Recent Improvements in CALIPSO Aerosol Products

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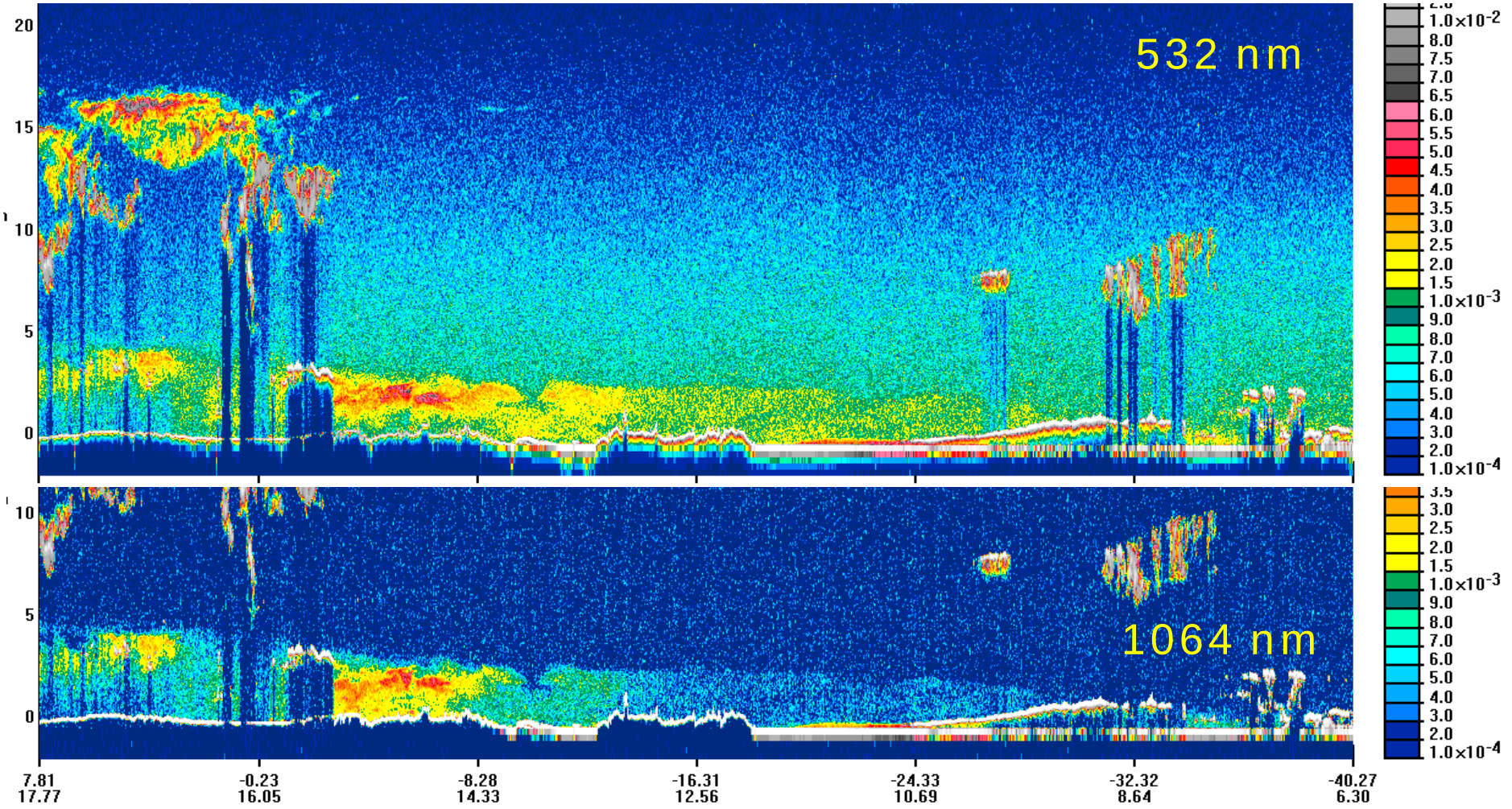
1) NASA LaRC

2) SSAI, Hampton

3) NASA Postdoctoral Program

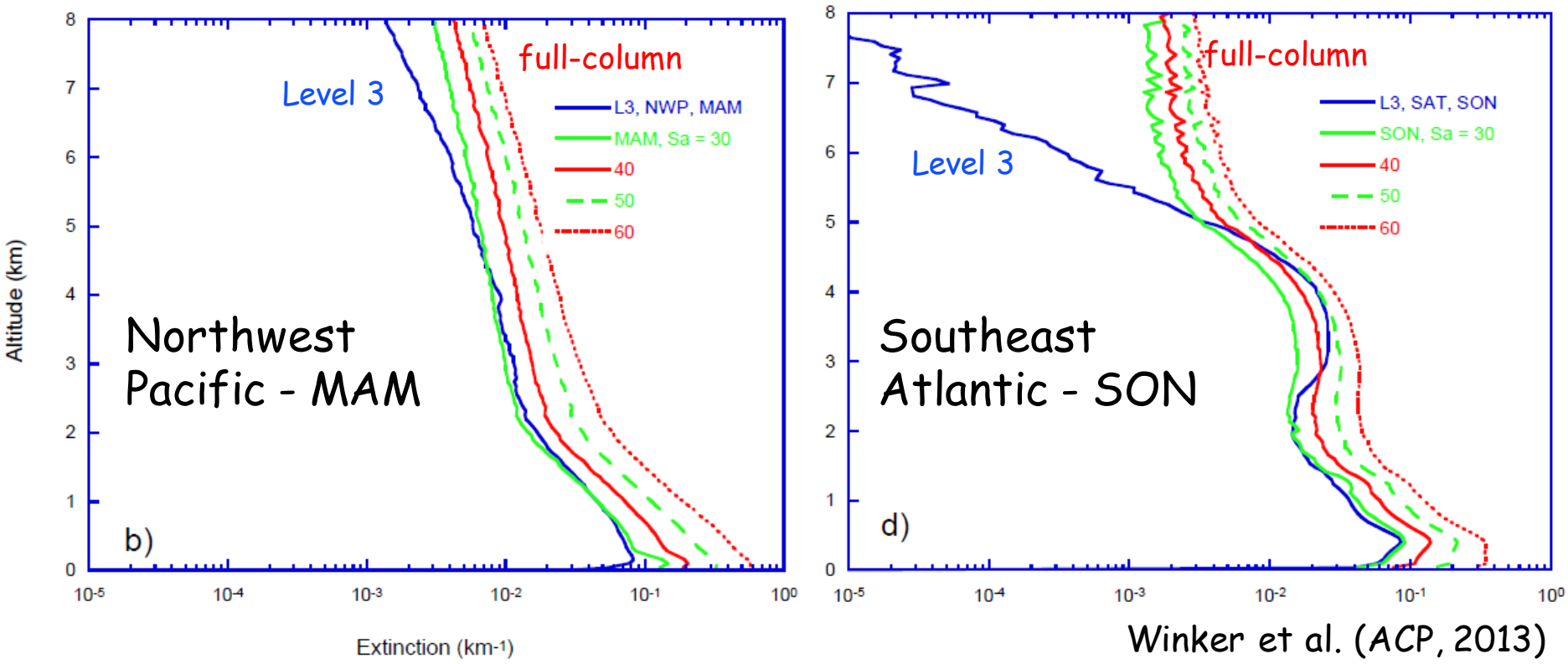
Reminder 1

this is raw data, not a retrieval !



Reminder 2

- In upper troposphere: standard CALIOP products represent a lower bound on aerosol extinction
- Accuracy of research-mode full-column retrievals probably limited by calibration error in upper troposphere



Winker et al. (ACP, 2013)

CALIOP Level 1 Updates

- Level 1 V4.0 released – 2015
  - Reduced tropical biases (4%-8%) to 1%~2%
  - Removed day-night and seasonal biases seen in V3
  - Removed large 1064 latitudinal biases
- Level 1 V4.10 (minor update) released Nov 2016
  - Replaced Version 3 DEM with new CloudSat DEM
  - Update meteorology from GMAO-FPIT to MERRA-2
  - Several minor bugs fixed
- Paper describing V4 night-time calibration just submitted to AMT
- Level 1 V4.10 used as basis for new V4 Level 2

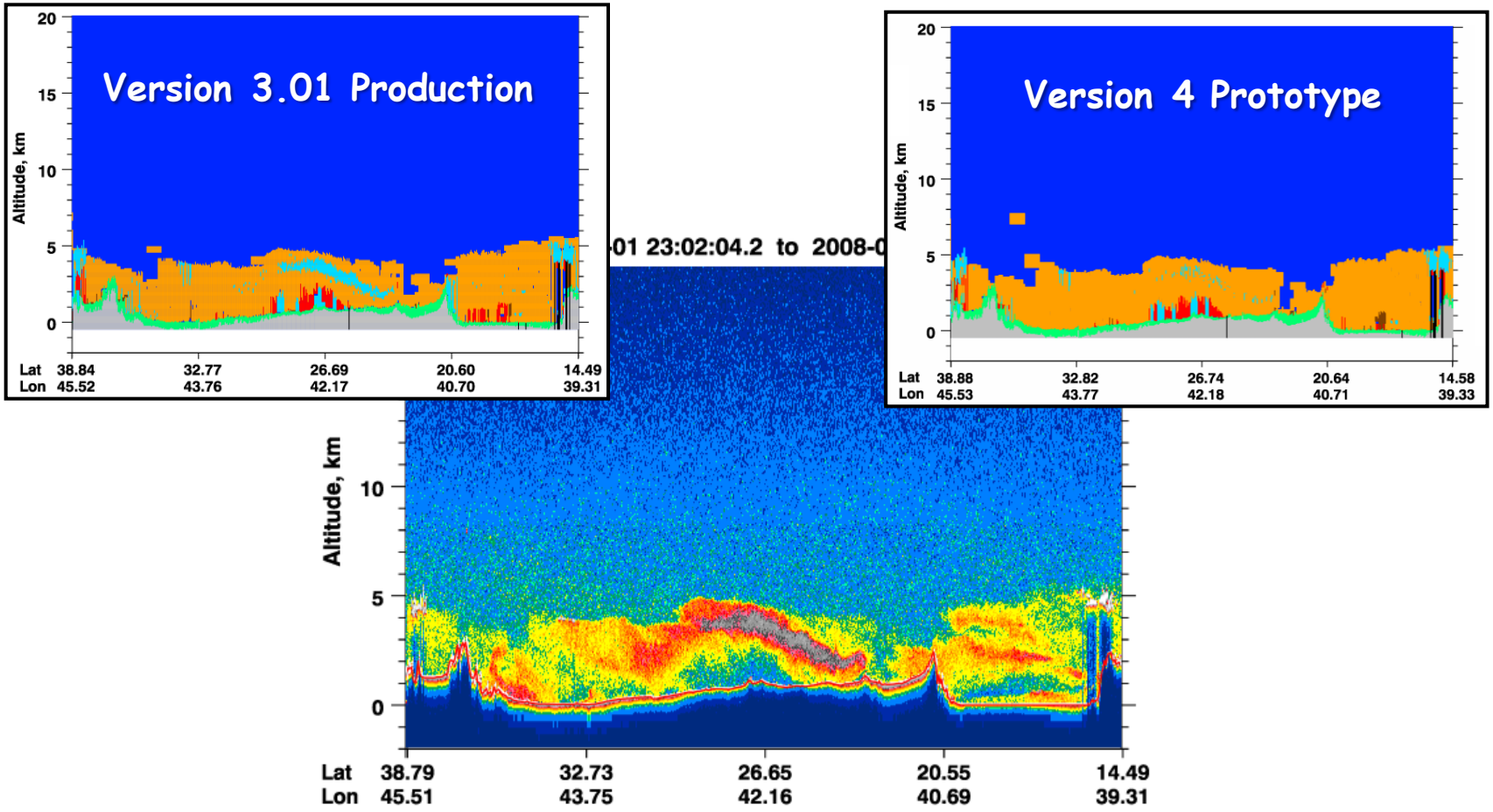
Current Level 2: Version 4.10 (released Nov 2016)

Many improvements:

- New distribution functions for Cloud-Aerosol Discrimination (CAD)
- Now perform CAD at 1/3 km
  - V3: all layers detected at 1/3 km assumed to be cloud
- Many improvements to aerosol typing
- More realistic lidar ratios for dust, marine aerosol
- New surface detection algorithm
  - More accurate detection of "opaque" layers
- New constrained retrieval algorithm for opaque layers
- CAD now applied in stratosphere
  - New stratospheric aerosol typing algorithm
- Many V3 bugs fixed (elevated marine aerosol, …)

Cloud-Aerosol Discrimination (CAD)

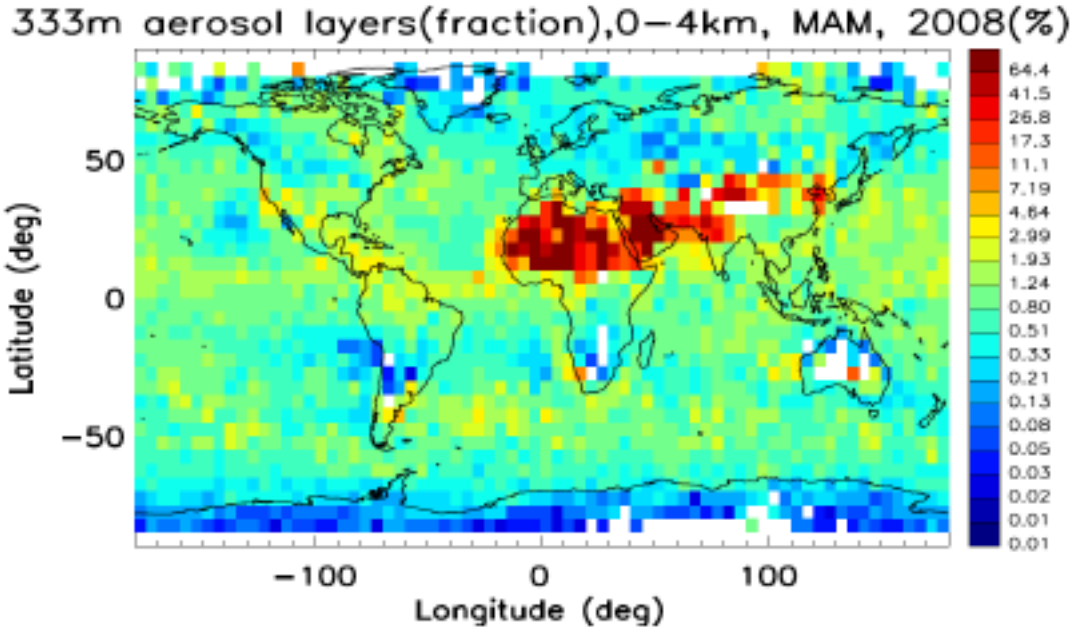
CAD now applied to single-shot data



CAD on 1/3 km profiles

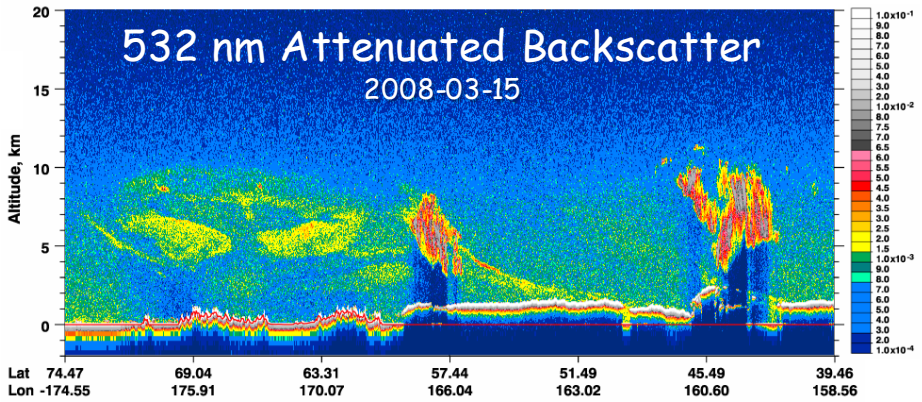
- In Version 3, anything detected on single-shots was classified as cloud
  - Dense smoke and dust layers often classified as cloud
- In Version 4, Cloud-Aerosol Discrimination (CAD) algorithm will be applied to single-shot profiles

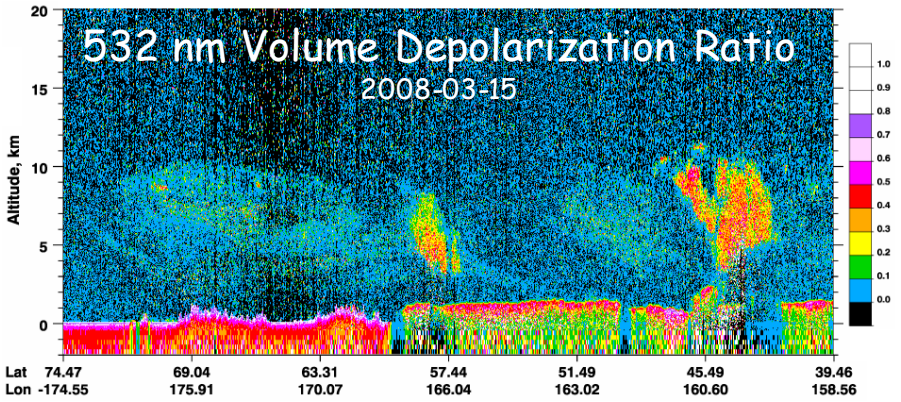
Results from 1/3 km CAD:
(most 1/3 km aerosol layers correspond to dense dust)

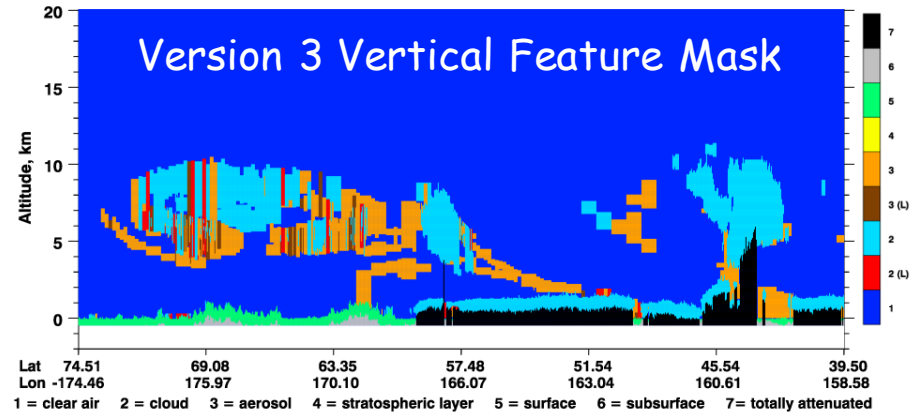


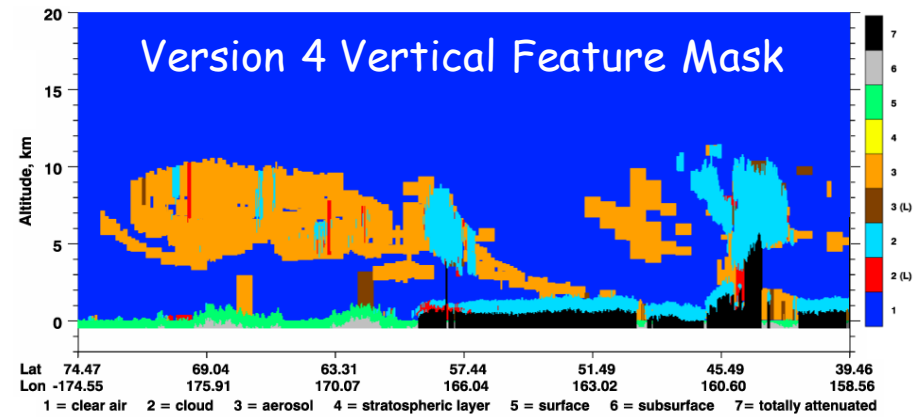
Cloud-Aerosol Discrimination (CAD)

- Revised CAD algorithm required to accommodate new (V4) calibration
- Fixes several V3 problems (misclassification of high-latitude aerosol)







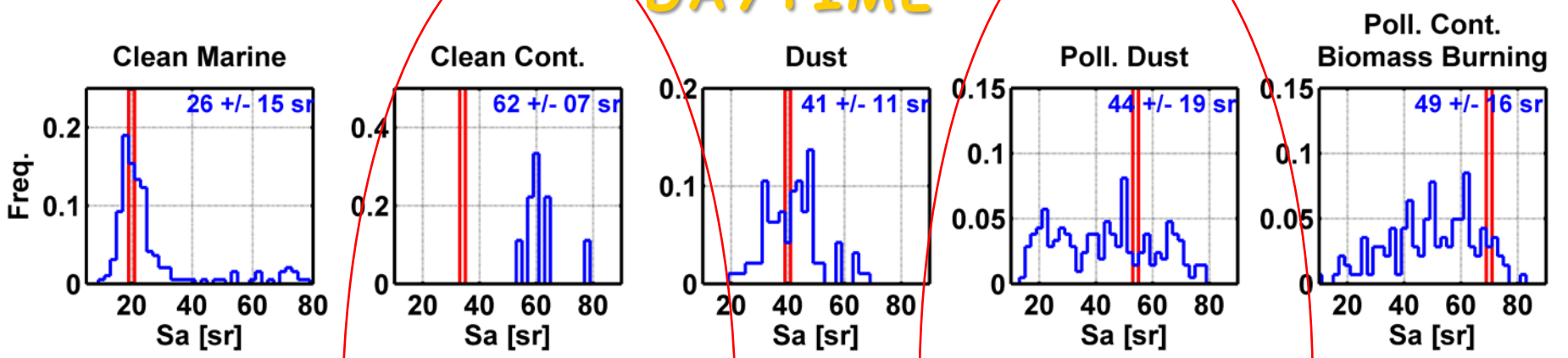


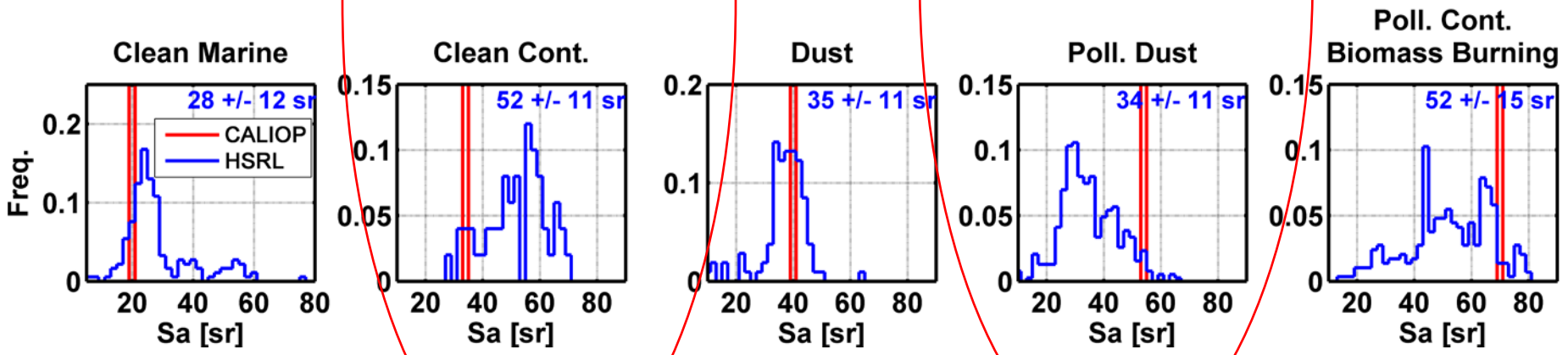
Evolution of Aerosol Typing

- Some of the aerosol lidar ratios updated
- "Dusty Marine" type added
- It does not seem possible to discriminate smoke and polluted continental based on color ratio with acceptable fidelity
  - No statistic examined could cleanly separate smoke color ratio signature from other types either on a large average scale or for individual case studies
- Now perform aerosol typing in stratosphere in V4

Lidar ratio updates guided by regional HSRL measurements

DAYTIME

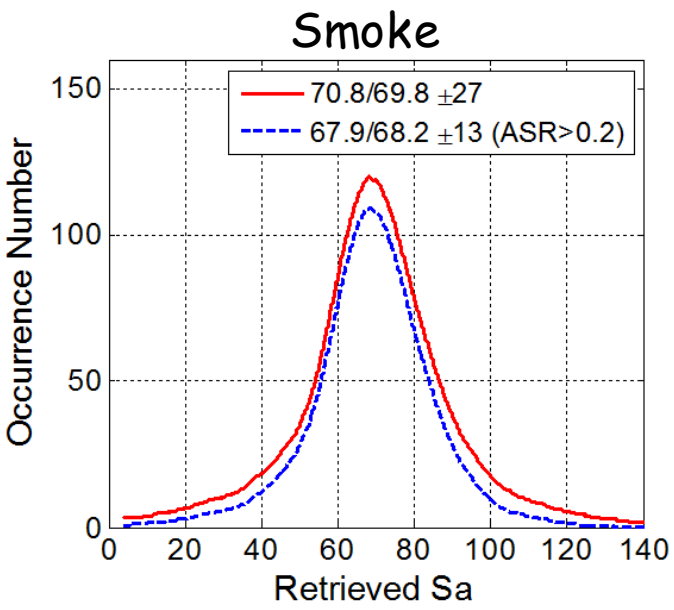


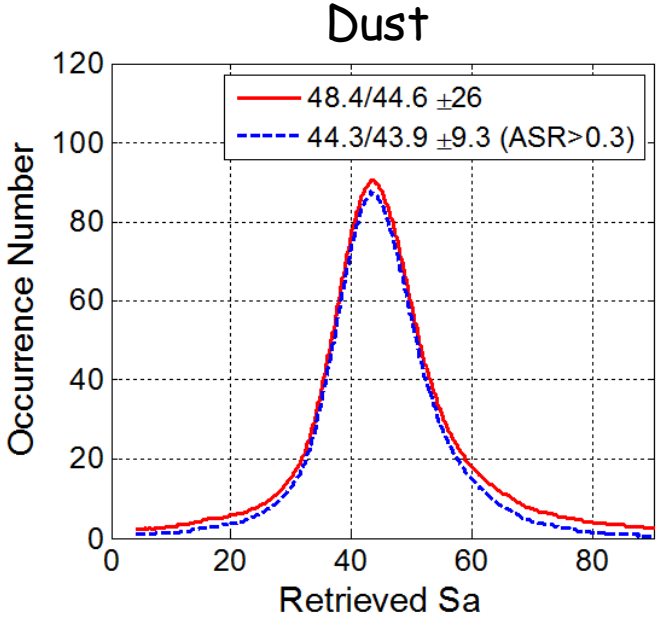


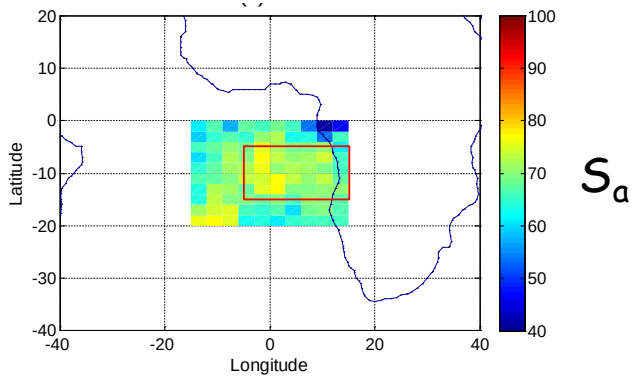
NIGHTTIME

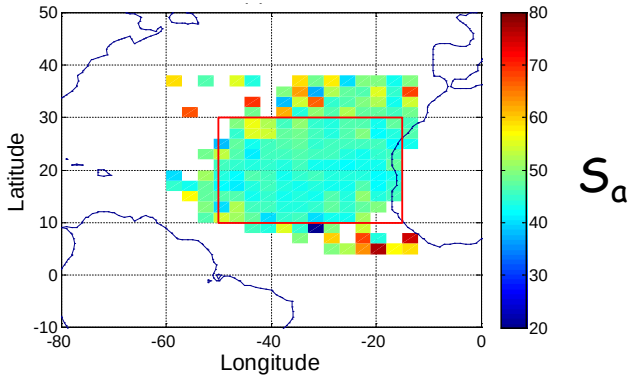
(Rogers et al., 2014)

Dust/Smoke also guided by regional constrained retrievals









Z. Liu, D. Winker, et al (2015), Evaluation of CALIOP 532nm aerosol optical depth over opaque water clouds, *ACP* **15**, 1265–1288

V4 Tropospheric Aerosol Lidar Ratios
(estimated uncertainties mostly smaller in V4)

Layer Type	532 nm Lidar Ratios (sr)	
	Version 3	version 4
Dust	40 ± 20 (50%)	44 ± 9 [A,B]
Smoke	70 ± 28 (40%)	70 ± 16 [A]
Clean Continental	35 ± 16 (45%)	53 ± 11 [C]
Polluted Continental	70 ± 25 (35%)	70 ± 25
Polluted Dust	55 ± 22 (40%)	55 ± 22 (40%) [D]
Clean Marine	20 ± 6 (30%)	23 ± 5 [E]
Dusty Marine	---	37 ± 15 [F]

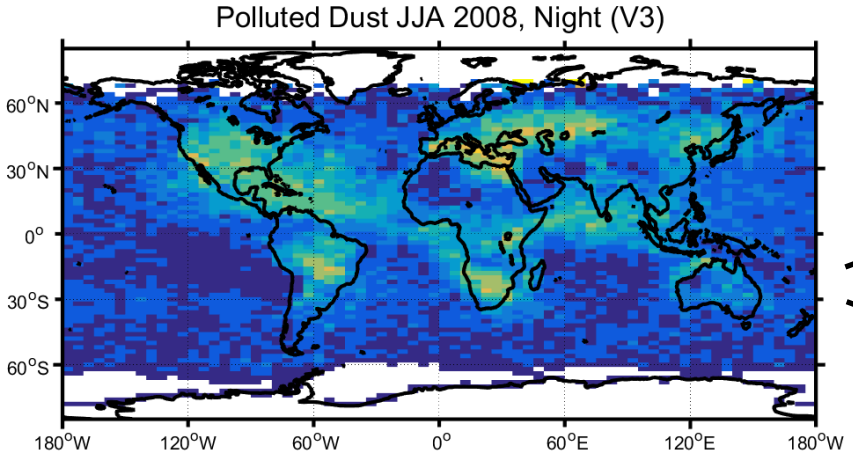
[A] CALIOP constrained retrievals Liu et al. (2014)
[B] HSRL measurements of transported Saharan dust
[C] Based on HSRL S_a measurements (Rogers et al., 2014)
[D] Based on microphysical measurements made during NAMMA.
[E] S_a measured by HSRL in multiple field campaigns & Müller et al. (2007). No λ dependence
[F] S_a based on mixture of dust and marine aerosol (65/35 by surface area).

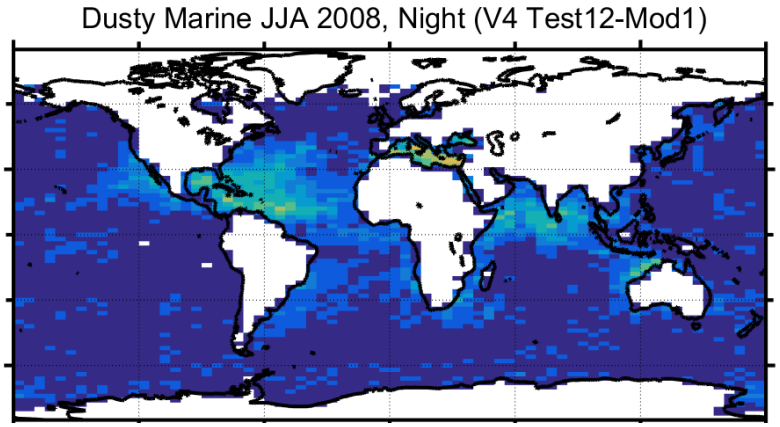
Aerosol Typing Improvement

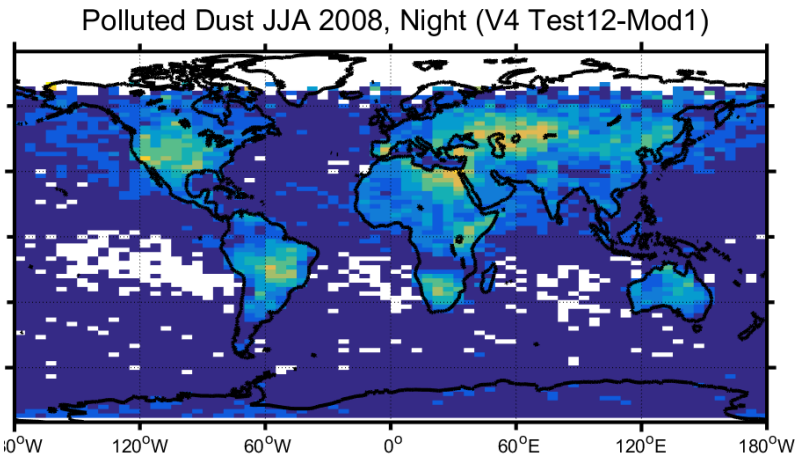
Too much "Polluted Dust" in V3

partly due to dust mixed into marine boundary layer

New "Dusty Marine" type improves AOD and identification of type







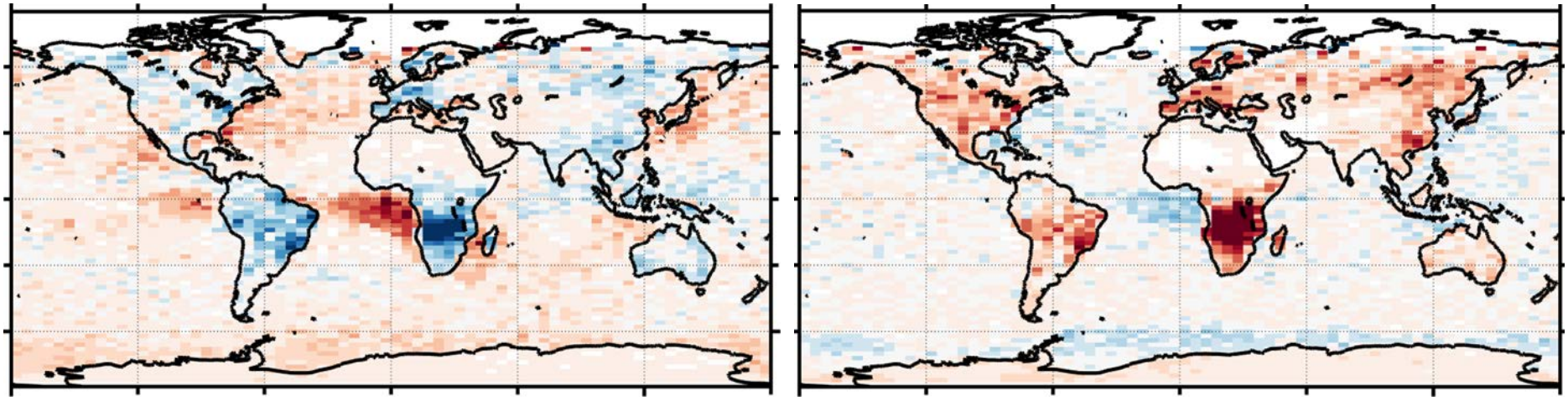
V4 lidar ratios:

Marine	23 sr
Dusty marine	37 sr
Polluted dust	55 sr

New Interpretation of "Smoke"

V4-V3 change: smoke

V4-V3 change: polluted continental



JJA 2007, night

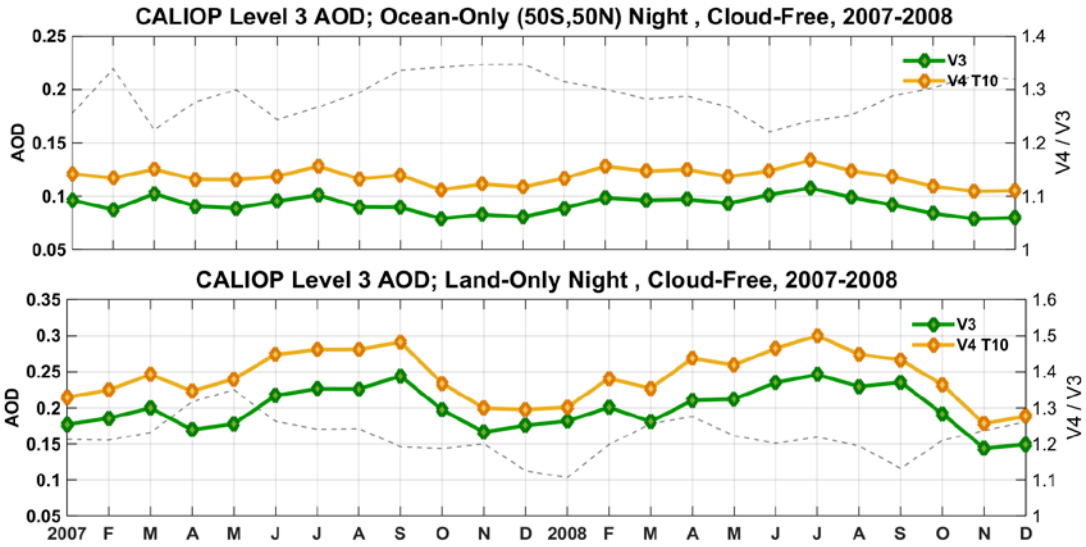
-40 -32 -24 -16 -8 0 8 16 24 32 40

Frequency Difference (percent)

Revised nomenclature:	smoke	elevated smoke
	polluted continental	polluted continental/smoke

(same lidar ratio still used for smoke and polluted continental: 70 sr)

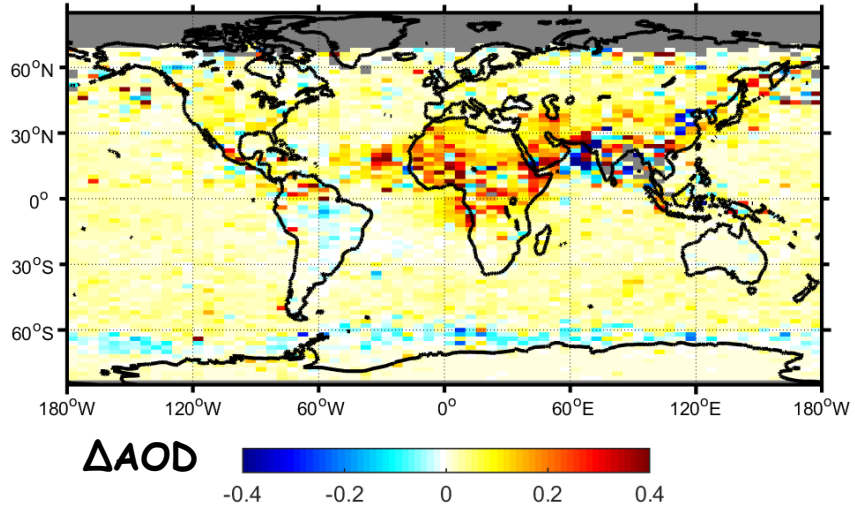
V4-V3 AOD Difference, Night



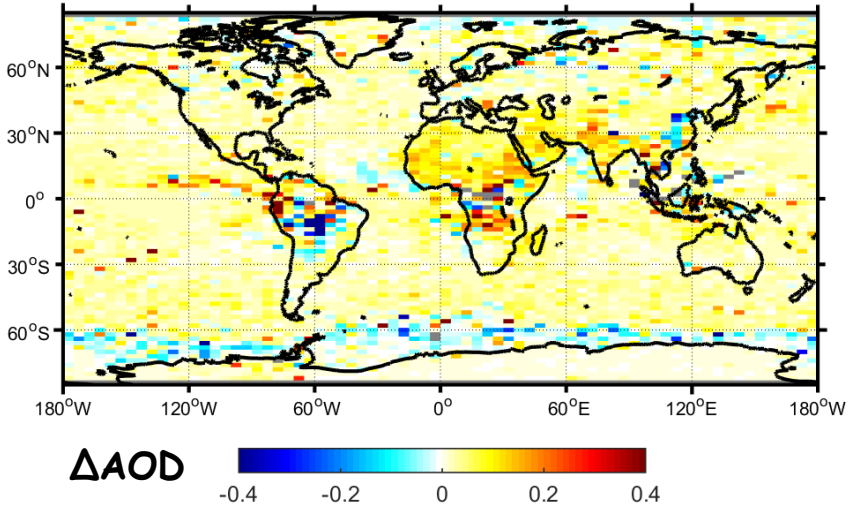
Ocean:
- V3 = 0.092
- V4 = 0.118
- ΔAOD = +28%

Land:
- V3 = 0.199
- V4 = 0.243
- ΔAOD = +22%

AOD Difference CloudFree, JJA-2007N; V4 Test 10 - V3



AOD Difference CloudFree, SON-2007N; V4 Test 10 - V3



CALIPSO V4 vs MODIS C6

Combined effect of V4 improvements: <u>global mean AOD now consistent with MODIS</u>

- improved calibration
- improved CAD
- lidar ratios increased for several species
- dense dust and smoke (1/3 km) now included

	V3	V4	MODIS C6
Mean AOD (± SD)	0.081 ± 0.138	0.091 ± 0.164	0.093 ± 0.114
Median AOD (± MAD*)	0.048 ± 0.035	0.052 ± 0.035	0.064 ± 0.031
Mean AOD Bias	**-0.012** ± 0.109	**-0.002** ± 0.123	
Mean Absolute Difference	**0.058** ± 0.093	**0.059** ± 0.108	

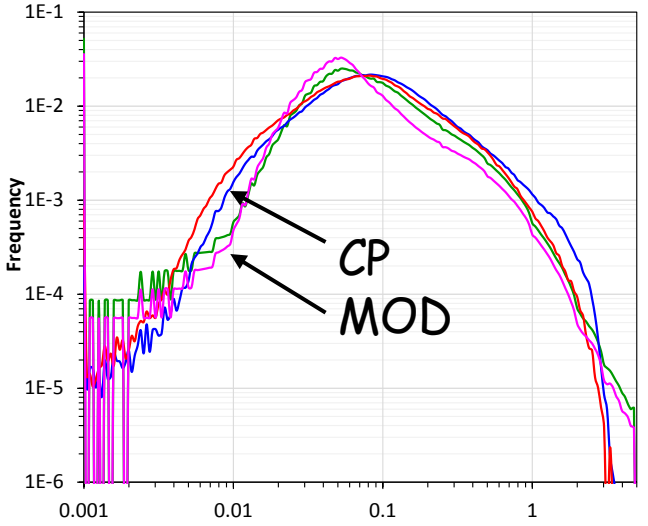
*MAD (Median Absolute Deviation) = $\text{median}(\ |x_i - \text{median}(x)|\ )$

(Number of collocated data = 630,622)

AOD: CALIOP vs MODIS

Non-opaque retrievals only

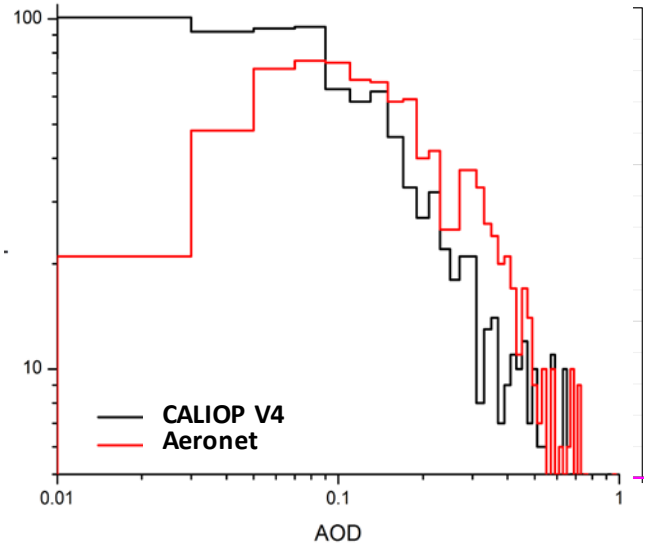
V4 AOD has increased, across the AOD spectrum
- for AOD < 0.1: closer to MODIS
- for 0.1 < AOD < 2: greater difference
- MODIS >> CALIOP for AOD > 2



CALIOP V3 **CALIOP V4**
MODIS C6 (30%) **MODIS C6 (0%)**

Annual Mean Day AOD

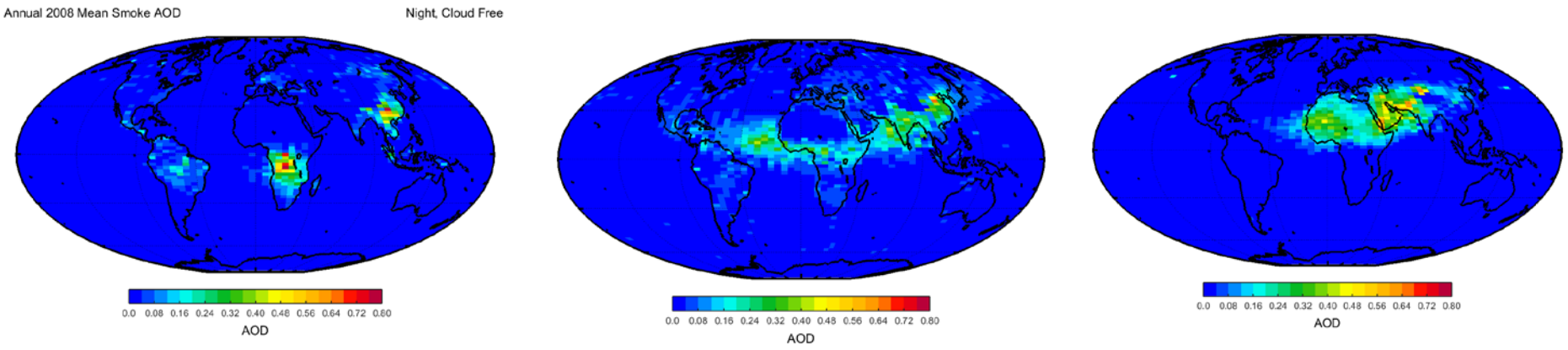
	Co-located	All Data
CALIOP V3	0.081	0.085
CALIOP V4	0.091	0.112
MODIS C6	0.093	0.110



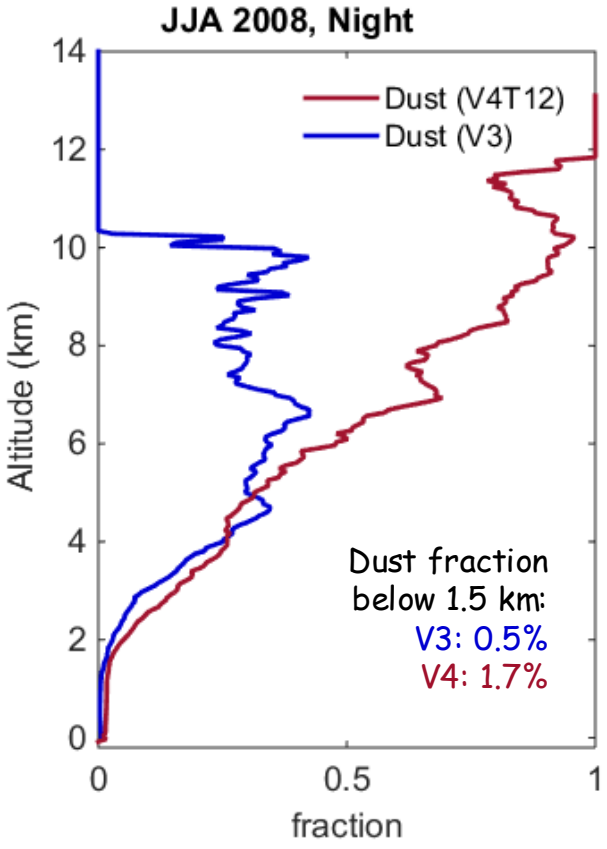
Level 3 Product Status

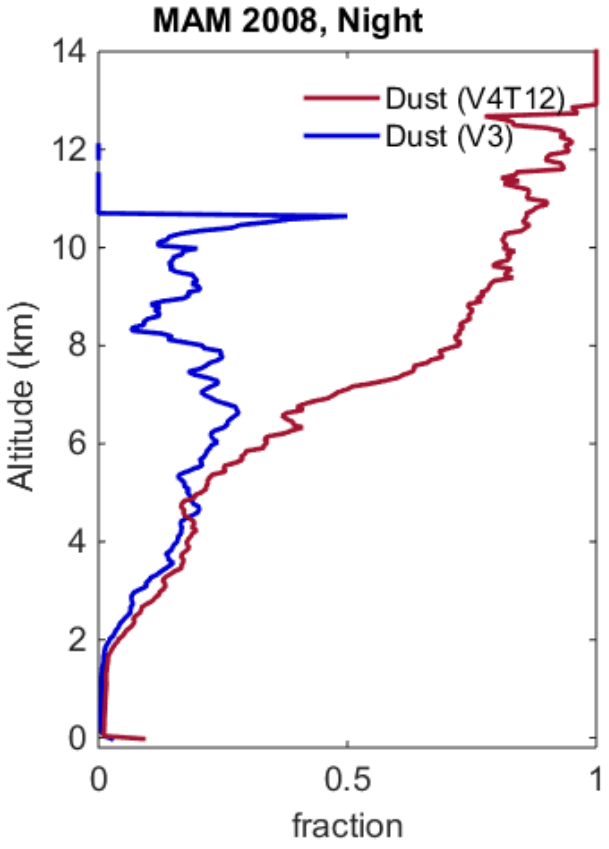
- Current (3D) Level 3 product released fall 2015
  - replaced initial (2012) beta-version
  - Includes extinction partioned by Smoke/Dust/Polluted Dust
  - Paper to be submitted "soon"
- Current L3 based on V3 Level 2, update to V4 underway
  - Not entirely trivial though → UT dust issues, sfc contamination

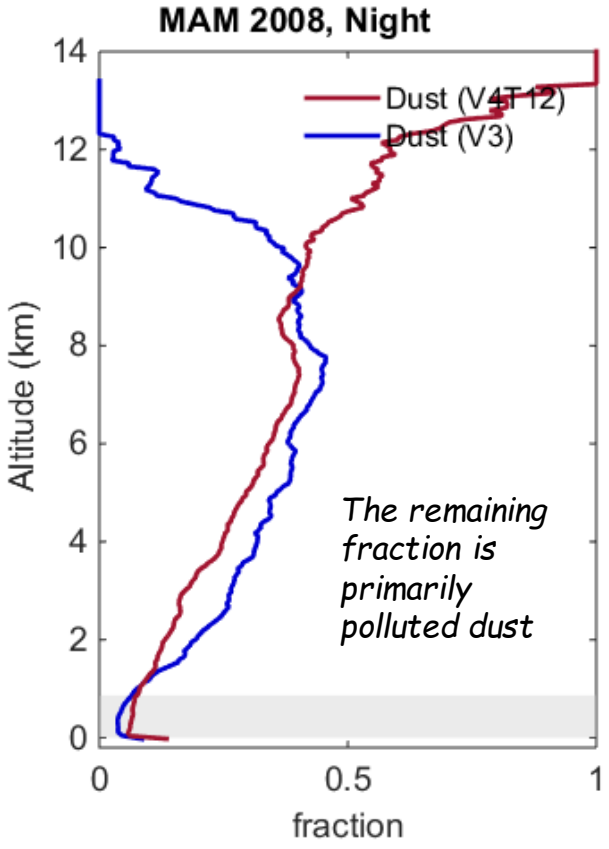
AOD: Smoke **Polluted Dust** **Dust**



Dust fraction







Southern Pacific
30S,55S
180W,105W

Asian dust outflow:
northern Pacific
30N,60N
140W,180W

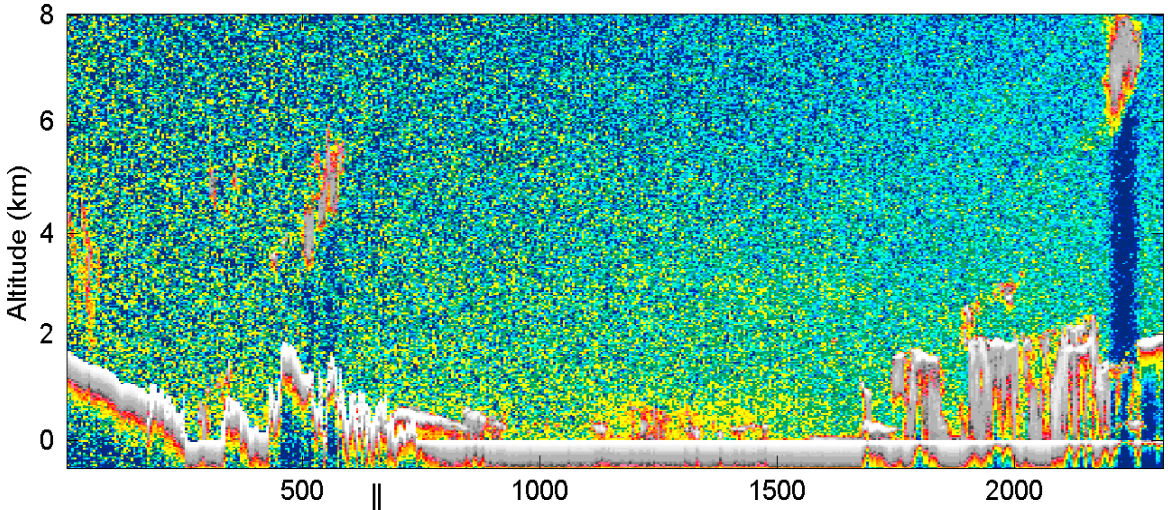
Level "1.5" Products

- A special near-real time product intended for operational NWP centers has been produced since 2010
- Motivation:
  - verification of aerosol estimates from NWP models
  - Development of assimilation schemes for CALIOP aerosol data
- NRT latency requirements are on the order of 5-24 hours
  - Requires use of Level 1 "Expedited" data → "calibration issues"

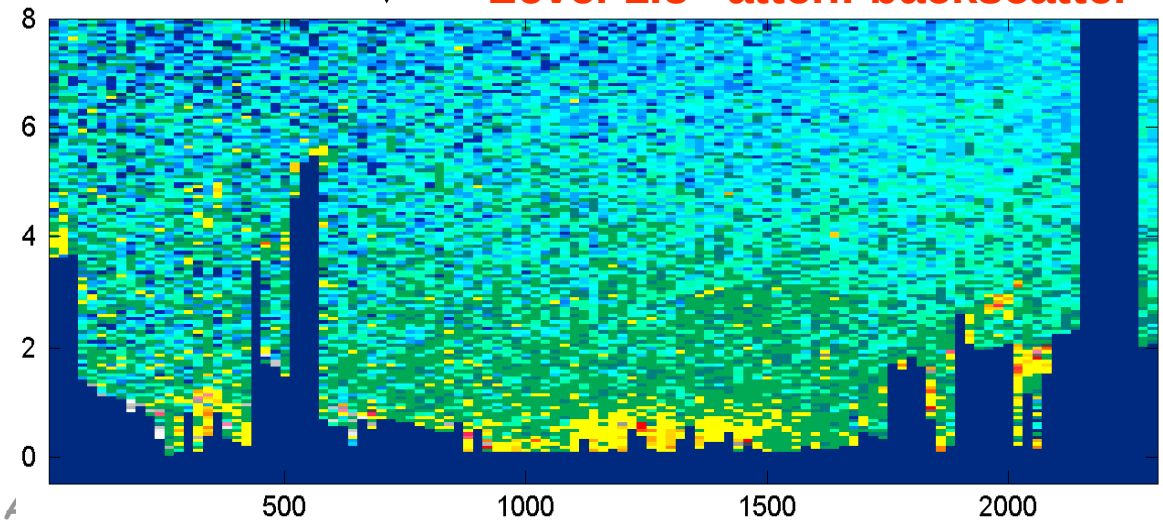
- Level 1.5 're-analysis" product now in development
  - Designed for evaluating aerosols in climate applications
- Level 1.5 algorithm will be applied to Version 4 L1 and L2 data
  - Improved CALIOP calibration
  - Data latency now 4-6 weeks, no longer useful to NWP centers
- Will process entire CALIPSO dataset (11+ years)

Near-Real Time Aerosol Product

Level 1 - 532 nm



"Level 1.5" atten. backscatter



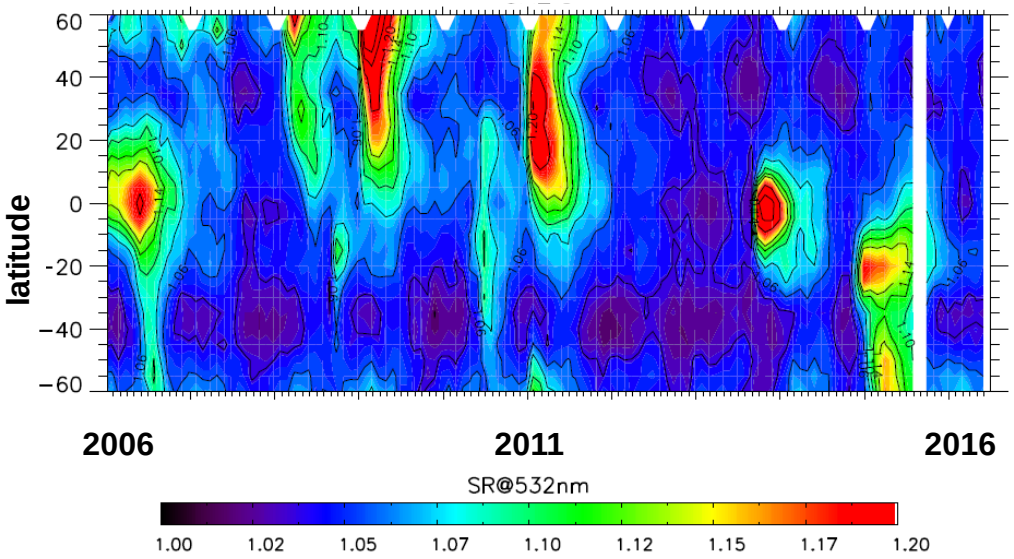
"Level 1.5" NRT product

1/3 km x 30 m Level 1 data is cloud-cleared using L2 cloud mask, then averaged to 20 km x 60 m

Uses V3 L1 and L2 data and shipped to operational centers for evaluating air-quality predictions

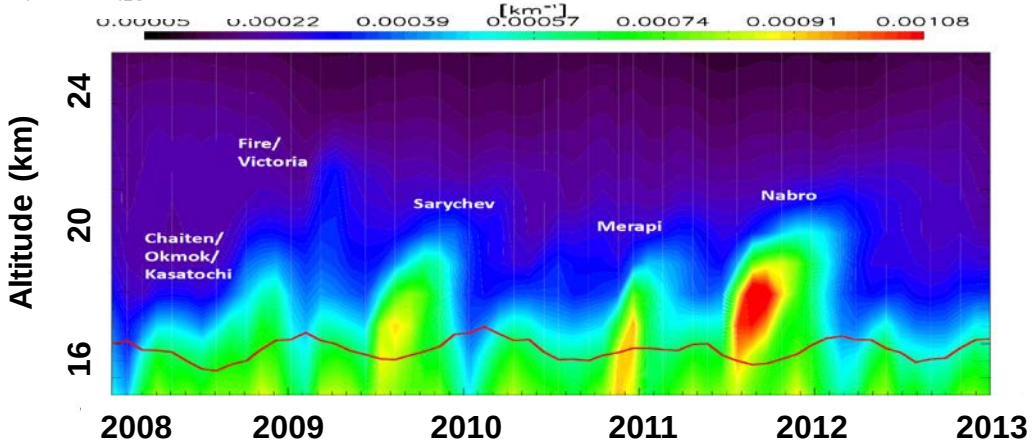
Stratospheric aerosol product to be released by end of this year

Latitudinal distribution



Evolution of the average SR profile, 10 km to 35 km

Courtesy Jean-Paul Vernier:



Evolution of the vertical profile of background extinction (22.5S-22.5N)

Lidar Data Products: Status

- Level 1 & Level 2 Version 4.10 released November 2016
  - Processed full mission (since June 2006)
  - Data latency now 4-6 weeks due to new calibration scheme
  - V3 Expedited products still produced
- Revised Level 3 aerosol product released fall 2015
  - Based on V3 L2
  - Will be updated to V4
- New Level 1.5 product to be released early 2018
  - Intended for model evaluation
  - Based on V4, will process entire mission
- Level 3 cloud product in development
  - Release of IWC product this year, followed by 3D cloud occurrence
- Stratospheric aerosol product in development.
  - To be released by the end of the year

Plans

- V4 algorithm papers/special issue underway
- No near-term improvements foreseen for Level 1
- Priorities for next version of Level 2:
  - An improved CALIOP AOD product using constraints from ocean surface and opaque water clouds to directly retrieve AOD
    - ✓ Alleviates AOD biases due to missed detection of tenuous aerosol
  - Use 1064 and depolarization profiles for layer detection in addition to 532
    - ✓ Improve detection of smoke base heights
  - Partition extinction into "Dust" and "Non-Dust" using depolarization-aided extinction retrieval