Cloud side remote sensing

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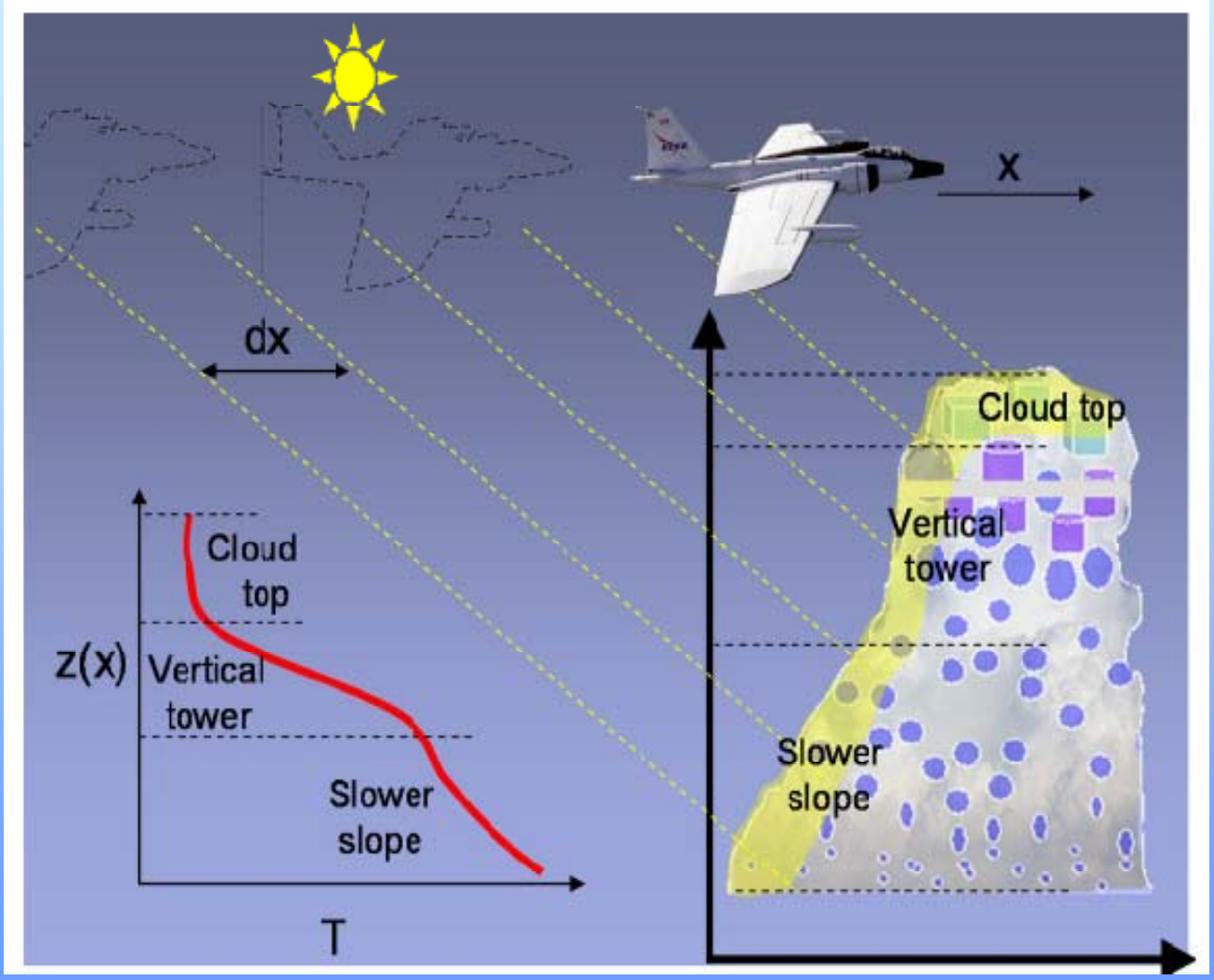
Cloud microphysics retrieval from cloud side measurements

- Cloud side measurements (the CLAIM-3D concept);
- Simulating observations for realistically complex clouds from CRM;
- Bayesian retrieval of vertical profiles of cloud phase and r_{eff};
- Independent synthetic test case;
- Does it work from the ground (show a movie)?

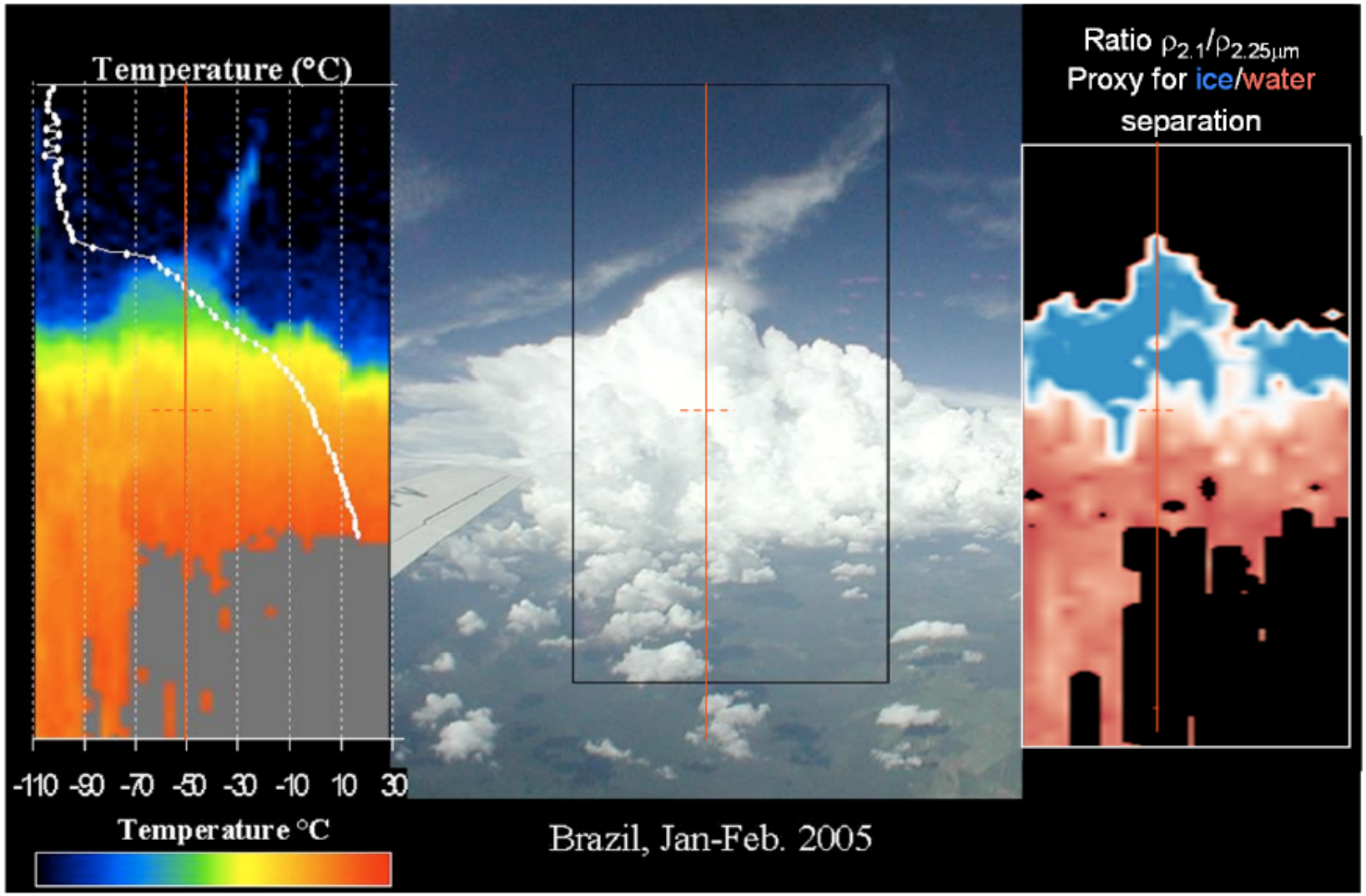
Schematic cloud side measurements

- high altitude aircraft or satellite;
- cloud observed from a single view angle;
- shadows are reduced by optimizing the geometry;
- the more vertical the cloud wall, the quicker change of T;
- cloud top shows nearly constant T with satellite displacement.



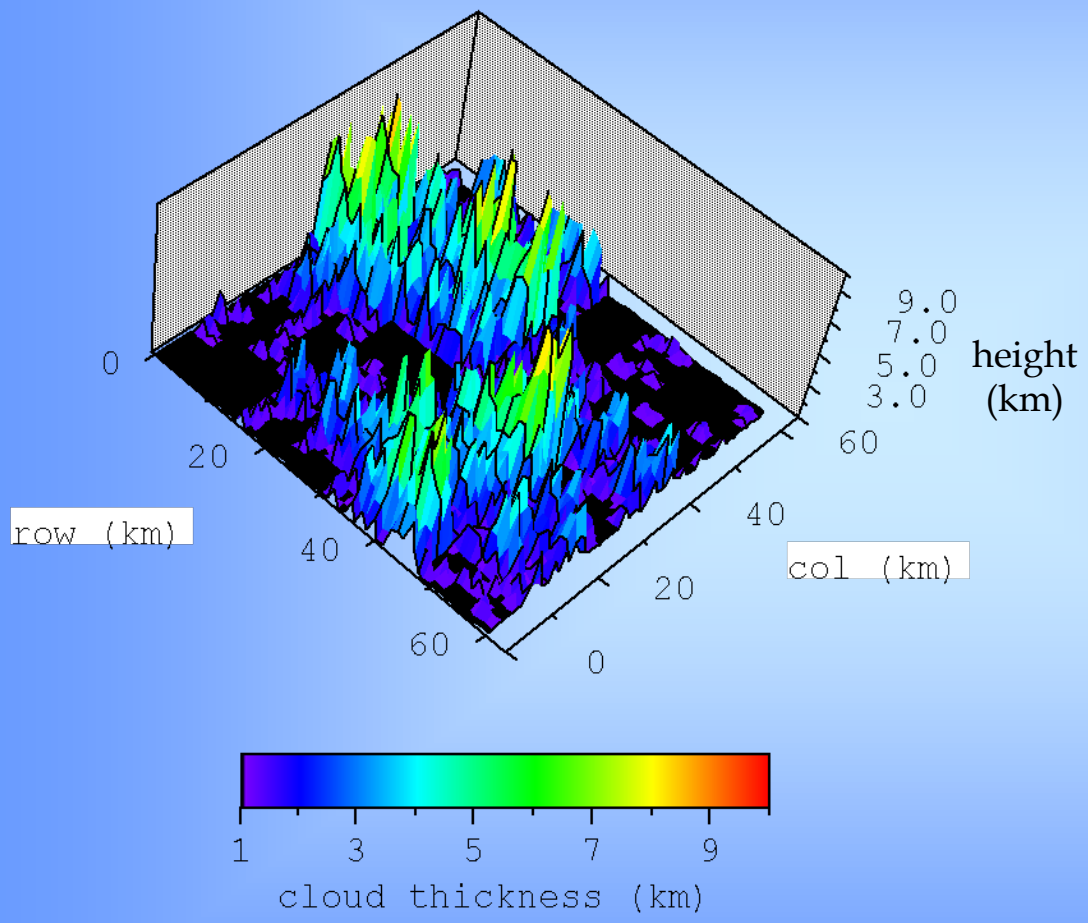
Martins et al., ACPD 2007

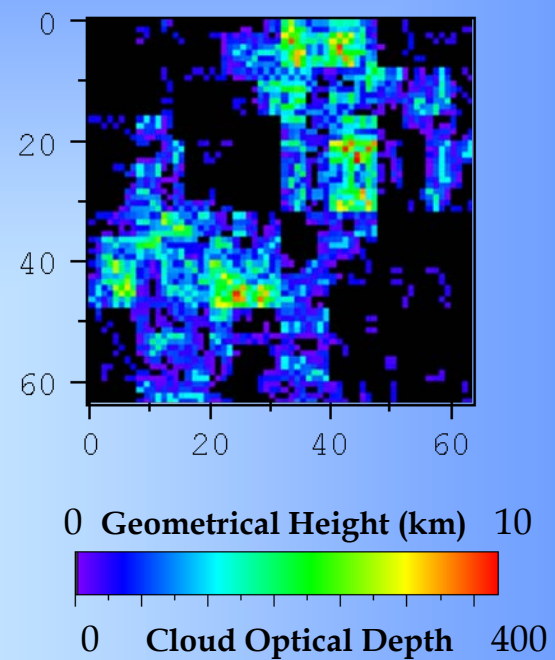
Real cloud side measurements

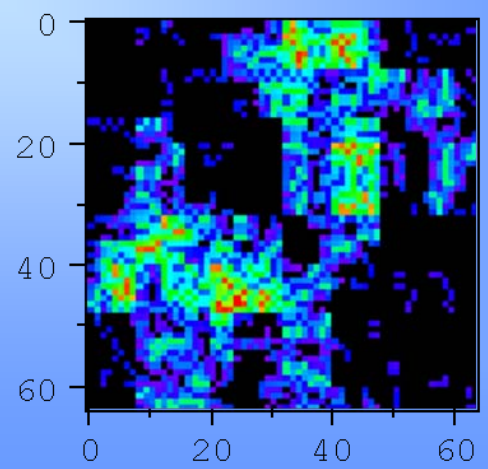


Martins et al., ACPD 2007

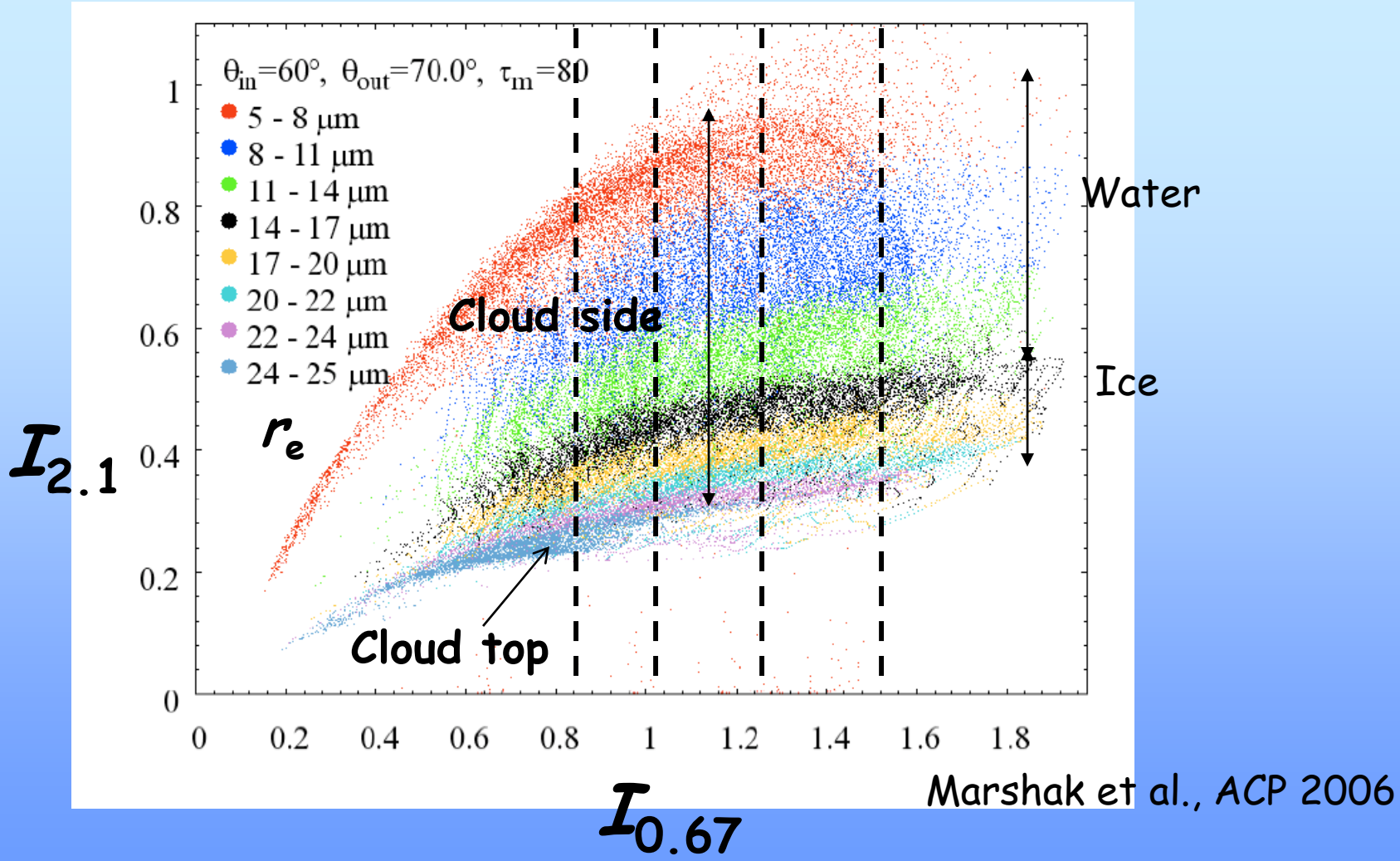
Simulation of Stochastic Cloud Fields







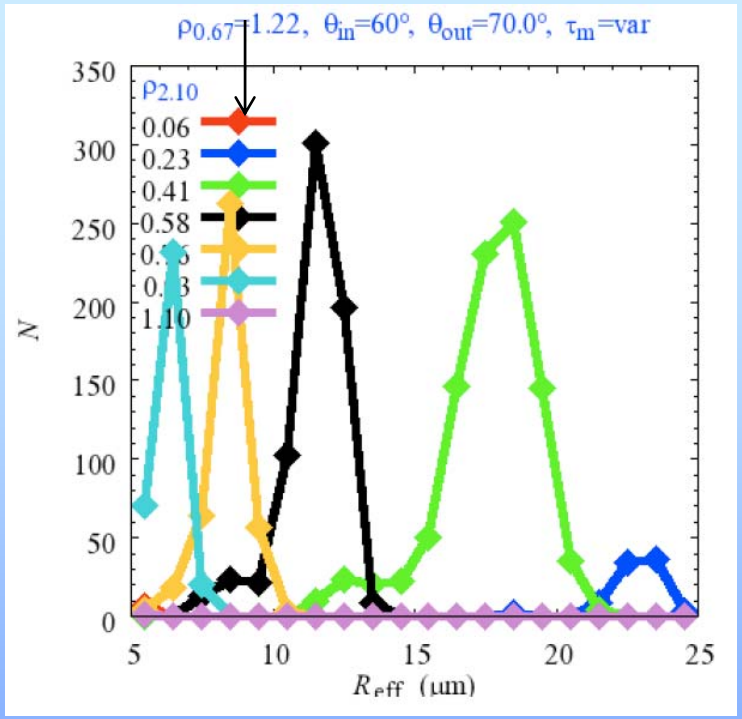
A 'Nakajima-King' type scatter plot: 0.67 vs 2.1 μm, but from both cloud top and cloud side

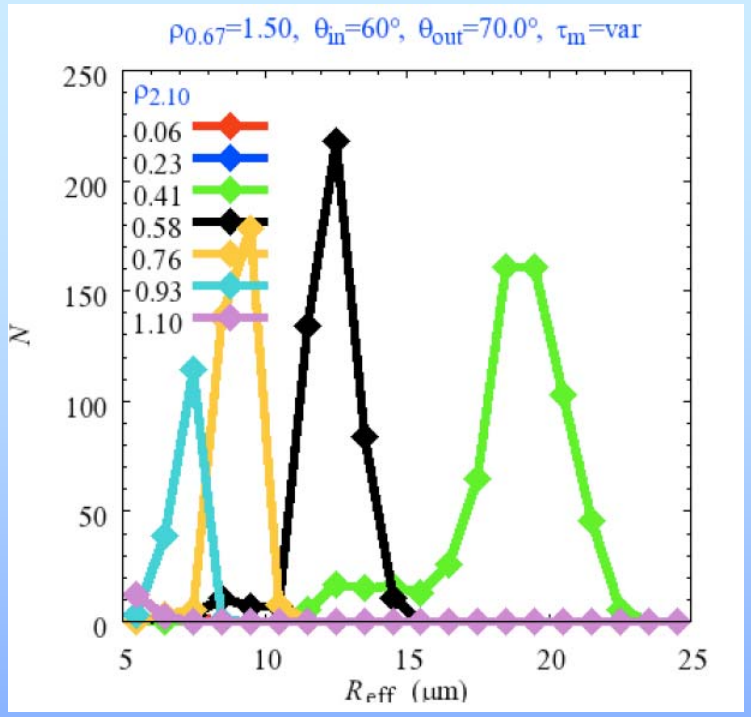


Marshak et al., ACP 2006

Distributions of vertical profiles $p(r_e|I_{0.67}, I_{2.1})$

$I_{2.1}$





$I_{0.67}$ = 1.22±0.02

$I_{0.67}$ = 1.50±0.02

r_e (μm)

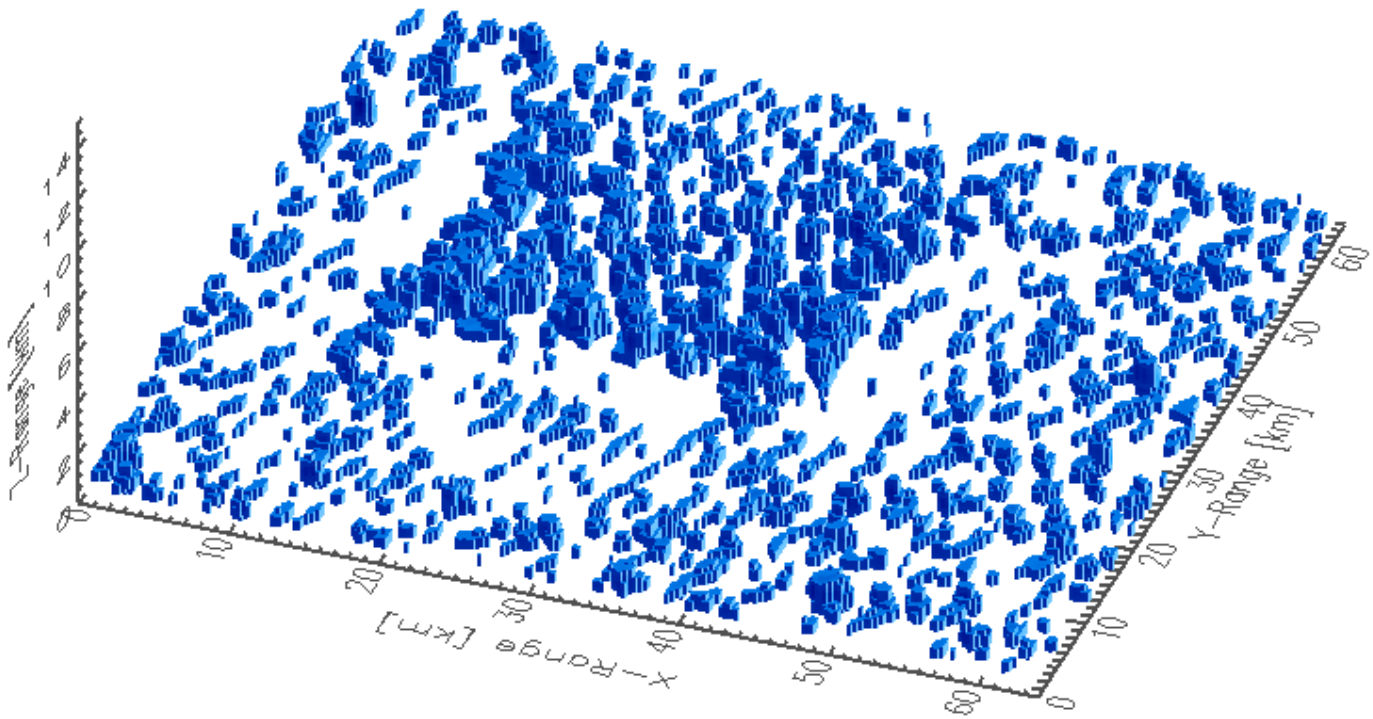
$$\langle r_e \rangle = \int_0^\infty r_e p(r_e|I_{0.67}, I_{2.1}) dr_e$$

$$\sigma = \sqrt{\int_0^\infty (r_e - \langle r_e \rangle)^2 p(r_e|I_{0.67}, I_{2.1}) dr_e}$$

Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

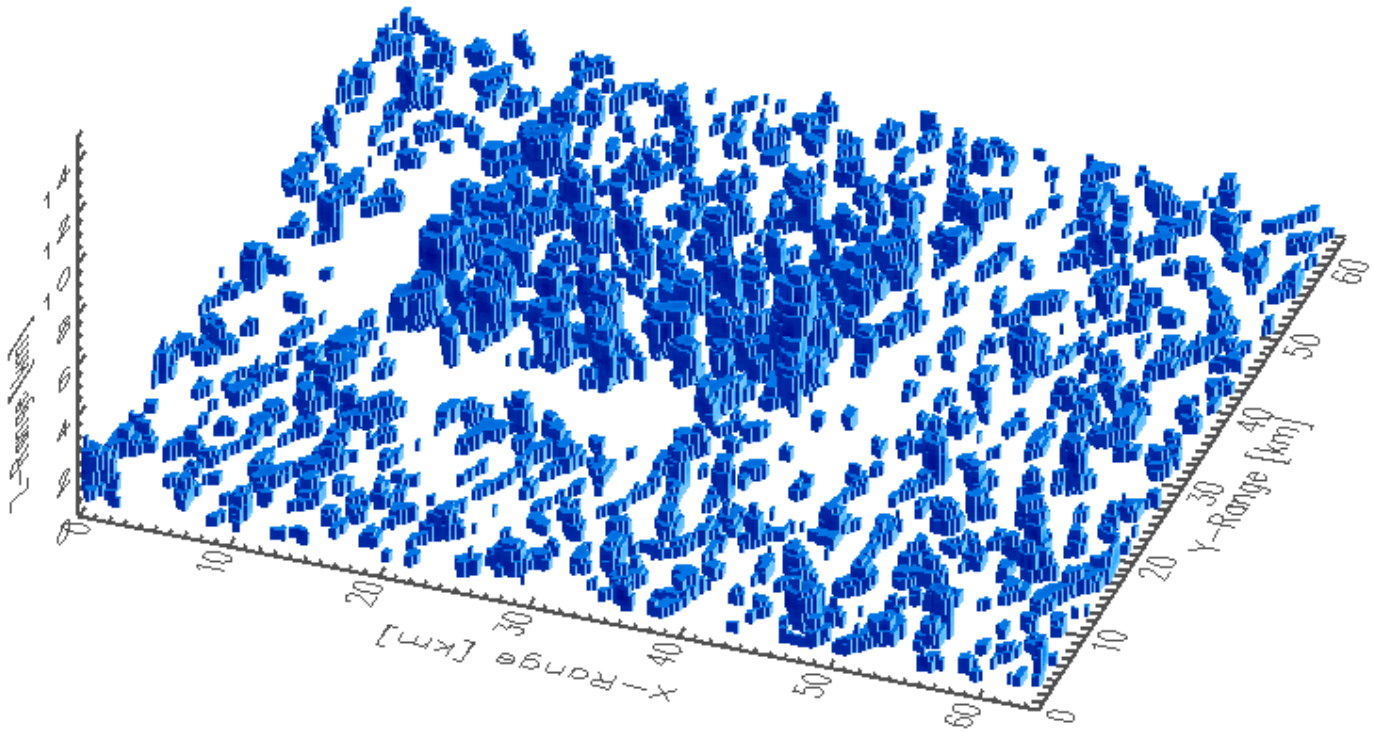
180 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

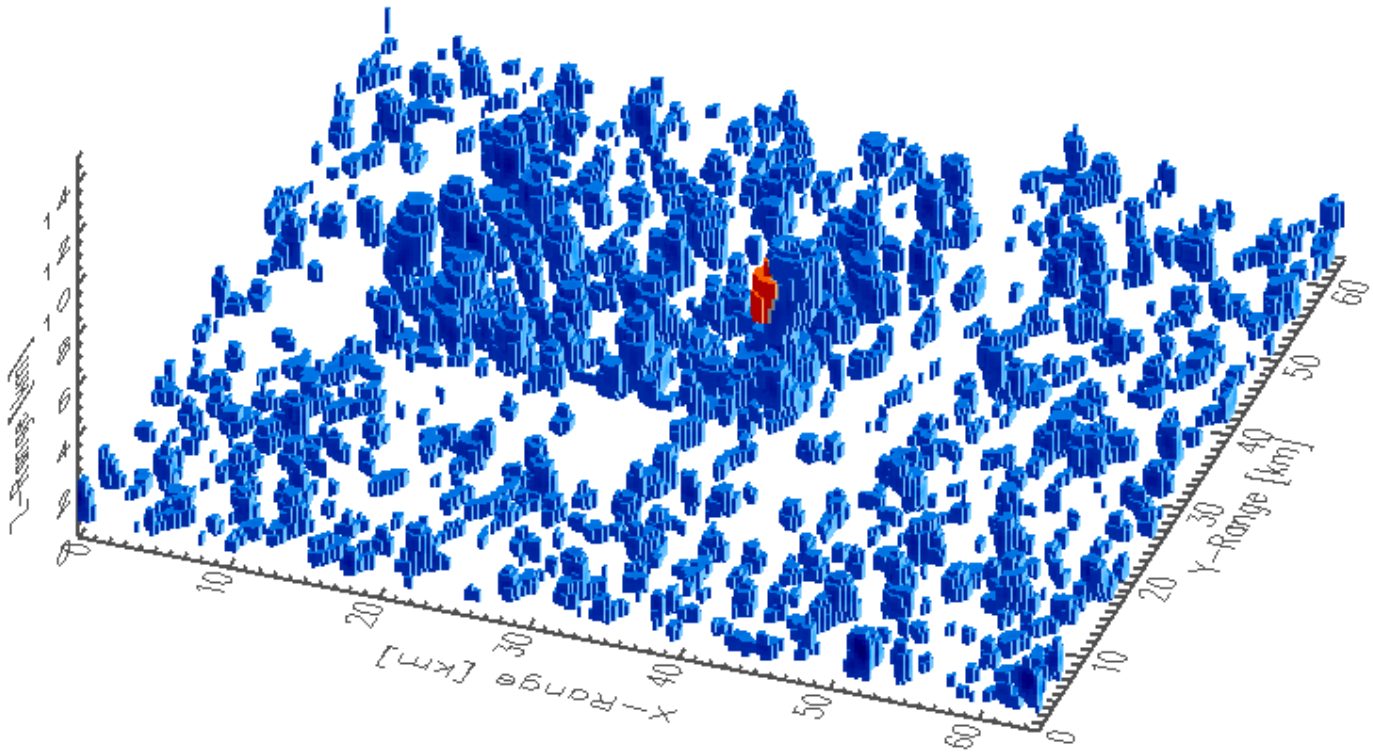
190 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

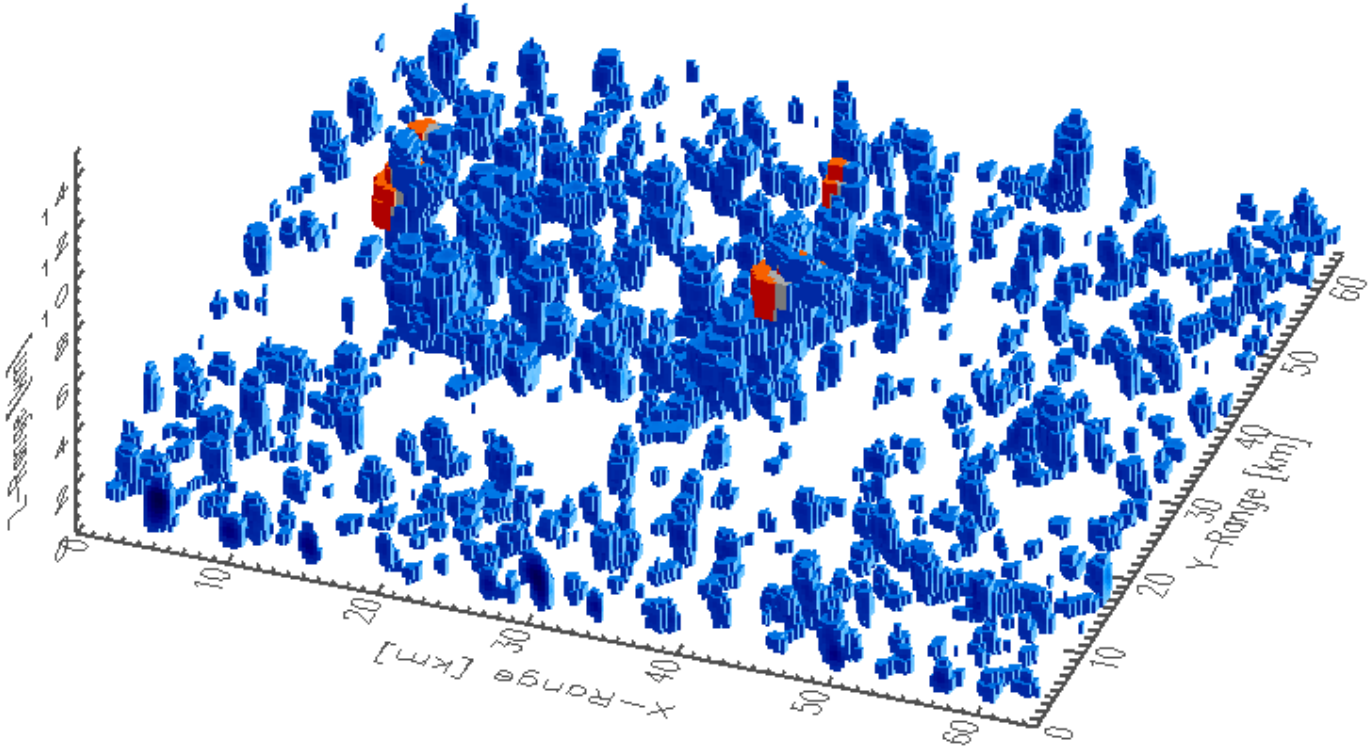
200 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

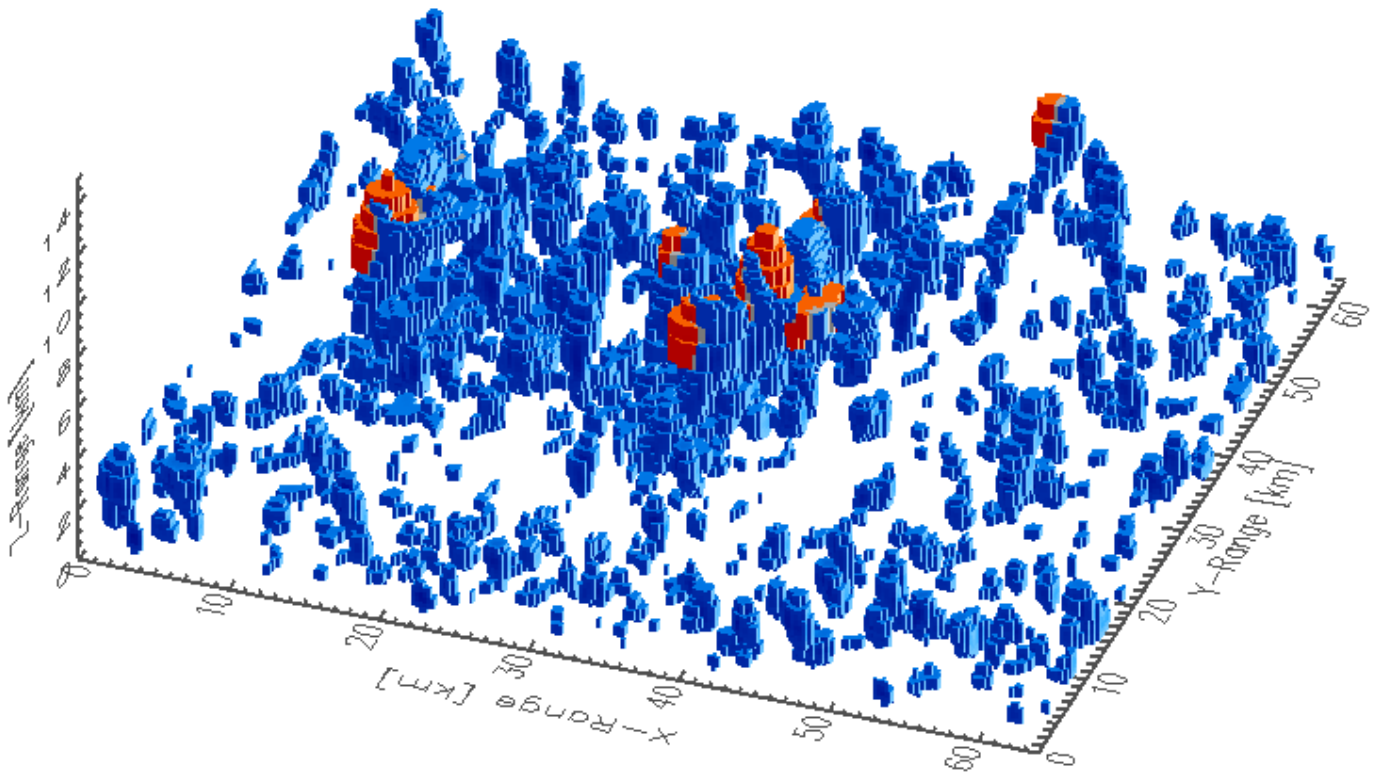
210 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

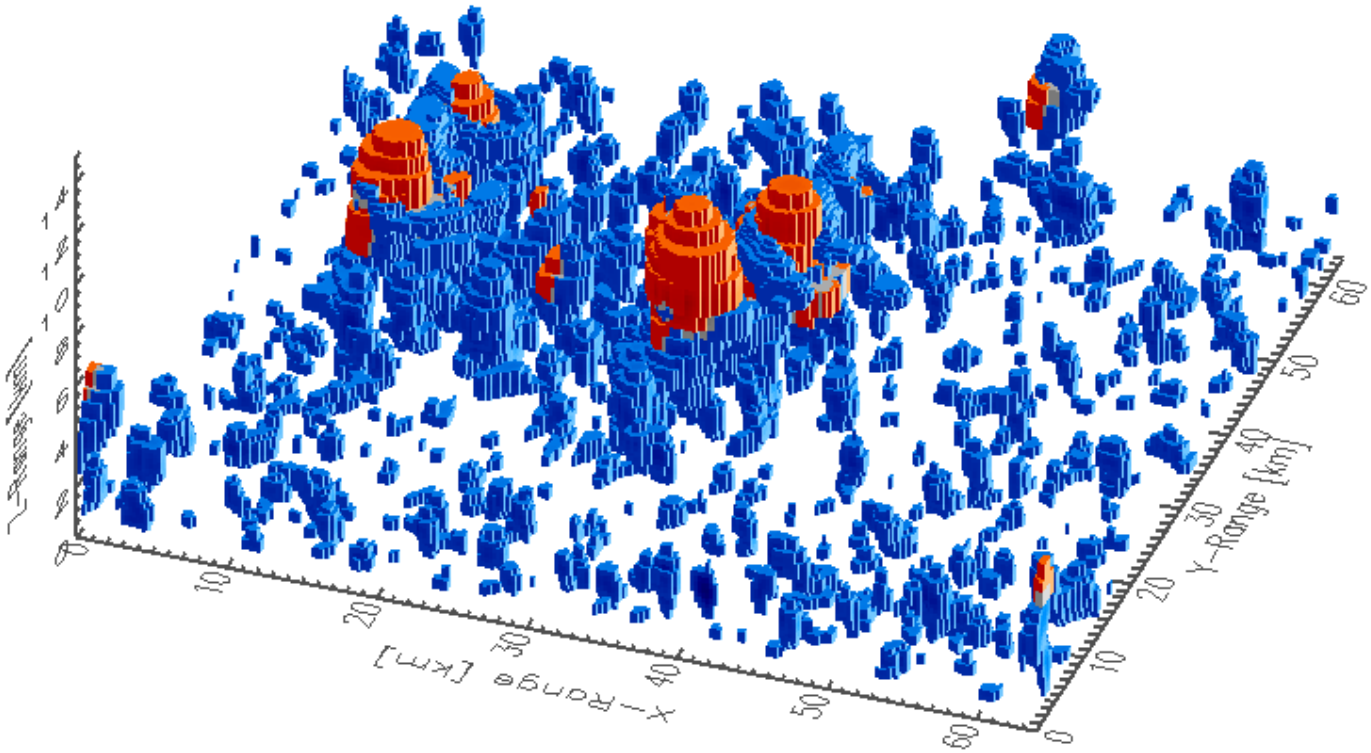
220 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

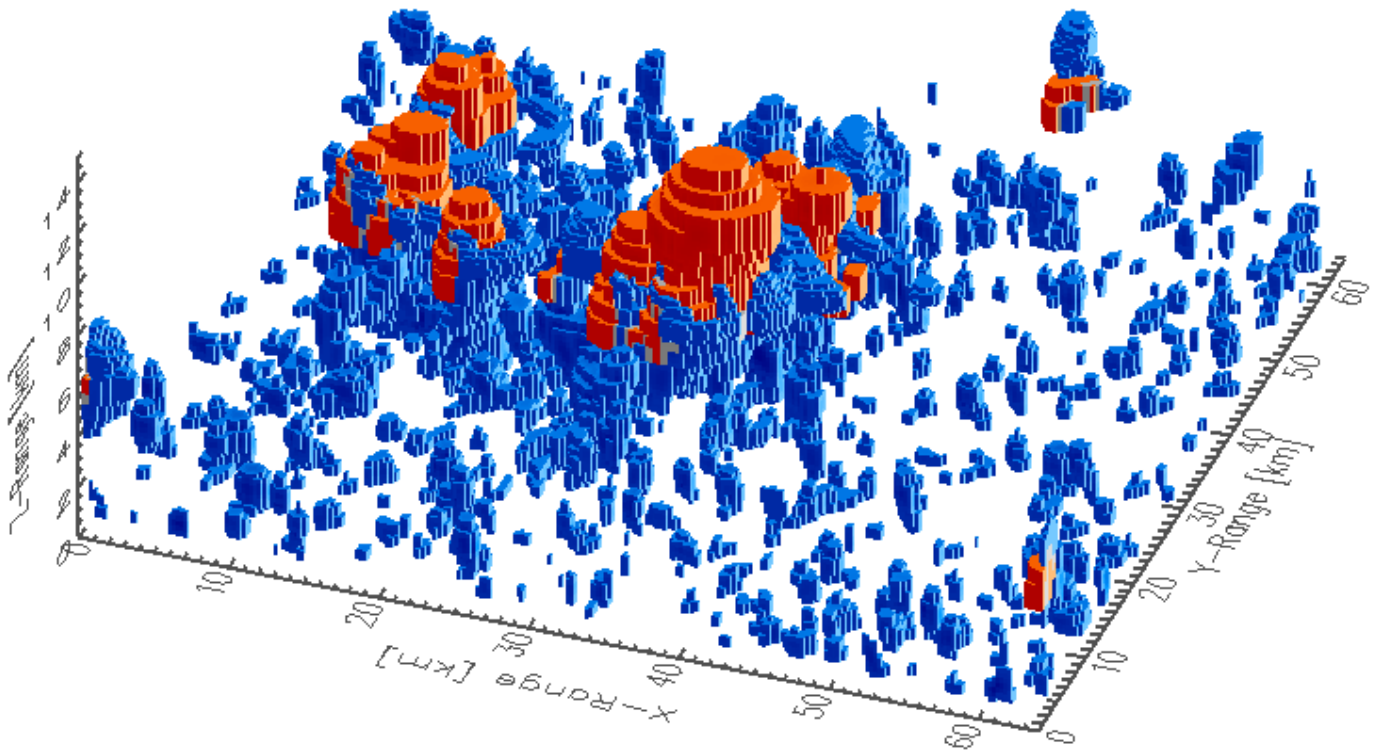
230 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

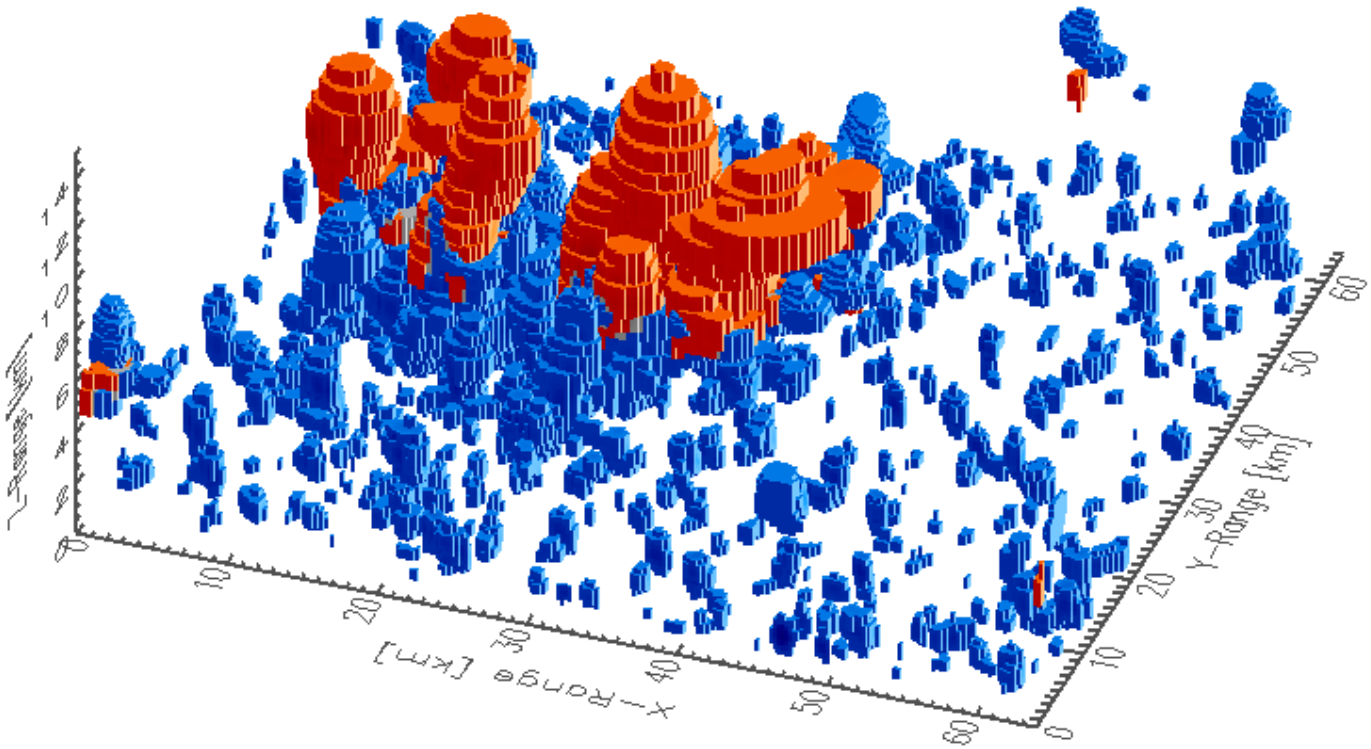
240 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

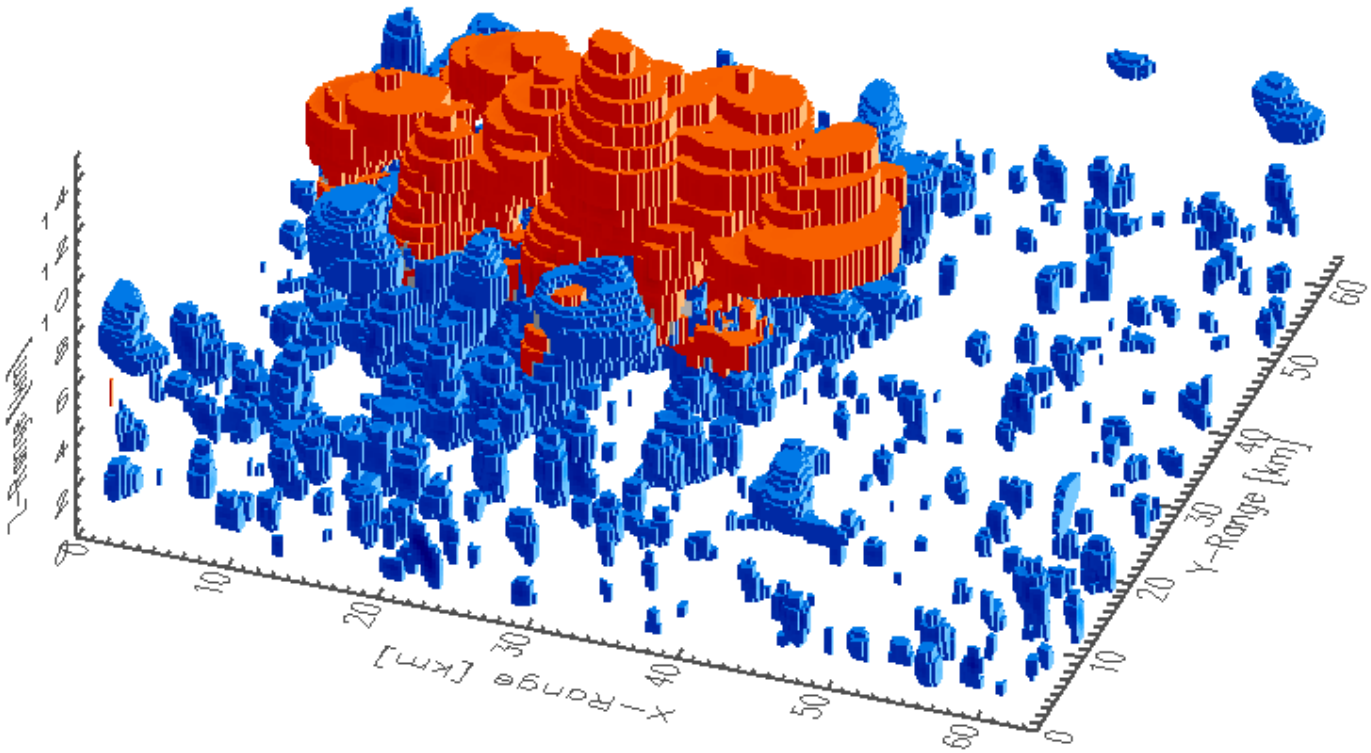
250 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

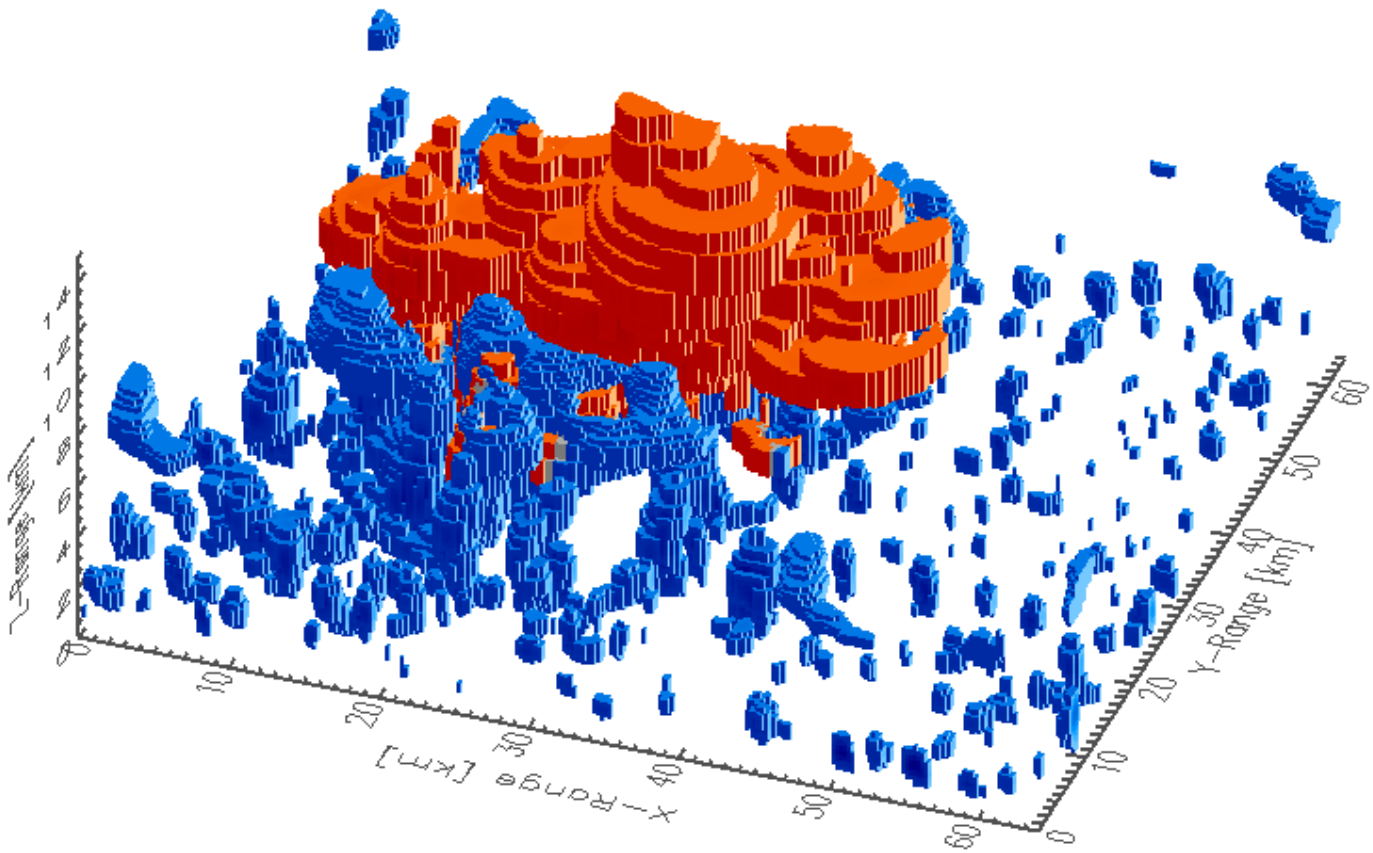
260 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

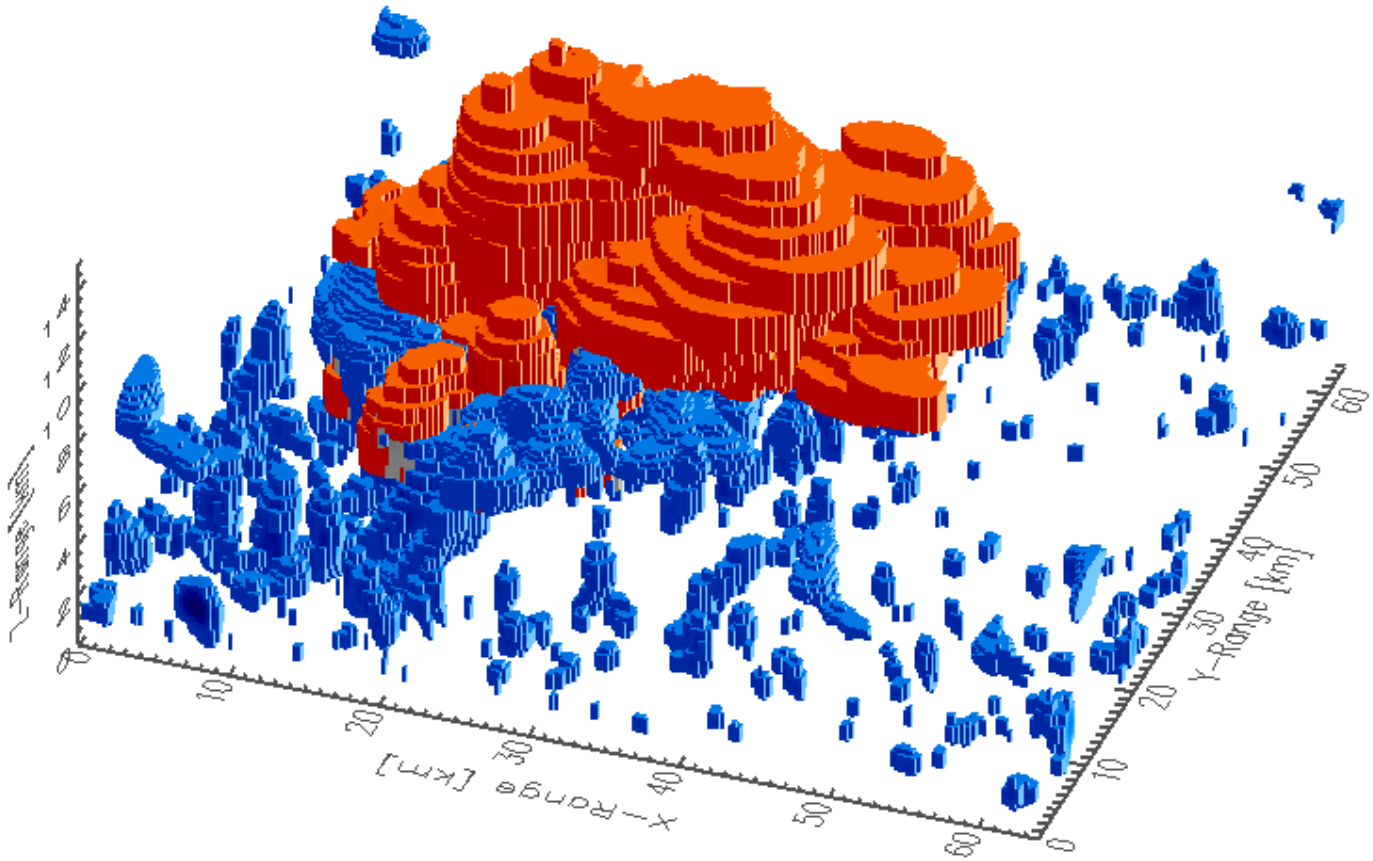
270 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

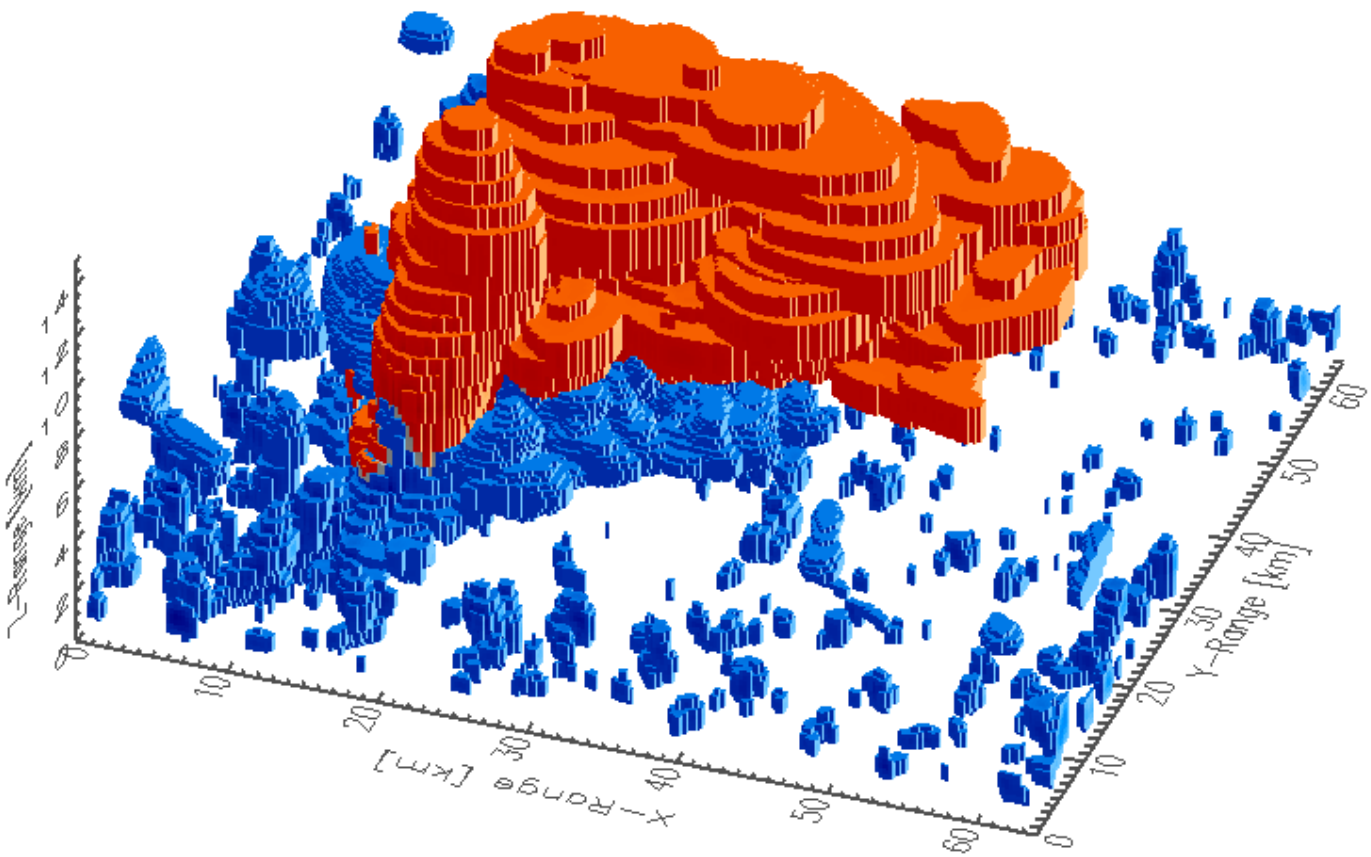
280 min



Real Clouds

Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

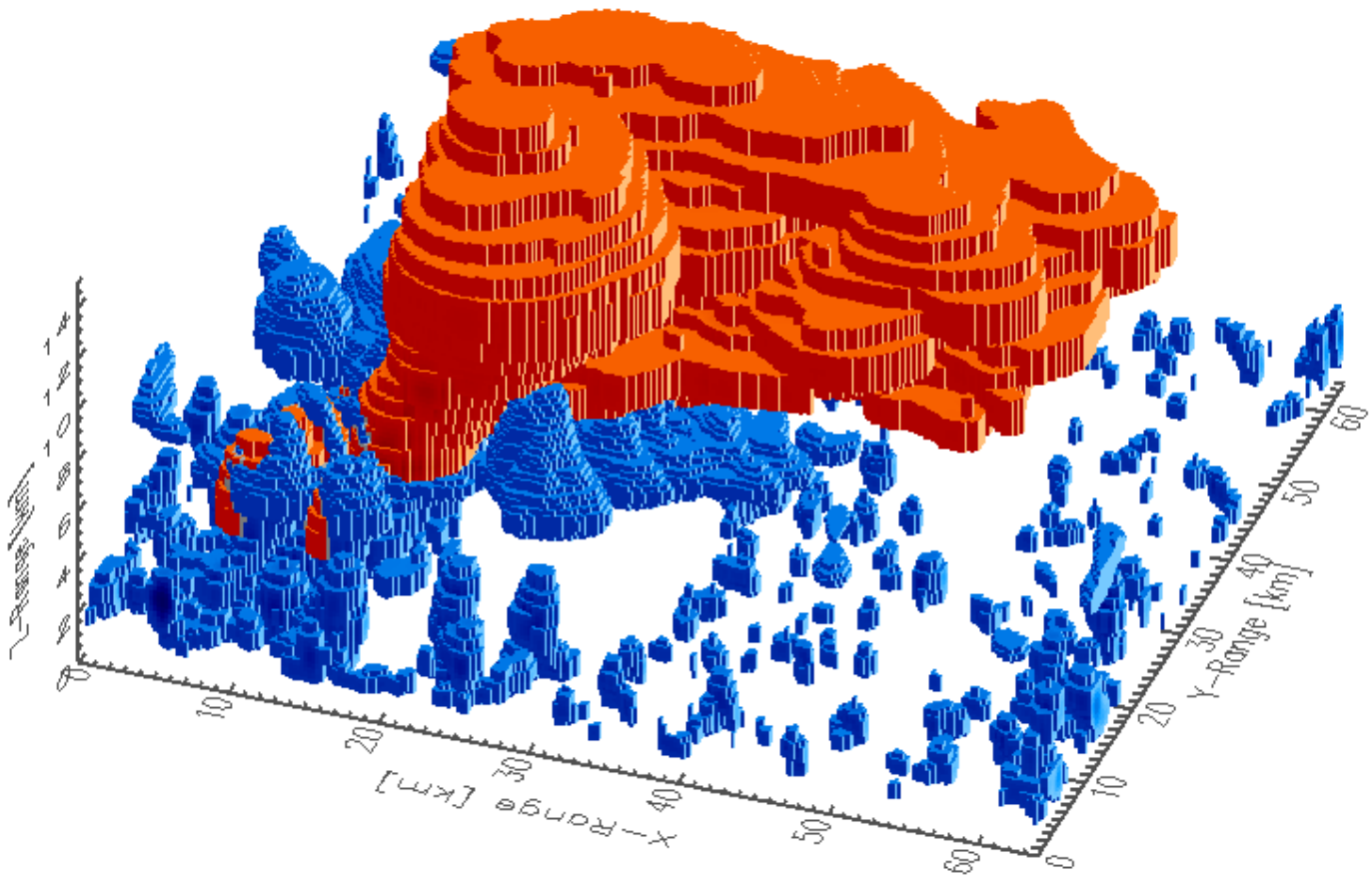
290 min



Real Clouds

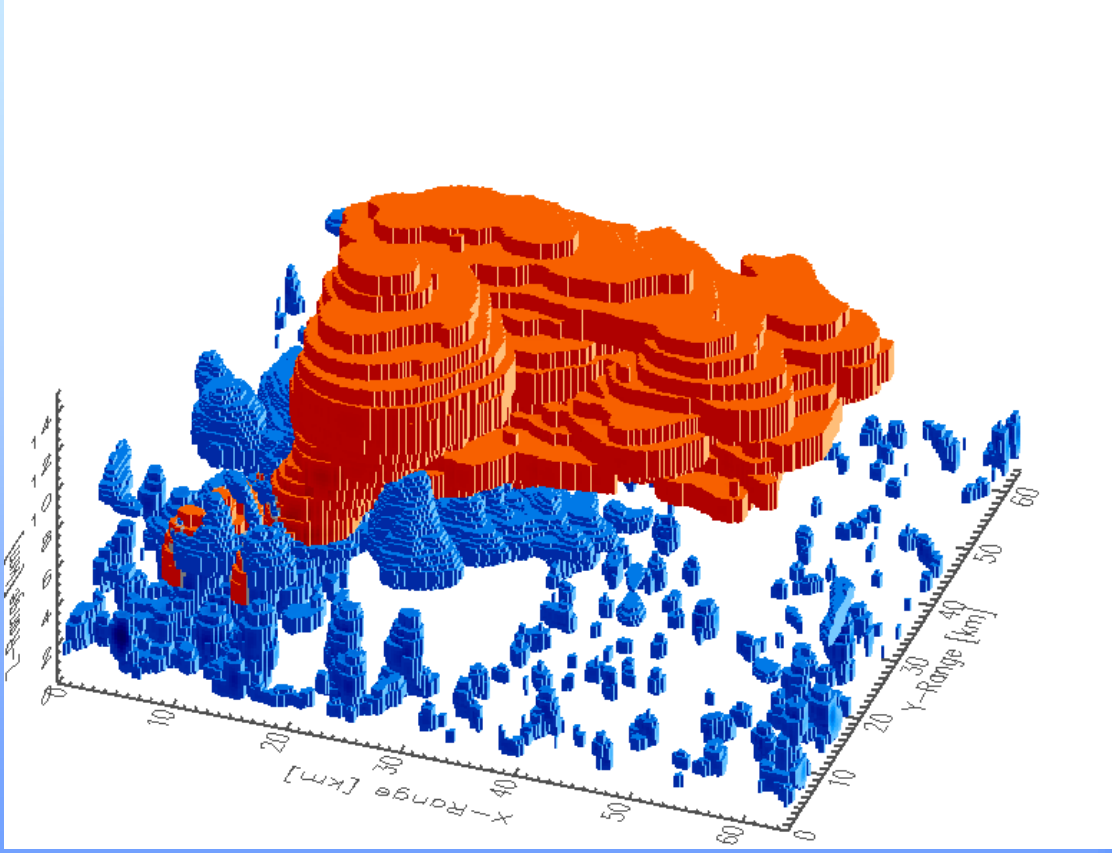
Goddard Cumulus Ensemble Model ***(Tao et al, 1998)***

300 min



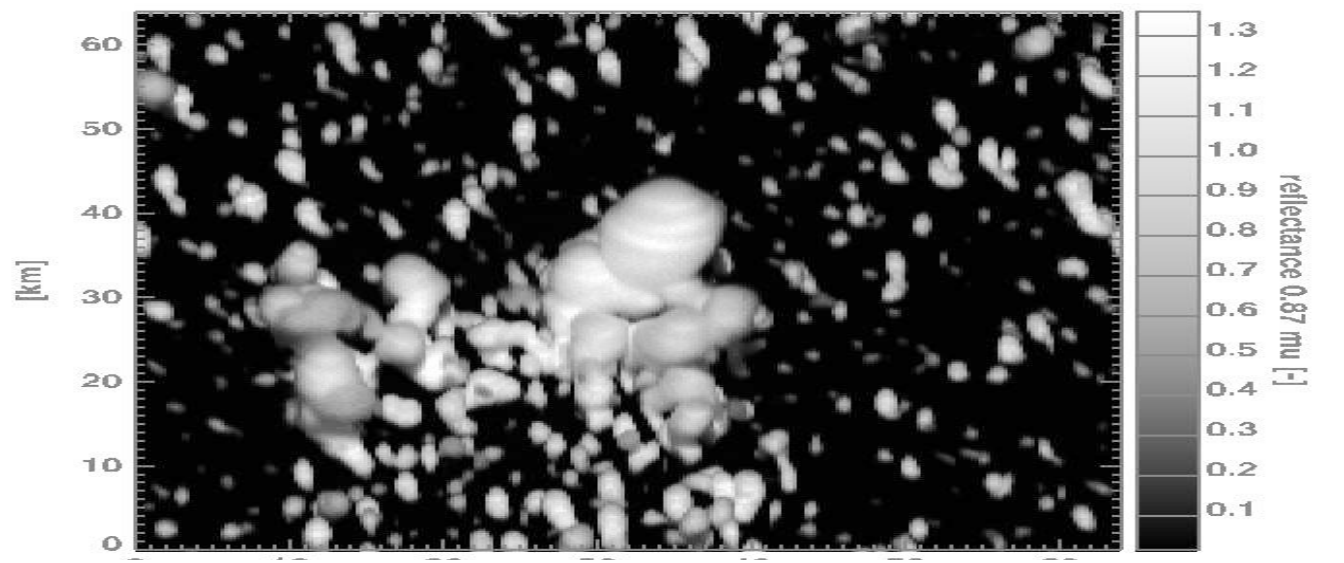
Forward Simulation

- 50 scenes from the Goddard Cumulus Ensemble Model
- 3D Monte Carlo (libRadtran/MYSTIC) simulations on a 200 processor cluster
- VZA=60°, SZA=45°
- 4 wavelengths: 0.87, 2.1, 2.25, 10.8 µm
- surface albedo = 0

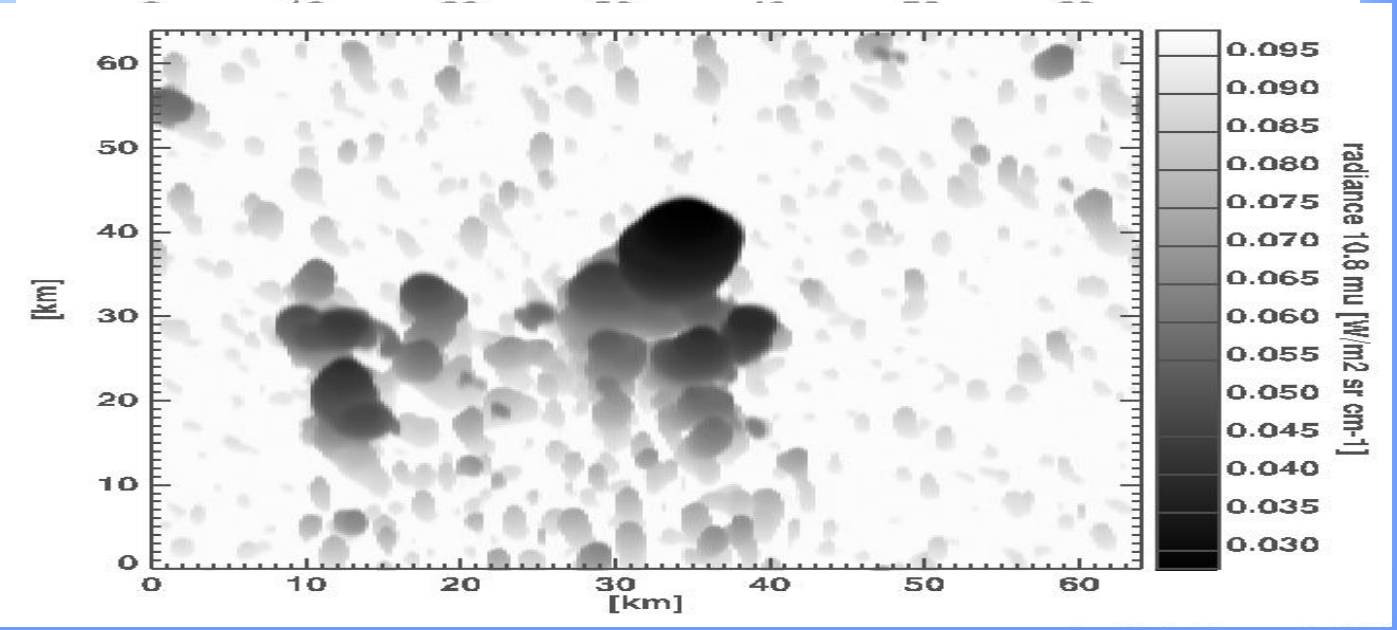


Forward Simulation

λ= 0.87 μm



λ= 10.8 μm



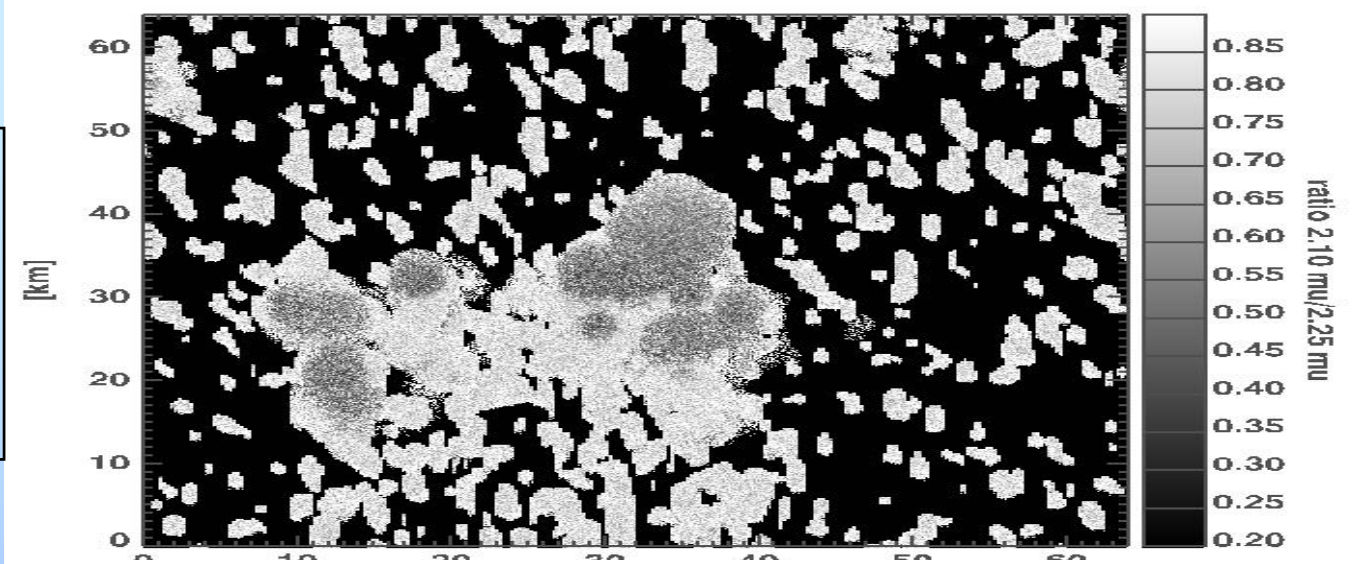
Forward Simulation

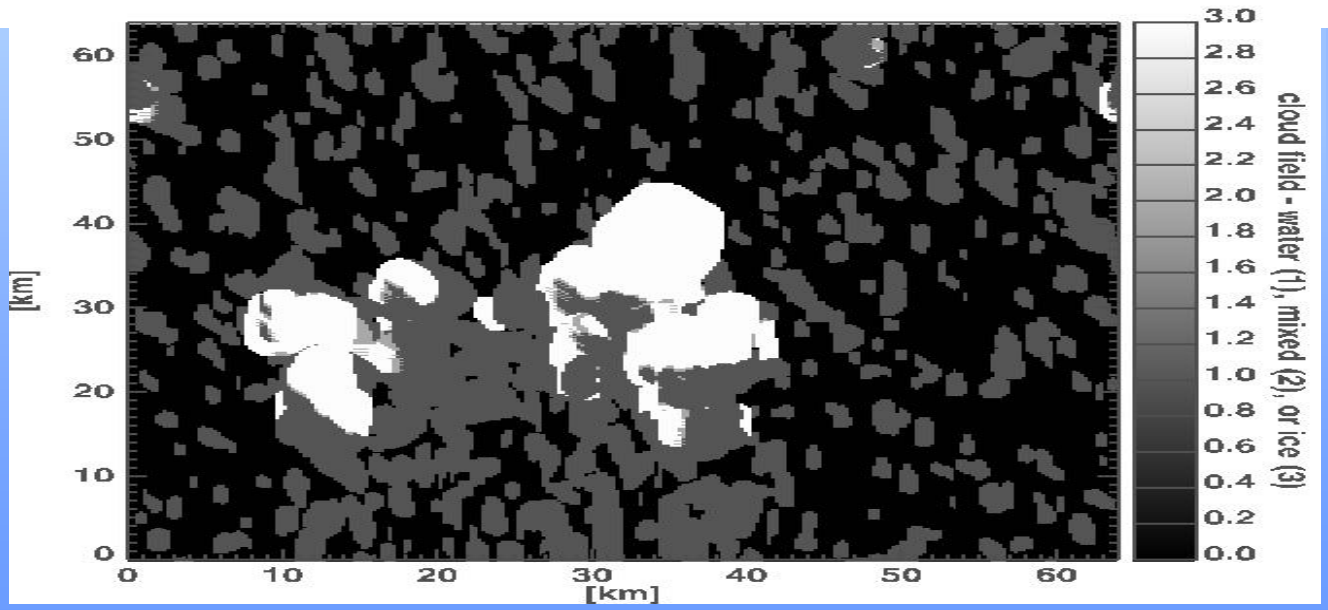
phase retrieval:

ratio

$$ratio = \frac{I_{2.1}}{I_{2.25}}$$

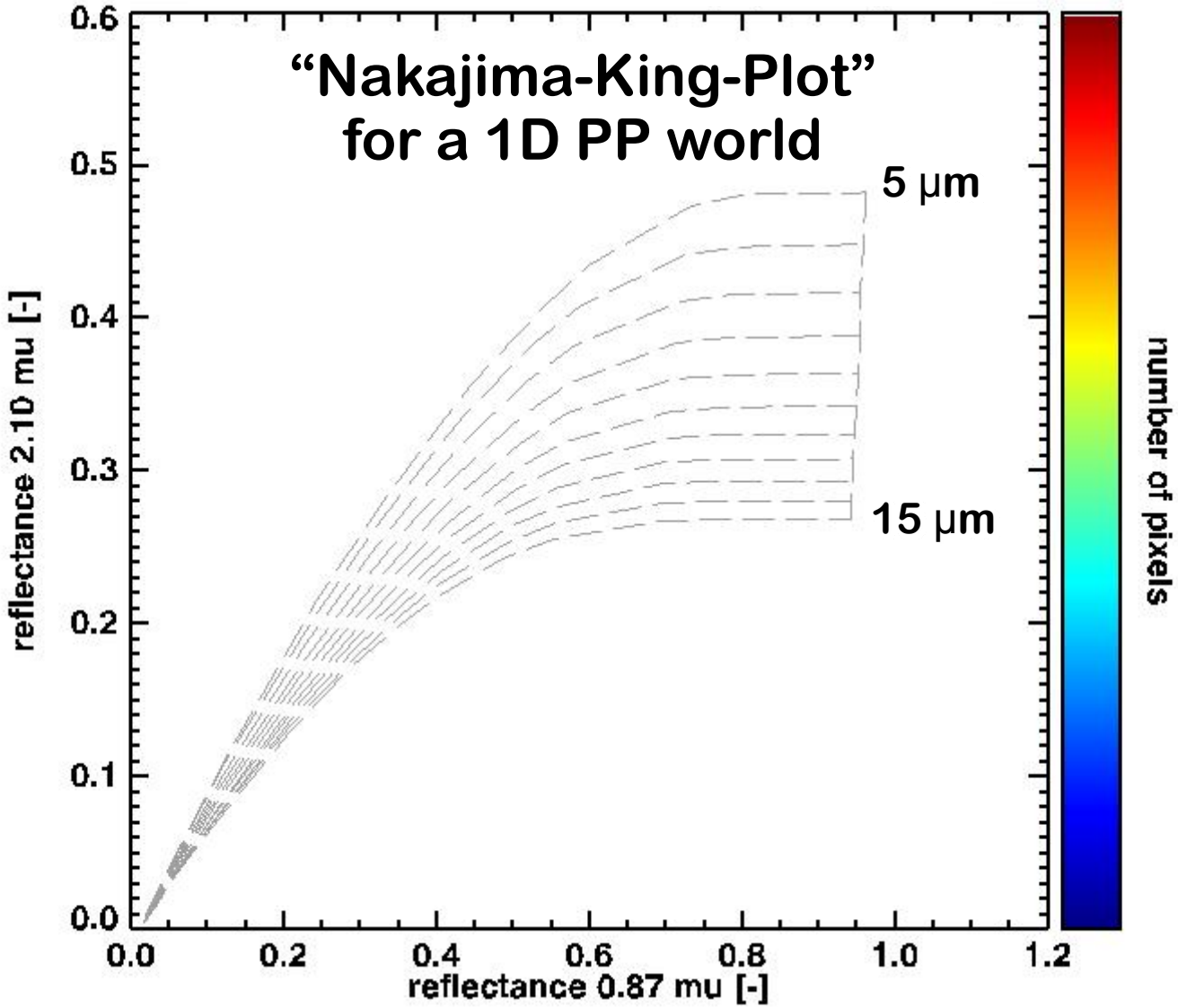
2.1μm/2.25μm



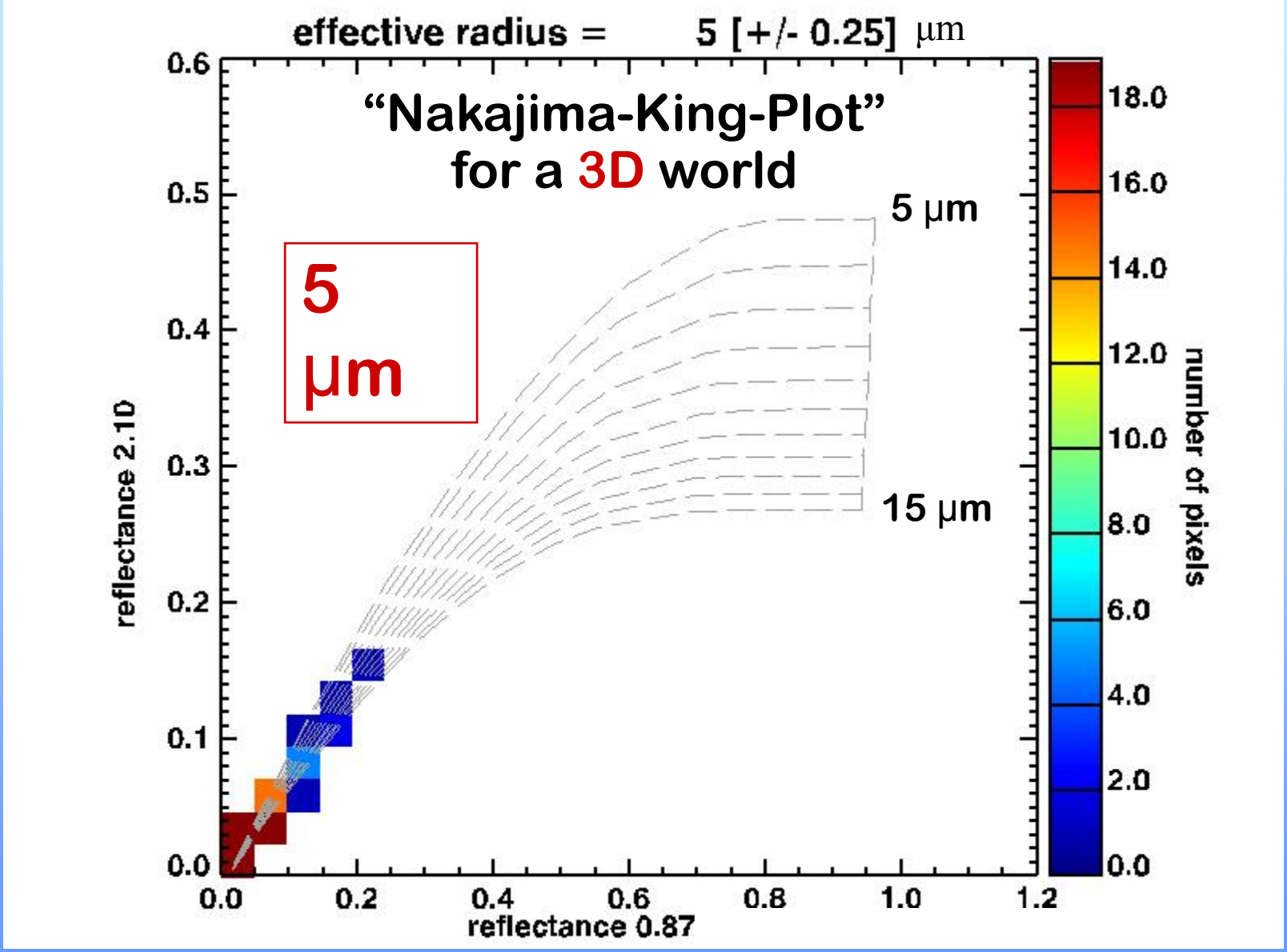


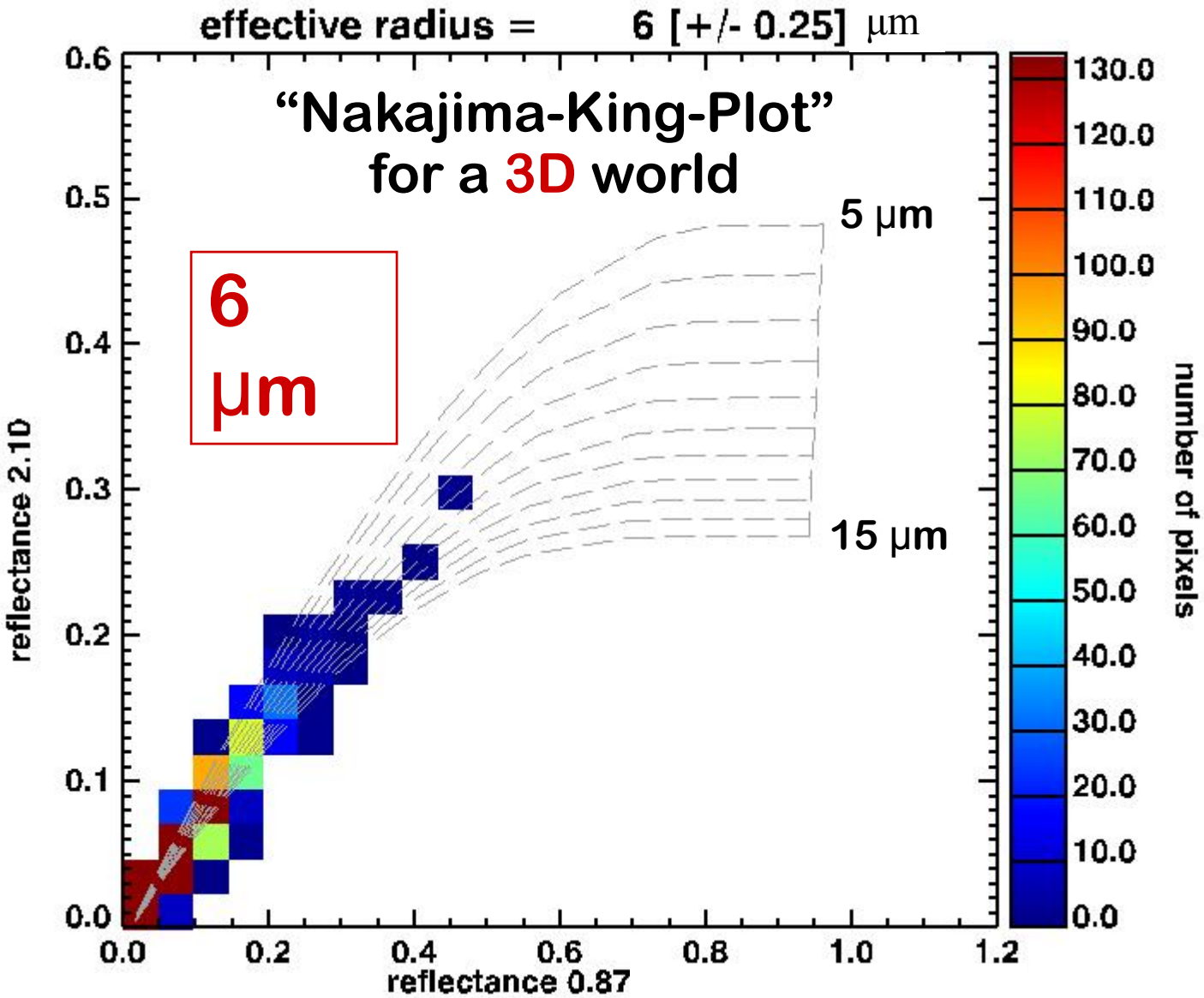
"truth"
white = ice

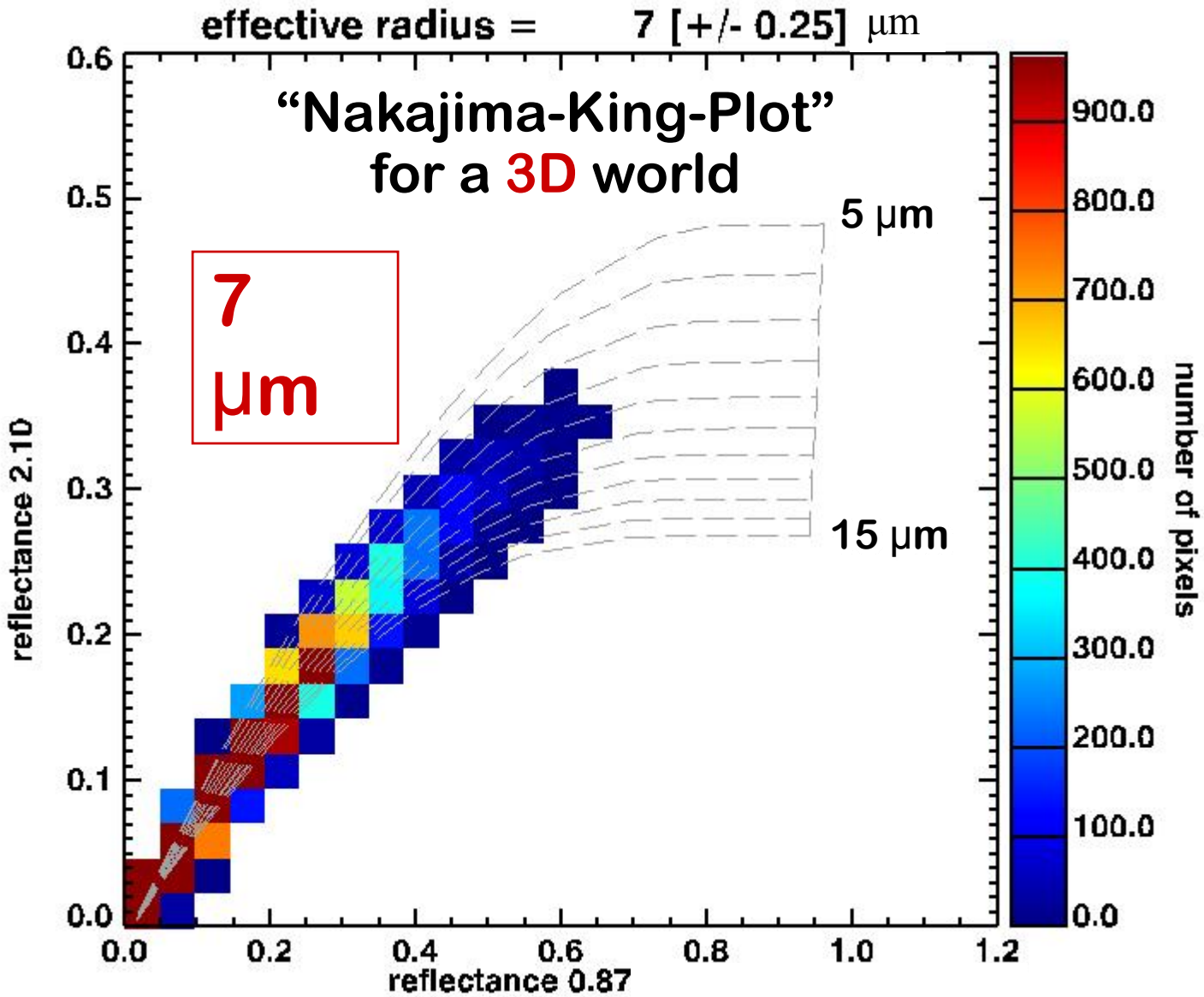
Forward Simulation

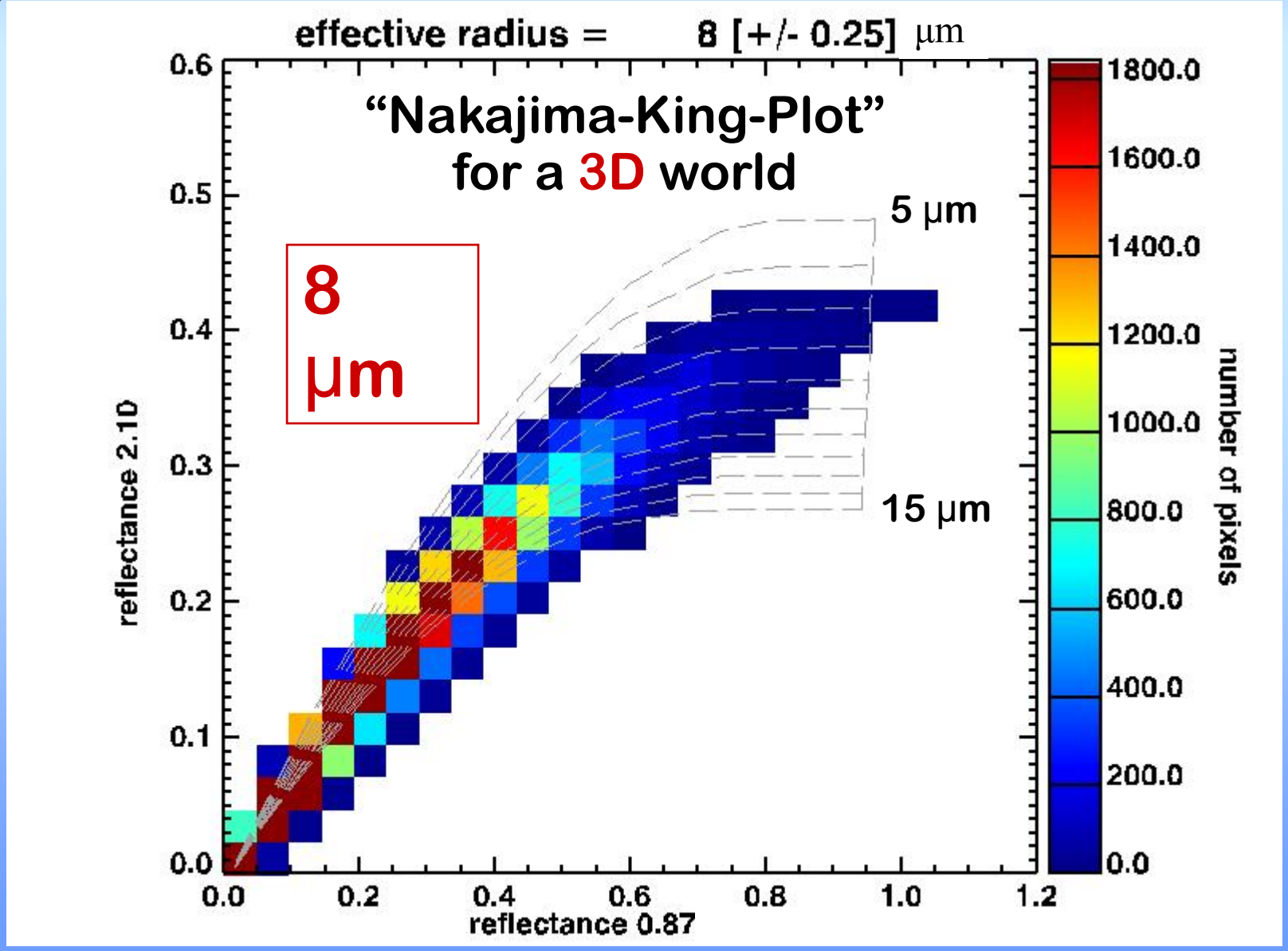


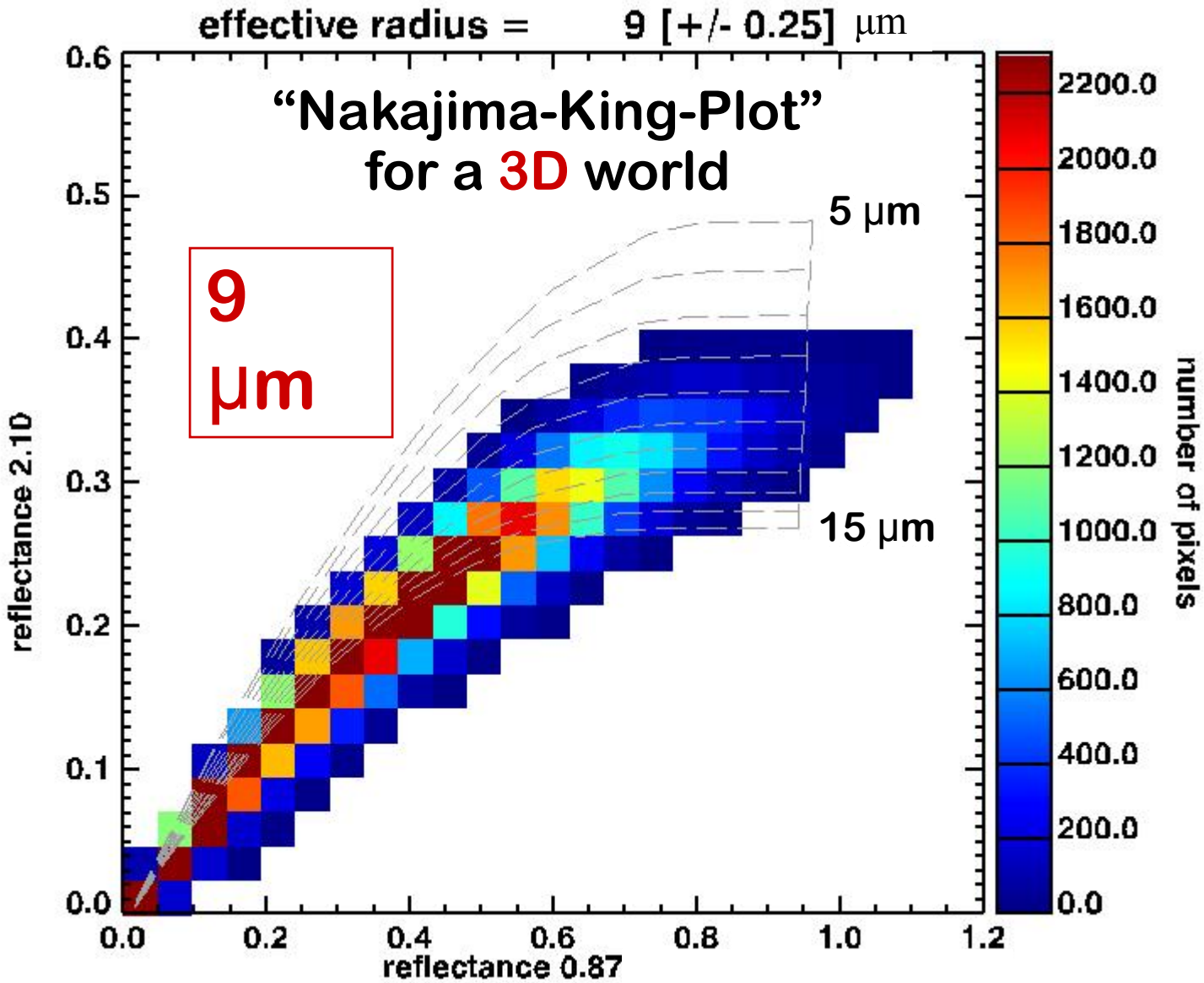
Forward Simulation

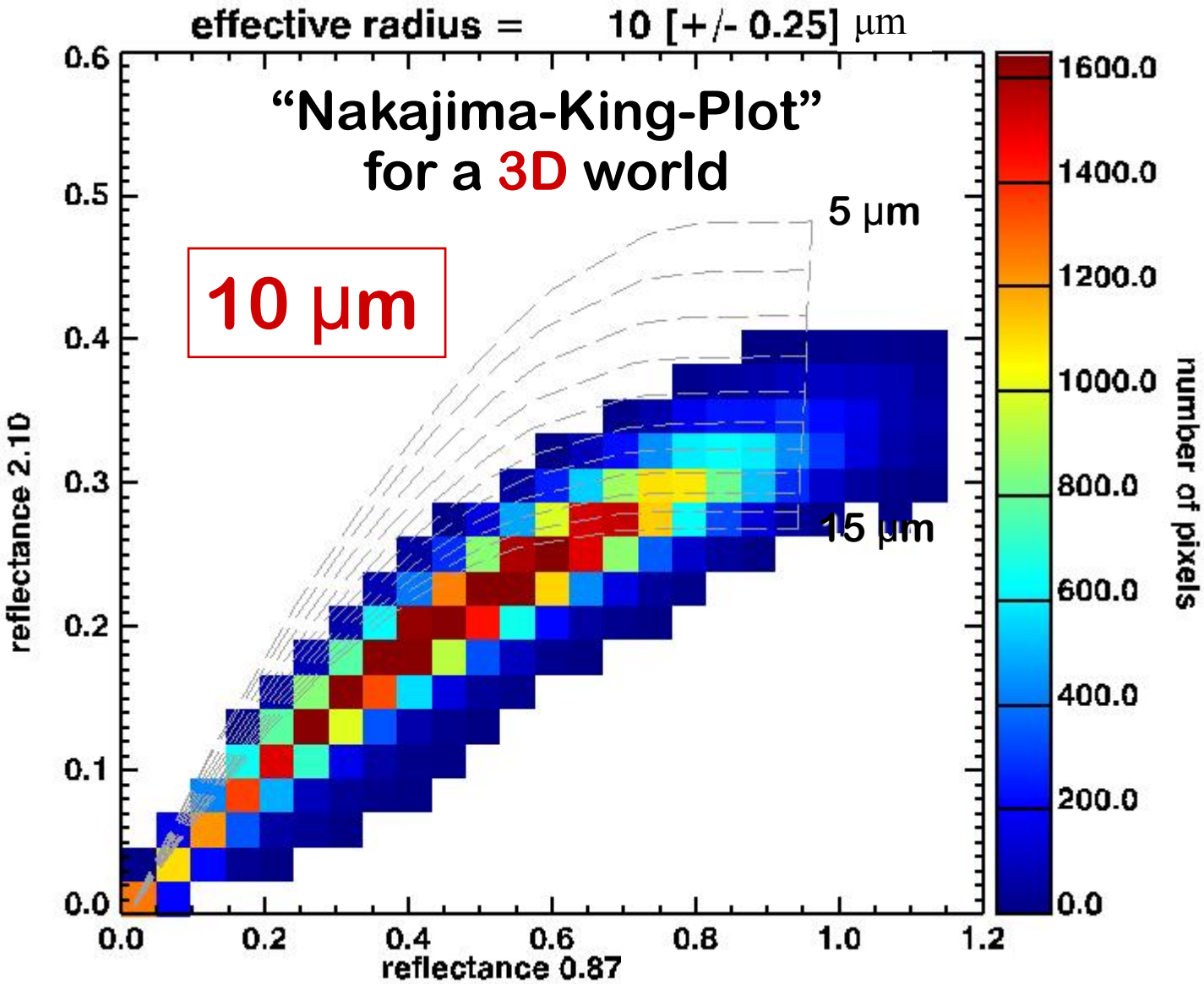


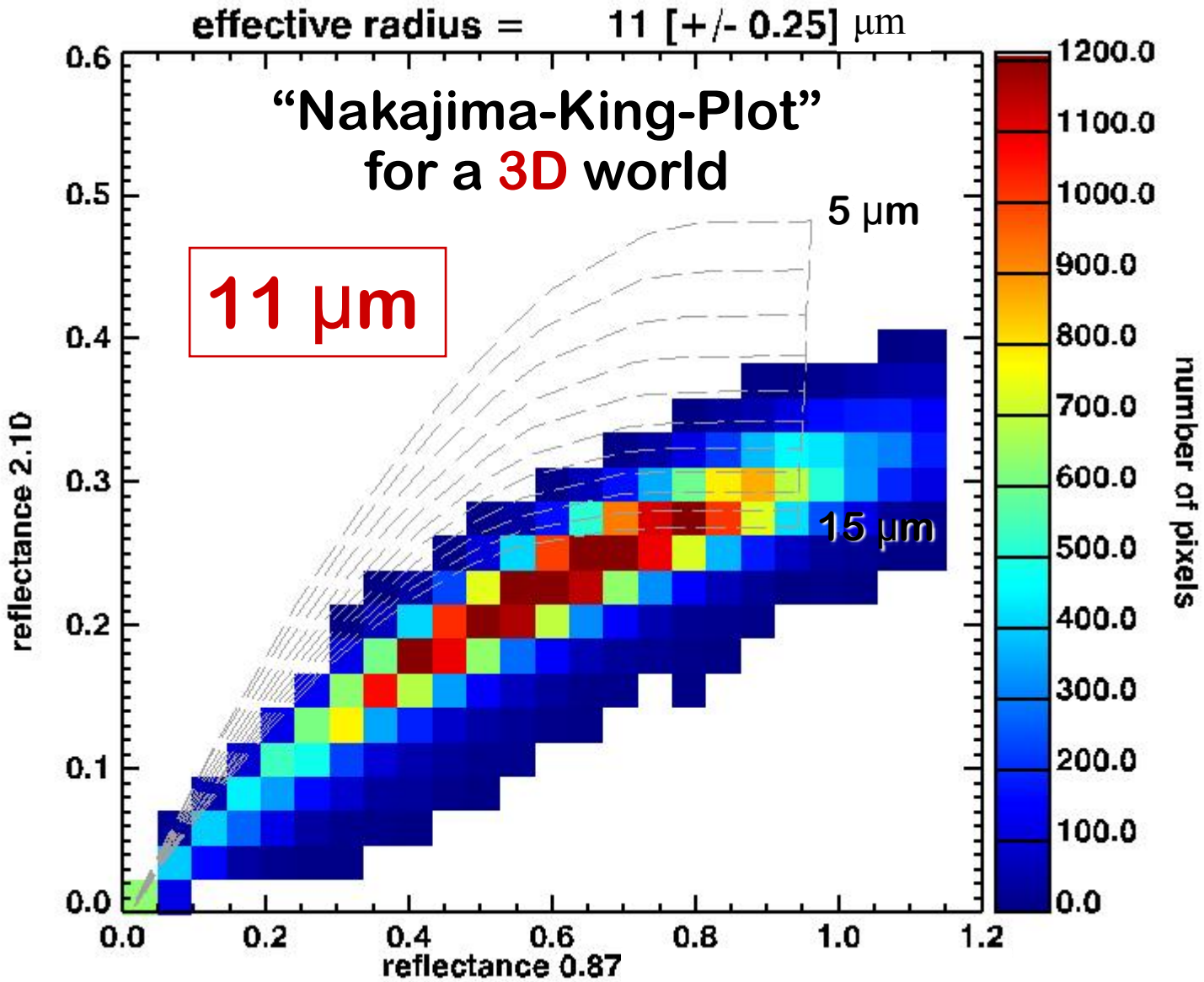

effective radius = 6 [+/- 0.25] µm
"Nakajima-King-Plot"
for a 3D world
6 µm
5 µm
15 µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0

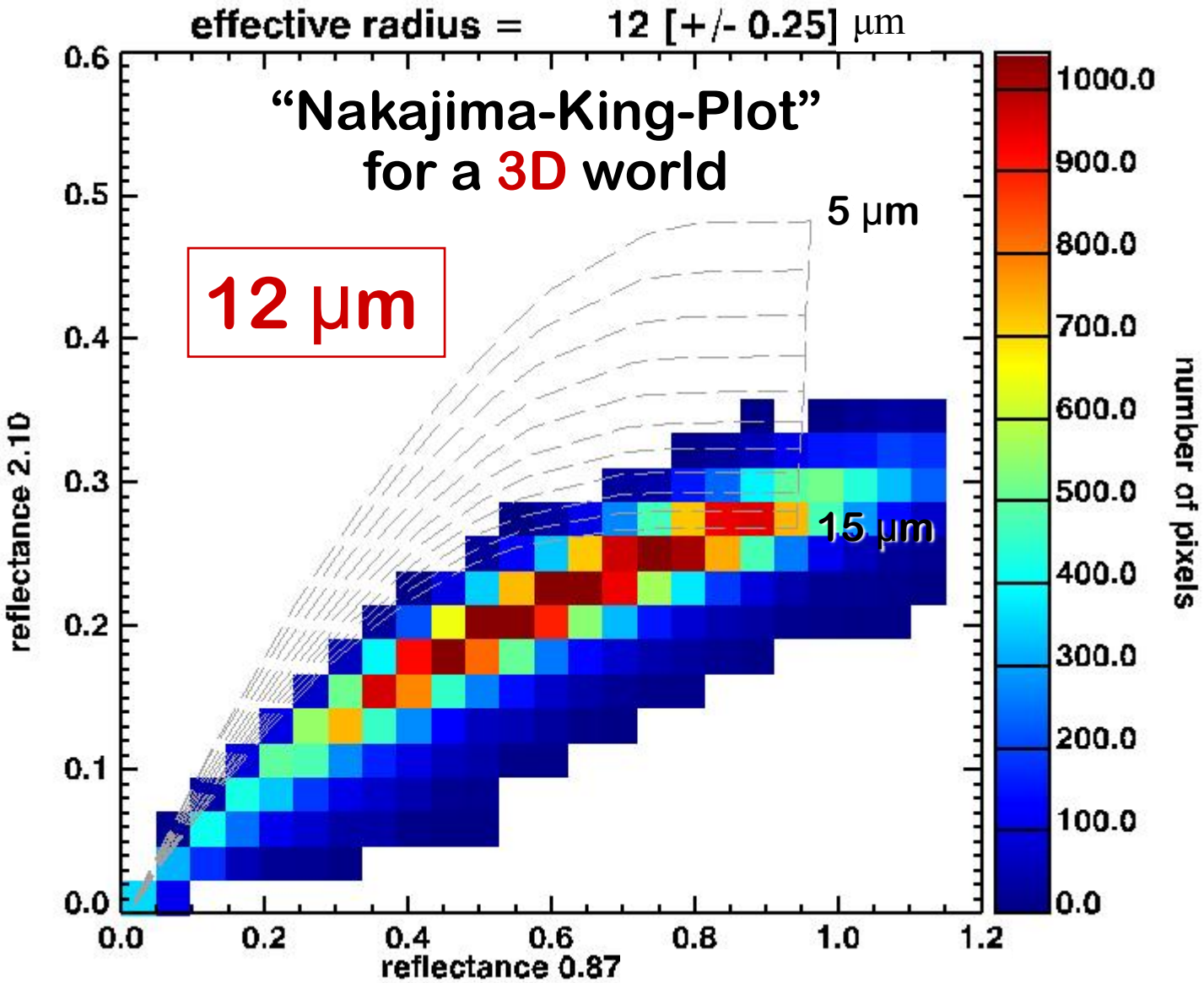

effective radius = 7 [+/- 0.25] µm
"Nakajima-King-Plot"
for a 3D world
7 µm
5 µm
15 µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0

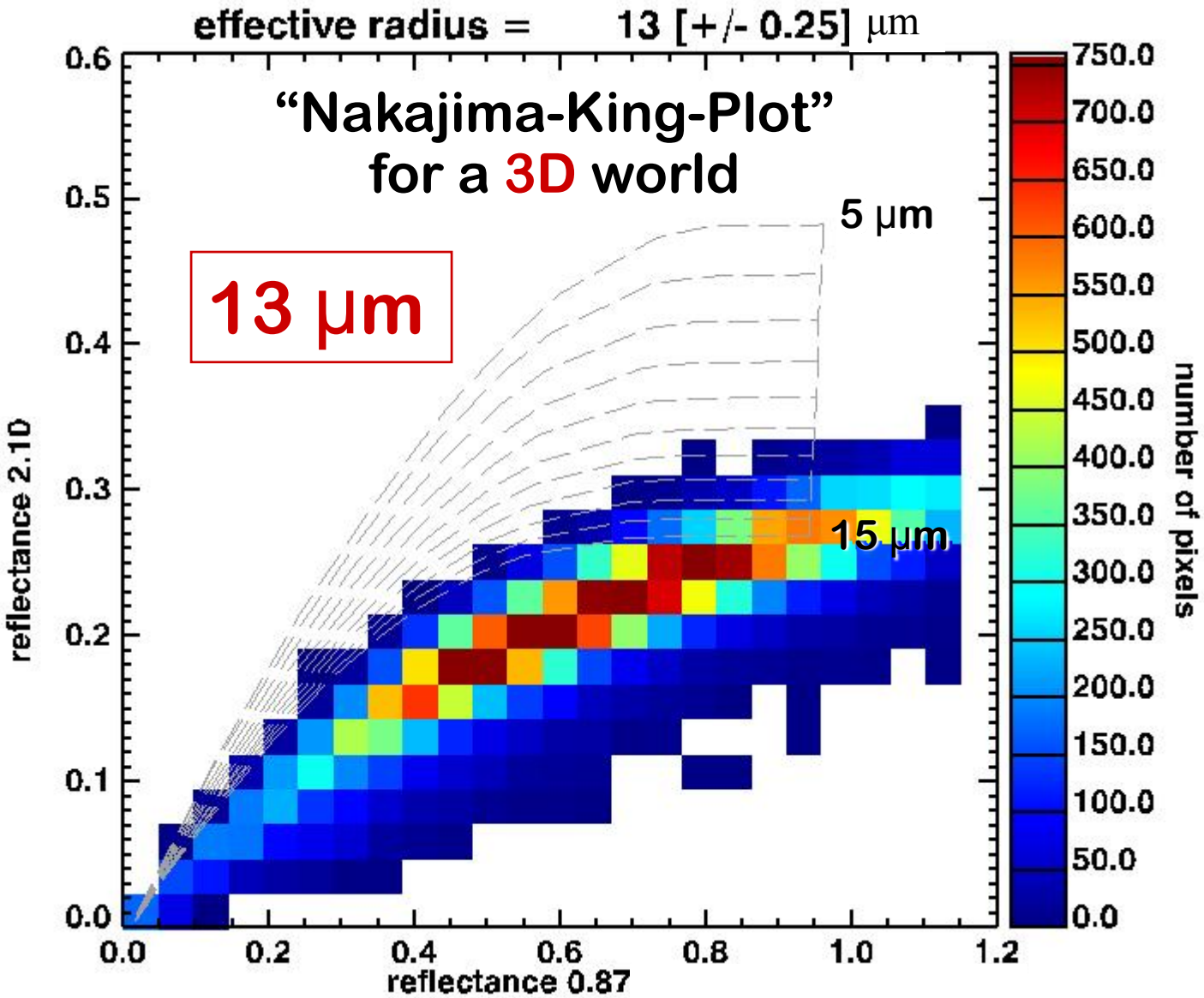

effective radius = 8 [+/- 0.25] µm
"Nakajima-King-Plot"
for a 3D world
8 µm
5 µm
15 µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
1800.0

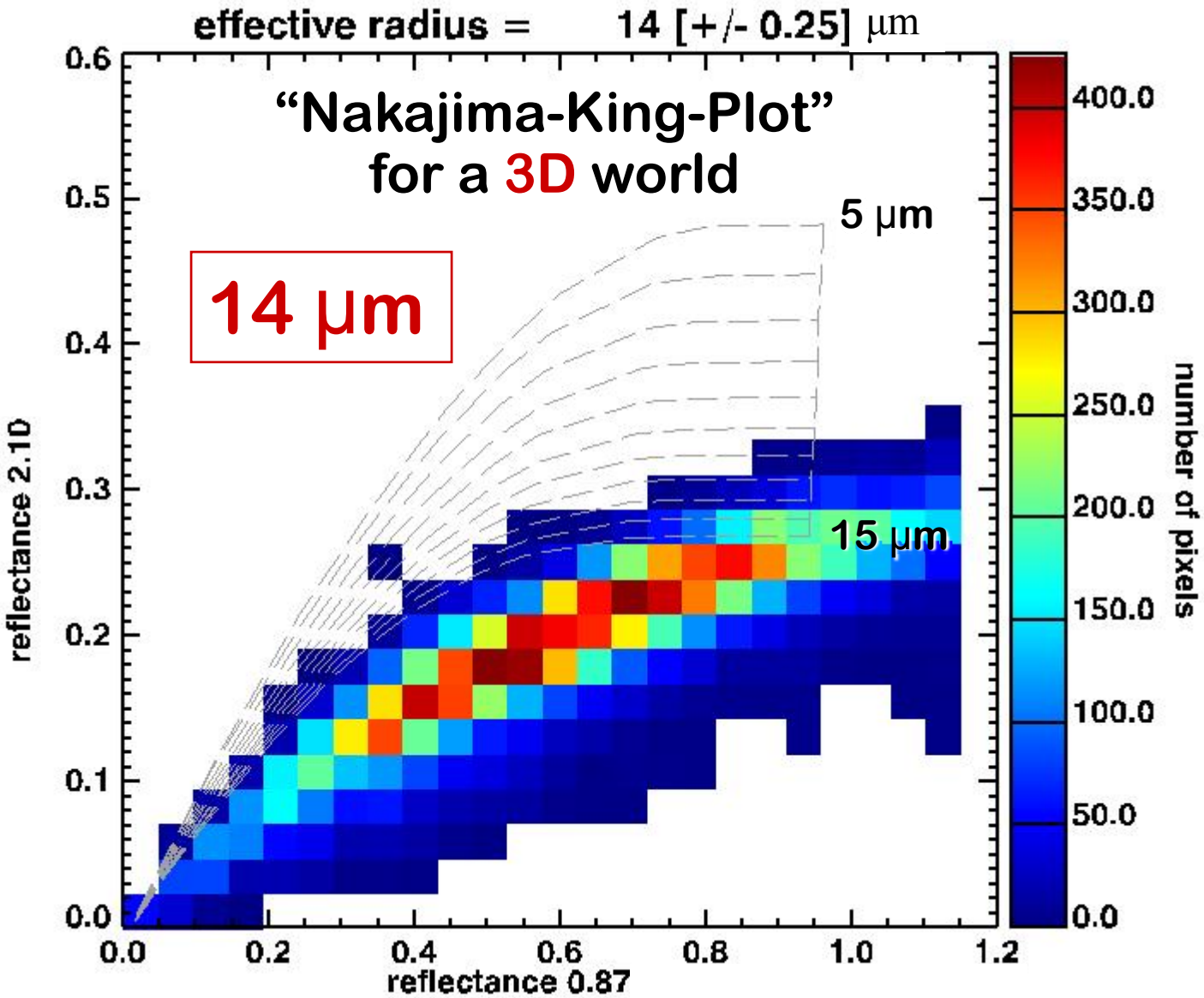

effective radius = 9 [+/- 0.25] µm
"Nakajima-King-Plot"
for a 3D world
9 µm
5 µm
15 µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
1800.0
2000.0
2200.0

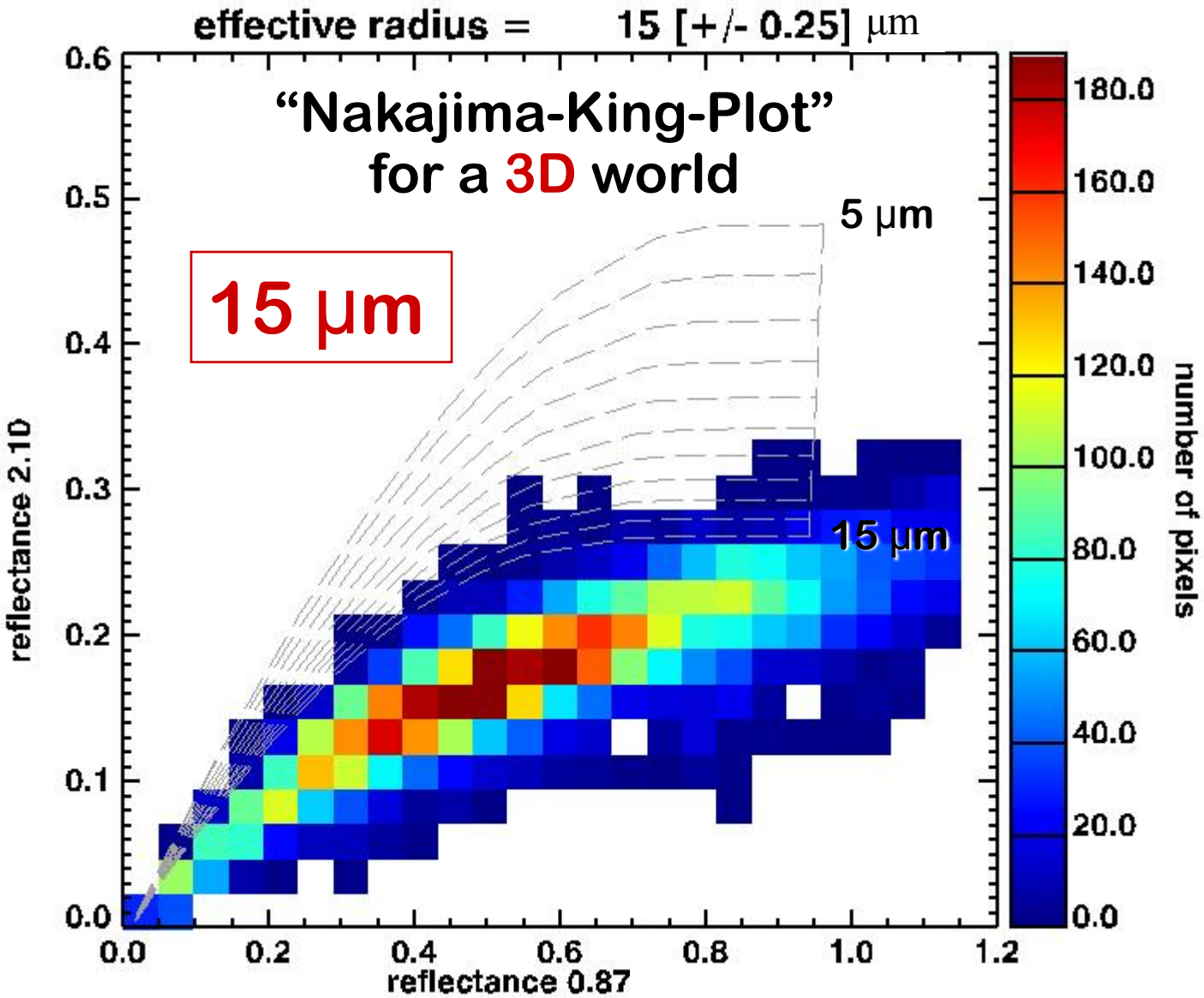

effective radius = 10 [+/- 0.25] µm
"Nakajima-King-Plot"
for a 3D world
10 µm
5 µm
15 µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0

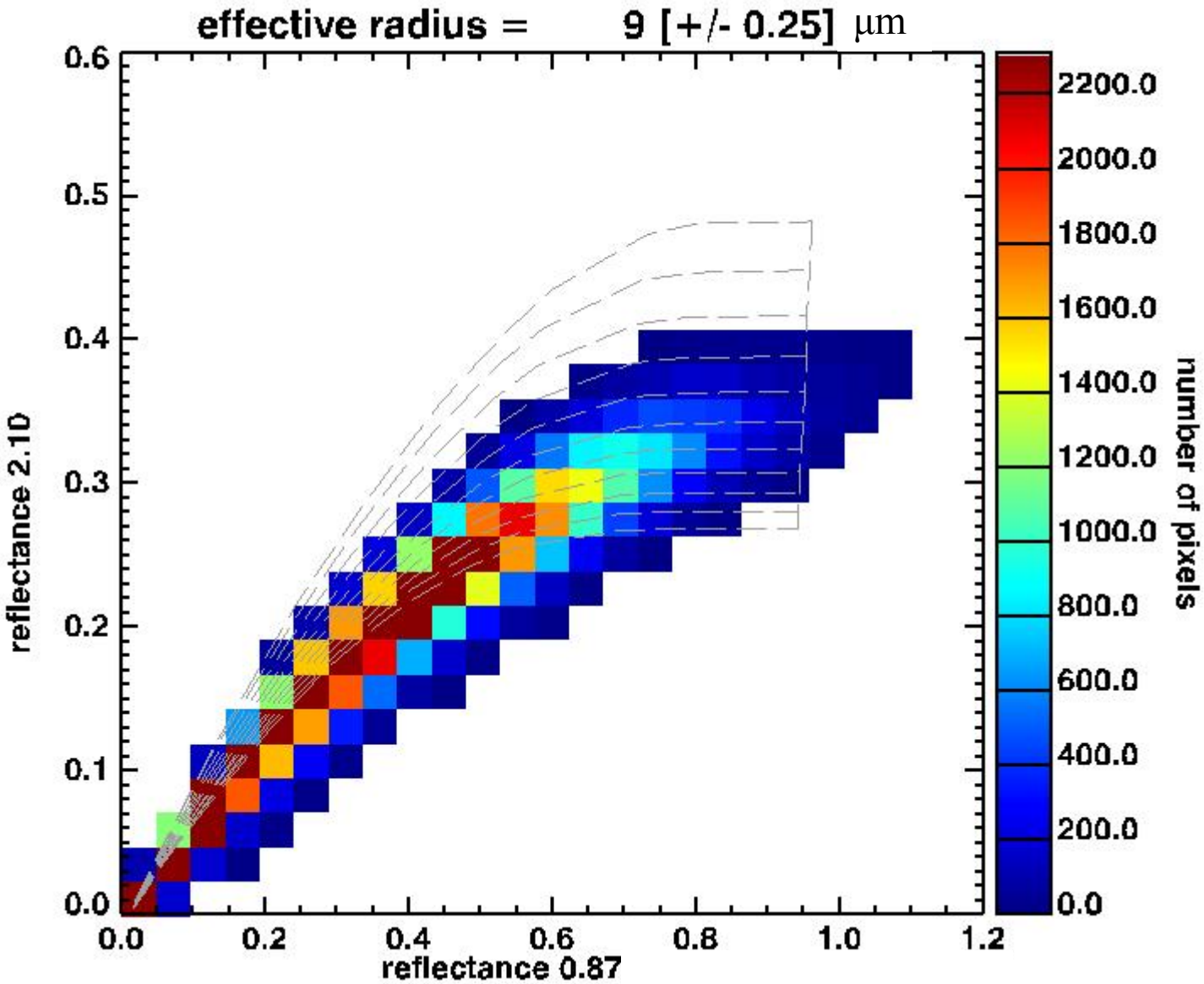

effective radius = 11 [+/- 0.25] µm
"Nakajima-King-Plot"
for a 3D world
11 µm
5 µm
15 µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
1100.0
1200.0

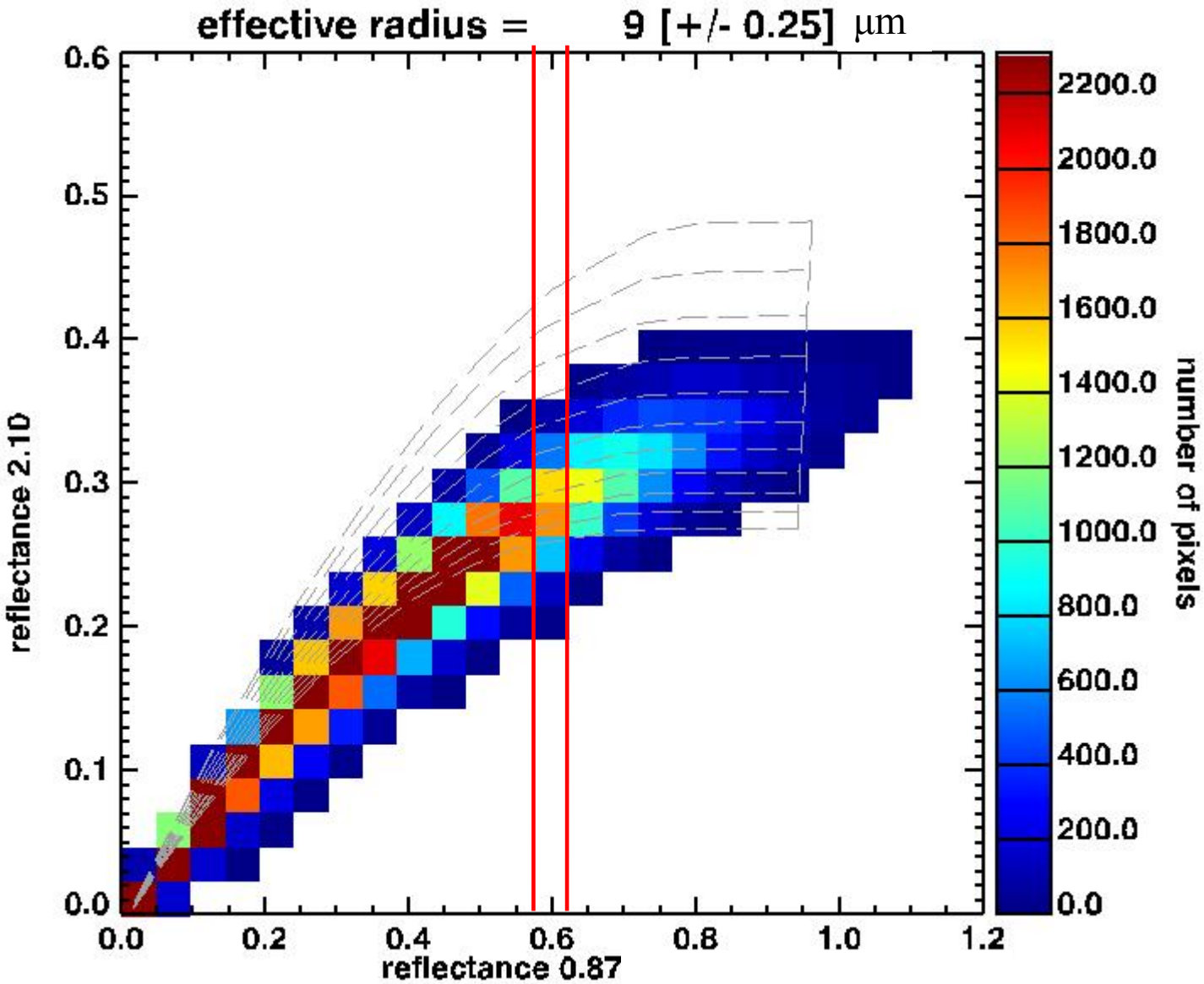

effective radius = 12 [+/- 0.25] µm
"Nakajima-King-Plot"
for a 3D world
12 µm
5 µm
15 µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0

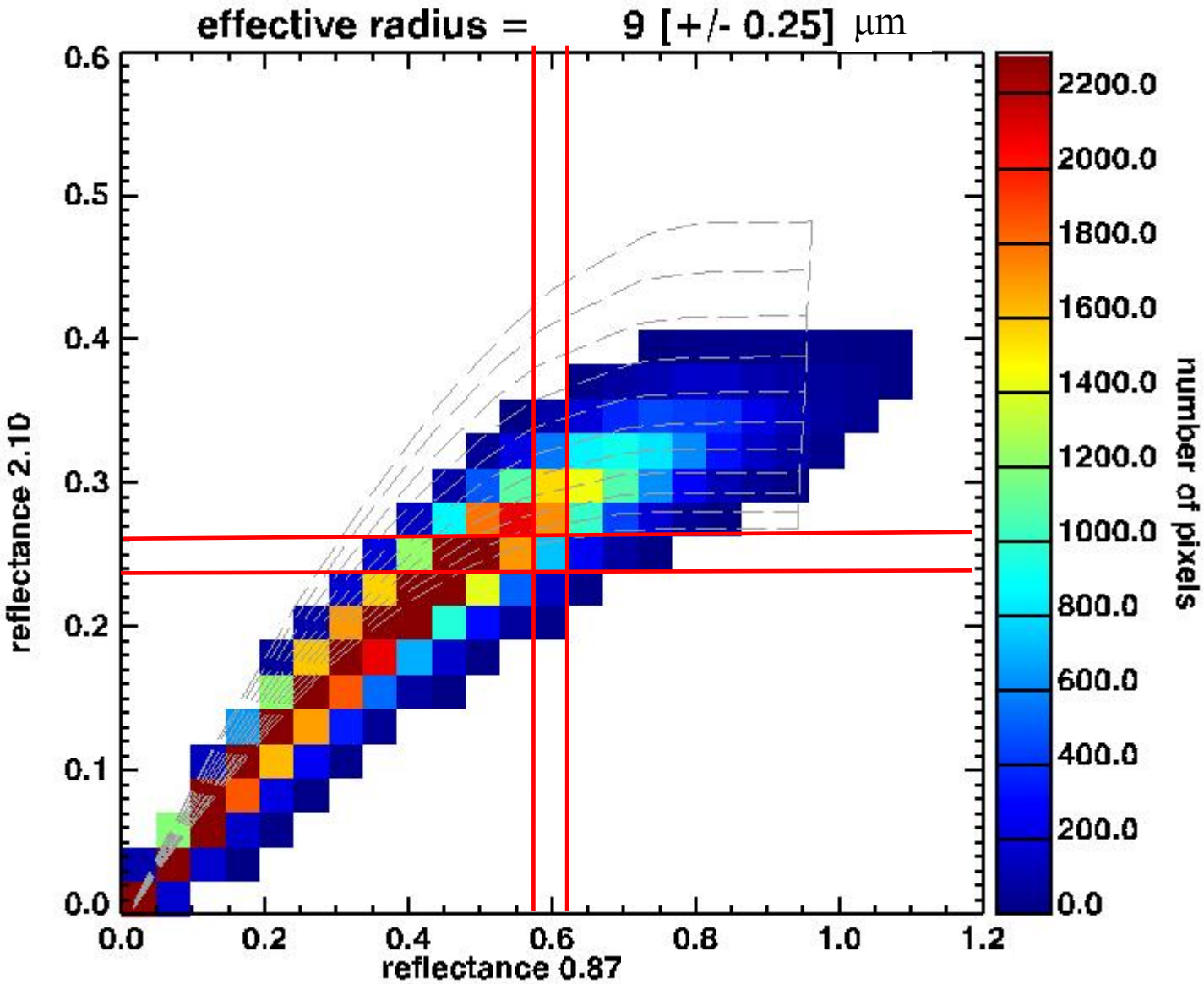

effective radius = 13 [+/- 0.25] µm
"Nakajima-King-Plot"
for a 3D world
13 µm
5 µm
15 µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
750.0
700.0
650.0
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0


effective radius = 14 [+/- 0.25] µm
"Nakajima-King-Plot"
for a 3D world
14 µm
5 µm
15 µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0

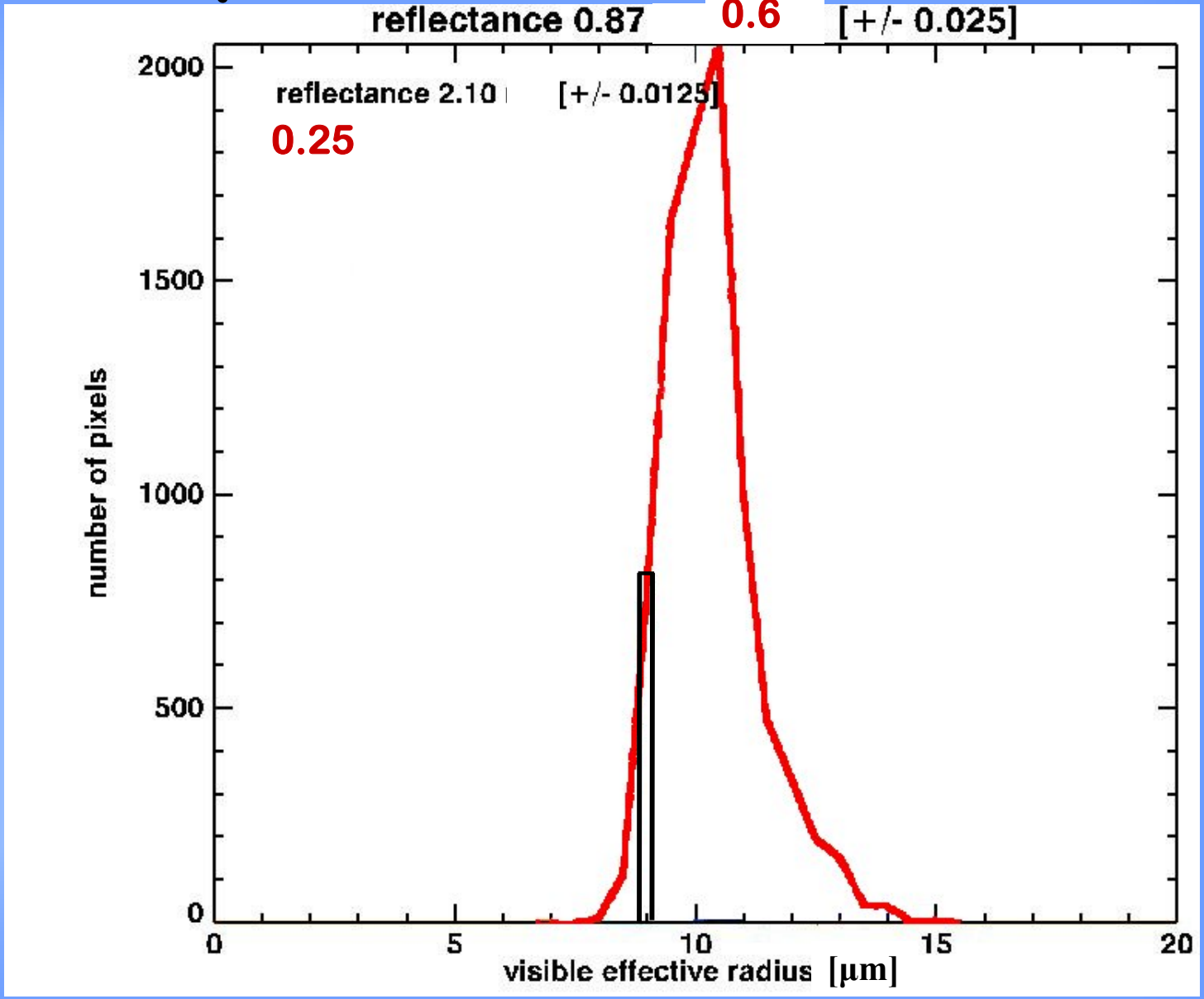

effective radius = 15 [+/- 0.25] µm
"Nakajima-King-Plot"
for a 3D world
15 µm
5 µm
15 µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0


effective radius = 9 [+/- 0.25] μm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2200.0
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0

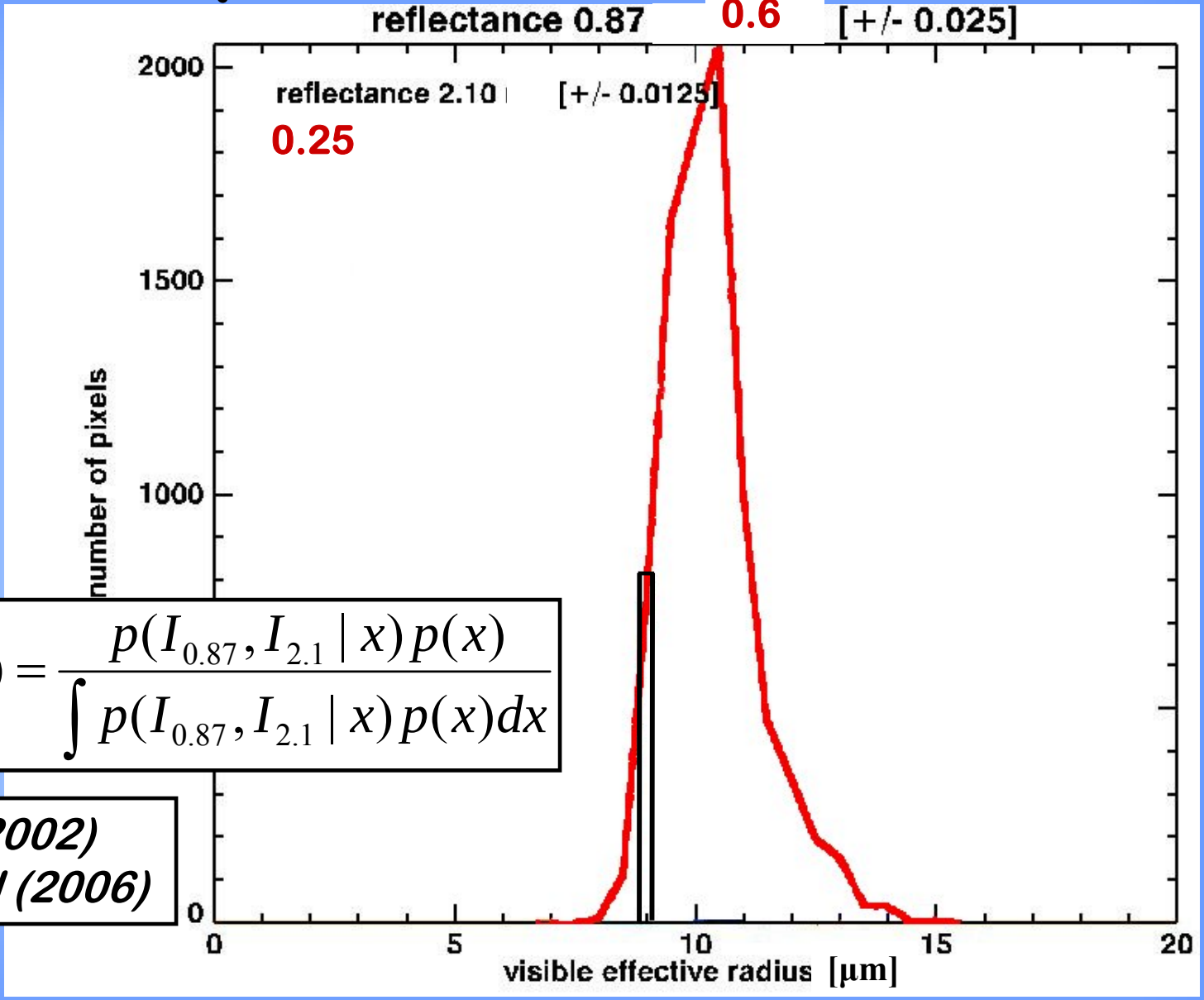

effective radius = 9 [+/- 0.25] µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2200.0
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0


effective radius = 9 [+/- 0.25] µm
reflectance 2.10
reflectance 0.87
number of pixels
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
1800.0
2000.0
2200.0

Bayesian Retrieval



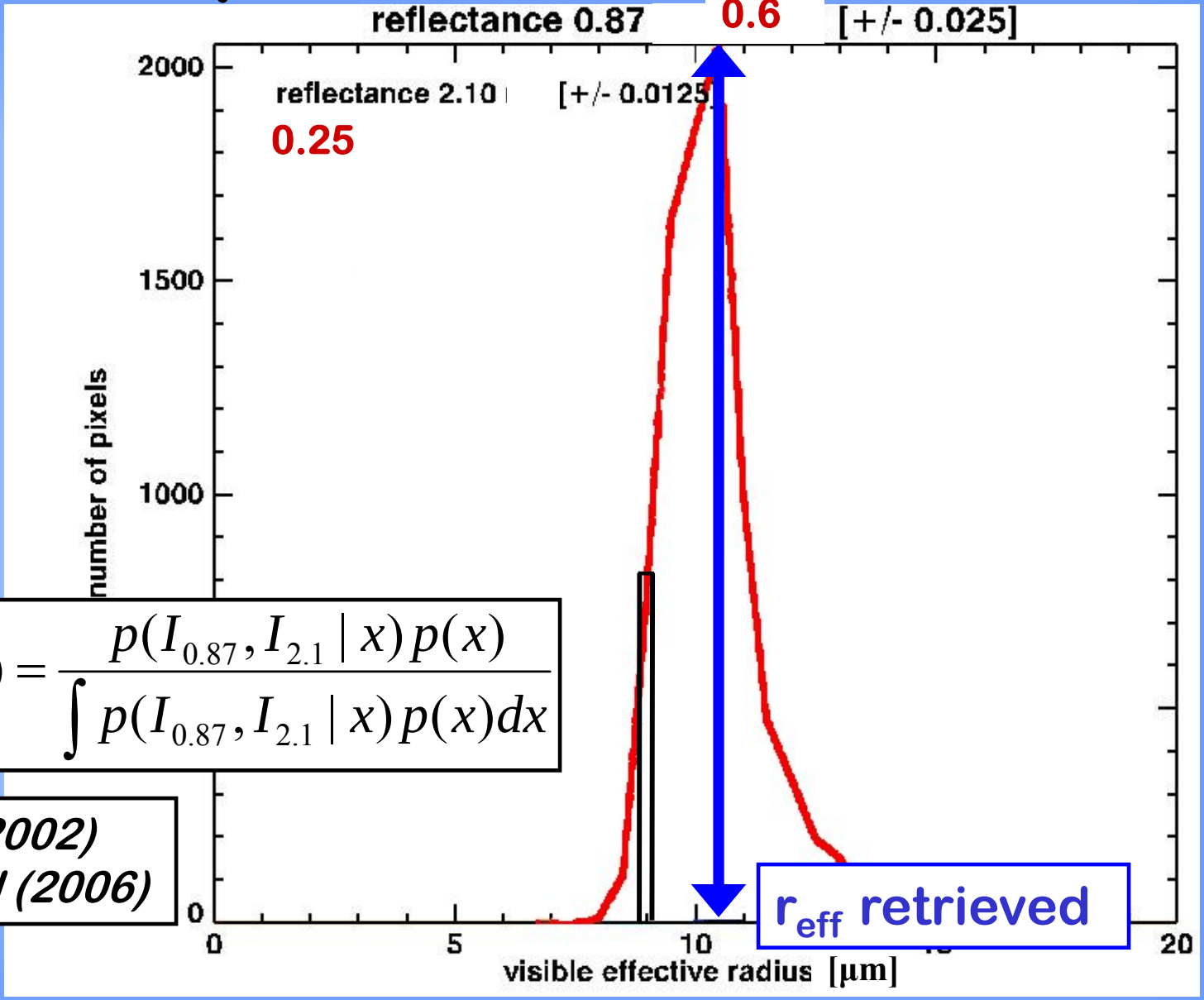
Bayesian Retrieval



$$p(x \mid I_{0.87}, I_{2.1}) = \frac{p(I_{0.87}, I_{2.1} \mid x)\, p(x)}{\int p(I_{0.87}, I_{2.1} \mid x)\, p(x)\, dx}$$

Evans et al (2002)
Marshak et al (2006)

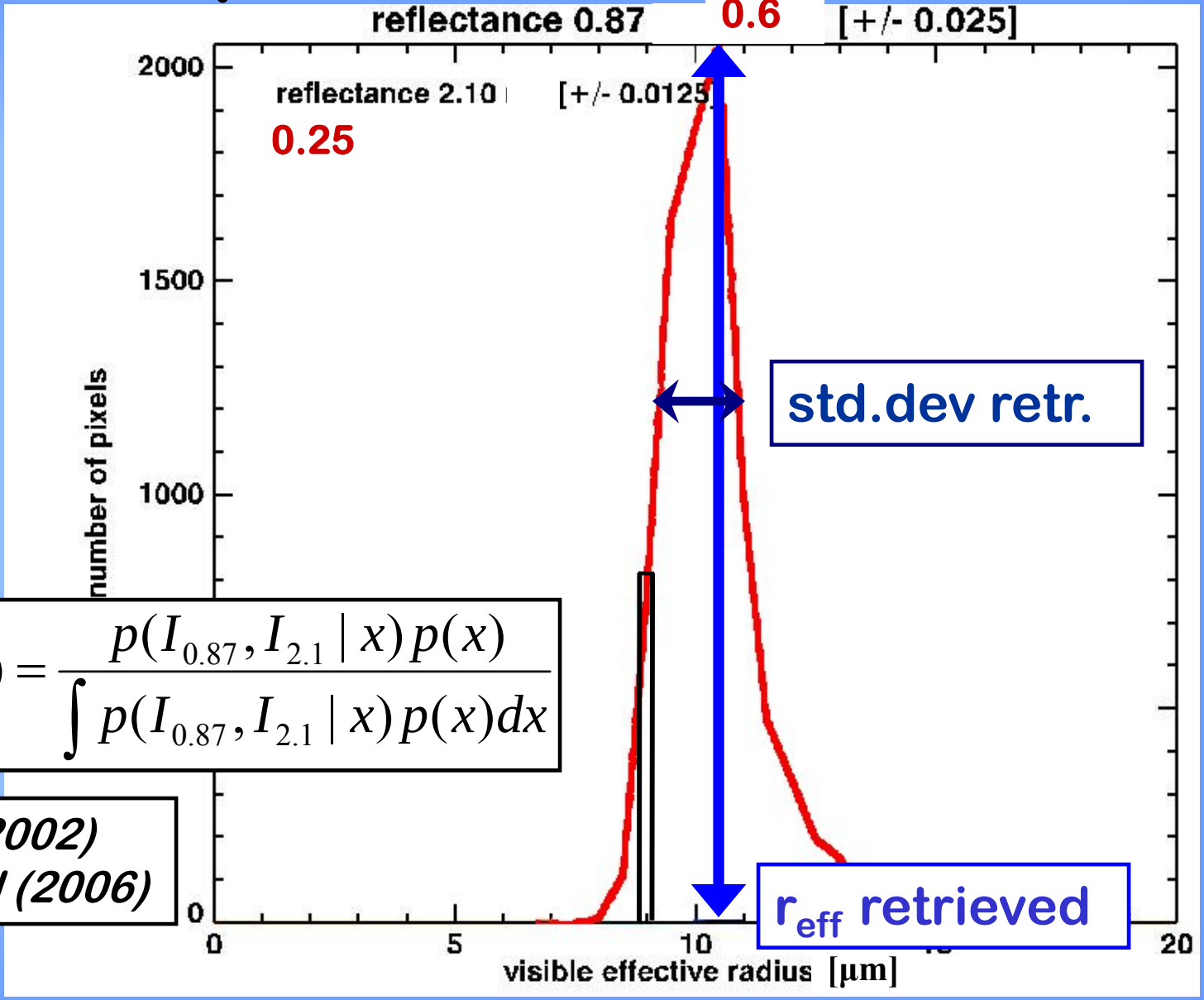
Bayesian Retrieval



$$p(x \mid I_{0.87}, I_{2.1}) = \frac{p(I_{0.87}, I_{2.1} \mid x)\, p(x)}{\int p(I_{0.87}, I_{2.1} \mid x)\, p(x)\, dx}$$

Evans et al (2002)
Marshak et al (2006)

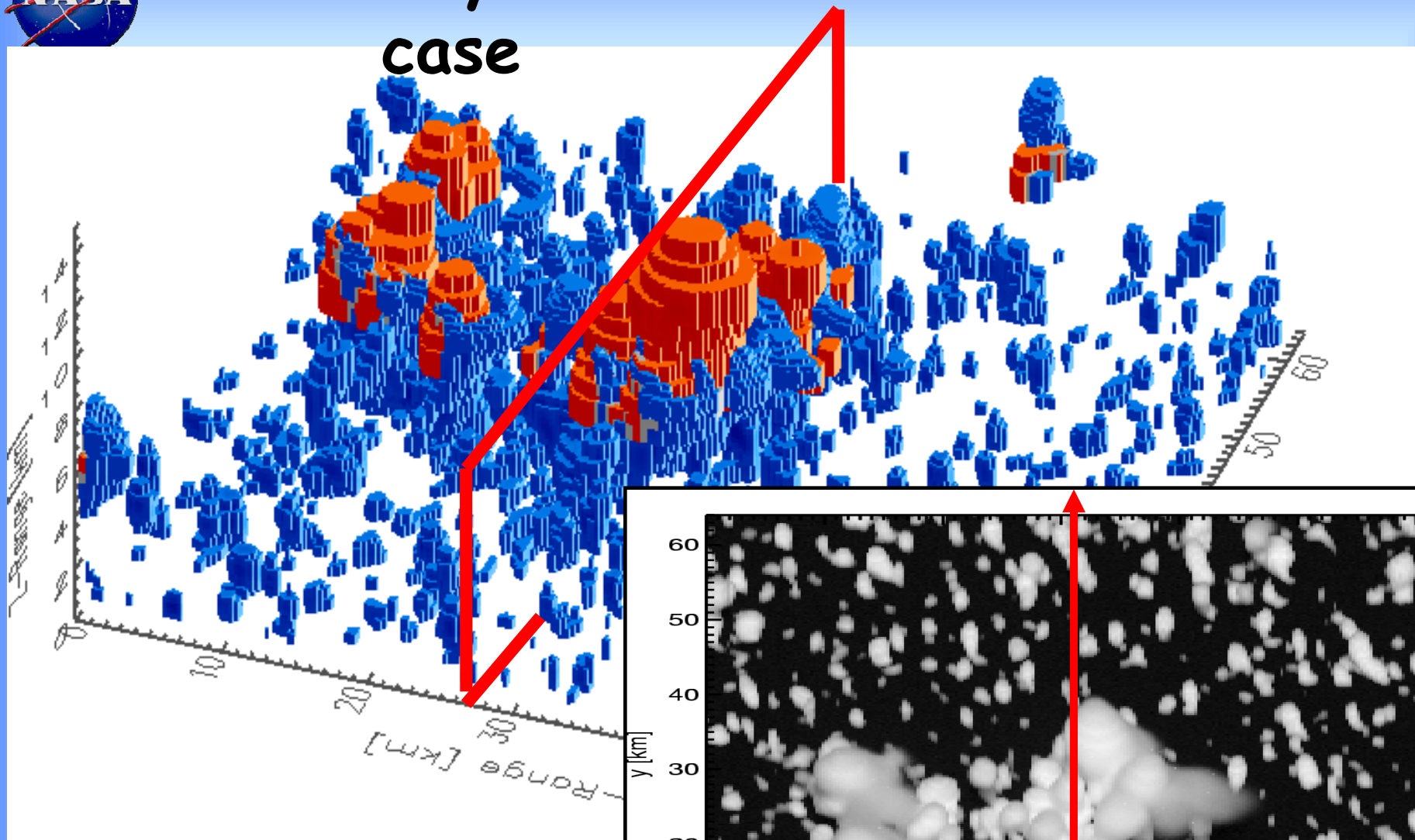
Bayesian Retrieval

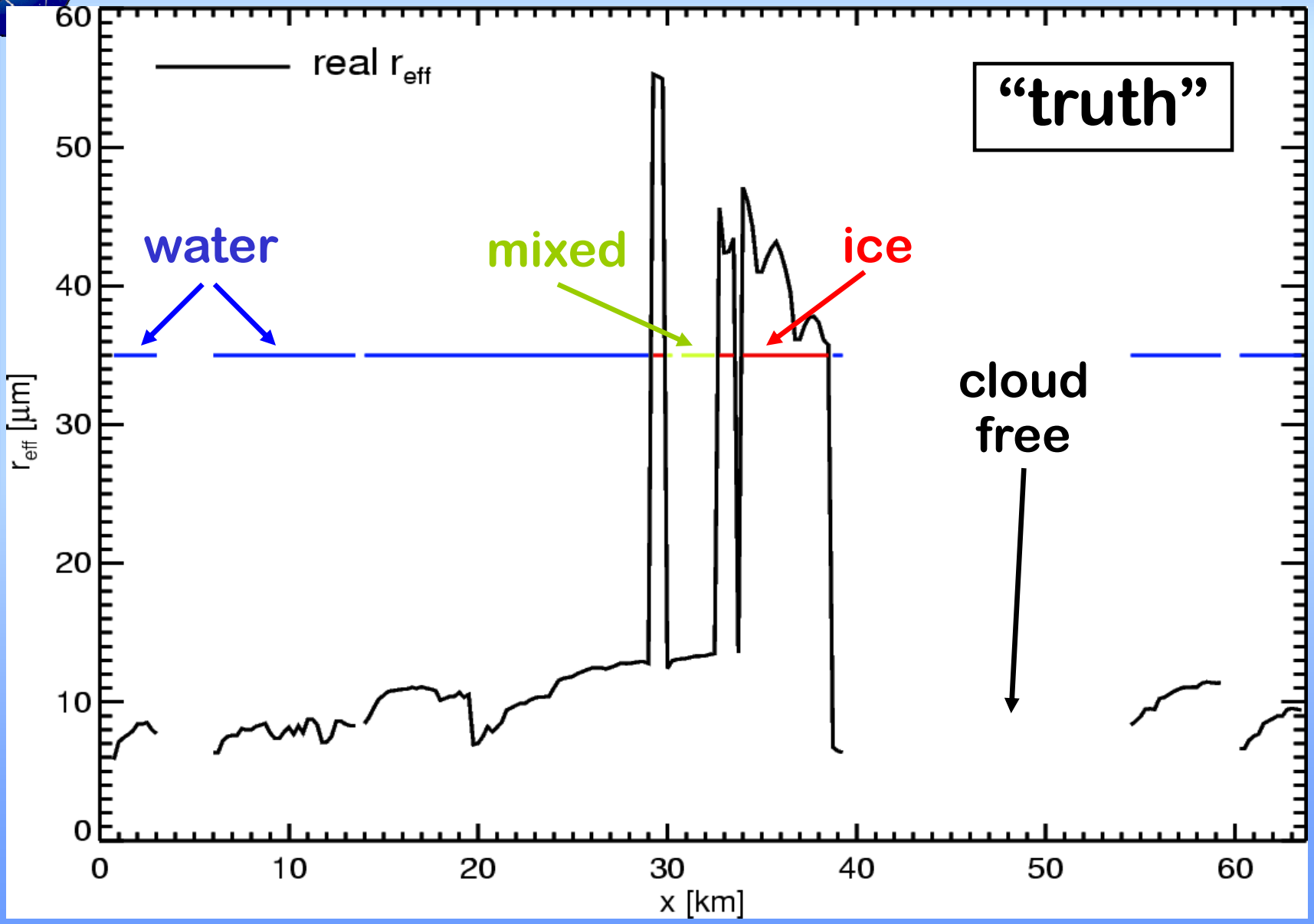


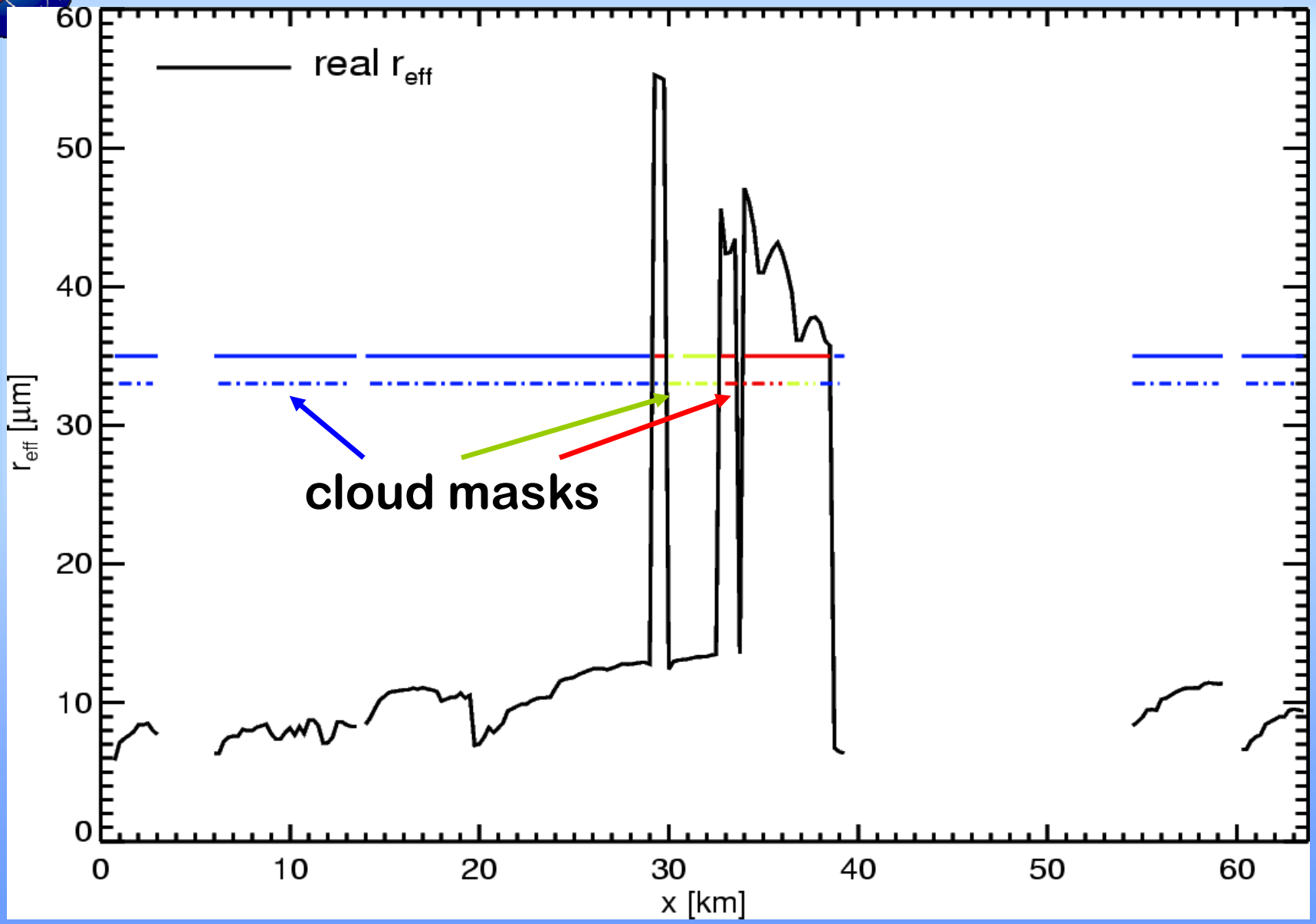
$$p(x \mid I_{0.87}, I_{2.1}) = \frac{p(I_{0.87}, I_{2.1} \mid x)\, p(x)}{\int p(I_{0.87}, I_{2.1} \mid x)\, p(x)\, dx}$$

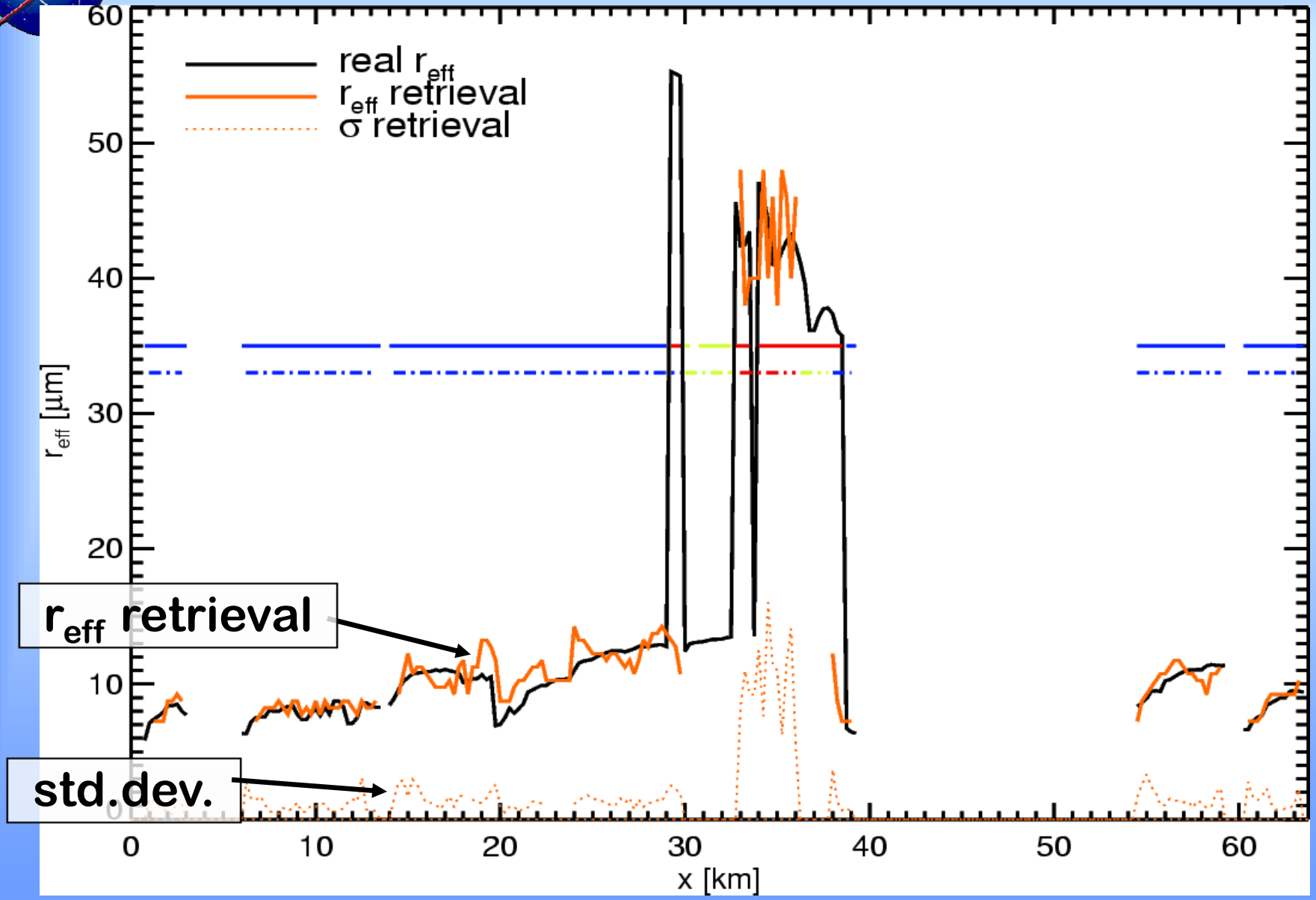
Evans et al (2002)
Marshak et al (2006)

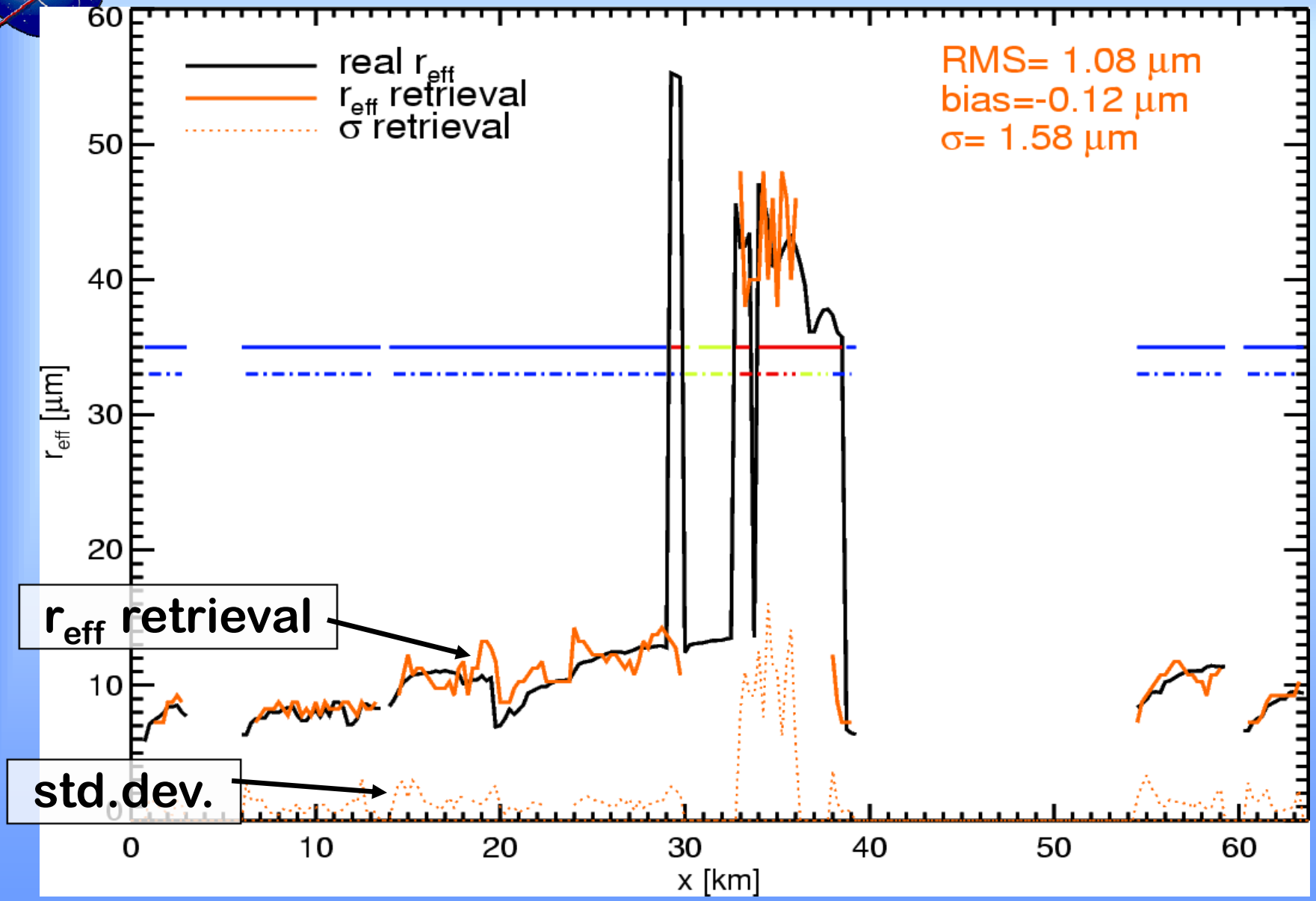
Bayesian retrieval-Test case

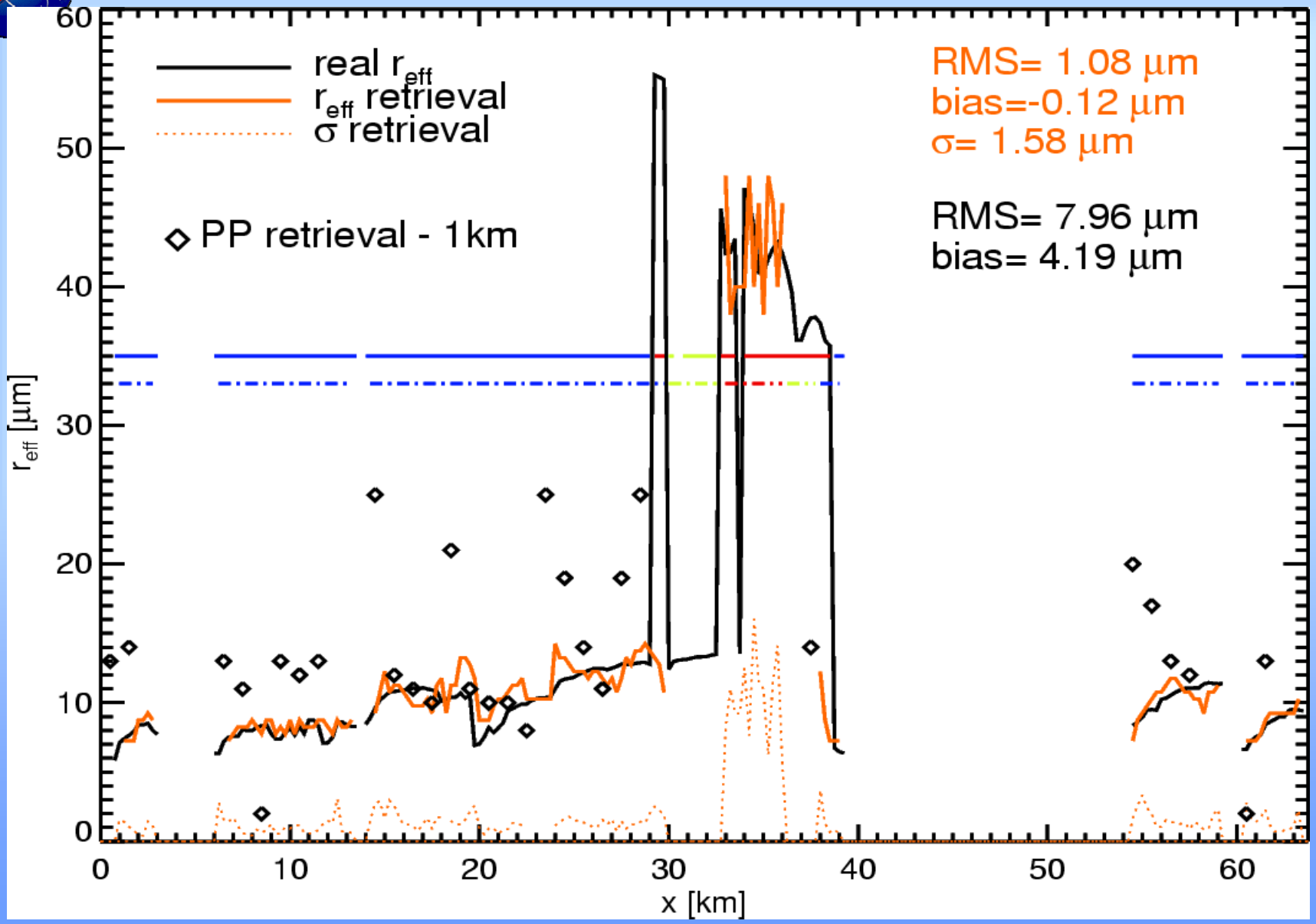



real r_{eff}
"truth"
water
mixed
ice
cloud free
r_{eff} [µm]
x [km]
0
10
20
30
40
50
60

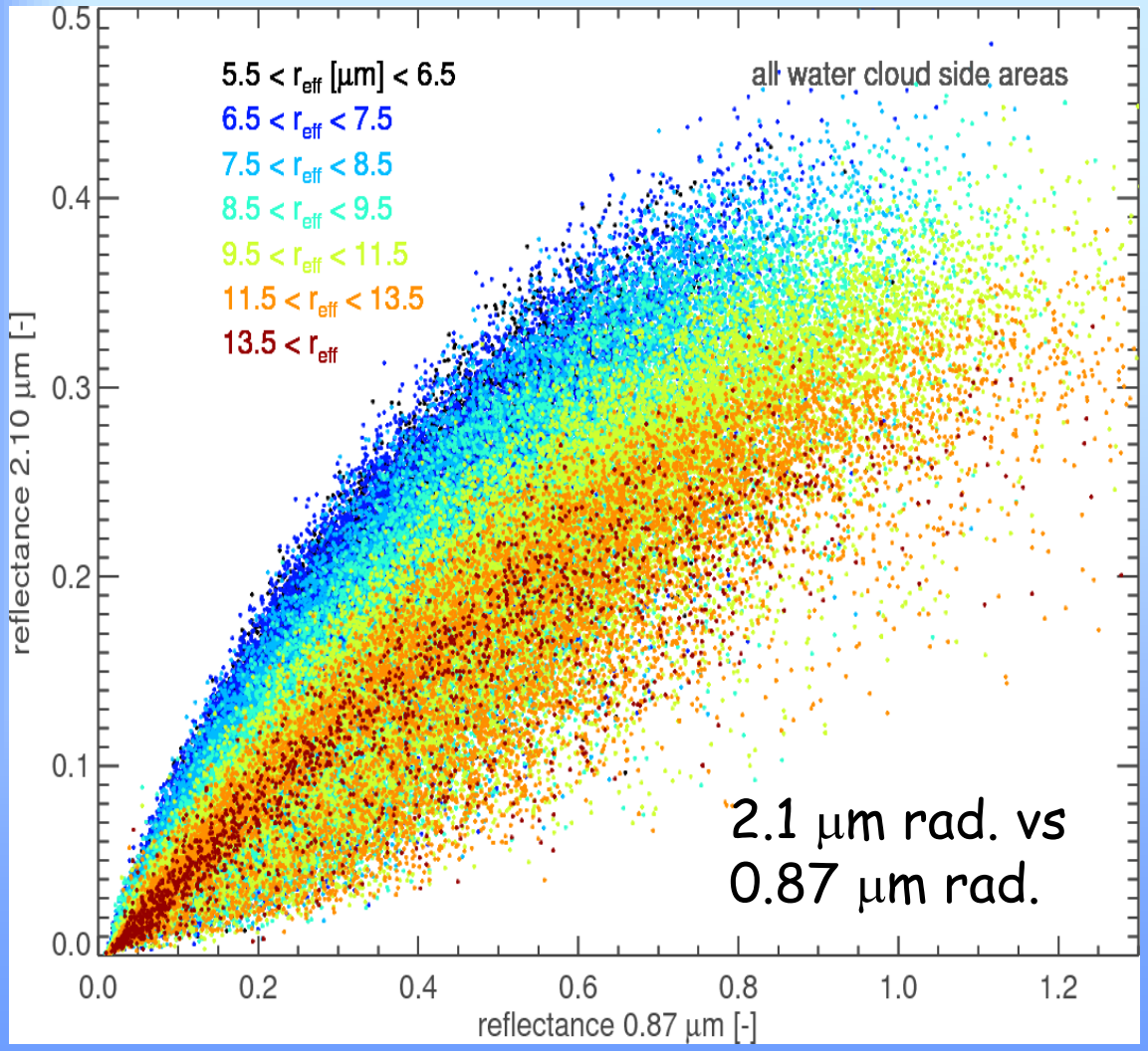

real r_{eff}
cloud masks
r_{eff} [µm]
x [km]
0
10
20
30
40
50
60

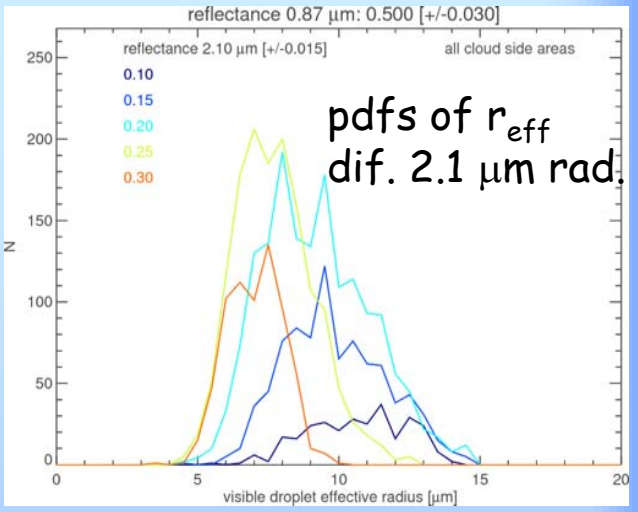

real r_{eff}
r_{eff} retrieval
σ retrieval
r_{eff} [μm]
x [km]
0
10
20
30
40
50
60
r_{eff} retrieval
std.dev.

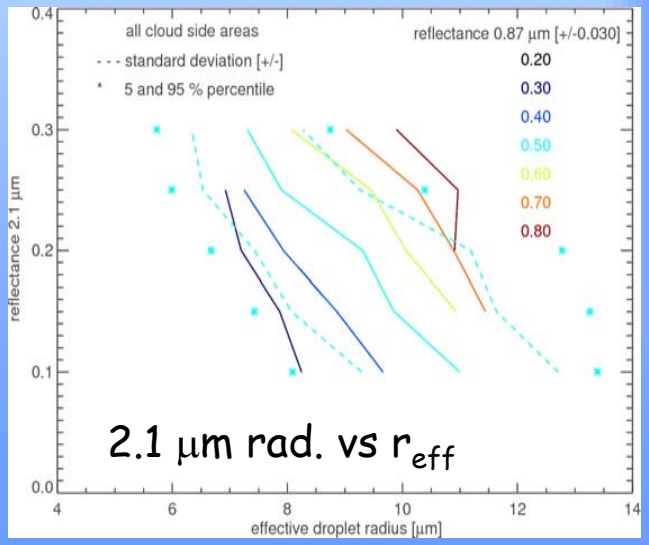

real r_{eff}
r_{eff} retrieval
σ retrieval
RMS= 1.08 μm
bias=-0.12 μm
σ= 1.58 μm
r_{eff} [μm]
x [km]
0
10
20
30
40
50
60
r_{eff} retrieval
std.dev.


real r_{eff}
r_{eff} retrieval
σ retrieval
PP retrieval - 1km
RMS= 1.08 μm
bias=-0.12 μm
σ= 1.58 μm
RMS= 7.96 μm
bias= 4.19 μm
r_{eff} [μm]
x [km]
0
10
20
30
40
50
60

From the Ground; Test Case







Show movie Mt. Gibbs NC

Summary

- **Cloud side remote sensing of cloud droplet size** rather than cloud top (or cloud base) remote sensing
- **Statistical retrievals** rather than deterministic retrievals
- Extensive forward 3D RT simulations
- Proof-of-concept of the potential for **retrievals of cloud droplet size accounting for 3D RT effects** and high resolution cloud variability

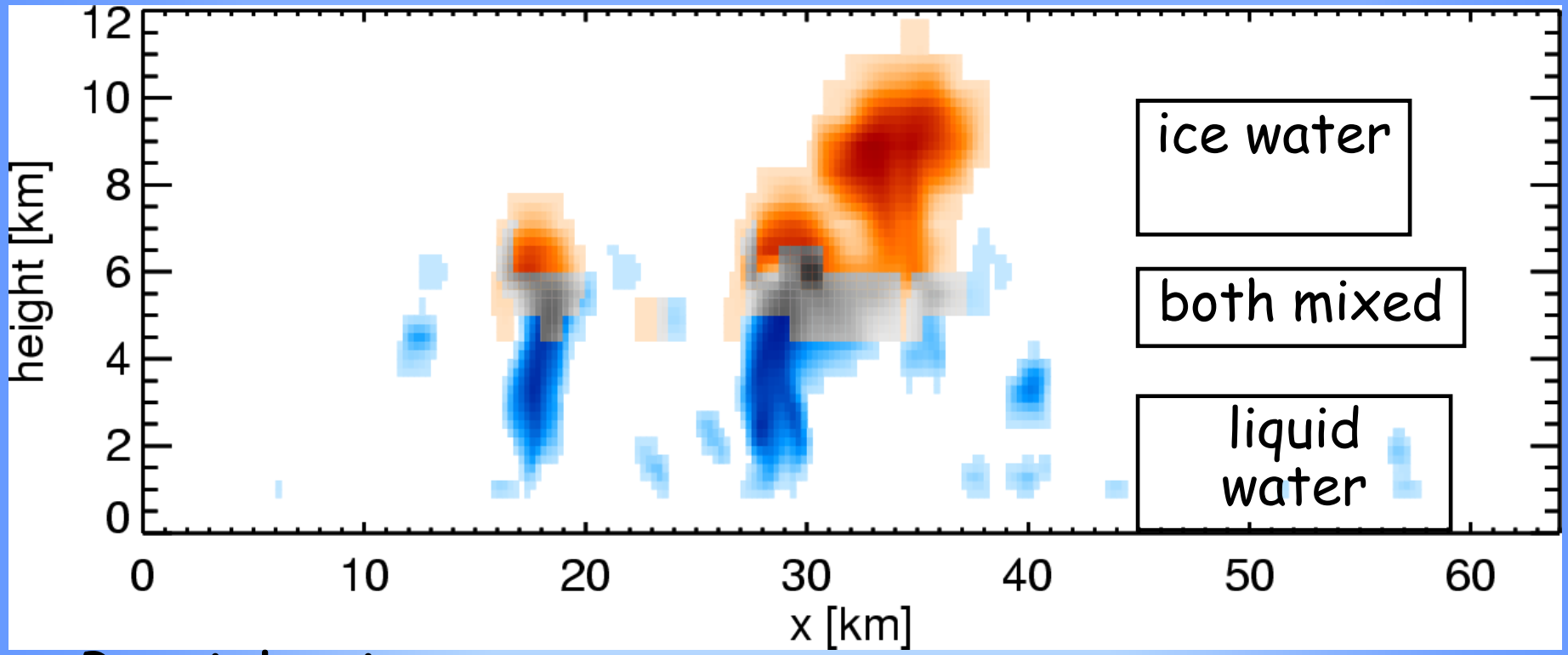
MYSTIC Monte Carlo

"Monte Carlo code for the physically correct tracing of photons in cloudy atmospheres"

- Mayer (1999/2000, I3RC)
- Mayer + Kylling (ACP, 2005)

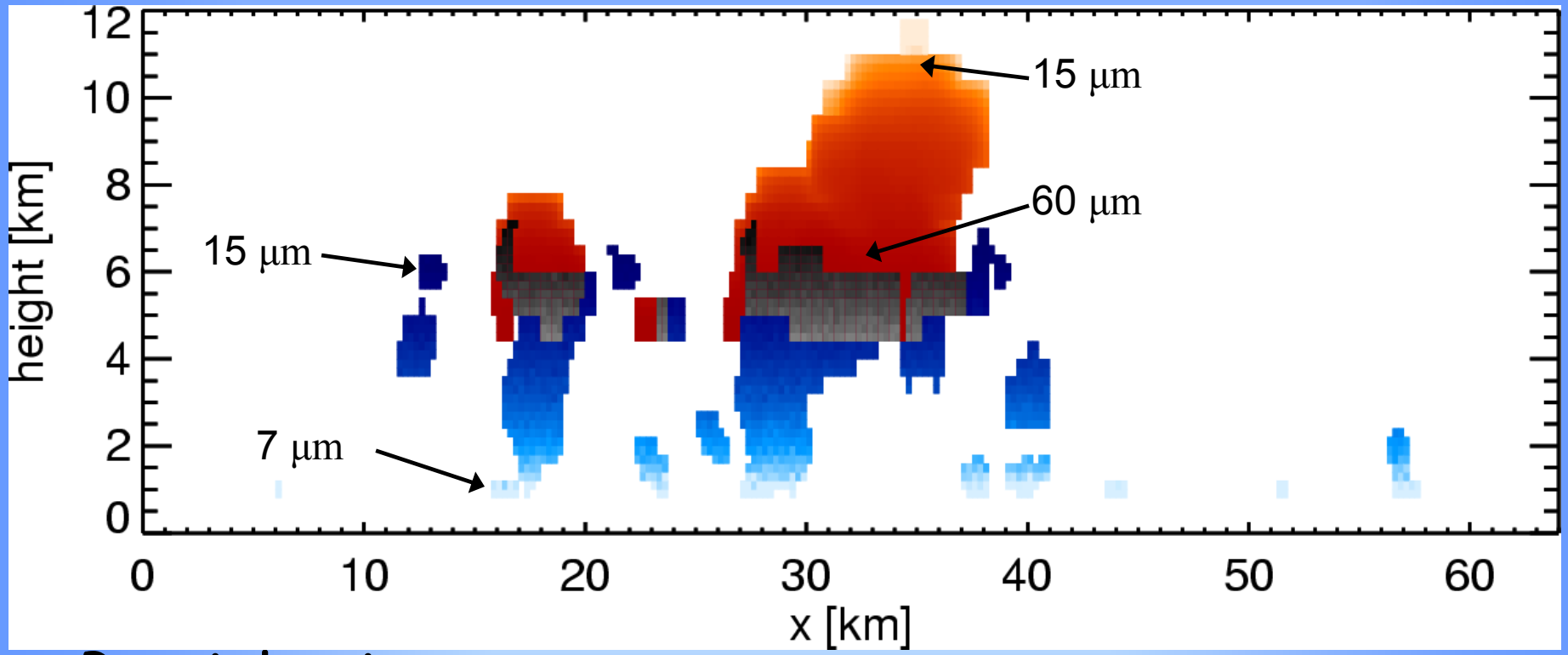
- We optimized it using Delta-Eddington approximation (8 times faster)

Goddard Cumulus Ensemble model



Particle size:
???

Goddard Cumulus Ensemble model



Particle size:

droplet: $r_{eff} = f(\Delta z)$ "semi-adiabatic" + noise

ice: $r_{eff} = f(IWC,T)$ *(Wyser, 1998)*