PACE Atmosphere Team Working Group Breakout

Overview of Cloud Requirements in Sect. 2.4

S. Platnick et al.

Section 2.4 (Cloud) Summary

ACE Overview/Context

- How do the macrophysical, microphysical, and radiative properties of clouds and precipitation change as a function of the thermodynamic and dynamic environment?
- How do the distributions of these properties differ with changes in aerosol properties?
- Cloud science questions subdivided according to cloud type (cirrus, deep convection, boundary layer and cumulus, midlatitude frontal, and polar clouds), each with its own specific retrieval requirements.
- Mapping PACE measurements into ACE cloud science objectives problematic because the passive measurement were closely tied with objectives that required the full ACE active and passive instrument suite.

Section 2.4 (Cloud) Summary, cont.

Threshold OES/OES+ (3 addition NIR/SWIR channels):

- Cloud pressure :
  - 5 nm O_2 A-band (OES) expected to be very useful for low cloud pressure retrievals, especially in regions of temperature inversions and where geometrical thickness is small or well constrained. Will be of limited use for high thin clouds but can carry potential information on cloud geometrical thickness.
  - Additional information from 940nm band (OES+)
- Cloud phase, microphysics:
  - Addition of VIIRS 2.25 µm channel (OES+) improves phase information that can help compensate for the loss of the IR channels and provide continuity with associated VIIRS microphysical retrieval.
- Continuity relative to MODIS/VIIRS:
  - Will not achieve continuity for high clouds
  - Will achieve some level of continuity for low clouds (O_2 A-band vs. lack of heritage 3.7 µm microphysical retrieval, etc.)

Section 2.4 (Cloud) Summary, cont.

Goal OES+ (spectral & enhanced spatial) and 3MI:

- OES+ 250 m spatial resolution in selected channels/bands:
  - Reduce systematic biases in τ_c, and 1.6 and 2.1 µm r_e retrievals vs. 3.7 µm channel in broken maritime low clouds (Zhang and Platnick, 2011; Zhang et al., 2012; Di Girolamo et al., 2010).
- 3MI and synergy w/OES+:
  - Cloud-top pressure closer to IR-based retrieval (Rayleigh polarization coupled w/3MI cloud retrievals)
  - Improved phase
  - Information on vertical cloud microphysical structure and multilayer detection
  - Constraints on ice spectral radiative models (angular, spectral information)
- Continuity relative to POLDER/MISR/ATSR:
  - Exceeds continuity w/POLDER: improved spatial (4km nadir), spectral (13 channels, 8 w/polarization, 0.41–2.1 µm), wider swath and more view angles (10-14)
  - MISR, ATSR?

Section 2.4 (Cloud) Summary, cont.

2.4.4 Recommendations for Phase-A Clouds Studies. No cloud sensor/mission has ever been flown without an IR capability. Recommended that several aspects of OES+ and/or 3MI Threshold and Goal cloud retrieval capabilities be set aside for further study during Phase-A. These include:

1. Cloud (aerosol) height/vertical information content, including multilayer detection, from: (a) Threshold measurement requirements: a combination of A-band (two adjacent 5 nm channels and/or a broader 10 nm channel), 940 nm water vapor channel (OES+), and O_2-O_2 and O_2 B-band absorption; (b) Goal measurement requirements: synergy of OES+ and 3MI observations.
2. Phase information content available from: (a) Threshold measurement requirements: combination of OES+ SWIR channels (1.62, 2.13, and 2.25 µm); (b) Goal measurement requirements: synergy of OES+ and 3MI observations.
3. Daytime studies using MODIS and/or VIIRS cloud mask algorithms, with and without application of IR detection tests, to quantify the reduction in cloud detection skill for the OES+ channel selection.
4. Low cloud spatial resolution studies of retrieval biases in τ and r_e as a function of spatial resolution (<1 km) using theoretical models with explicit microphysics (e.g., LES), aircraft imager data, and/or 500 m MODIS data.
5. Other?

Table 2.4.1. Expected daytime cloud parameter retrieval accuracies with OES/OES+ and 3MI. Optical thickness (τ_c) and water path (WP) accuracies are appropriate for single layer/phase scenes; effective cloud particle radius (r_e) accuracies are for upper cloud layers with a weighting dependent on spectral channel or technique (total radiance vs. polarization). OES+ τ_c, r_e, and WP accuracies are taken from the GEWEX cloud assessment for MODIS (Stubenrauch et al., 2012). The shortwave radiative effect and cloud detection numbers are from ACE Cloud Working Group wide swath imager tables. 3MI accuracies are from …

Category	**Parameter (from ACE STM)**		**Nominal Retrieval Accuracy**		
			OES baseline	**OES+**	**3MI**
Macroscale/ morphology	1.	Cloud Layer Detection	TBD	5-10% (τ_c >0.3?) (function of surface)	
	2.	Multiple Cloud Layer Detection	–	TBD (A-band channel(s) + NIR water vapor)	*Via Rayleigh polarization + A-band + OES NIR water vapor?*
	3.	Cloud Top Pressure (CTP)	Mid Cloud Pressure (MCP): Low cloud, optically thick and/or over a dark surface (≈CTP): ≤ 50 hPa High cloud: > 50 hPa	Mid Cloud Pressure (MCP): *same as OES baseline*	*Via Rayleigh polarization + A-band? Use numbers from Sneep, Vanbauce and Fischer papers*
Microphysics, water amount	4.	Cloud Phase (upper layer)	limited capability	TBD (function of τ_c, r_e, ice model assumptions)	*Extract numbers from S. Zeng PhD dissertation*
	5.	Cloud Water Path (by phase)	–	~30% (liquid) ~50% (ice) (function of τ_c, r_e, surface)	
Radiative/ Energetics	6.	Optical Thickness (by phase)	–	~20% (liquid, small sub-pixel heterogeneity), ~30% (ice) (function of τ_c, surface)	
	7.	Effective Radius (upper layer weighting, by phase)	–	~20% (liquid, small sub-pixel heterogeneity), ~30% (ice) (function of τ_c,	

Table 2.3.1. Aerosol retrieval requirements. Products (table rows) taken from ACE aerosol working group white paper.

(*a*)

Category	Parameter (from ACE STM)		Nominal Retrieval Accuracy		
			OES baseline	OES+	3MI
Macroscale (effective column value)	1.	Aerosol Detection			
	2.	Effective Layer Altitude	~0.5 km		~0.5 km if $\tau(0.44) \geq \sim 0.2$
	3.	Aerosol Type			yes
Microphysics (effective column value)	4.	Effective Radius (column, multiple modes)	±30% (total)		~30%
	5.	Effective Variance (column, multiple modes)			~15% (fine) ~ 30% (coarse)
	6.	Fraction of total visibile optical depth contributed by the fine mode	±0.25		
	7.	Sphericity Characterizati on			Fraction of spherical particles ~ 10%, if $\alpha \leq 0.6$
	8.	Number Concentration			(volume conc.) $< 0.05 \mu m^3/\mu m^2$ or $< 10\%$

Table 2.3.1. Aerosol retrieval requirements. Products (table rows) taken from ACE aerosol working group white paper.

(*b*)

Radiation (effective column value)	9.	Optical Depth (spectral, multiple modes)	The largest: ±0.05 or 30% in th UV; ±0.03 or 10% over ocean in the visible; ±0.05 or 15% over land in the visible; (all total)	*Accuracy by aerosol type*?	(**over land**): 0.04 or 10% (total); 0.05 or 20% (coarse); 0.04 or 25% (fine); (**over ocean**): 0.02 or 10% (total); 0.03 or 15% (coarse); 0.02 or 10% (fine)
	10.	Absorption Optical Depth (spectral, multiple modes)			TBD (???): **over land**:0.02 **over ocean**: 0.01
	11.	Single Scattering Albedo (spectral, multiple modes)	±0.03 independently in 2 channels in the range from UV to 412 nm		**over land**: 0. 03 ($\tau \geq 0.4$) 0.05($0.1 \leq \tau < 0.4$) **over ocean**: 0. 03 ($\tau \geq 0.3$) 0.05($0.1 \leq \tau < 0.3$)
	12.	Refractive Index/Real (spectral)			~ 0.03 for $\tau(0.44) \geq$ ~0.5
	13.	Asymmetry Parameter (?)			TBD
	14.	Direct Radiative Effect			TBD

PACE Atmosphere Team Summary Slides

Measurement Requirements

S. Platnick et al.

Atmosphere Measurement Requirements

CW (µm)	BW (FWHM, nm)	Rmax [a] (μ_0=1)	Lmax [a] (W/m²-sr-µm)	Rtyp [a,b] (μ_0=1)	Ltyp [b] (W/m²-sr-µm)	NEdR@Rtyp	SNR@Ltyp [a]	Spatial Resolution (m) [Threshold, Goal [c]]
Augmentation to baseline OES								
0.940	25	0.80	210	0.03	7.8	0.0002	130	1000
1.378	10 [d]	0.80	95	0.03	3.5	0.0003	90	1000
2.250 [e]	50	0.90	21	0.03	0.7	0.0003	90	1000 250
		Additional info. and/or modification to baseline OES channels						
0.665								1000 250
0.865								1000 250
1.640								1000 250
2.135								1000 250
0.763	5nm; CW tolerance: ±2.5nm; BW/CWL knowledge: < 0.1 nm							1000 250

Table notes:

a. Values consistent with Lmax, Rmax, and S/N@Ltyp for MODIS at native resolution (0.5–1km); VIIRS SWIR channel S/N's ≈40% less (750m).

b. Rtyp corresponds to cirrus optical thickness of ~0.2–0.3

c. "Goal "spatial resolution for reduction of low cloud heterogeneity biases. SDT report calls out for further specific studies in Phase A.

d. MODIS 30nm BW found to be too large for adequate cirrus detection. VIIRS: 15nm found to be significantly better.

e. For cloud phase and VIIRS/ABI cloud microphysics continuity

Atmosphere Measurement Requirements: Threshold vs. Goal

	OES Baseline	OES w/additional NIR/ SWIR Spectral Channels	OES w/Spectral + Improved Spatial (selected)	3MI
Aerosol Continuity (MODIS,VIIRS, OMI)	T			
Aerosol Continuity (POLDER/MISR/ ATSR) + Advances				G
Low Cloud Continuity (MODIS, VIIRS)		T		
Low Cloud Advances (broken regimes)			G	
Cloud Continuity (POLDER, MISR, ATSR) + Advances				G

PACE Atmosphere Team Summary Slides

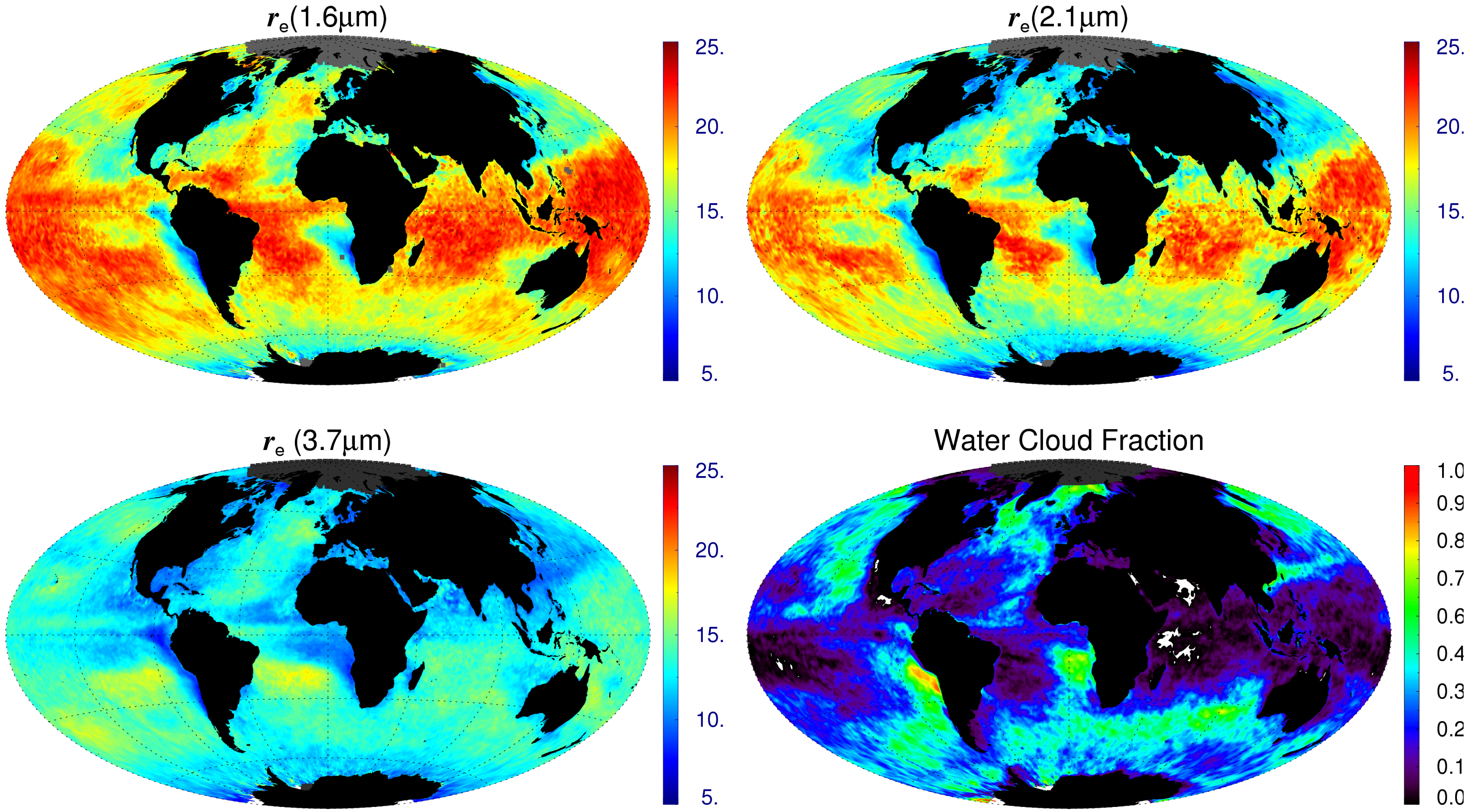
Clouds & Spatial Resolution

S. Platnick et al.

Spatial Resolution Studies of Marine Liquid Water Clouds

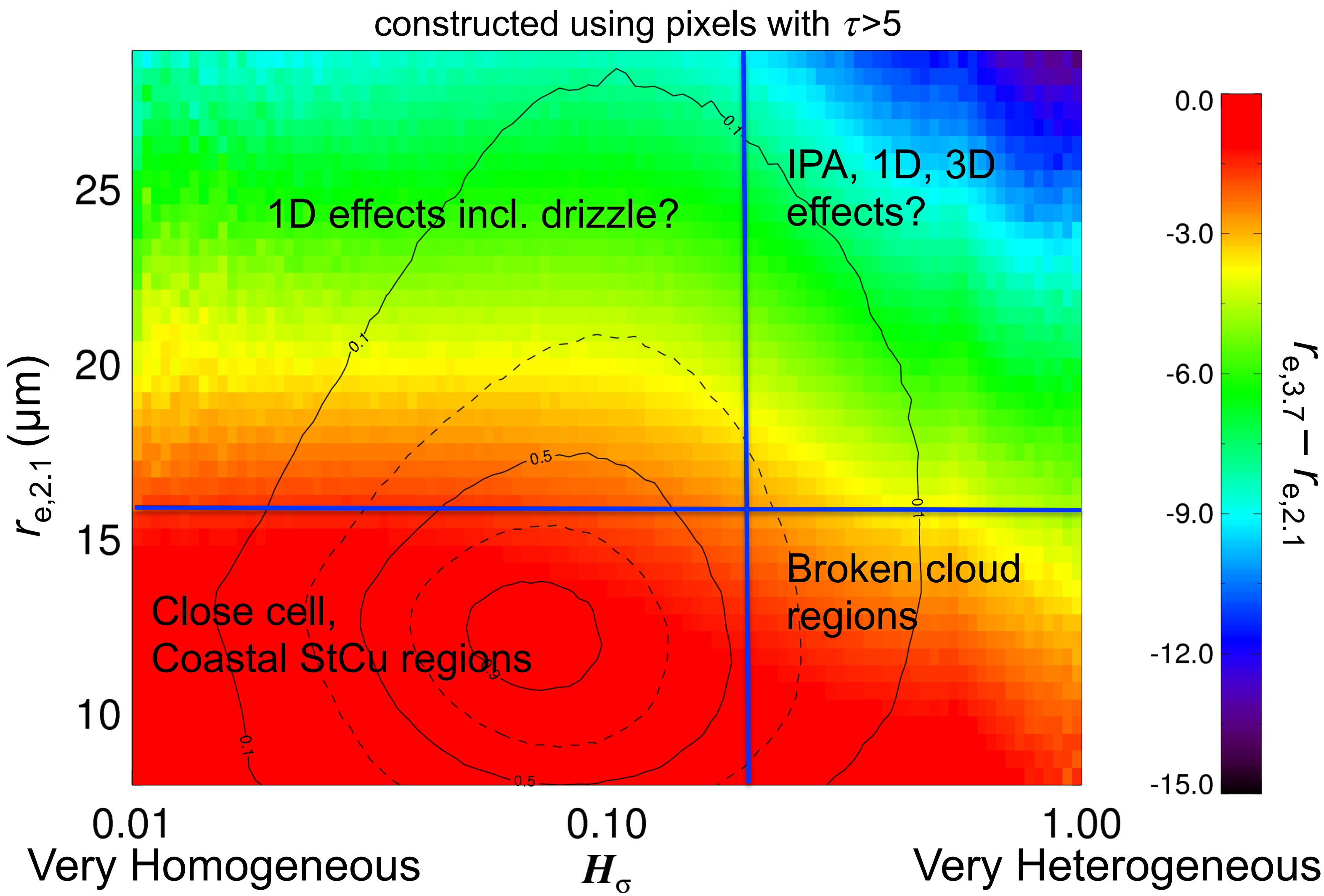
- MODIS empirical studies
  - Analysis of standard 1km retrievals vs. cloud heterogeneity
  - MODIS 500m vs. 1km retrievals
- LES modeling studies of boundary layer marine StCu

MODIS monthly mean r_e retrievals for maritime liquid clouds



Zhang and Platnick (2011)

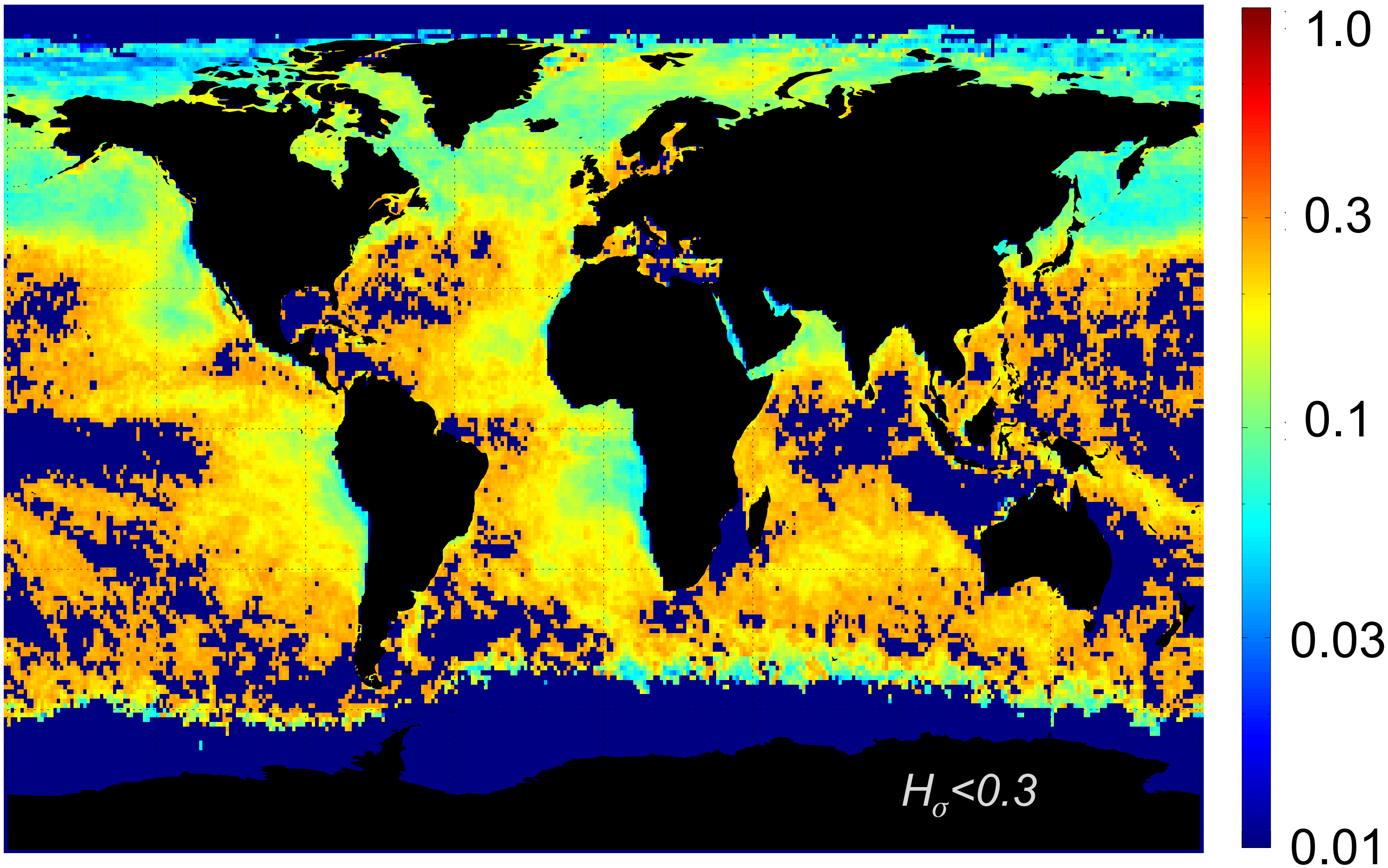
MODIS Microphysical Differences/Biases: Separation of cloud regimes



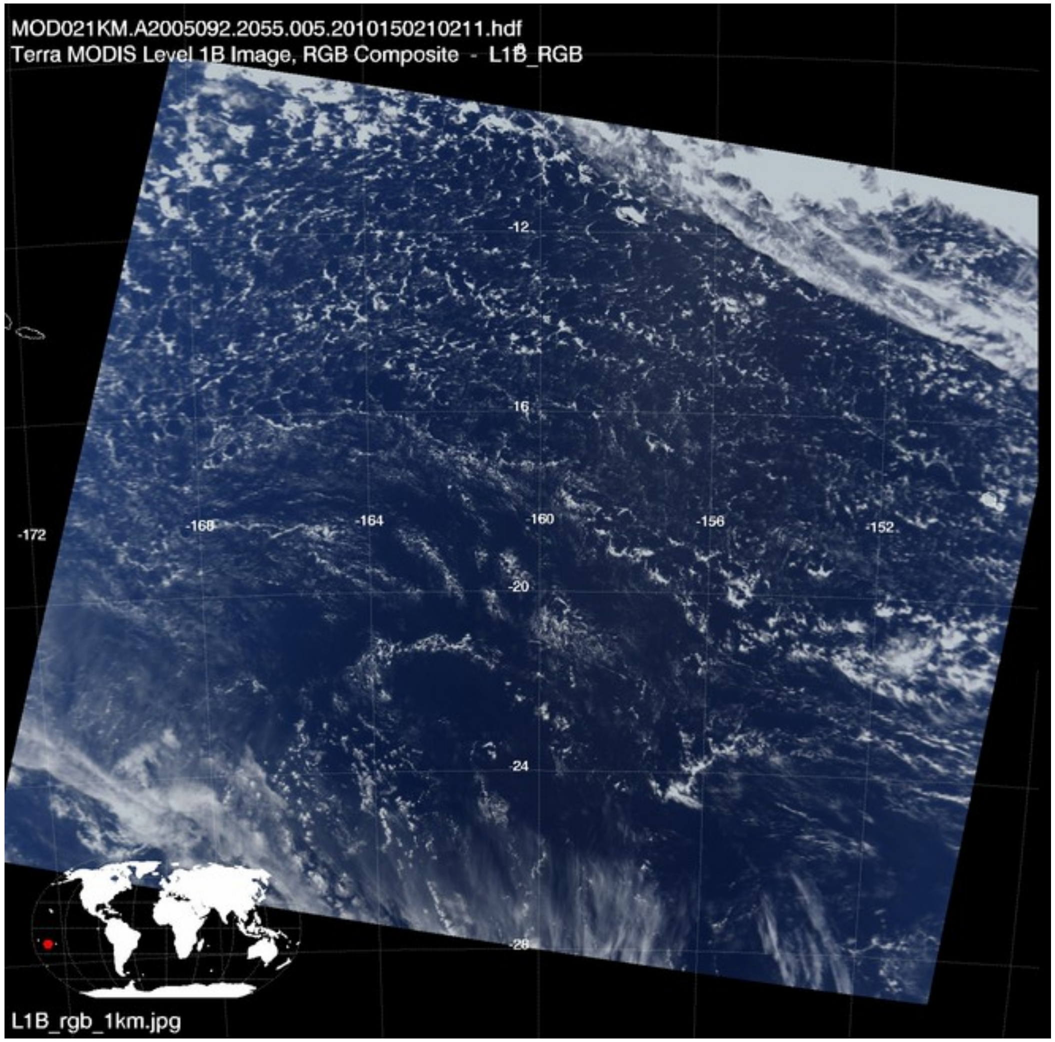
Zhang and Platnick (2011)

Monthly mean Heterogeneity Parameter (H_σ) for maritime liquid clouds

(Hyoun-Myoung Cho, Z. Zhang)

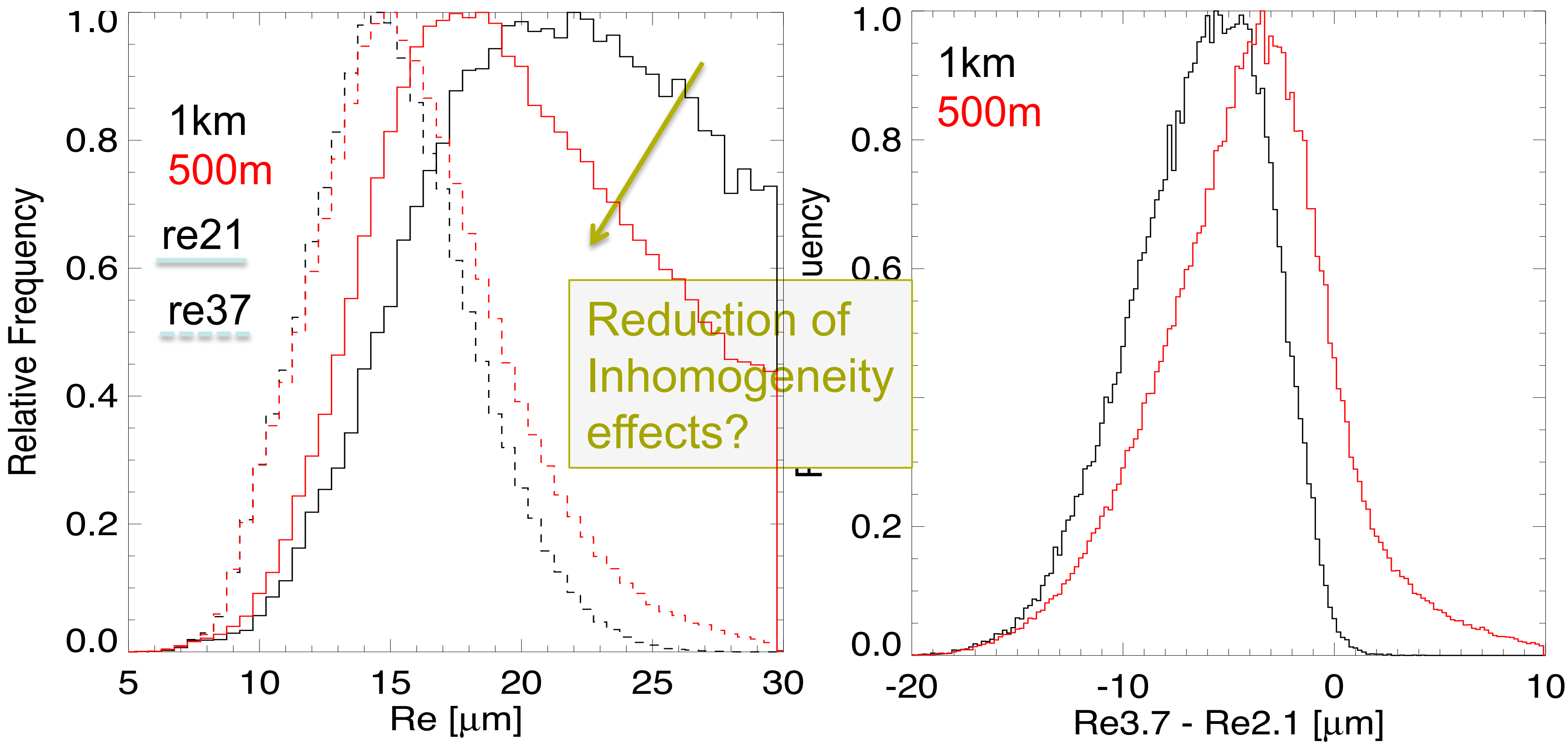


MODIS 1km vs 500m Retrieval Sensitivity



MODIS 1km vs 500m Retrieval Sensitivity, cont.

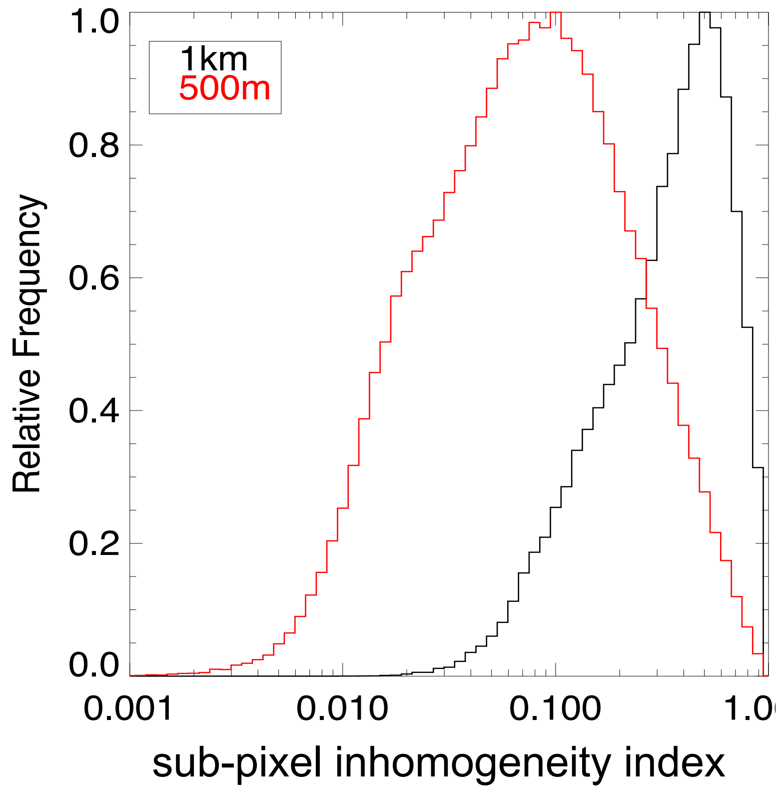
liquid water cloud retrievals



Pixel filtering: liquid cloud over ocean, no sun glint, tau > 3.0, successful re21 and re37 retrievals

MODIS 1km vs 500m Retrieval Sensitivity, cont.

liquid water cloud retrievals, 500m heterogeneity only samples 4 pixels (not 16)



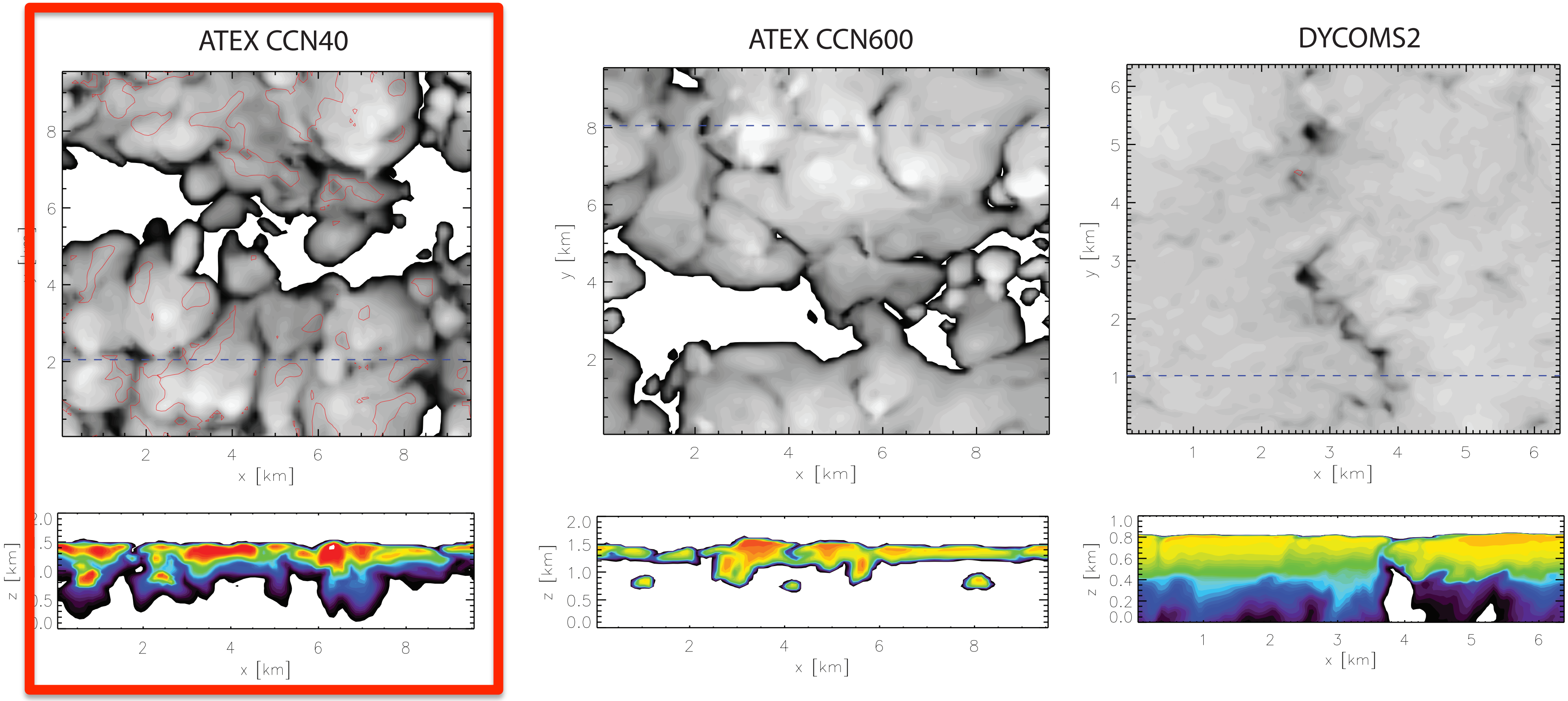
Substantial reduction of sub-pixel inhomogeneity:

- At 500m: 3-D effect and other uncertainty dominate?
- At 1km: in addition to 3-D effects and retrieval uncertainties, horizontal inhomogeneity becomes important?

LES case studies

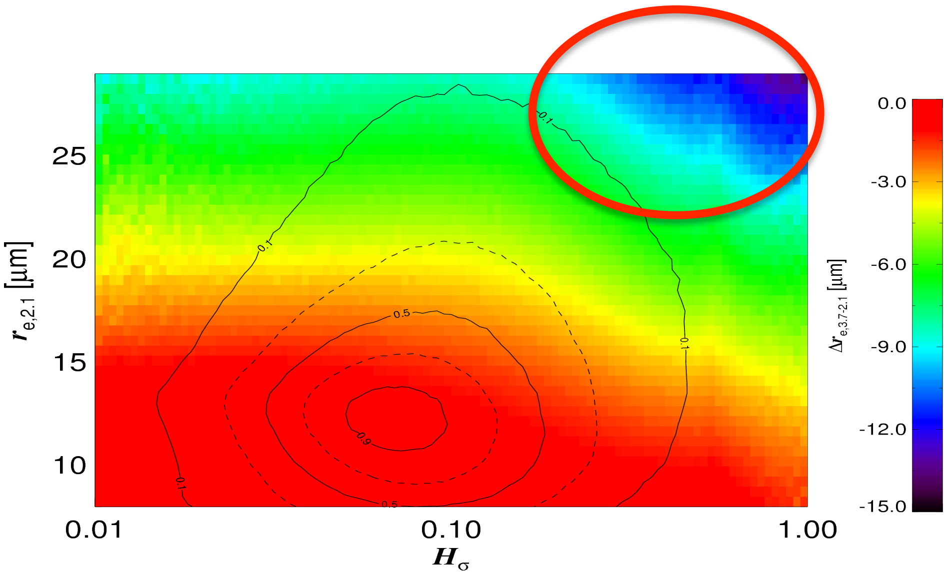
(Zhang et al., 2012, submitted)

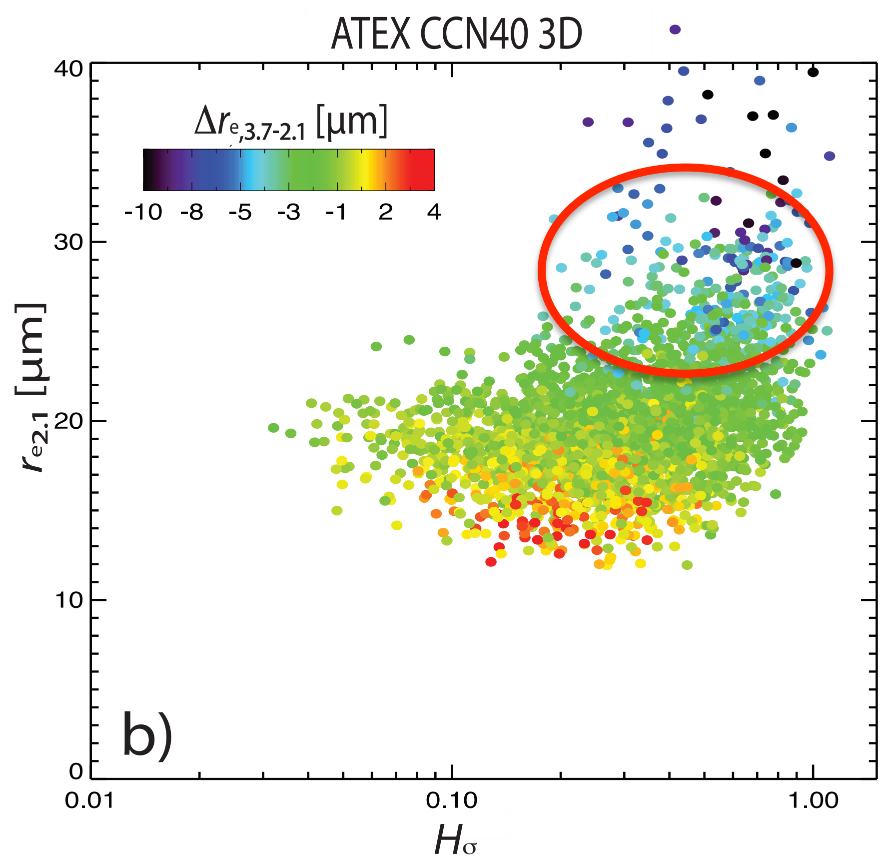
LES simulations are based on the DHARMA model with bin-microphysics scheme (Ackerman et al. 2004). The horizontal resolution of LES simulation ~ 50 m.



LES StCu Model Results : Δr_e vs. r_e vs. Inhomogeneity

(Zhang et al., 2012, submitted)





LES StCu Model Results: Retrieval Biases vs. Pixel Size

(Zhang et al., 2012, submitted)

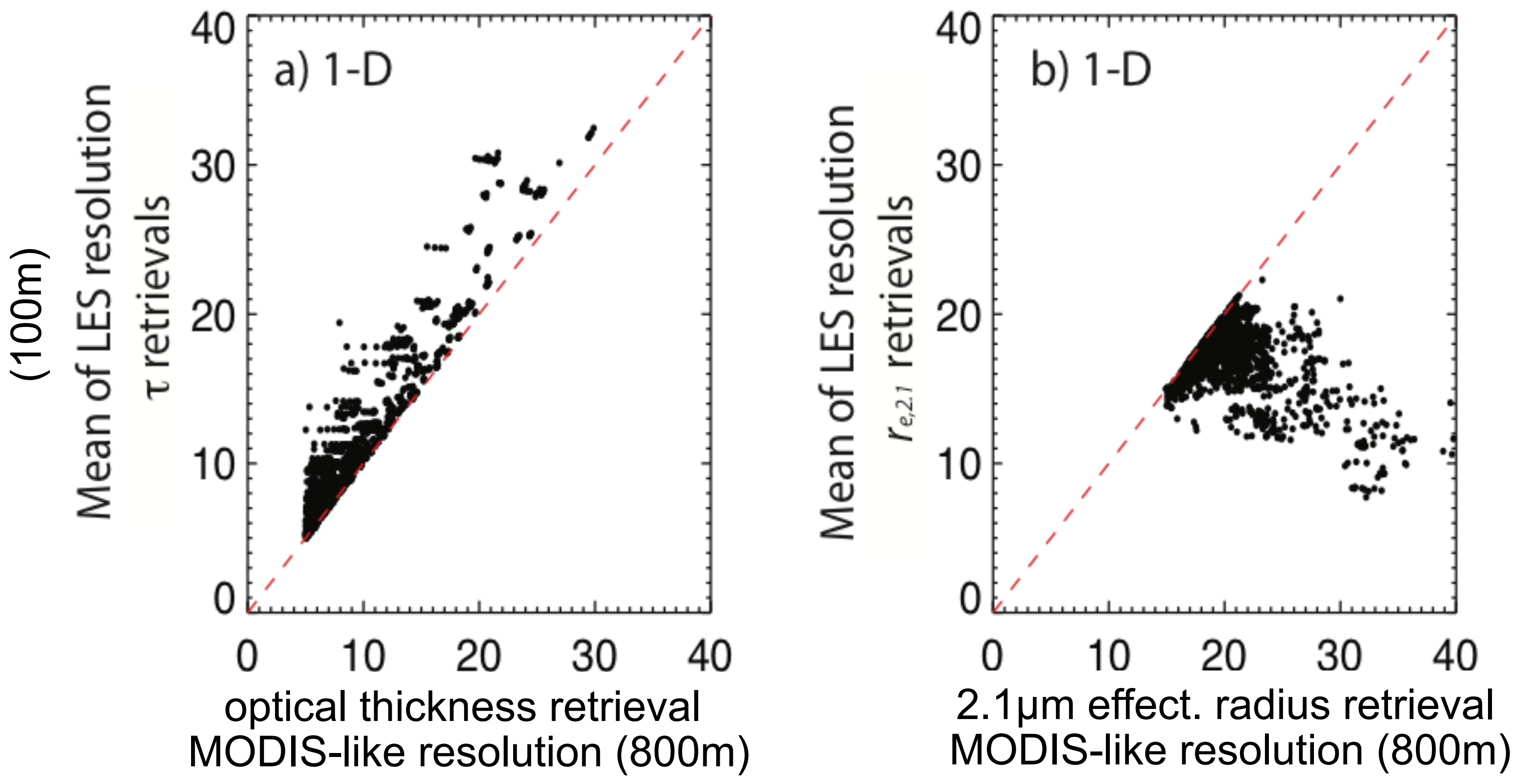


Figure 11 Comparions between the mean value of LES resolution (i.e., 100 m) retrievals with MODIS resolution retreivals (i.e., 800 m) based on averaged radiance for a) τ and b) $r_{e2.1}$ based on 1-D radiative transfer simulation. c) and d) are same as a) and b), repsetively, but based on 1-D radiative simulation

LES StCu Model Results: Retrieval Biases vs. Pixel Size

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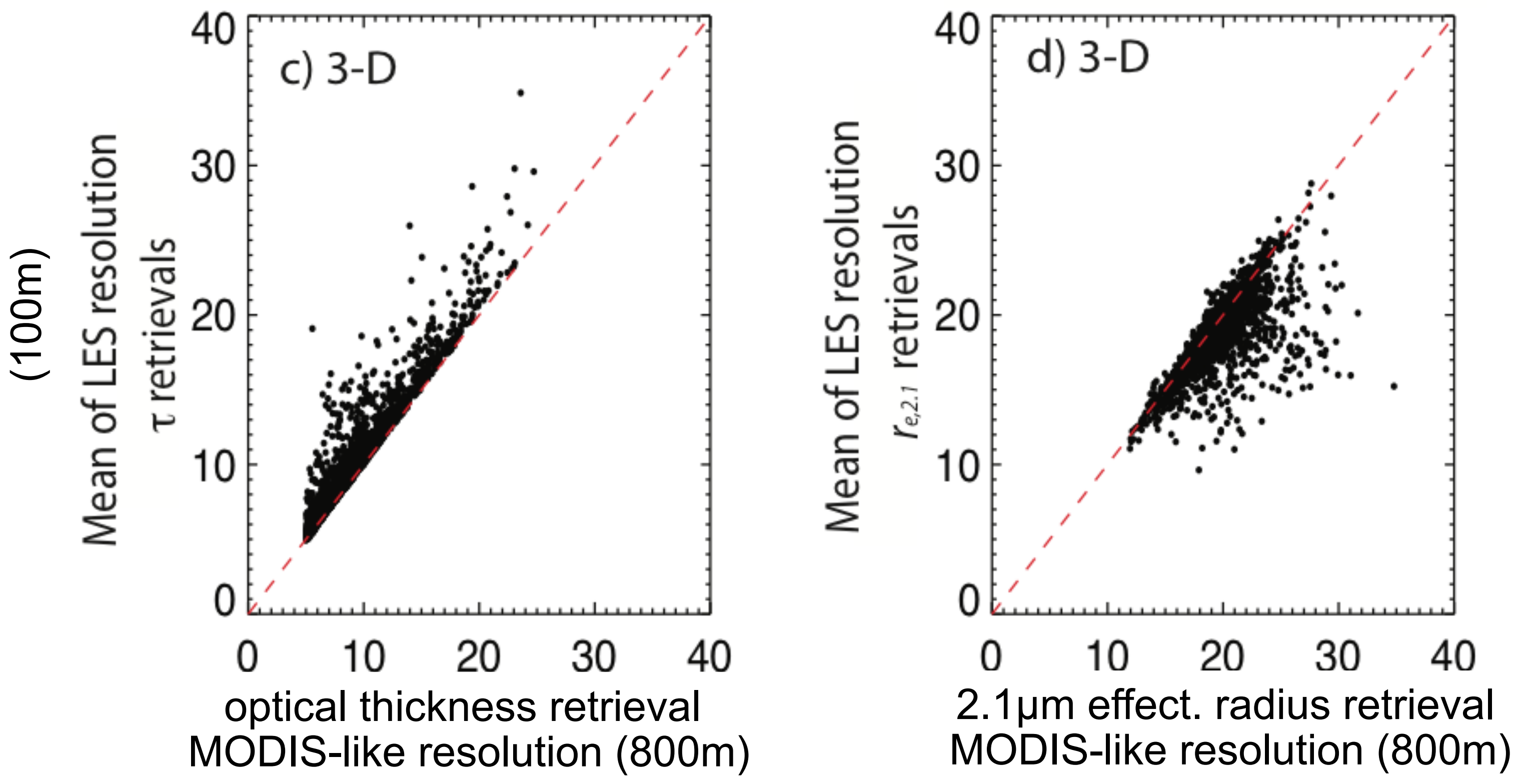

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Spatial Resolution Summary of Marine Liquid water Clouds

- MODIMODIS empirical studies
  - Difference in water cloud effective radius retrievals between 2.1 and 3.7 μm channels ($r_{e,2.1}$-$r_{e,3.7}$) increases with both cloud heterogeneity (pixel resolution?) and $r_{e,2.1}$
  - An issue for low broken maritime clouds
  - Smaller τ and some reduction in $r_{e,2.1}$-$r_{e,3.7}$ seen in MODIS 500m retrieval case study.
- LES studies:
  - In three cases studies, $r_{e,2.1}$ and $r_{e,3.7}$ retrievals at the LES resolution agree reasonably well with one another regardless of whether a 1-D or 3-D radiative transfer model is used.
  - At resolution similar to MODIS, large $r_{e,2.1}$-$r_{e,3.7}$ differences can occur
    - similar functionality as in MODIS analysis
    - sub-pixel heterogeneity plays the dominant role (can be improved by higher spatial resolution), optimal resolution requires further study

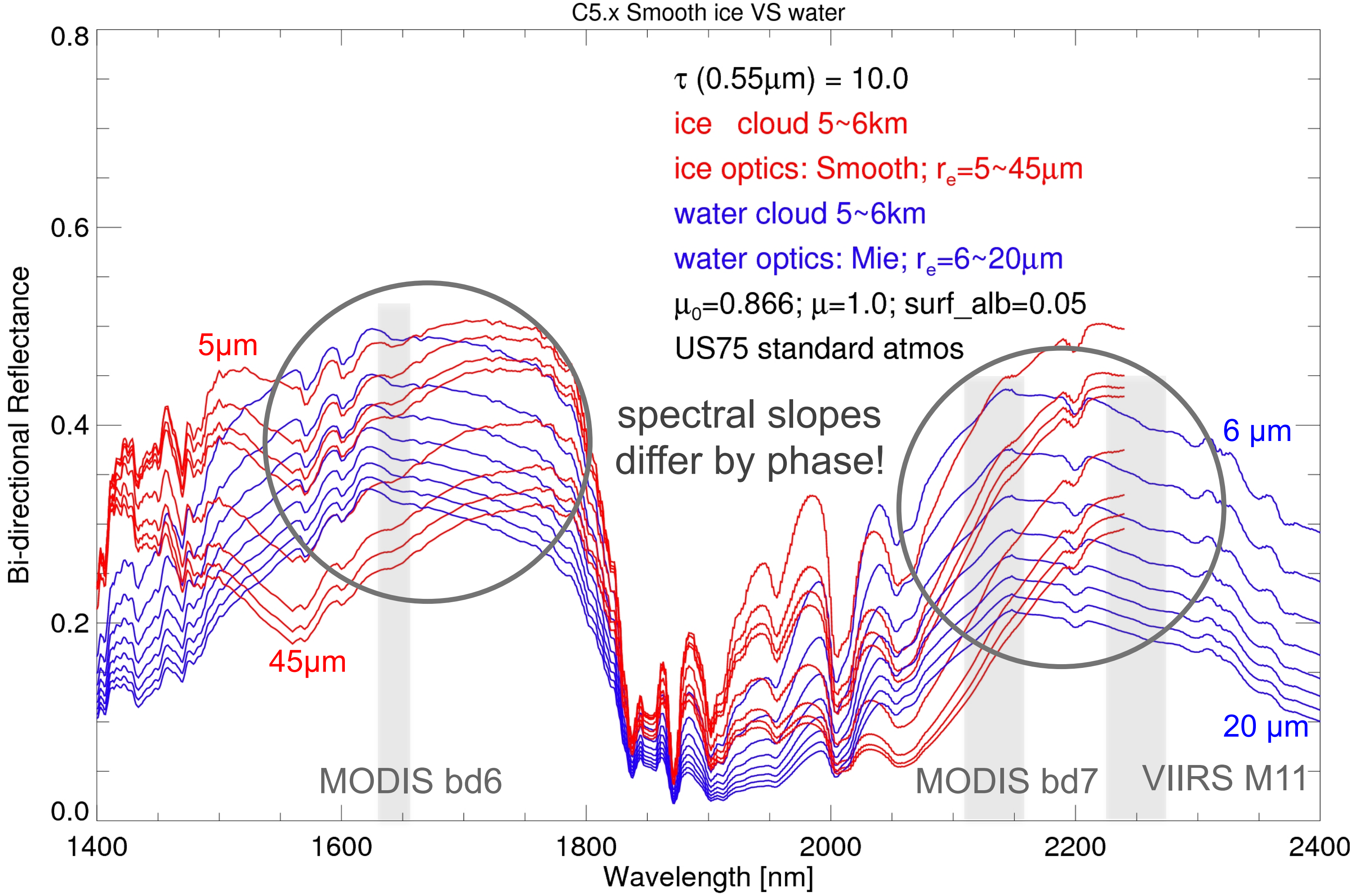
PACE Atmosphere Team
Summary Slides

Cloud Thermodynamic Phase

S. Platnick et al.

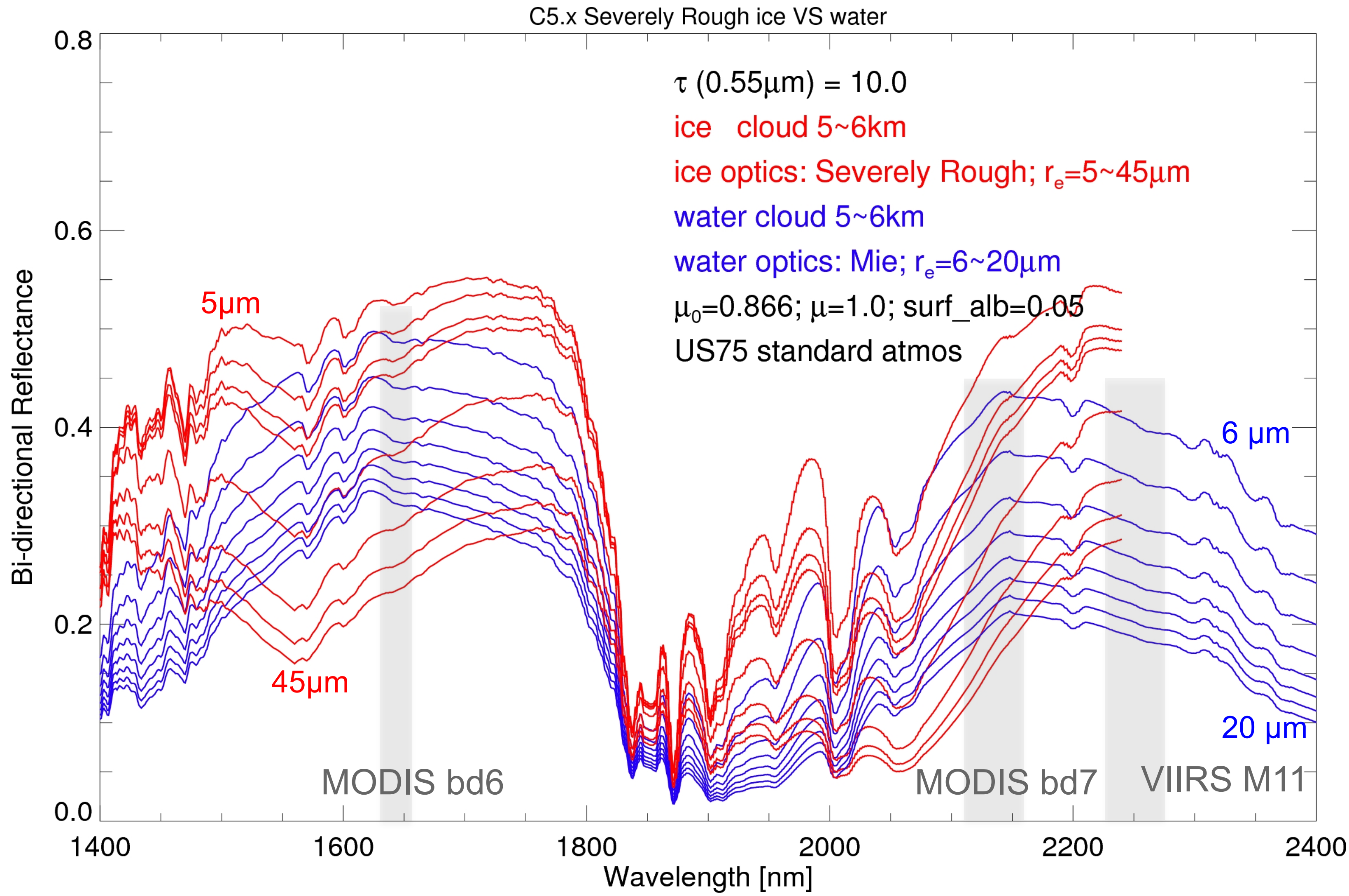
τ, r_e Spectral Reflectance vs. Phase

(MODIS cloud retrieval group)



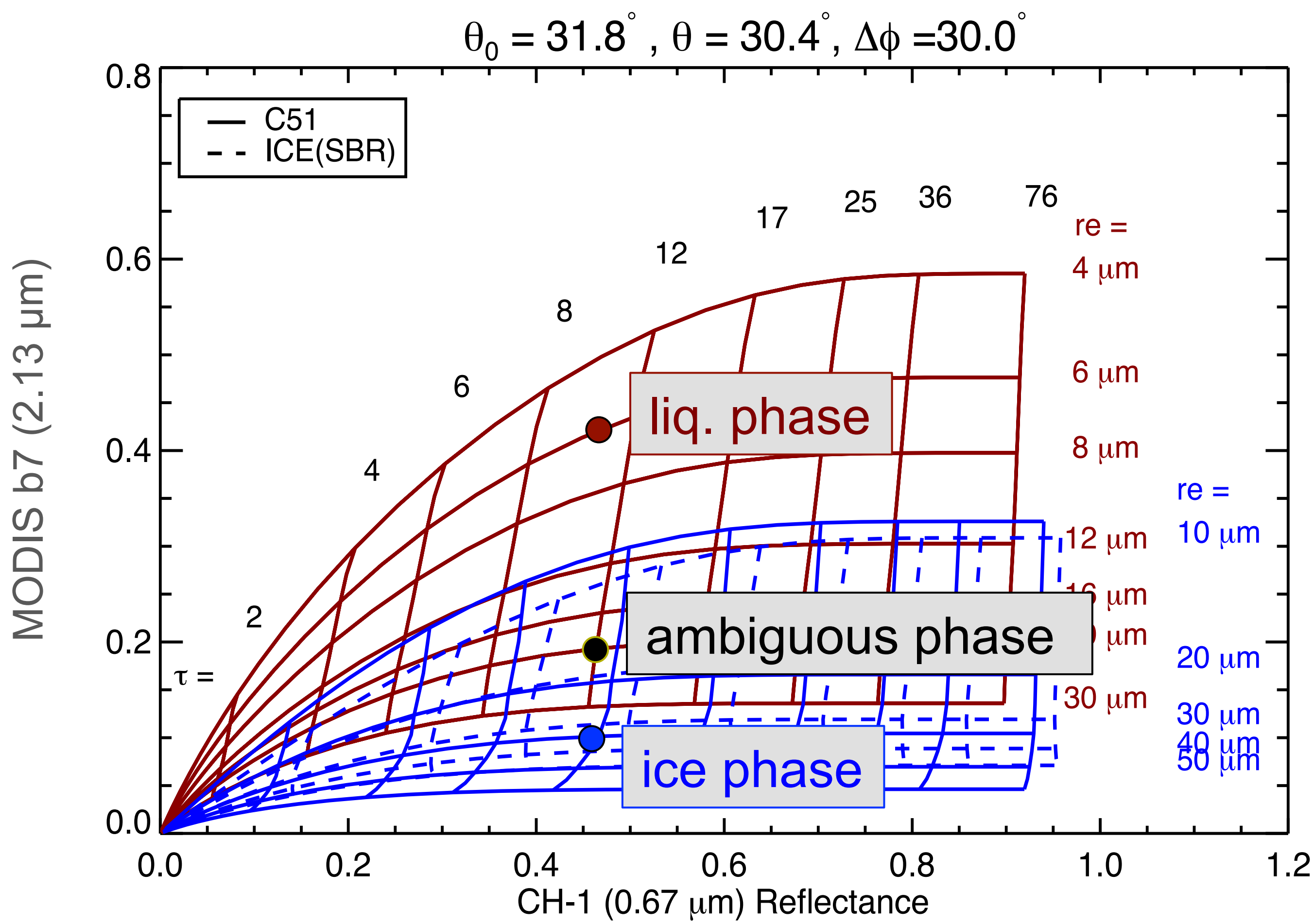
τ, r_e Spectral Reflectance vs. Phase

(MODIS cloud retrieval group)



τ, r_e Solution Space for MODIS & VIIRS Channels

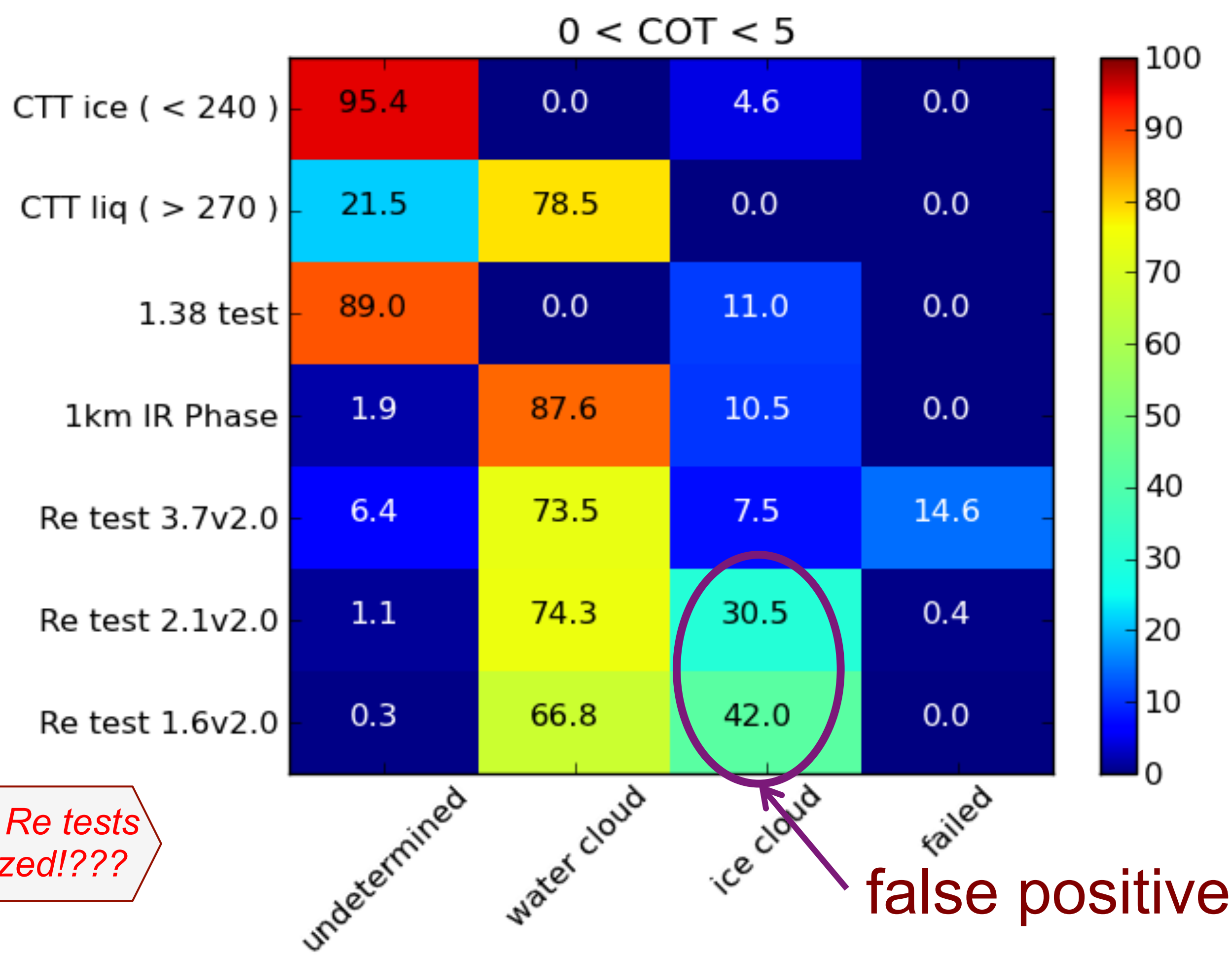
(MODIS cloud retrieval group)



Individual MODIS IR and SWIR Phase Tests vs. CALIOP

(B. Marchant et al.)

CALIOP Phase = liq. water
(ocean, 1 km, w/sfc. detection or opaque layers)



*** Caveat: Re tests not normalized!???

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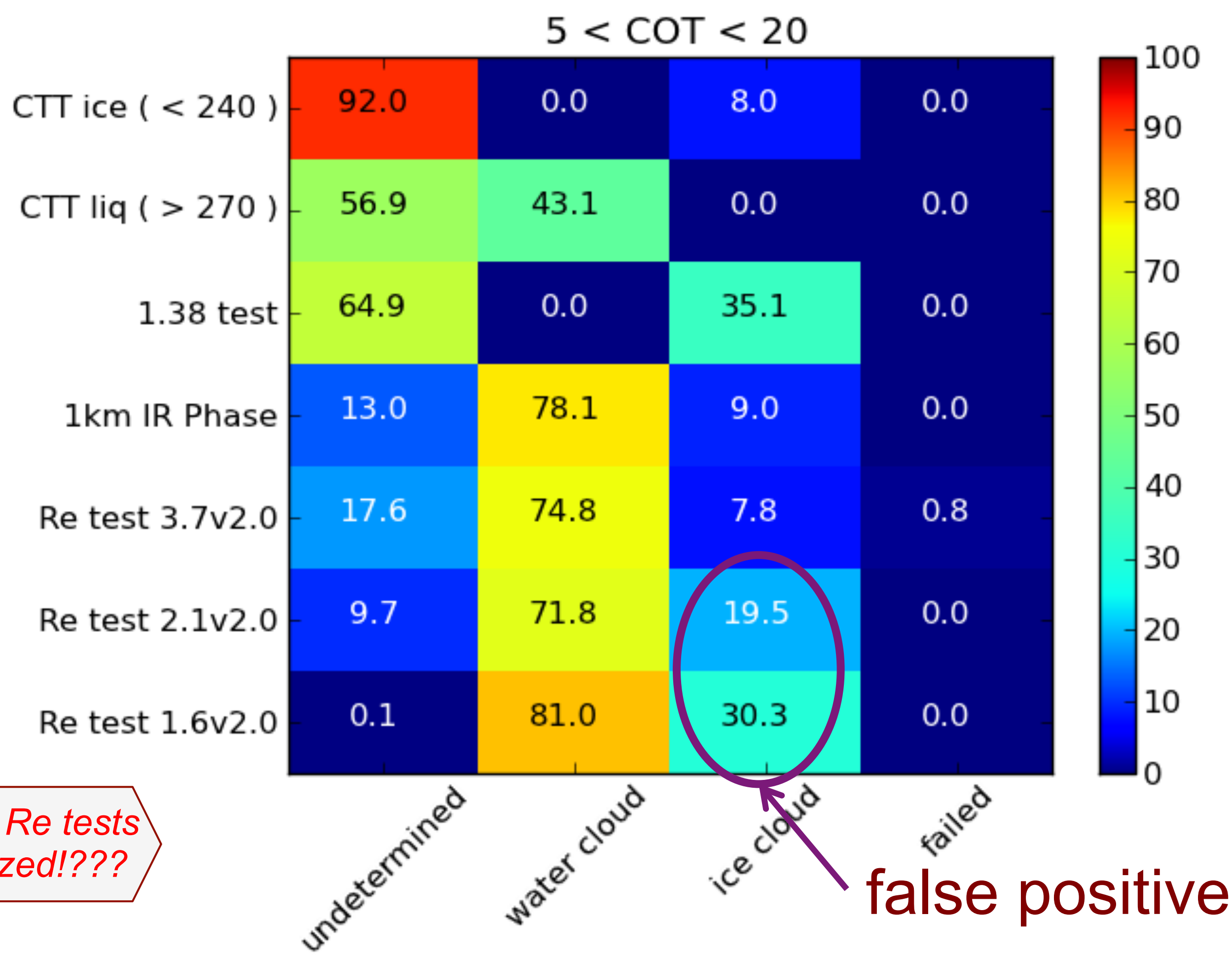
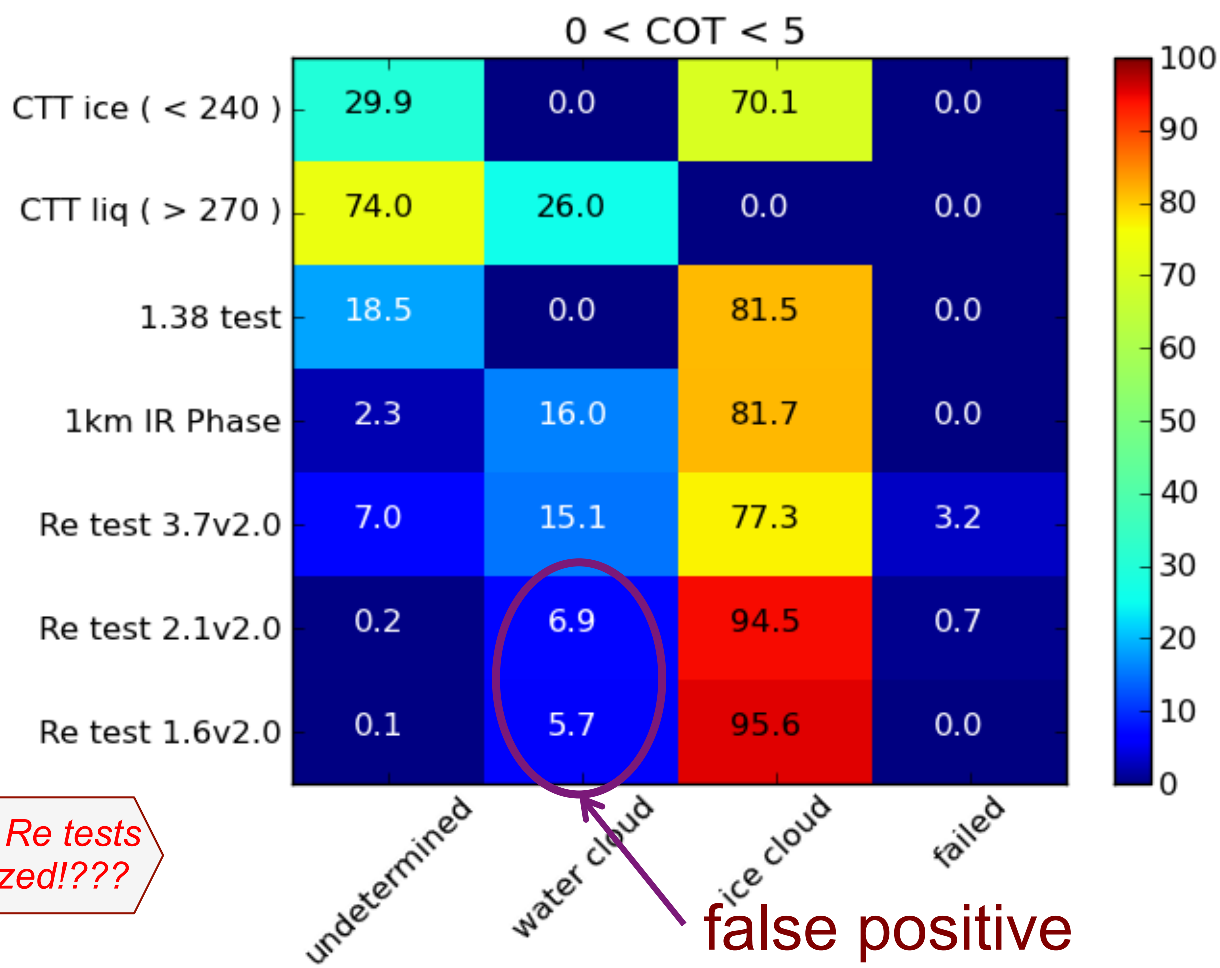


*** Caveat: Re tests not normalized!???*

Individual MODIS IR and SWIR Phase Tests vs. CALIOP

(B. Marchant et al.)

CALIOP Phase = ice
(ocean, 1 km, w/sfc. detection or opaque layers)



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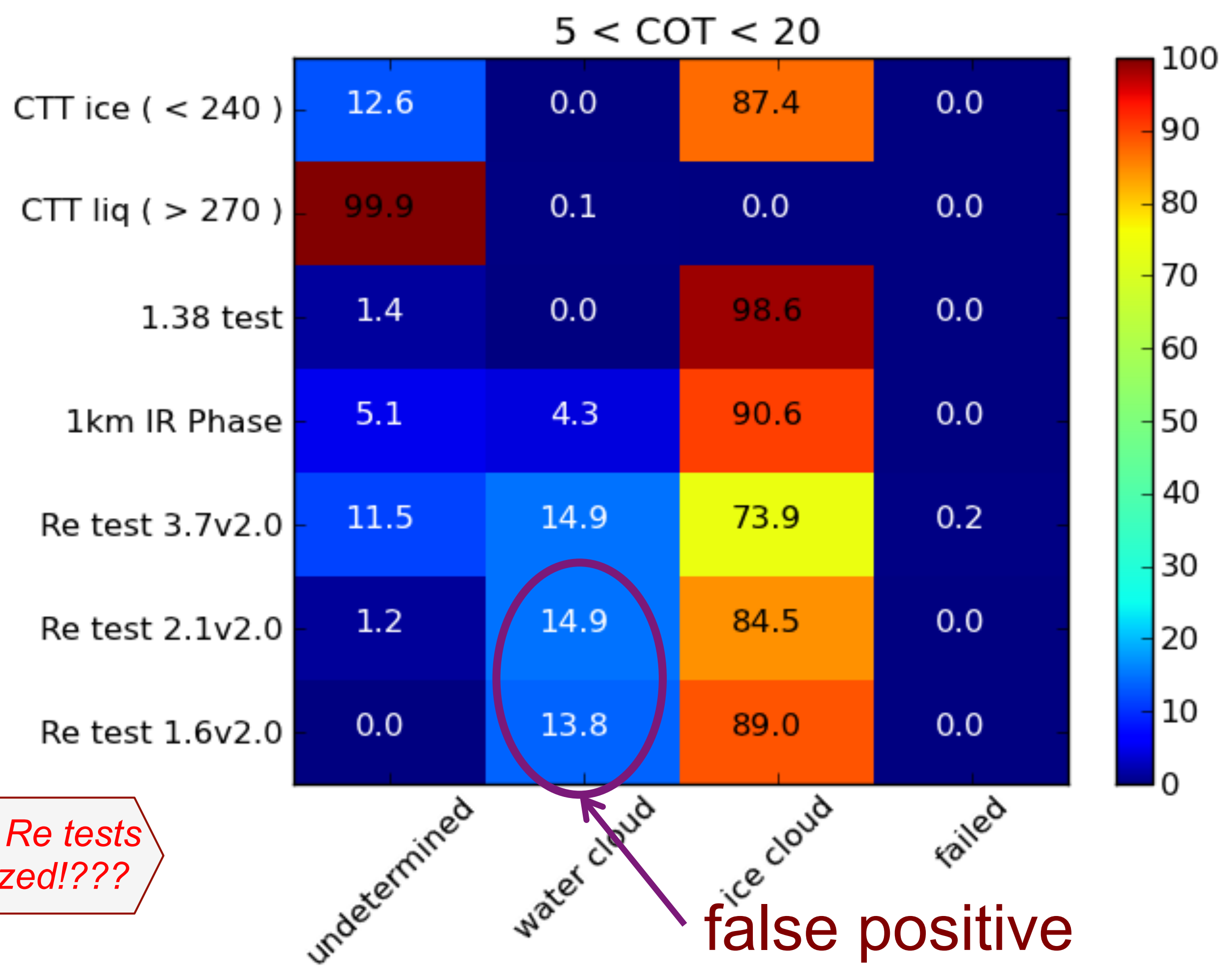
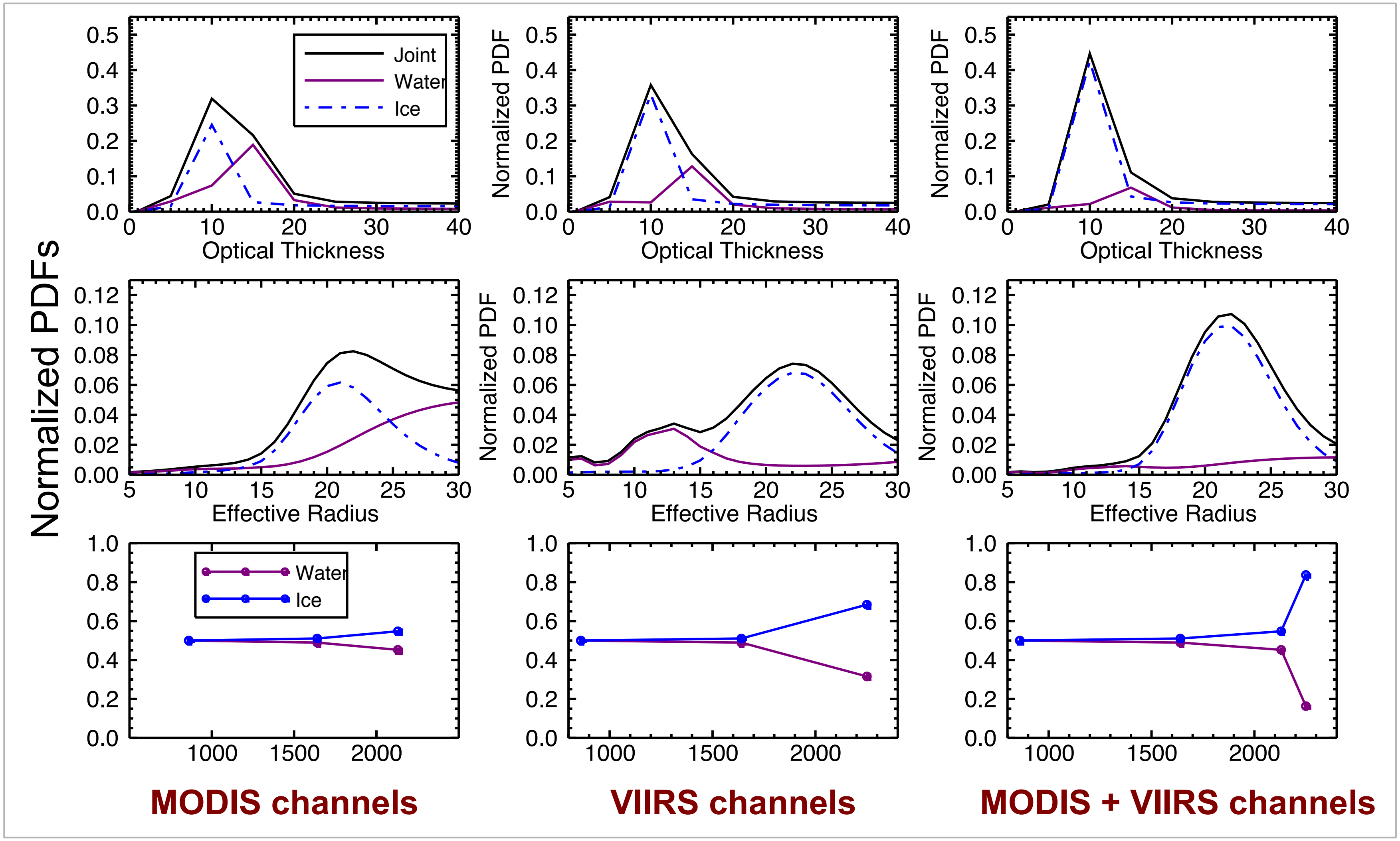


**** Caveat: Re tests not normalized!???*

Shannon Information Content Study

O. Coddington and S. Schmidt (CU/LASP), personal communication

(example: *tau*=10, $r_{e,2.1}$=20 μm, ice phase w/severely roughened Solid Bullet Rosette LUT, meas error=3%, model error=2%; see Coddington et al., 2012 for methodology)



Cloud Phase Summary

- MODIS IR channels provide important skill for phase detection.
- By themselves, MODIS SWIR channels are phase-challenged. The VIIRS 2.25 µm channel expected to provide more skill.
  - If given a sensor that could only have a single 2.1 um window channel, the VIIRS spectral location would be better ...
  - ... but the addition of both the VIIRS and MODIS channels are better than either one alone!
  - Bonus: having both the MODIS (2.13 µm) and VIIRS (2.25 µm) channels allows for r_e continuity with both MODIS and VIIRS.