Improvements in CALIPSO Version 3 and New Products

Dave Winker
and Mark Vaughan, Ali Omar,
Zhaoyan Liu, Yongxiang Hu, Brian Getzewich, and Jason Tackett

CERES/GERB Mtg, Paris, Sept 2010
Version 3 Highlights

Version 2
3-D CAD
(no depol!)

Altitude +

532 nm Attenuated Backscatter (particle amount)

1064/532 Attenuated Backscatter Ratio (particle size)
New CAD algorithm
3D → 5D Classification

Version 3
5-D CAD

Altitude +

Latitude +

532 nm Attenuated Backscatter (particle amount)

1064/532 Attenuated Backscatter Ratio (particle size)

532 nm Volume Depolarization Ratio (particle shape)

Liu et al., The CALIPSO Cloud and Aerosol Discrimination: Version 3 Algorithm and Test Results, ILRC 25
New CAD algorithm
3D → 5D Classification

Separation between cloud and aerosol & dust classification improved in V3

3D, V2.01

10N-20N, 0-1km, night

Attenuated backscatter

Depolarization ratio

Dense Dust

20N-30N, 0-1km, night

Attenuated backscatter

Depolarization ratio

Dense Dust

“Continuum” due to cloud-clearing bug

5D, v2.94

10N-20N, 0-1km, night

Attenuated backscatter

Depolarization ratio

V2.01, 3D CAD misclassification @ 5-km

V3.01, 5D CAD correct classification @ 5-km
CAD_score logic flaw corrected in V3

Distribution of $\gamma_{532}$ and $\chi'$ for
- $0.15 < \delta < 0.20$
- $20^\circ$ N < latitude < $30^\circ$ N
- $0$ km < $Z_{\text{mid}}$ < $1$ km

CAD score = $100 \left( \frac{P_{\text{cloud}} \text{(layer)} - P_{\text{aerosol}} \text{(layer)}}{P_{\text{cloud}} \text{(layer)} + P_{\text{aerosol}} \text{(layer)}} \right)$

CAD score = $100 \left( \frac{(P_{\text{cloud}} \text{(layer)} + \Delta P_{\text{cloud}}) - (P_{\text{aerosol}} \text{(layer)} + \Delta P_{\text{aerosol}})}{(P_{\text{cloud}} \text{(layer)} + \Delta P_{\text{cloud}}) + (P_{\text{aerosol}} \text{(layer)} + \Delta P_{\text{aerosol}})} \right)$
Two Issues

VERSION 2
software bug in low-altitude cloud-clearing loop, aerosol base detection not always good
V2 Aerosol base detection sometimes too high

532 nm Attenuated Backscatter

1064 nm Attenuated Backscatter

Vertical Feature Mask
VERSION 3.01
cloud-clearing bug fixed
improved aerosol bases

Improved Aerosol Base Detection

532 nm Attenuated Backscatter (km$^2$sr$^{-1}$) 2007-08-04, ~18:24:55 UTC
Result: single-layer low clouds

Version 2.01
When all 5-km clouds are counted, global mean cover of single-layer low cloud reduced from 26.1% to 21.8% in V3 – but 5-km clouds are optically thin ($\tau \ll 1$)

Biggest effects in low latitude oceans

Version 3

ratio of V3 / V2 low cloud
Restructured Profile Products

Version 2:
Profiles of aerosol and cloud 532 and 1064 extinction and backscatter only
Aerosol profiles reported at 40 km, clouds at 5 km

Version 3:
Both aerosol and cloud profile products now retrieved at 5-20-80 km and reported at 5-km horizontal resolution

Additional profiles:
532 nm perpendicular backscatter and particle depolarization
Atmospheric Volume Description (cloud/aerosol/clear etc.)
Cloud fraction
Backscatter and extinction uncertainties

Added column parameters
Column optical depth: cloud, aerosol, stratosphere
Column integrated attenuated backscatter (IAB)

Data quality information
CAD score, Ext_QC flag, Feature type QA flags
New aerosol profile product

Version 2.01: Aerosol Profile Product Resolution
40 km Horizontal, 120 m Vertical

532 nm Aerosol Backscatter Coefficient, 2007-08-18/19
Aerosol profiles now reported at 5-km

**Version 2.01:** Aerosol Profile Product Resolution
40 km Horizontal, 120 m Vertical

**Version 3.01:** Aerosol Profile Product Resolution
5 km Horizontal, 60 m Vertical
also includes: depol, uncertainties, cloud flags, etc
Uncertainties now included.
Uncertainty in Particulate Backscatter Coefficients at Altitude $n$

$$\frac{\sigma^2(\beta_{p,n})}{\beta_{p,n}^2} = A_n^2 \left( \frac{\sigma^2(\chi_n)}{\chi_n^2} + \left( \frac{1}{R_n} \right) \frac{\sigma^2(\beta_{m,n})}{\beta_{m,n}^2} + \left( 2\eta \tau_{p,n} \right)^2 \left( \frac{\sigma^2(S)}{S^2} + \frac{\sigma^2(\eta)}{\eta^2} \right) + \left( \frac{\sigma^2(T_{p,n-1}^2)}{T_{p,n-1}^2} \right)^2 + B_n^2 \left( \frac{\sigma^2(\beta_{p,n-1})}{\beta_{p,n-1}^2} \right) \right)$$

---

**LEGEND**

- $S$ = lidar ratio
- $\beta$ = backscatter coefficient
- $R$ = scattering ratio
- $\sigma^2(x)$ = variance of $x$
- $T$ = transmittance
- $\tau$ = optical depth
- $m$ = molecular
- $p$ = particulate (e.g., aerosol)
- $P$ = measured data
- $C$ = calibration constant
- $\eta$ = multiple scattering factor
- $\chi_n$ = normalized backscatter coefficient
- $A_n$ = calibration constant
- $B_n$ = extinction uncertainty

$$\chi_n = \frac{r_n^2 \cdot P(r_n)}{C \cdot T_m^2(r_n)}$$

$$A_n = \left( \frac{R_n}{R_n - 1} \right) \cdot \frac{1}{1 - R_n \cdot \beta_{mn} \cdot S \cdot \eta \cdot \Delta r_n}$$

$$B_n = S \cdot \eta \cdot \Delta r_n \cdot \beta_{p,n-1}$$

Includes errors due to calibration (SNR), molecular density (again), offset calculations, polarization gain ratio, and polarization cross-talk ranging.
Reduced artifacts in cloud ice-water phase

Oriented ice now properly classified (HOI → water in V2)
Improved CAD reduces mis-classification of dust as cloud

Version 2.01

Version 3

Number of ‘ice’ clouds with tops below 3.25 km
New V3 product: IWC

Ice-Water Phase: 5 August 2007

IWC parameterization from Heymsfield et al (2005)

IWC = $C_0 \left( \frac{\sigma}{1000} \right)^{C_1}$

$C_0 = 119 \text{ g/m}^3$

$C_1 = 1.22$
IWC Comparison

CALIOP V3.01 Cloud Ice:
Preliminary Comparison: TC4

IWC: CALIPSO vs. CloudSat

- CALIOP doesn’t capture the higher IWC
- CALIOP retrieves thin cloud ice between 10-15 km, comparable to in situ
- CloudSat IWC appears to be overestimated
• Level 3 Cloud product
  – Based on Version 3 Level 2
  – Builds on experience from products recently developed (using Version 2) for CMIP5/GOCCP comparison and GEWEX Cloud Assessment

• Level 3 aerosol product
  – Primarily: time-averaged gridded profiles of aerosol extinction, type
  – Based on Version 3 Level 2, with additional quality control

• Near-realtime Level 1-like aerosol product for operational forecast centers
Level 3 Aerosol Extinction - preliminary

Mean Extinction Coefficient 532 nm, Ext QC 532 nm No clouds overhead
Day & Night, (80° N, 80° S; 70° W, 60° W), Aug 2007, Version 3.01, Total samples: 260942

All clear-air + above-cloud

Screening: ExtUnc, ExtQC, CADscore, cloud artifacts

QC applied

Level 3 Aerosol Extinction - preliminary

Mean Extinction Coefficient 532 nm, Ext QC 532 nm No clouds overhead
Day & Night, (80° N, 80° S; 70° W, 60° W), Aug 2007, Version 3.01, Total samples: 260942

All clear-air + above-cloud

Screening: ExtUnc, ExtQC, CADscore, cloud artifacts

QC applied

Level 3 Aerosol Extinction - preliminary

Mean Extinction Coefficient 532 nm, Ext QC 532 nm No clouds overhead
Day & Night, (80° N, 80° S; 70° W, 60° W), Aug 2007, Version 3.01, Total samples: 260942

All clear-air + above-cloud

Screening: ExtUnc, ExtQC, CADscore, cloud artifacts

QC applied
Aerosol product for model verification/assimilation by operational centers
- ECMWF, NRL, GMAO, …
Level 1 profiles (1/3 km x 30-60 m) are cloud-cleared using VFM,
then averaged to 20 km x 60 m
Nominal delivery within 5-6 hours → “semi-global”
Operational in early 2011
Have now acquired 4+ years of data
  - Validation continuing
  - Level 3 products in development

Version 3 products recently released
  - new parameters
  - significant improvements over Version 2
  - New Level 2 IIR product by end of 2010: $D_{eff}$ and IWC from lidar+IR
  - Further improvements to AOD and aerosol extinction underway

Payload still healthy
  - Likely mission life: 2014-16

Continuity of cloud/aerosol profiling:
  - ADM (ESA): 2011 (??)
  - EarthCare (ESA/JAXA): 2014
  - ACE (NASA): post-2020 (??)