Bias in MODIS cloud drop effective radius for oceanic water clouds as deduced from measured cloud optical thickness variability across scattering angles

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Background

- For MODIS-VIIRS-type systems, the Nakajima and King (1990)-type retrievals of cloud optical depth (τ) and effective radii (*Re*) remains the state-of-the-art and is rooted in the 1-D RT assumption.
  - Passive retrievals rooted in 3-D RT are decades away for global products

- We have a good handle on random errors under 1-D RT formulation from Platnick *et al.* (2004)… reported in product.
  - These errors match those had by observations for $H\sigma$ ~ 0 (Di Girolamo *et al*. 2010)

- Systematic errors, principally from the breakdown of 1-D RT for heterogeneous clouds, remain largely unknown in any global sense.

3-D RT Simulations

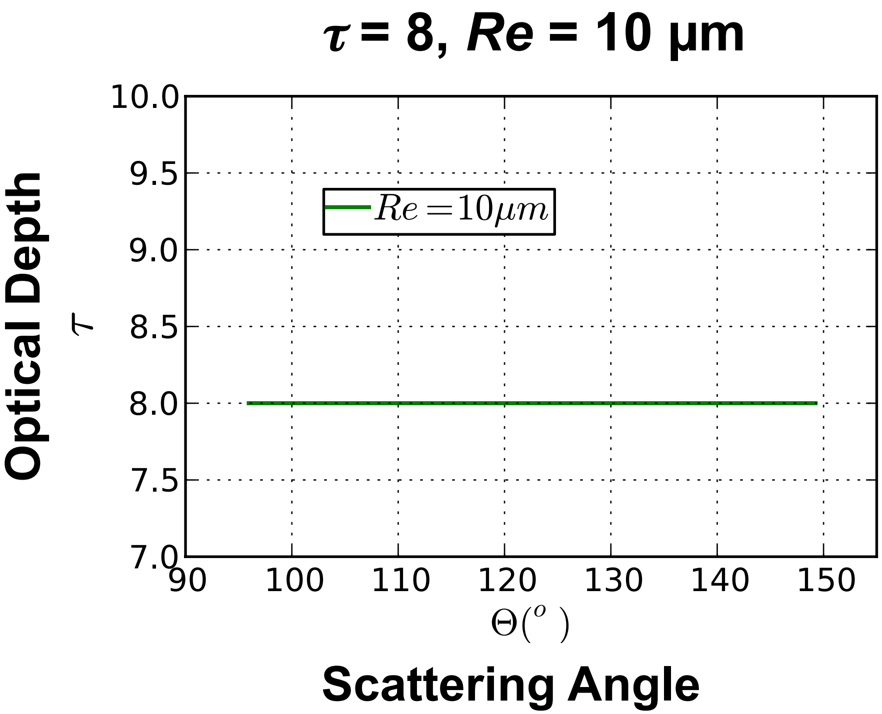
Marshak et al. (2006): *Re* overestimate by ~ factor of 2 are possible

Field Validation

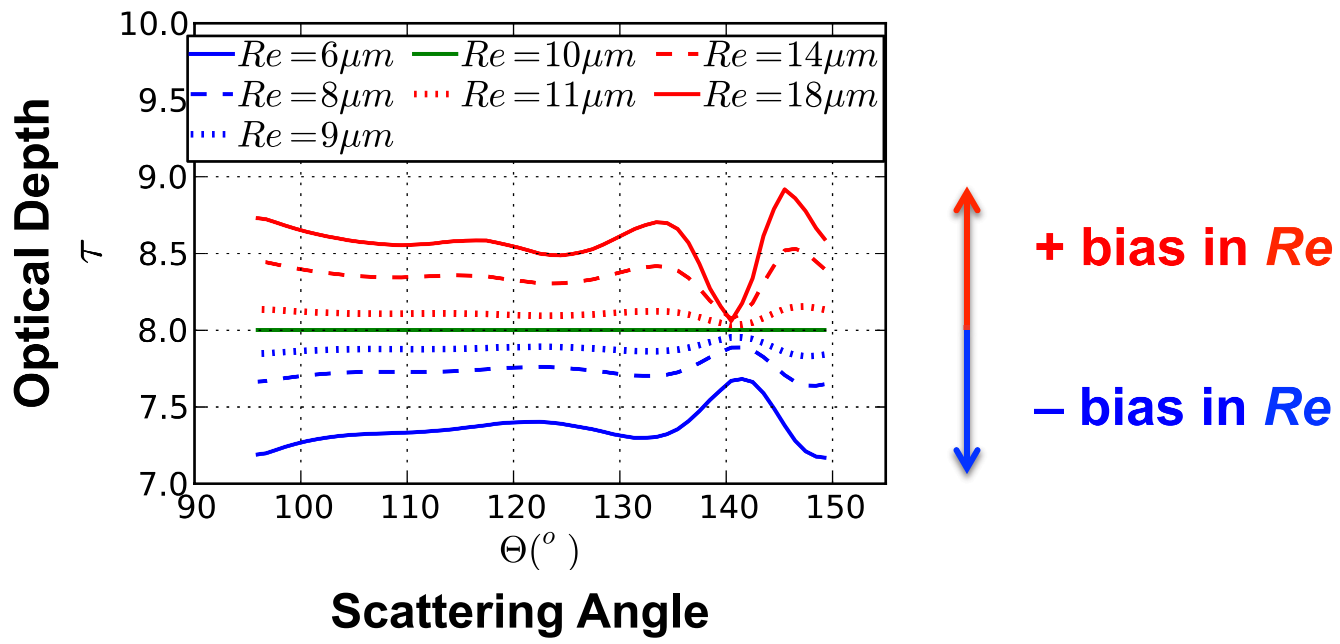
Painemal and Zuidema (2011) *Re* bias ~ +1 to 2 µm Stratocumulus, high sun

Haney (2013) *Re* bias ~ +7 to 12 µm Trade Cumulus, high sun

How do we characterize the *Re* bias over the globe?

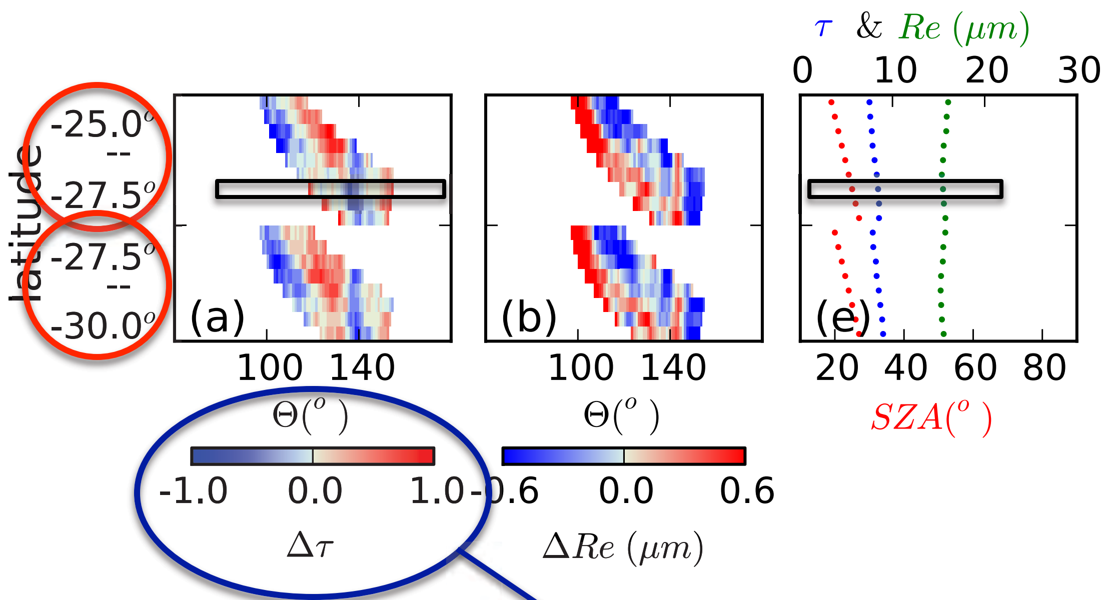


“Rainbow-dips” in the observations would indicate an **overestimate** of the retrieved *Re*



“Rainbow-bumps” in the observations would indicate an **underestimate** of the retrieved *Re*

MODIS Terra: January only, 2001-2012



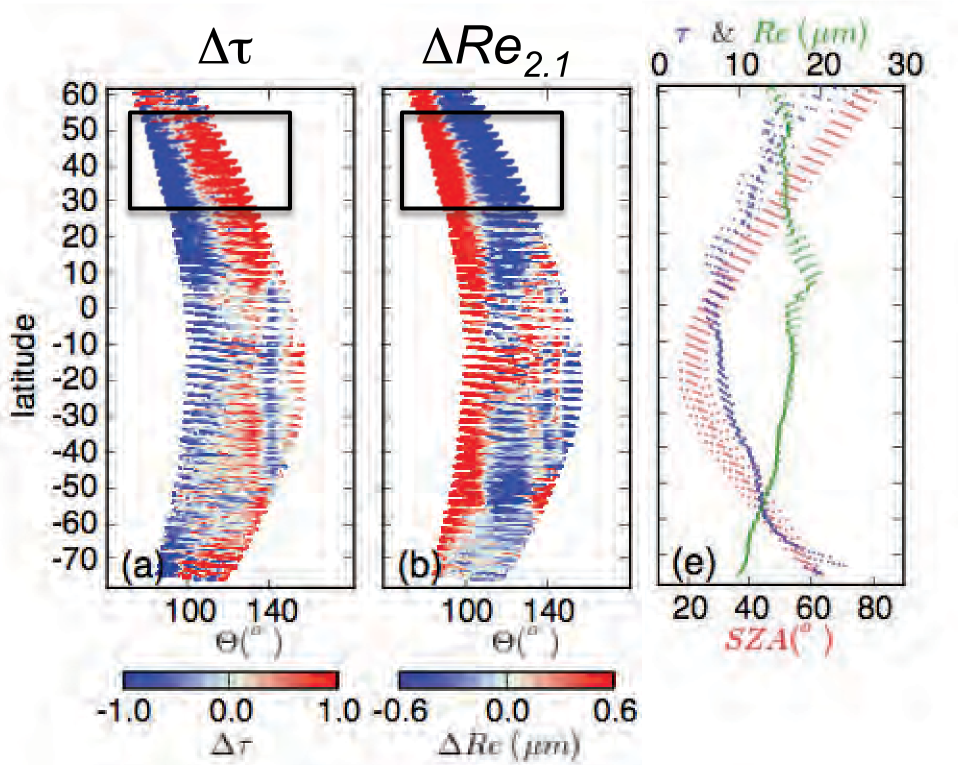
Latitude bins = 2.5°

Solar zenith angle bins = 1°

Δ*x*=*x*-<*x*>

<x> = mean within lat-SZA bin

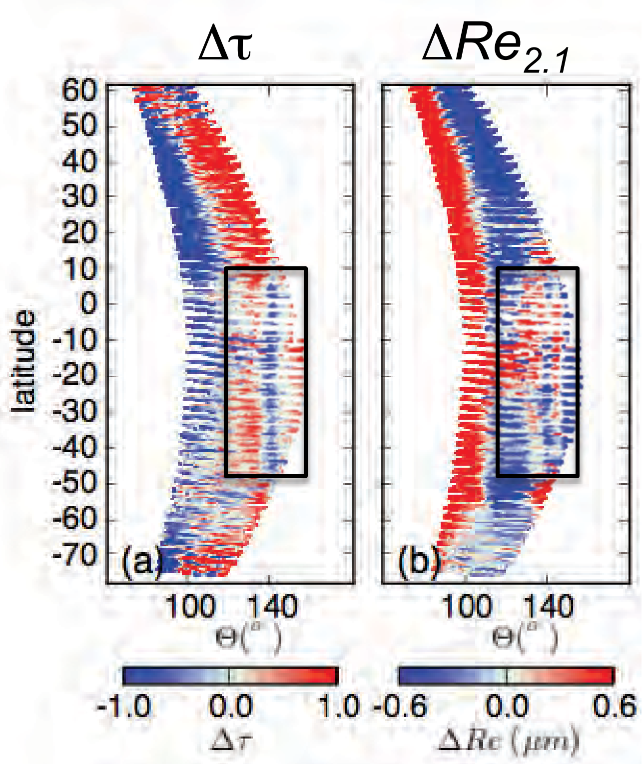
MODIS Terra: January only, 2001-2012

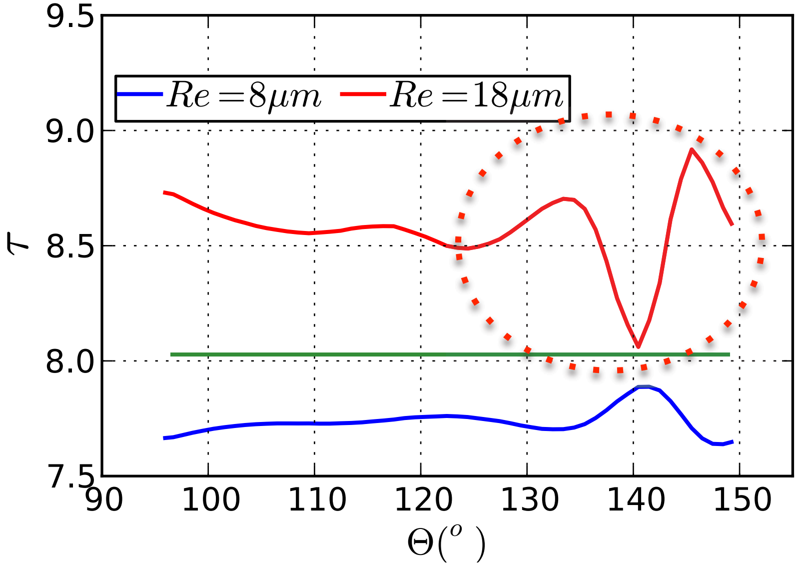


Traditionally interpreted as 3-D effects

Loeb and Coakley (1998)
Varnai and Marshak (2007)
Liang and Di Girolamo (2013)
Horvath et al. (2014)

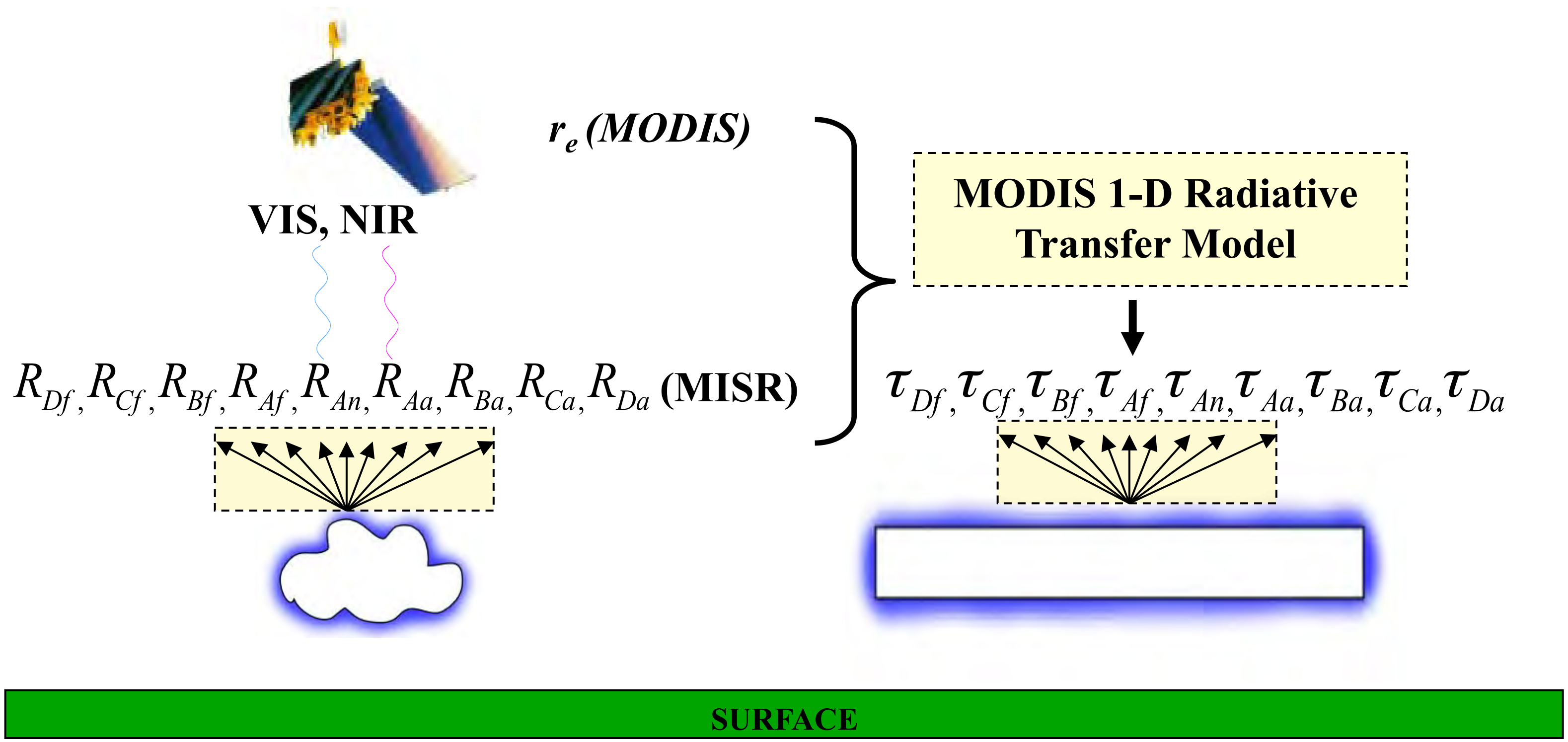
MODIS Terra: January only, 2001-2012





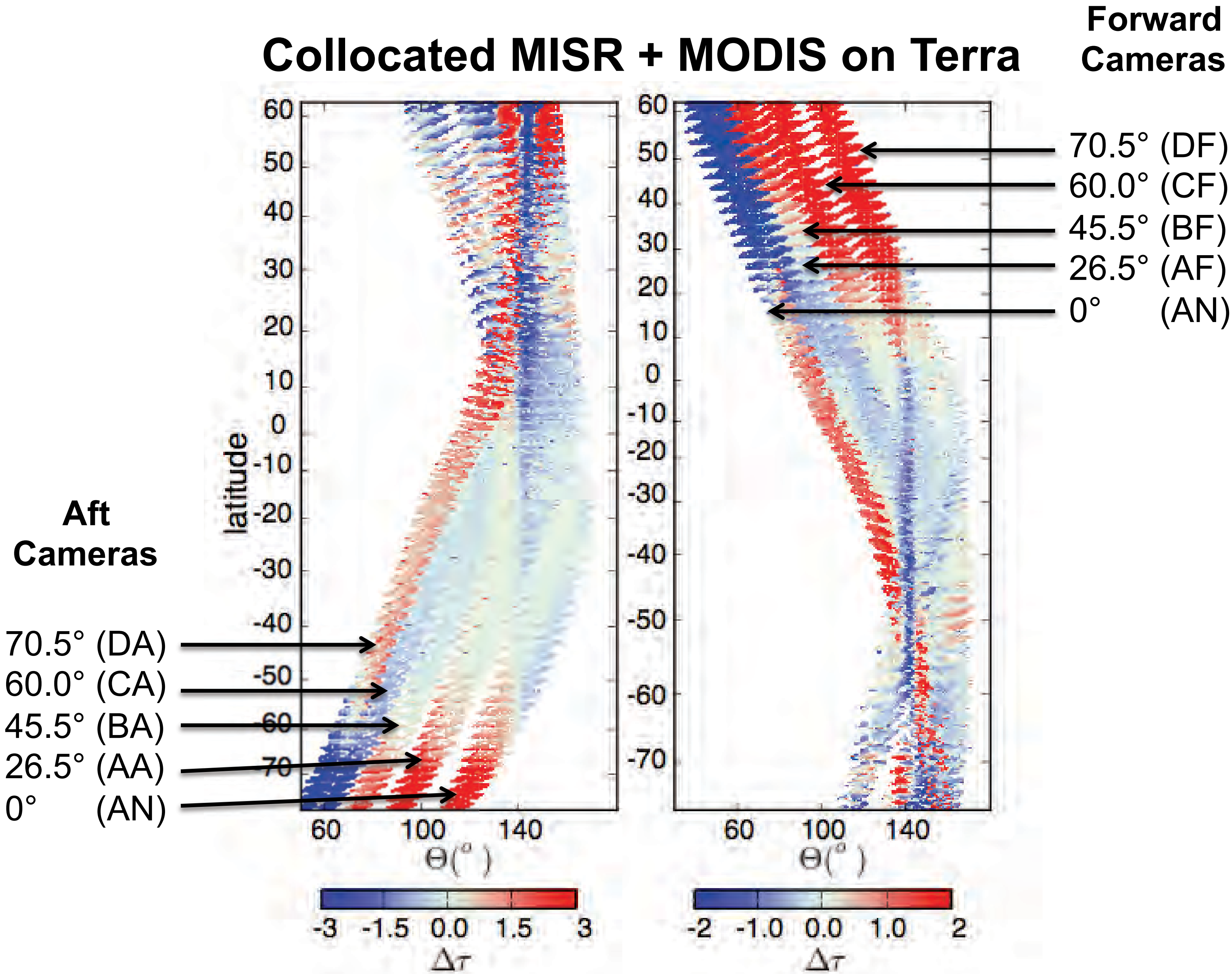
The presence of the "rainbow-dip" unequivocally shows the presence of a positive bias in the MODIS Re2.1 product

Collocated MISR + MODIS on Terra

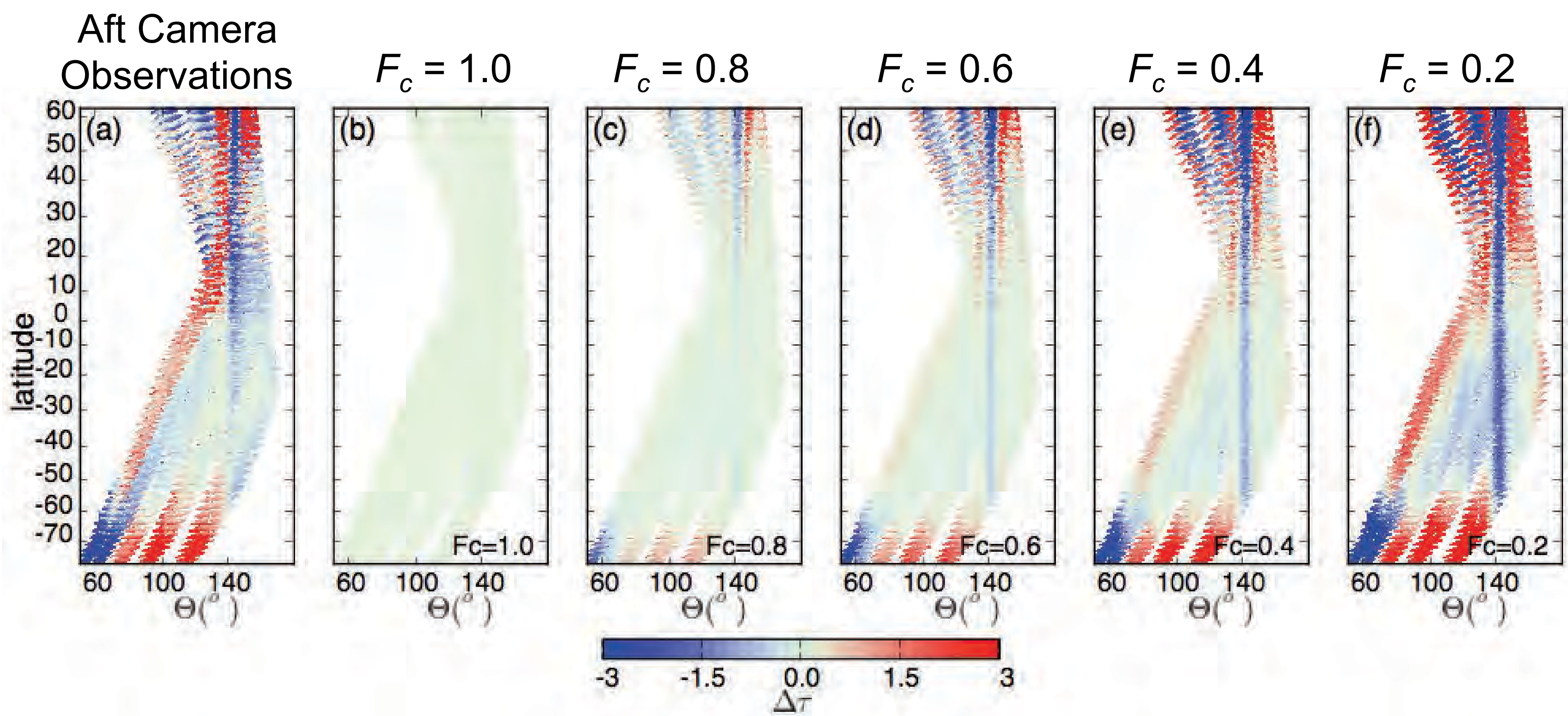


Liang, Di Girolamo, and Platnick, 2009, *Geophys. Res. Lett.*, 36, L09811, doi:10.1029/2008GL037124

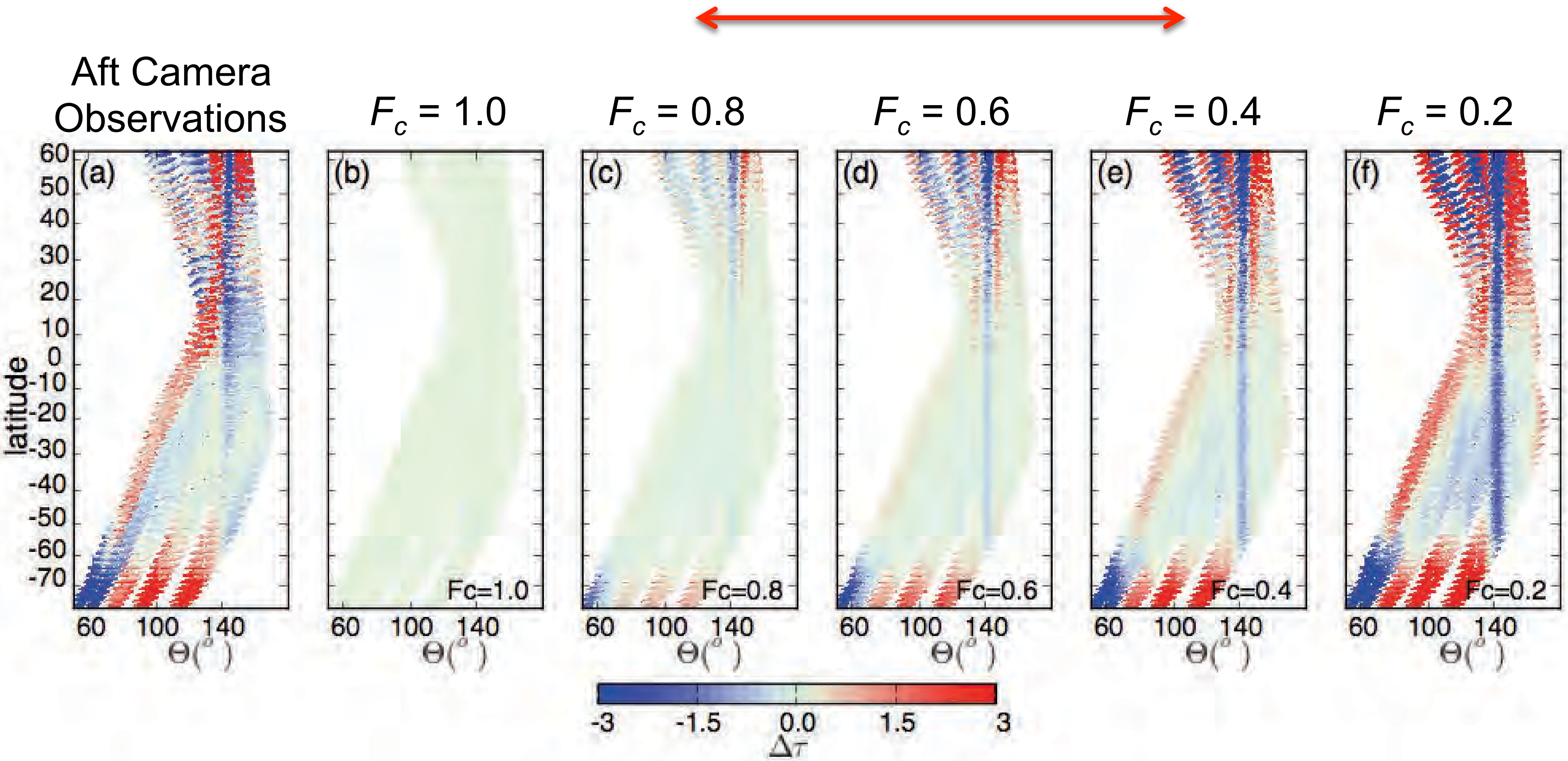
Collocated MISR + MODIS on Terra



- For each SZA-latitude bin, take true τ = mean τ from AN camera
- Assume true $Re = F_c \times Re_{2.1}$
- These are used in 1-D RT calculations to produce 0.866 µm BRFs at the MISR sun-view geometries
- Use these BRFs and $Re_{2.1}$ to retrieve τ



This range of Fc best matches the observations (i.e., a high bias of 20 to 60% in the zonal mean *Re2.1*)



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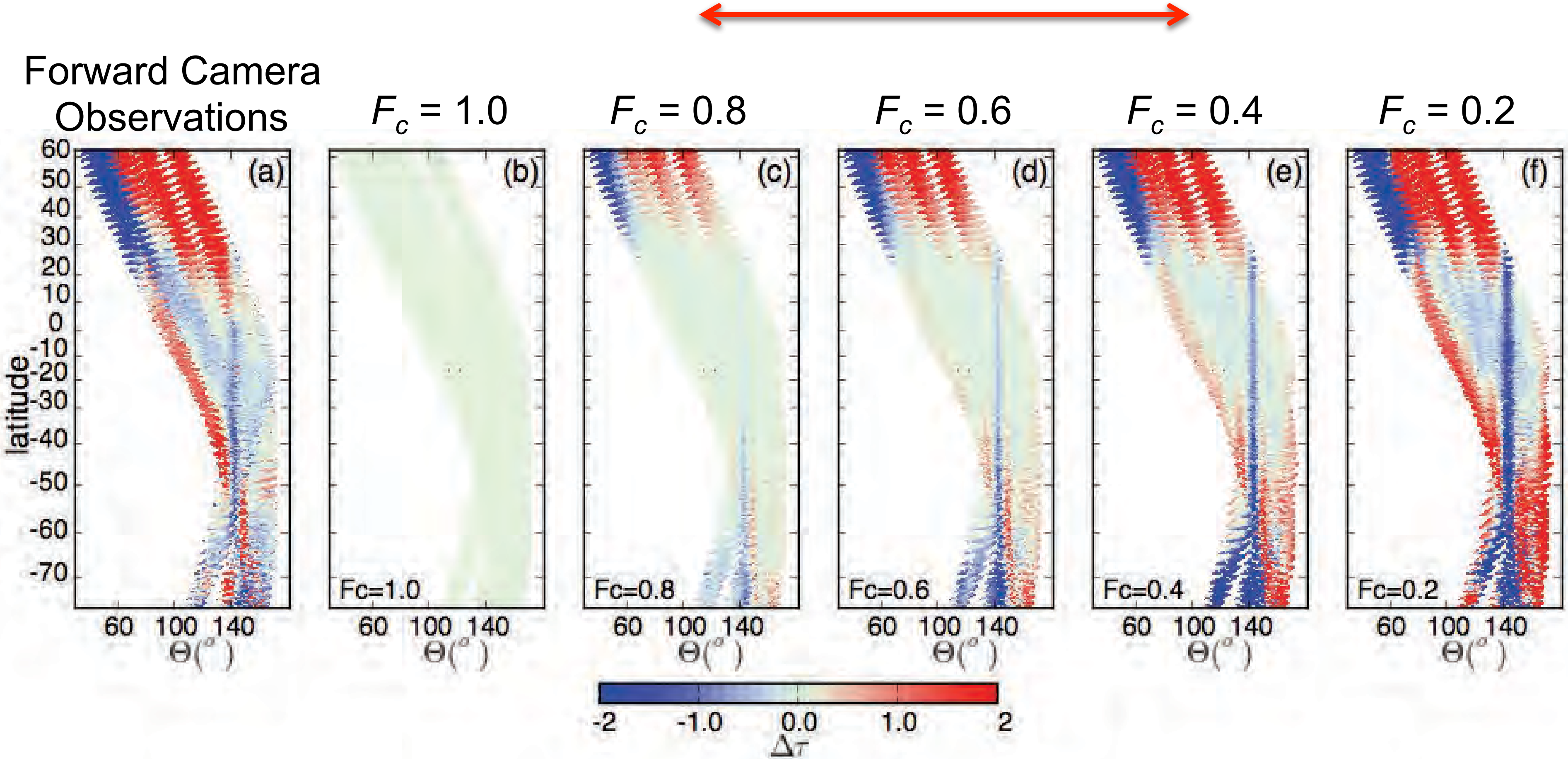
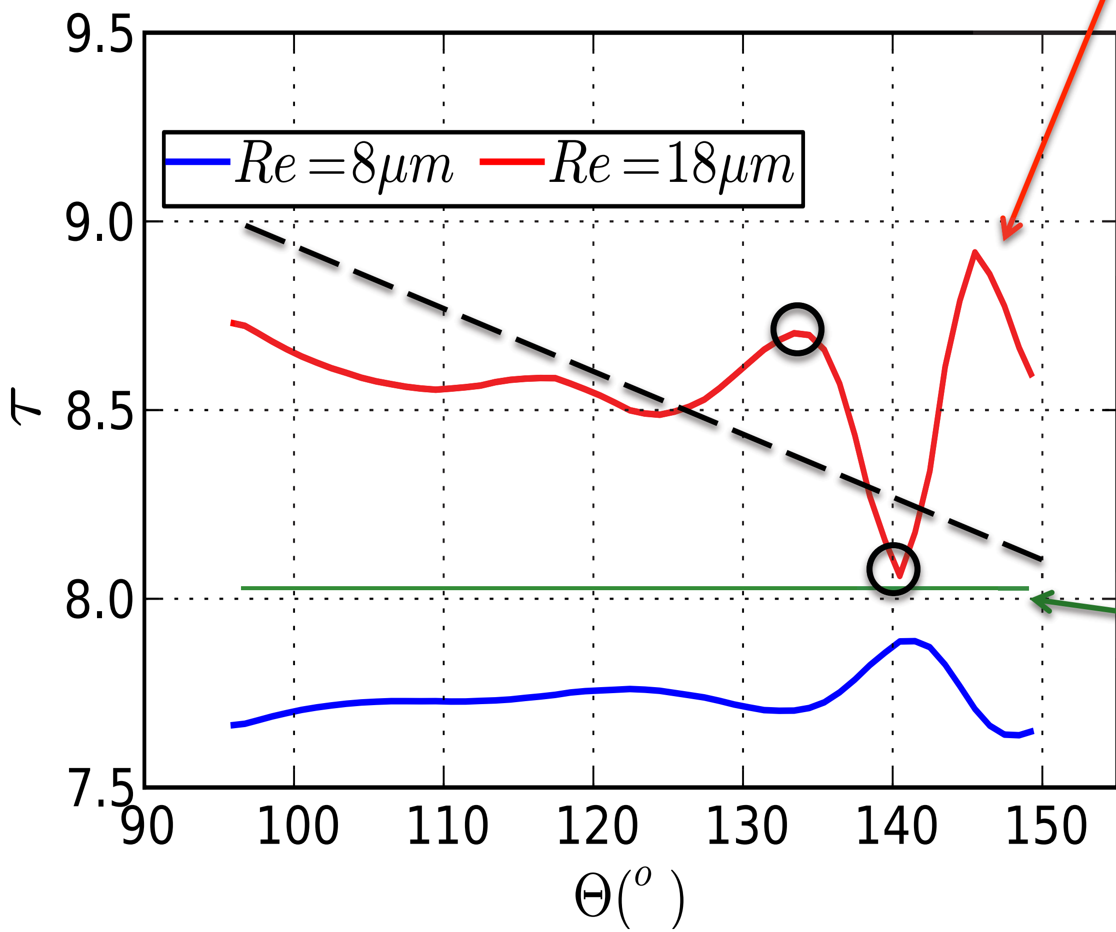


But there's τ variation due to 3D effects!

MISR retrieved τ using MODIS $Re_{2.1}$ = 18 µm



Use $Re = Re_{2.1} \times F_c$

Iterate

F_c = 1.00

F_c = 0.99

F_c = 0.98

.

.

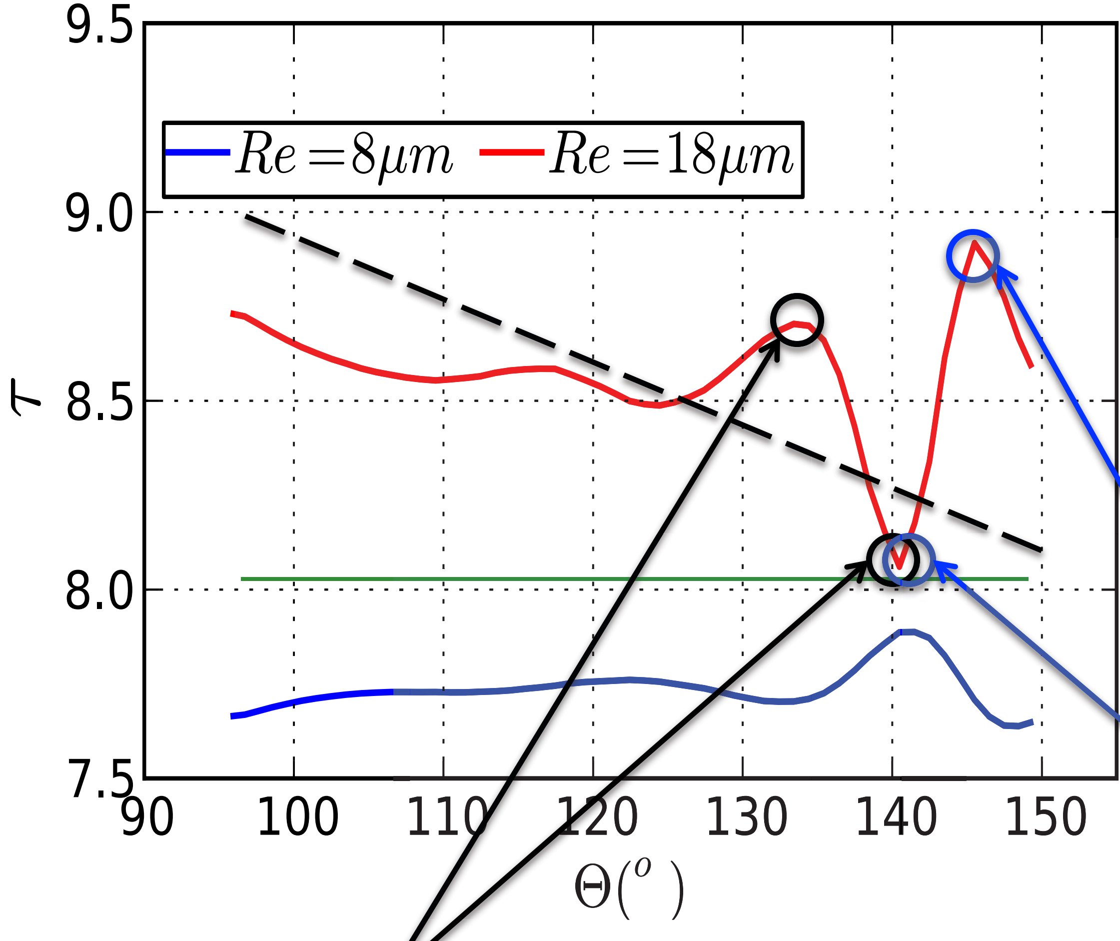
F_c = 0.56

Re = 18 µm x 0.56 = 10 µm

Biased… Argh!!!

Use MISR observations at any two points that are part of the rainbow dip

Fortunately, in many latitude bins, MISR observes both sides of the rainbow dip from multiple camera pairs



So while we can't compute a zonal mean bias in retrieved *Re*, we can put bounds on it

- Amplitude is enhanced by 3D
- Retrieval of F_c biased low
- Overestimate of *Re* bias

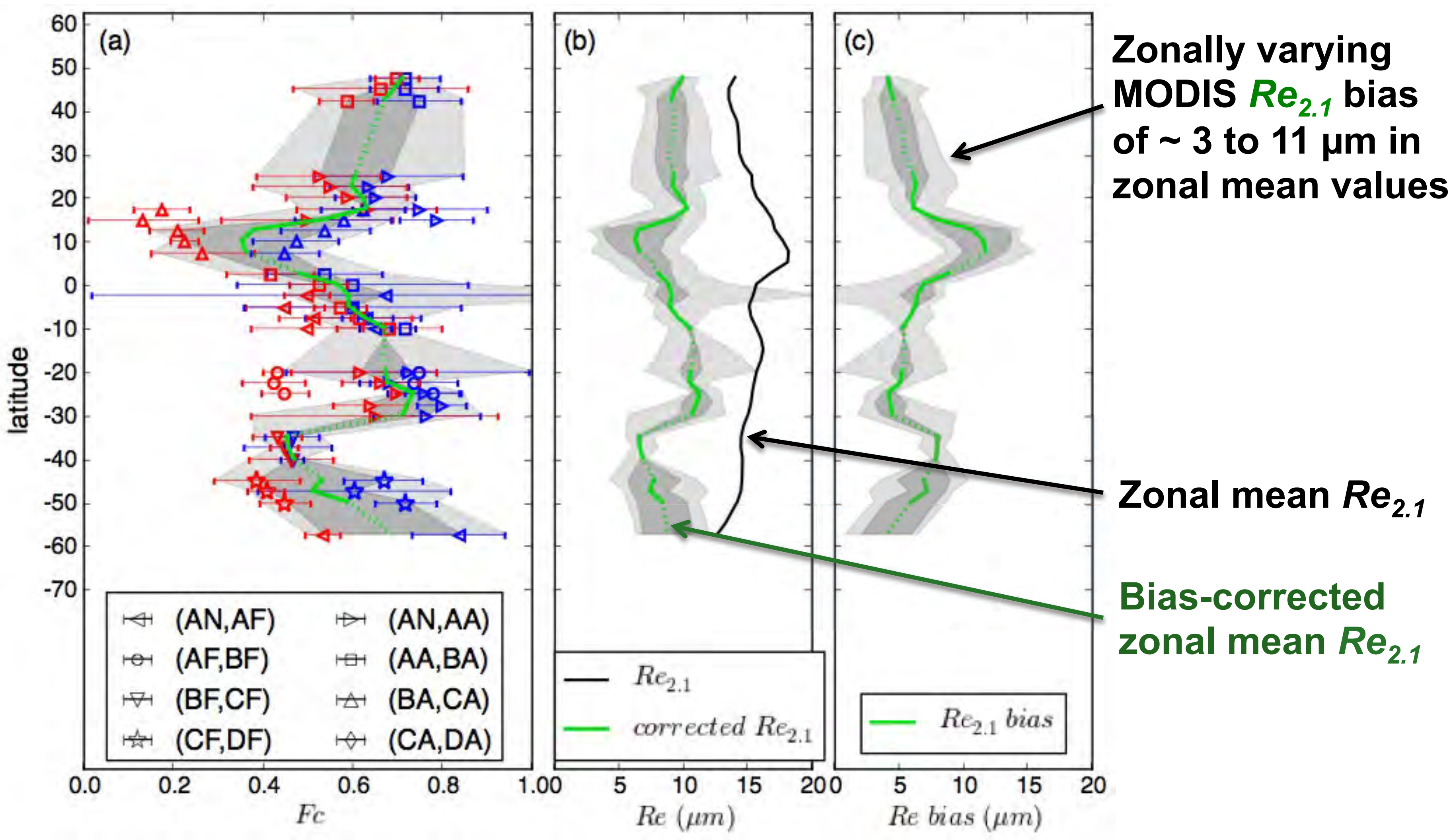
- Amplitude is reduced by 3D
- Retrieval of F_c biased high
- Underestimate of *Re* bias

Red = lower bound of zonal mean Fc computed from all SZA bins within a latitude bin

Blue = upper bound of zonal mean Fc computed from all SZA bins within a latitude bin

Green = midpoint of upper and lower bound

January



F_c Re Re bias

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Blue = upper bound of zonal mean Fc computed from all SZA bins within a latitude bin

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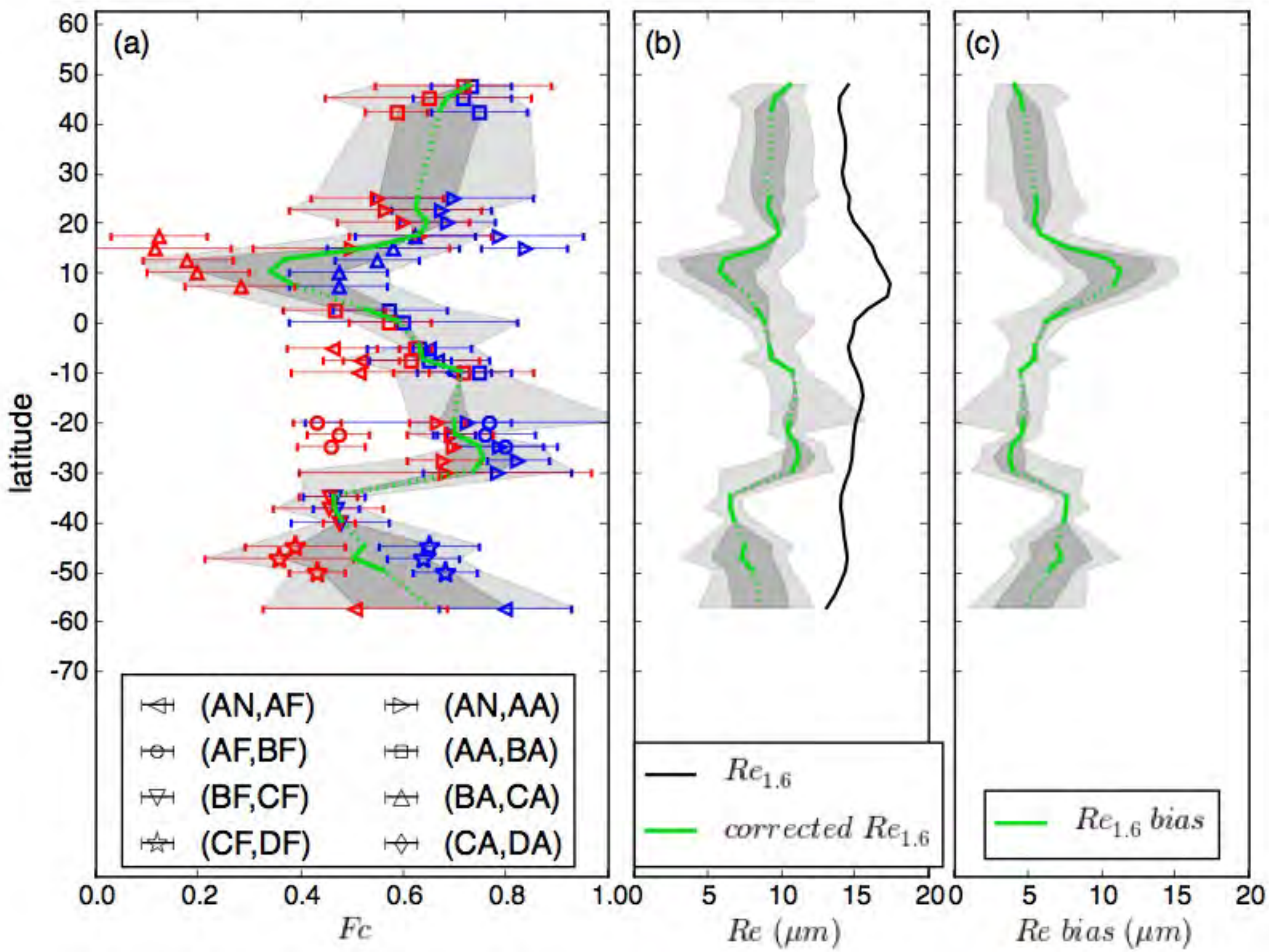
January



Zonally varying MODIS $Re_{1.6}$ bias of ~ 3 to 11 μm in zonal mean values

F_c *Re*   *Re* bias

Red = lower bound of zonal mean Fc computed from all SZA bins within a latitude bin

Blue = upper bound of zonal mean Fc computed from all SZA bins within a latitude bin

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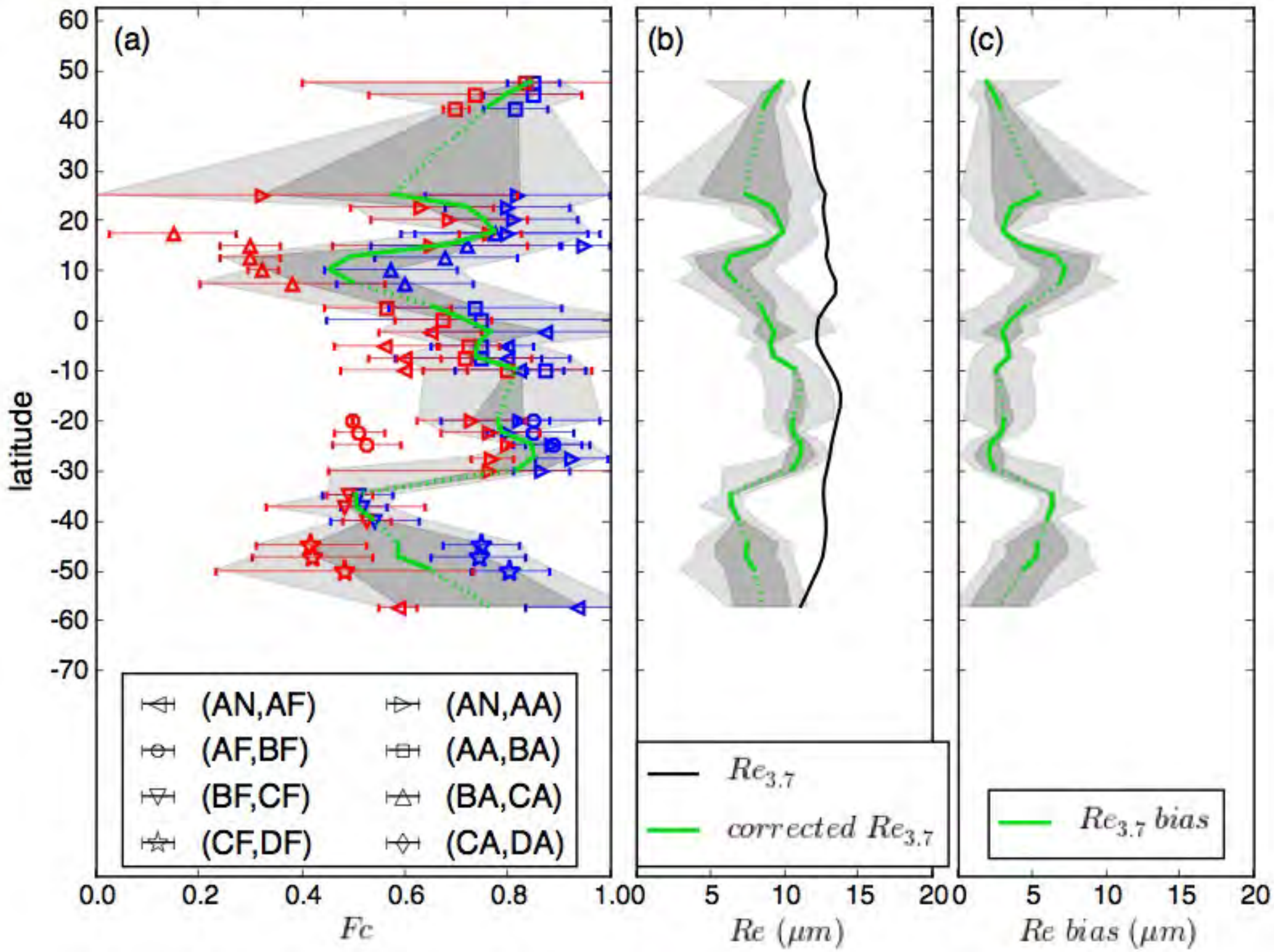
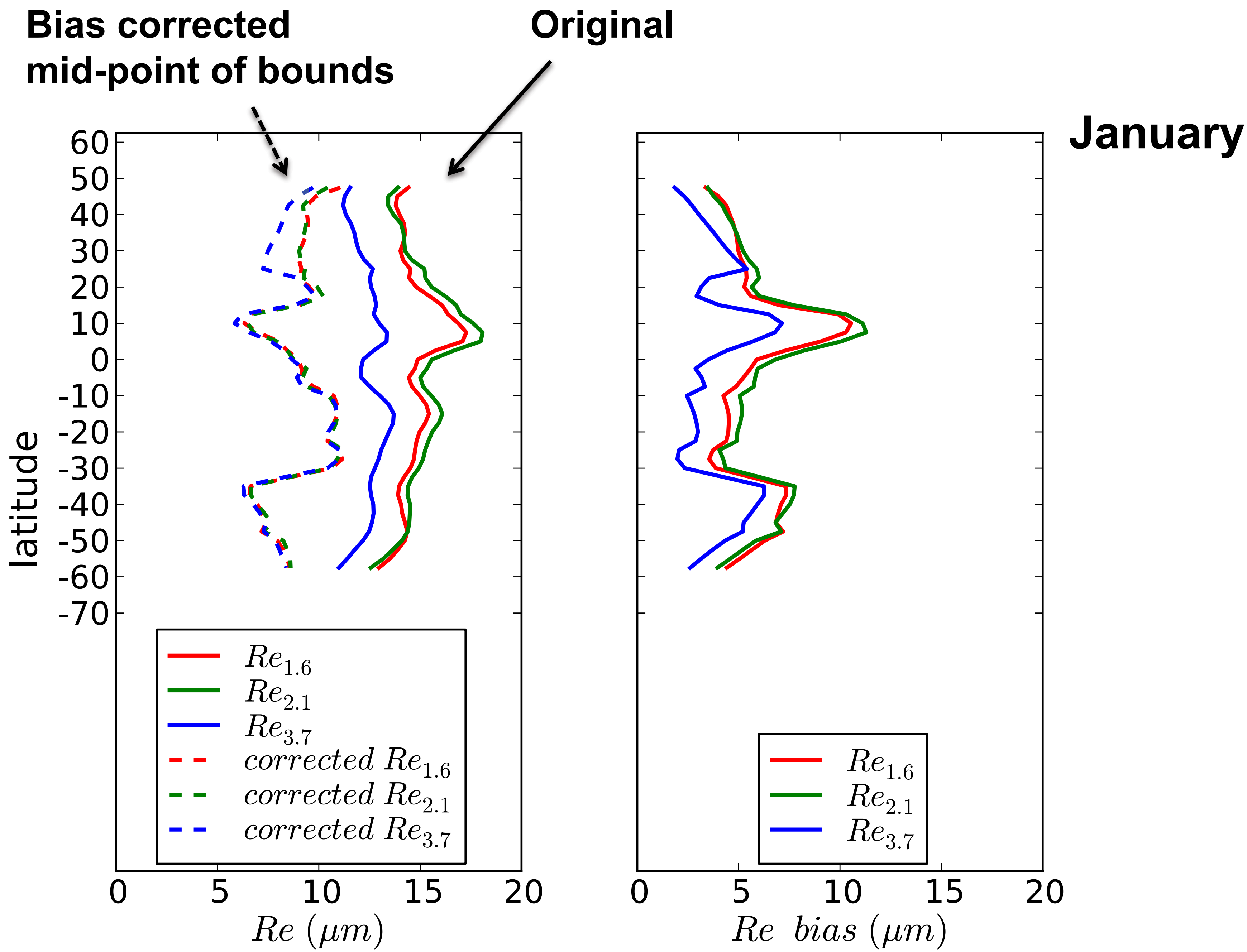
January



F_c Re Re bias

Zonally varying MODIS $Re_{3.7}$ bias of ~ 2 to 7 μm in zonal mean values



Bias corrected
mid-point of bounds
Original
January
latitude
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
0
5
10
15
20
Re (μm)
Re bias (μm)
Re1.6
Re2.1
Re3.7
corrected Re1.6
corrected Re2.1
corrected Re3.7

Summary

- Through MISR-MODIS fusion, we established bounds on the zonally mean bias in the samples of the MODIS-retrieved *Re*

- Midpoints of bounds indicate ~ 3 to 11 µm bias in zonal mean MODIS $Re_{1.6}$, $Re_{2.1}$, $Re_{3.7}$ values (bias of $Re_{3.7} < Re_{2.1} \sim Re_{1.6}$)

- Bias-corrected *Re* channel differences are much smaller than original

- Large meridional differences between original and bias-corrected *Re*

What's Next for MODIS *Re* Bias Correction?

- Quantification that gets at the mean bias rather than its bounds

- New MISR-MODIS fusion (i.e., Terra) product?

- Regress MISR-MODIS retrieved *Re* bias against variables that MODIS can measure (radiances, texture, τ, SZA, etc)… Collection 7?

Thanks!

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Cal Tech/JPL MISR Project

NASA Langley Research Center Atmospheric Sciences Data Center

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