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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For MODIS-VIIRS-type systems, the Nakajima and King (1990)-type retrievals of cloud optical depth ($\tau$) 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 $H\sigma \sim 0$ (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.

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

- 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?

![Graph showing Optical Depth vs. Scattering Angle with $\tau = 8$, $Re = 10 \, \mu m$]
“Rainbow-dips” in the observations would indicate an **overestimate** of the retrieved $Re$.

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+ bias in $Re$
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- bias in $Re$
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“Rainbow-bumps” in the observations would indicate an **underestimate** of the retrieved $Re$.
Latitude bins = 2.5°

Solar zenith angle bins = 1°

$\Delta x = x - \langle x \rangle$

$\langle x \rangle = \text{mean within lat-SZA bin}$
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)
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

Collocated MISR + MODIS on Terra

Aft Cameras
- 70.5° (DA)
- 60.0° (CA)
- 45.5° (BA)
- 26.5° (AA)
- 0° (AN)

Forward Cameras
- 70.5° (DF)
- 60.0° (CF)
- 45.5° (BF)
- 26.5° (AF)
- 0° (AN)
- For each SZA-latitude bin, take true $\tau = \text{mean } \tau$ from AN camera

- Assume $\text{true } Re = F_c \times Re_{2.1}$

- These are used in 1-D RT calculations to produce 0.866 $\mu$m BRFs at the MISR sun-view geometries

- Use these BRFs and $Re_{2.1}$ to retrieve $\tau$
This range of $F_c$ best matches the observations (i.e., a high bias of 20 to 60% in the zonal mean $Re2.1$)
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Use MISR observations at any two points that are part of the rainbow dip.

But there's $\tau$ variation due to 3D effects!

MISR retrieved $\tau$ using MODIS $Re_{2.1} = 18 \, \mu m$

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

Iterate

- $F_c = 1.00$
- $F_c = 0.99$
- $F_c = 0.98$
- $F_c = 0.56$

$Re = 18 \, \mu m \times 0.56 = 10 \, \mu m$

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

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

So while we can’t compute a zonal mean bias in retrieved $Re$, we can put bounds on it.

- 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

Zonally varying MODIS $Re_{2.1}$ bias of ~ 3 to 11 $\mu$m in zonal mean values
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

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

January
Red = lower bound of zonal mean \( F_c \) computed from all SZA bins within a latitude bin
Blue = upper bound of zonal mean \( F_c \) computed from all SZA bins within a latitude bin
Green = midpoint of upper and lower bound

Zonally varying MODIS \( Re_{3.7} \) bias of \( \sim 2 \) to 7 \( \mu \)m in zonal mean values
Bias corrected mid-point of bounds

January
Summary

- Through MISR-MODIS fusion, we established bounds on the zonally mean bias in the samples of the MODIS-retrieved \( R_e \)

- Midpoints of bounds indicate \( \sim 3 \) to \( 11 \) \( \mu \)m bias in zonal mean MODIS \( R_{e1.6}, R_{e2.1}, R_{e3.7} \) values (bias of \( R_{e3.7} < R_{e2.1} \sim R_{e1.6} \))

- Bias-corrected \( R_e \) channel differences are much smaller than original

- Large meridional differences between original and bias-corrected \( R_e \)

What’s Next for MODIS \( R_e \) 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 \( R_e \) bias against variables that MODIS can measure (radiances, texture, \( \tau \), SZA, etc)… Collection 7?
Thanks!

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