SHDOMPPDA
A Radiative Transfer Tool for Data Assimilation

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Project: *Efficient all-weather (cloudy and clear) observational operator for satellite radiance data assimilation*

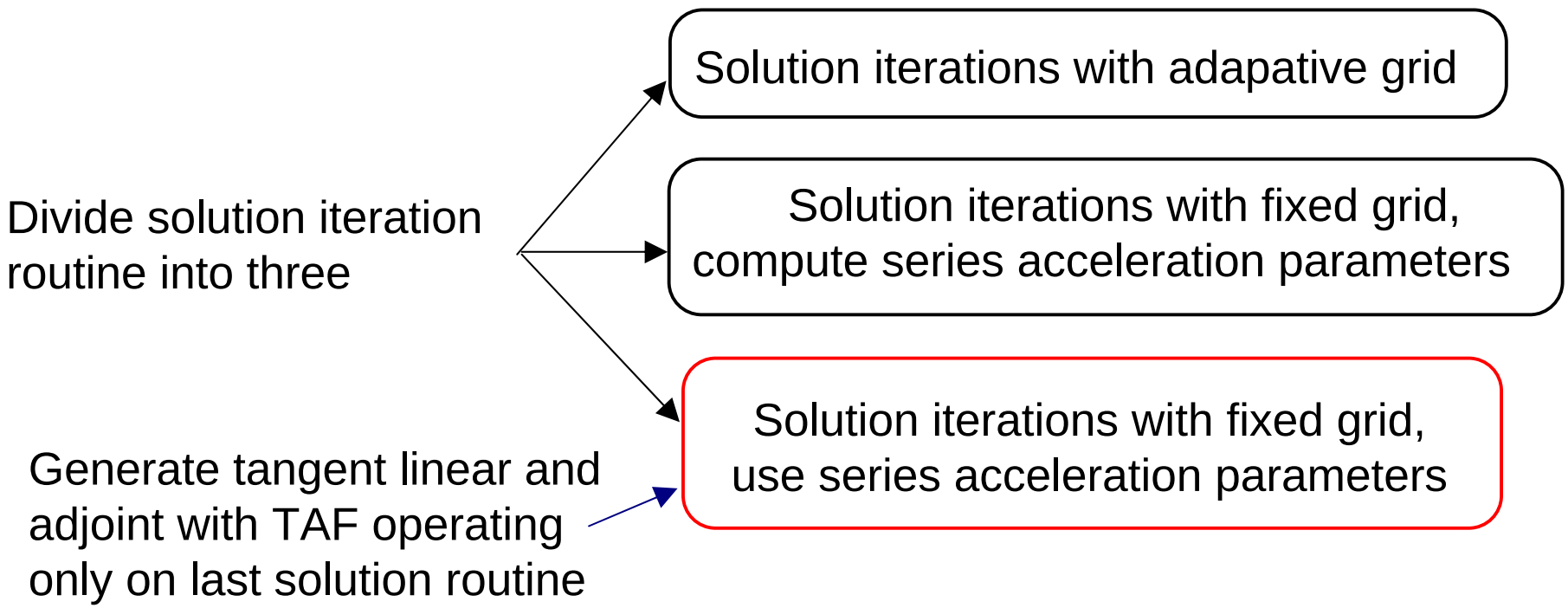
Goal: Flexible, fast, and accurate forward and adjoint models for cloudy scattering radiative transfer

Based on SHDOMPP forward model:

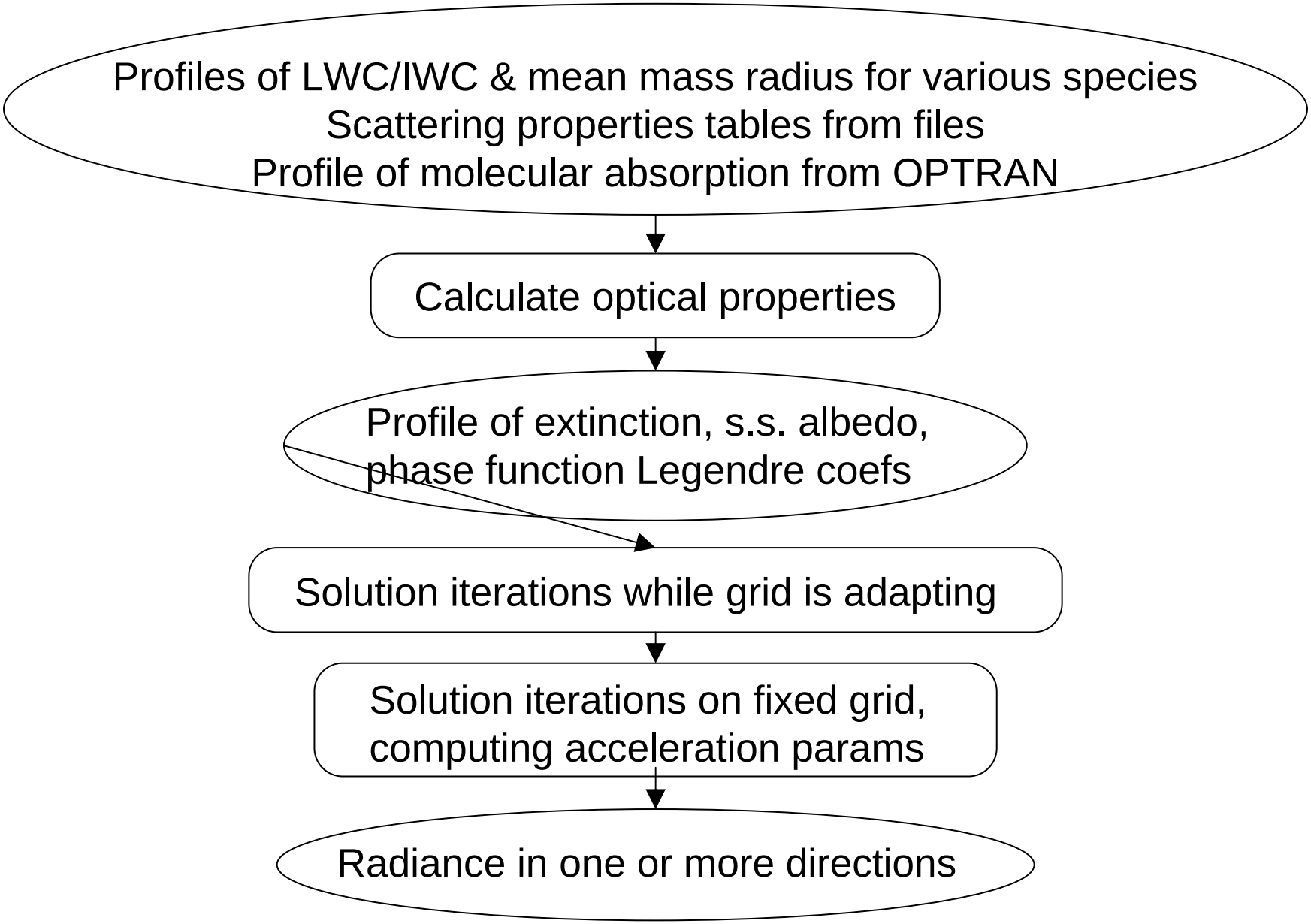
- Solves solar and/or thermal emission RT
- Arbitrary accuracy depending on angular and spatial resolution parameters chosen
- SHDOM modified for plane-parallel RT
- Source function represented with spherical harmonics on an optical depth grid
- Solution method: source function iteration using spherical harmonics and discrete ordinates
- Automatic adaptive layers to minimize error

Building the SHDOMPPDA Adjoint

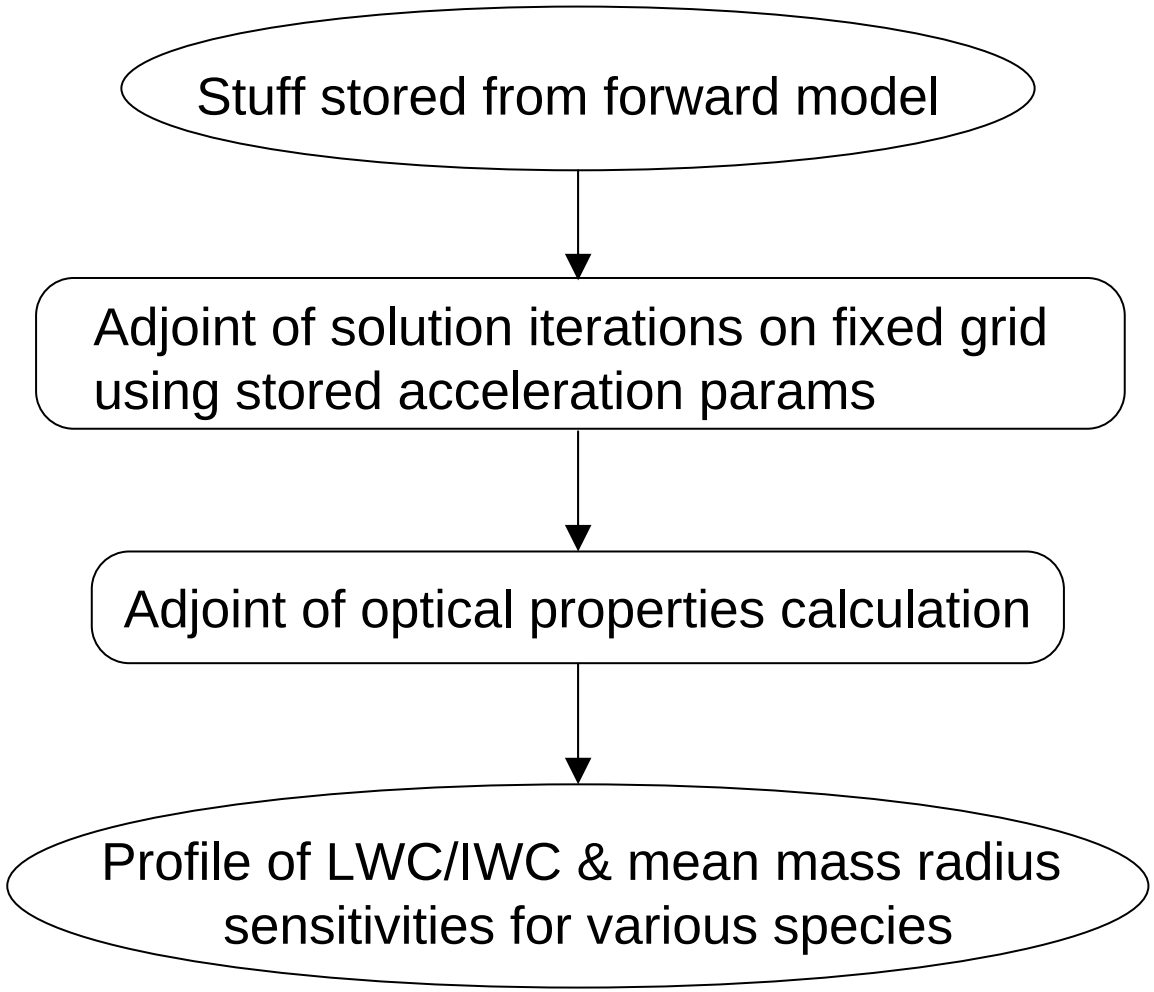
Philosophy: minimize hand coding of adjoint by modifying forward model to persuade TAF compiler to generate a decent adjoint



The SHDOMPPDA Forward Flow



The SHDOMPPDA Adjoint Flow



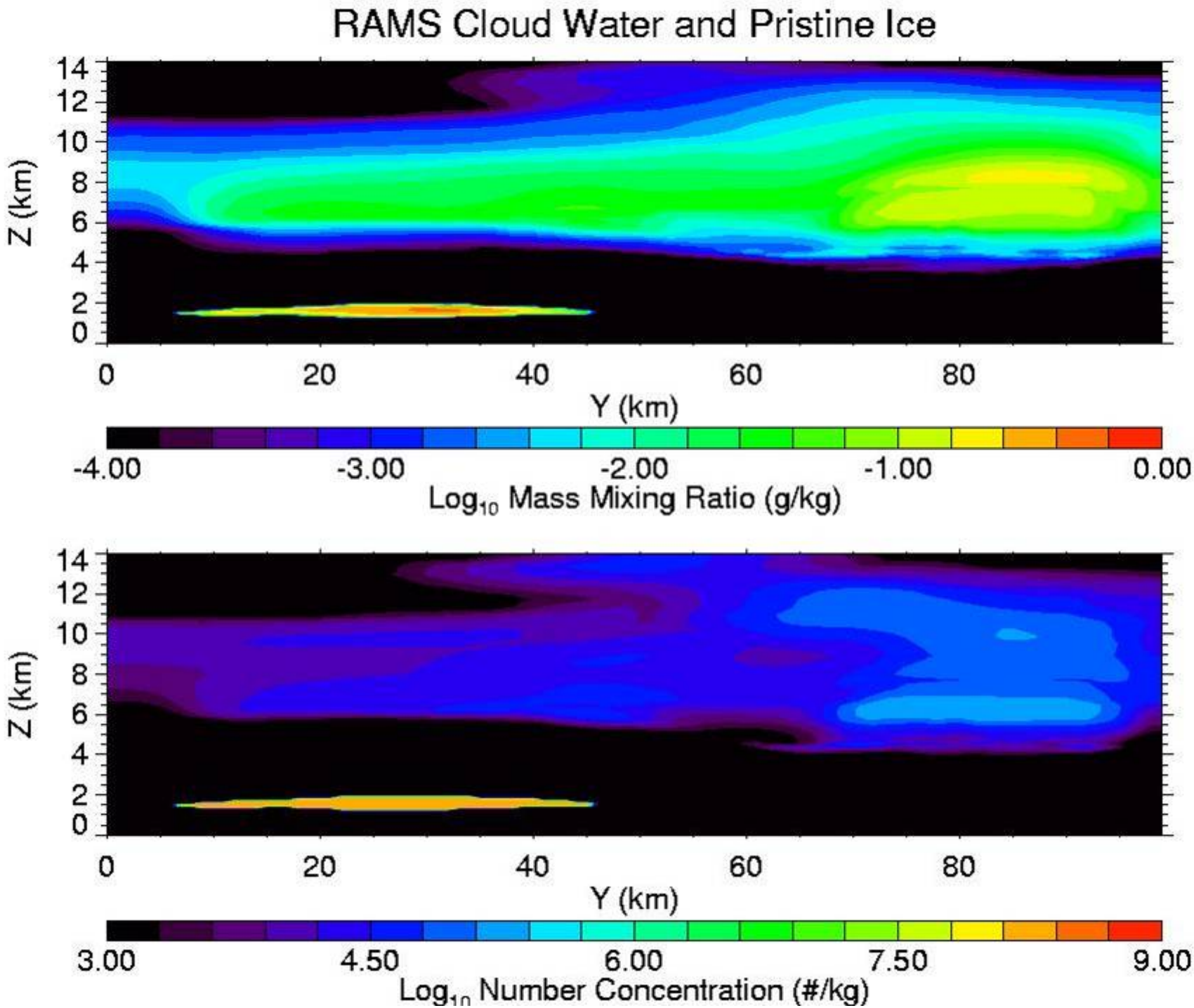
Testing SHDOMPPDA

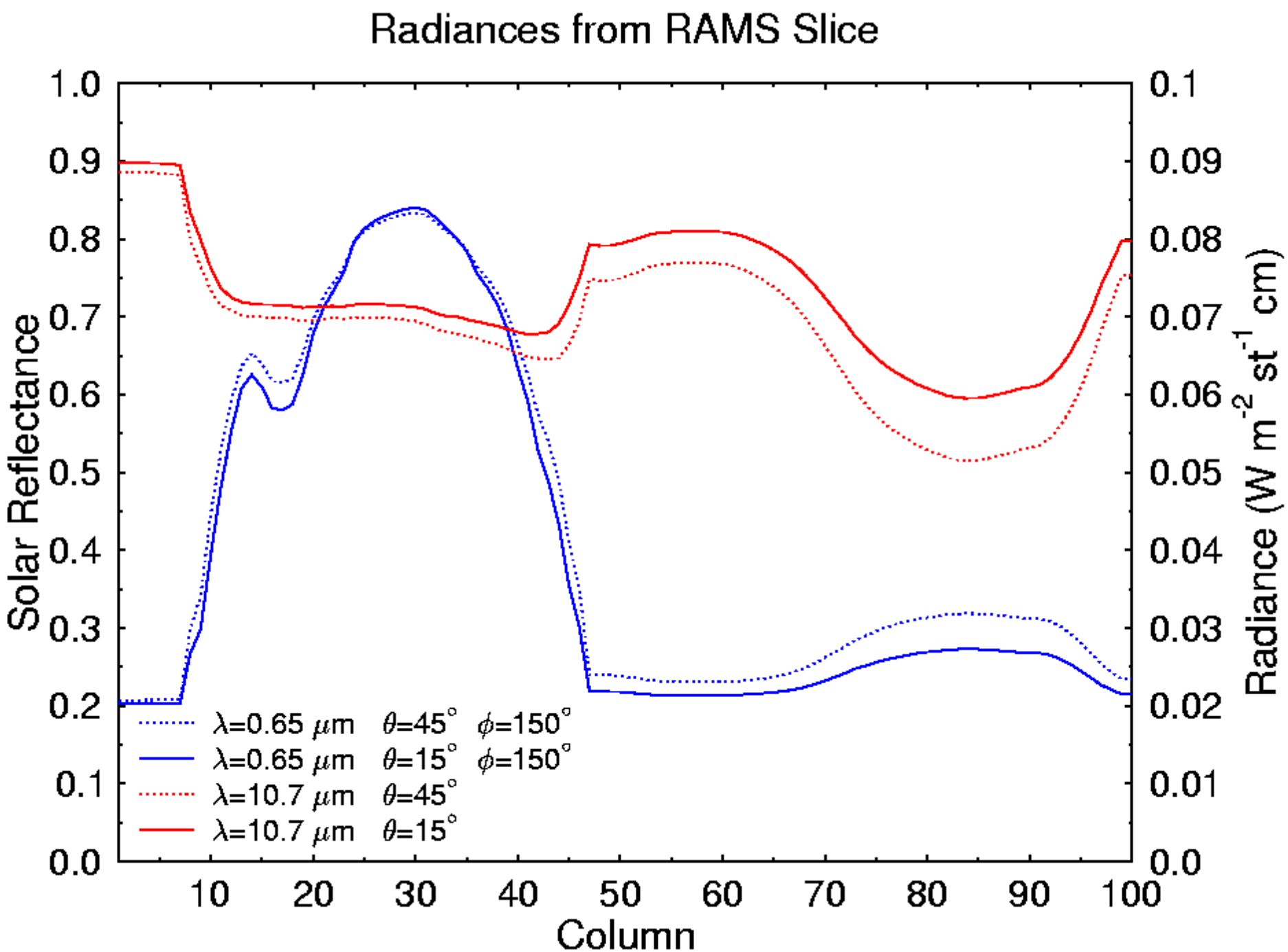
- Tests made for solar and thermal RT with multiple particle species
- Tangent linear compared with finite difference of forward model.
- Adjoint tested with tangent linear by comparing inner products:

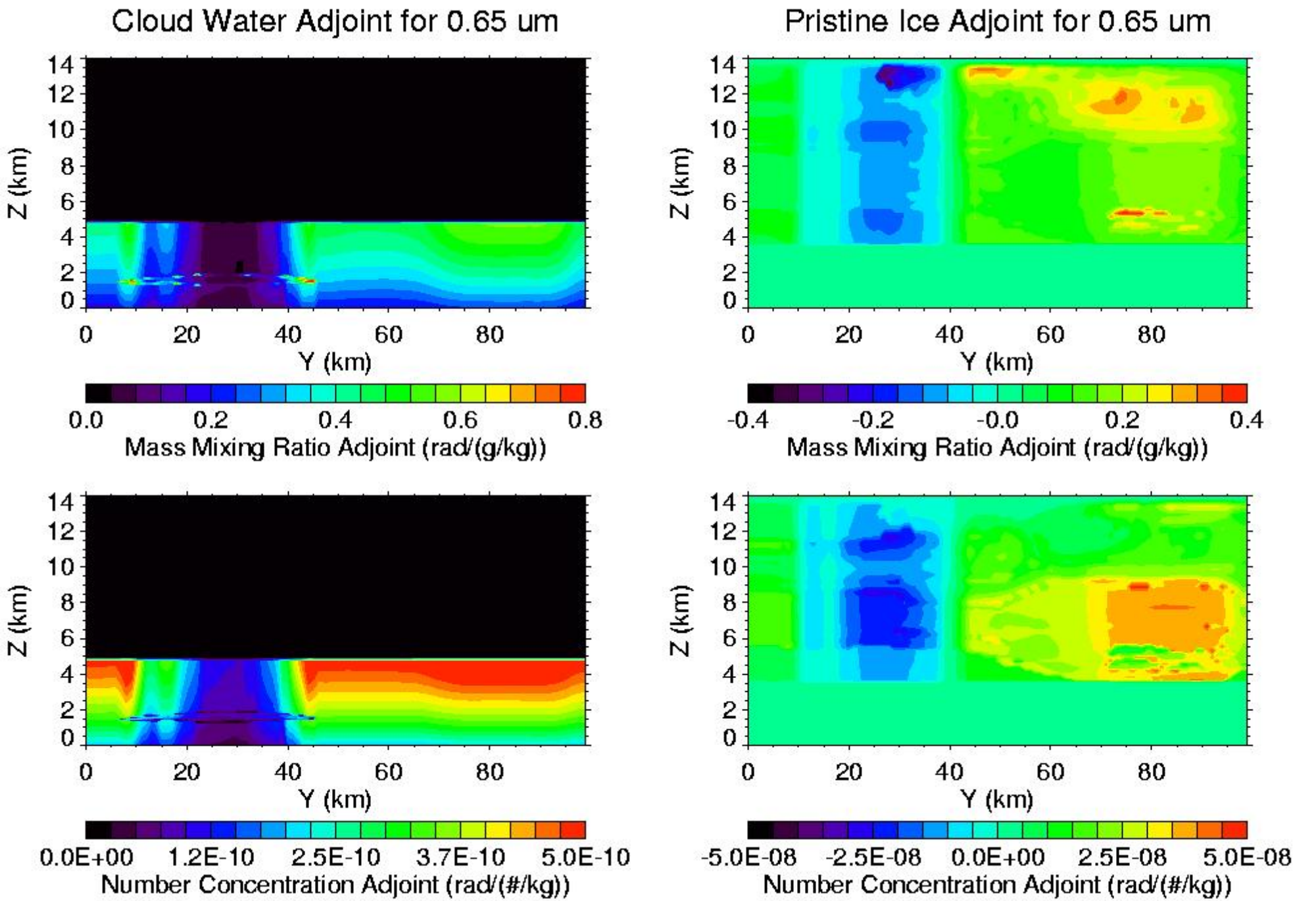
  $(\delta y\ H\ \delta x) = (\delta x\ H^T\ \delta y)$ to machine precision for many random input vectors δx (profiles of LWC, r_{mm}, T; surface temp/albedo) and output vectors δy (radiances).

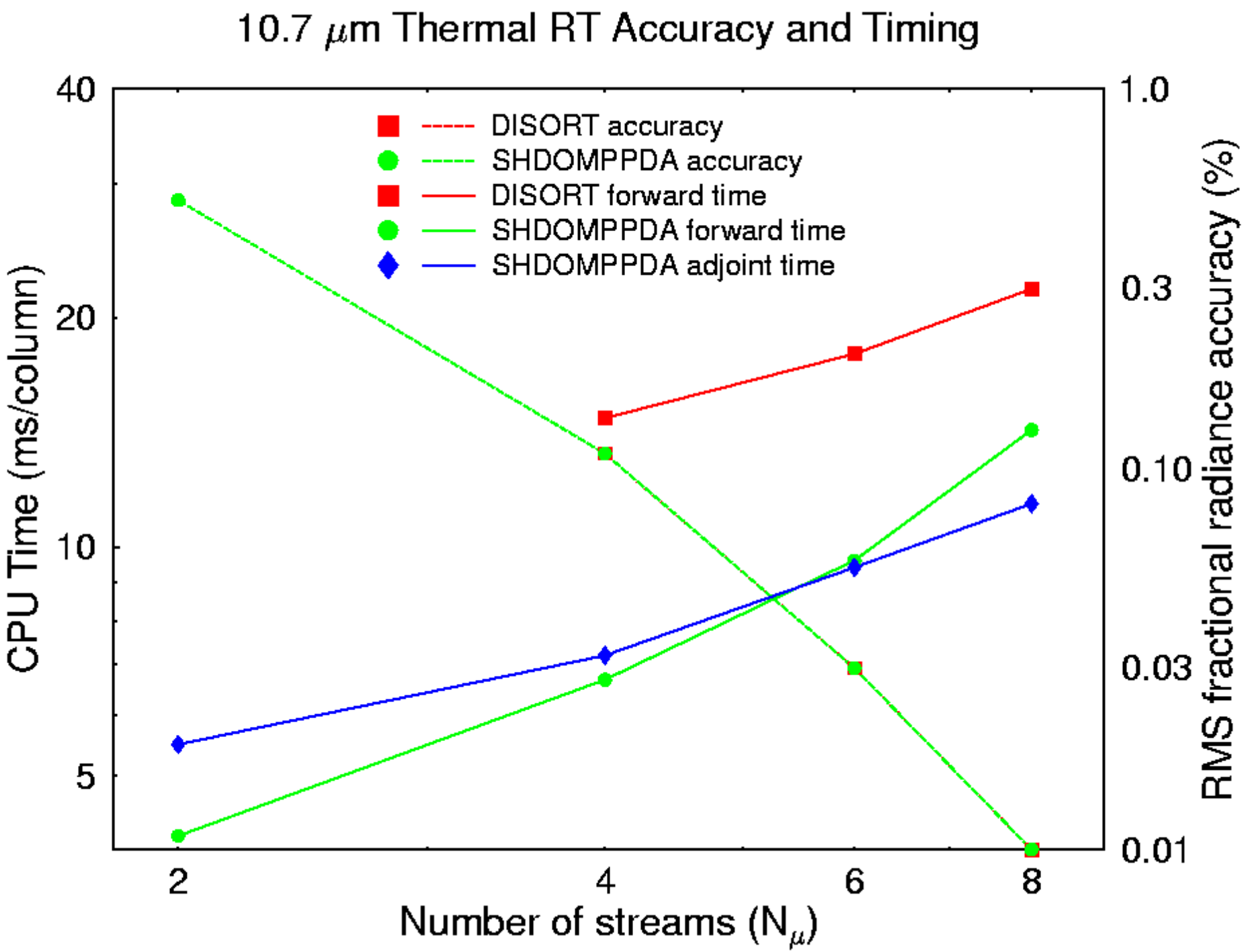
Forward and Adjoint Radiative Transfer Example

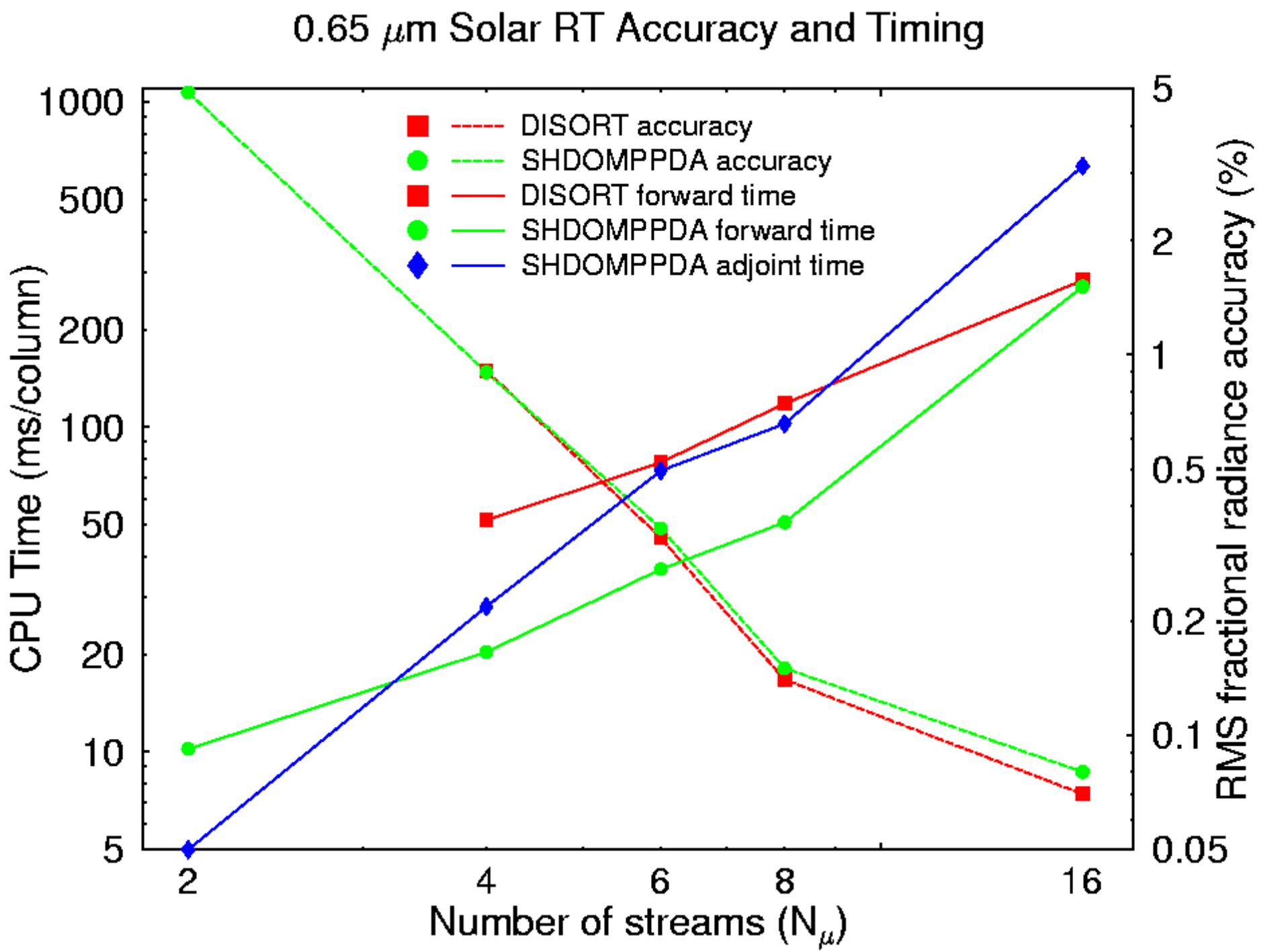
- RAMS simulation centered on ARM SGP site (March 21, 2000)
- X-Z slice from 100x100x84 grid
- Monochromatic radiative transfer without molecular absorption for cloud water (spheres) and pristine ice (bullet-rosettes)
- Thermal emission: 10.7 μm surf_emis=0.98
  5 radiance directions (θ=0, 15, 30, 45, 60^o)
- Solar reflection: 0.65 μm SZA=30 surf_albedo=0.2
  6 directions (θ=15, 30, 45^o; φ=150, 30^o)


RAMS Cloud Water and Pristine Ice
Z (km)
14
12
10
8
6
4
2
0
0
20
40
60
80
Y (km)
-4.00
-3.00
-2.00
-1.00
0.00
Log10 Mass Mixing Ratio (g/kg)
Z (km)
14
12
10
8
6
4
2
0
0
20
40
60
80
Y (km)
3.00
4.50
6.00
7.50
9.00
Log10 Number Concentration (#/kg)


Radiances from RAMS Slice
Solar Reflectance
Radiance (W m-2 st-1 cm)
Column
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.0
10
20
30
40
50
60
70
80
90
100
λ=0.65 μm θ=45° ϕ=150°
λ=0.65 μm θ=15° ϕ=150°
λ=10.7 μm θ=45°
λ=10.7 μm θ=15°


Cloud Water Adjoint for 0.65 um
Pristine Ice Adjoint for 0.65 um
Z (km)
Y (km)
0 2 4 6 8 10 12 14
0 20 40 60 80
0.0 0.2 0.4 0.6 0.8
-0.4 -0.2 -0.0 0.2 0.4
Mass Mixing Ratio Adjoint (rad/(g/kg))
0.0E+00 1.2E-10 2.5E-10 3.7E-10 5.0E-10
-5.0E-08 -2.5E-08 0.0E+00 2.5E-08 5.0E-08
Number Concentration Adjoint (rad/(#/kg))


10.7 μm Thermal RT Accuracy and Timing
DISORT accuracy
SHDOMPPDA accuracy
DISORT forward time
SHDOMPPDA forward time
SHDOMPPDA adjoint time
CPU Time (ms/column)
RMS fractional radiance accuracy (%)
Number of streams (N_μ)
40
20
10
5
1.0
0.3
0.10
0.03
0.01
2
4
6
8


0.65 μm Solar RT Accuracy and Timing
DISORT accuracy
SHDOMPPDA accuracy
DISORT forward time
SHDOMPPDA forward time
SHDOMPPDA adjoint time
CPU Time (ms/column)
RMS fractional radiance accuracy (%)
Number of streams (N_μ)
1000
500
200
100
50
20
10
5
2
4
6
8
16
5
2
1
0.5
0.2
0.1
0.05

Conclusions and Future Work

- SHDOMPPDA is a promising radiative transfer code for radiance assimilation in scattering atmospheres.
- Any number of hydrometeor species may be included with full phase function scattering tables read from files.
- Flexible time - accuracy tradeoff by specifying the number of discrete ordinates, adaptive grid accuracy, and convergence.
- Forward model is faster than or comparable to DISORT; adjoint model time is comparable to forward model.
- We plan to interface SHDOMPPDA to the CRTM framework.