Evaluating MODIS marine water cloud products with LES models

MODIS Science Team Meeting
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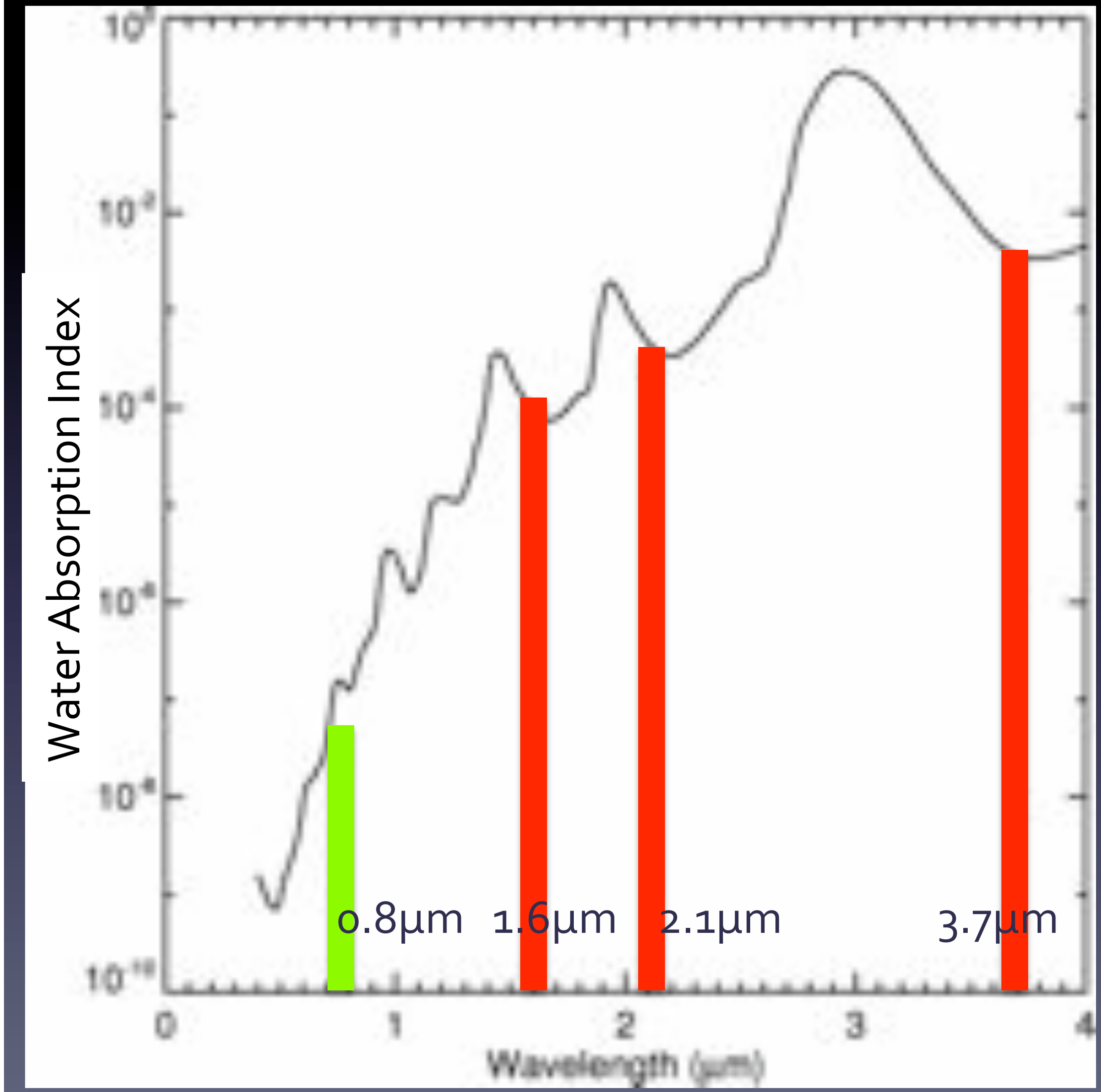
Outline

- Background
- Observational study of the difference between MODIS $r_e(1.6\mu\text{m})$, $r_e(2.1\mu\text{m})$ and $r_e(3.7\mu\text{m})$ for MBL clouds
- Pathway toward the future

Background

Spectral locations of MODIS cloud bands



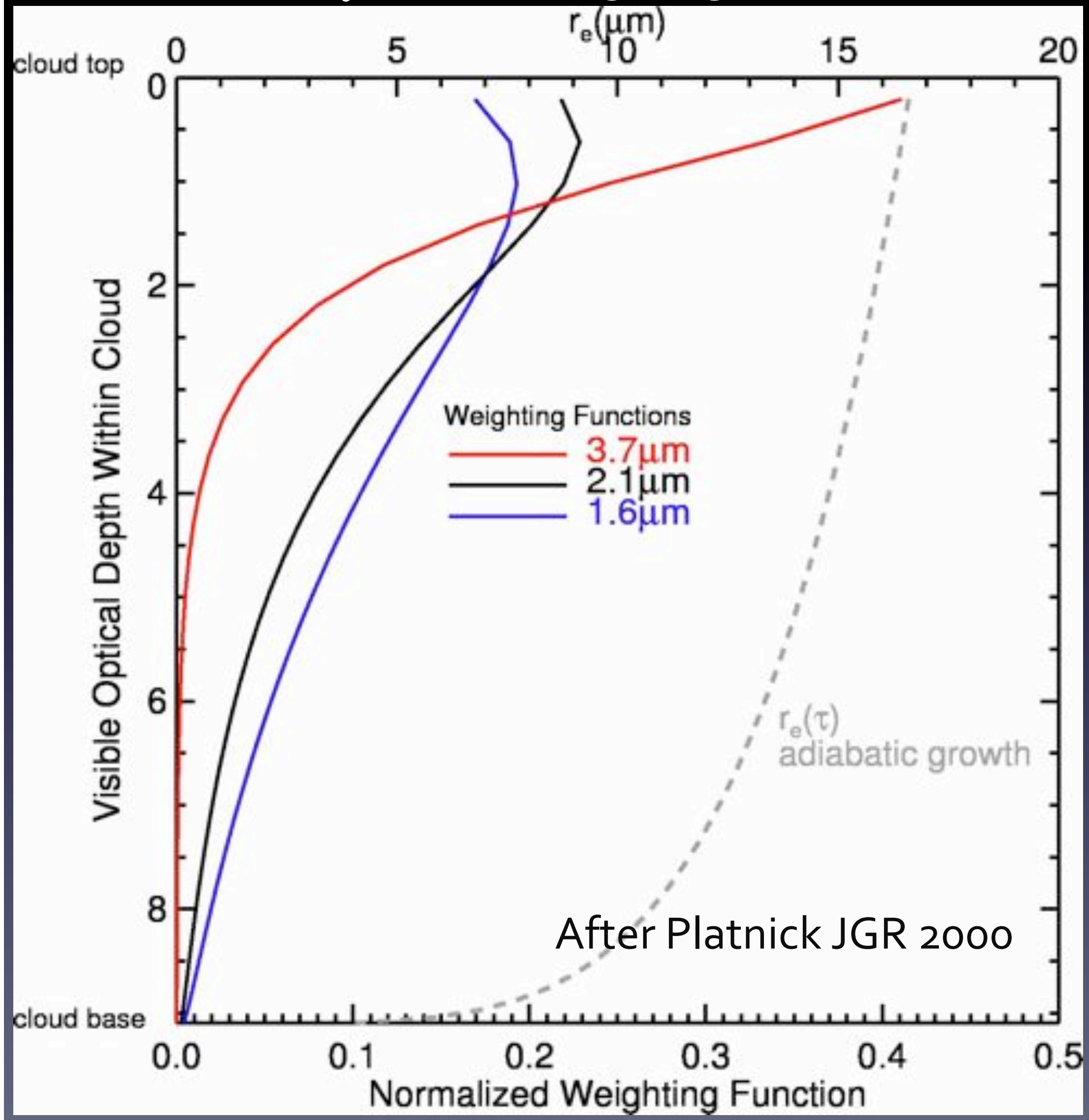
MODIS has three water absorbing SWIR/NIR bands, with band center located at 1.6µm, 2.1µm and 3.7µm.

Each of these absorbing bands can be coupled with a conservative band (e.g., 0.86µm) for simultaneous retrieval of τ and r_e

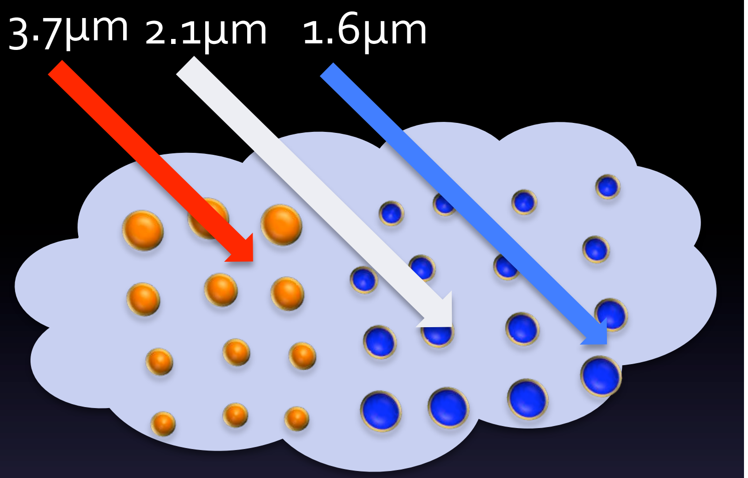
In Collection 05, r_e retrievals from these bands are reported in MOD06 product as
r_e(2.1µm)
r_e(1.6µm) - r_e(2.1µm)
r_e(3.7µm) - r_e(2.1µm)

Background

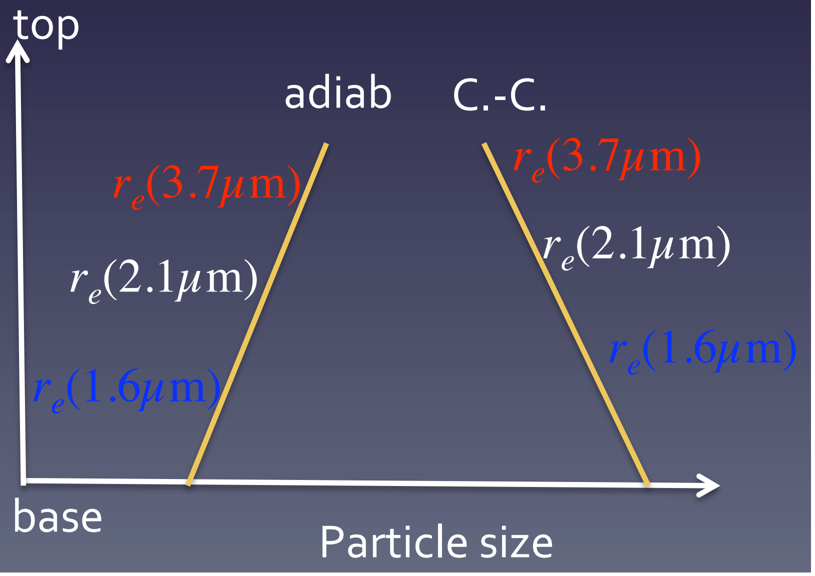
MODIS r_e retrieval weighting Function



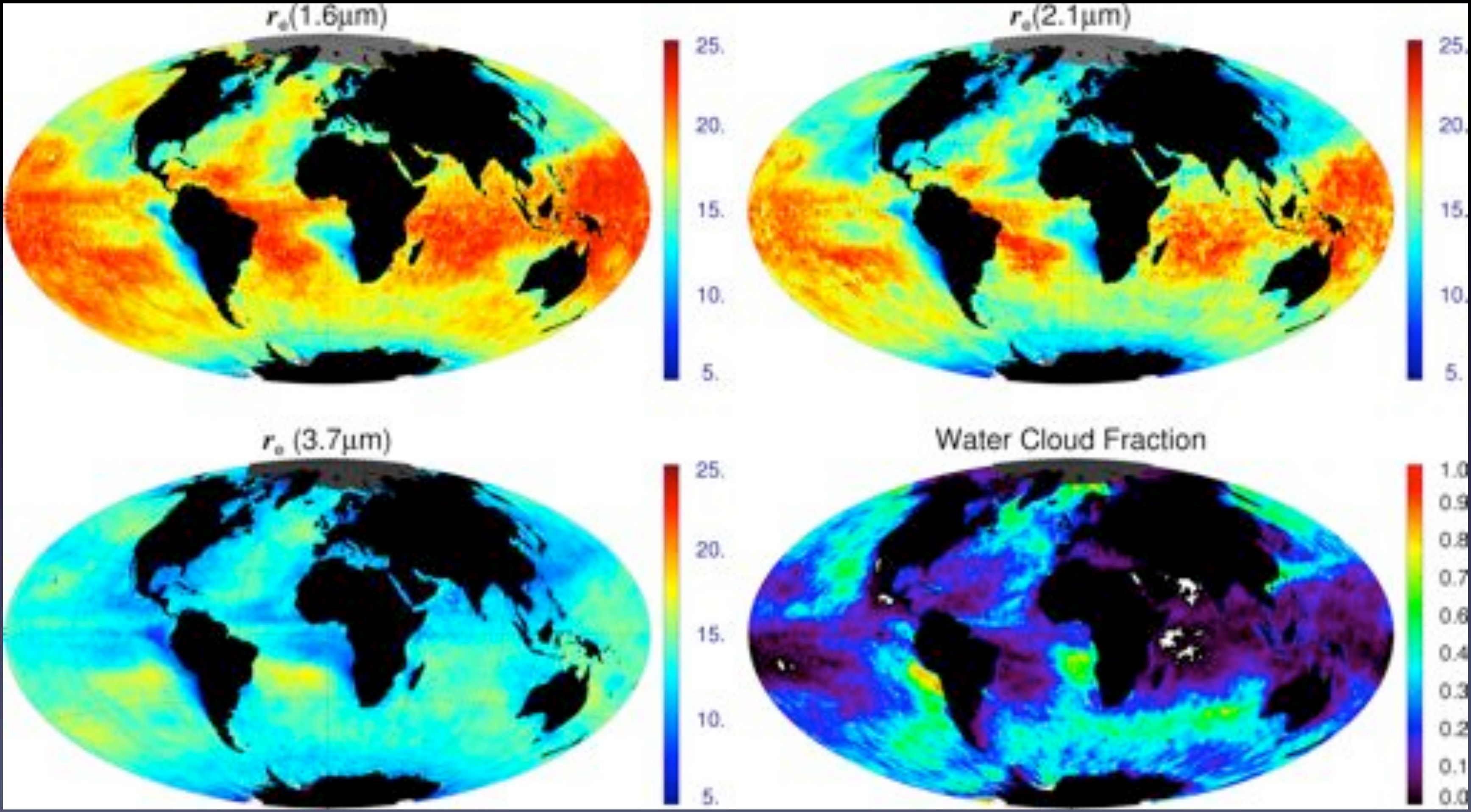
After Platnick JGR 2000



Penetration depth:
1.6µm > 2.1µm > 3.7µm

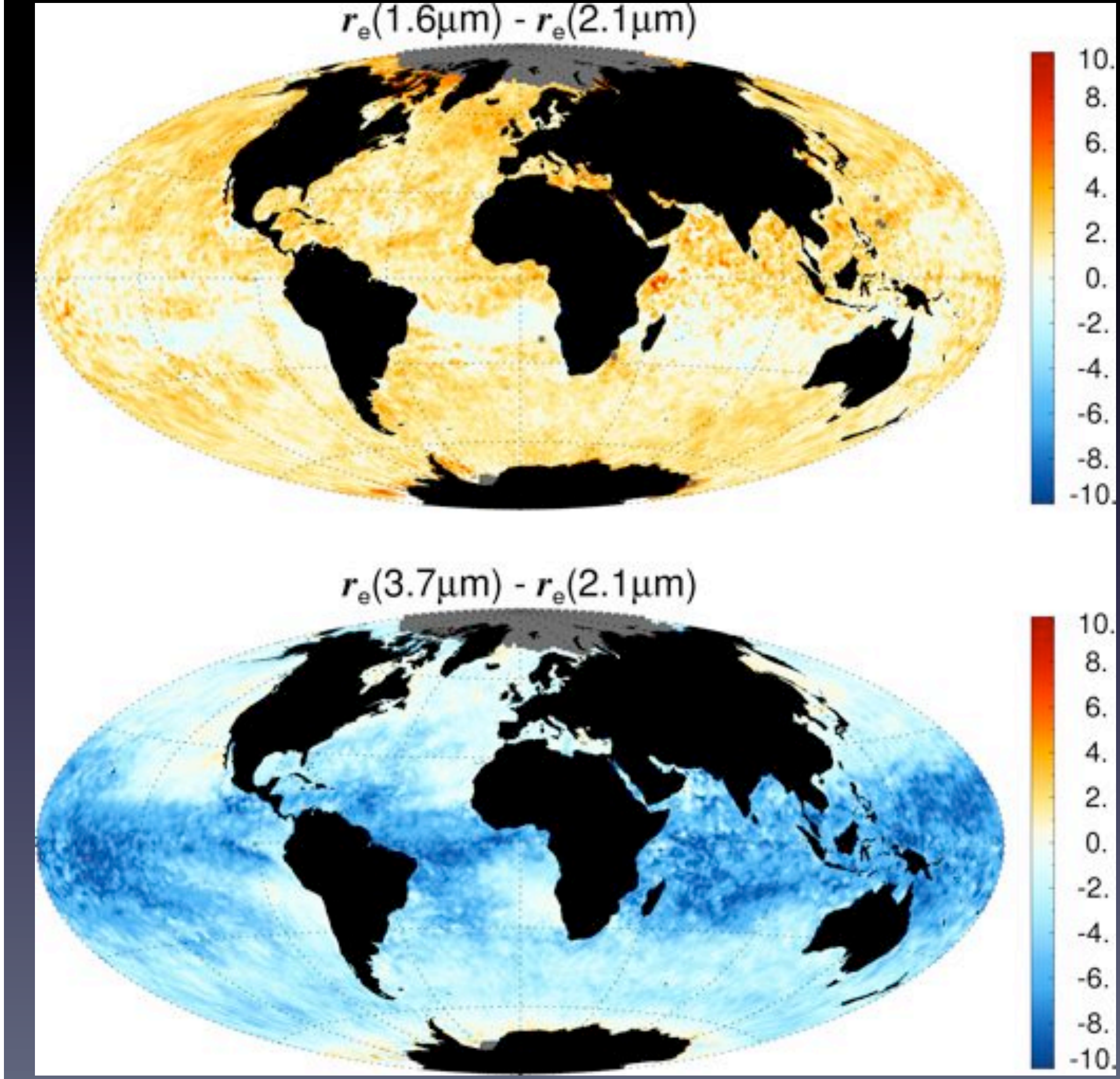


Monthly Mean Global MODIS r_e



Data from MODIS/Terra April 2005 used. Only water cloud pixels with Tc>273K selected

Monthly Mean Global Δr_e



Δr_e (1.6µm-2.1µm) is generally within ±3µm and has no obvious pattern

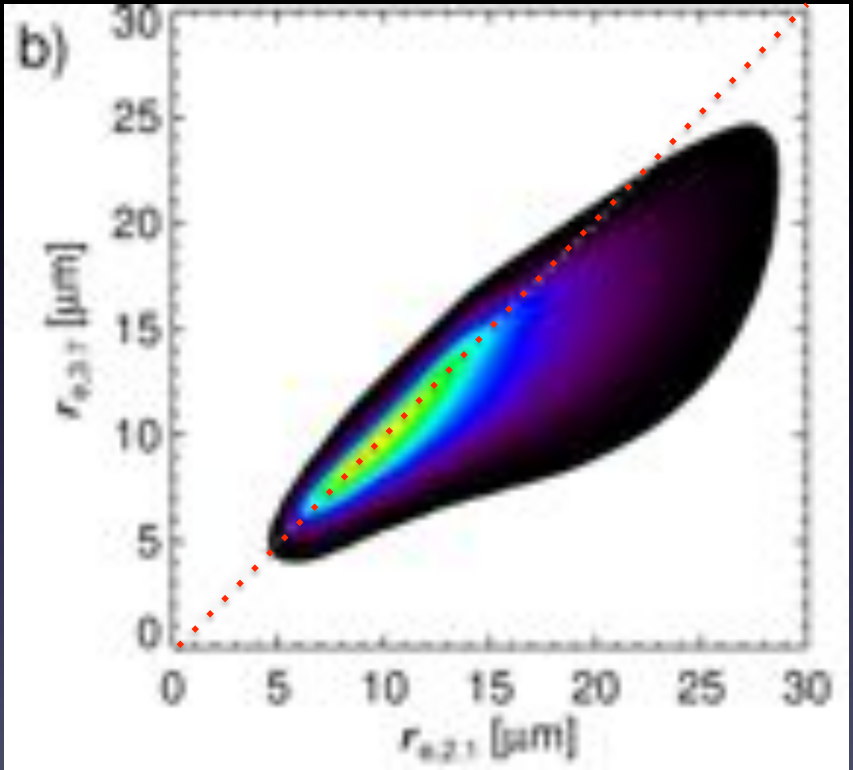
Δr_e (3.7µm-2.1µm) shows strong dependence on cloud regimes.

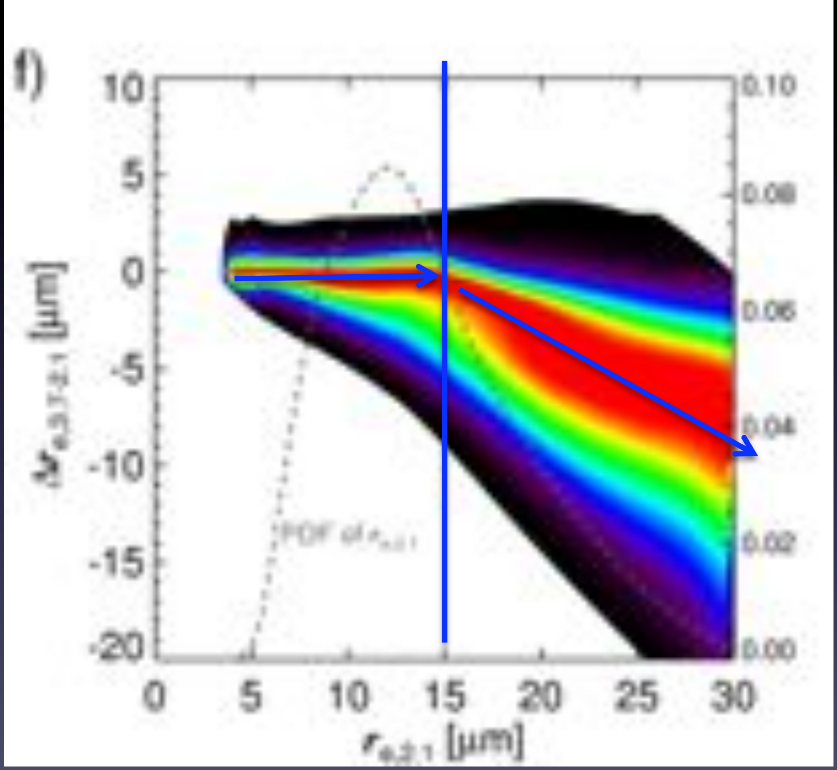
- Over the coastal StCu regions, Δr_e (3.7µm-2.1µm) is close to zero or even slightly positive.
- Over broken cloud regimes, Δr_e (3.7µm-2.1µm) < -5µm, sometimes ~-10µm

Similar to previous studies (Seethala and Horváth JGR 2010; Nakajima et al. JGR 2010)

Correlation studies: Δr_e vs. r_e

Correlation studies based more than 1.5billion pixels



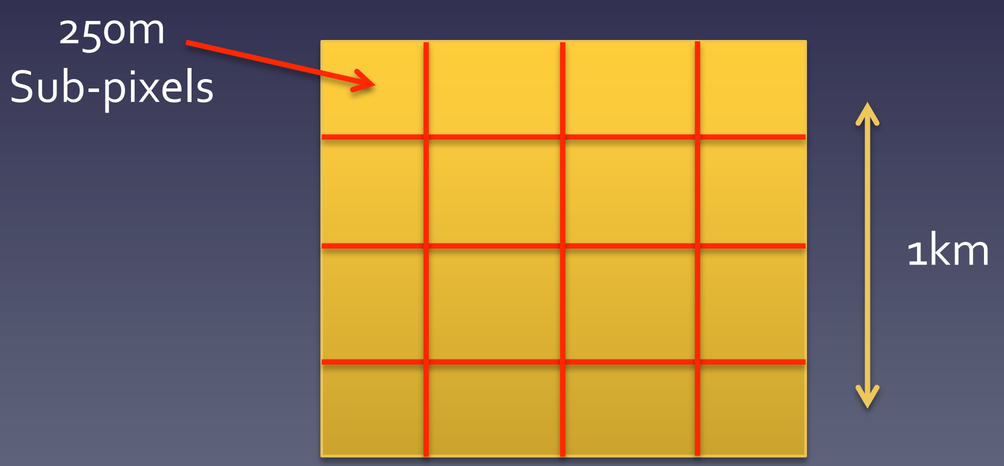


Threshold-like behavior of Δr_e(3.7μm-2.1μm) around r_e ~15μm
Coincidence or drizzle effect ?

Correlation studies: Δr_e vs. H_σ

$$H_\sigma = \frac{std\left(R_{0.86}(250m)\right)}{mean\left(R_{0.86}(250m)\right)}$$

Sub-pixel cloud inhomogeneity index
Defined as the standard deviation of sixteen 250m resolution
0.86µm band cloud reflection / the mean cloud reflection (Liang, Di Girolamo and Platnick 2009 GRL)

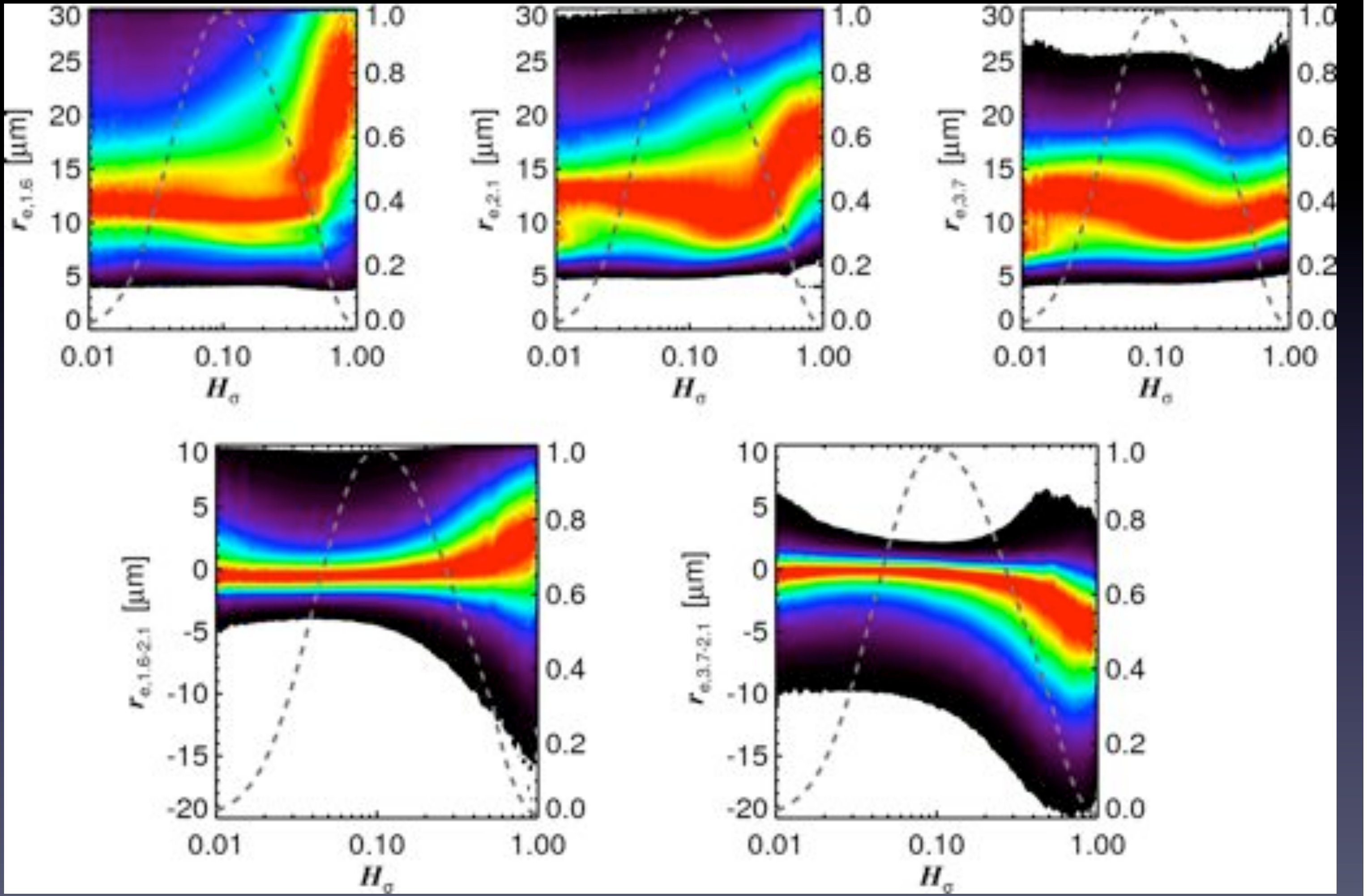


$H_\sigma \sim 0$ homogenous
$H_\sigma >> 0$ inhomogeneous

Correlation studies: r_e , Δr_e vs. H_σ

Joint histogram
r_e vs. H_σ

Joint histogram
Δr_e vs. H_σ



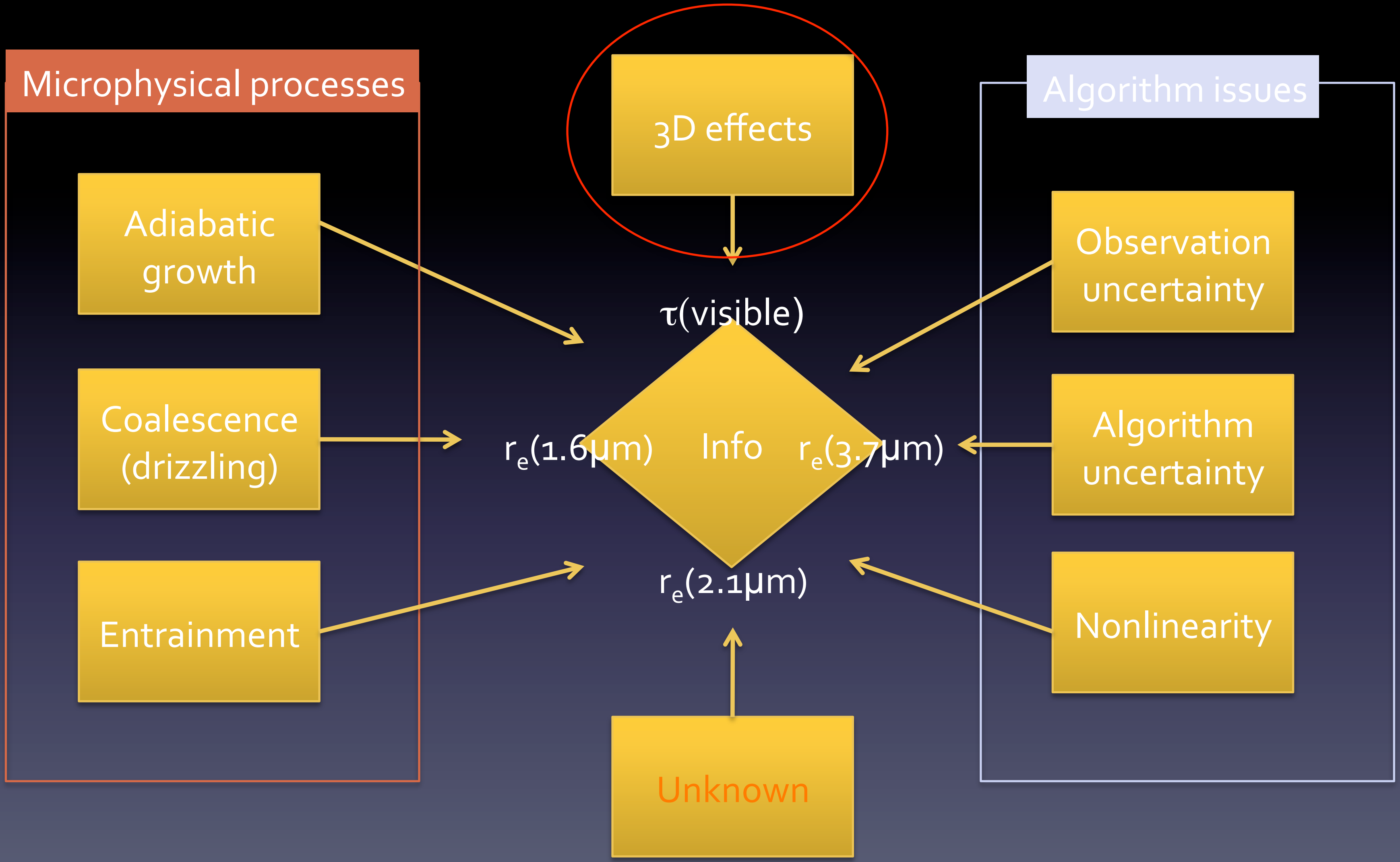
Red color corresponds to the most frequent r_e or Δr_e for a given value of H_σ

Lessons learned

Zhang and Platnick 2011 JGR submitted

- Significant differences are often found between $r_{e,2.1}$ and $r_{e,3.7}$, and the differences are a strong function of cloud regime.
- Correlation studies reveal that the difference between $r_{e,2.1}$ and $r_{e,3.7}$ are relatively small for clouds with $r_{e,2.1}$ smaller than about 15μm, but the difference increases quickly after $r_{e,2.1}$ exceeds 15μm.
- The correlation studies also reveal that both $r_{e,1.6}$ and $r_{e,2.1}$ have a clear dependence on cloud heterogeneity index H,. The different sensitivities of $r_{e,3.7}$ and $r_{e,2.1}$ to H_s aligns with the increasing difference between the two with increasing H_s.

What could cause Δr_e



Microphysical processes

Adiabatic growth

Coalescence (drizzling)

Entrainment

3D effects

τ(visible)

r_e(1.6μm)

Info

r_e(3.7μm)

r_e(2.1μm)

Unknown

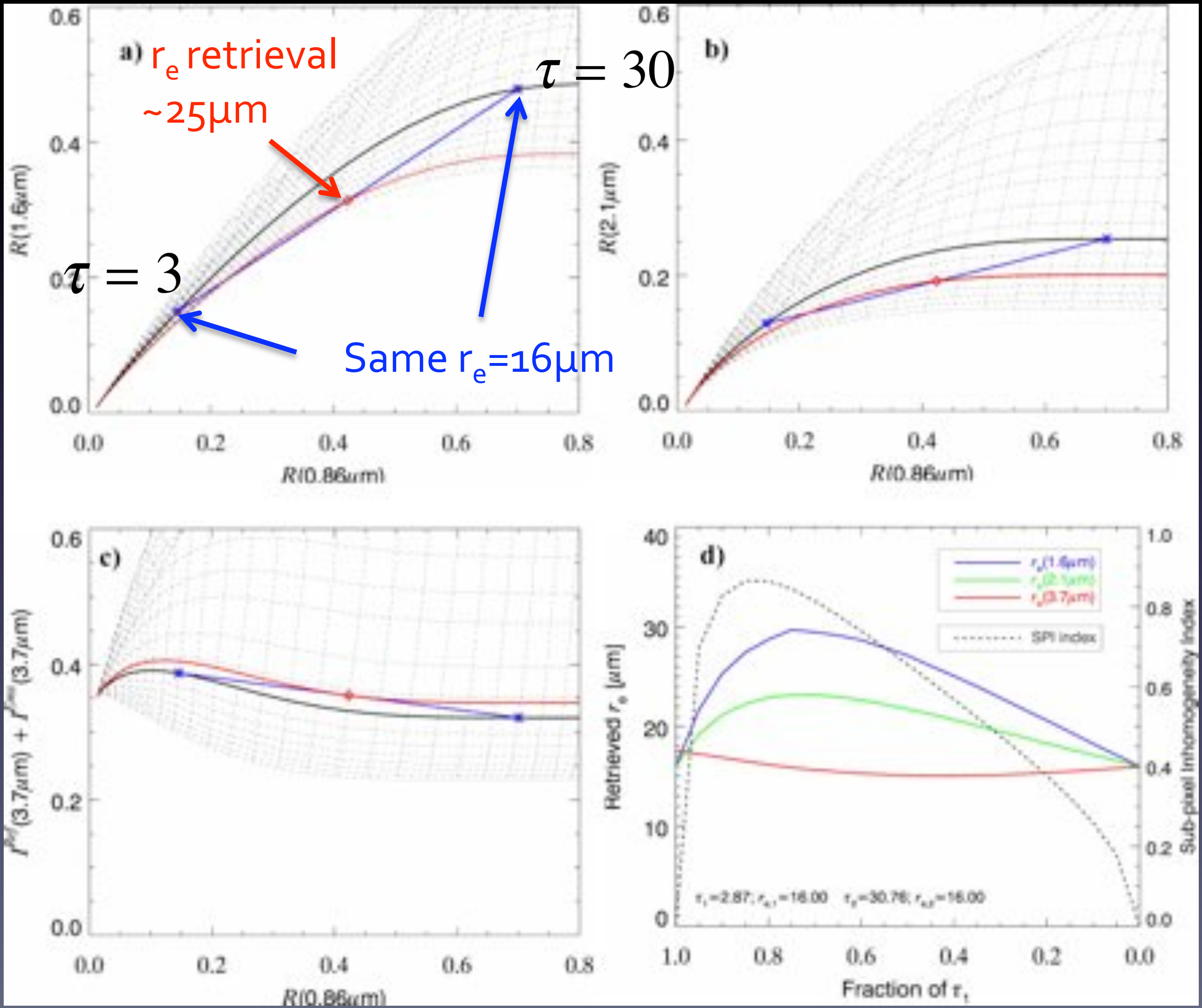
Algorithm issues

Observation uncertainty

Algorithm uncertainty

Nonlinearity

Impact of sub-pixel cloud inhomogeneity on r_e retrieval



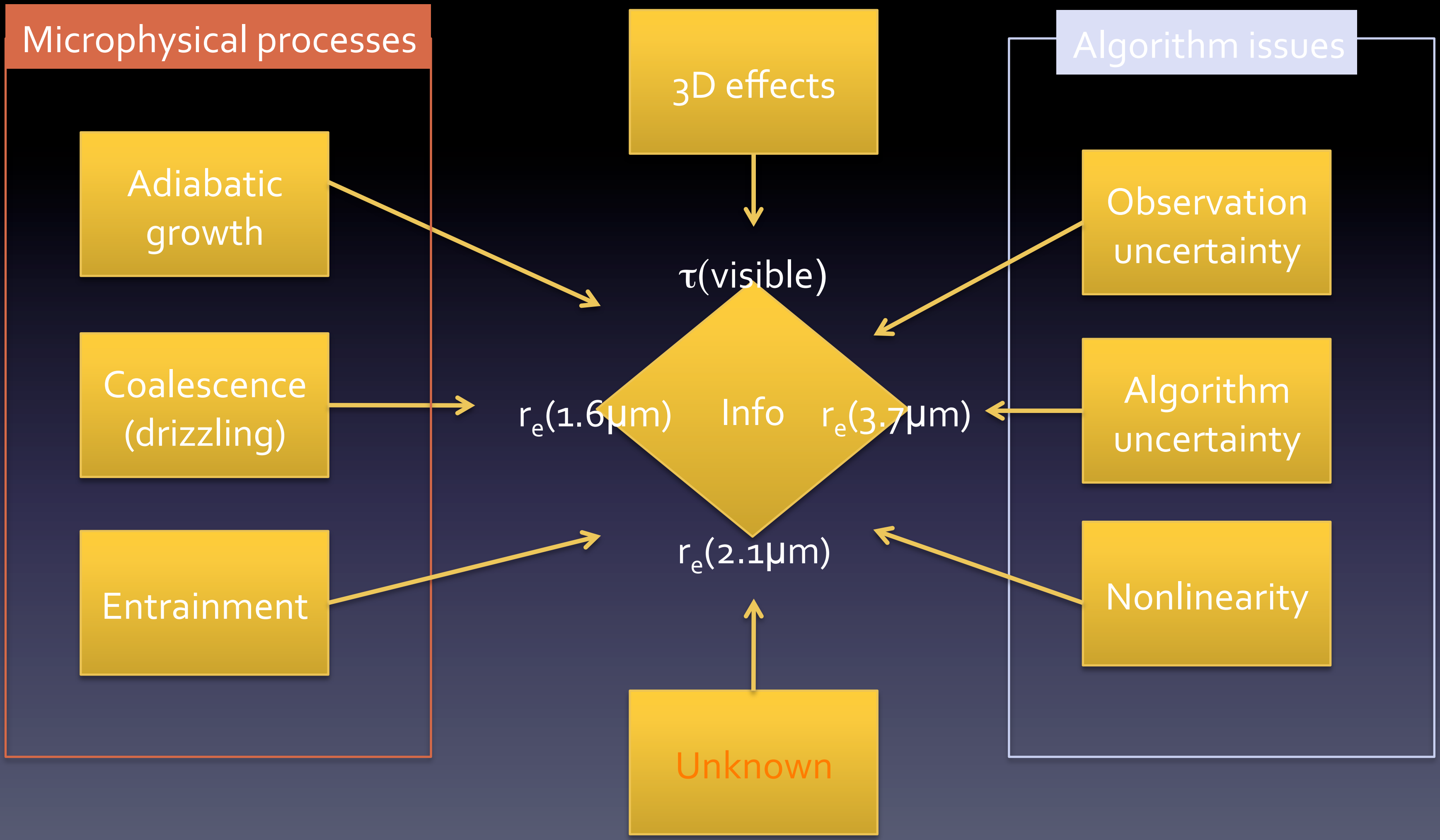
r_e retrieval ~25μm

$\tau = 30$

$\tau = 3$

Same r_e=16μm

What could cause Δr_e



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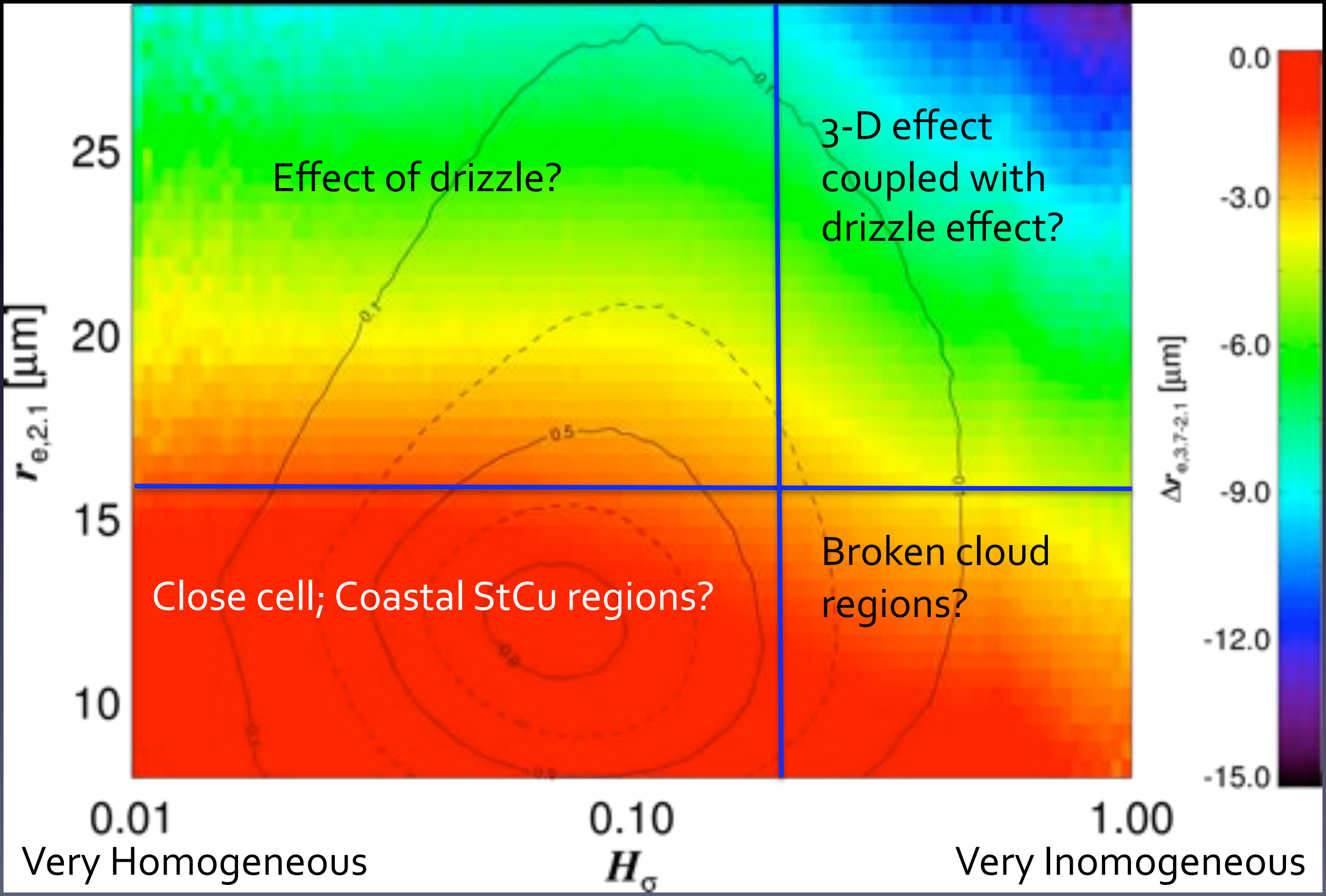
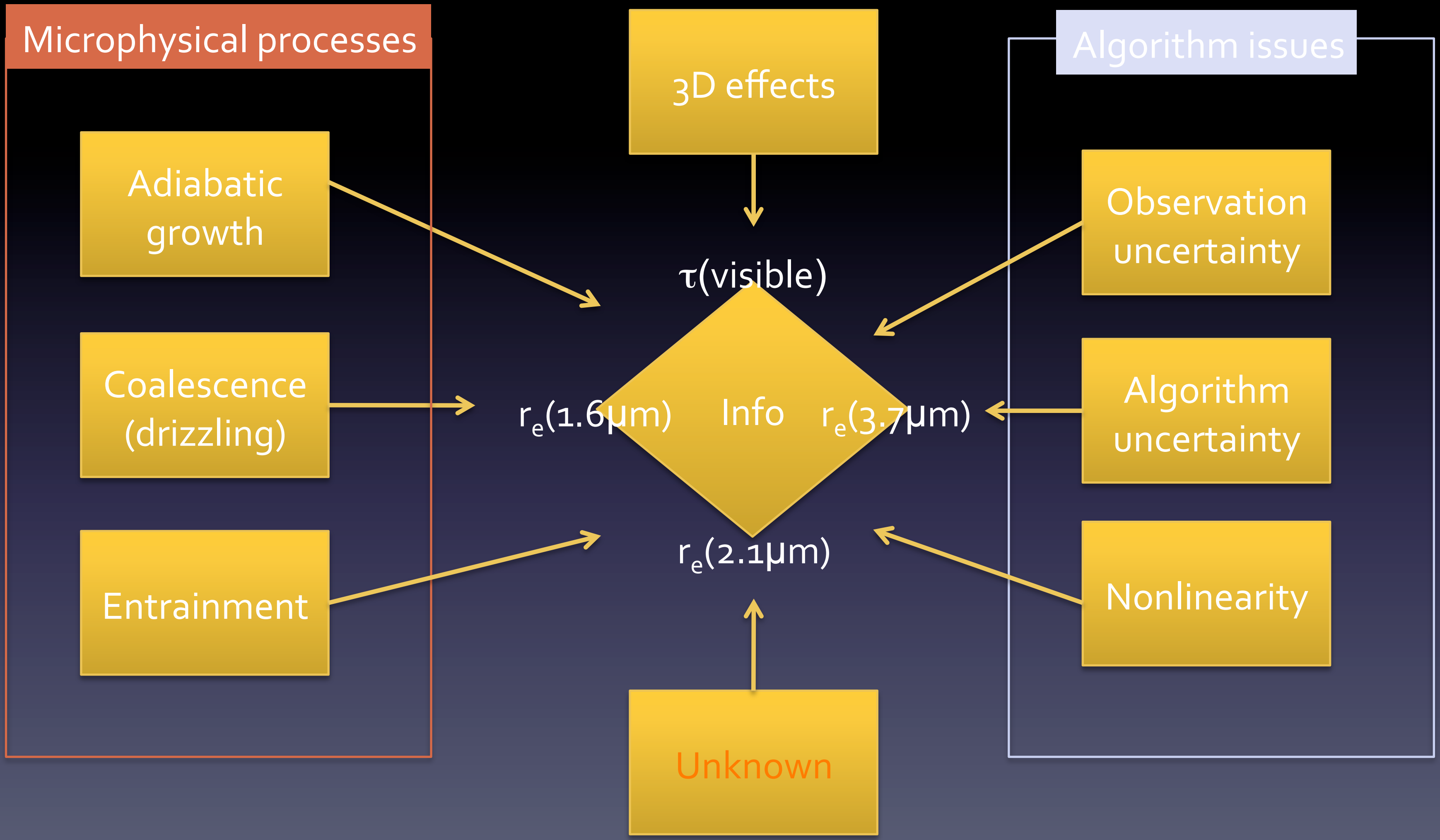
Separation of cloud regime

constructed using pixels with $\tau>5$



Zhang and Platnick JGR 2011 submitted

Entangled Problem



Microphysical processes

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τ(visible)

r_e(1.6μm)

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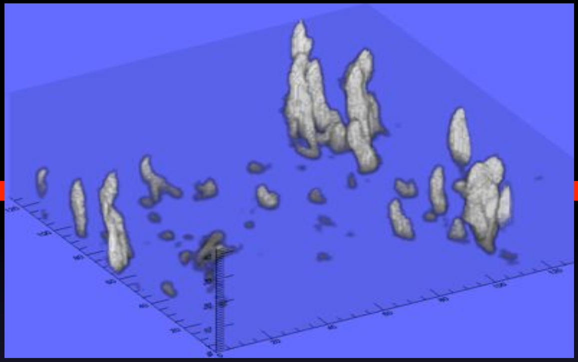
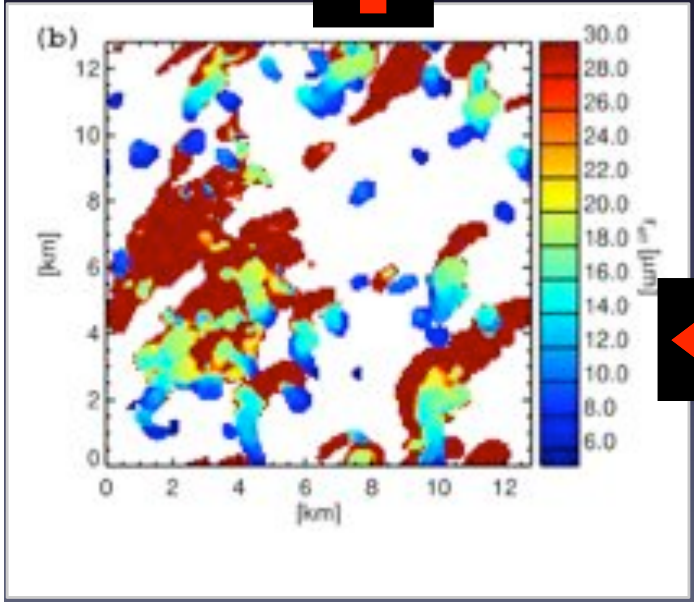
Pathway toward the future

LES Model with Bin Microphysics
(e.g., A. Ackerman, G. Feingold, B. Stevens)



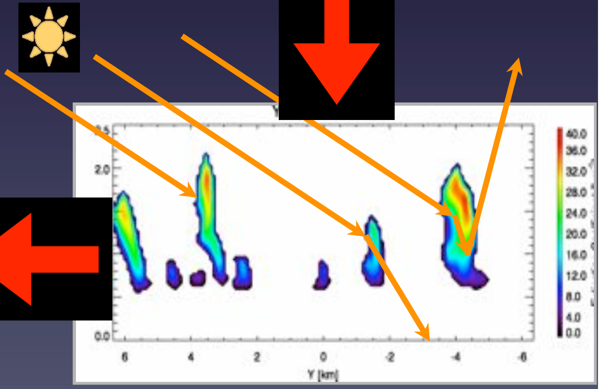
Radiative Transfer Models (3D & 1D)
(I3RC by R. Pincus)

$$r_e^* = \iiint_{Domain} w(\vec{r})\, r_e(\vec{r})\, d^3 r$$



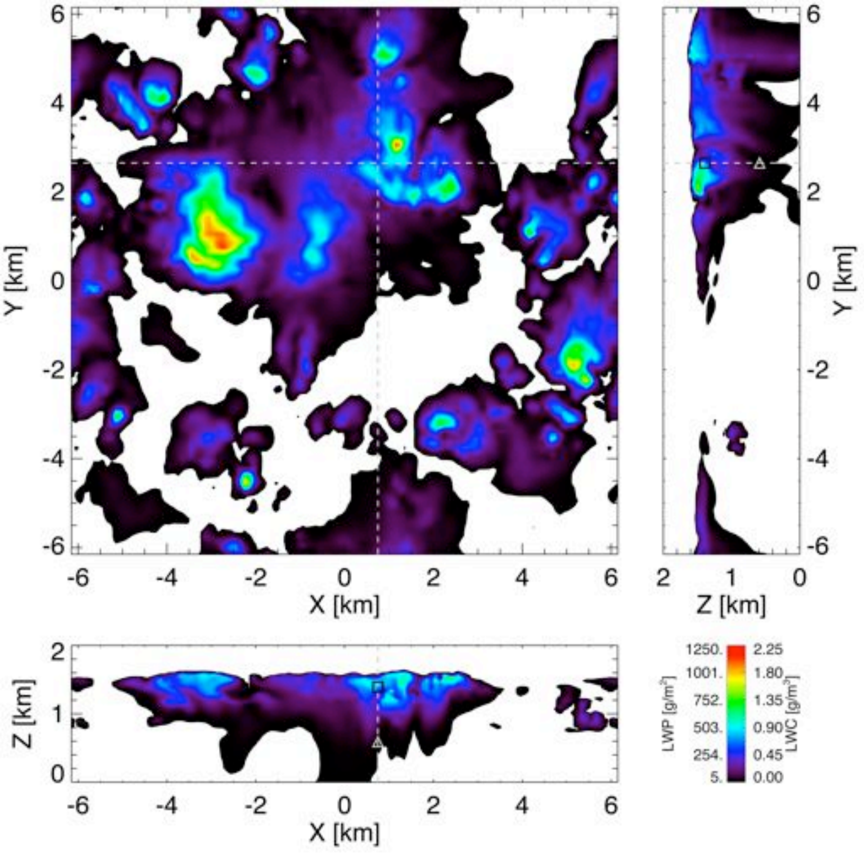
retrieved effective radius

MODIS MOD06 Retrieval Algorithm

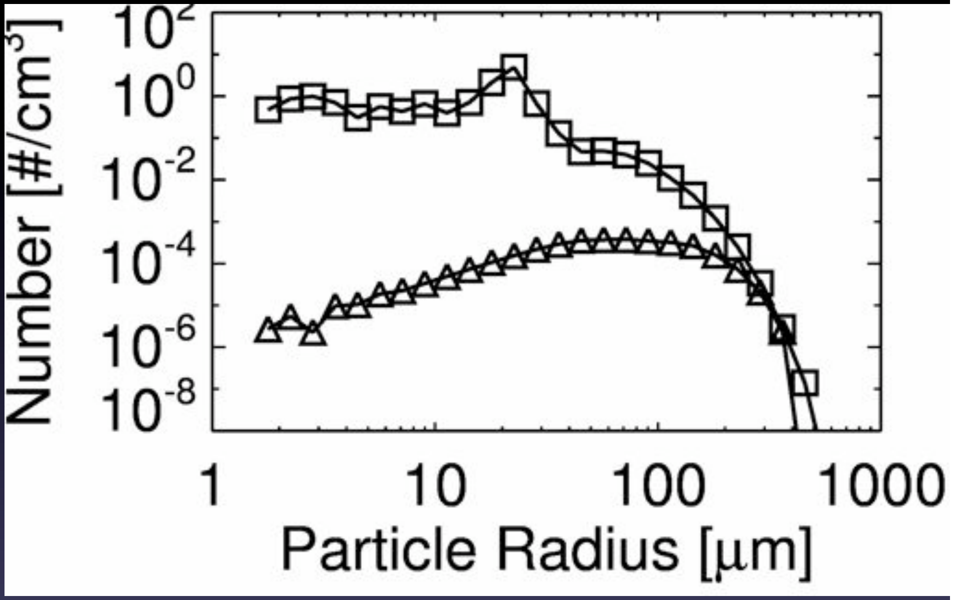


spectral reflectance/radiances

A seamless interface between bin-microphysics LES and I3RC



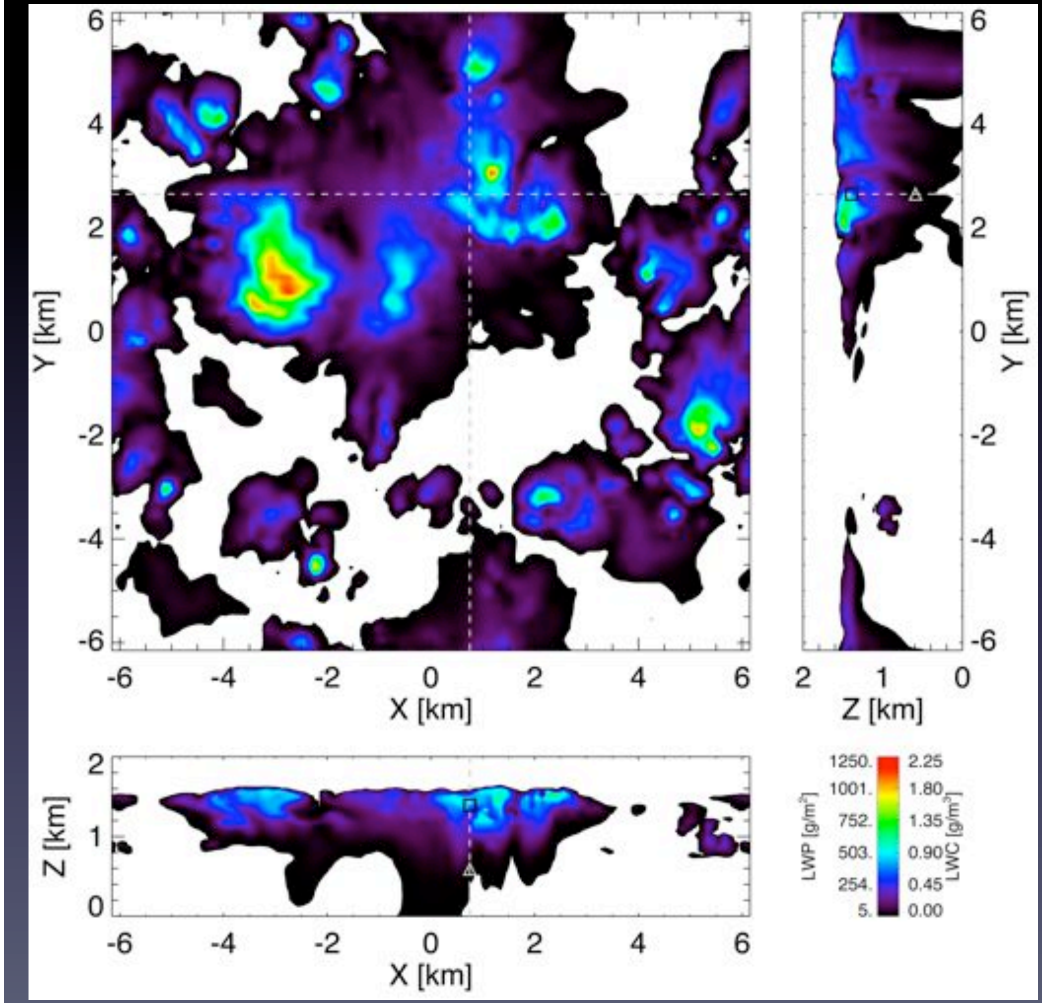
Cloud field simulated using LES model with bin-microphysics (Xue, Feingold and Stevens 2008 JAS)



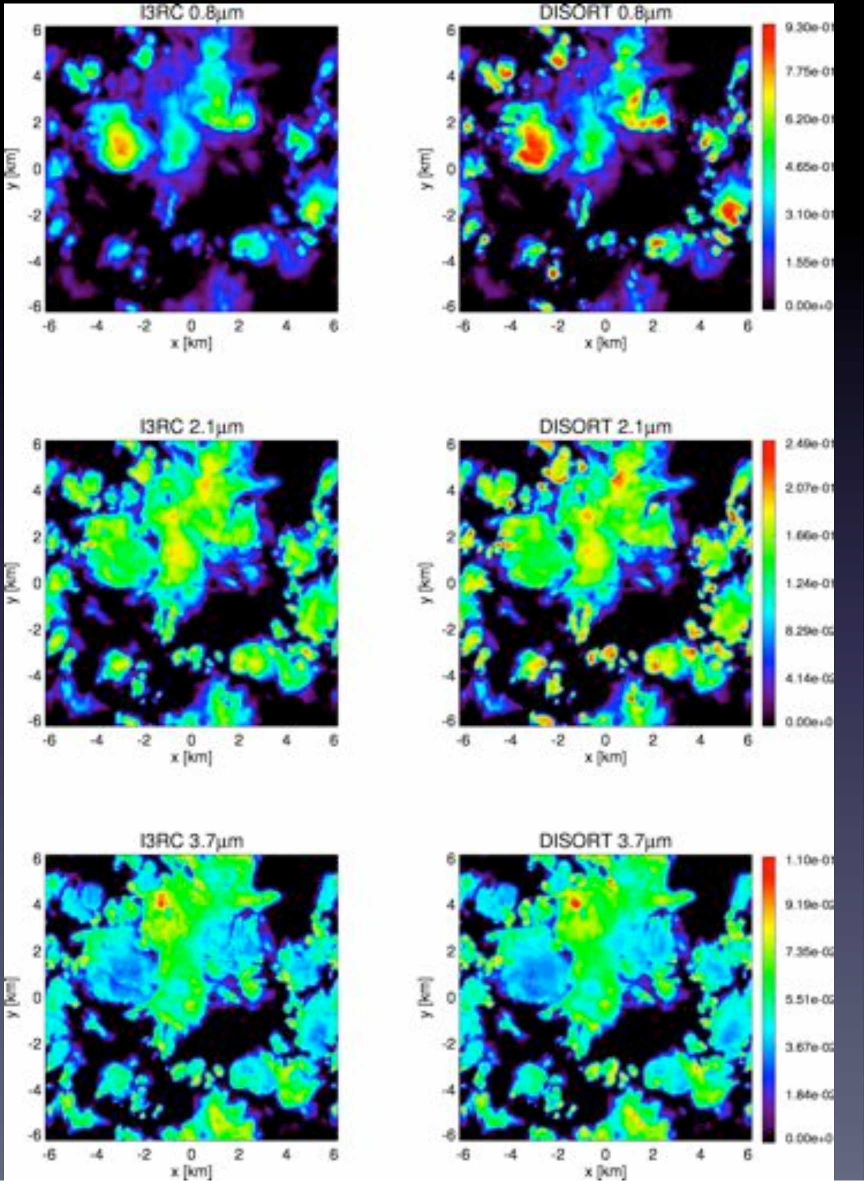
Every details of cloud microphysical structure from the LES simulation are dynamically re-constructed in 3D RT simulation (I3RC; Pincus and Evans 2010) based on the relative extinction distribution (F_i)

$$F_i = \sum_{m=1}^{i} \beta_m / \sum_{m=1}^{N} \beta_m$$

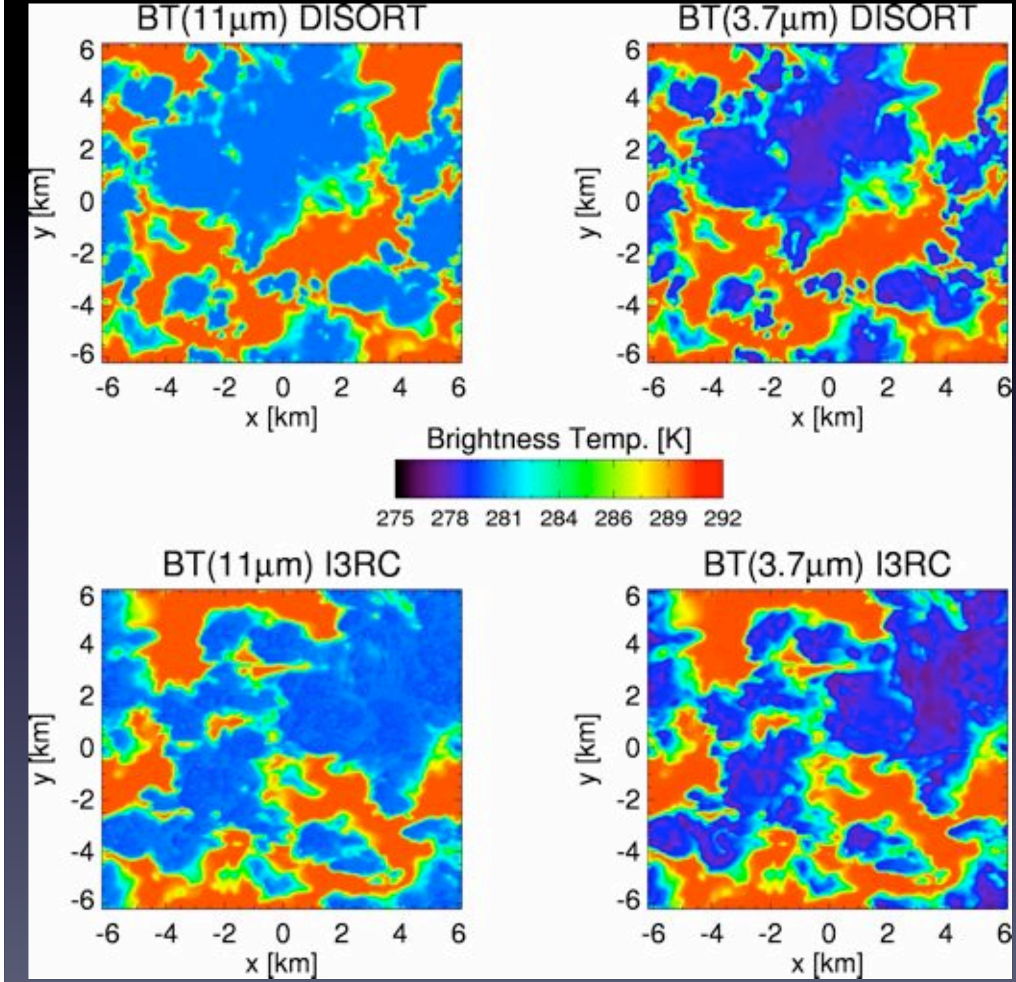
Preliminary results: reflection



Solar zenith 20° Nadir viewing; black surface



Preliminary results: emission



3-D emission simulation is implemented in I3RC based on the adjoint Monte-Carlo method

$$I_{ems}(x,y,z_{top},\Omega) = \int_x dx \int_y dy \int_z dz B\left[T_c(x,y,z)\right]E_c(x,y,z,\Omega) + B\left[T_s(x,y)\right]E_s(x,y,\Omega)$$

$E_c(x,y,z,\Omega)$ is the “escape function” corresponding to the contribution of a unit source in cloud at the location (x,y,z)

$E_s(x,y,\Omega)$ is the “escape function” corresponding to the contribution of a unit source at surface (x,y)

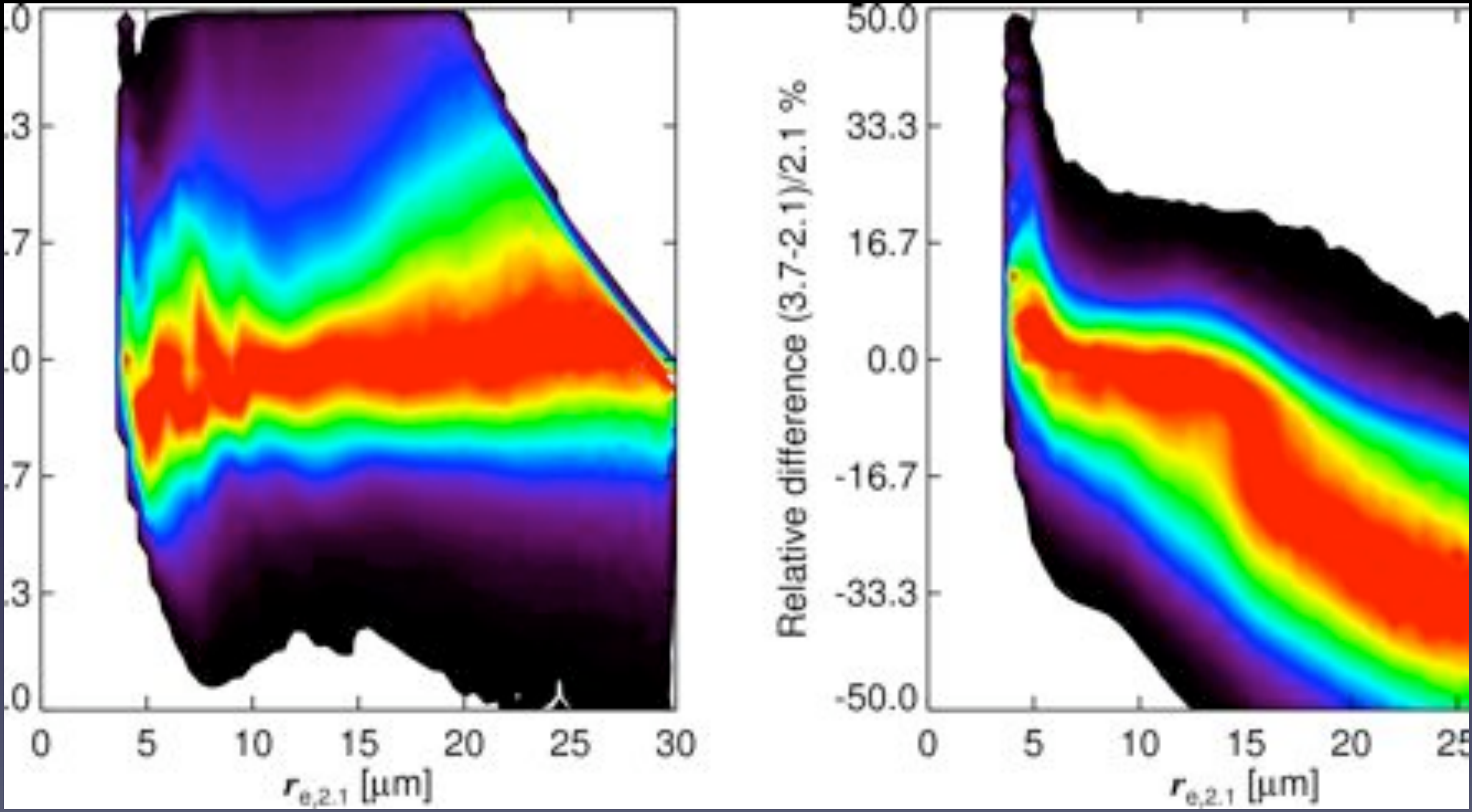
Cloud temp. 280K; surface temp. 290K

Summary & Conclusions

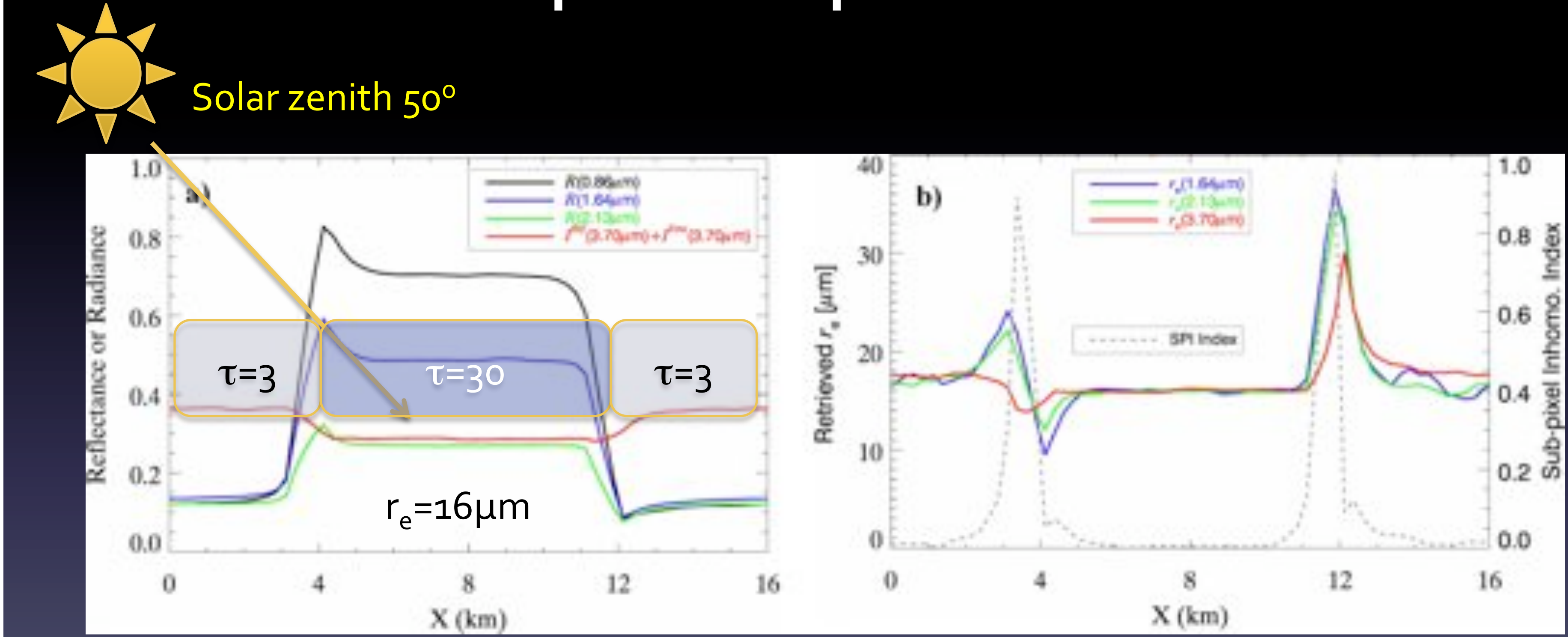
- Significant differences are often found between $r_{e,2.1}$ and $r_{e,3.7}$, and the differences have a strong dependence on cloud regime.
- Potential reasons are discussed
- Furthur studies based on the combination of LES and 3-D radiative transfer models are underway.

Backup

Relative difference



Impact of 3-D effect: A simple step cloud case



Solar zenith 50°

τ=3

τ=30

τ=3

r_e=16µm