The capabilities of lidar datasets for radiative heating rate and flux calculations

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Lidars and radiative fluxes

Vertical profiles of visible-wavelength extinction coefficients
Lidars and radiative fluxes

**Vertical profiles of visible-wavelength extinction coefficients**

- Synergy with cloud radar
  - Complementary sensitivities to cloud
    (radar: poorer sensitivity; lidar: attenuation)
  - For ice, radar+lidar $\rightarrow$ particle size
    (e.g. Wang and Sassen 2002; Delanoe and Hogan 2008)

- Aerosol properties
A-train: CALIPSO

ARM: CloudSat MPL (micropulse lidar) MMCR (millimeter cloud radar)

• Both sets are large quantities of data, commonly used (separately)
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Compute cloud radiative effect using ARM and A-train radar+lidar observations over Darwin, Australia
Cloud radiative effect (Thorsen et al. 2013a)

- Up to 1.4 K/day difference
Cloud radiative effect (Thorsen et al. 2013a)

- Up to 1.4 K/day difference
- Mostly due to differences in lidar occurrence profiles: MPL detects much less cirrus than CALIPSO
  - Combination of complete attenuation and a poorer sensitivity
The elastic lidar equation

We are using extinction from these lidars BUT

- Single-channel elastic backscatter lidars don’t actually measure extinction

\[ S_{\lambda_0}(z) \propto \beta_{p,\lambda_0}(z) \times \exp \left[ - \int_0^z \alpha_{p,\lambda_0}(z') dz' \right] \]
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• Assume “lidar-ratio” profile: \( S_p(z) = \alpha_p(z)/\beta_p(z) \)
• The lidar ratio is not constant \( \rightarrow \) large errors in extinction
The ARM Raman lidar (RL)

- Measures an elastic signal and a Raman-scattered nitrogen signal
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- More sensitive than the ARM MPL; cirrus occurrence agrees well with CALIPSO; cloud/aerosol detection is unbiased by the solar background (Thorsen et al. 2013b)
- Bonus: water vapor and temperature (Turner et al., 2002; Newsom et al., 2010)
RL-FEX (Feature detection and EXtinction retrieval)

- New automated retrieval algorithm for the ARM RL
- Comprehensively addresses the lidar retrieval problem

(Merger et al. 2015; Thorsen and Fu 2015)
**RL-FEX** (Feature detection and EXtinction retrieval)

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- RL-FEX makes possible statistical comparisons of CALIPSO cloud/aerosol properties to an advanced lidar
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- RL-FEX makes possible statistical comparisons of CALIPSO cloud/aerosol properties to an advanced lidar
  - All previous work has focused on comparisons using case studies or small sample sizes
- We now have a true climatology of cloud/aerosol extinction

(Thorsen et al. 2015; Thorsen and Fu 2015)
How does using extinction from an elastic lidar (e.g. CALIPSO/MPL) affect your radiative flux calculation?
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1. Calculate flux using RL-FEX best-estimate extinction
2. Calculate flux using elastic channel-only retrieved extinction (i.e. assumed lidar ratios)
   - TOA & surface aerosol/cloud radiative effect (i.e. subtract clear-sky flux)
   - Multiyear mean values
SGP site (Oklahoma): Raman vs. elastic extinction

- Aerosols: 25–30% difference
- Clouds: ≤ 15% difference, some cancellation in the net
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- Aerosols: 25–30% difference
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- This is a “lidar-biased” view (only ∼3-4 optical depths worth of particulates)
CALIPSO and Raman lidar aerosol occurrence
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- **Transparent profiles only** (laser has fully penetrated the atmosphere)
- **CALIPSO detects much less aerosol than the RL**
• Is the aerosol missed by CALIPSO radiatively important?

1. Calculation using all aerosol detected by the RL
2. Calculation using RL data, but with aerosol randomly removed (multiple times) to force a CALIPSO-like occurrence profile (“RL degraded to CALIPSO’s sensitivity”)
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- Significant biases of ∼ 50–75%
Global estimates of shortwave direct aerosol effects at TOA
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- Passive sensors: $-5 \text{ Wm}^{-2}$ (mostly limited to clear-sky ocean)
  
  (Yu et al. 2006 and references therein)

- Active sensors: -0.6 to -1.9 Wm$^{-2}$ (using CALIPSO: all-sky, land+ocean, vertically-resolved)
  
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Are these estimates smaller due to CALIPSO's poor sensitivity? (causes a $\sim 70\%$ reduction at the two ARM sites)
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Summary

- CALIPSO+CloudSat better suited for heating rate calculations than MPL+MMCR due to the MPL’s lack of sensitivity.
- RL-FEX: new retrieval for the ARM Raman lidar. Provides directly-retrieved cloud/aerosol extinction coefficients.
- Assumptions needed to obtain extinction from elastic lidars results in $\sim 25\%$ biases in the inferred aerosol radiative effects and $\leq 15\%$ in the cloud radiative effects.
- A significant amount of aerosol goes undetected by CALIPSO
  - This lack of aerosol reduces the inferred aerosol radiative effects significantly ($\sim 50$–$75\%$)
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  (Oikawa et al. 2013; Matus et al. 2015)
  - Clear-sky ocean: $-2.6$ to $-3.2 \ Wm^{-2}$
Radiative transfer model details

- NASA Fu-Liou, 2 streams
- Pressure / temperature / water vapor from radiosondes; standard profiles (MLS / MLW/ TROP) fill in above
- Ozone: standard profiles
- Surface albedo = 0.2
- Clouds: extinction from RL
  - Liquid: \( R_e = 8 \mu m \)
  - Ice: \( D_{ge} = 30 \mu m \)
- Aerosol
  - RL extinction at 355 nm
  - SGP: d’Almedia continental model
  - TWP: d’Almedia maritime model
Introduction

ARM vs. A-train

ARM Raman lidar

Raman vs. elastic extinction

CALIPSO aerosol detection

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**SGP**

**Day**

Solid: transparent

Dashed: all

**Night**

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**TWP**

**Day**

Solid: transparent

Dashed: all

**Night**
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(a) \( \delta \)

Height [km]

00 03 06 09 12 15 18 21

0 2 4 6 8 10 12 14

(b) \( \beta_{p, BE} \) [log\((km^{-1}sr^{-1})\)]

Height [km]

00 03 06 09 12 15 18 21

0 2 4 6 8 10 12 14

(c) \( K_{p,EN}^{'} \) & \( \bar{K}_{p,E} \) [sr]

Height [km]

00 03 06 09 12 15 18 21

0 2 4 6 8 10 12 14

(d) Feature classification

Hour [UTC]

00 03 06 09 12 15 18 21

0 2 4 6 8 10 12 14

Clr
Liq
Rn
Ice
HOI
Aer

(19/13)
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Day

(a)

RL: 2min/30m

RL: 9min/30m

RL: 15min/60m

CALIPSO

0.0 0.1 0.2 0.3 0.4

Height [km]

0 2 4 6 8 10 12 14 16 18 20

Cloud occurrence (transparent profiles)

Night

(b)

RL: 2min/30m

RL: 9min/30m

RL: 15min/60m

CALIPSO

0.0 0.1 0.2 0.3 0.4

Height [km]

0 2 4 6 8 10 12 14 16 18 20

Cloud occurrence (transparent profiles)