REVEX 2015

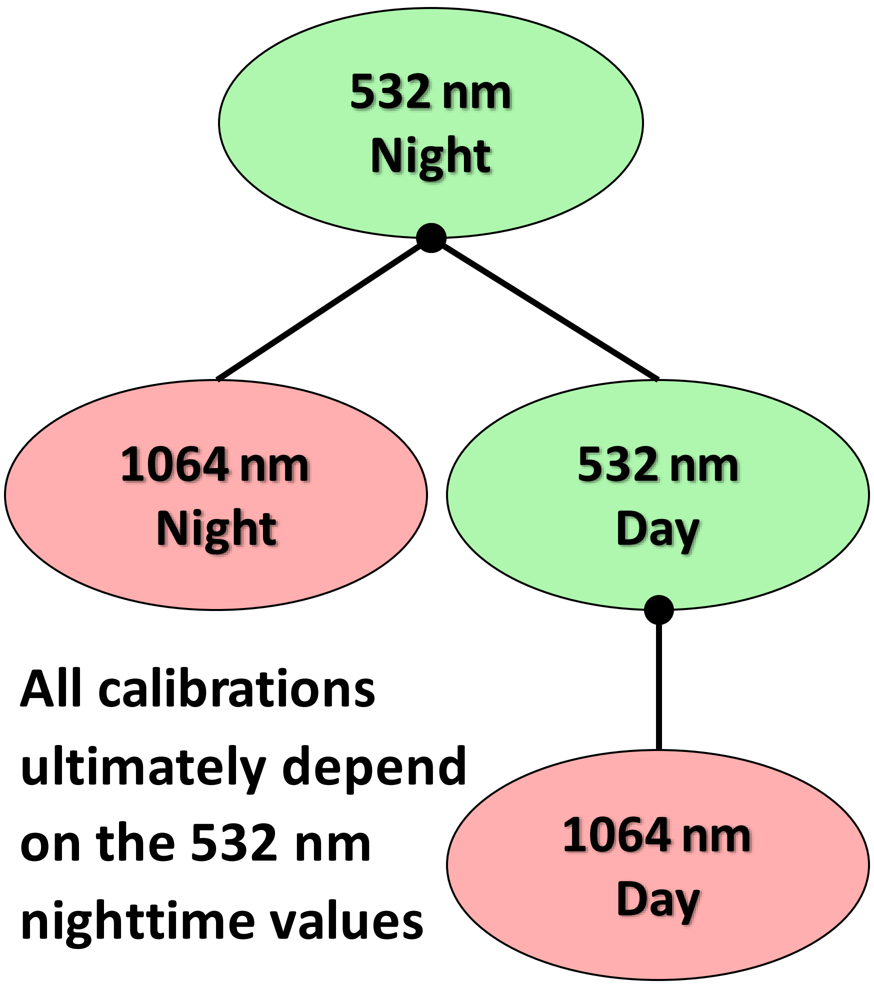
Lidar Product Quality Assessment/Validation and Development Plan

Highlights

- ❑ CALIOP Algorithm Development Plan
  - ➢ Overview of Level 1 Version 4 findings
  - ➢ Outline of major improvements for Level 2 and 3 products
- Description of Development Process and Metrics
  - Define Requirements
  - Peer-review major algorithm or format changes
  - Verify performance against requirements
  - Characterize and document impacts
- Data Product Validation Status
  - Advancement to higher maturity

Calibration Modifications for Version 4

DEPENDENCIES



All calibrations ultimately depend on the 532 nm nighttime values

VERSION 4

532 nm NIGHT

- Molecular normalization:
  - Moved from 30-34 km, along-track averaging to 36-39 km and averaging over multiple granules

532 nm DAY

- **Night-to-Day calibration transfer** factors were computed from “clear air” at 8-12 km – moved upward into stratosphere (400K surface).

1064 nm DAY & NIGHT

- **532 nm-to-1064 nm scale factors now calculated over multiple granules, as function of latitude**

CALIOP Level 1 V4 Improvements

- Significant revision to CALIOP 532 nm calibration algorithm completed
  - Removed impacts from stratospheric aerosol (biases of ~ 5% in tropics)
  - Filtered spurious noise spikes – especially near South Atlantic Anomaly
  - Improved calibration near day/night transitions
  - Applied detector baseline slope corrections to improve high-altitude daytime calibration by ~40%

- First major improvement to CALIOP 1064 nm calibration procedure
  - Added more robust calibration transfer techniques from 532 nm using cloud features identified with CALIPSO Imaging Infrared Radiometer (IIR)
  - Removed instrument artifacts believed to be caused by thermal stresses to lidar boresight alignment (up to 35% variations along orbit)

- Expected Outcomes
  - Stable calibration record (removed day-night, seasonal, and residual volcanic aerosol signals)
  - Improved detection capabilities and reduced uncertainties in Level 2 products
  - Improved calibration enables reliable use of 1064/532 color ratio in Level 2 classification algorithms

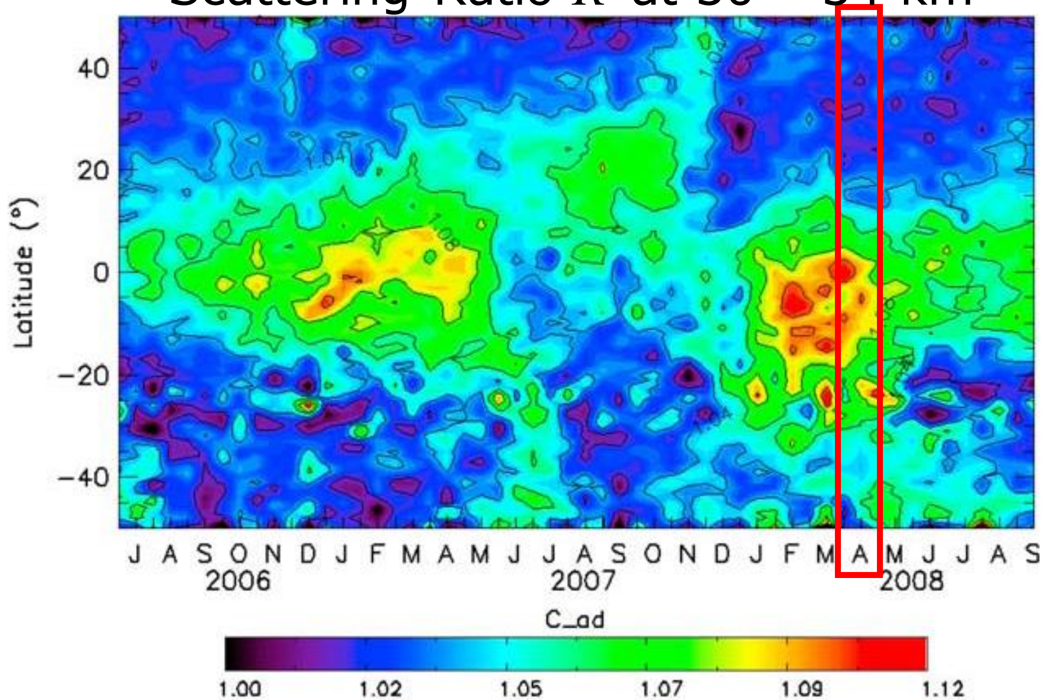
532 nm Night Calibration
Molecular Normalization

Normalization altitude:

moved from 30-34 km (in V3) to 36-39 km (in V4)

Lower SNR: required averaging over multiple orbits

Scattering Ratio R' at 30 – 34 km



$$R' = \frac{\beta'_{aerosol} + \beta'_{molecular}}{\beta'_{molecular}} \equiv 1.0$$

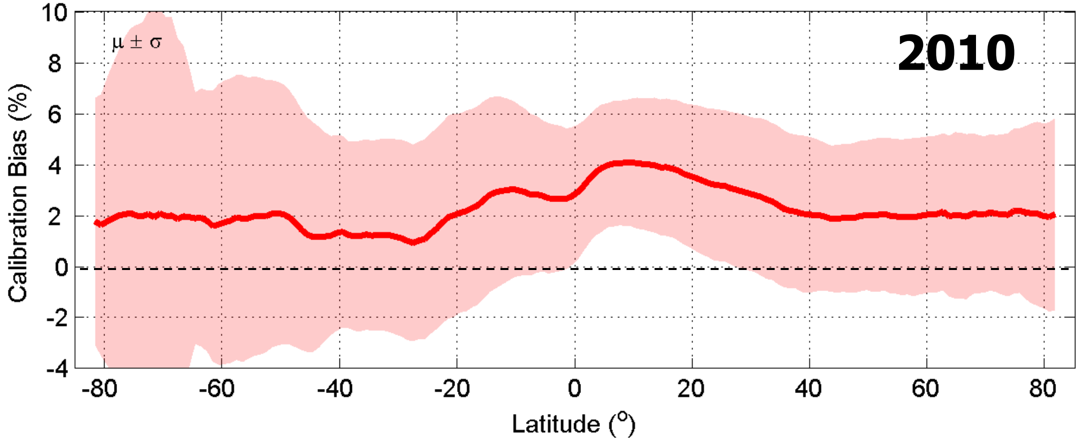
Aerosol exists in Version 3 normalization region

Moving to a higher region with Version 4 reduces this impact

Vernier et al., 2009

532 nm Night Calibration
Version 3 Biases

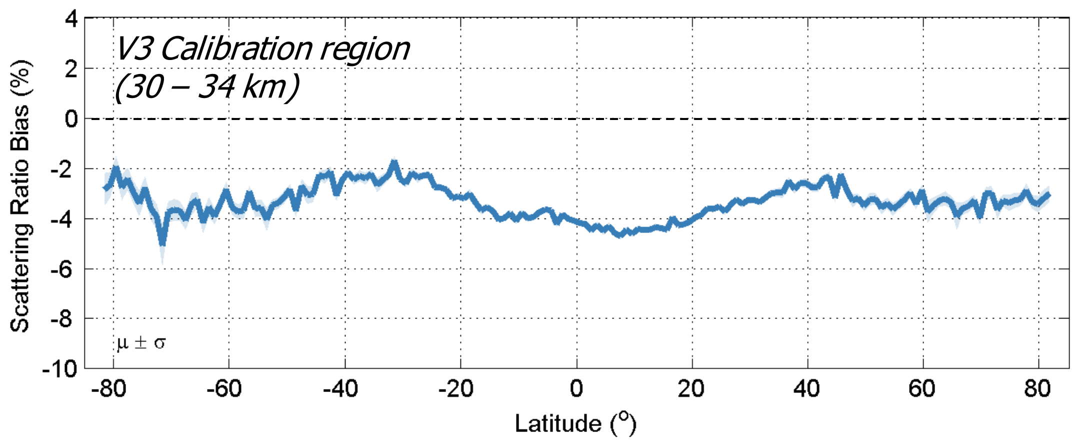
V3 calibration bias, night (compared to V4)



$$R' = \frac{\beta'_{aerosol} + \beta'_{molecular}}{\beta'_{molecular}} \equiv 1.0$$

V3 night calibration biased high by 2-4%, yielding a 2-4% low bias in attenuated backscatter.

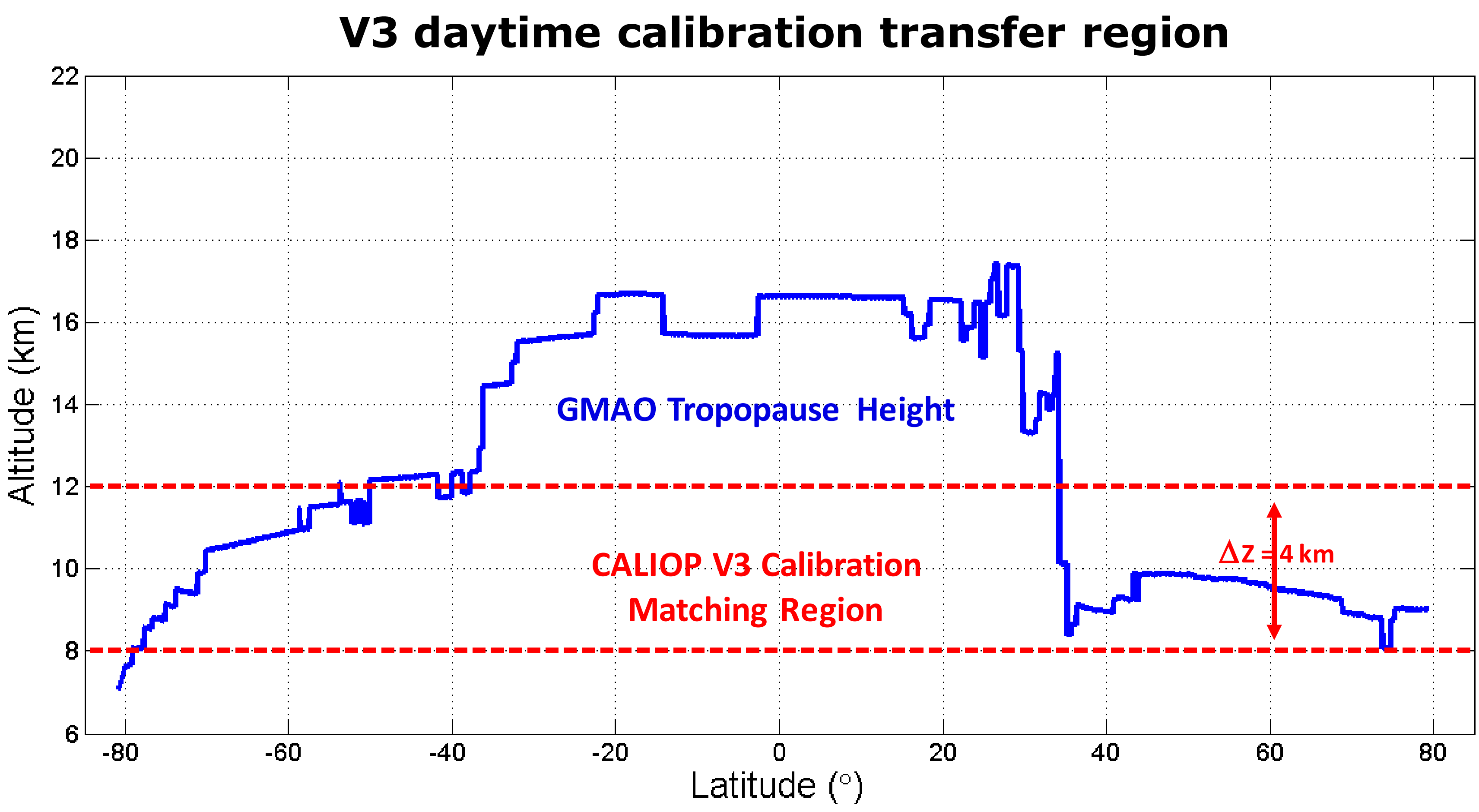
V3 scattering ratio bias, night (compared to V4)



The largest bias is in the tropics.

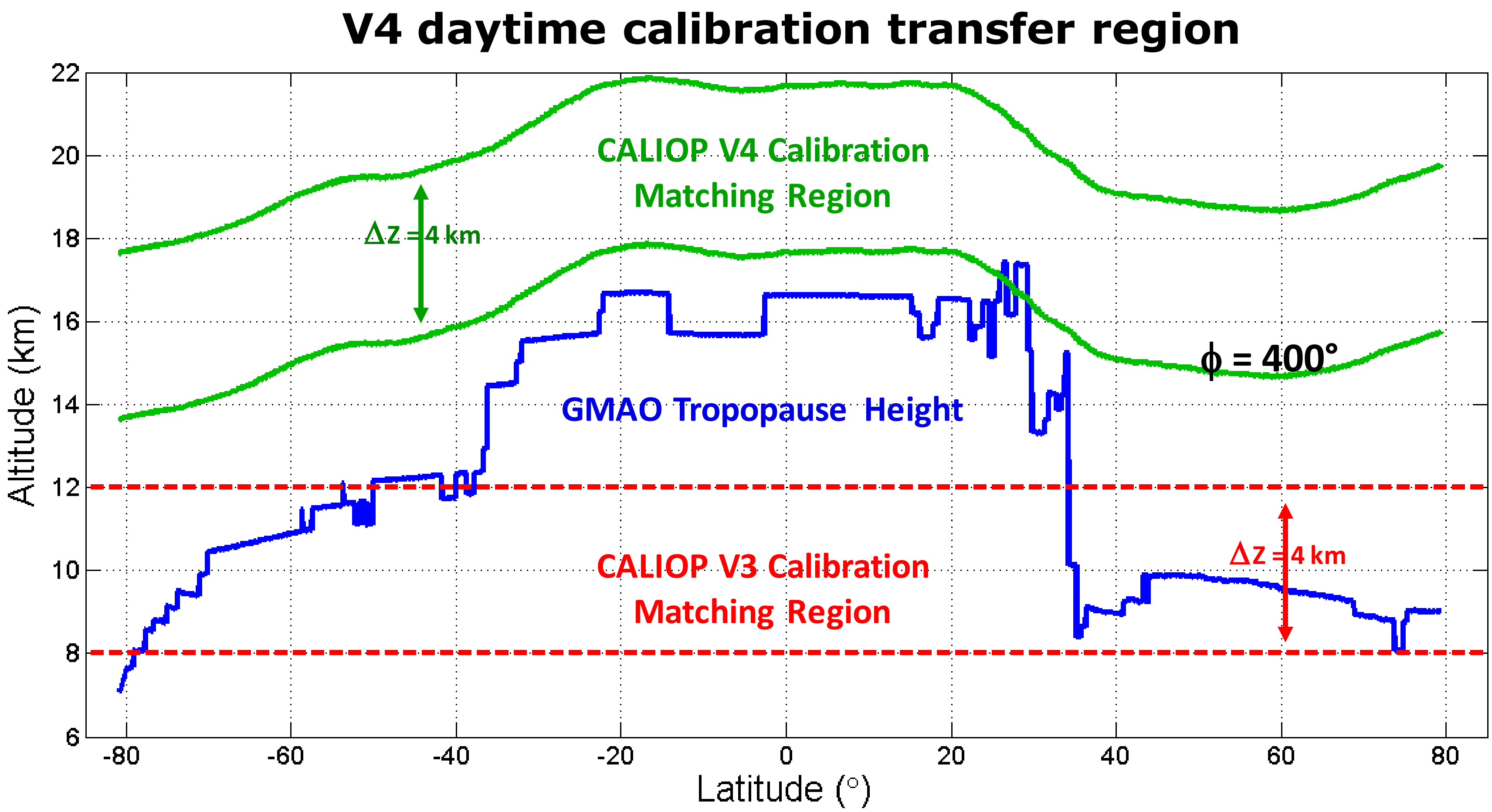
532 nm Day Calibration: V3

Transfer night calibration

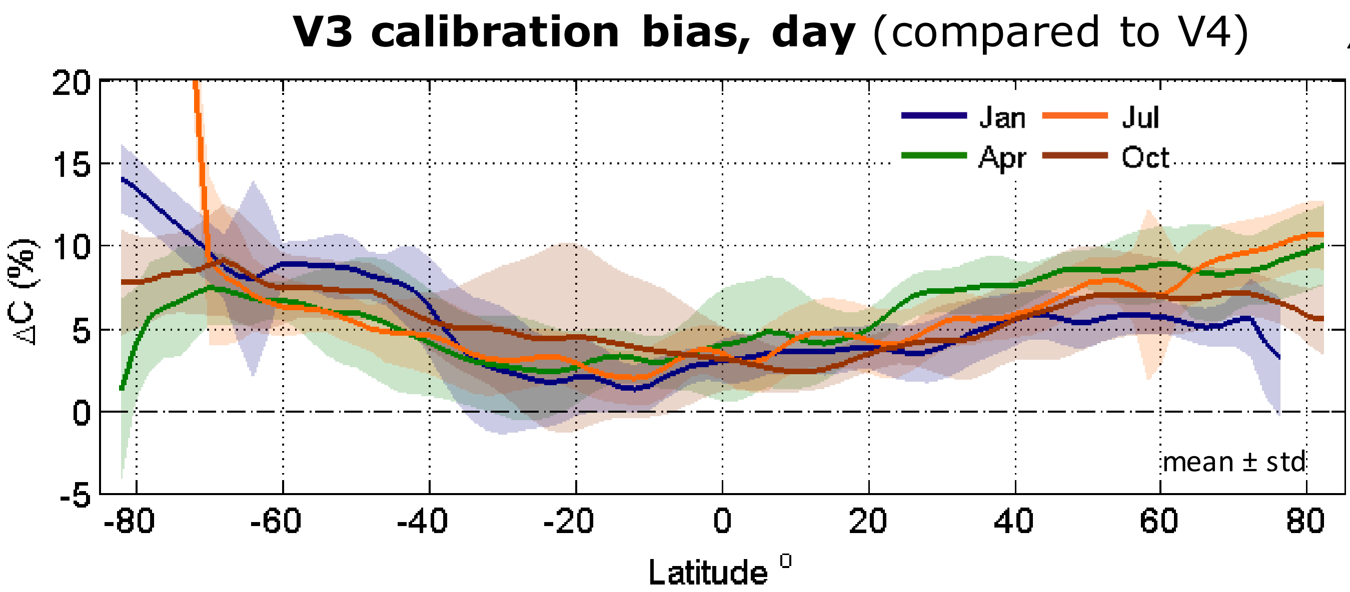


532 nm Day Calibration: V4

Transfer night calibration



532 nm Day Calibration: V3 bias



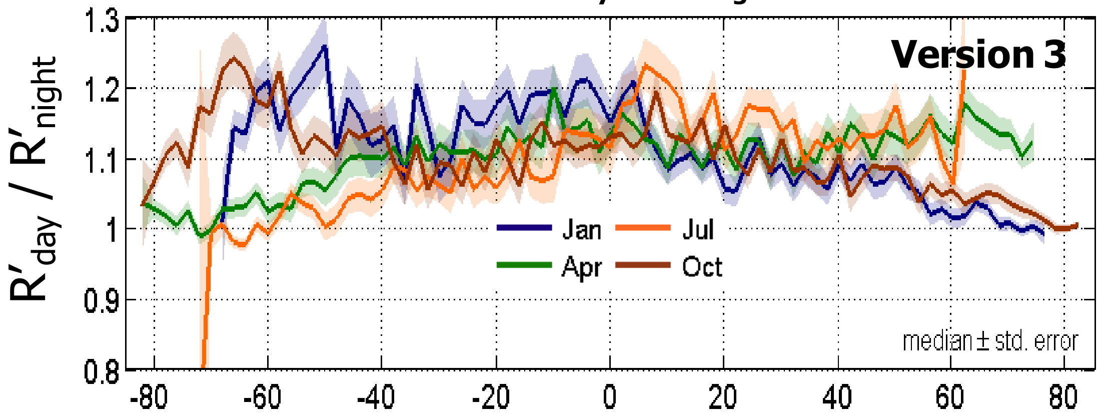
All months 2010

V3 daytime calibration biased high by 2-8%

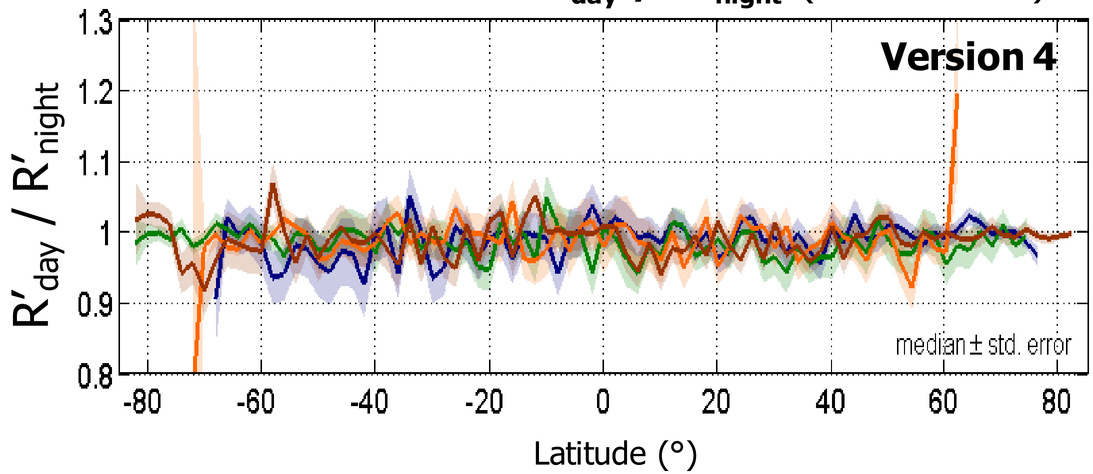
The largest bias at high latitudes

532 nm Day Calibration: V3 bias

Ratio of clear-air R'_{day} / R'_{night} (24 – 30 km)



Ratio of clear-air R'_{day} / R'_{night} (24 – 30 km)

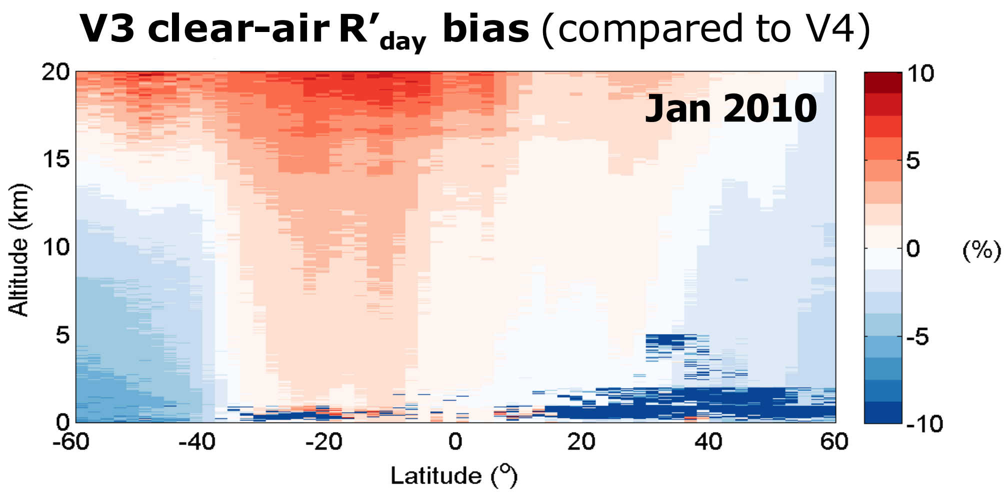


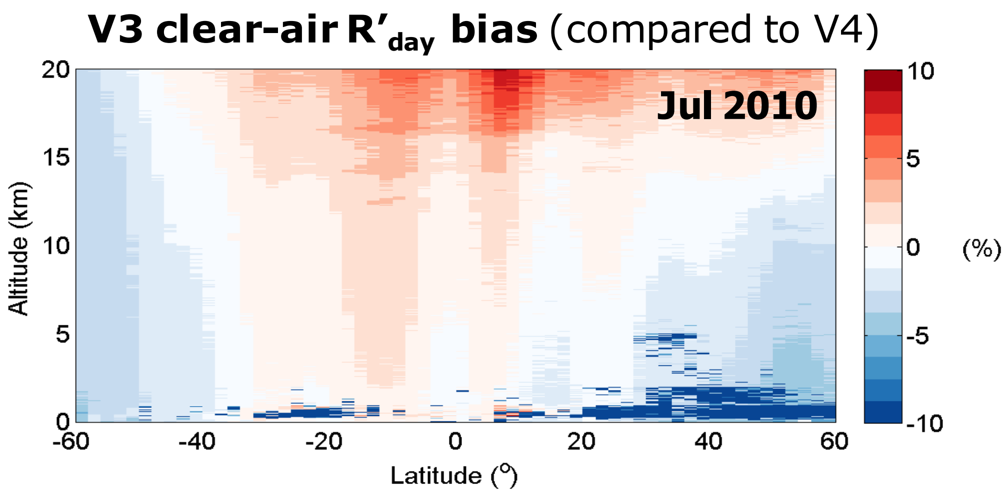
All months
2010

Errors up to 20% exist in V3 daytime scattering ratios where calibration improperly transferred from night to day.

Errors vary with latitude and season.

532 nm Day Calibration: V3 slope bias





Sign and magnitude of bias in V3 daytime scattering ratio (R') changes with altitude and season. Below 2 km at mid-latitudes, the absolute bias around 2%.

CALIOP Level 1 Version Calibration Biases
(comparison with Version 4)

Summary

Level 1 calibration improved with Version 4 release

<u>Version 3:</u>
Calibration biased high by 2-4% at night and 2-8% at day
Largest bias in tropics at night and in high latitudes at day.

<u>Consequences to level 1.5:</u>
Attenuated backscatter bias:
(night) low by 2-8%
(day) ± 5% below 10 km depending on latitude, altitude and season
Some optically thin clouds not removed.

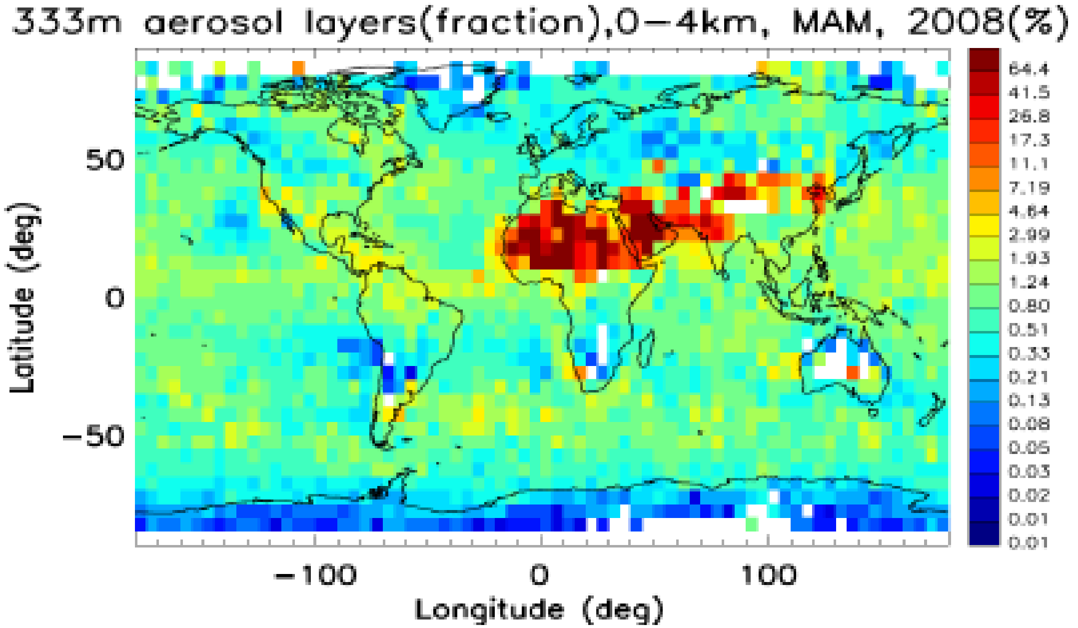
Primary Version 4 Level 2 Improvements

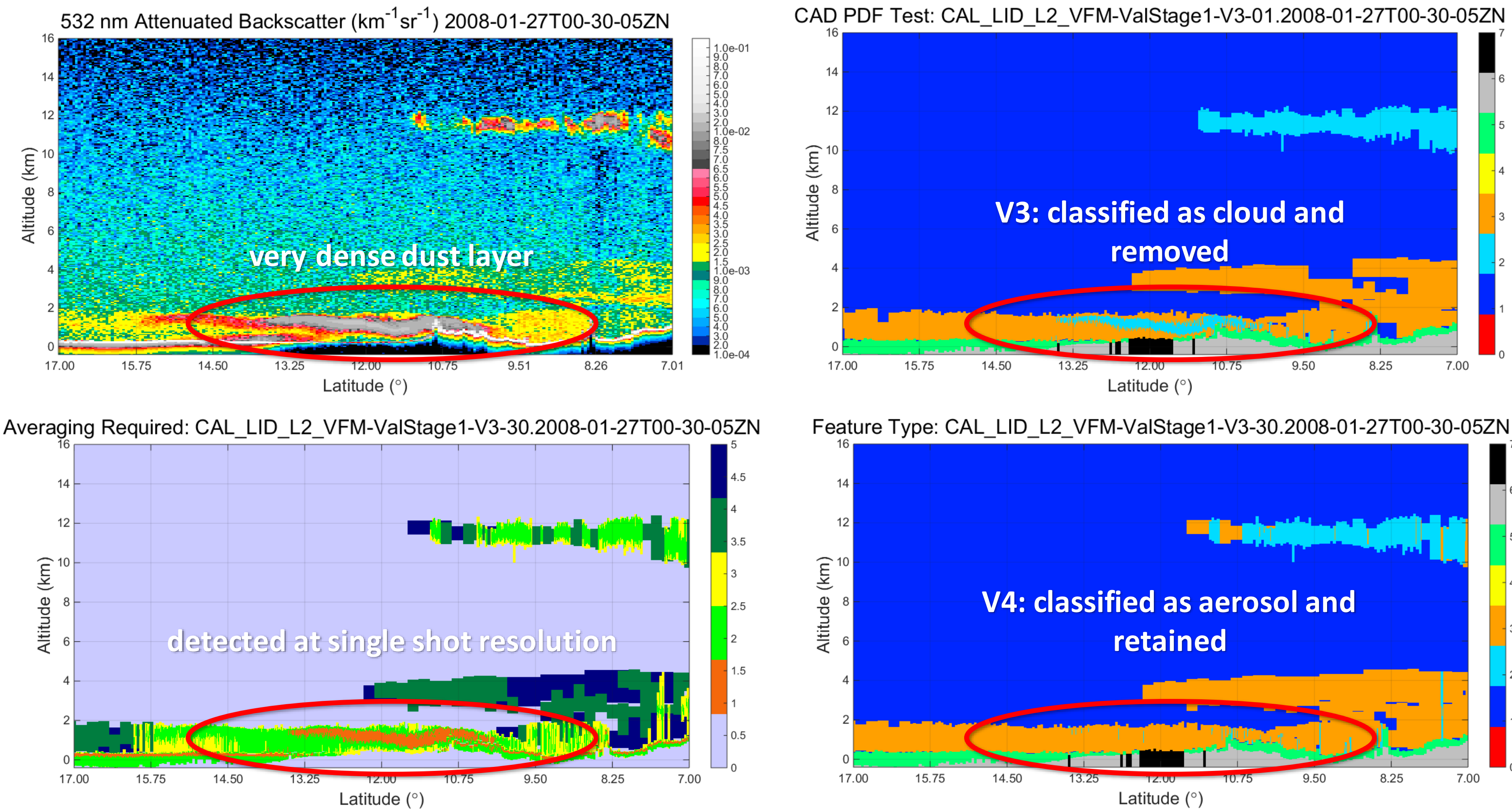
Category	Tasks
Cloud-Aerosol Discrimination (CAD)	Create new Probability Distribution Functions apply CAD to stratosphere apply CAD to 1/3 km layers fix high alt. smoke to cirrus add 1/3-km to 5-km
Surface Detection	new surface detection algorithm fix negative surface spikes
Cirrus Retrievals	new lidar ratios remove threshold from Quality Code 2 parameter opaque retrievals
Aerosol Typing	elevated marine Dust/Pollution Dust errors R_{532} dust scaling
Lidar view-angle step change	Ice/Water phase extinction retrievals of HOI output I/W phase diagnostic codes
Miscellaneous	new aerosol lidar ratios and dust New Ice Water Content parameterization cloud subtype bug

V4 Level 2 - summary of top 16

- new distribution functions (pdfs) for Cloud-Aerosol Discrimination (CAD)
- implement CAD at 1/3 km; retain 1/3 km aerosols
- add 1/3 km cloud data to 5-km cloud product (for IIR)
- improve performance of aerosol typing algorithm (elevated marine, D vs PD)
- revise default lidar ratios for aerosol and cirrus, as needed
- improve performance of the surface detection algorithm
- Improve constrained retrieval technique
  - Improve performance for optically thin cirrus
  - Implement constrained retrievals for opaque layer
- reduce dependence of cloud properties on lidar view angle
- improved parameterization for Ice Water Content (IWC)
- eliminate 'stratospheric' feature type and apply CAD

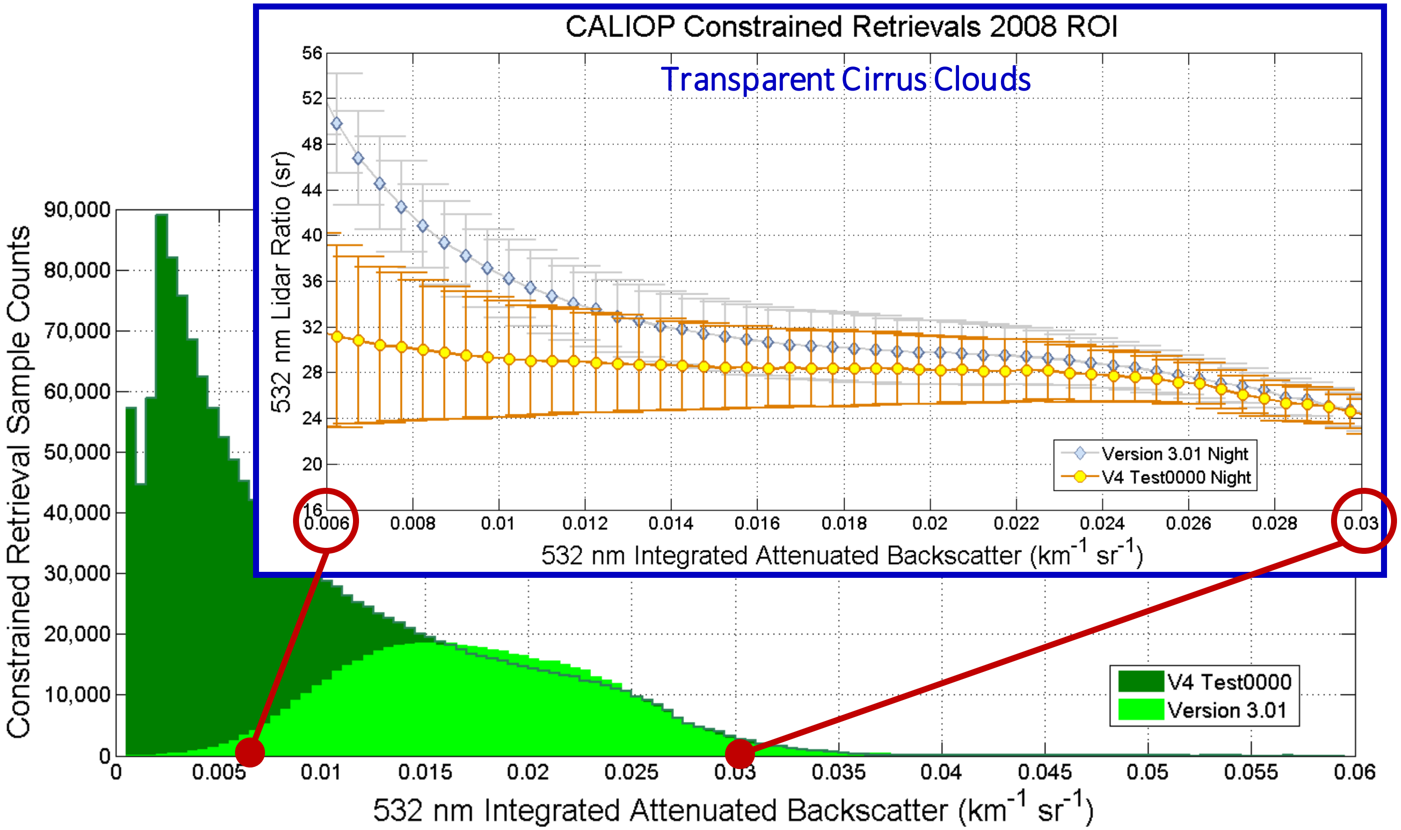
Example #1: 1/3 km CAD





532 nm Attenuated Backscatter (km^{-1}sr^{-1}) 2008-01-27T00-30-05ZN
very dense dust layer
CAD PDF Test: CAL_LID_L2_VFM-ValStage1-V3-01.2008-01-27T00-30-05ZN
V3: classified as cloud and removed
Averaging Required: CAL_LID_L2_VFM-ValStage1-V3-30.2008-01-27T00-30-05ZN
detected at single shot resolution
Feature Type: CAL_LID_L2_VFM-ValStage1-V3-30.2008-01-27T00-30-05ZN
V4: classified as aerosol and retained
Altitude (km)
Latitude (°)

Increase number of constrained retrievals for thin cirrus, improve accuracy



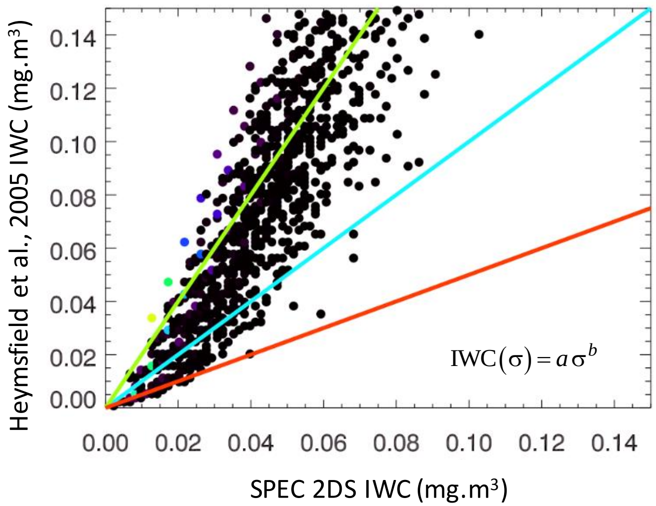
Recent Validation Results

- **Most significant recent validation papers:**
  - Zhaoyan Liu OWC paper
    - more confidence in dust, smoke Sa
  - Garnier IIR paper
    - observationally establish the value of a_{vis}/a_{IR} to 10%
    - What to highlight?
  - IWC parameterization

REVISED ICE-WATER CONTENT PARAMETERIZATION

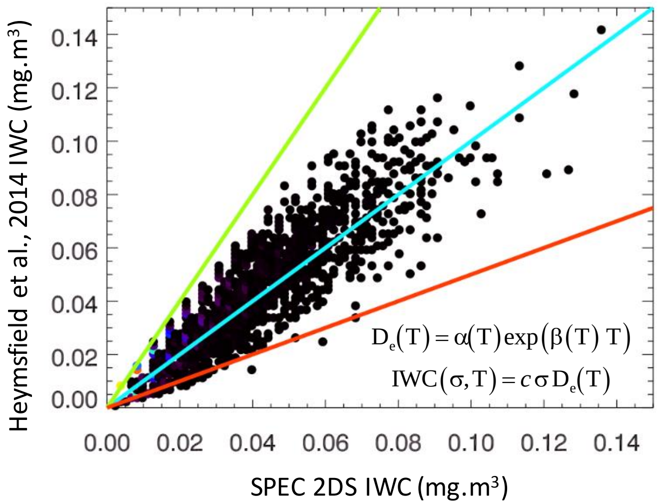
Initial evaluation of temperature-dependent IWC parameterization shows much better agreement with retrievals from in-situ cloud probe measurements of very cold (< -80° C) ice clouds during CR-AVE

CALIPSO V3



Heymsfield et al., 2005
(http://dx.doi.org/10.1029/2005GL022742)

CALIPSO V4

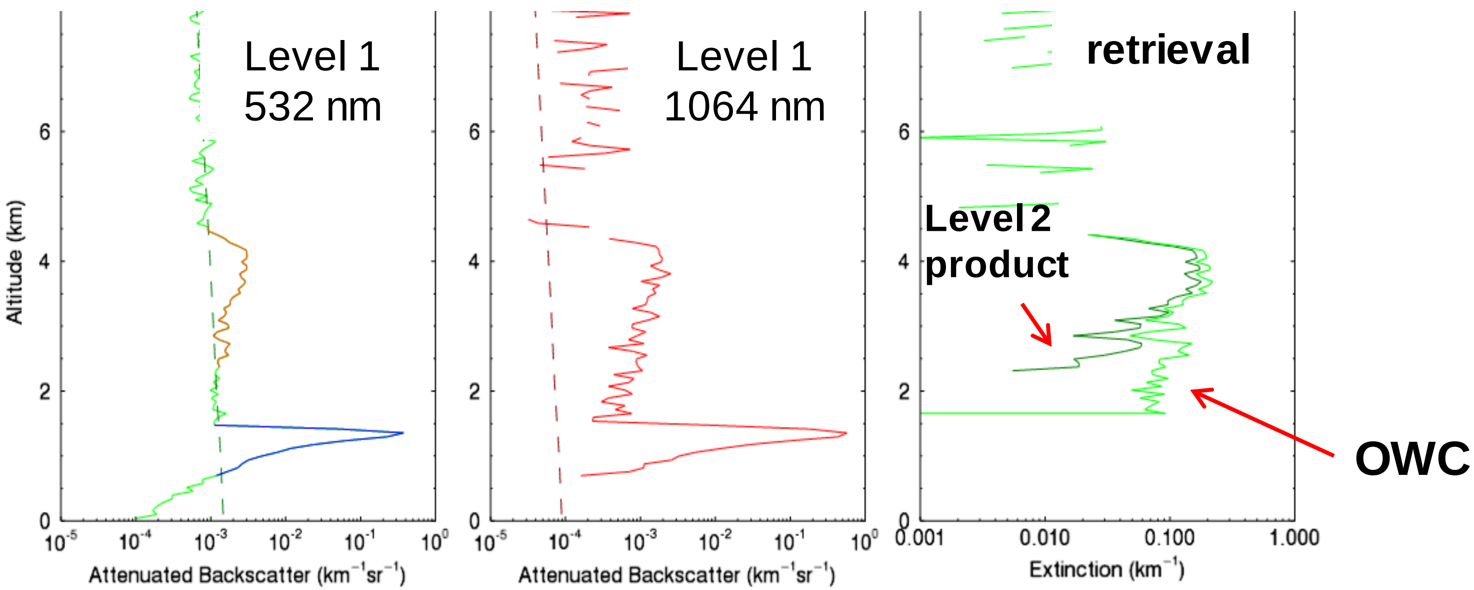


Heymsfield et al., 2014
(http://dx.doi.org/10.1175/JAMC-D-13-087.1)

Above-cloud aerosol retrievals

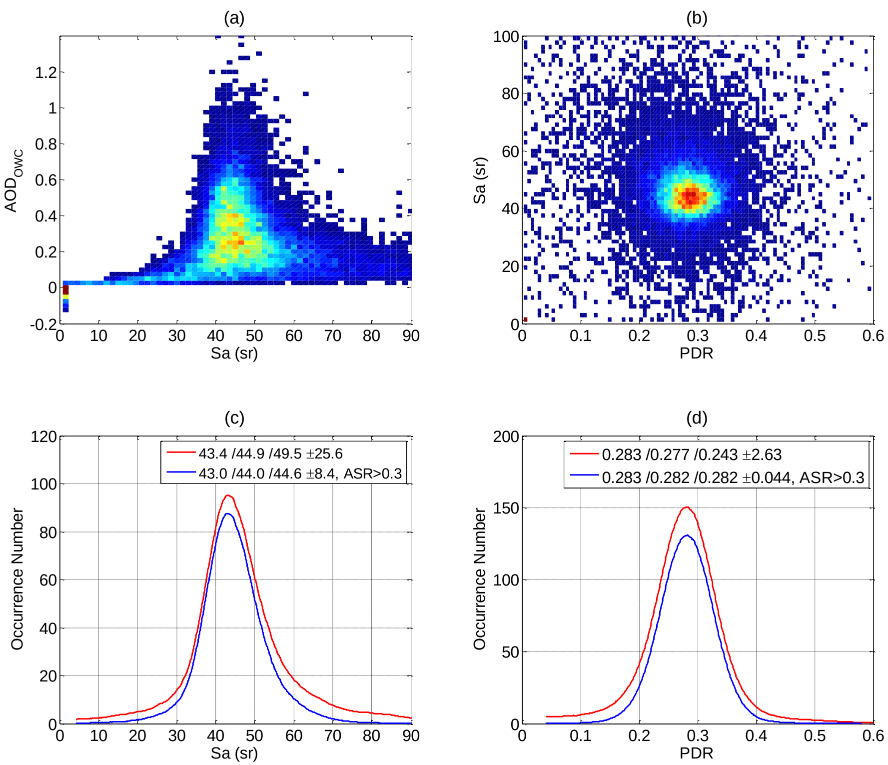
- **Opaque Water Cloud (OWC) retrieval (Hu et al. 2007) uses opaque water cloud as standard target to retrieve AOD and aerosol lidar ratio**
- **AOD derived directly from water cloud returns, used as constraint for retrieval of extinction profile and lidar ratio**
- **Entire column is retrieved, not just within detected layer**
  - ACPD: Zhaoyan Liu, D. Winker et al

Smoke region:

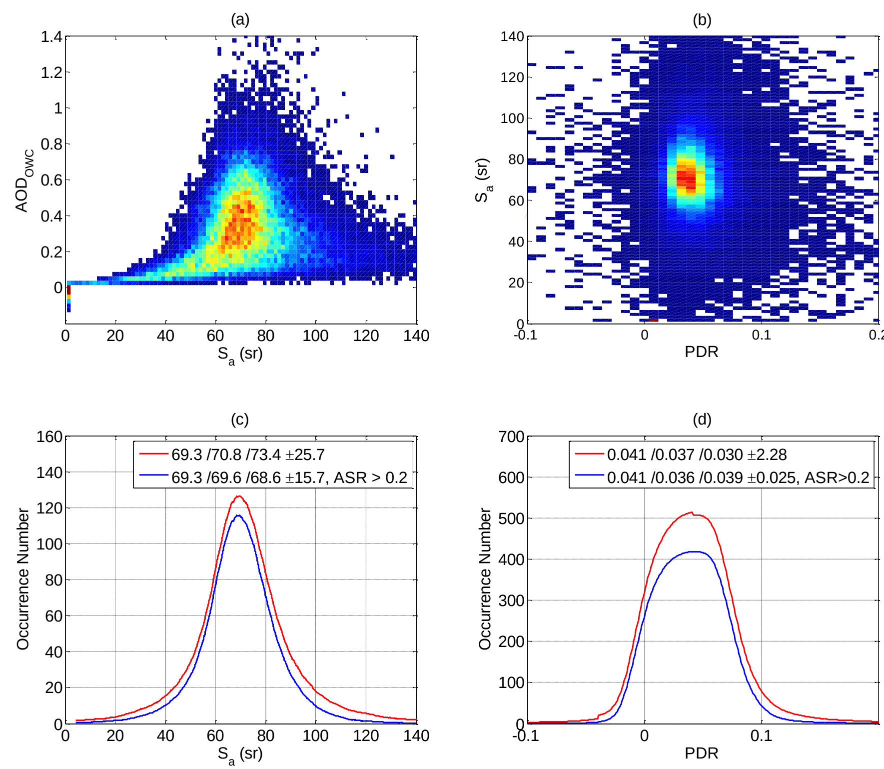


Retrieval of lidar ratio, particle depol
show map?

Dust



Smoke



Partitioning error sources with OWC: findings

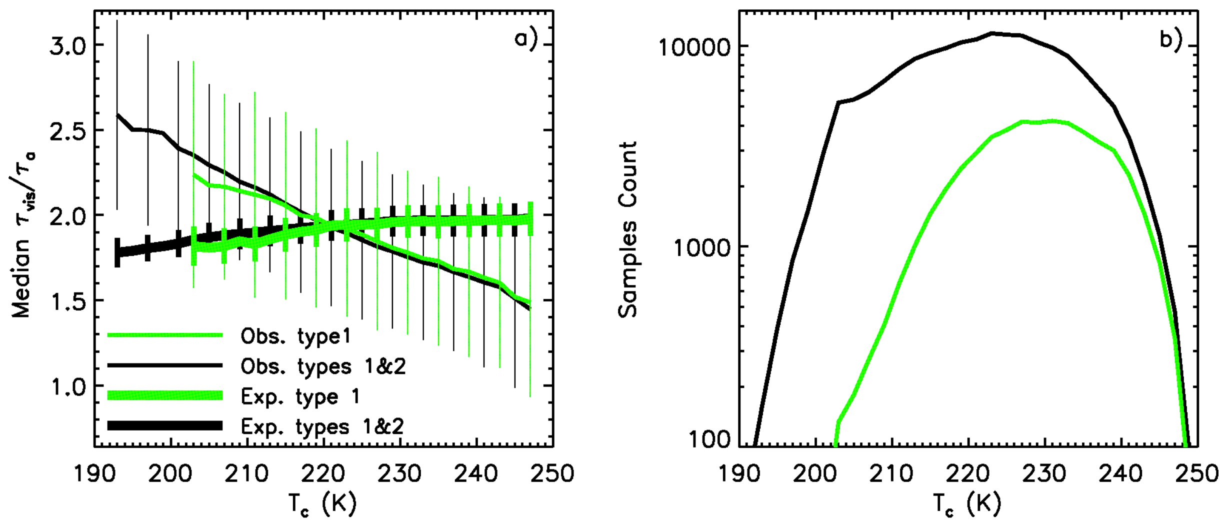
- **Smoke:**
  - Validated default smoke lidar ratio
  - Smoke AOD is underestimated by ~40% due to
    - Failure to detect full vertical extent of the smoke layer
    - Errors in aerosol typing also contribute (will be fixed in V4)
- **Dust**
  - Lidar ratio used for dust (40 sr) is about 10% too small
  - High confidence in identifying "Dust" type
  - Dust AOD is underestimated by ~25%
    - Mostly due to default lidar ratio

Main cause for discrepancy in smoke AOD:
failure to detect full vertical extent,
but typing errors also contribute

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

Constrained cirrus OD retrievals ...

Using IIR to improve constrained retrievals …



Garnier et al. (AMTD, 2015)

Fig. 8: (a) Median observed (thin lines) and expected (thick lines) τ_{vis}/τ_a and (b) associated sample count vs temperature for clouds with measured R_{BG} (green) and all clouds (black). Data set: single-layered cirrus ROI with high confidence, base temperature < -20°C, extended CALIOP optical depth measurements, $2t_a > 0.3$, over ocean, 2008.

Validation: S_{ci}

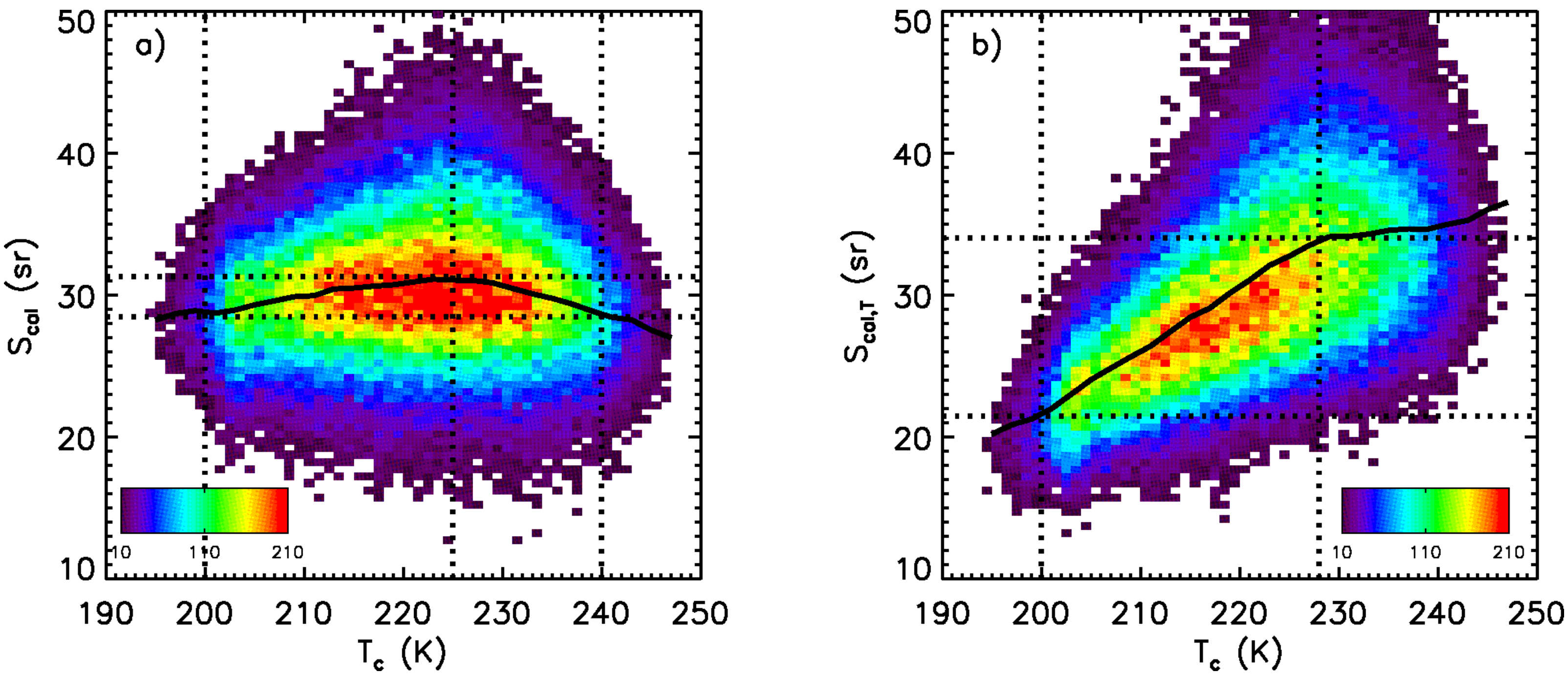


Fig 12: 2D-histogram of lidar ratio (a) S_{cal} (h=0.6) and (b) $S_{cal,T}$ (h_T from this study), and centroid temperature T_c. The color code is the number of samples. The black solid line is the median value.

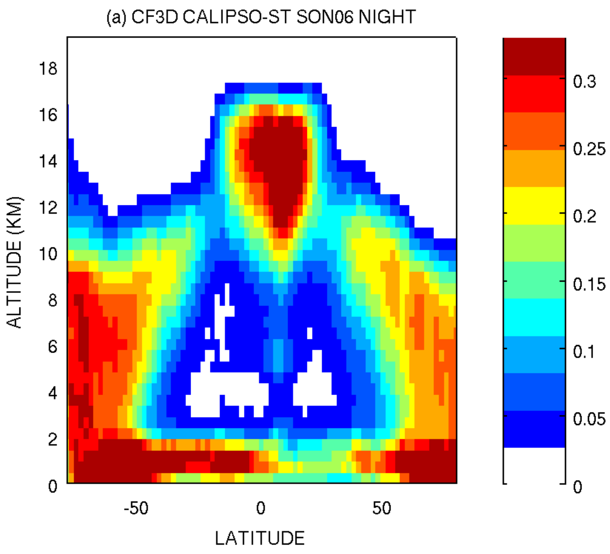
Revised Level 3 Aerosol Product

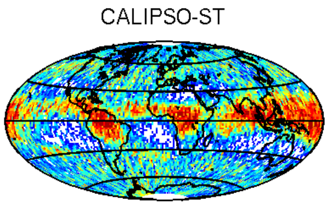
- Improved data filters to reduce artifacts
- Improve methodology for computing averages
- Group profile data by aerosol type and for more realistic sky conditions
- Product Maturity will be promoted from **Beta** to **Provisional**
- Release in summer 2015

Changes	Version 1	Version 2
Revised sky conditions	All-sky Cloud-free Above-cloud Combine (cloud-free + above-cloud)	All-Sky Cloud-Free Cloudy-Sky, Transparent Cloudy-Sky, Opaque
Add profiles of individual species	All species Dust	All species Dust Polluted Dust Smoke
Correct the way single-species averages are calculated	Ignored	Assign extinction = 0.0 /km
Correct computation of column AOD	Average of column AODs	Integral of average extinction
Extinction scale height (63%, 90%)	n/a	Included

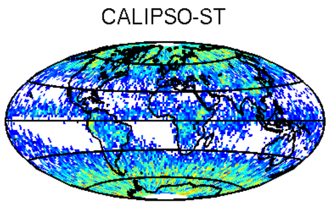
Level 3 Cloud Products

- **A limited Level 3 cloud product has been developed for comparison with the GOCCP product**
    - Contains 3D cloud occurrence, cloud ice-water phase
    - 480 m x 2^{o} x 2^{o}, 2006-2007 only
- **Full Level 3 cloud product in development, to be based on V4 Level 2**
    - Adds more parameters:
        - optical depth, IWC
        - De, IWP from IIR retrievals
        - Co-variations of lidar and IIR properties
- **Analysis underway to refine product definition**

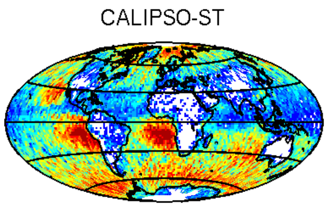




High

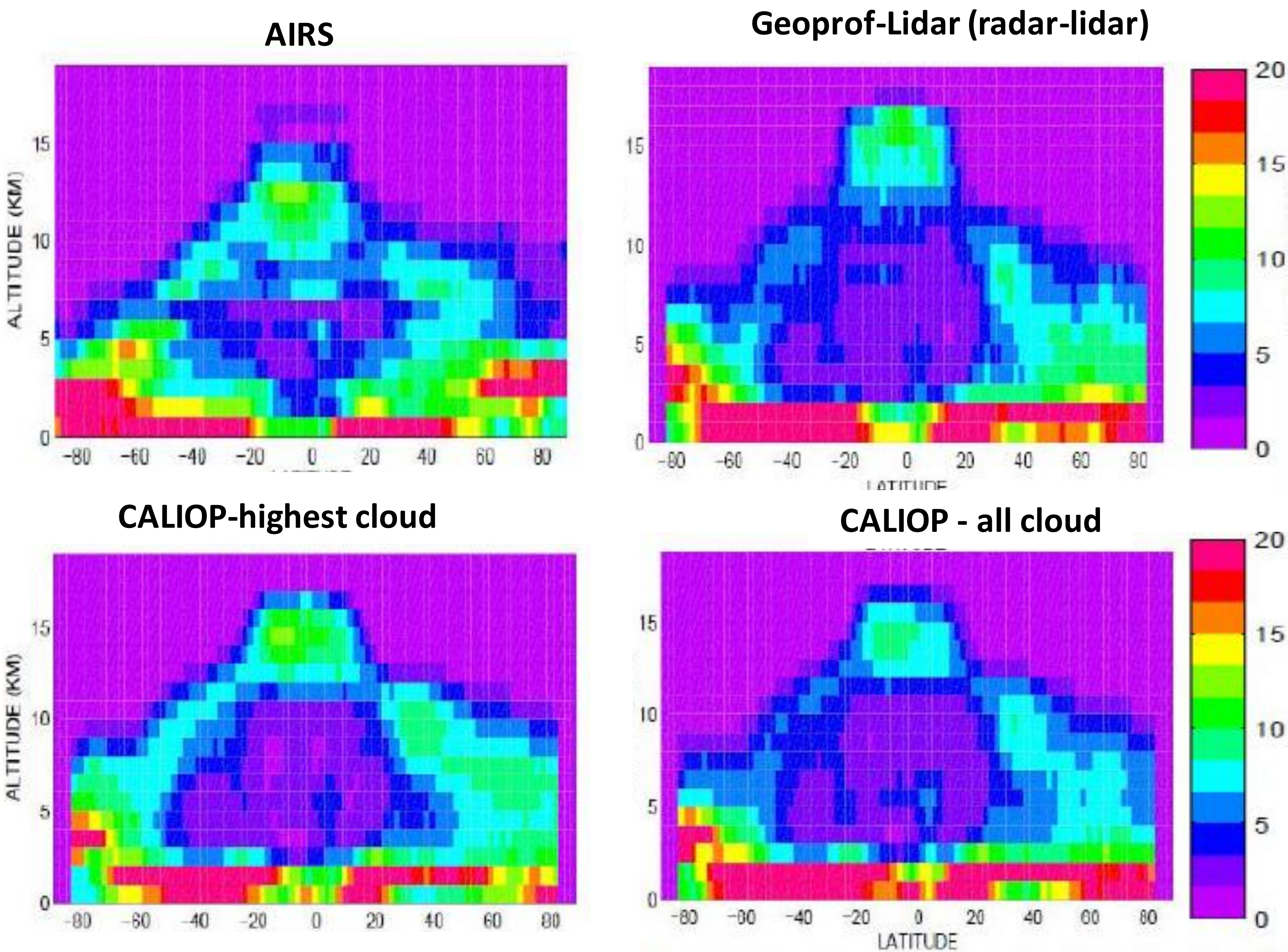


Mid



Low

Zonally averaged cloud occurrence



Version 4 Lidar Development Plans: Level 1

- **Version 4 release, completed last year, incorporates major improvements**
- **Several small revisions needed:**
  - Snow/Ice data not included in L1 surface types
  - GMAO preparing to upgrade to new model version
  - Incorporation of more modern DEM

Version 4 Lidar Development Plans: Level 1.5

- **Level 1.5 continues to be provided as a near-realtime product**
  - Cloud-cleared Level 1 profiles, horizontally averaged over 20 km
- **A re-analysis version will be produced from Version 4 Level 1**
  - Represents and aerosol climate data record
  - To NASA Goddard GMAO for assimilation into the MERRAero re-analysis product
  - To PCMDI for use in evaluation of climate models
- **Target date:**
  - Have produced one year, based on V3 L1

Version 4 Lidar Development Plans: Level 2

- **Changes in L1 calibration require development of new pdf's for cloud-aerosol discrimination (CAD) algorithm**
  - Largely completed
- **Target date for L2 release: spring 2016**

Version 4 Lidar Development Plans: Level 3

- **Level 3 Aerosol Product**
  - Revisions to current version identified and defined
    - Revised scene definitions
    - Added extinction profiles for smoke, polluted dust
    - Correction of several errors
  - Implementation underway
  - Target release date: summer 2015
- **Level 3 Cloud Product**
  - Product definition is underway
  - Requirements document in development
  - Target release of initial version: spring 2016
  - Includes update of CALIPSO-CA and CALIPSO-ST

Summary (updated from 2014)

- Level 1 Version 4 released since spring 2014. Objectives and requirements have been met. Documentation in peer-reviewed papers is underway.
- Level 2 algorithm priorities for Version 4 identified and development is underway. Release planned in spring 2016.
- Revision of Level 3 aerosol product underway, to be released this summer.
- Level 3 cloud product definition underway. New analyst on-board to support effort.
- Validation efforts continue. Findings are routinely incorporated into product development cycle.