Solar Channel Calibration Using Deep Convective Clouds

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Objectives

- We first examined characteristics of MODIS-derived cloud products by comparing simulated MODIS radiances with observed radiances at fifteen bands.
- Well-calibrated IR measurements are used to select deep convective cloud (DCC) pixels.
- Cloud optical parameters such as cloud optical thickness (COT) and effective radius (r_e) are assumed for the simulation of TOA visible radiances over selected DCC targets.
- The developed IR-based vicarious calibration algorithm is applied to MODIS bands to evaluate the algorithm.
- Simulated SEVIRI band 1 radiances are compared with observed radiances and then consistency between pre-existing calibration and developed algorithm is examined.

Cloud scattering property data

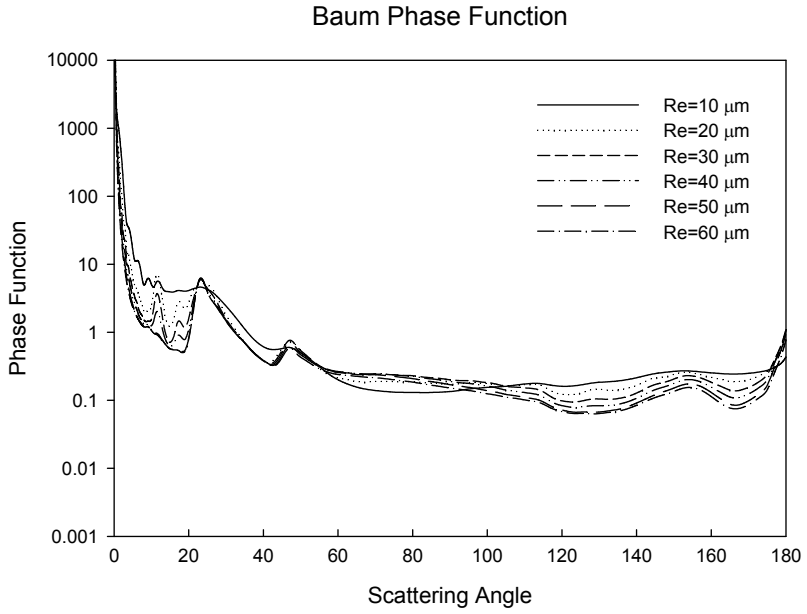
- Baum *et al.* (2005a and 2005b) for nonspherical ice particles

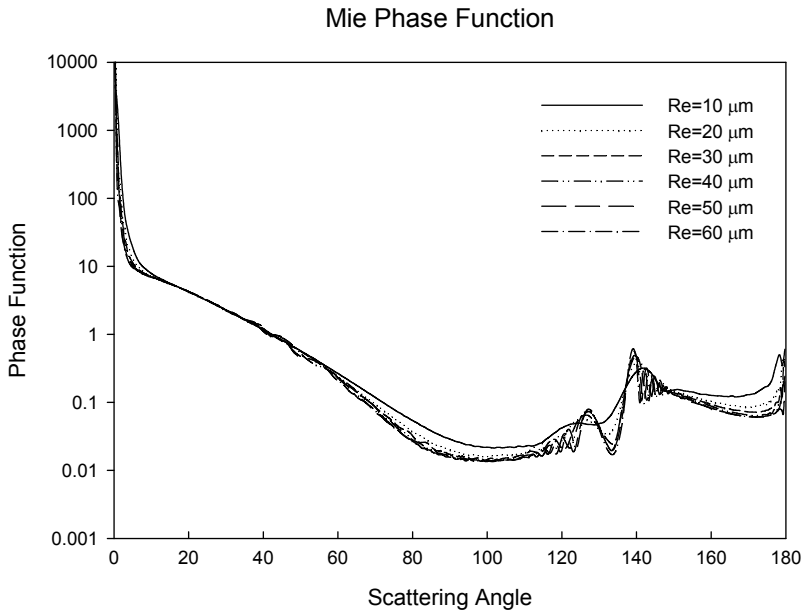
  - based on in-situ measurements to obtain habit fractions (Heymsfield *et al.*, 2002)

  - use single scattering properties of droxtals, hexagonal plates, hollow columns, solid columns, bullet rosettes, and aggregates (Yang and Liou, 1996a and 1996b; Yang *et al.*, 2003a and 2003b)

  - band averaged scattering properties with respect to r_e by integration of single scattering properties Q_{ext}, ω, g, $P(\Theta)$, f_d
  (extinction efficiency, SSA, asymmetry factor, phase function, and delta transmitted energy)

- Mie theory for water particles - Lorentz-Mie theory





Cloud radiative transfer modeling

- Discrete Ordinates Radiative Transfer (DISORT) with 32 streams

  - accurate and efficient RTM for cloudy atmosphere

- Transformation of cloud optical parameters

(1) Step 1: Delta transmission method

- strong forward scattering due to larger cloud particles
- Forward peak of phase function is replaced by Dirac-delta function.

$$P(\Theta) = 2f\delta(1-\cos\Theta) + (1-f)P'(\Theta)$$
$$\tau' = (1-\omega f)\tau$$
$$\omega' = \frac{(1-f)\omega}{1-\omega f}$$

$P(\Theta)$: phase function
f: fraction of Dirac-delta function in the phase function
δ: Dirac-delta function
τ : COT
ω: SSA

(2) Step 2: Truncation method

$$P'(\Theta) = 2f_d\delta(1-\cos\Theta) + (1-f_d)P''(\Theta)$$
$$\tau'' = (1-\omega' f_d)\tau'$$
$$\omega'' = \frac{(1-f_d)\omega'}{1-\omega' f_d}$$

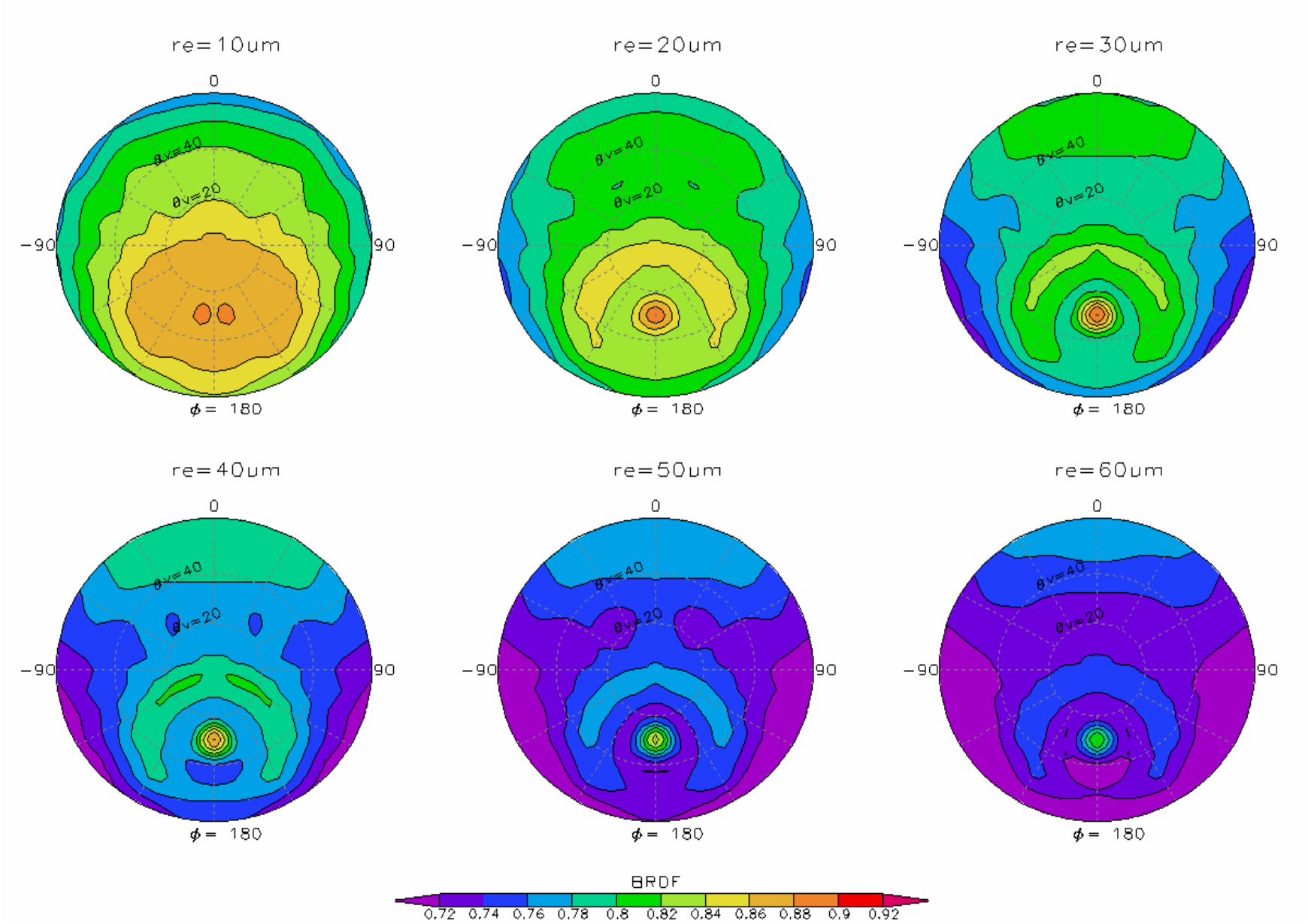
f_d : fraction of delta transmitted energy

- Calculate cloud optical thickness for the given band by scaling Q_{ext}

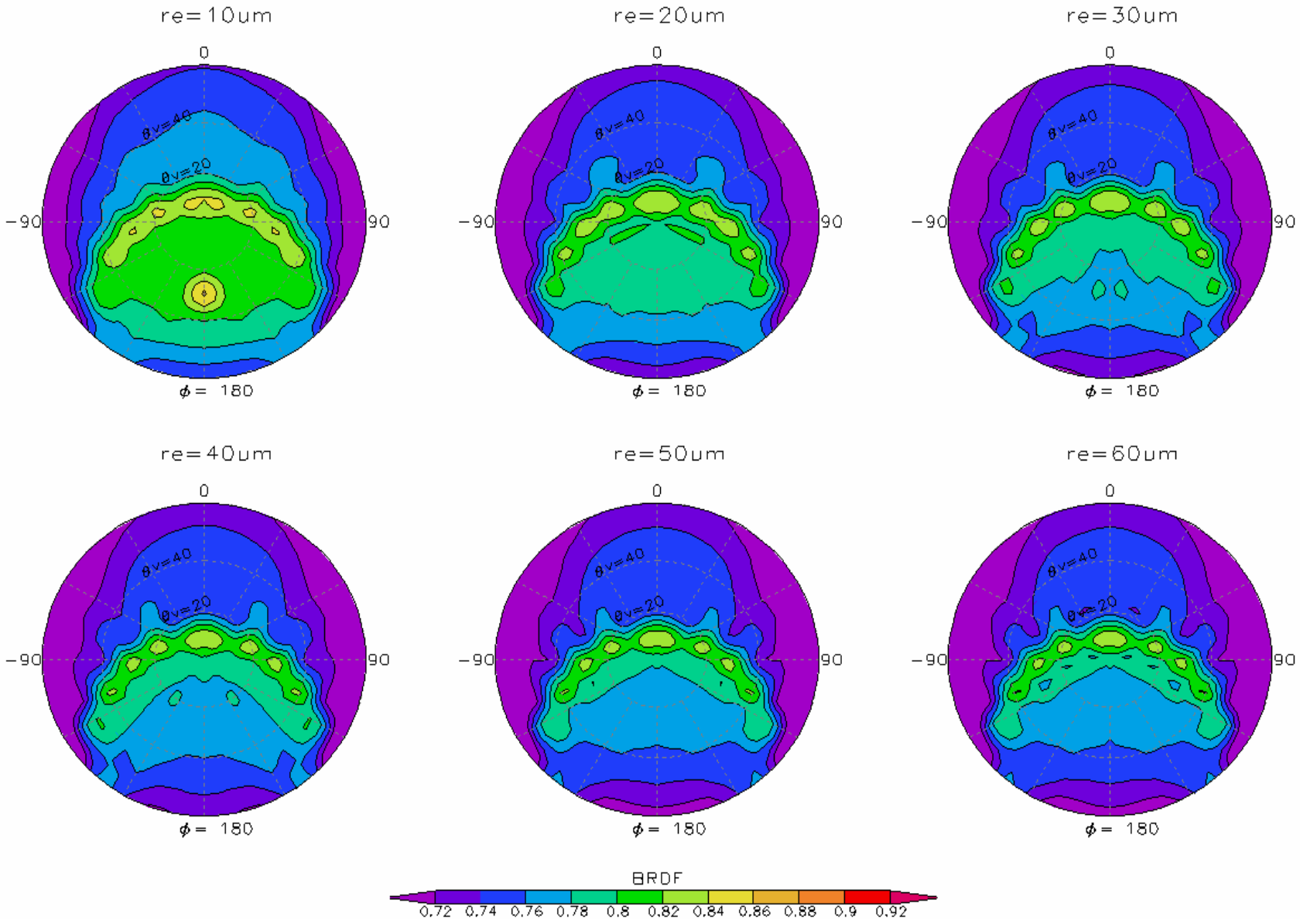
$$\tau_{c,\lambda} = \tau_{c,0.646}\frac{Q_{ext,\lambda}}{Q_{ext,0.646}}$$

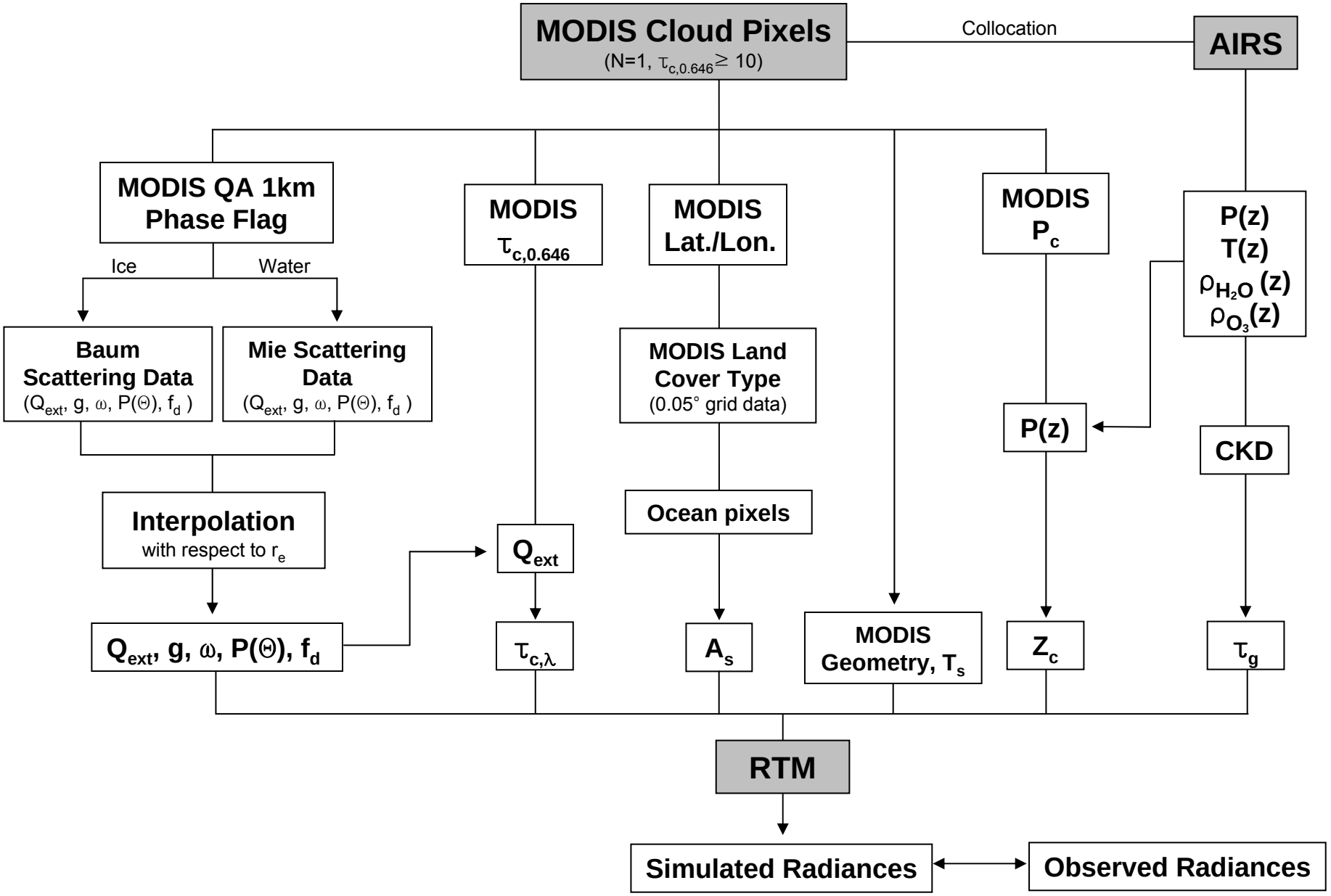
Q_{ext}: extinction efficiency

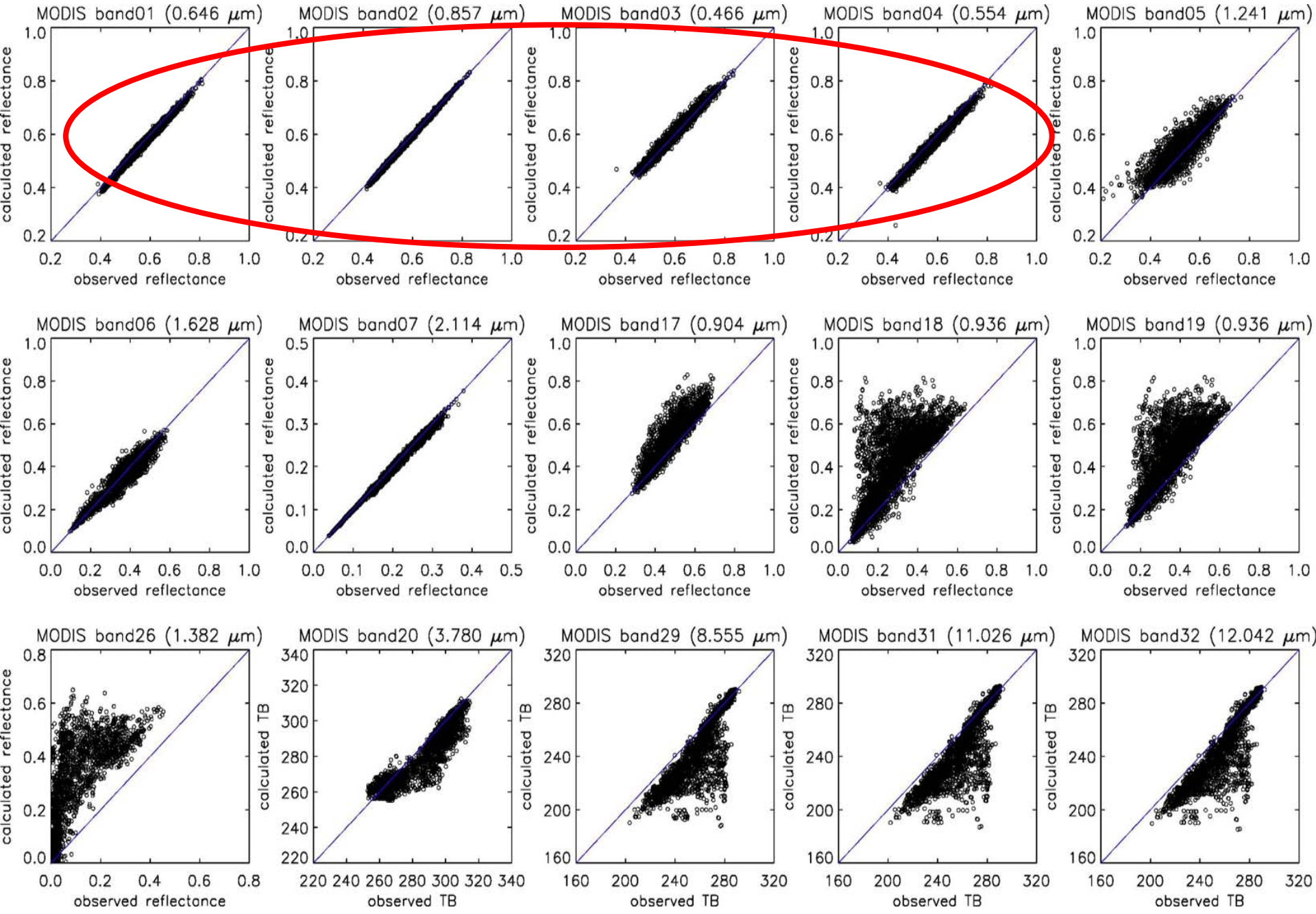
Cloud BRDF using Baum phase function (COT=40, SZA=30°)



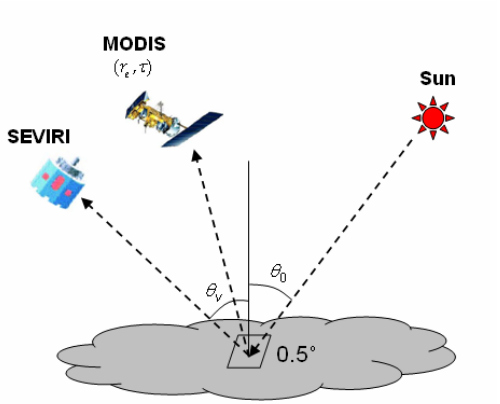
Cloud BRDF using Mie phase function (COT=40, SZA=30°)




MODIS Cloud Pixels
(N=1, $\tau_{c,0.646} \geq 10$)
Collocation
AIRS
MODIS QA 1km Phase Flag
Ice
Water
MODIS $\tau_{c,0.646}$
MODIS Lat./Lon.
MODIS P_c
P(z)
T(z)
$\rho_{H_2O}(z)$
$\rho_{O_3}(z)$
Baum Scattering Data
(Q_{ext}, g, ω, P(Θ), f_d)
Mie Scattering Data
(Q_{ext}, g, ω, P(Θ), f_d)
MODIS Land Cover Type
(0.05° grid data)
P(z)
CKD
Interpolation
with respect to r_e
Ocean pixels
Q_{ext}
Q_{ext}, g, ω, P(Θ), f_d
$\tau_{c,\lambda}$
A_s
MODIS Geometry, T_s
Z_c
τ_g
RTM
Simulated Radiances
Observed Radiances


MODIS band01 (0.646 μm)
MODIS band02 (0.857 μm)
MODIS band03 (0.466 μm)
MODIS band04 (0.554 μm)
MODIS band05 (1.241 μm)
MODIS band06 (1.628 μm)
MODIS band07 (2.114 μm)
MODIS band17 (0.904 μm)
MODIS band18 (0.936 μm)
MODIS band19 (0.936 μm)
MODIS band26 (1.382 μm)
MODIS band20 (3.780 μm)
MODIS band29 (8.555 μm)
MODIS band31 (11.026 μm)
MODIS band32 (12.042 μm)
calculated reflectance
observed reflectance
calculated TB
observed TB

MODIS vs. SEVIRI



MODIS Cloud Product
(τ, r_e, z_c, T_c, P_c)

SEVIRI Radiance Data
(0.640 μm)

Gridization (0.5°)

collocation
(Time difference ≤ 6 min)

Gridization (0.5°)

Purely Cloudy Grid

No

Yes

Check Homogeneity

No

$STD_{COT,3x3} \leq 10$

$STD_{CTP,3x3} \leq 30$ hPa

Yes

Cloud Targets

$\tau<10$ or $\tau>99$

$10 \leq \tau \leq 99$

MODIS Cloud Parameter
(τ, r_e, z_c, T_c, P_c)

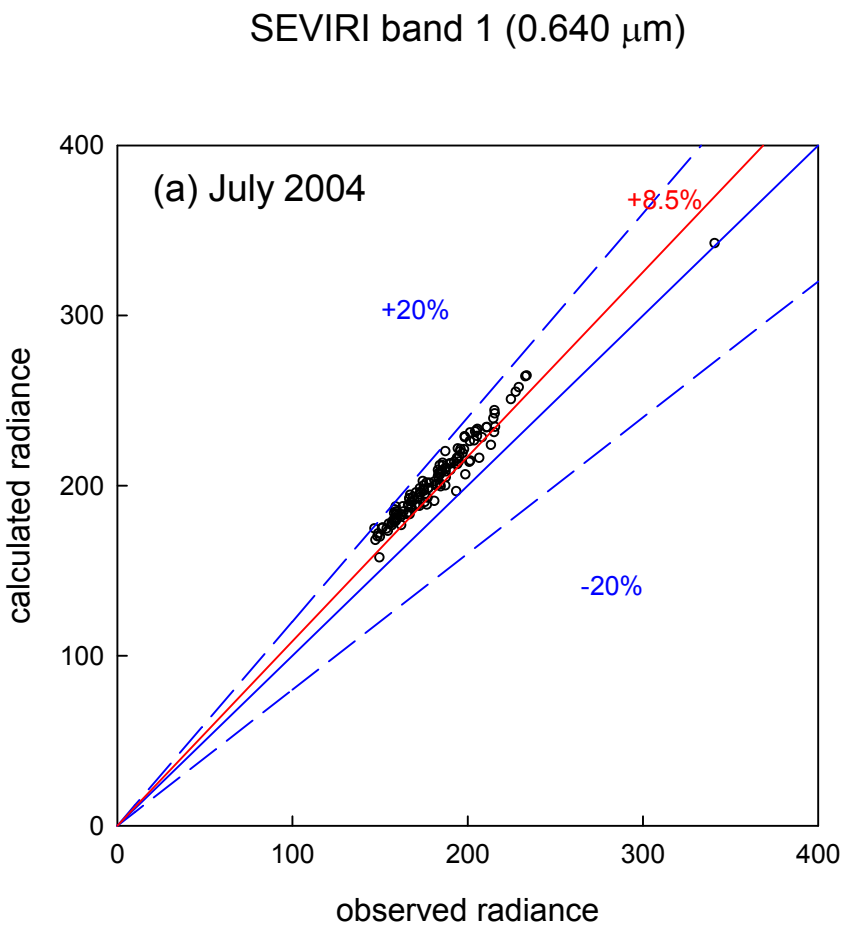
Cloud Radiative Transfer Modeling

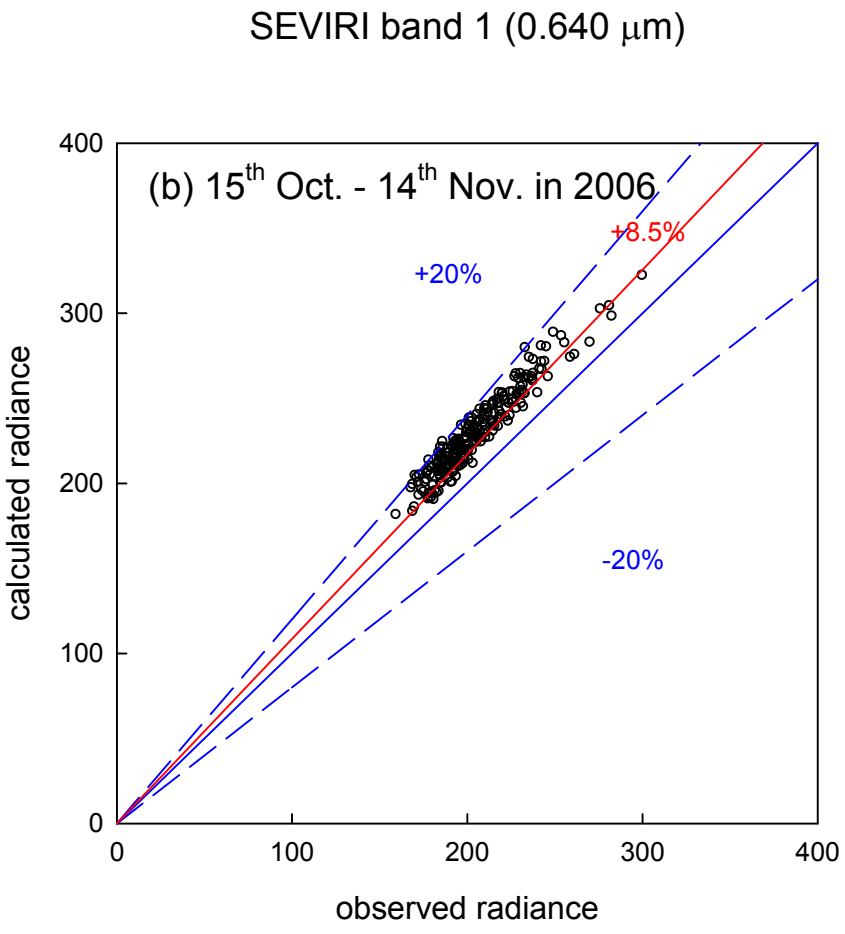
Simulated SEVIRI band

Observed SEVIRI band

Vicarious Calibration
(Monitoring of pre-existing calibration system)

Comparisons between simulated and observed SEVIRI radiances at 0.640 μm





Comparing with Doelling's Results

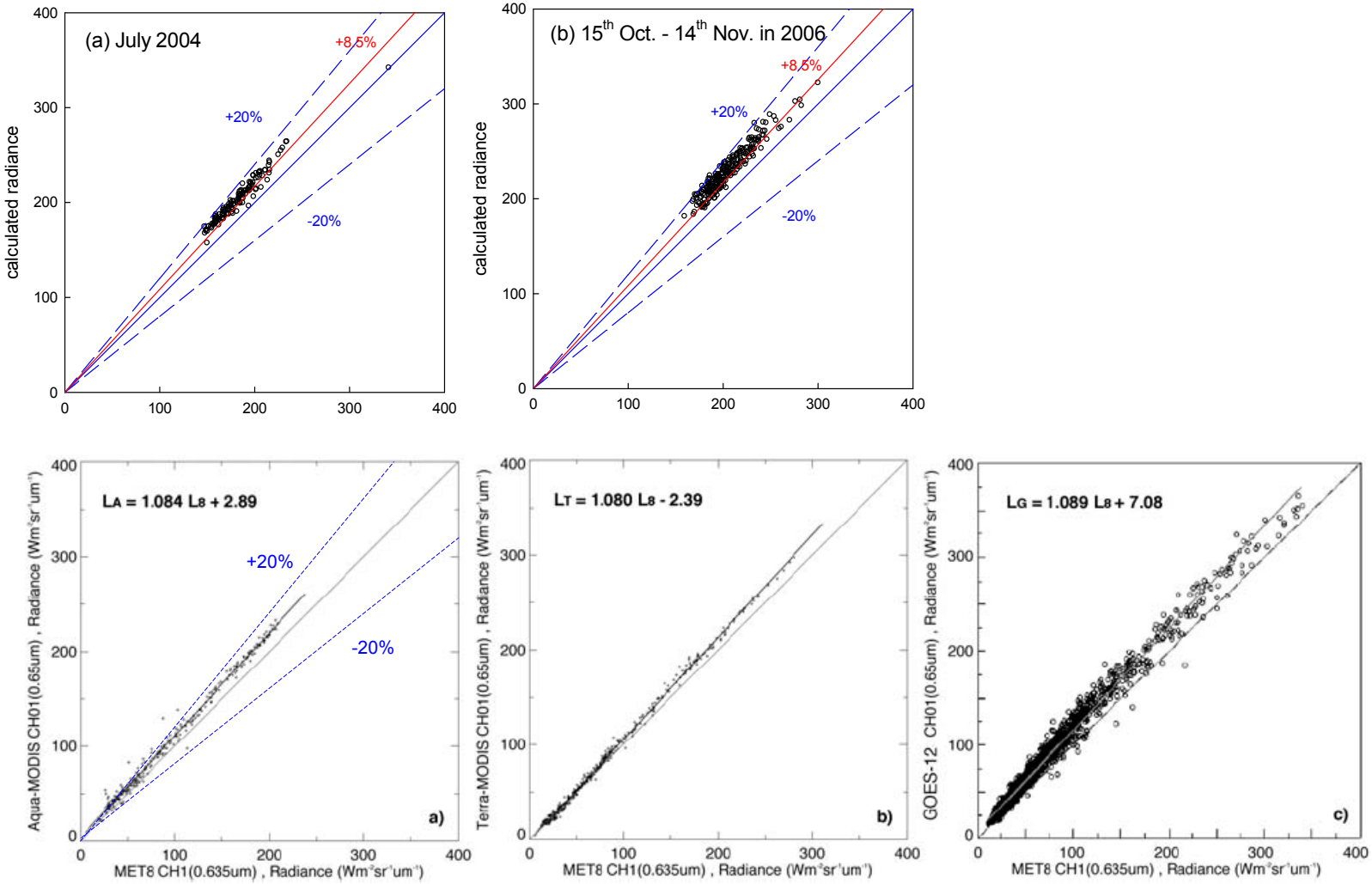


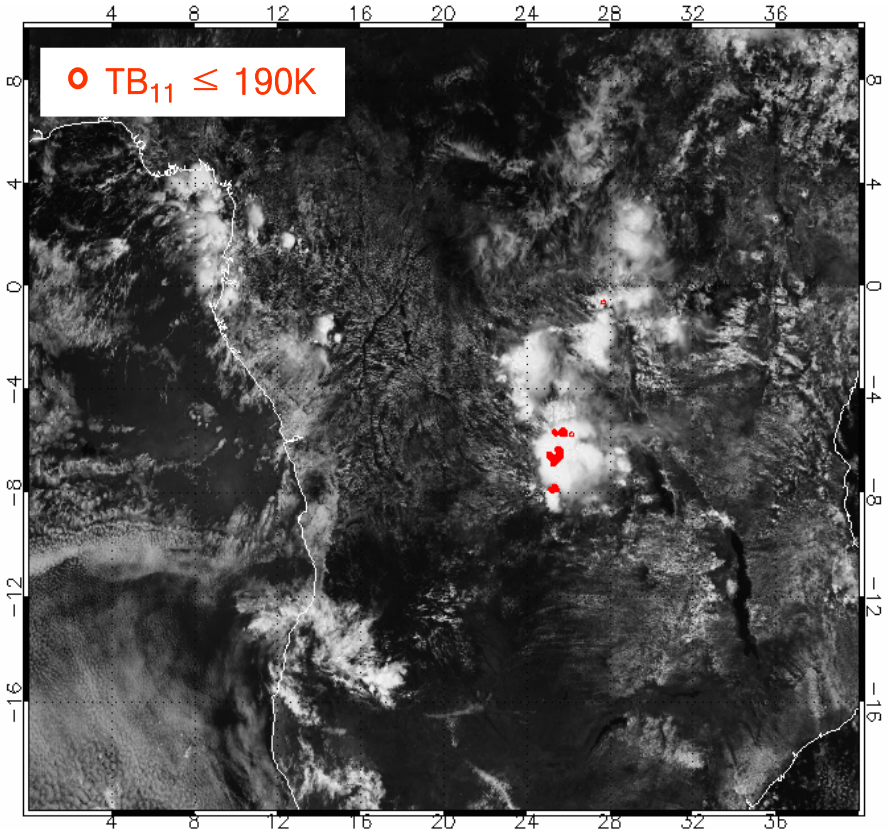
Figure 3. Regression fits for SEVIRI and (a) *Aqua*, (b) *Terra*, and (c) *GOES-12* 0.65-µm data, April 2004.

Doelling, D. R., L. Nguyen, and P. Minnis, 2004: Calibration comparisons between SEVIRI, MODIS, and GOES data. *Proc. 2004 EUMETSAT Meteorological Satellite Conf.,* Prague, Czech Rep., 17 - 20 May.

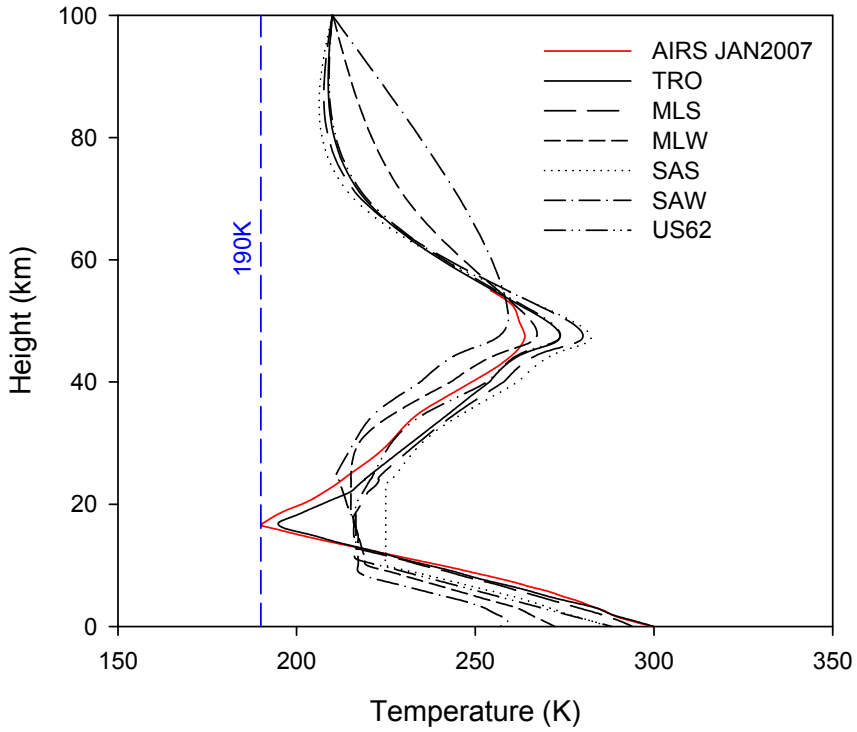
Use of deep convective cloud targets

Cold cloud top temperature (CTT) of deep convective clouds (DCCs)

SEVIRI 0.640 μm Image



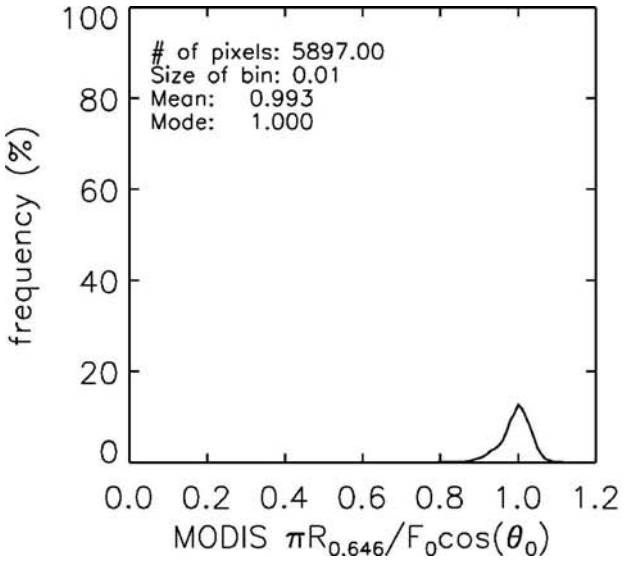
Temperature profiles

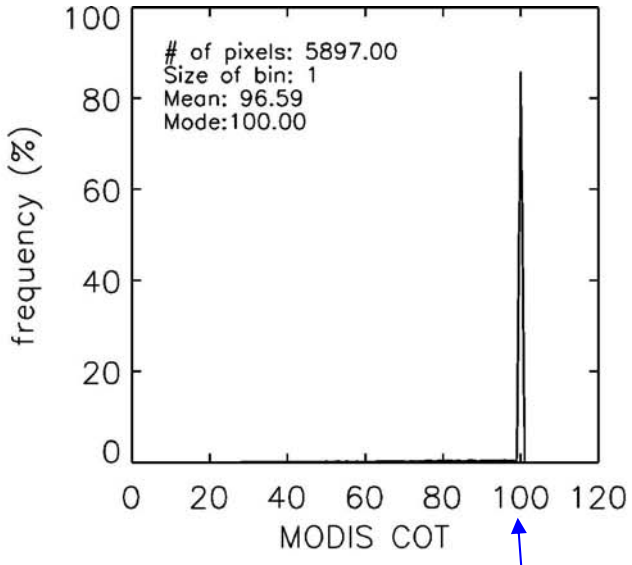


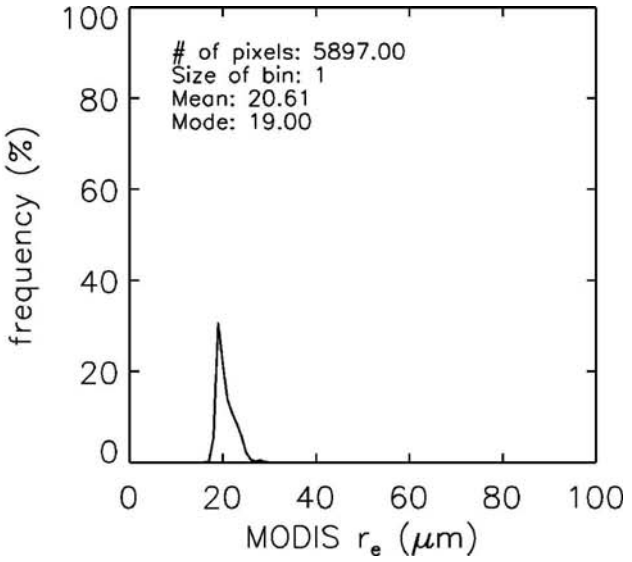
→ Considering seven temperature profiles, cold CTT less than 190K can be explained only by DCCs involving strong upward motion lacking of exchange with environmental air (Lattanzio *et al.*, 2006).

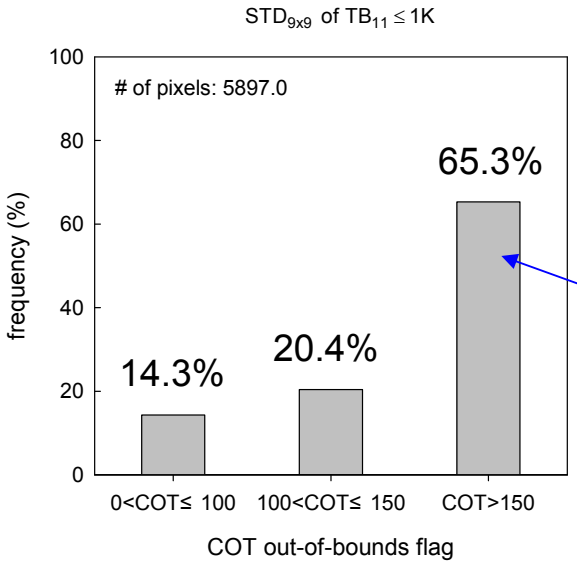
MODIS-derived cloud properties for cold clouds (TB ≤ 190K)

Criteria: TB_{11} ≤ 190K, $STD_{9\times9}$ of TB_{11} ≤ 1K







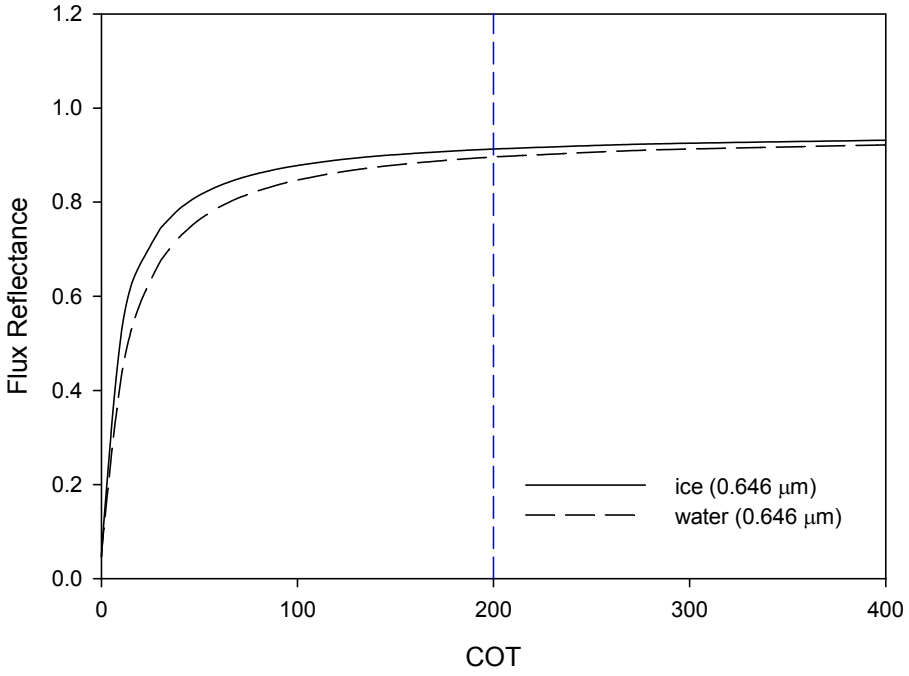


More than 85% pixels show COT=100 which means that real COT could be greater than 100.

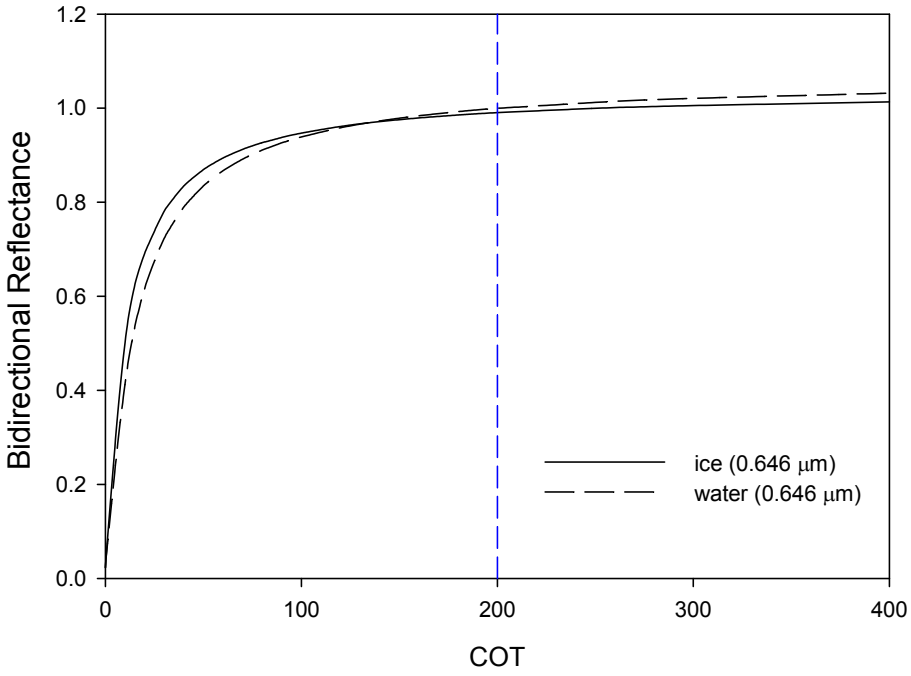
About 65% of pixels show COT > 150.

Sensitivity of 0.646 μm reflectances to COT

SZA=30, r_e=20 μm

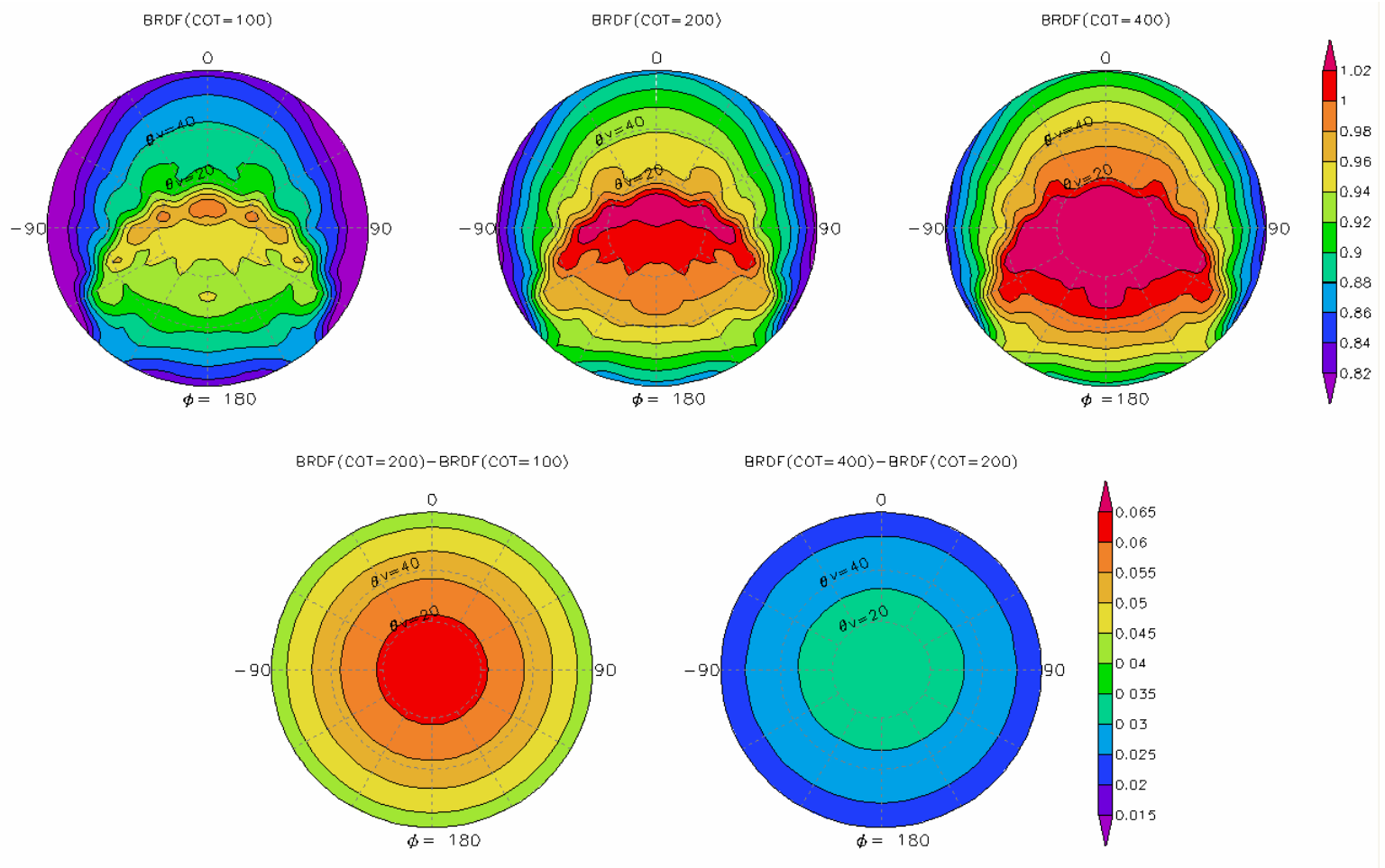


SZA=30, VZA=20, RAA=30, r_e=20 μm



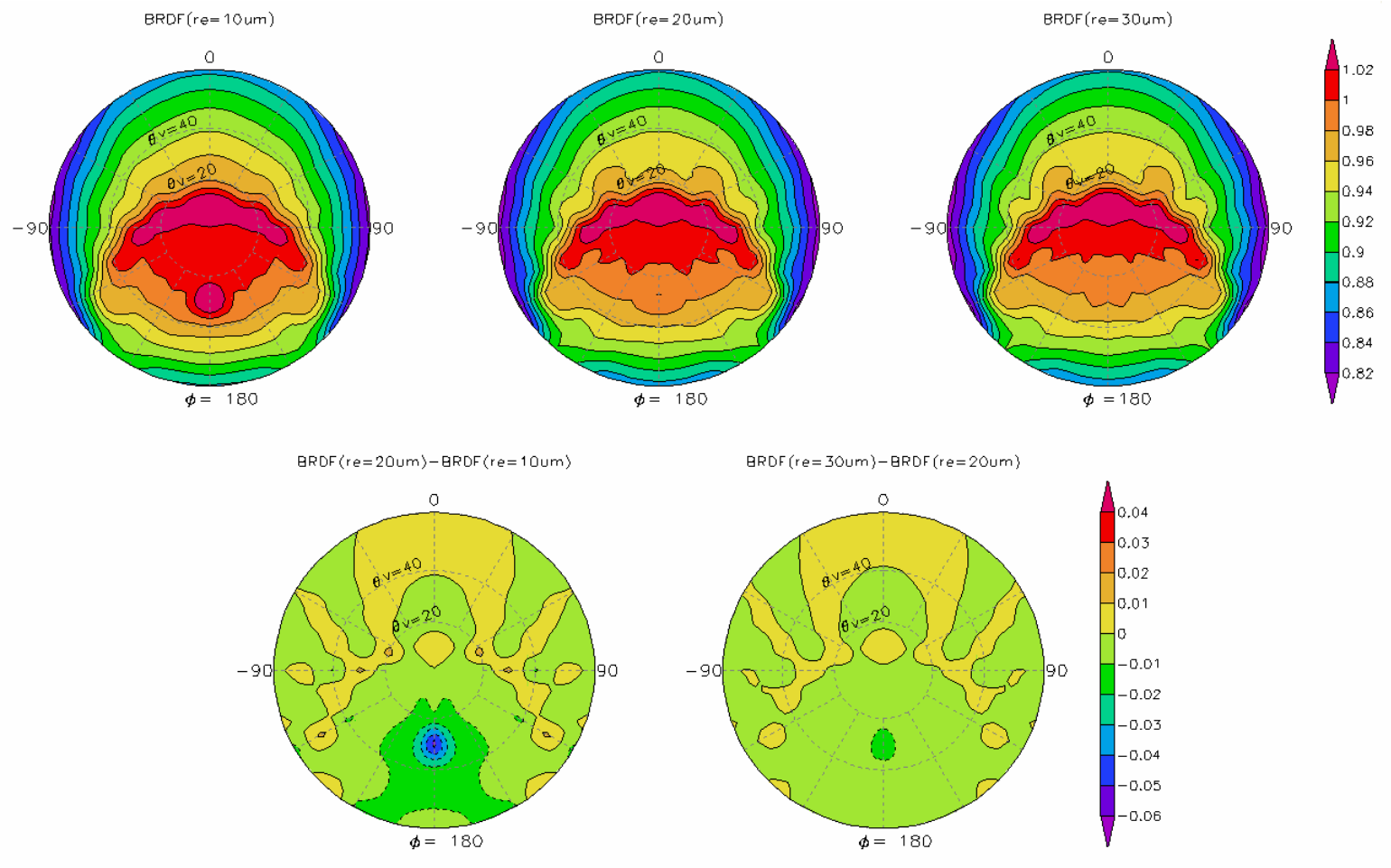
TOA reflectances are not sensitive to COT values anymore when COT exceeds 200.

Sensitivity of 0.646 μm reflectances to COT (SZA=30°)



→Cloud bidirectional reflectance distribution function (BRDF) varies up to 6% when COT increases from 100 to 200 while BRDF changes up to 3% when COT increases from 200 to 400.
→ If we assume the COT to be 200 even though real COT values are from 100 to 400, then BRDF error caused by uncertain COT values would be less than 6%.

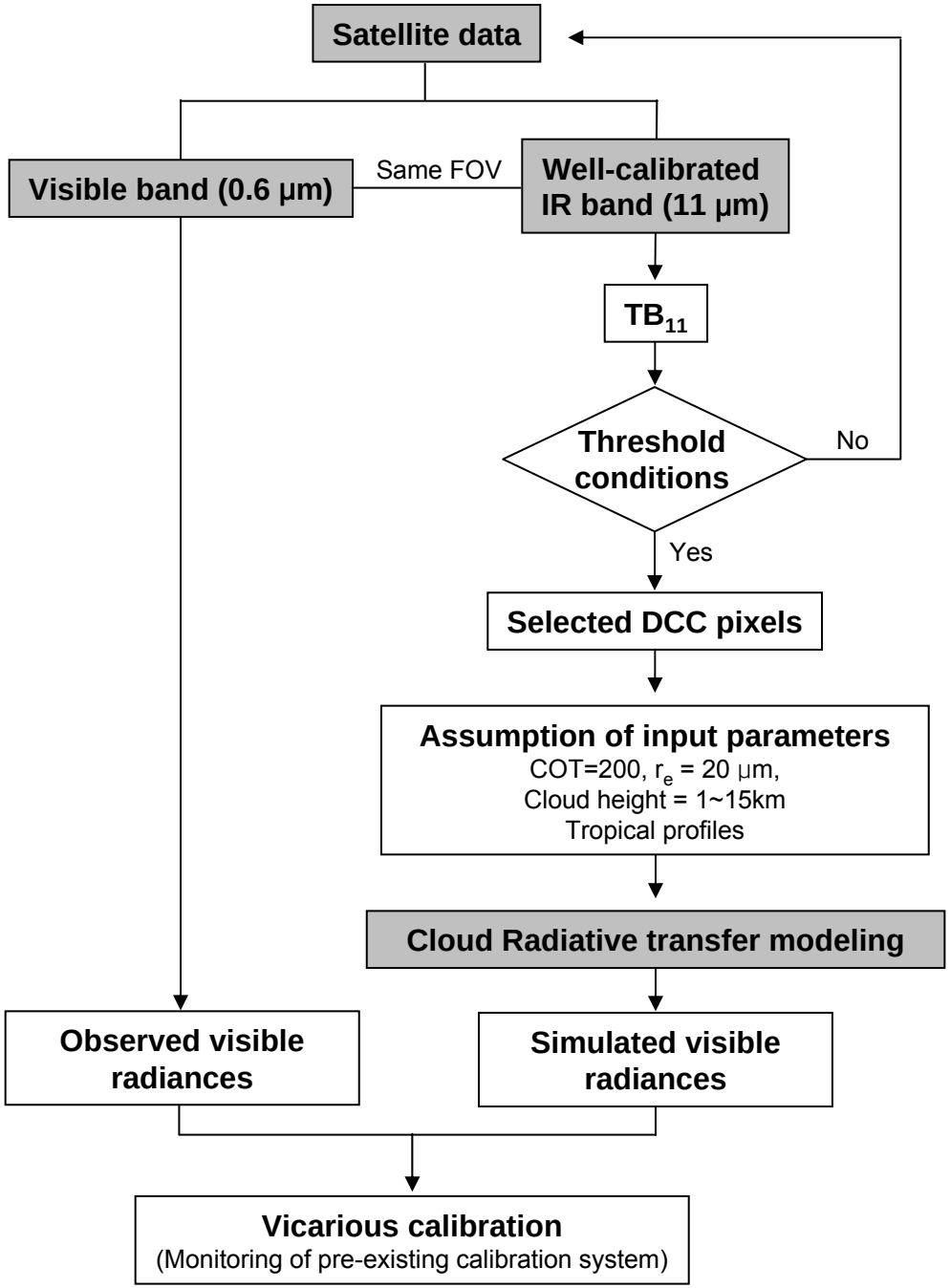
Sensitivity of 0.646 μm reflectance to r_e (SZA=30°, COT=200)



→Cloud bidirectional reflectance distribution function (BRDF) varies up to 2% when effective radius (r_e) increases from 10 to 20 μm while BRDF changes up to 1% when r_e increases from 20 to 30 μm except aureole region.

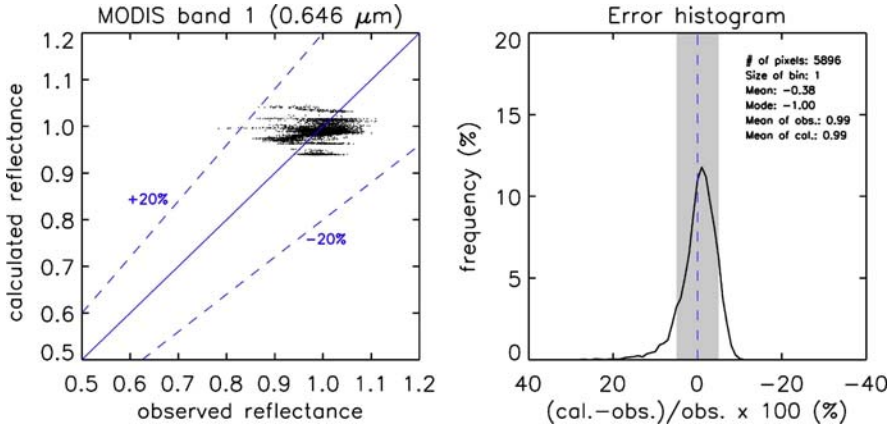
→ If we assume r_e as 20 μm even though real r_e values are from 10 to 30 μm, then BRDF error caused by uncertain r_e values would be less than 2%.

IR-based vicarious calibration of visible bands



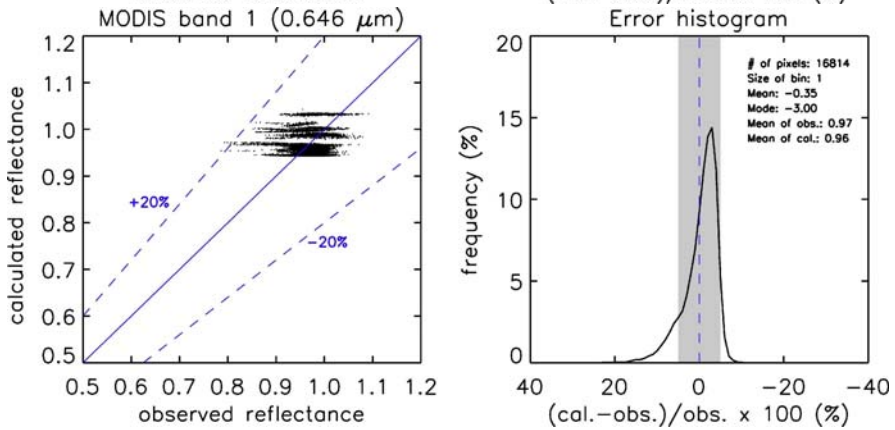
Simulation of MODIS reflectances by assuming r_e=20 μm, COT=200 (pixel-based value)

Jan2006



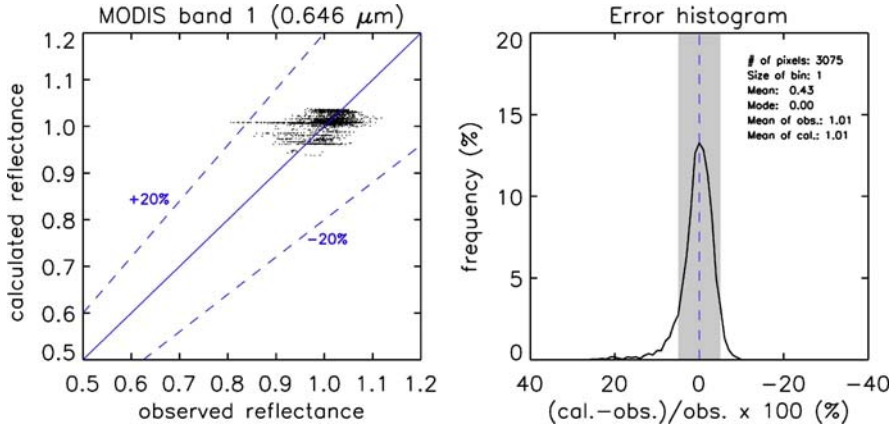
About 85% pixels show less than 5% errors.

Feb2006



About 89% pixels show less than 5% errors.

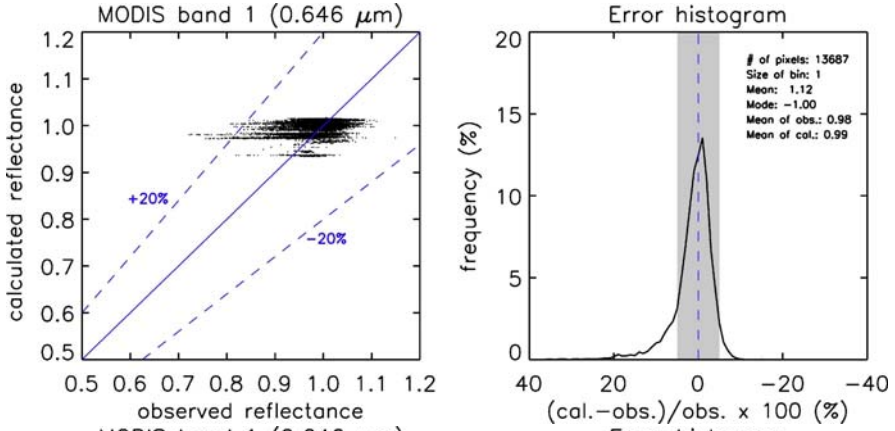
Mar2006



About 90% pixels show less than 5% errors.

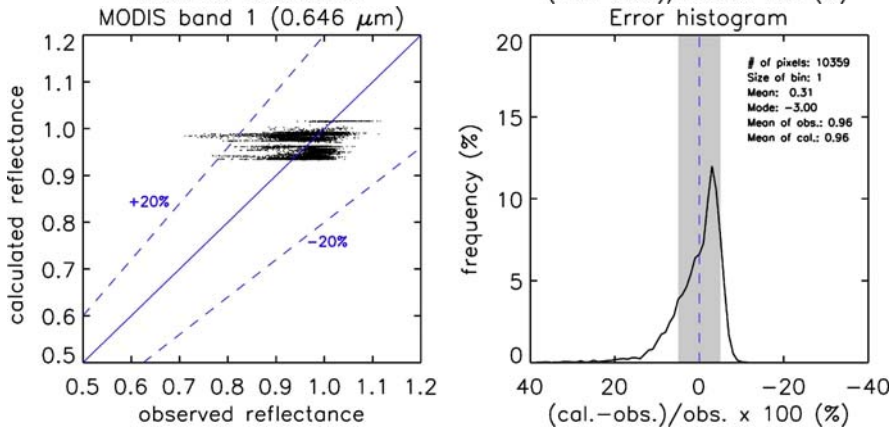
Simulation of MODIS reflectances by assuming r_e=20 μm, COT=200 (pixel-based value)

Apr2006



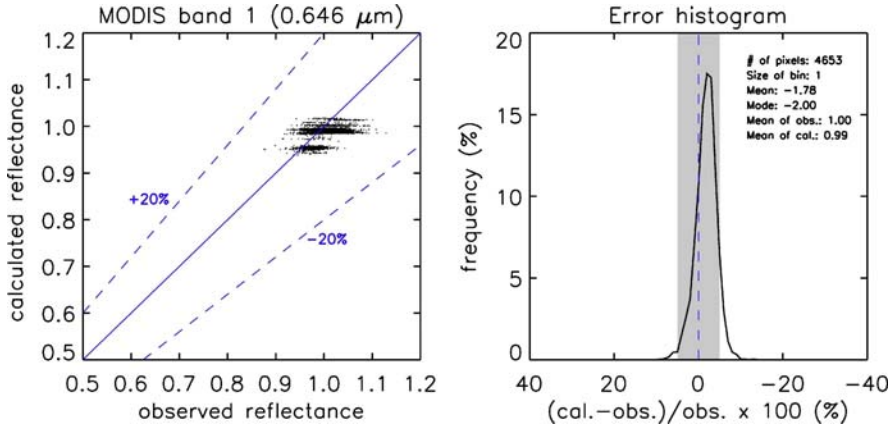
About 86% pixels show less than 5% errors.

Mar2006



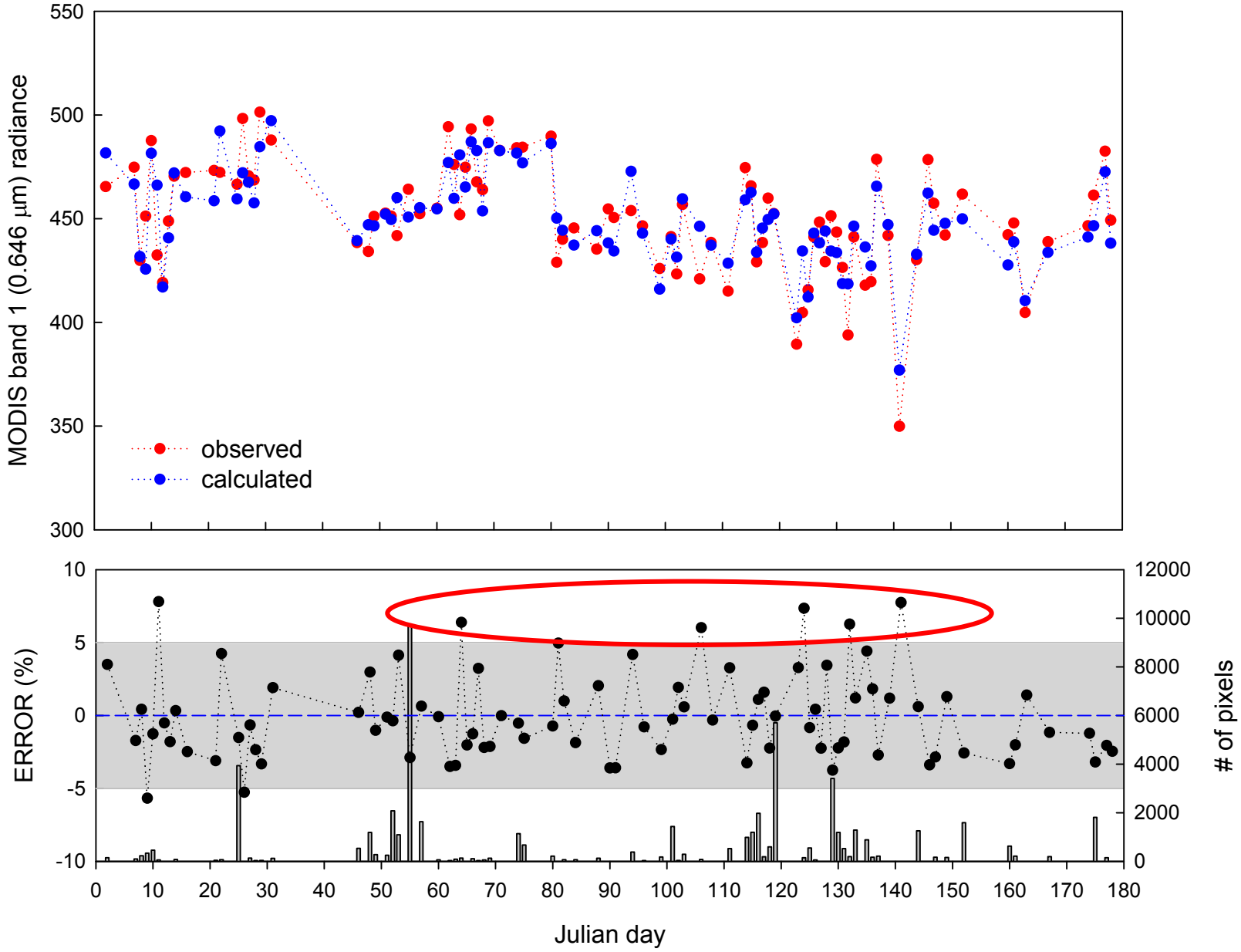
About 78% pixels show less than 5% errors.

Jun2006



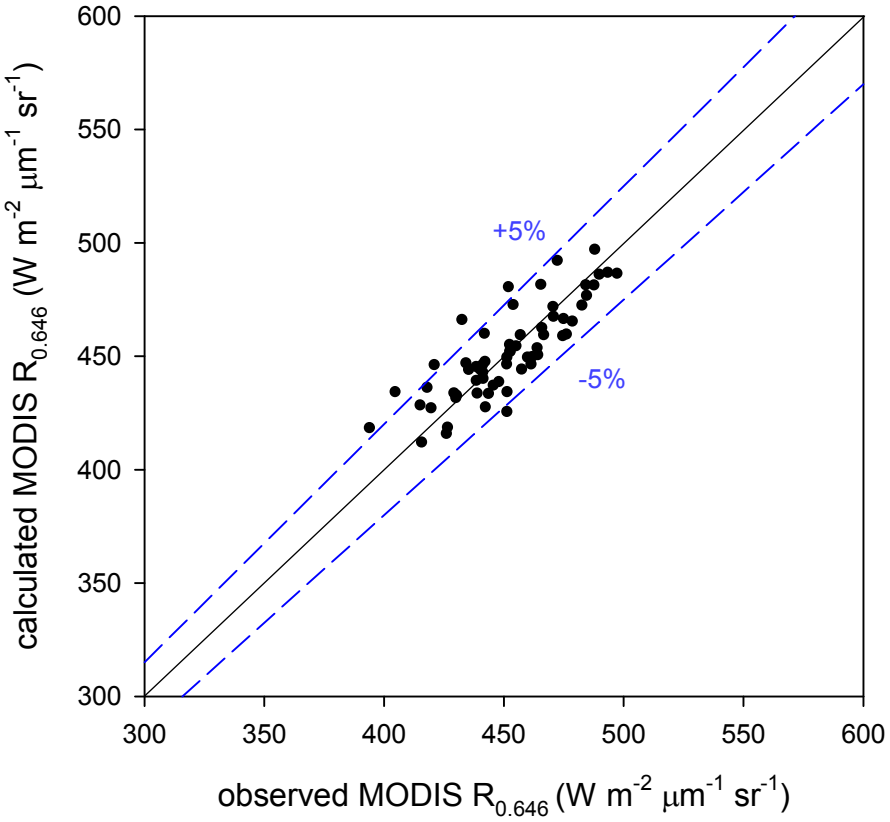
About 94% pixels show less than 5% errors.

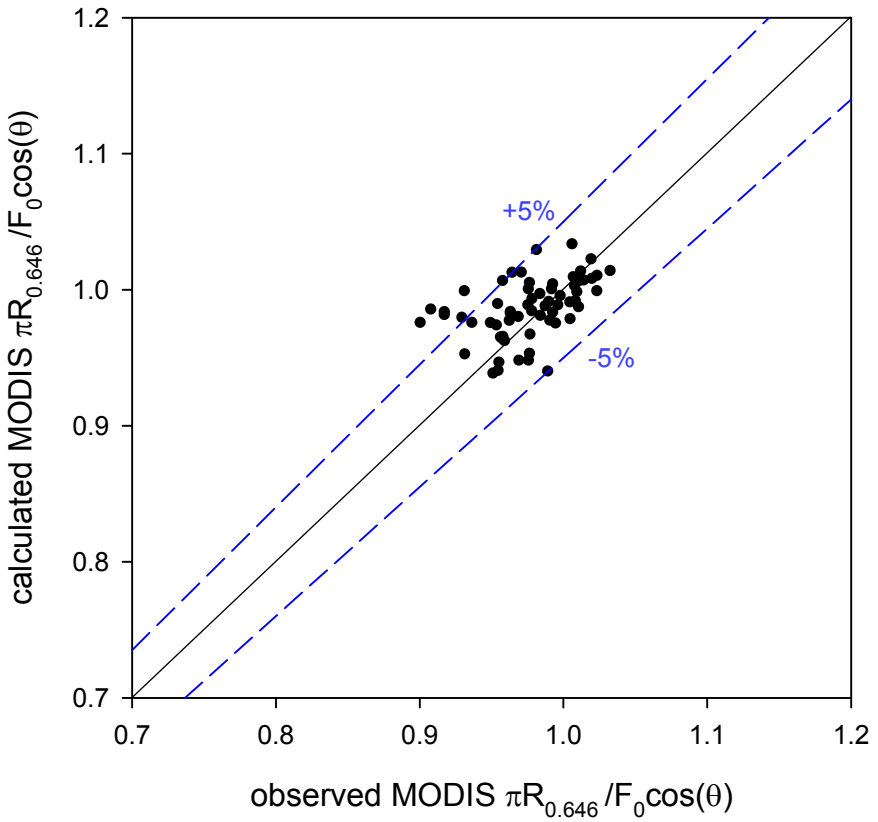
Time series of simulated and observed MODIS reflectances



ERROR (%) = (cal. – obs.)/obs. X 100 (%)

Comparisons of simulated with observed MODIS reflectances on a daily basis

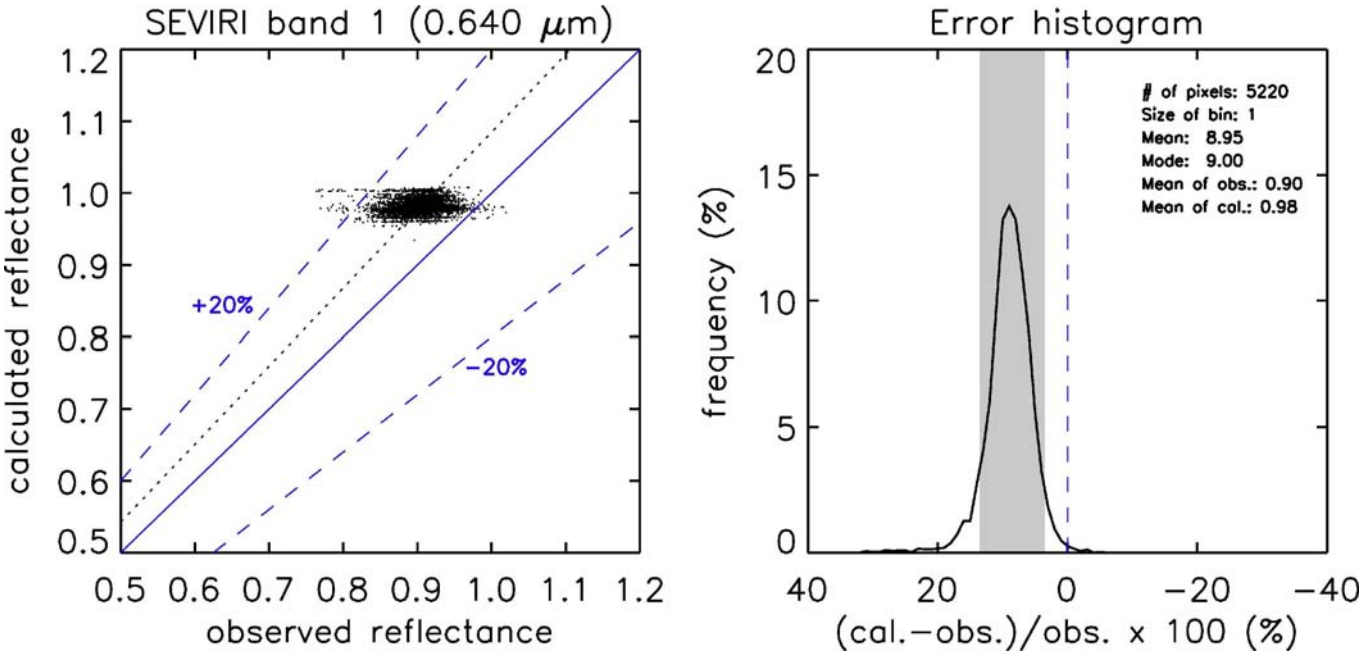




Daily mean values are calculated if the number of cloud pixels are greater than 10.

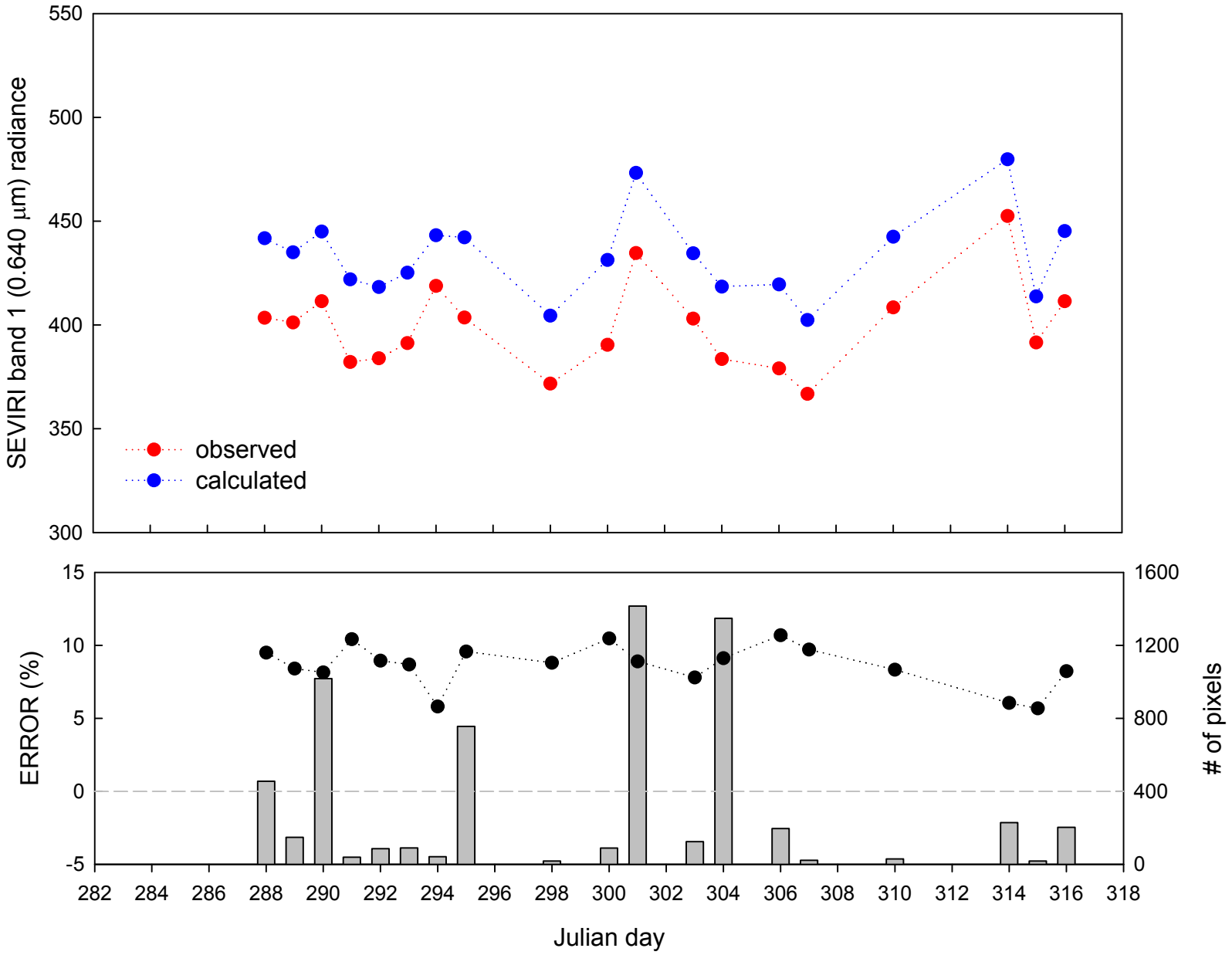
Simulation of SEVIRI reflectances by assuming r_e=20 μm, COT=200

Oct2006



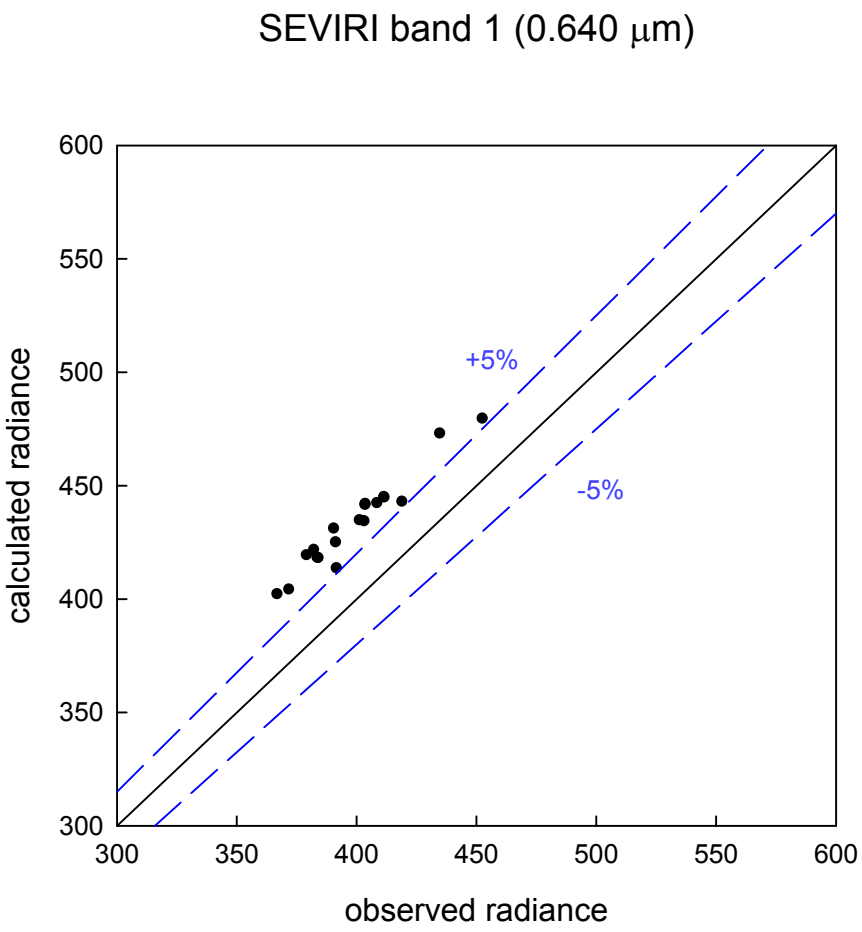
About 88% pixels show errors within the range 8.5±5%.

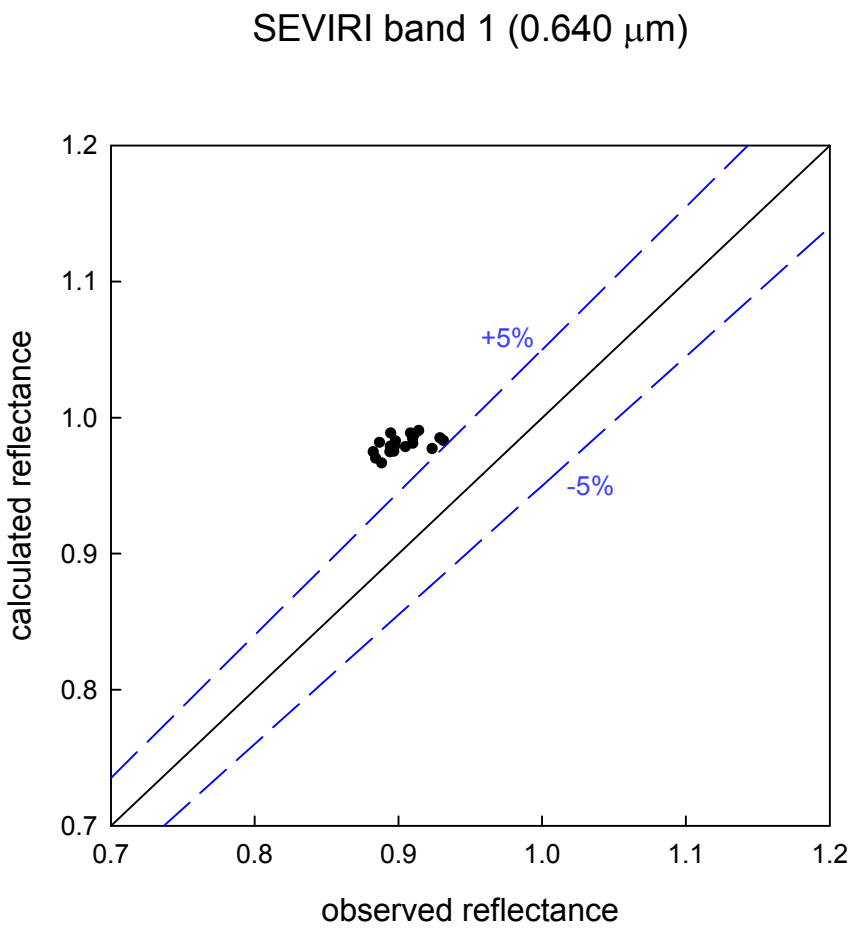
Time series of simulated and observed SEVIRI reflectances



ERROR (%) = (cal. – obs.)/obs. X 100 (%)

Comparisons of simulated with observed SEVIRI reflectances on a daily bases

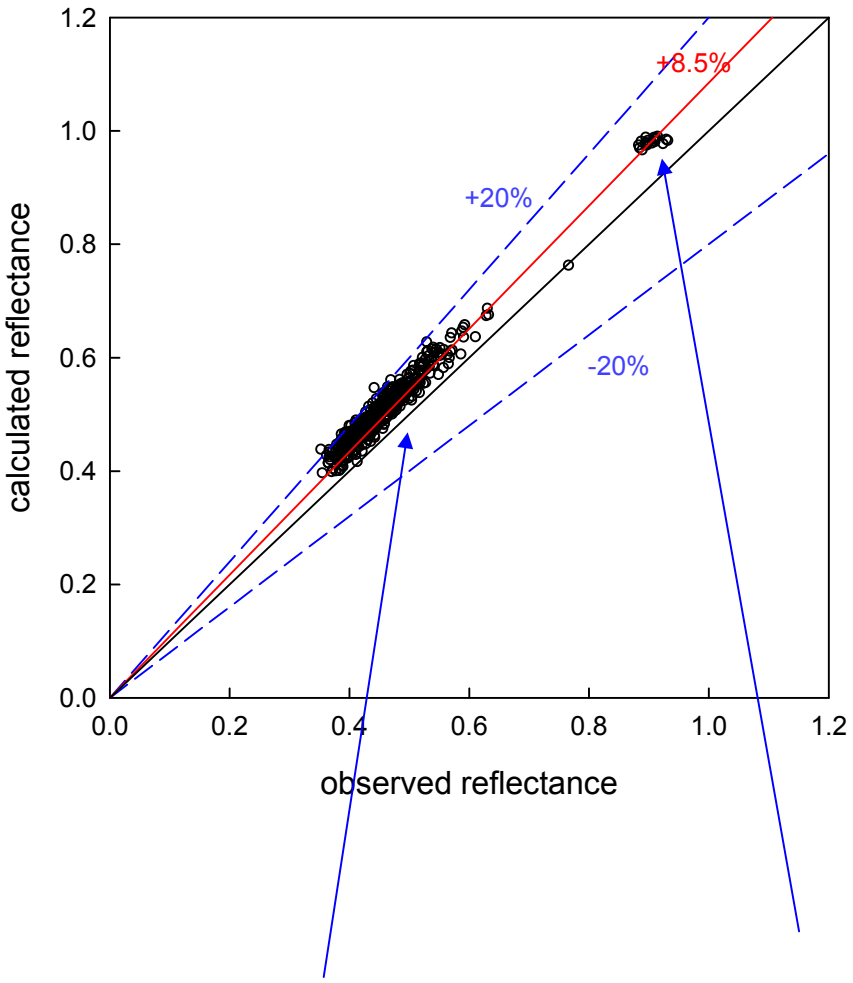




Daily mean values are calculated if the number of cloud pixels are greater than 10.

Consistency check of two calibration method

SEVIRI band 1 (0.640 μm)



Conclusions

- MODIS-derived cloud parameters provide sufficient information for the radiance simulations at shortwave bands.
- SEVIRI 0.640 μm band radiances are simulated using collocated MODIS cloud products as RTM inputs, and the results show that simulated values seem to be overestimated about 8.5% compared to observed radiances.
- Application to MODIS visible bands of IR-based vicarious calibration method (the method using DCCs) shows that the method can be applied within 5% uncertainties on a daily basis.
- Simulated SEVIRI 0.640 μm band radiances from IR-based vicarious calibration method show 8.5% larger values compared to observed values.
- Overall, both two calibration methods suggest that pre-existing SEVIRI calibration algorithm may derive underestimated radiance values.