Comments on Level 3 profiles and Retrievals and Validation of Above-Cloud Aerosol Properties

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Comments on Aerocom Phase I Profile Intercomparison (Koffi et al. 2012)

Application of the CALIOP layer product to evaluate the vertical distribution of aerosols estimated by global models: AeroCom phase I results

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Differences: Aerocom vs. CALIPSO Level 3 profiles

1) Different aerosol products were used
   – Aerocom: 5-km aerosol layer product
   – CALIPSO: 5-km aerosol profile product

2) Averaging of all-sky extinction is different
   – Aerocom: aerosol extinction within cloud set to zero
   – CALIPSO: clouds ignored when averaging aerosol extinction

3) Vertical grid
   – Aerocom: 100 m
   – CALIPSO: 60 m (multiple of vertical sampling)

4) Different corrections applied to account for undetected aerosol in lowest range bins
layer vs. profile product

Level 2 extinction for single layer:

From profile product:
\[ \sigma(z) = f(z) \]

From layer product:
\[ \sigma(z_1, z_2) = \frac{\tau}{z_1 - z_2} \]

Magnitude of the differences depends on the detected layer thicknesses and shape of the true profile
How to deal with overlapping layers?
Overwrite coarser resolution layers with higher resolution layers.

**Level 2 extinction profile**
Overlapping layers in a single column

How the extinction profile should look:

- 20 km resolution
- 5 km resolution
How **NOT** to deal with overlapping layers.

Ignore horizontal resolution and sum all extinction.

**Level 2 extinction profile,**
Overlapping layers in a single column

**Sum of all extinction,**
ignoring horizontal resolution

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- 20 km resolution
- 5 km resolution

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$\sigma$

$z$

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$\sigma$

$z$
Next slide compares mean extinction profiles computed three ways:
1) profile product: extinction
2) layer product: AOD/thickness, correctly handling overlapping layers
3) layer product: AOD/thickness, and summing overlapping layers.

Averages are computed only to analyze impact of differences in technique: **no quality screening**, use 100 m vertical grid.
Profile product vs. Layer product
JJA 2007, Night, Cloud-Free

When layers are shallow: good agreement

When overlapping layers are added, extinction is larger than it should be.

AOD is overestimated when overlapping layers are summed.

From L2 profile product (like CALIOP level 3)

From L2 layer product, correct treatment of overlapping layers

From L2 layer product, incorrect treatment of overlapping layers (like Koffi et al, 2012)
2) All-sky Averaging

Computing average extinction at altitudes where clouds occur:
- CALIPSO: treats regions inside cloud as ‘unobserved’ and ignored
- Aerocom: within clouds, aerosol extinction set to 0.0 /km and included

CALIOP Level 3 extinction will be larger at altitudes where clouds are frequent.
cloudy regions ignored vs. included
JJA 2007, Night, Cloud-Free

North Atlantic
- Blue: Cloudy $\sigma_{\text{aer}}$ ignored
- Red: Cloudy $\sigma_{\text{aer}}$ = 0
- Dashed: Koffi et al., 2012

Central Atlantic
- Blue: Cloudy $\sigma_{\text{aer}}$ ignored
- Red: Cloudy $\sigma_{\text{aer}}$ = 0
- Dashed: Koffi et al., 2012

South Africa
- Blue: Cloudy $\sigma_{\text{aer}}$ ignored
- Red: Cloudy $\sigma_{\text{aer}}$ = 0
- Dashed: Koffi et al., 2012

As in CALIOP L3

Like CALIOP level 3
Like Koffi et al, 2012
Actual data from Koffi et al, 2012
Summary

1. Using L2 layer product for L3 profiles tends to:
   - Over-estimate mean extinction in upper boundary layer,
   - Under-estimate mean extinction in lower boundary layer

2. Double-counting overlapping layers:
   - Same consequence as above, but a stronger effect

3. Including cloudy regions in aerosol average:
   - Decreases aerosol extinction at altitudes where clouds are prevalent
   - But, in most cases, not by a lot

4. Averaging onto a grid which is non-multiple of 30 meters:
   - Introduces artifacts into profile
Part 2: Above-Cloud Aerosol Retrievals

- Technique of Hu et al. (2007) used to study aerosol above opaque water clouds
- AOD derived directly, used as constraint for retrieval of extinction profile and lidar ratio
- Entire column is retrieved, not just within detected base and top
- Results used to evaluate standard retrieval
  - Quantify AOD error
  - Identify sources of error

- Now in ACPD: Zhaoyan Liu, D. Winker et al
Basis of Opaque Water Cloud (OWC) Retrieval

• It has been noted that 532 nm lidar ratio for water clouds is nearly constant:

Based on Miles et al. (2000)
Basis of OWC Retrieval (2)

• And the integrated signal from opaque cloud is related to the lidar ratio:

\[ \gamma'_{WC, SS, NA} = \int_{base}^{top} \beta'_{SS}(r) dr = \frac{1 - \exp(-2\tau)}{2S_{WC}}; \]

\[ \approx \frac{1}{2S_{WC}}, \text{ for opaque water clouds (} \tau > \sim 3), \]

• Finally, the integrated single-scatter lidar return can be estimated from the depolarization signal:

\[ H = \frac{\gamma'_{ss}}{\gamma'_{ms}} = \left( \frac{1 - \delta_l}{1 + \delta_l} \right)^2 \]
Basis of OWC Retrieval (3)

- So the AOD above cloud can be retrieved directly from measured quantities:

\[
\tau_{aerosol} = -\frac{1}{2} \ln \left( \frac{\gamma'_{WC,SS}}{\gamma'_{WC,SS,NA}} \right)
\]

\[
= -\frac{1}{2} \ln \left( \frac{H \gamma'_{WC,MS}}{1} \right) = -\frac{1}{2} \ln \left( 2S_{WC} \gamma'_{WC,MS} \left( \frac{1-\delta_I}{1+\delta_I} \right)^2 \right)
\]

- \( \gamma'_{WC,SS} \) is not exactly constant though, so is derived locally from opaque clouds without aerosol above
2 regions selected for analysis
Level 1 profiles
532 nm | 1064 nm

Retrieved 532 nm extinction (regional averages)

Level 2 product
OWC
Retrieval of lidar ratio, particle depol

**Dust**

- **AOD**
  - Occurrence Number
  - Diagram (a)

- **OWC**
  - Diagram (b)

- **Sa** (sr)

**Smoke**

- **PDR**
  - Occurrence Number
  - Diagram (d)

- **Sa** (sr)

**Additional Information**

- Dust: ASR > 0.3
- Smoke: ASR > 0.2
AOD error of 0.1, and lidar ratio errors if constant $\gamma'_{WC}$ is used
Comparison of 4 methods: Dust

L2 vs. OWC

Corrected L2 vs. OWC

(d)

Level 2
Corrected Level 2
Opaque Water Cloud
Full-Column (S = 40, 45 sr)
Error Budgets: comparison of L2, OWC, FC retrievals

Dust transport region, JJA 2007 – 2012

AOD
• Good agreement and correlation
• Level 2 AOD underestimates OWC AOD by ~26%

Subtyping
• Excellent performance
• 99% success, dust identification
• Mistyping contributes ~10% to AOD discrepancy

Layer detection
• Reasonably good
• Can fail to detect layer bases of dense dust
• Detection failure responsible for 39% of AOD discrepancy

Main cause for discrepancy in dust AOD: dust lidar ratio
40 sr (Level 2) vs. 44.6 sr (retrieved by OWC)
Comparison of 4 methods: Smoke

L2 vs. OWC

Corrected L2 vs. OWC

(d)

Level 2
Corrected Level 2
Opaque Water Cloud
Full-Column (S = 70, 75 sr)
Error Budgets: comparison of L2, OWC, FC retrievals
Smoke transport region, JJA 2007 – 2012

AOD
• Agreement not as good as in dust transport region
• L2 AOD underestimates OWC AOD by \(~39\%\)

Subtyping
• Reasonably good
• 83% success, smoke identification
• Mistyping contributes \(~26\%\) to AOD discrepancy

Layer detection
• 77% AOD discrepancy caused by failed detection of smoke layer bases.
• Level 2 smoke model is valid in terms of lidar ratio

Main cause for discrepancy in smoke AOD:
failure to detect full vertical extent, but typing errors also contribute
Intrinsic properties of Saharan dust largely constant during transport across the Atlantic Ocean. Consistent with previous case studies and in situ measurements.
A final note: Product Updates

- Version 4 Level 1 data is now available
- Update to Level 3 aerosol product is underway
  - Adding smoke-only, polluted dust-only profiles
  - Changing sky conditions from:
    all-sky, combined
    to:
    all-sky, clear-sky, cloudy-sky
  - Have identified two reasons for near-surface drop-off
    - Will correct for one in next version of Level 3
    - Other one requires changes to Level 2
  - Will fix error in computation of Column AOD