer and column resolution
240 minute simulation
3 second time step
5 minute radiation time step
shortwave - 3D*
longwave -1D RRTM
microphysics - water, ice, graupel, snow, rain (Lin et al.)
surface layer physics - Monin-Obukov
turbulence – TKE scheme*
ocean/soil surface layers - thermal diffusion
open/periodic boundaries
initial temperature perturbation

* modified for air-surface exchange


RRTM MCWRAPPER
band loop
cloud field
RRTM
READ ATM, CLOUD, AER PROFILES &COMPUTE COLUMN OPTICS.
TAU OPT. PROP COLUMN STORAGE
column loop
DISORT
MONTE CARLO
yes
ERROR
*For experiments ICA performed by Monte Carlo
ICA out*
3D out


Case 2
Case 3
Case 4
F↑
F↓
Layer #
0
2
4
6
8
10
12
0
200
400
600
800
MC – DISORT
MC – DISORT
MC – DISORT
Layer #
−10
−5
0
5
10
Wm-2
Wm-2
Wm-2

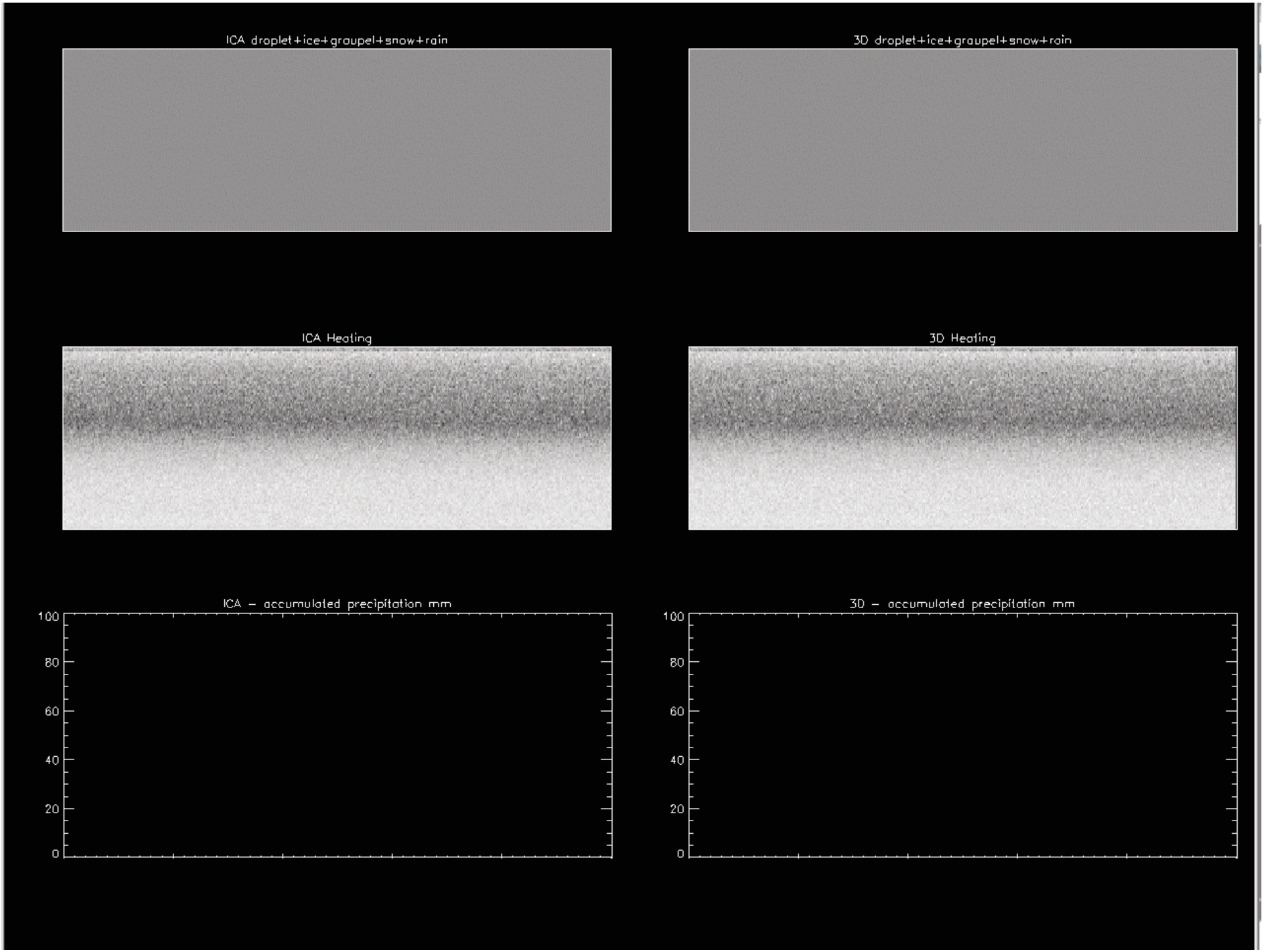


Two not so well thought out experiments comparing generated cloud fields using *3D and ICA radiation schemes

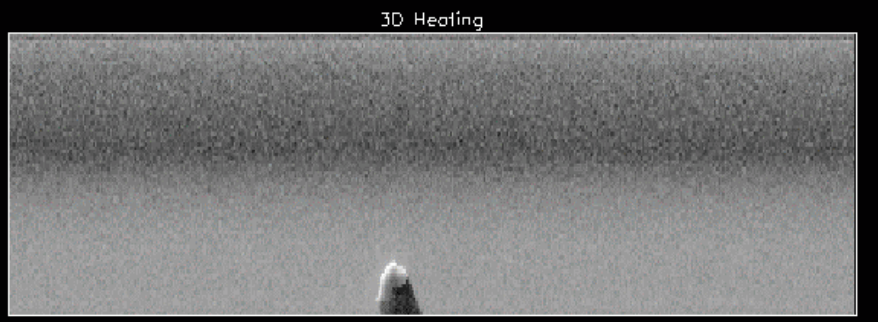
A. Deep convection over water - periodic boundary conditions for dynamics and radiation.

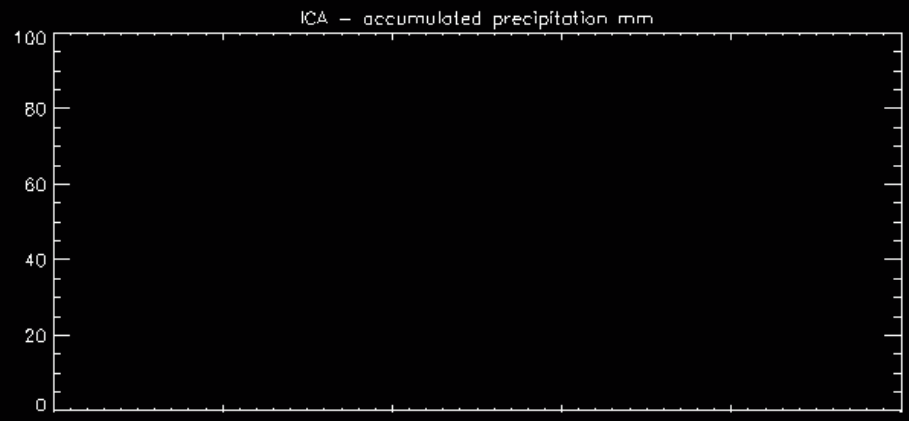
B Deep convection over land - open x boundary for dynamics, periodic boundary for radiation.

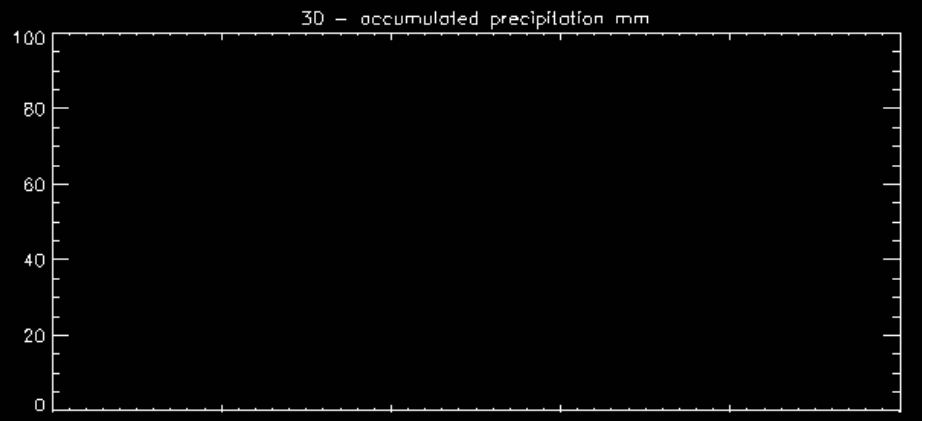
*3D radiation on 2D field


ICA droplet+ice+graupel+snow+rain
3D droplet+ice+graupel+snow+rain
ICA Heating
3D Heating
ICA – accumulated precipitation mm
100
80
60
40
20
0
3D – accumulated precipitation mm
100
80
60
40
20
0

periodic boundary 35 min

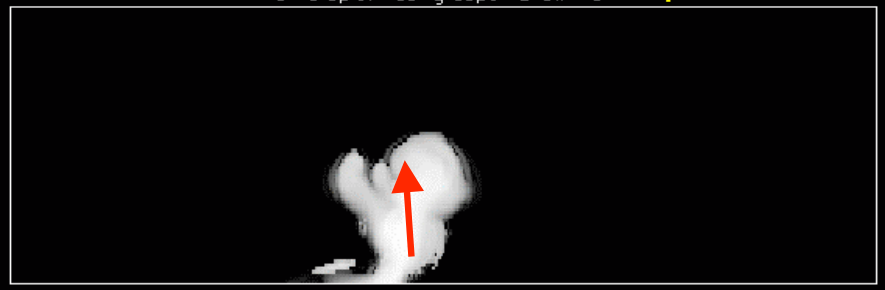




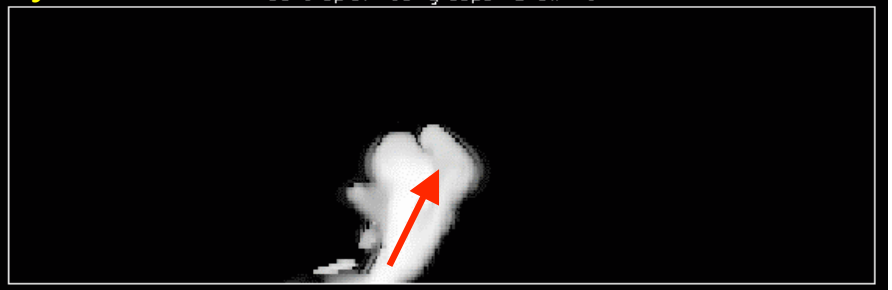


periodic boundary 55 min

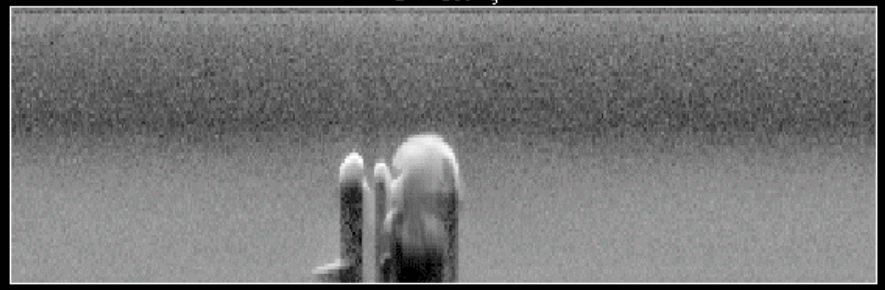
ICA droplet+ice+groupel+snow+rain



3D droplet+ice+groupel+snow+rain

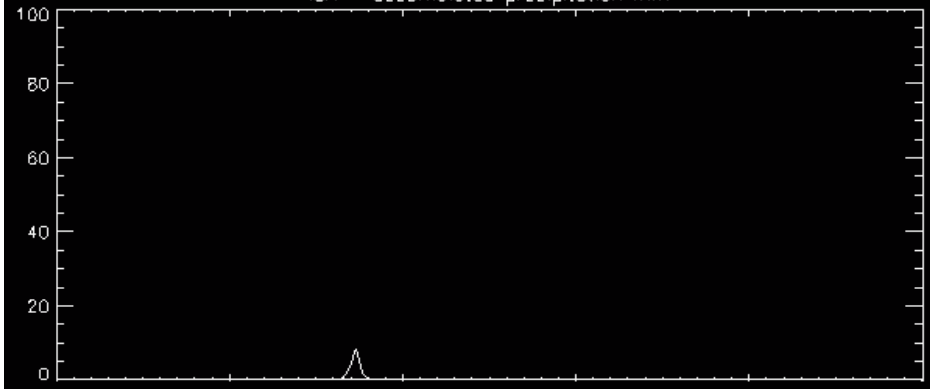


ICA Heating

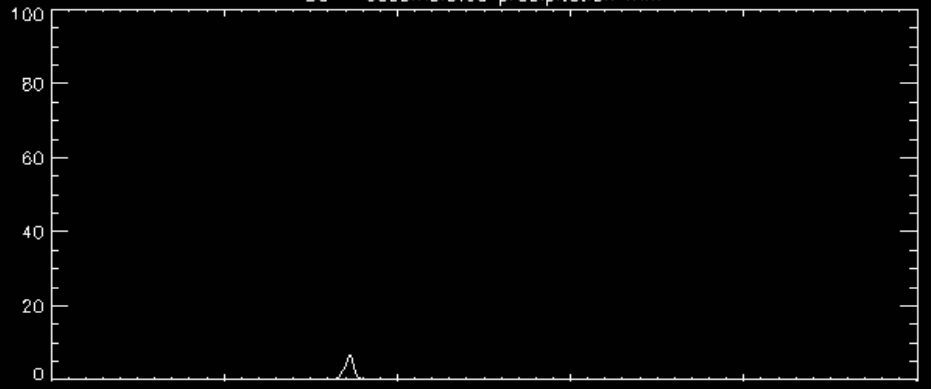


3D Heating

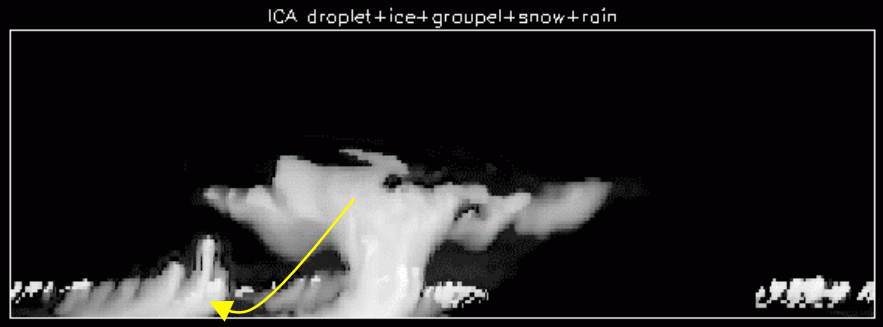
ICA – accumulated precipitation mm

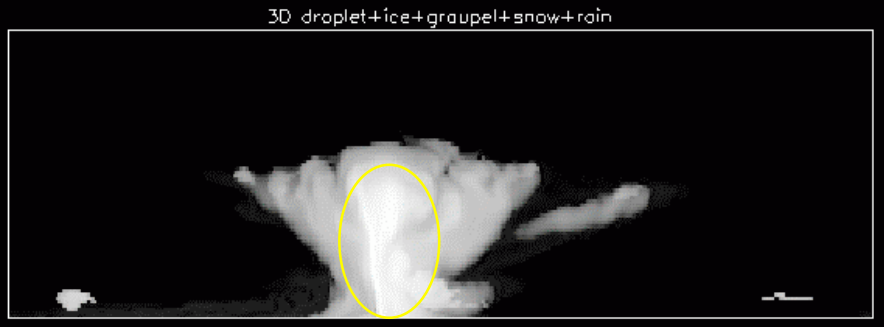


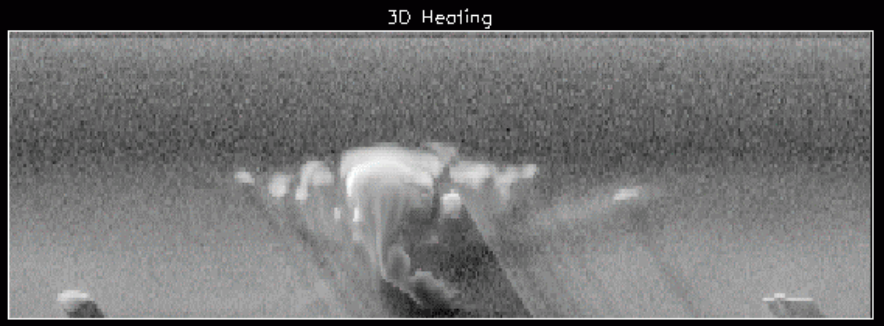
3D – accumulated precipitation mm

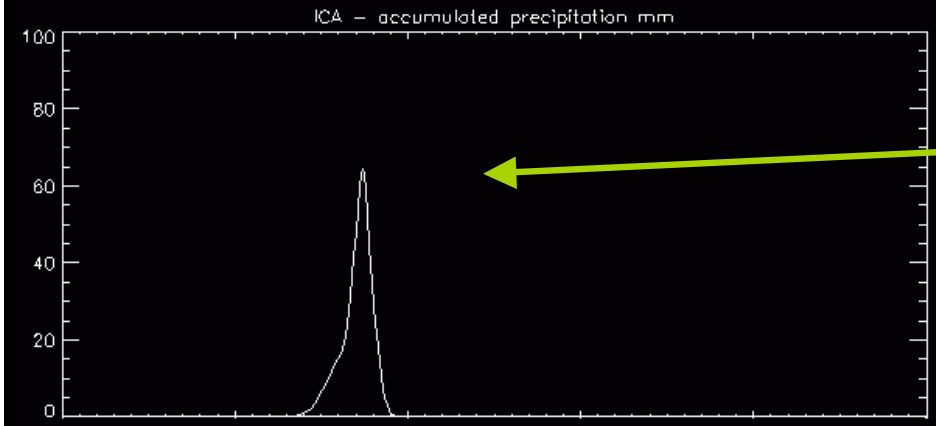


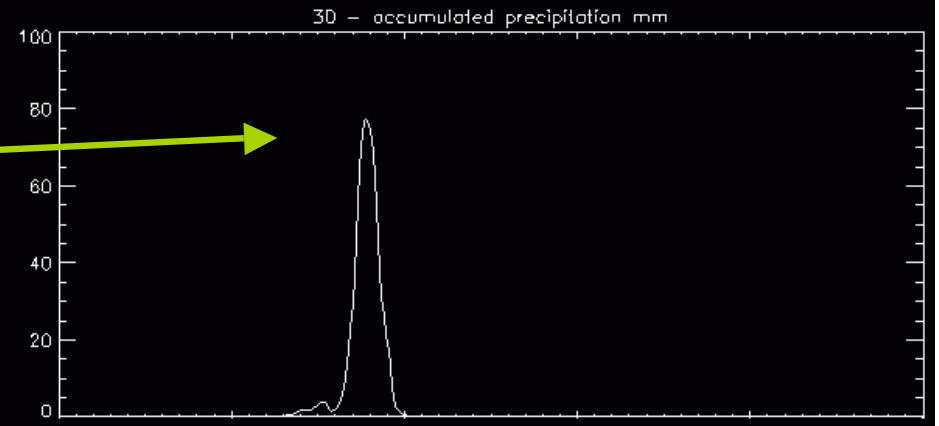
periodic boundary 110 min



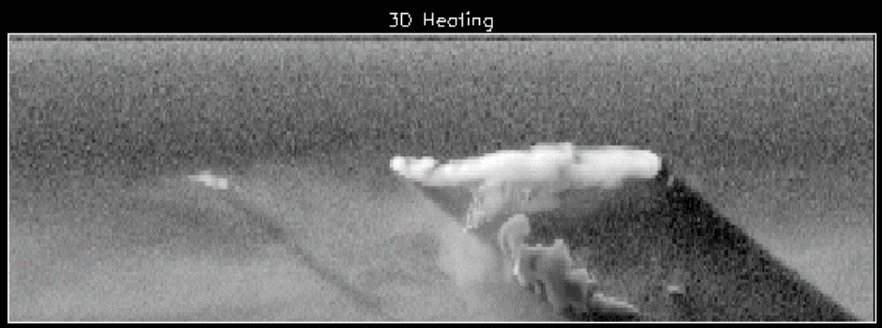


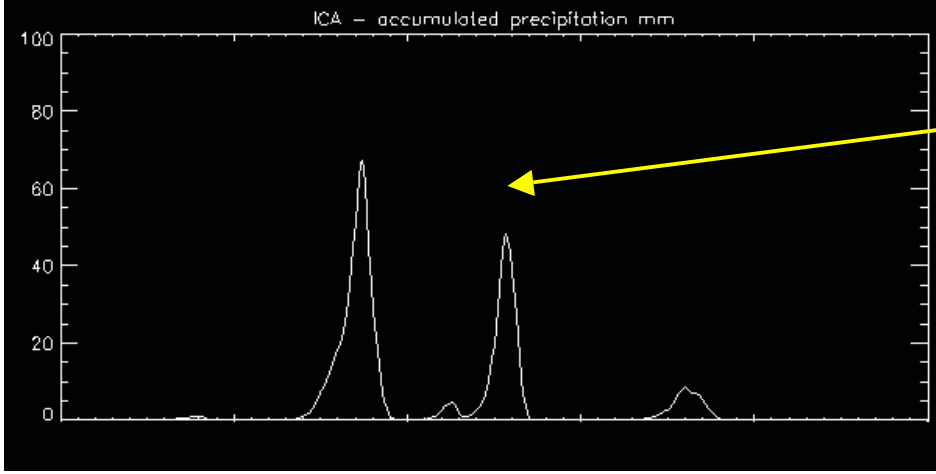


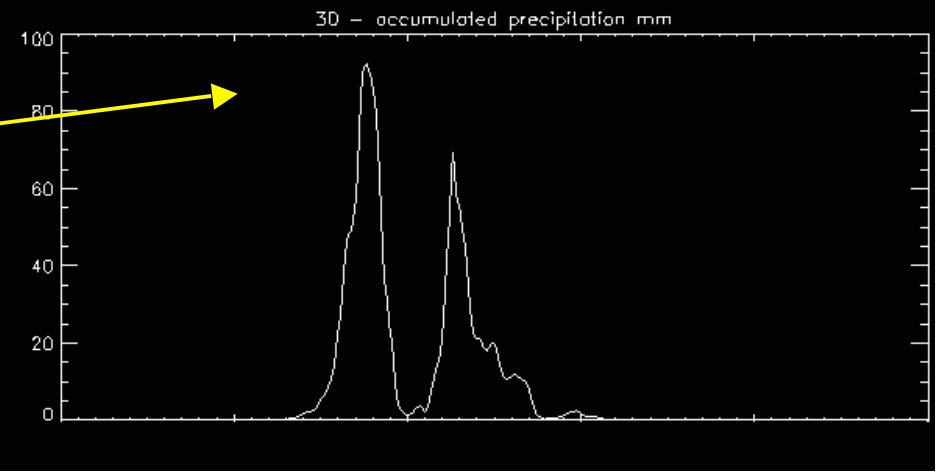




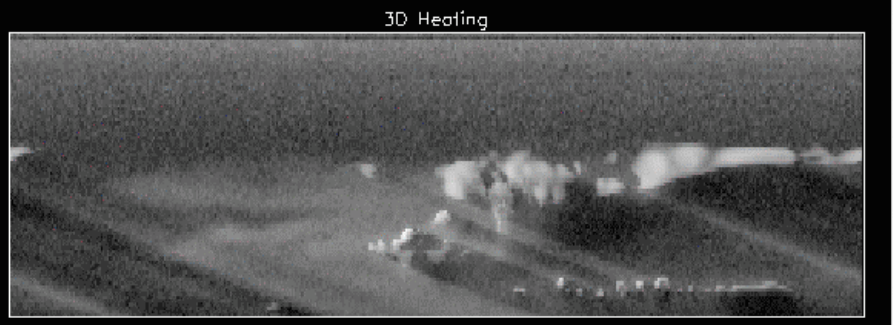
periodic boundary 195 min

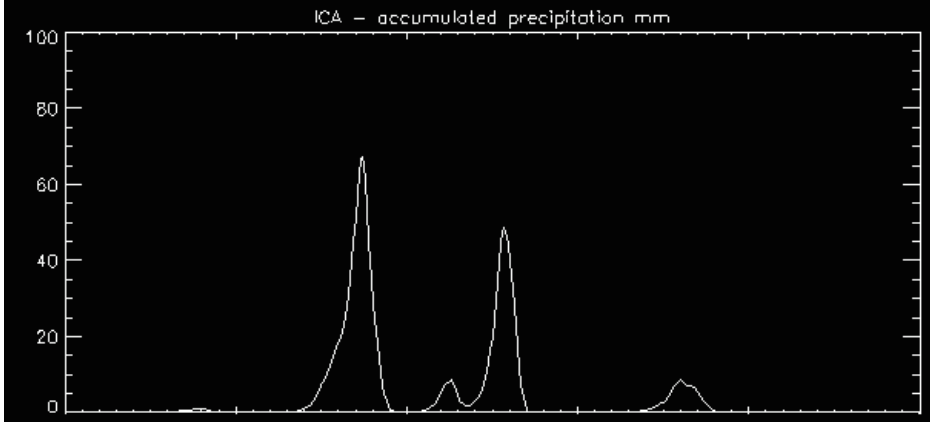


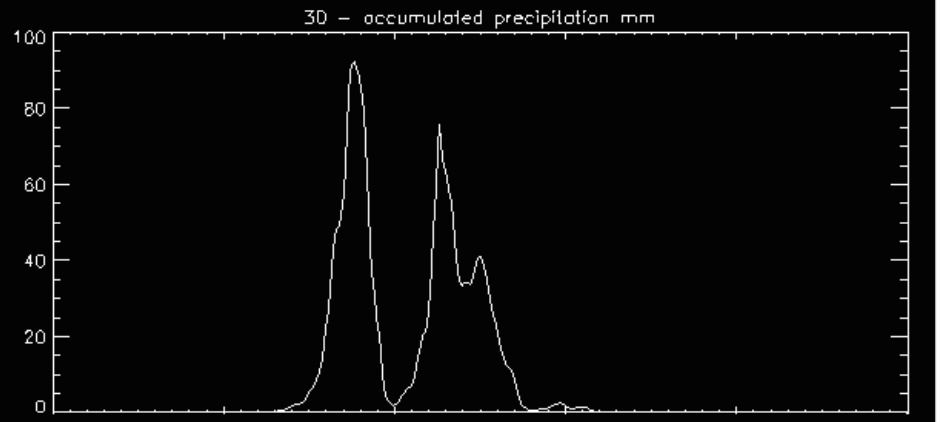




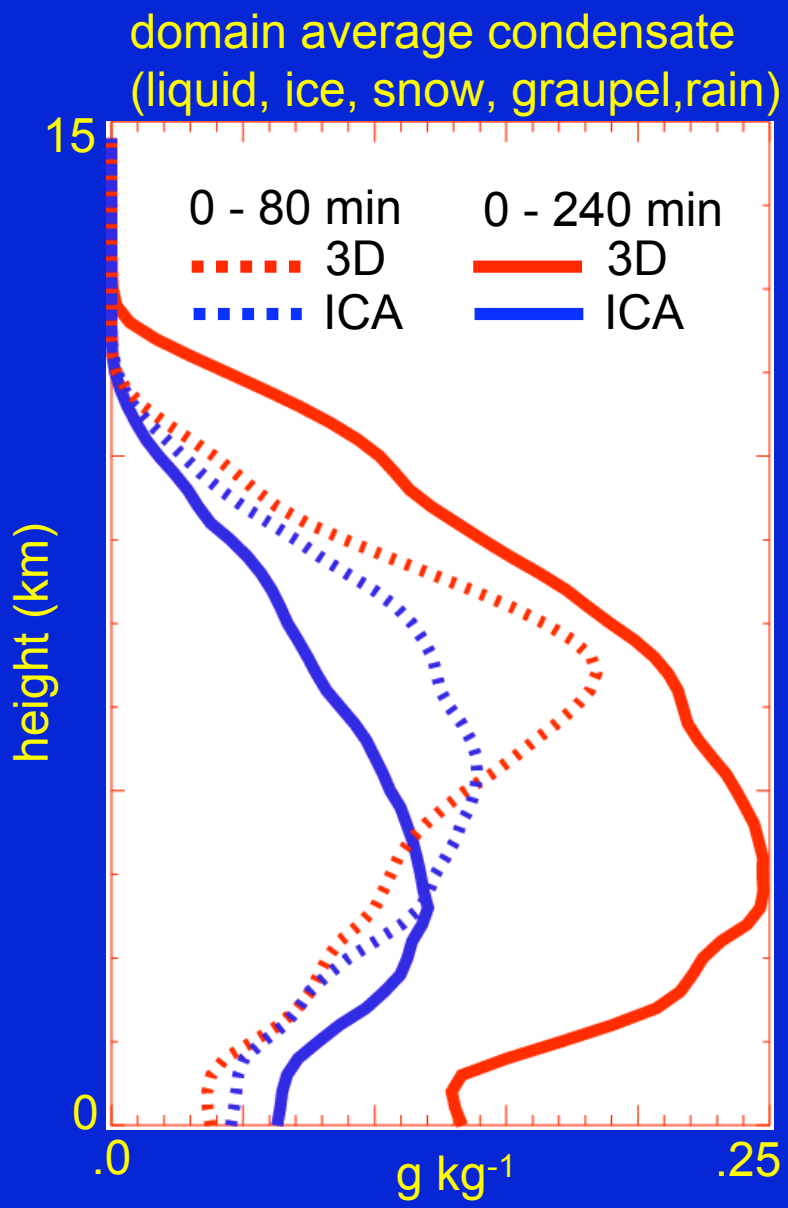
periodic boundary 220 min

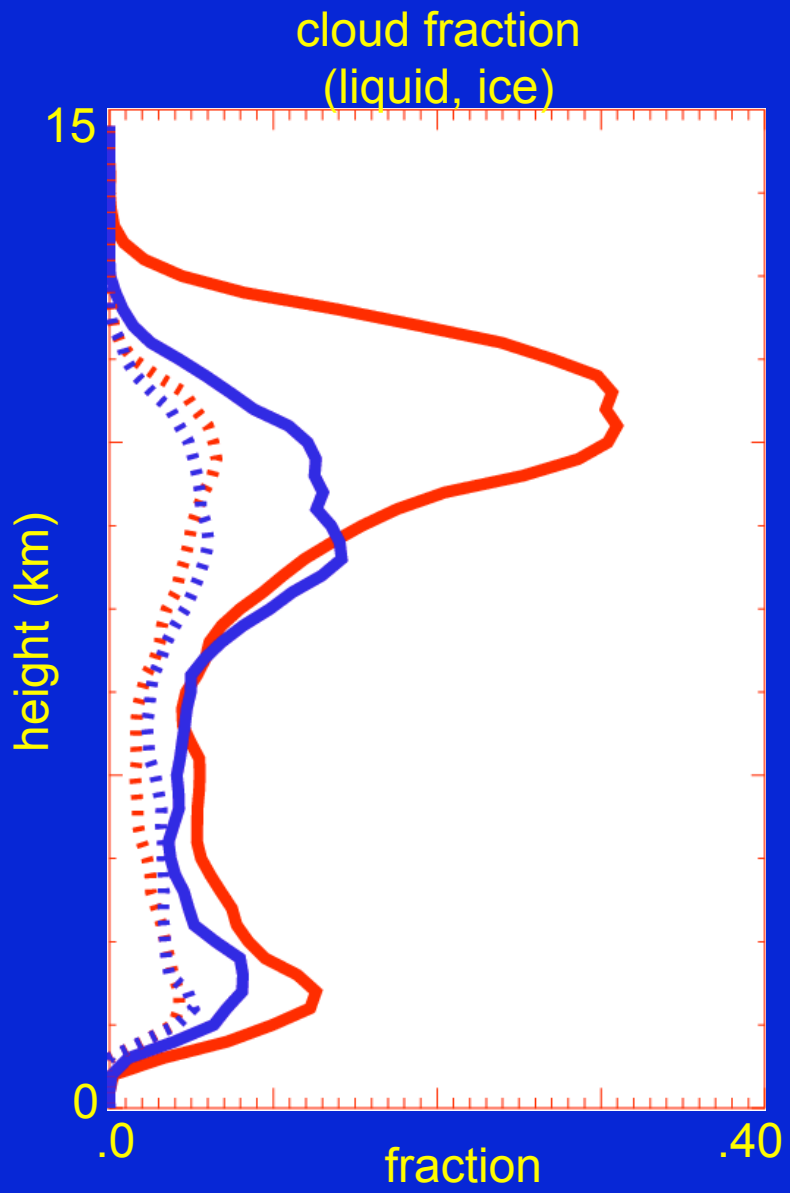




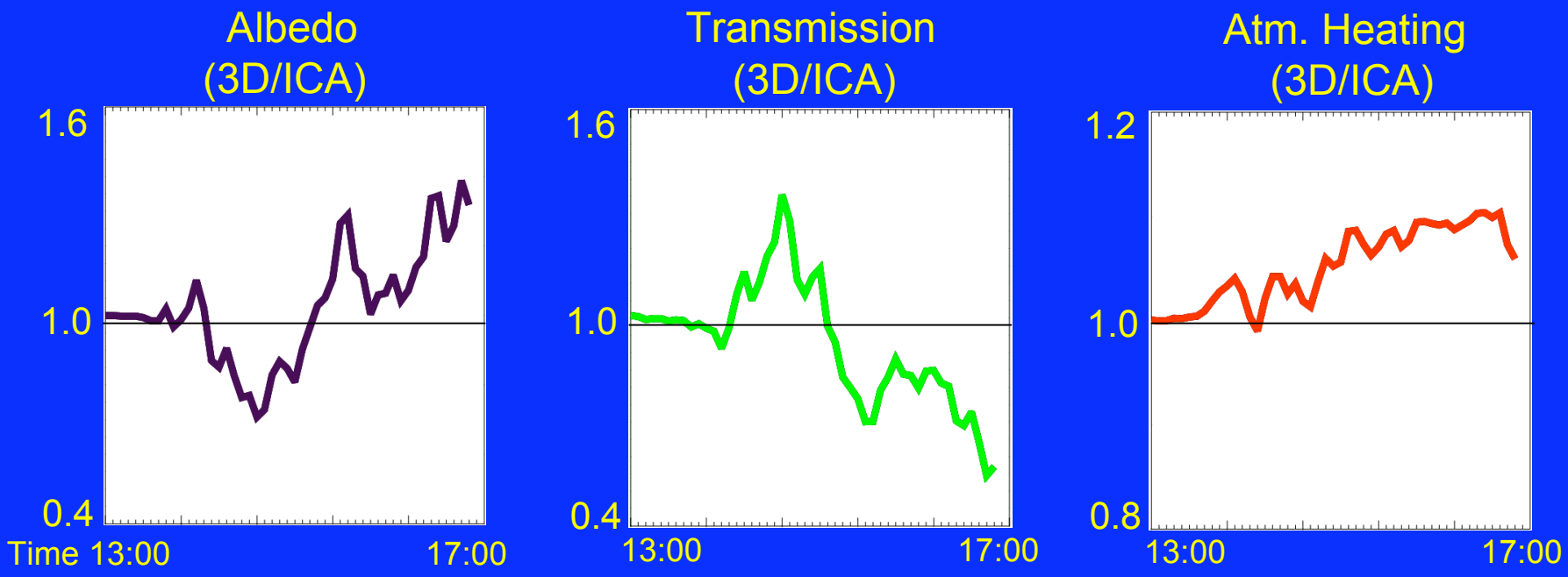


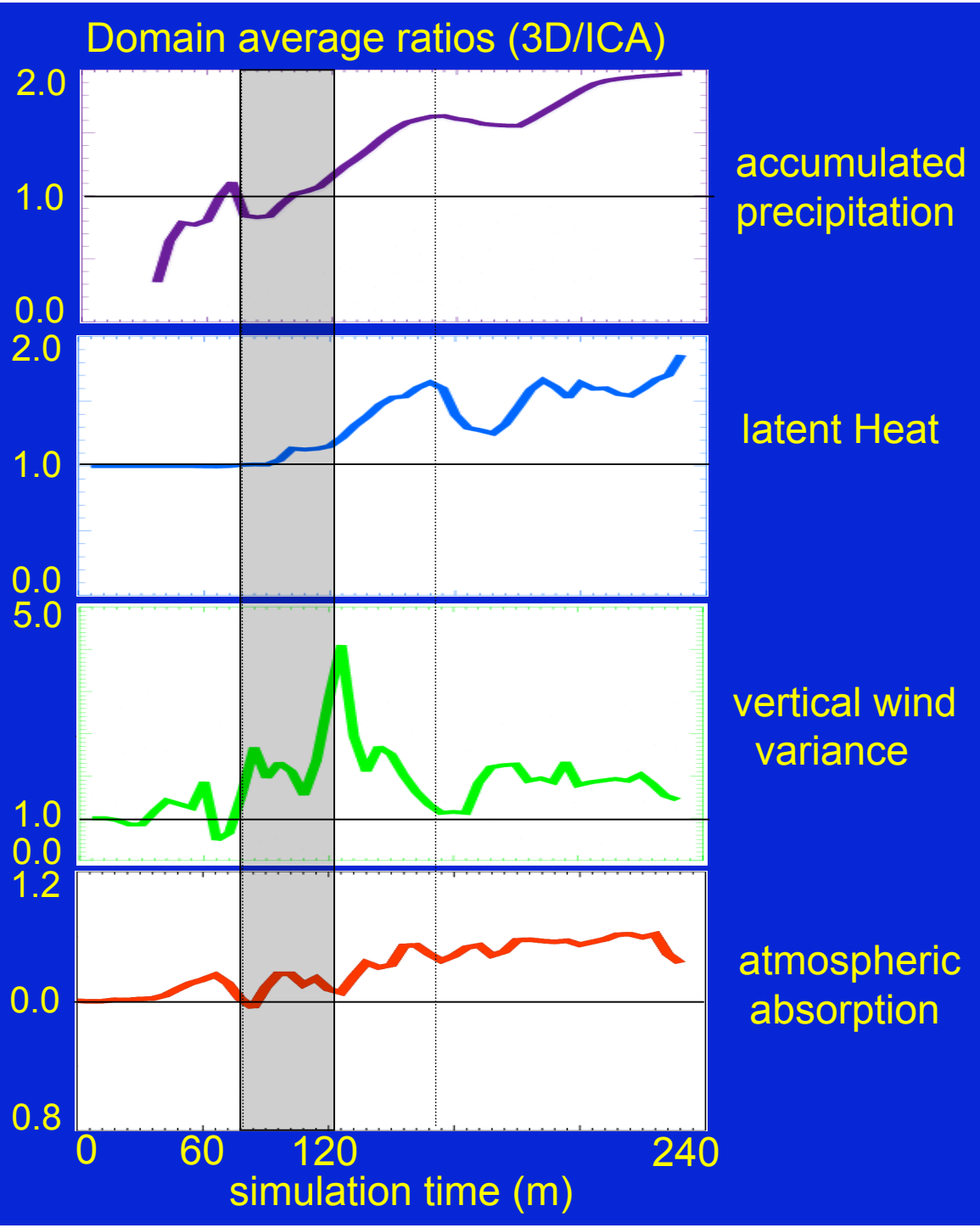
Periodic boundary

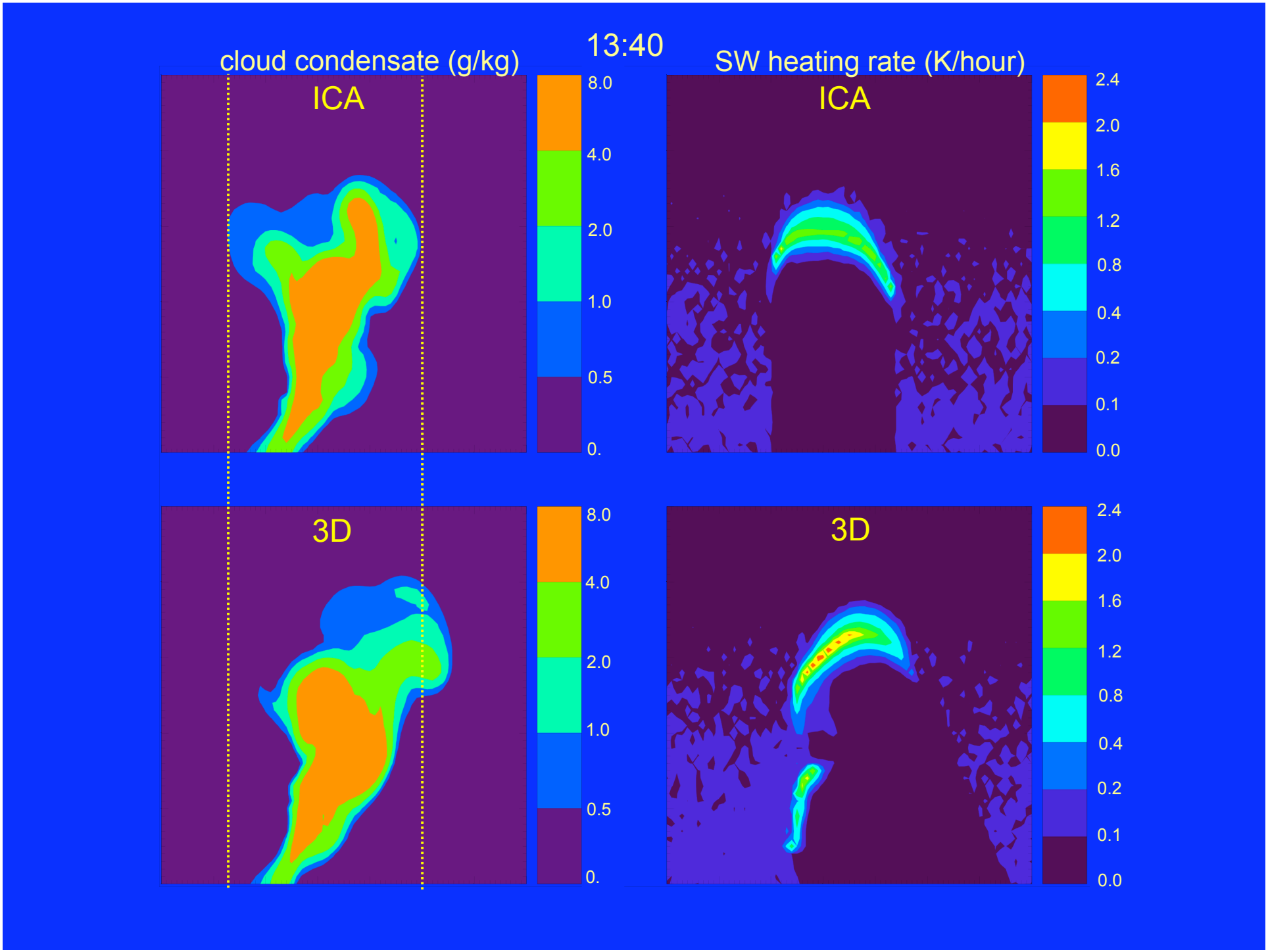


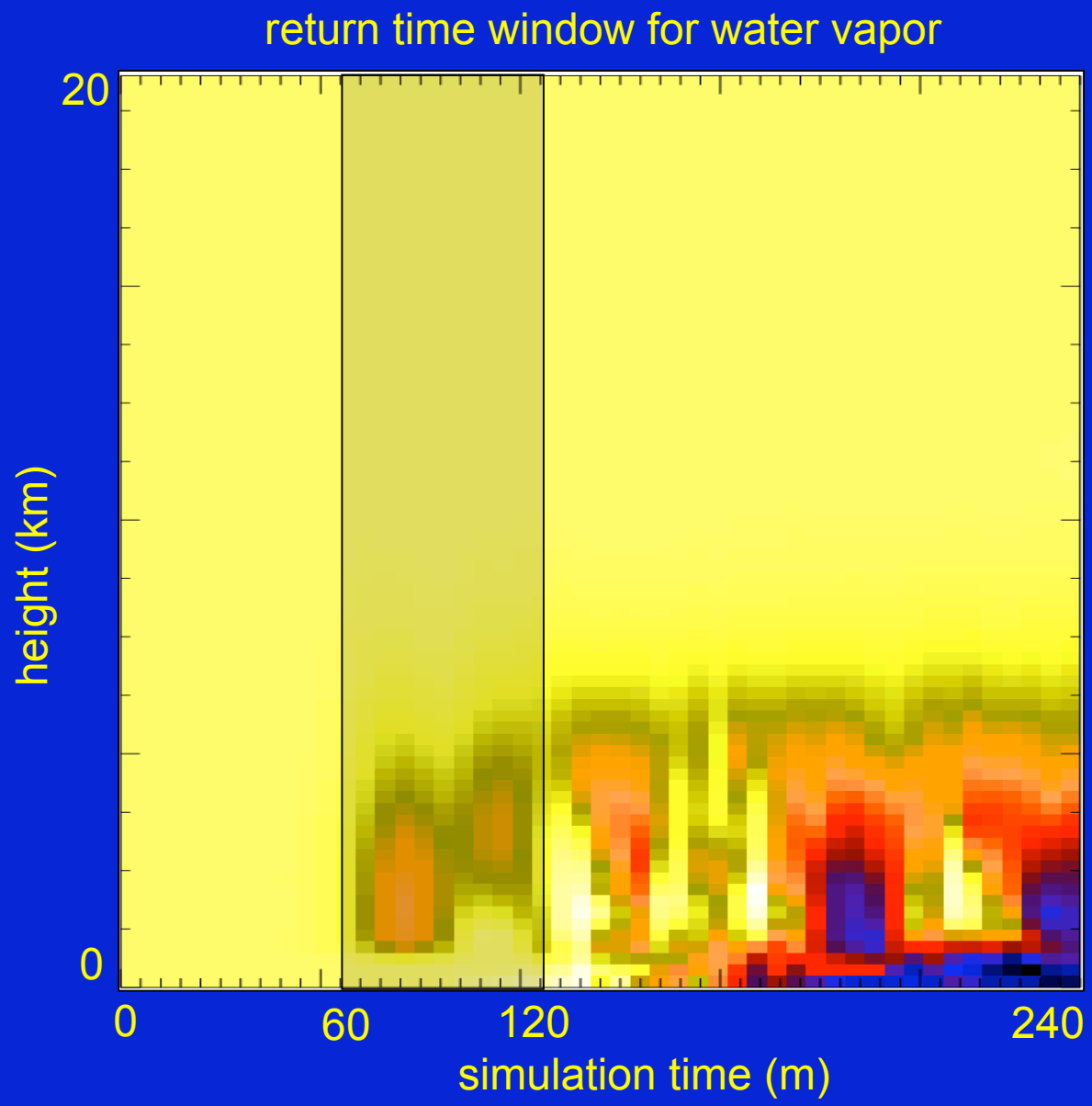


Domain Average




Domain average ratios (3D/ICA)
2.0
1.0
0.0
accumulated precipitation
2.0
1.0
0.0
latent Heat
5.0
1.0
0.0
vertical wind variance
1.2
0.0
0.8
atmospheric absorption
0
60
120
240
simulation time (m)


13:40
cloud condensate (g/kg)
ICA
3D
8.0
4.0
2.0
1.0
0.5
0.
SW heating rate (K/hour)
ICA
3D
2.4
2.0
1.6
1.2
0.8
0.4
0.2
0.1
0.0

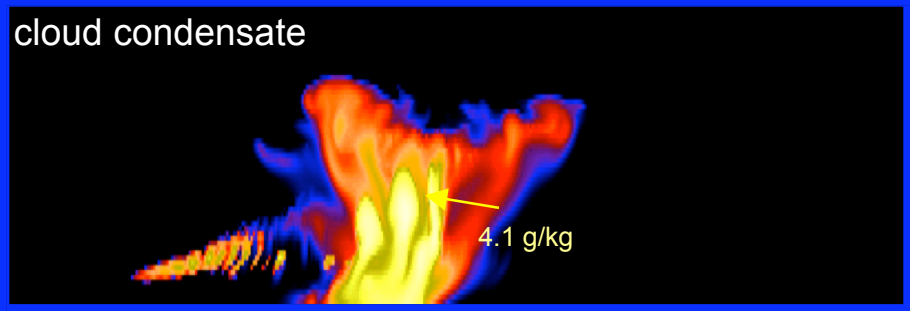


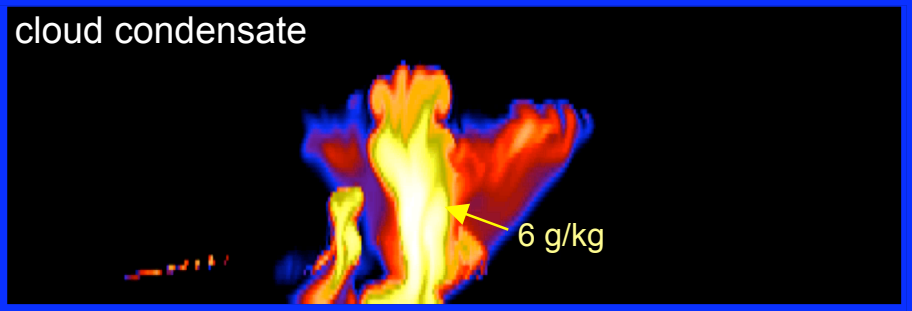
qv(t) - qv(0) at 0 km

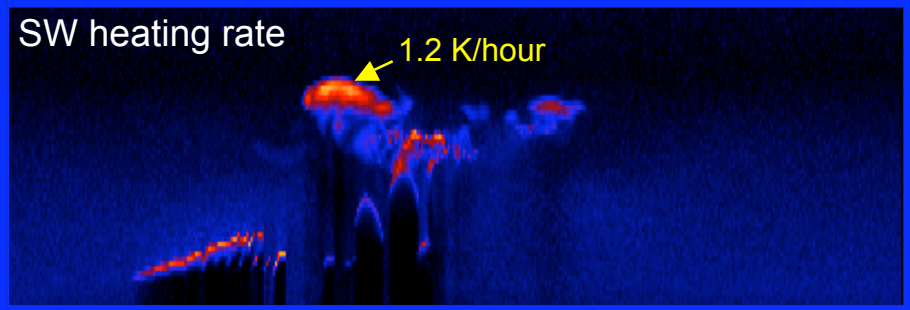
14:40

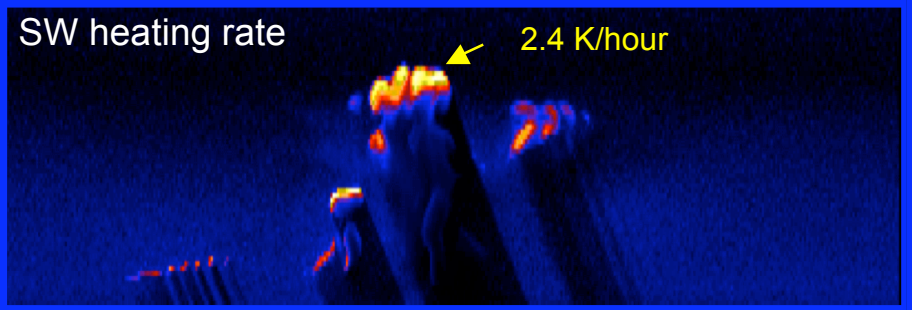
ICA

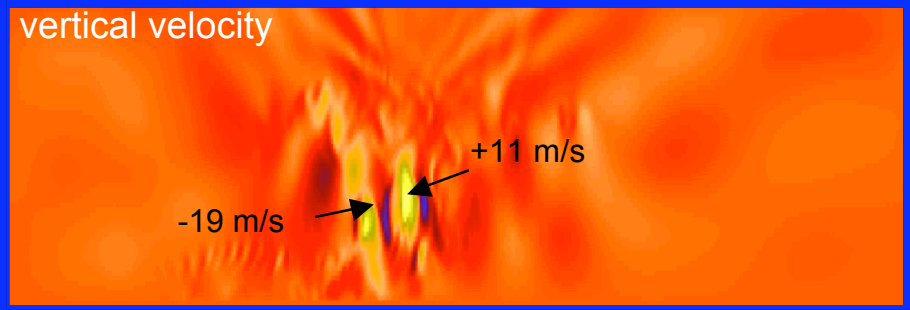
3D

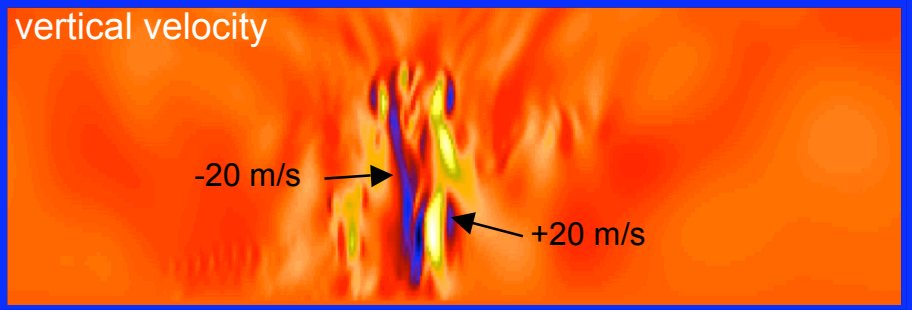






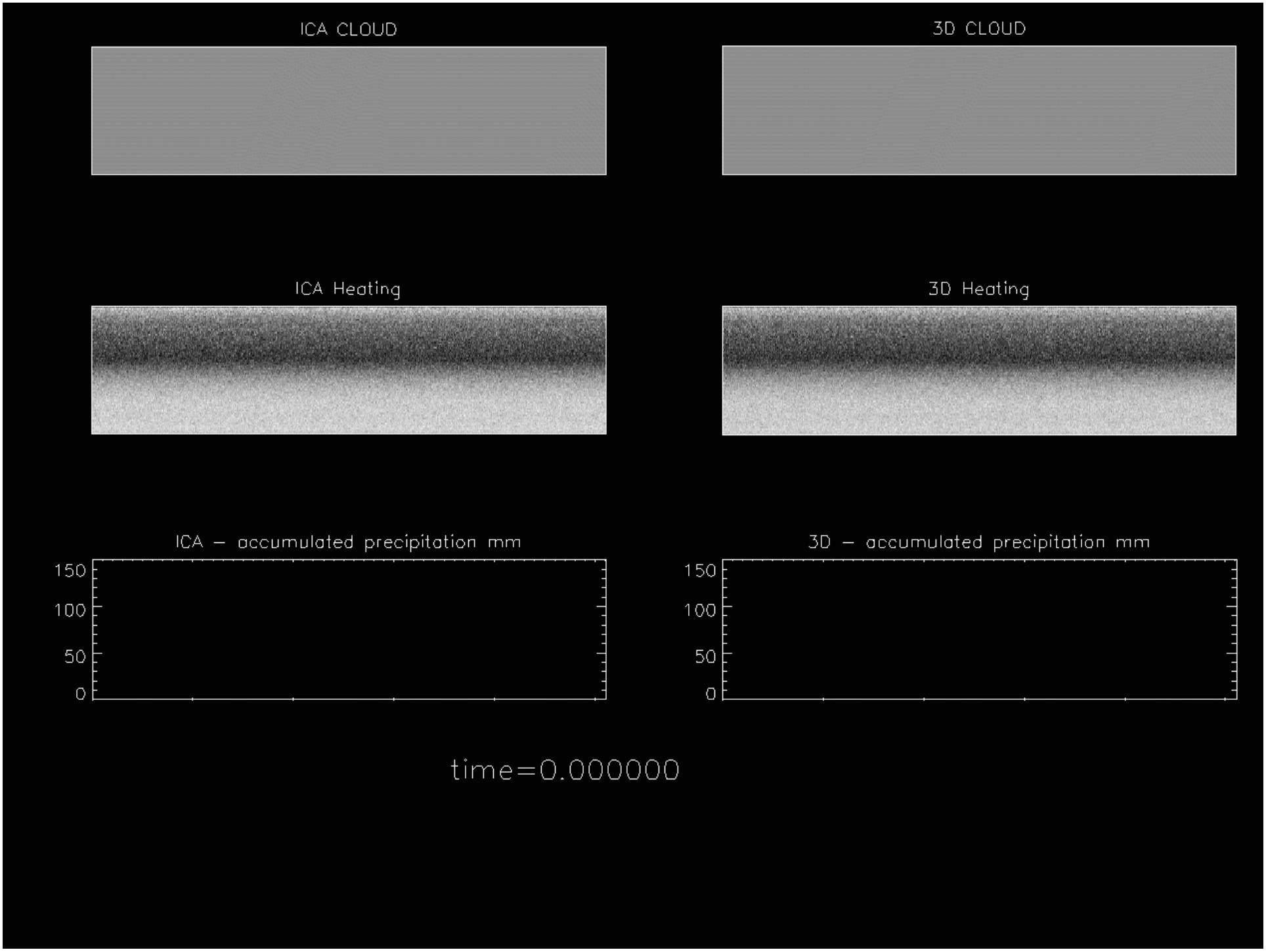






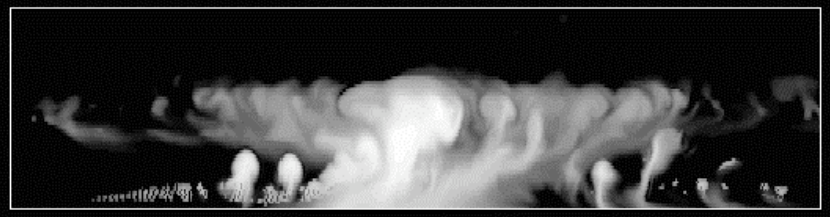
0 km 100

0 km 100

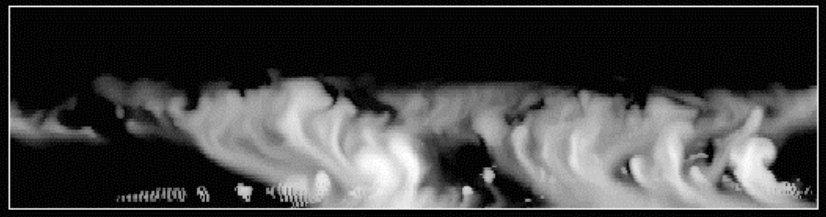

ICA CLOUD
3D CLOUD
ICA Heating
3D Heating
ICA – accumulated precipitation mm
150
100
50
0
3D – accumulated precipitation mm
150
100
50
0
time=0.000000

open boundary 120 min

ICA CLOUD



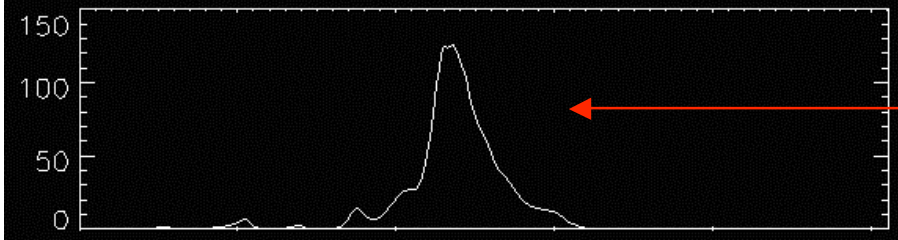
3D CLOUD



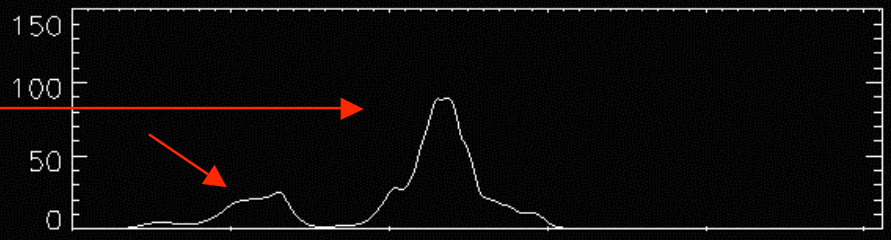
ICA Heating

3D Heating

ICA – accumulated precipitation mm



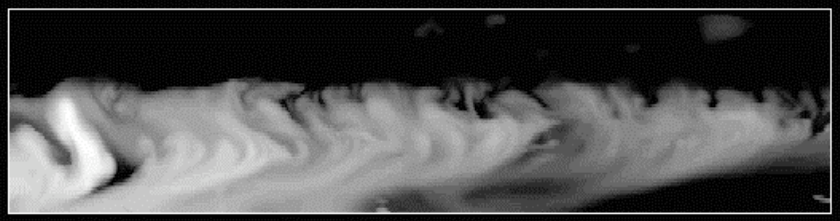
3D – accumulated precipitation mm



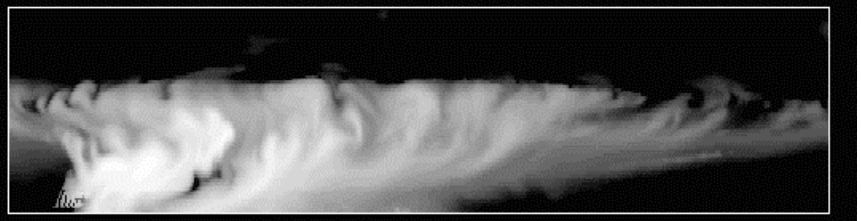
time=120.000

open boundary 240 min

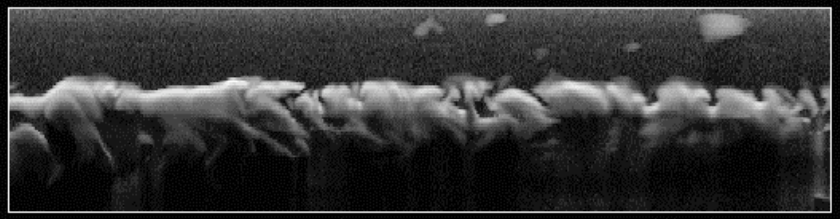
ICA CLOUD



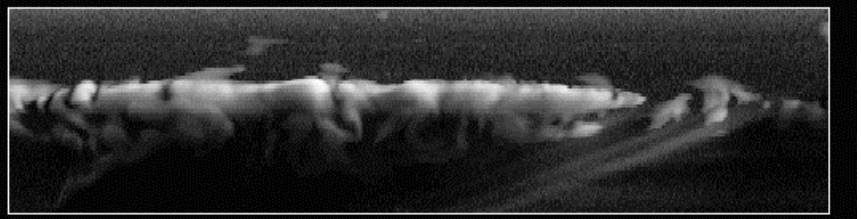
3D CLOUD



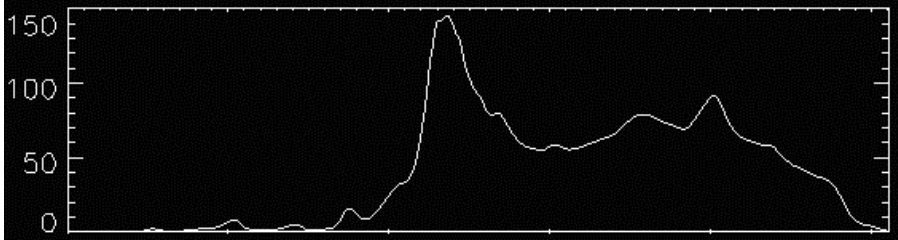
ICA Heating



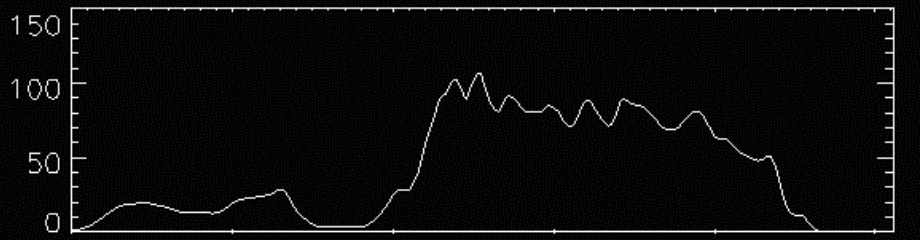
3D Heating



ICA – accumulated precipitation mm



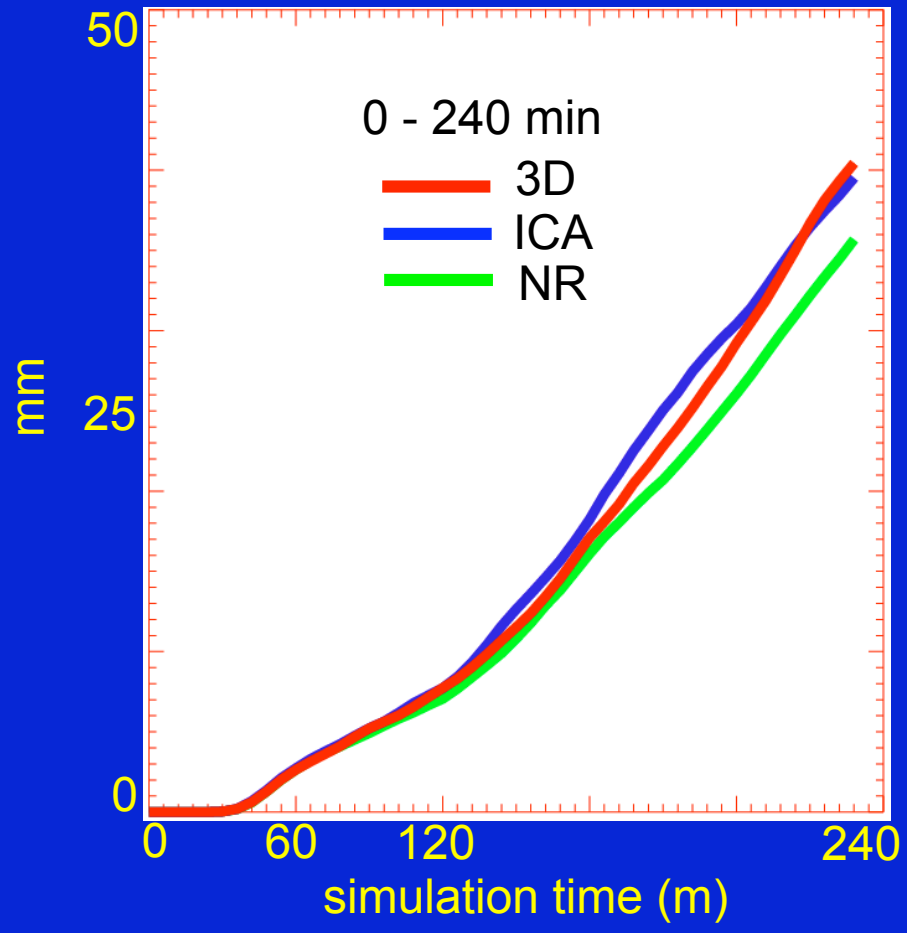
3D – accumulated precipitation mm

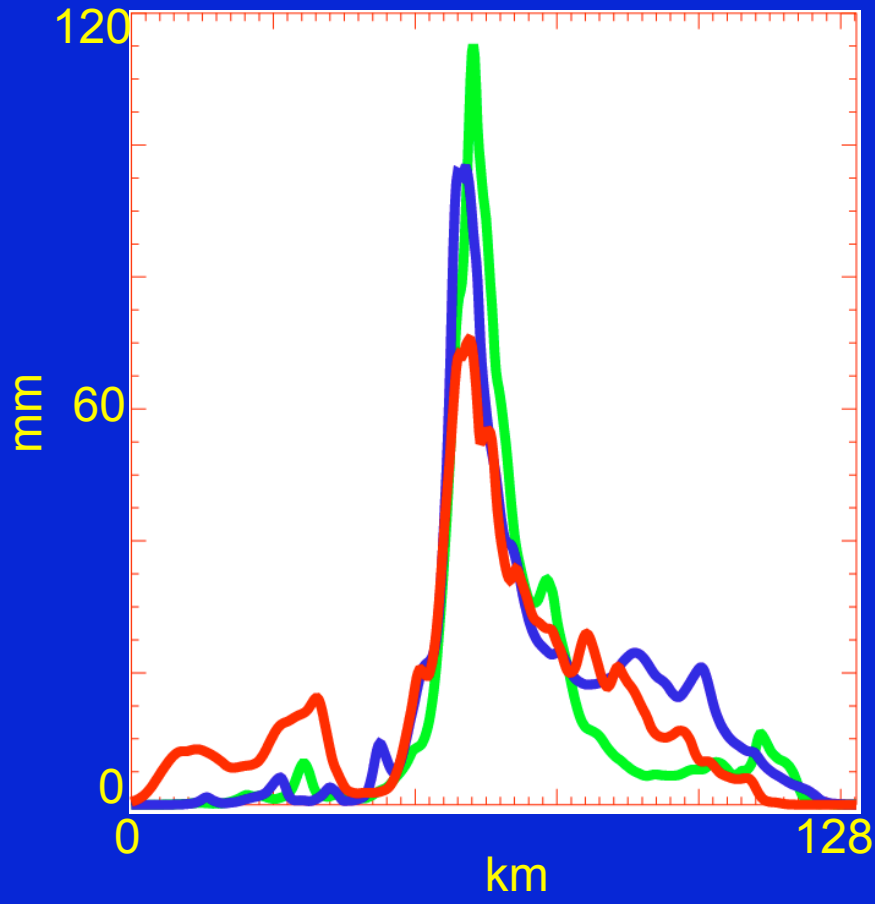


time=240.000

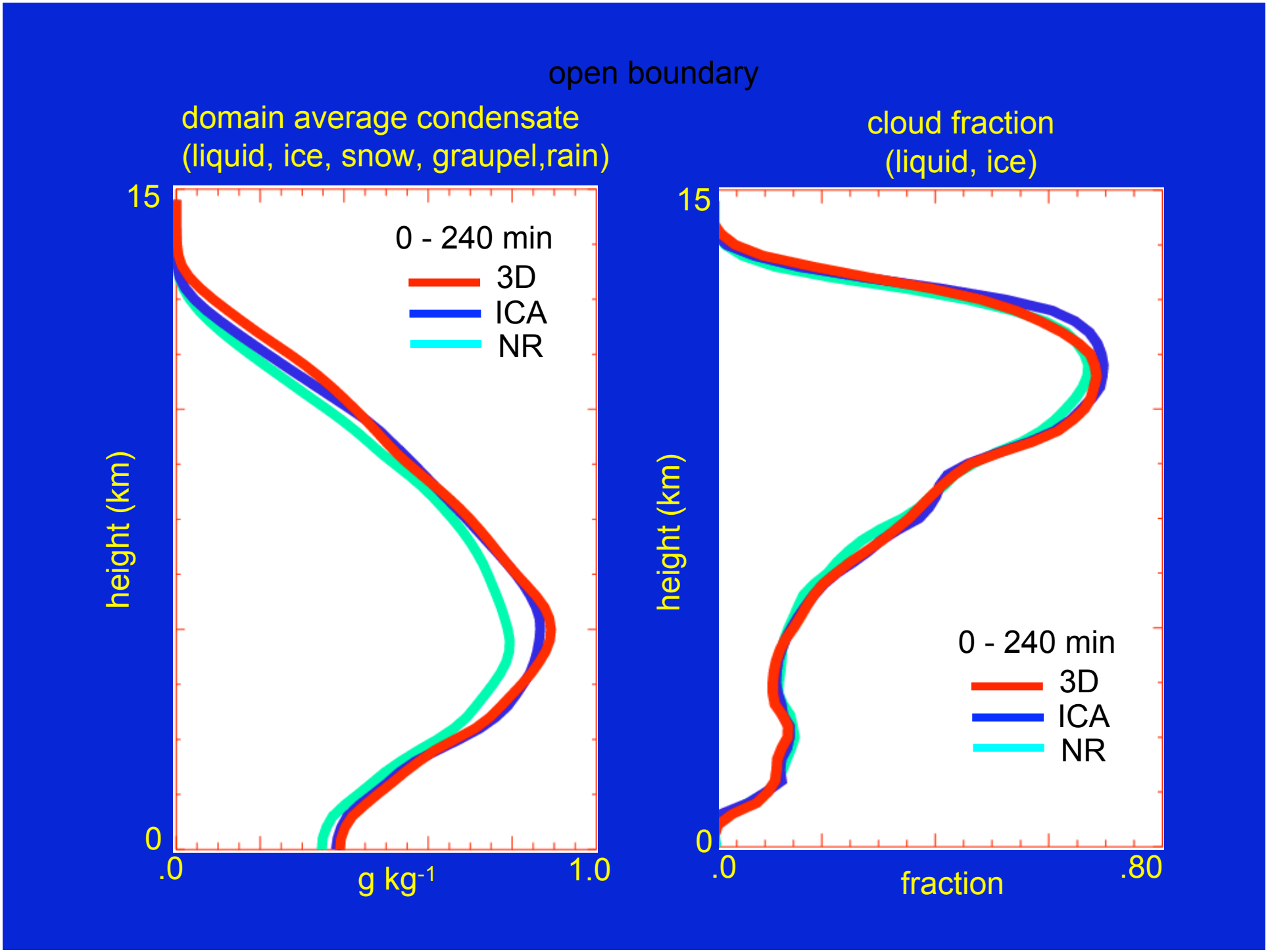
open boundary

domain average accumulated precipitation



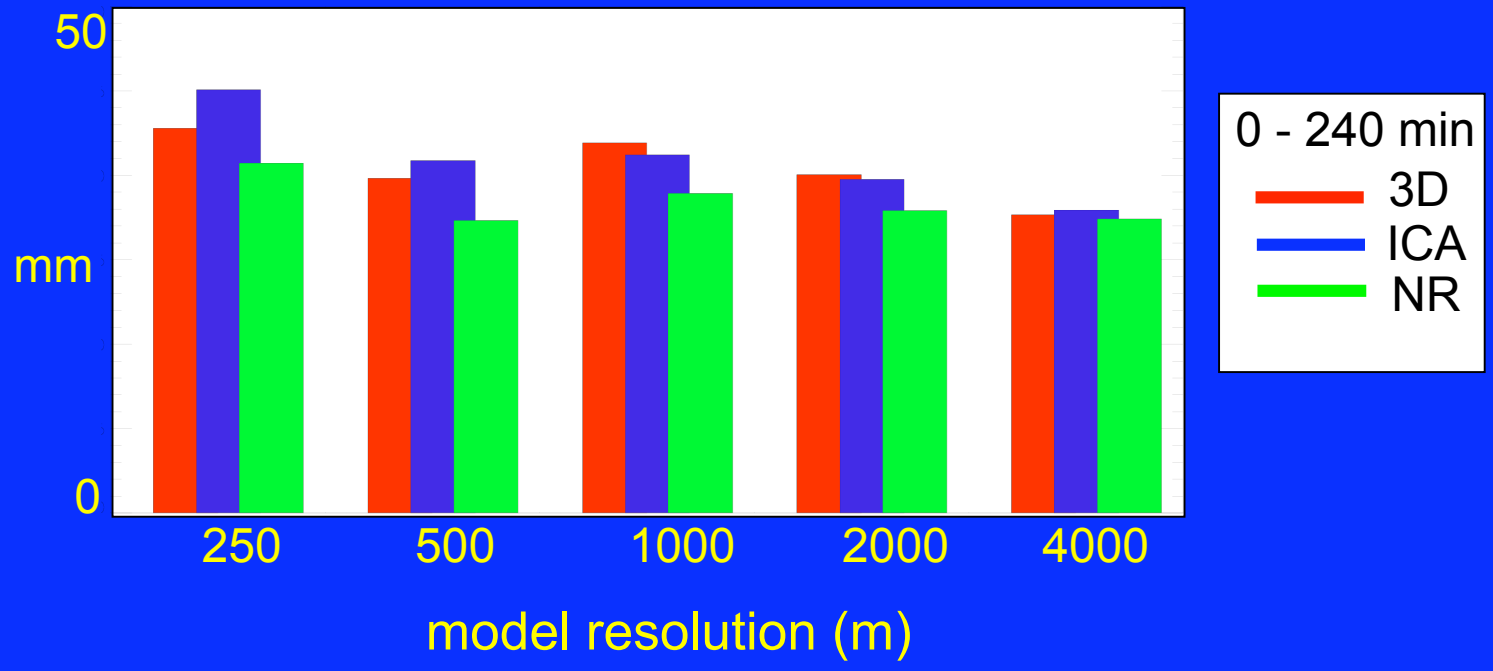


open boundary

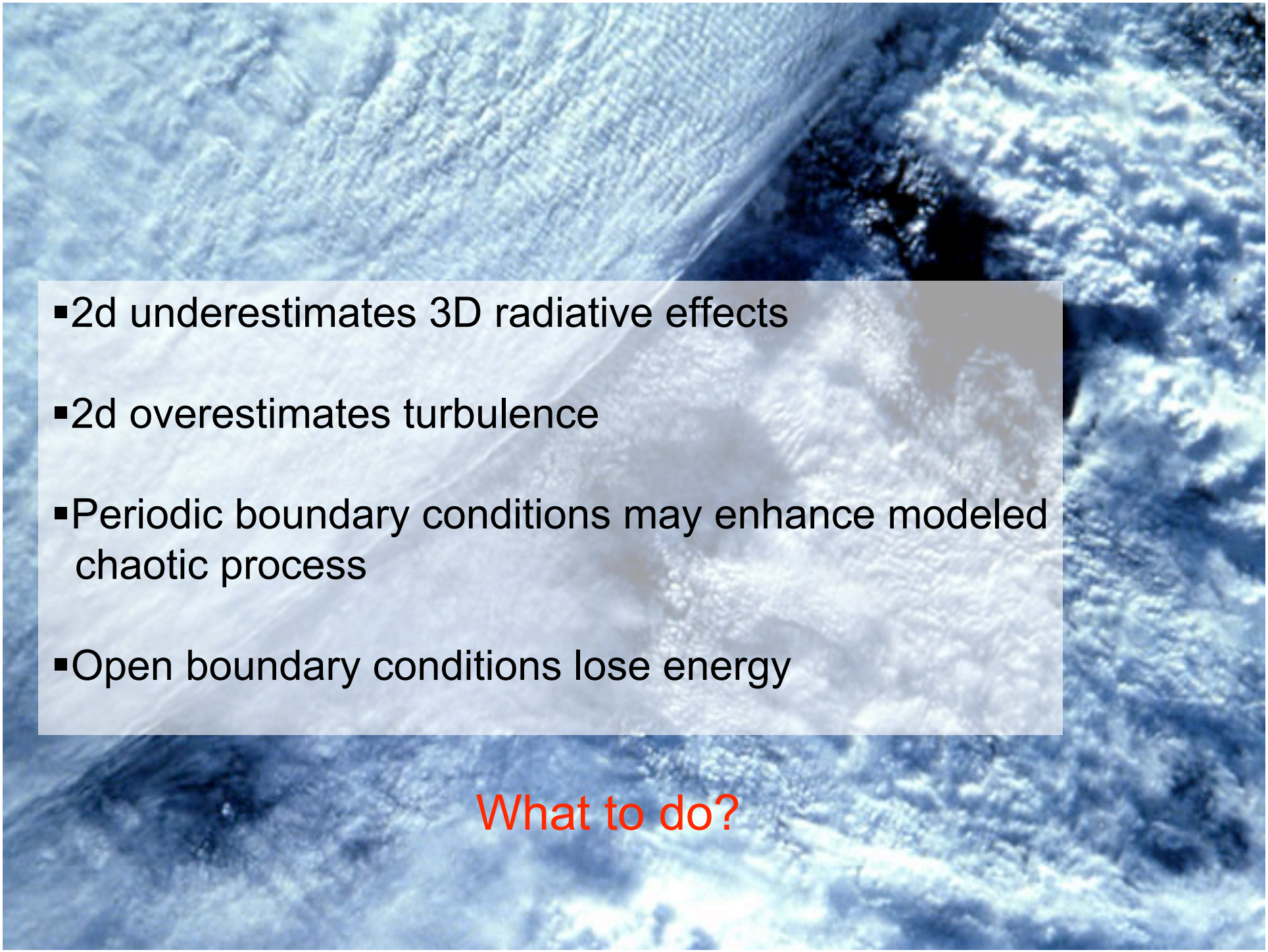


open boundary

domain average precipitation

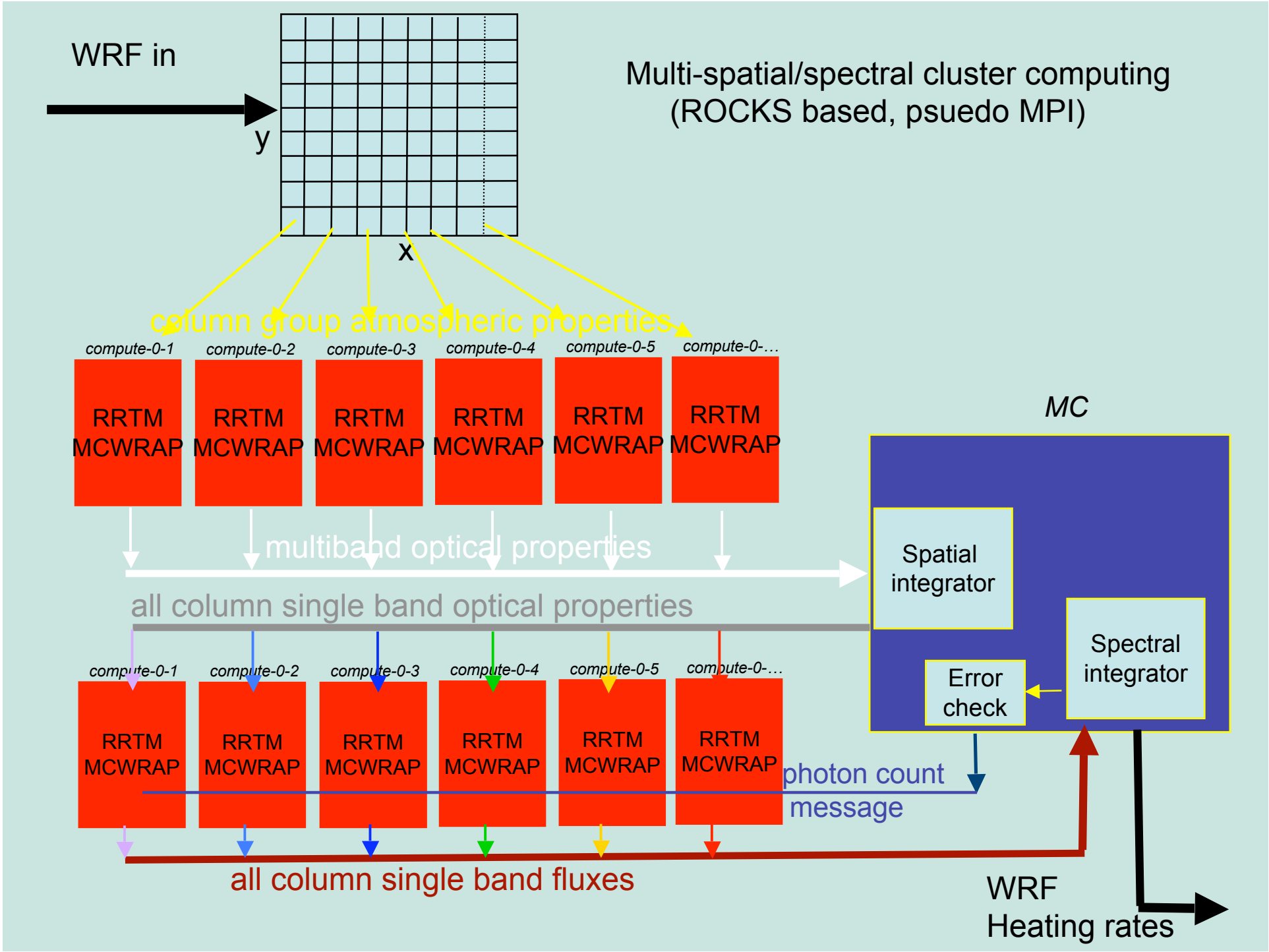


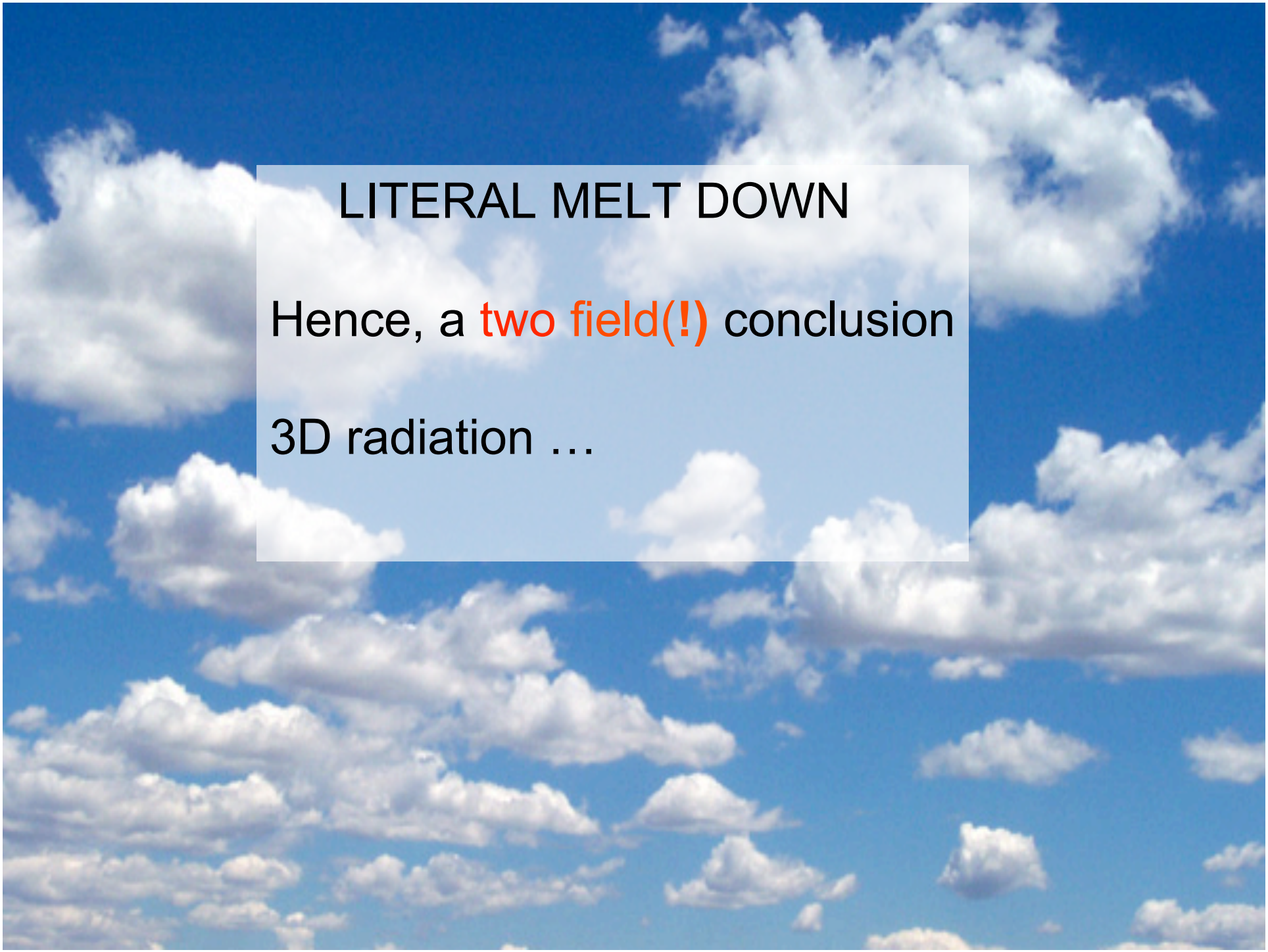
5 → 2 RT min timestep – little difference



- 2d underestimates 3D radiative effects
- 2d overestimates turbulence
- Periodic boundary conditions may enhance modeled chaotic process
- Open boundary conditions lose energy

What to do?


WRF in
y
x
Multi-spatial/spectral cluster computing
(ROCKS based, psuedo MPI)
column group atmospheric properties
compute-0-1
compute-0-2
compute-0-3
compute-0-4
compute-0-5
compute-0-…
RRTM MCWRAP
MC
Spatial integrator
Spectral integrator
Error check
multiband optical properties
all column single band optical properties
photon count message
all column single band fluxes
WRF Heating rates


LITERAL MELT DOWN
Hence, a two field(!) conclusion
3D radiation …