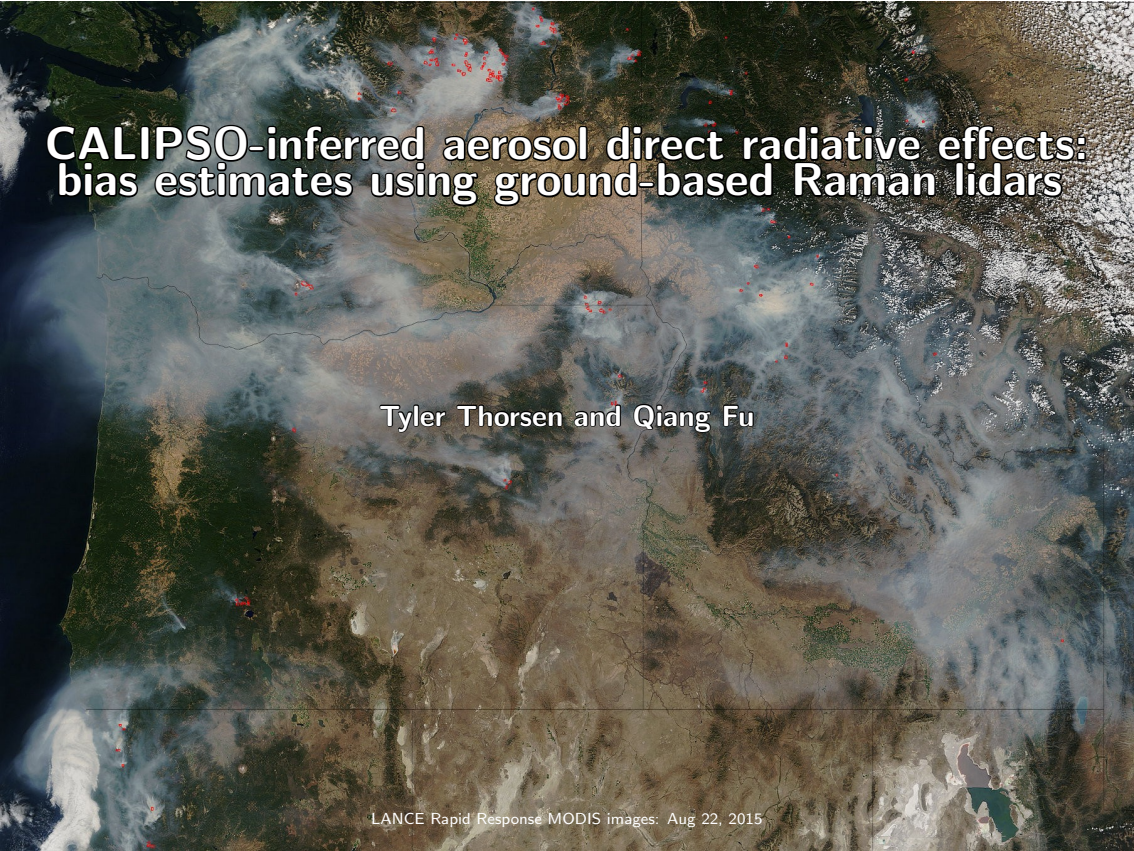
CALIPSO-inferred aerosol direct radiative effects: bias estimates using ground-based Raman lidars

Tyler Thorsen and Qiang Fu



LANCE Rapid Response MODIS images: Aug 22, 2015

Aerosol direct effect (DRE)

- The change in radiative flux caused by the presence of aerosols (both natural and anthropogenic)

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- The change in radiative flux caused by the presence of aerosols (both natural and anthropogenic)
  - How aerosol affects the Earth's radiation balance in the present climate
  - Evaulate how GCMs represent aerosol chemistry, transport and radiative properties (e.g. Kinne JGR 2003)
  - Estimation of aerosol radiative forcing (i.e. anthropogenic aerosols) (Bellouin et al. Nature 2005, Kaufman GRL 2005, Su et al. JGR 2013)

Satellite estimates of aerosol DRE

- Many estimates of the shortwave (SW) aerosol DRE have been made using passive remote sensors (Yu et al. ACP 2006 and references therein)
  - Longwave aerosol DRE is usually much smaller
  - Mostly MODIS-based

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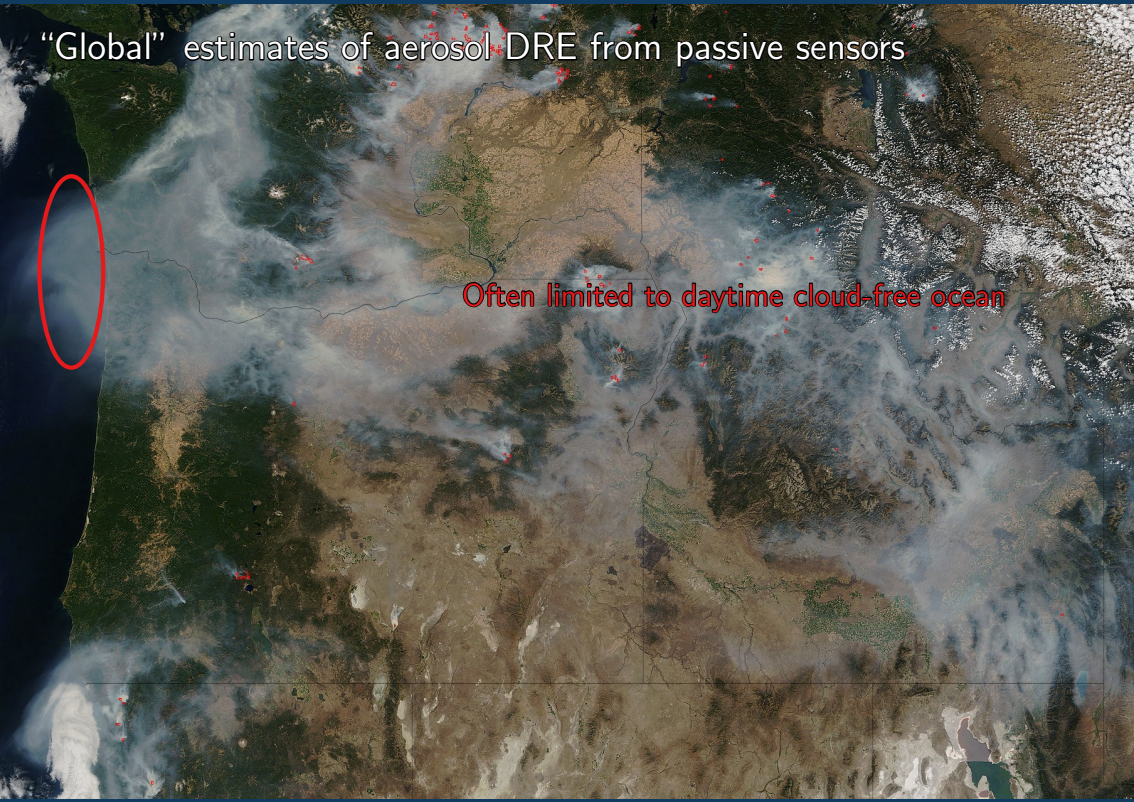
  - Longwave aerosol DRE is usually much smaller
  - Mostly MODIS-based
- The global-mean SW aerosol DRE at the TOA is about $-5.0\ Wm^{-2}$
  - The presence of aerosols increases the amount of reflected SW by 5.0 Wm^{-2}

"Global" estimates of aerosol DRE from passive sensors



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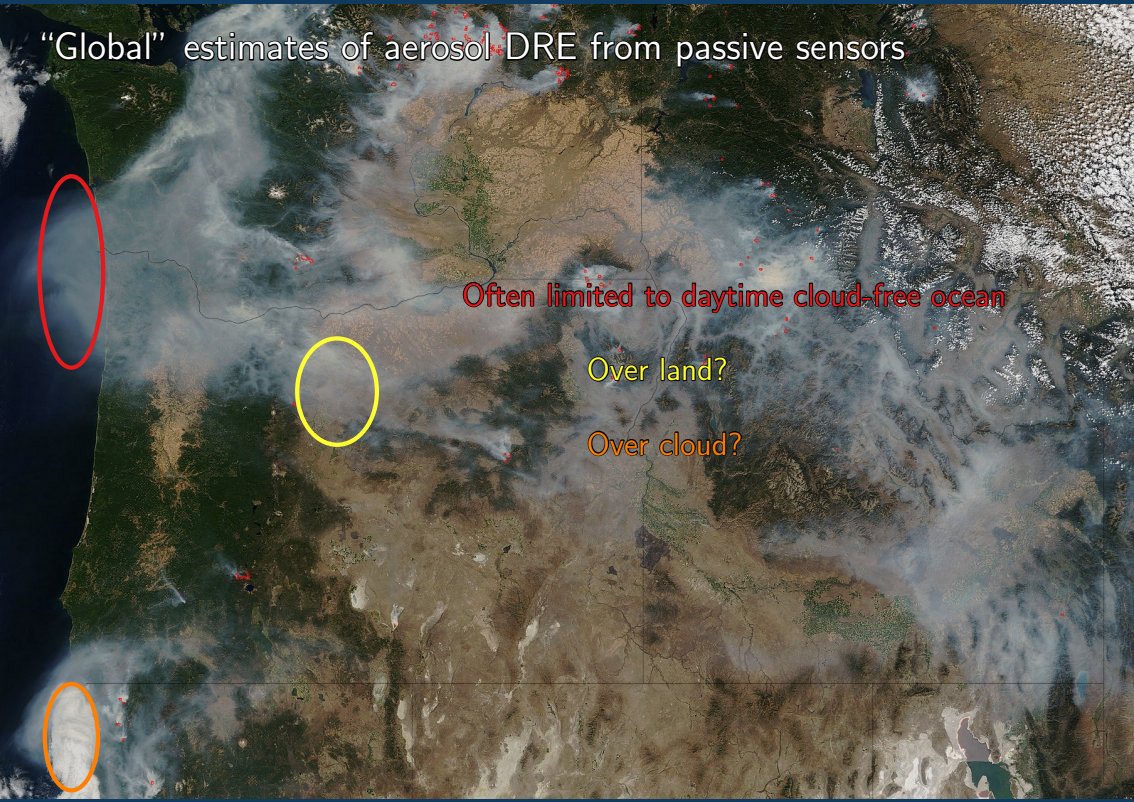

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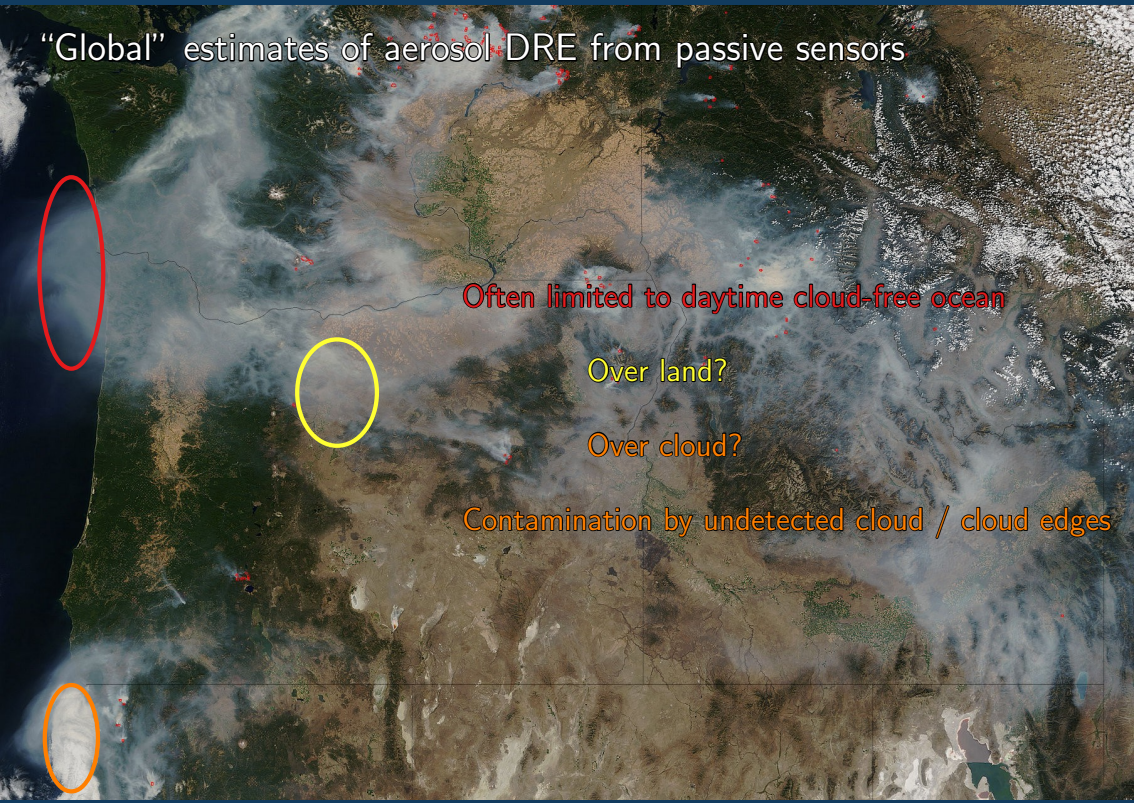

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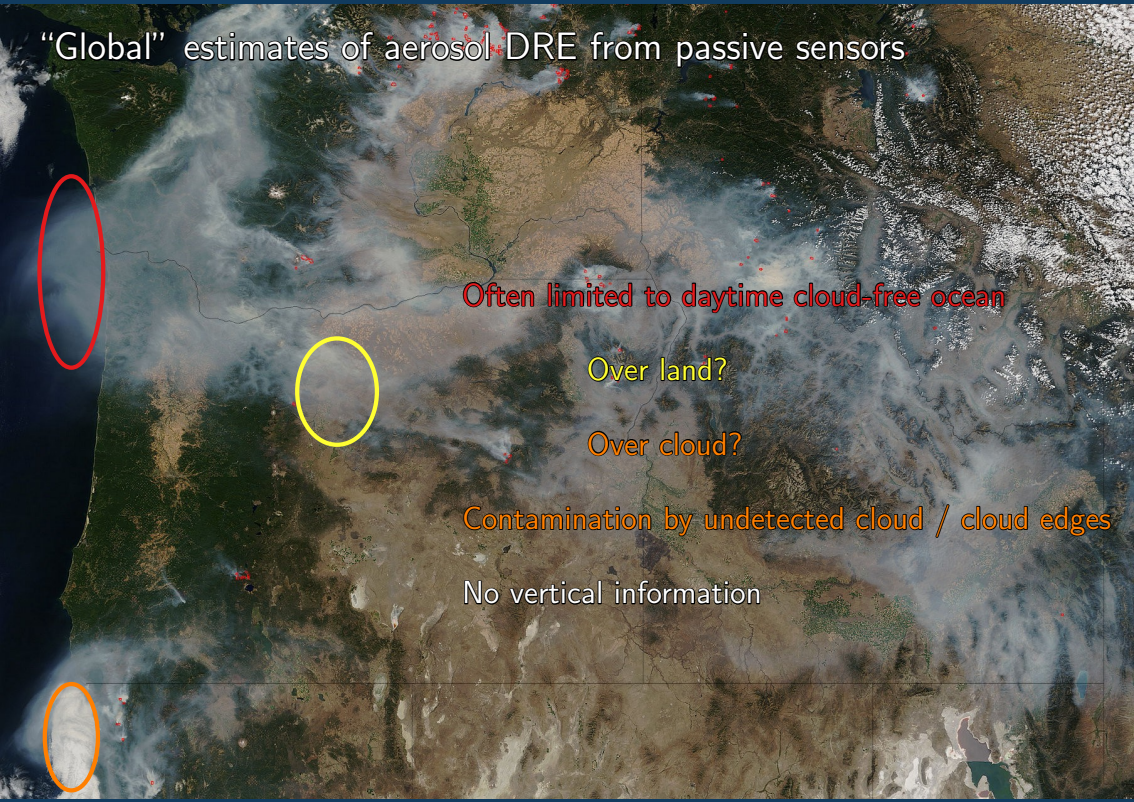

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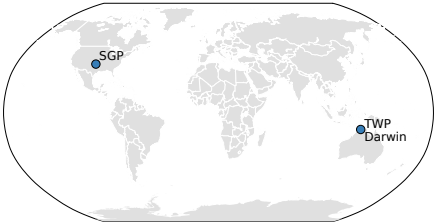
Assess CALIPSO's capabilities for deriving the aerosol DRE to better understand this discrepancy

Evaluating CALIPSO

ARM Raman lidars (RL)



Evaluating CALIPSO

1. Radiative flux → aerosol extinction → assumed lidar ratio (ratio of extinction-to-backscatter)

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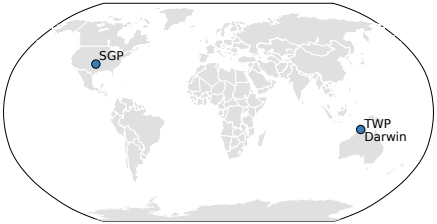


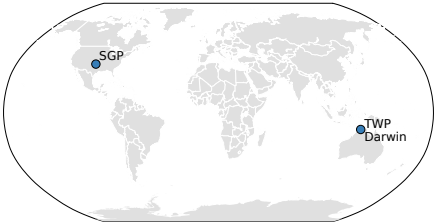
1. Direct extinction measurements

(no critical assumptions)

Evaluating CALIPSO

1. Radiative flux → aerosol extinction → assumed lidar ratio (ratio of extinction-to-backscatter)
2. Is all radiatively-significant aerosol detected? (Kacenelenbogen et al. 2014, Rogers et al. 2014, Thorsen et al. 2015)

ARM Raman lidars (RL)



1. Direct extinction measurements (no critical assumptions)
2. Strong signals from aerosols (it's closer)

Methodology

- Collocate ($\pm$200 km, $\pm$2 hr) CALIPSO aerosol products (VFM, ALay) and ARM RL-FEX product over a 5 year period at SGP, 4 year period at TWP

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- Collocate ($\pm$200 km, $\pm$2 hr) CALIPSO aerosol products (VFM, ALay) and ARM RL-FEX product over a 5 year period at SGP, 4 year period at TWP
- Calculate aerosol DRE using the NASA Langley Fu-Liou radiative transfer model:

$$DRE^{\uparrow}(TOA) = F^{\uparrow}_{\text{aerosol}}(TOA) - F^{\uparrow}_{\text{no aerosol}}(TOA)$$

$$DRE^{\downarrow}(SFC) = F^{\downarrow}_{\text{aerosol}}(SFC) - F^{\downarrow}_{\text{no aerosol}}(SFC)$$

- Modify RL retrievals to mimic CALIPSO to test effect of ❶ lidar ratio assumptions and ❷ detection sensitivity

Effect of assumed lidar ratios

- Detect $\rightarrow$ cloud/aerosol $\rightarrow$ 6 aerosol subtypes $\rightarrow$ lidar ratio $\rightarrow$ extinction $\rightarrow$ flux

Effect of assumed lidar ratios

- Detect → cloud/aerosol → 6 aerosol subtypes → lidar ratio → extinction → flux

Perform a CALIPSO-like retrieval using the RL with 3 types of lidar ratio averages

1. "Profile": single vertical-mean in each profile

   (majority of CALIPSO profiles contain a single aerosol type)

2. "Overpass": single temporal- and vertical-mean in each collocated overpass

   (majority of aerosol in an overpass is a single type)

3. "Climo": single climatological value

   (50.08 sr at SGP and 40.26 sr at TWP)

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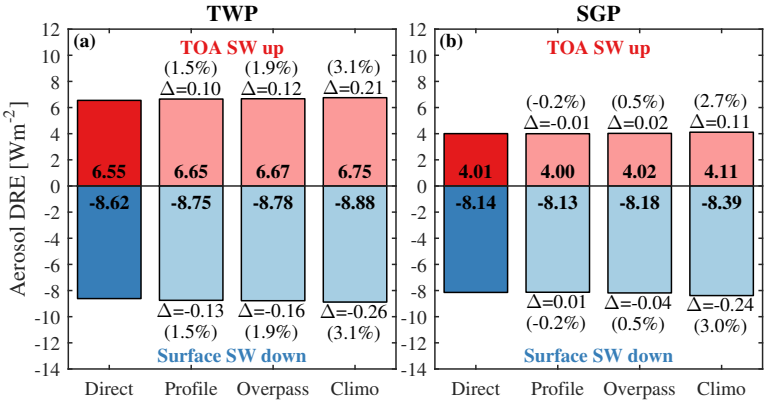

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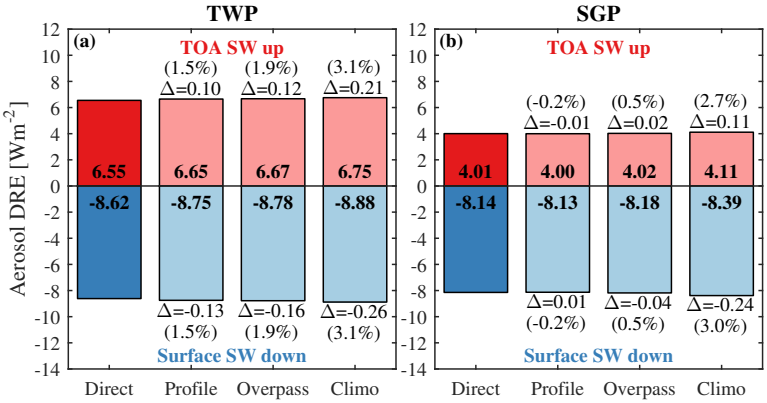
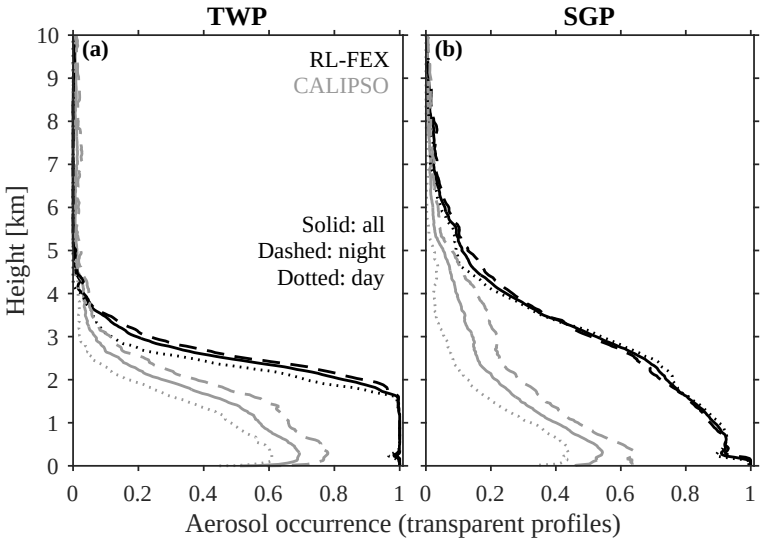


Lidar ratio assumptions introduce minimal error in CALIPSO-inferred mean aerosol DRE

Detection sensitivity



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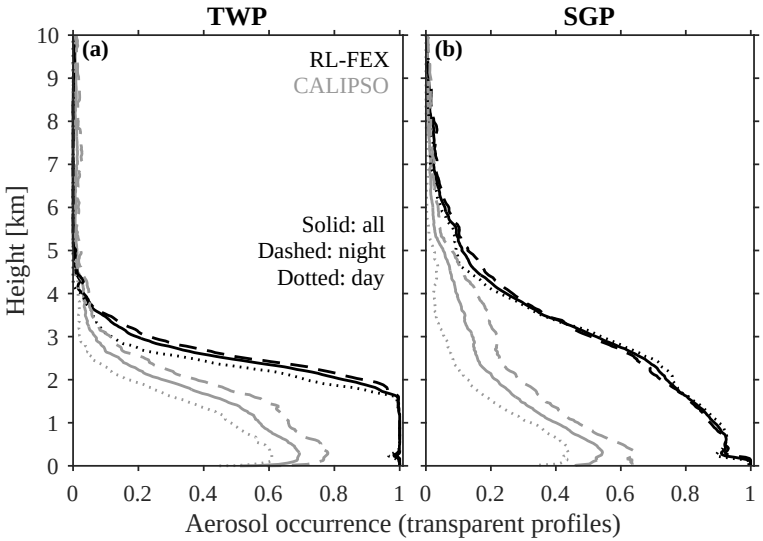

Is this undetected aerosol radiatively-significant?

Effect of detection sensitivity

- In each collocated overpass: force RL aerosol occurrence profile to match CALIPSO's by removing aerosol
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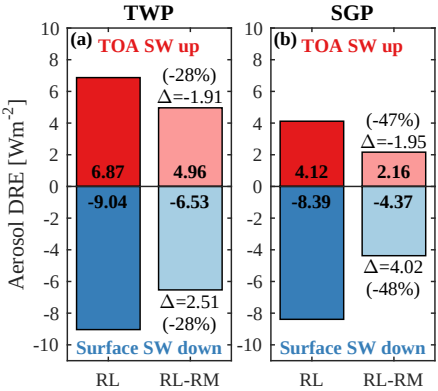

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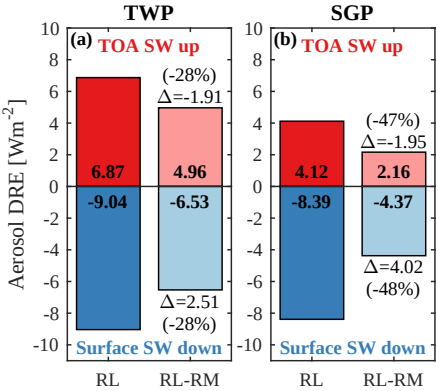

CALIPSO's lack of sensitivity causes a significant reduction of 30–50% in the magnitude of the aerosol DRE

Conclusions

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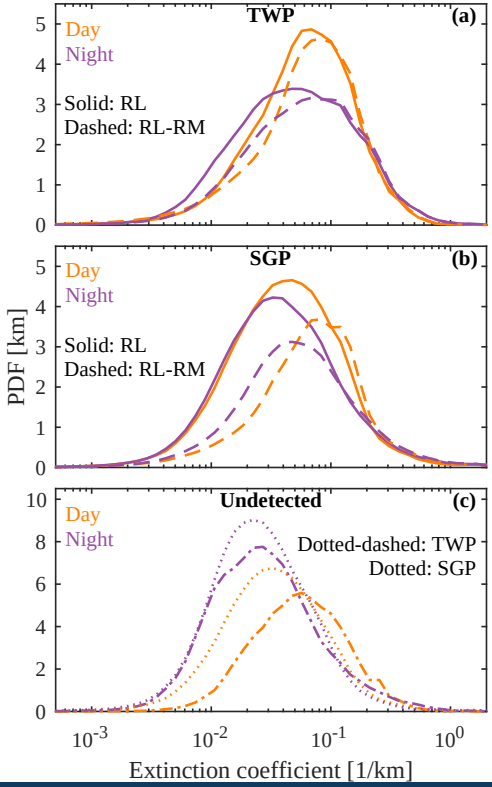
Conclusions

- Assumptions about the aerosol lidar ratio used by CALIPSO likely cause minimal error in global estimates of the aerosol DRE.
- CALIPSO is unable to detect all radiatively-significant aerosol, resulting in an underestimate in the magnitude of the aerosol DRE by 30–50%.
- Therefore, global estimates of the aerosol DRE inferred from CALIPSO observations are likely too weak.
  - CALIPSO-based: $-0.61\ Wm^{-2}$ to $-1.9\ Wm^{-2}$ (Oikawa et al. JGR 2013, Matus et al. JCLIM 2015)
  - Passive-based: $-5\ Wm^{-2}$ (Yu et al. ACP 2006)
- What is the aerosol DRE?

Undetected aerosol extinction

- "RL-RM" = CALIPSO-like
- What goes undetected is consistent with random noise considerations
- CALIPSO's SNR is too low to detect all aerosol during both day and night.



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  - Previous passive estimates: $-5.0\ Wm^{-2}$
  - Not just due to reduced DRE over cloud/land
    clear-sky ocean = $-3.21\ Wm^{-2}$ / $-2.6\ Wm^{-2}$