Radiative Cloud Forcing Over Darwin
Using Inputs from Multiple Ground-based and Satellite Remote Sensors

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Introduction

- The vertical distribution of radiative heating plays an important role in determining dynamic atmospheric processes. An accurate representation of heating rates in the atmosphere is limited by our ability to describe the thermodynamic state and cloud properties of the atmosphere.
- Observations from multiple remote sensing instruments are required to obtain a comprehensive view of clouds.
- Using observations from the A-train satellite constellation allows for a near-global set of radiative heating profiles.
- Comparisons to radiative heating rate profiles derived from ARM observations provide insight into the advantages and disadvantages present in each data set and provide guidance on how such data sets might be improved.

Datasets

Satellite: CCCM

- **C**ALIPSO-**C**loudSat-**C**ERES-**M**ODIS (Kato et al., *JGR*, 2010).
- Integrates observations from level 2 CALIPSO/CloudSat products:
  - CALIPSO: VFM / 05kmCLay / 05kmCPro
  - CloudSat: CLDCLASS / CWC-RO
- MODIS retrievals done by CERES cloud algorithm. Optical depth used to scale extinction profile.
- Cloud detected by:
  - CALIPSO: CALIPSO β + MODIS $R_e \rightarrow IWC/LWC$
  - CloudSat: CloudSat IWC/LWC + CloudSat $R_e \rightarrow \beta$
  - Both: CALIPSO β + CloudSat $R_e \rightarrow IWC/LWC$

ARM: COMBRET

- PNNL combined retrieval: MMCR + MPL + MWR
- Phase: Shupe, *GRL* (2007)
- *LWC*: Liao and Sassen, *AR* (1994), scaled by MWR
- Liquid R_e: Lognormal distribution
- *IWC* / Ice R_e: Wang and Sassen, *JAM* (2001)
- RWC: Marshall-Palmer distribution with Wood, *JAS* (2005) rain rate
- Radar/lidar-only: fitting approach for ice clouds following Hogan et al., *JAM* (2006)

Nomenclature: IWC/LWC = Liquid/ice water content, β = visible extinction, R_e = effective radius

Comparison Method

- Comparison from July 2006 through June 2010. Only periods when all instruments (MMCR/ MPL/ CALIPSO/ CloudSat) are producing quality data are used.
- CCCM data taken from a $5^\circ \times 5^\circ$ domain.
- Focus our comparison on radiative cloud forcing:

$$\overline{CF} = \bar{Q}_{R,total-sky} - \bar{Q}_{R,clear-sky}$$

- In this comparison we use the full set of ARM data with the daytime solar zenith angle fixed at the mean value from the CCCM data.
- Limiting ARM data to within 2 hours of A-train overpasses produces statistically identical heating rate profiles to this fixed solar zenith angle data.

Cloud forcing

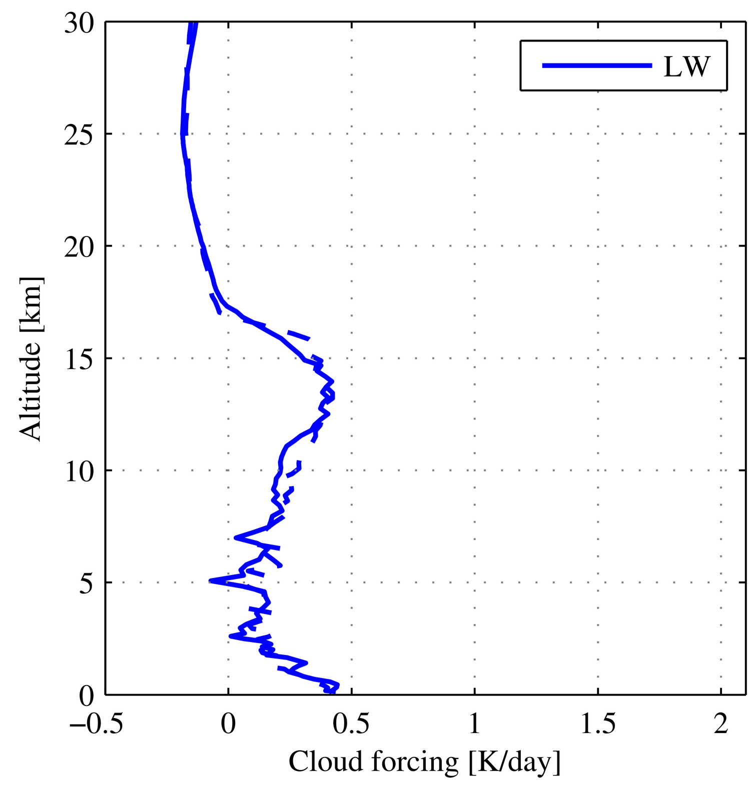


Figure: **Nighttime** cloud forcing

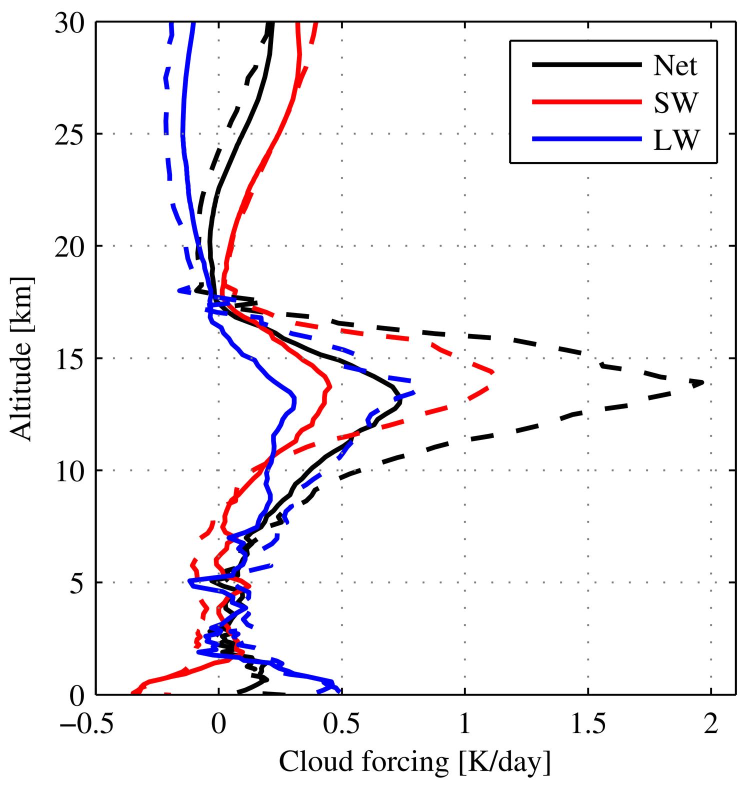


Figure: **Daytime** cloud forcing.

- Large significant differences in *CF* during daytime only with the CCCM *CF* much larger from about 10–16 km.

Ice water content and effective diameter

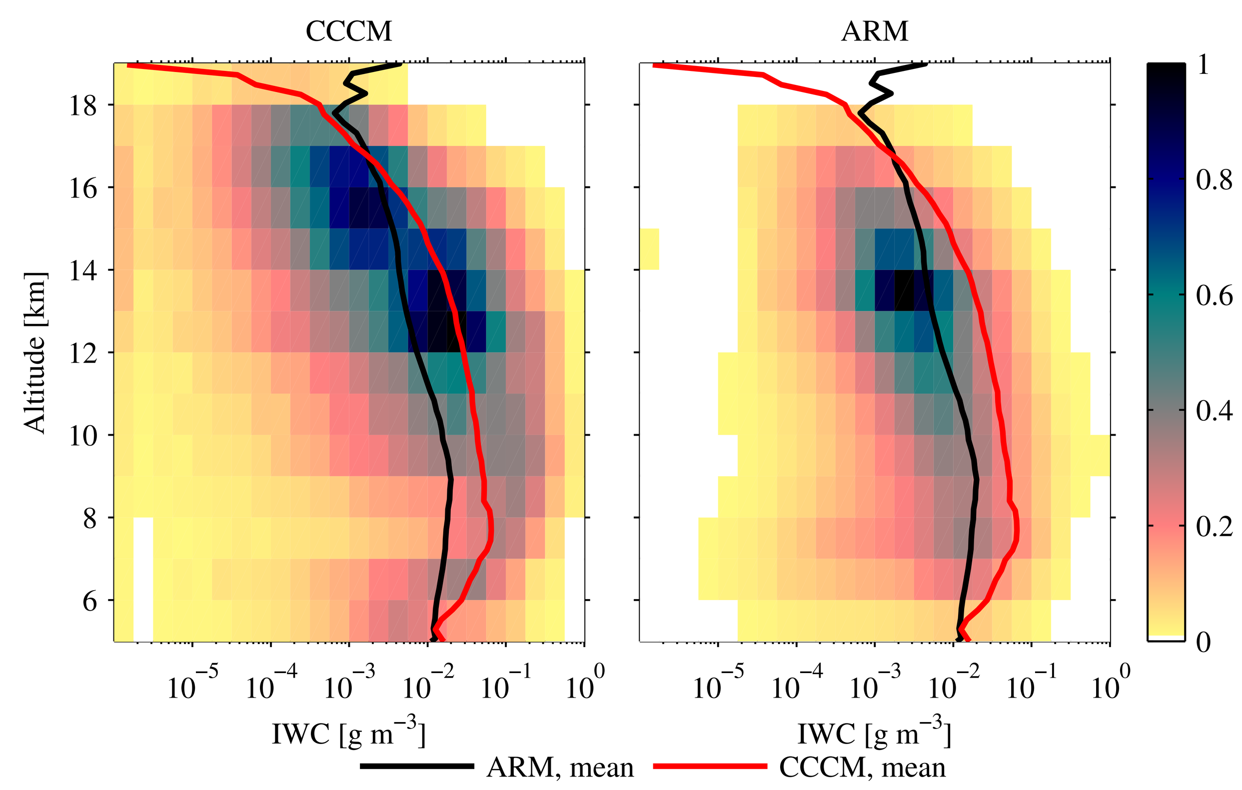


Figure: Joint PDF of IWC and mean in-cloud profiles.

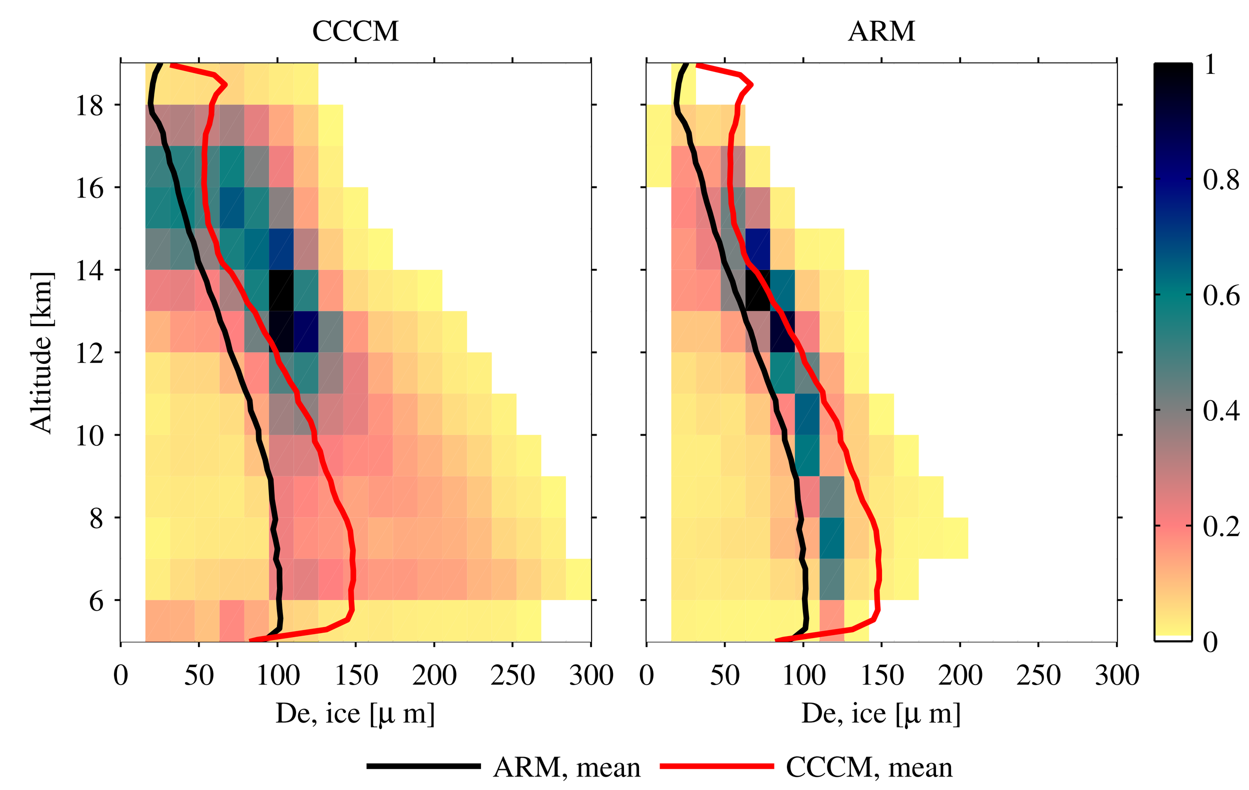


Figure: Joint PDF of ice effect diameter and mean in-cloud profiles.

- CCCM IWC is much larger below about 16 km.
- This difference is larger during the daytime (not shown).
- CCCM has positive bias of about $10 - 34\ \mu m$. Other studies have shown that the CloudSat CWC-RO product has a positive bias (de Boer et al., *JGR*, 2008; Protat et al., *JTECH*, 2010).

Diurnal extinction

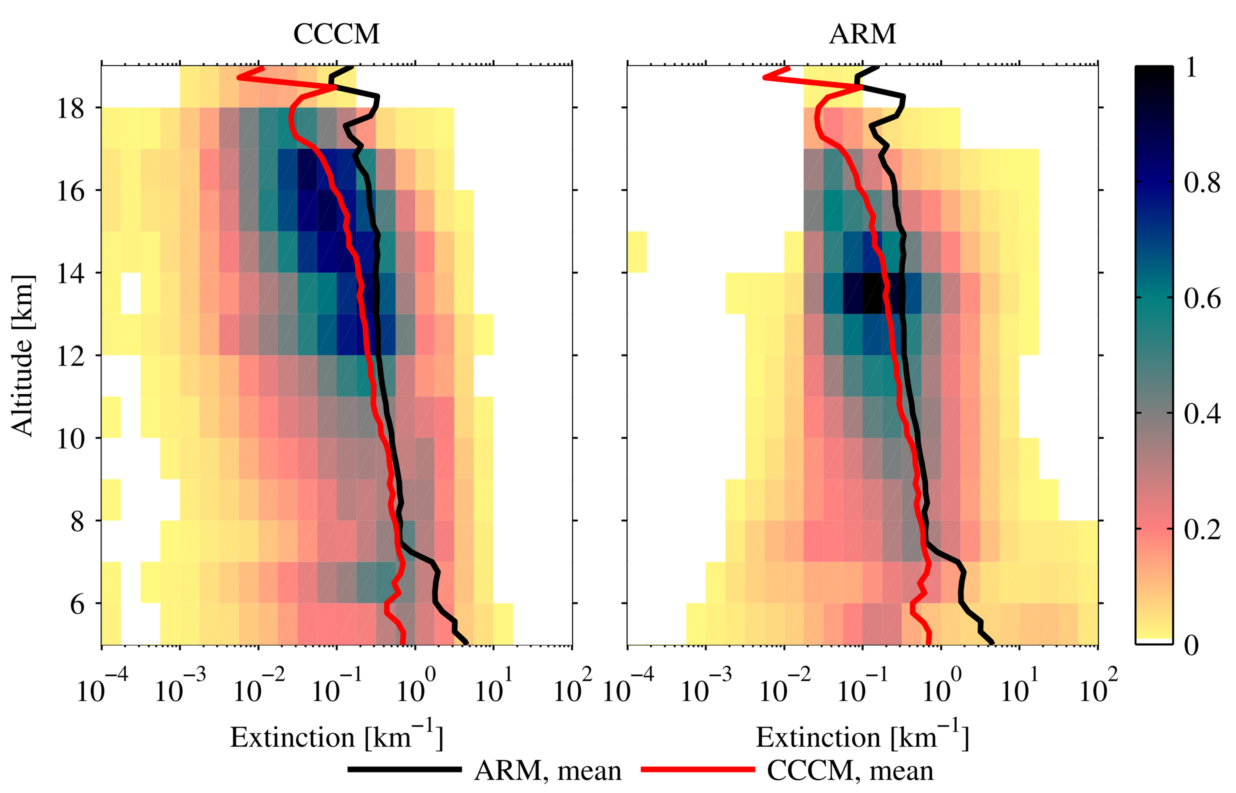


Figure: Joint PDF of **nighttime** visible extinction and mean in-cloud profiles.

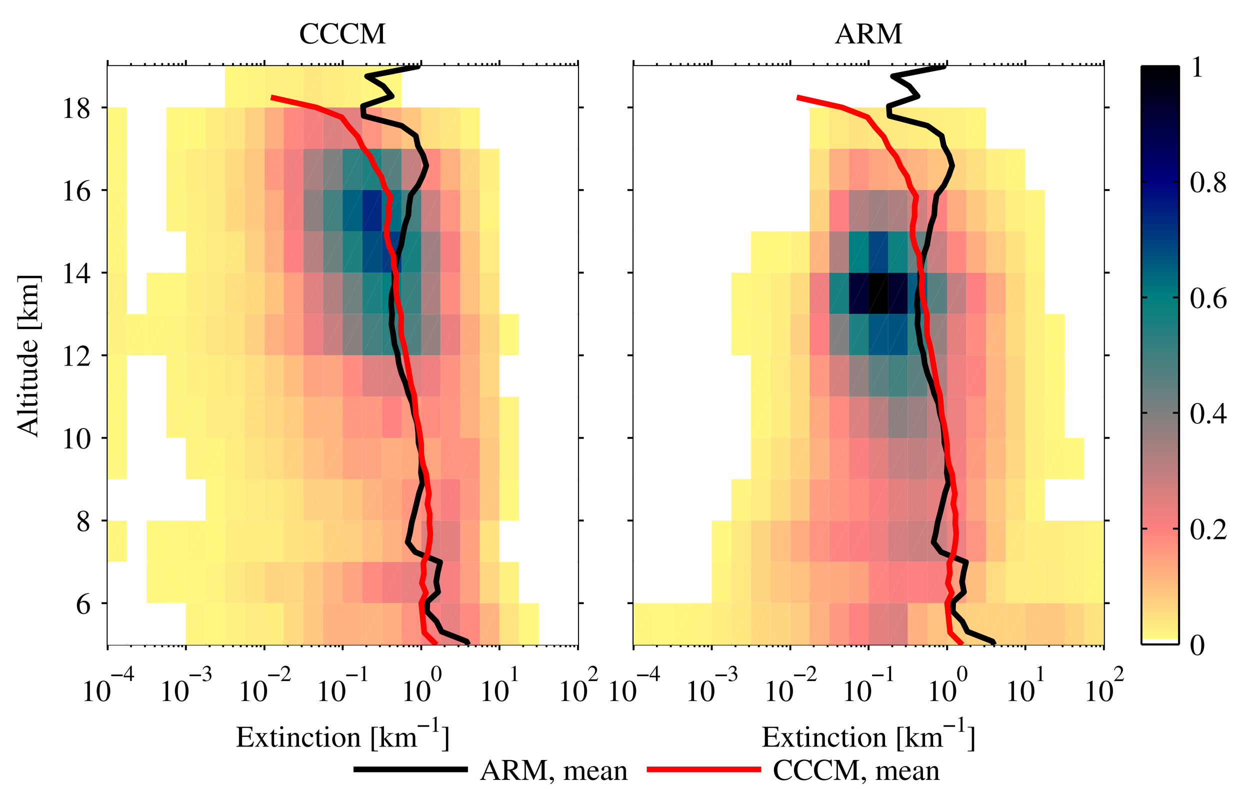


Figure: Joint PDF of **daytime** visible extinction and mean in-cloud profiles.

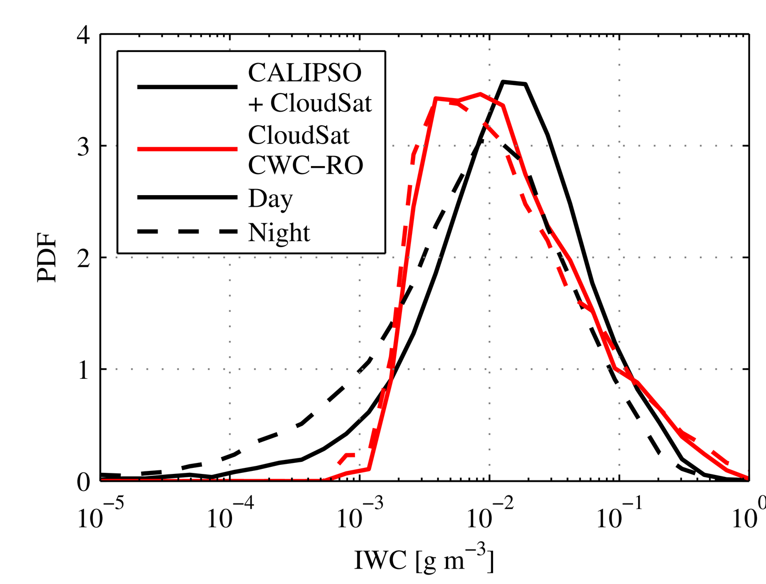
- Both datasets show that clouds are optically thinner at night.
- CCCM extinction biased low relative to ARM at night.
- Overall extinction agrees better than *IWC* or D_e.
- Better daytime agreement, with CCCM extinction smaller above 14 km.

Why is daytime CCCM CF so much larger?

Relationship between extinction, IWC and effective diameter (Fu, *JCLIM*, 1996):

$$\beta = \frac{4(3)^{1/2}}{3\rho_i}\frac{IWC}{D_{ge}}$$

- Protat et al. (*JTECH*, 2010) showed that CloudSat CWC-RO product tends to underestimate β above 11 km.

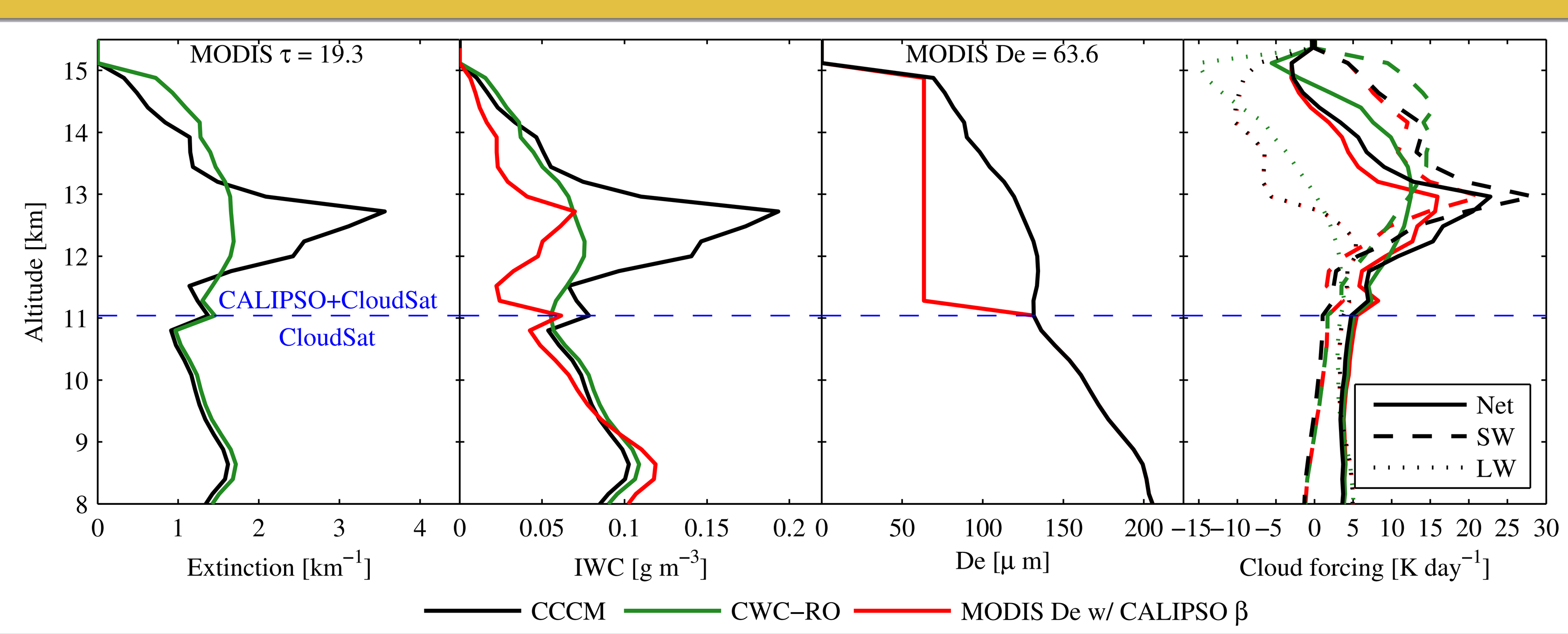


In the CCCM dataset, when both CALIPSO and CloudSat detect a cloud: Use CALIPSO β (> CloudSat β) and CloudSat D_e (large positive bias) $\rightarrow$ large *IWC* and a large *CF*

- Daytime (nighttime) CALIPSO + CloudSat IWC 69% (-2%) larger than CWC-RO.
- This will effect the mean profiles of *CF* more for:
  - Optically thick clouds which have large *CF* already (both ARM and CCCM datasets show that clouds are optically thicker during the day)
  - In addition, optically thick clouds attenuate CALIPSO which means these enhanced IWCs will occur near cloud top only, which is already the most radiatively active portion of the cloud.

Potential impact on CF

- Test case: cloud from surface to 15 km (precipitating), focusing on the cloud top region.
- Using CWC-RO alone smooths/reduces peak in SW *CF* by around $15\ \mathrm{K\ day^{-1}}$. Also increases the LW cooling at cloud top.
  - Note: CloudSat FLXHR product does not show the large heating seen in the CCCM product (not shown).
- Using MODIS D_e with CALIPSO β reduces peak in SW *CF* by around $8\ \mathrm{K\ day^{-1}}$.



Conclusions

- Using CALIPSO extinction with CloudSat size to infer IWC may produce inaccurate profiles of *CF*.
- Reprocessing of the CCCM of the dataset will definitively show if this is the case.
- We also performed this analysis for Nauru which shows very similar results.

We'd like to acknowledge Seiji Kato for useful discussions about the CCCM product. This research was supported by the Office of Science (BER), U.S. Department of Energy, grant DE-FG02-09ER64769