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

(horizontal transport)
SZA = 45

Surf ↓ 3D < ICA
TOA ↑ 3D > ICA
ABS 3D > ICA
3D shortwave radiative effects tend to cancel on the scale of GCMs.
Shortwave heating rate (K/hour)

ICA

3D

3D-ICA

12 km

0 km

0 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

Toa upwelling, surface downwelling irradiances, atmospheric heating rates

RRTM_SW
16 Band k-distribution

Monte Carlo 5 % column accuracy
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
MONTE CARLO
TAU OPT. PROP
COLUMN STORAGE

READ ATM, CLOUD, AER PROFILES & COMPUTE COLUMN OPTICS.

DISORT

TAU OPT. PROP COLUMN STORAGE

MONTE CARLO

ERROR

ICA out*

3D out

cloud field

column loop

band loop

*For experiments ICA performed by Monte Carlo
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
periodic boundary 35 min
periodic boundary 55 min
periodic boundary 195 min
periodic boundary 220 min
Periodic boundary

domain average condensate
(liquid, ice, snow, graupel, rain)

cloud fraction
(liquid, ice)

0 - 80 min
0 - 240 min

3D
ICA

height (km)

0 - 80 min
0 - 240 min

3D
ICA

height (km)

g kg$^{-1}$

fraction
Albedo (3D/ICA)

Transmission (3D/ICA)

Atm. Heating (3D/ICA)

Domain Average

Time 13:00 - 17:00
Domain average ratios (3D/ICA)

- Accumulated precipitation
- Latent Heat
- Vertical wind variance
- Atmospheric absorption

Simulation time (m):

- 0
- 60
- 120
- 240
return time window for water vapor

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

time=240,000
open boundary

domain average accumulated precipitation

0 - 240 min
- 3D
- ICA
- NR

mm

simulation time (m)

km

mm

0 60 120 240

0 60 120

0 128

50

25

25
open boundary

domain average condensate (liquid, ice, snow, graupel, rain)

cloud fraction (liquid, ice)

0 - 240 min
3D
ICA
NR

height (km)

g kg$^{-1}$

fraction

height (km)

0 - 240 min
3D
ICA
NR

0.0
1.0
0.0
0.80
domain average precipitation

model resolution (m)

mm

open boundary

0 - 240 min

3D

ICA

NR

2 RT min timestep – little difference

5
- 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

Multi-spatial/spectral cluster computing
(ROCKS based, psuedo MPI)

Spatial integrator

Error check

Spectral integrator

MC

all column single band optical properties

multiband optical properties

column group atmospheric properties

compute-0-1 RRTM MCWRAP
compute-0-2 RRTM MCWRAP
compute-0-3 RRTM MCWRAP
compute-0-4 RRTM MCWRAP
compute-0-5 RRTM MCWRAP
compute-0-…

WRF Heating rates

Spatial

Error check

Spectral integrator

MC

all column single band fluxes

compute-0-1 RRTM MCWRAP
compute-0-2 RRTM MCWRAP
compute-0-3 RRTM MCWRAP
compute-0-4 RRTM MCWRAP
compute-0-5 RRTM MCWRAP
compute-0-…

photon count message
LITERAL MELT DOWN

Hence, a two field(!) conclusion

3D radiation …