Developments in CALIOP Aerosol Products

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Outline

- Level 3 aerosol product (beta-version)
- Version 4 Level 1 product
- A few CALIOP assimilation results
- Product Plans

Recent Activities

- Beta-version of Level 3 aerosol product available since 2012
  - Scheduled for update to Provisional "soon"
- Validation of Level 2 products continues
- Emphasis during the last year has been on development of new Version 4 Level 1 product with improved calibration
  - 532 night: reduction of tropical bias (stratospheric aerosol)
  - 532 day: reduction of day/night bias
  - 1064: reduction of latitudinal bias
- Other new Level 2/3 products also in development

Level 3 Aerosol Product

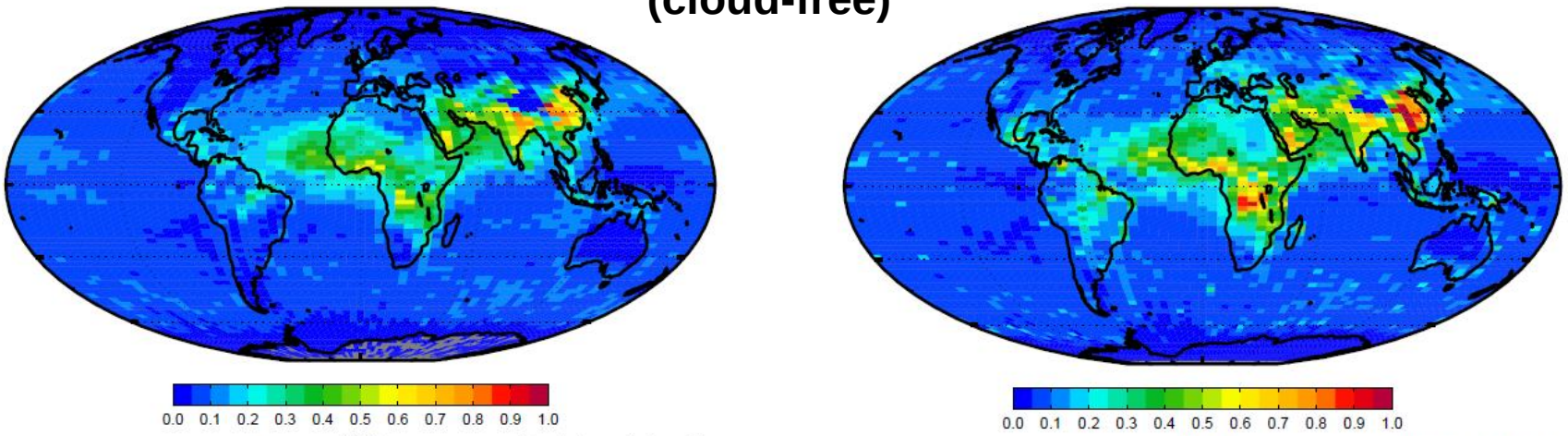
Gridded monthly-average profiles:

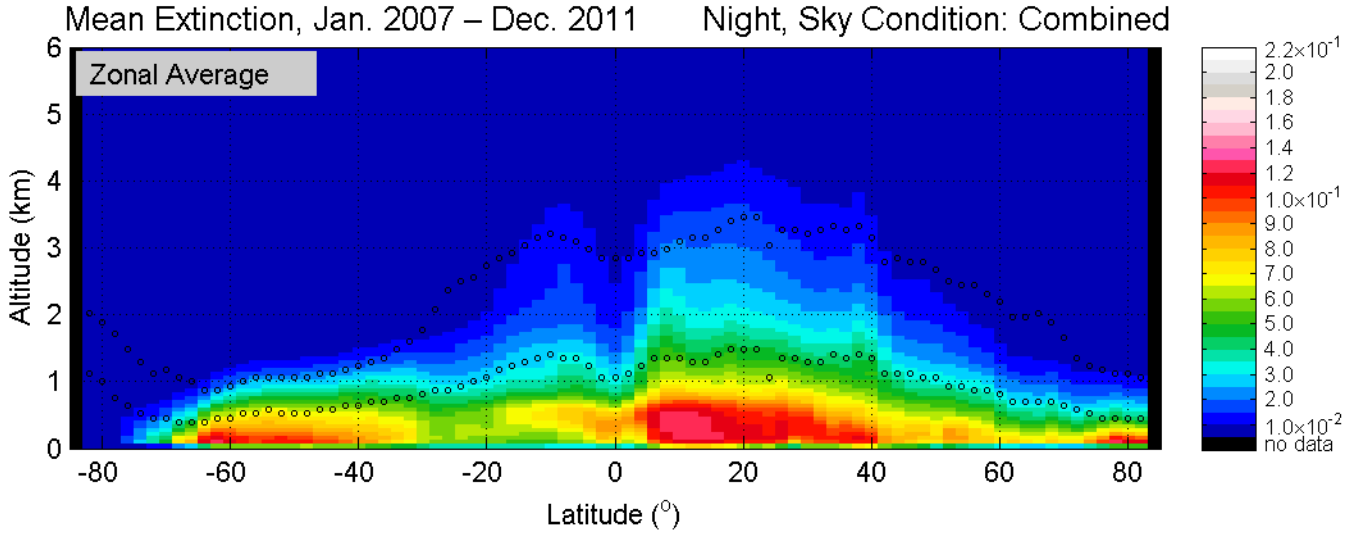
- Beta-version reported on a 2° x 5° grid (lat x long)
- Extensive quality control applied to Level 2 extinction data
- Extinction in 'clear-air' set to 0.0 km^{-1} and averaged along with retrievals
- Several types of near-surface artifacts are removed
- Available from June 2006, updated monthly
- Reference:
  - Winker et al., 2013: The global 3-D distribution of tropospheric aerosols as characterized by CALIOP, ACP

2008 Annual Mean

Day **Night**

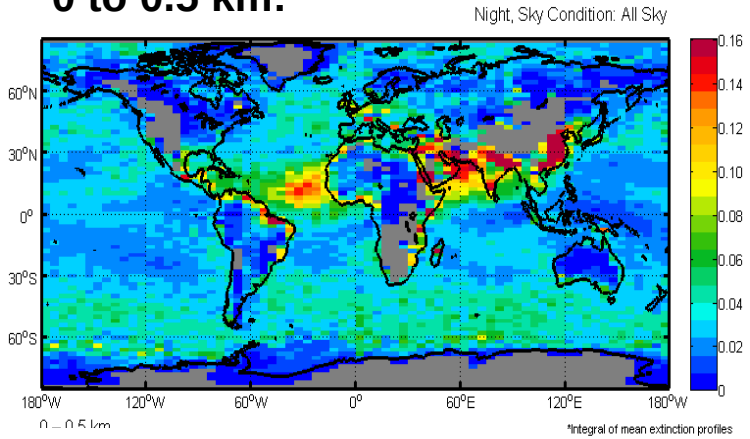
(cloud-free)



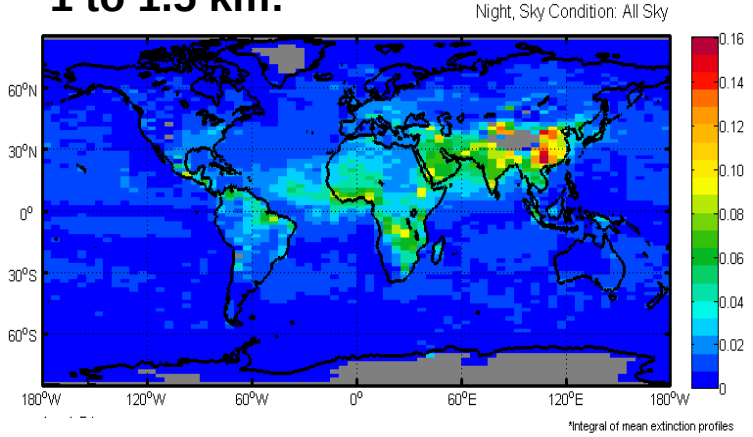


Vertically Resolved AOD

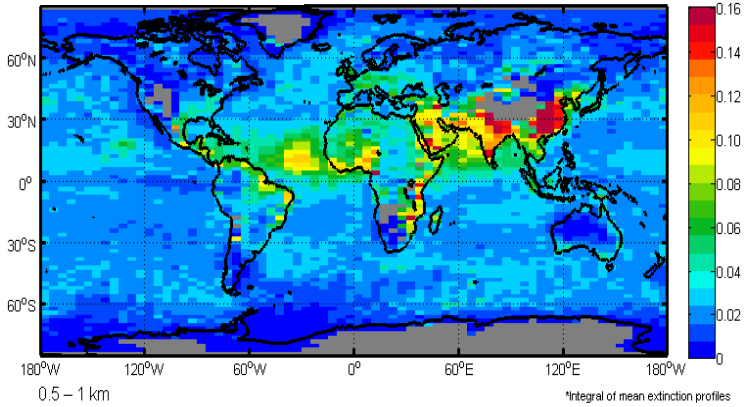
0 to 0.5 km:



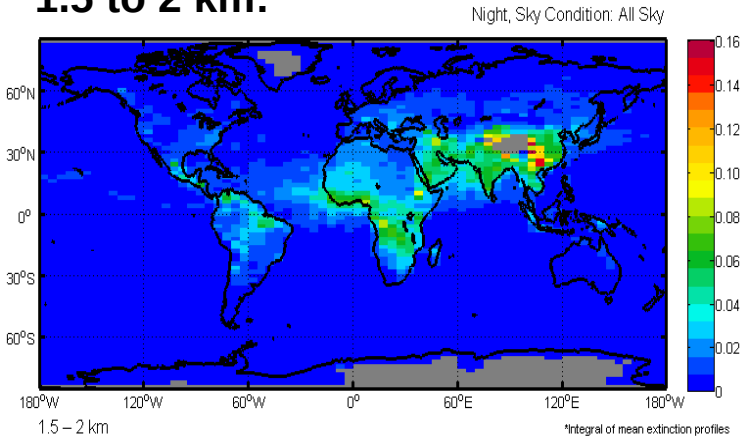
1 to 1.5 km:



0.5 to 1 km:

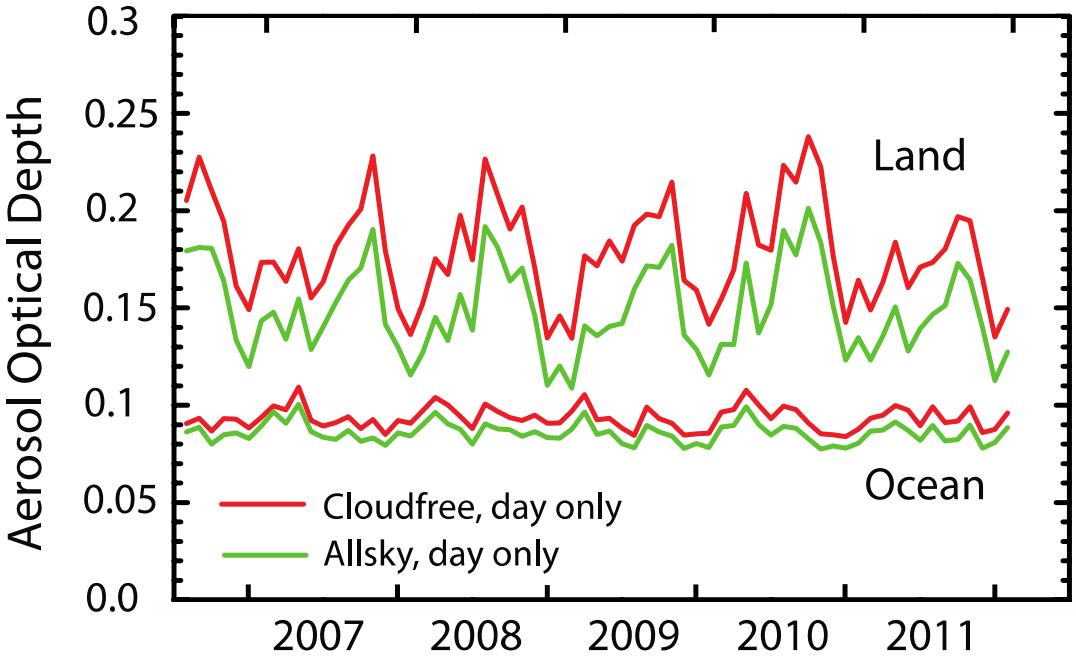


1.5 to 2 km:



Global Mean AOD

	global ocean			global land		
	CALIOP		MODIS C5	CALIOP		MODIS C5
	night	day		night	day	
cloud-free	0.087	0.093	0.13	0.21	0.18	0.19
all-sky	0.098	0.086	---	0.19	0.15	---

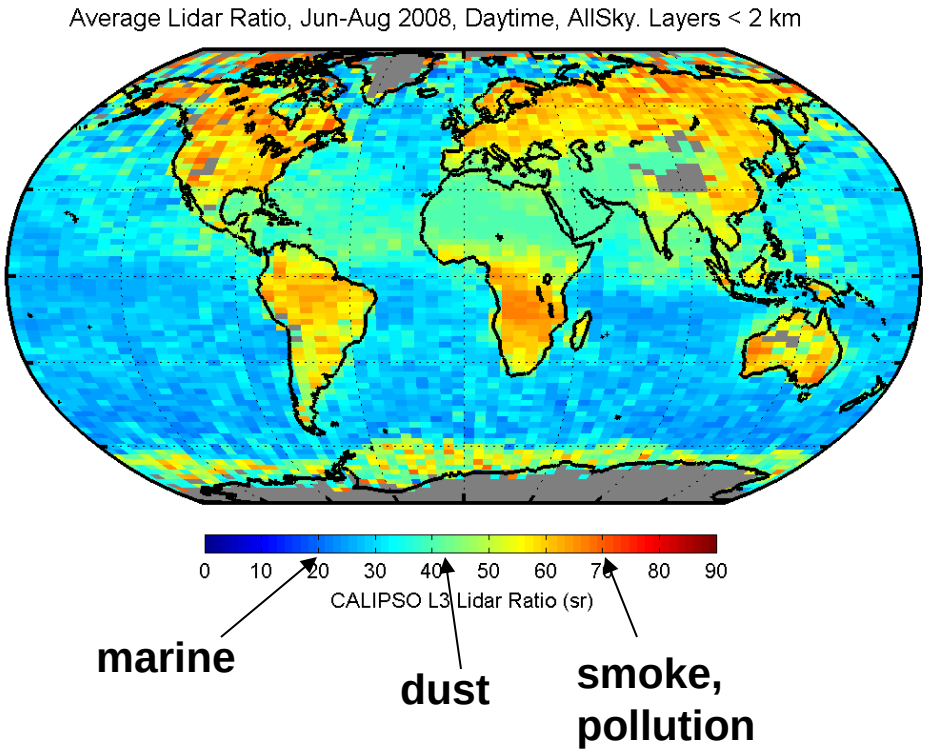


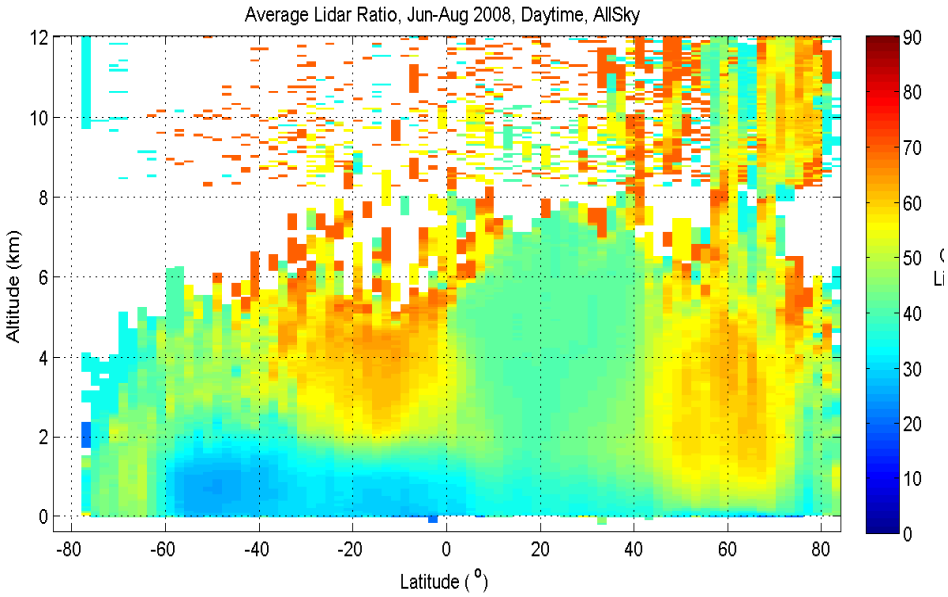
De-seasonalized trend:

ocean: −0.0004 per decade

land: −0.0080 per decade

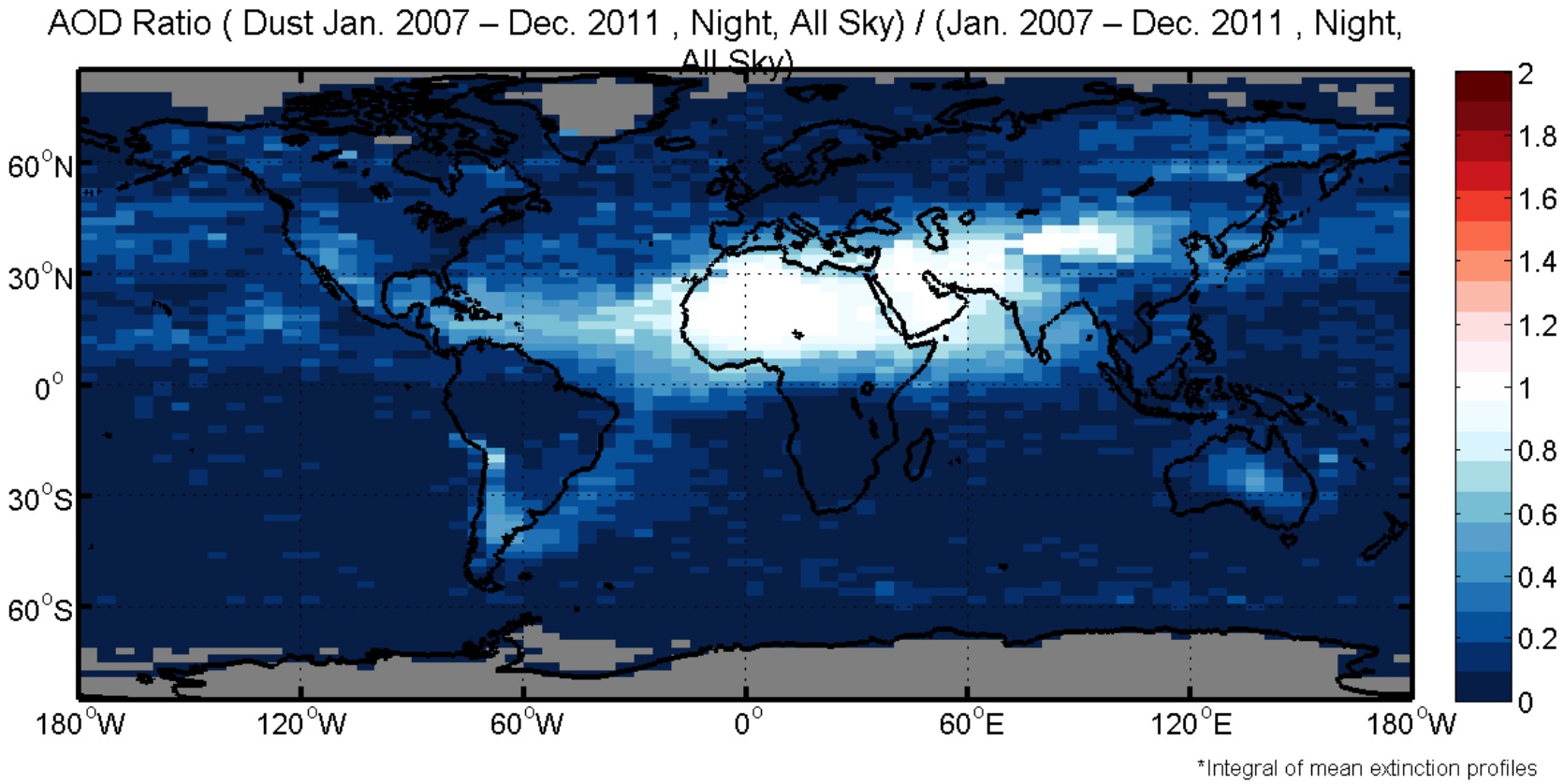
Aerosol Type, JJA 2008



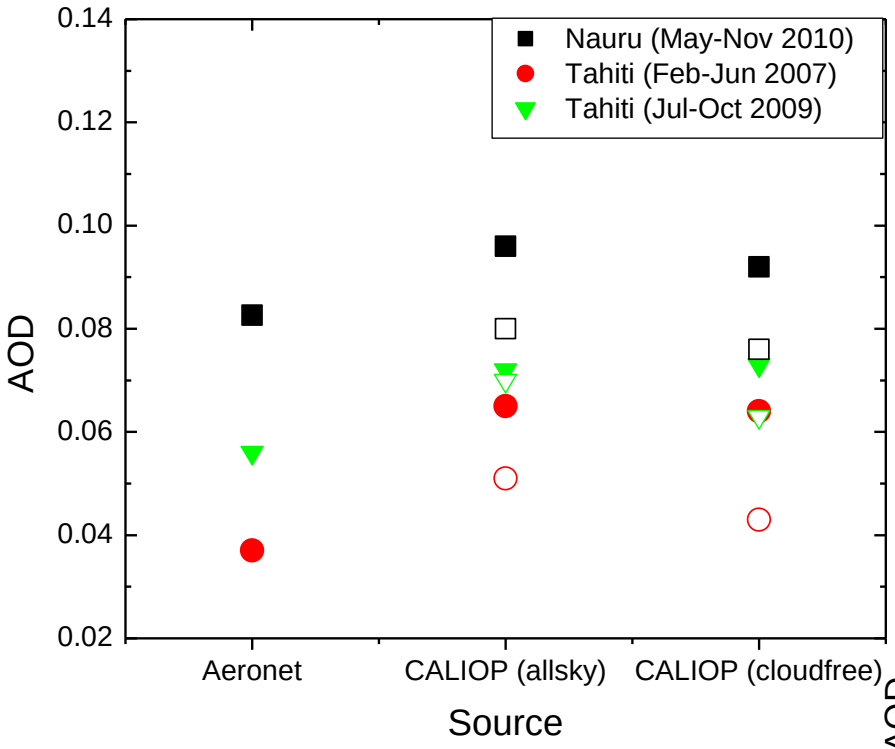


Fraction of AOD due to Dust

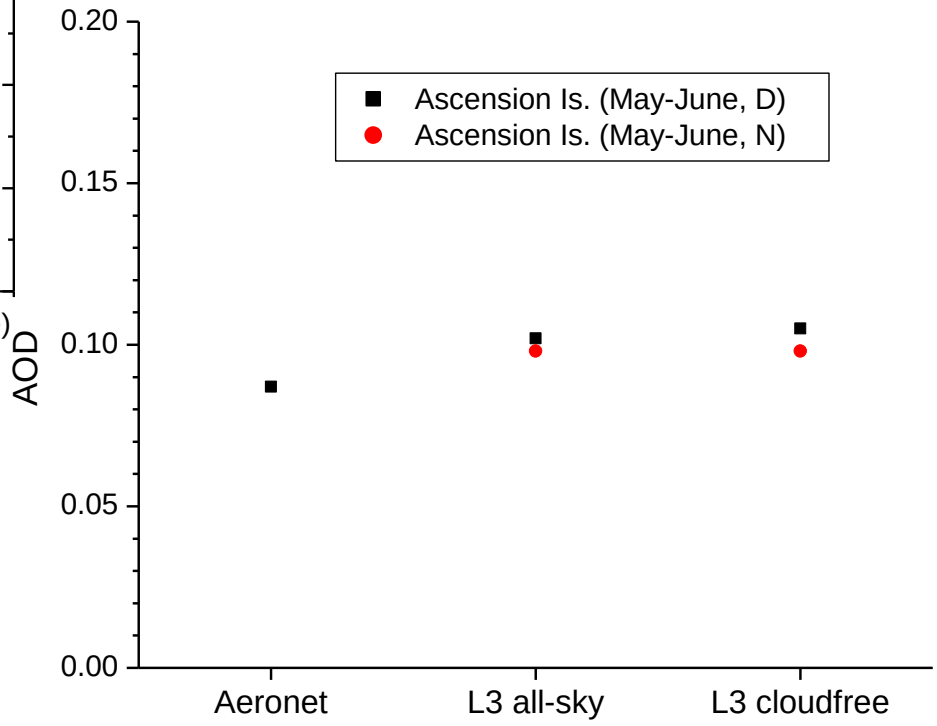
Depolarization allows robust identification of dust



Clean Marine Regions: Level 3 vs. Aeronet

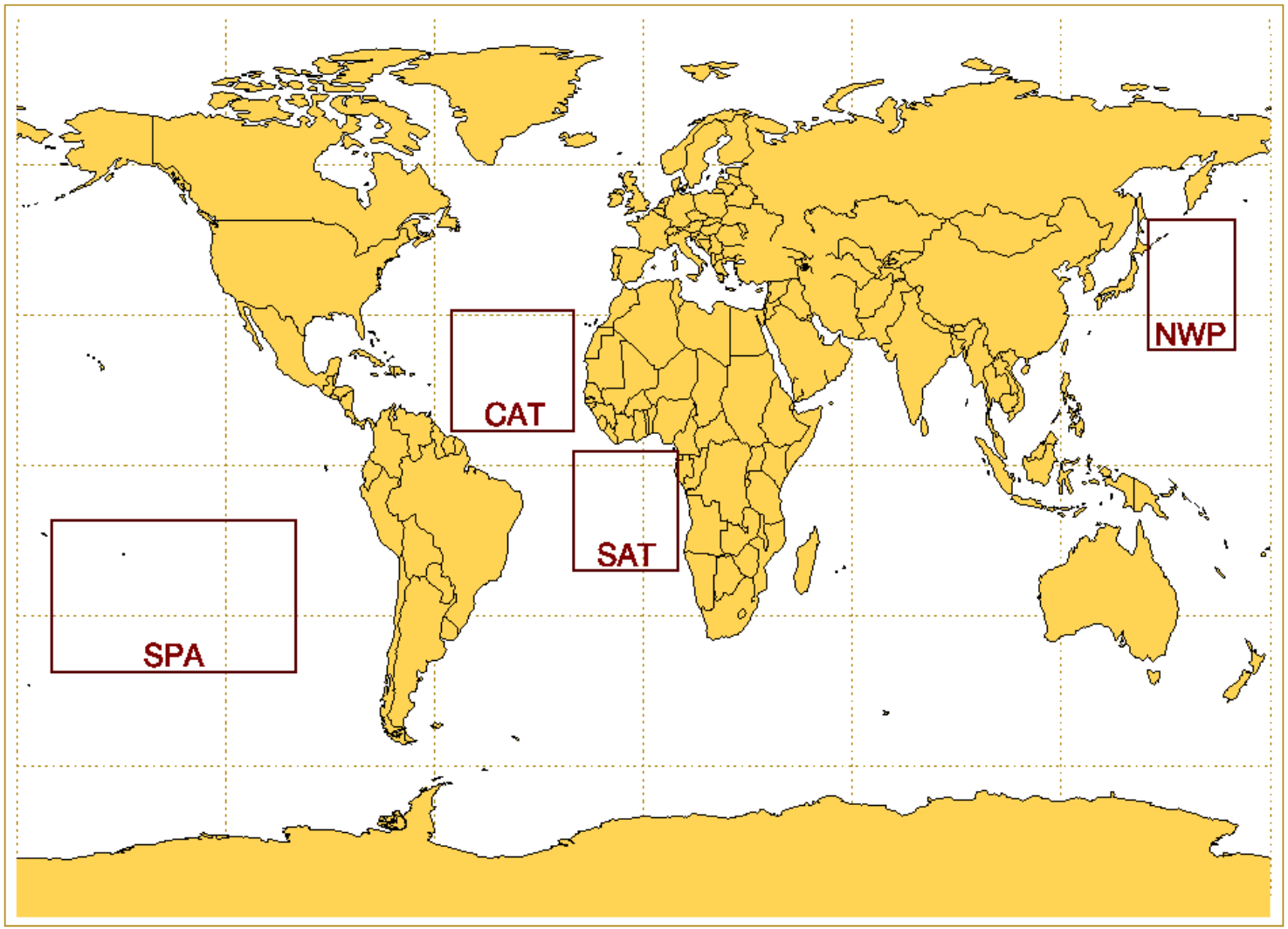


Based on regional-seasonal averages

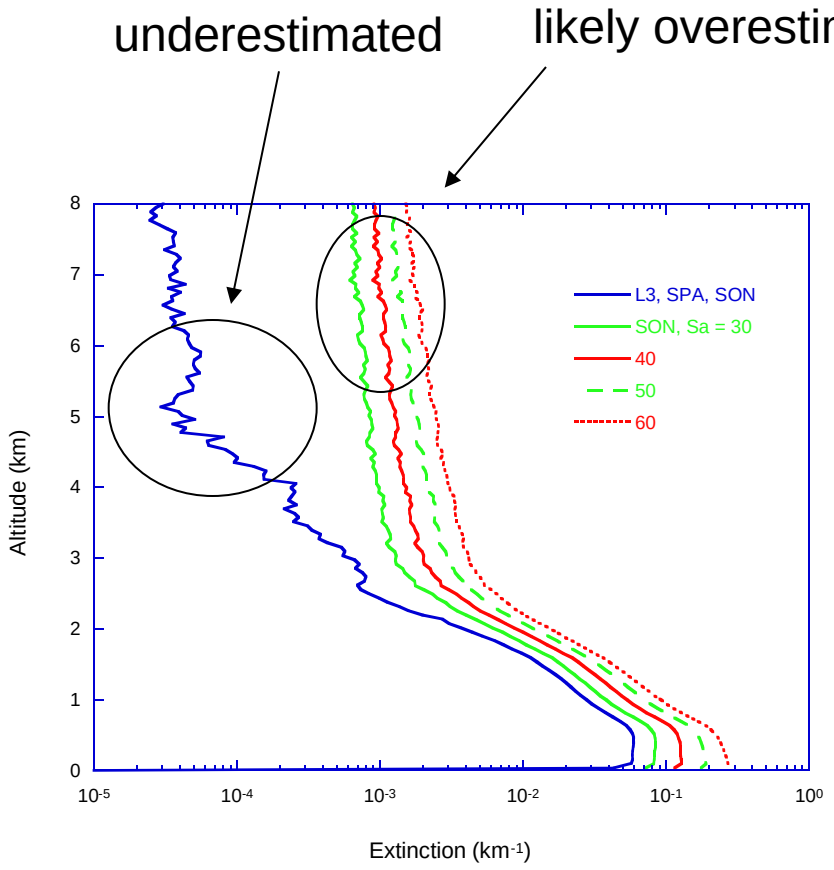


CALIOP region		
Nauru	4S-4N	160E-170E
Tahiti	16S-20S	160W-140W

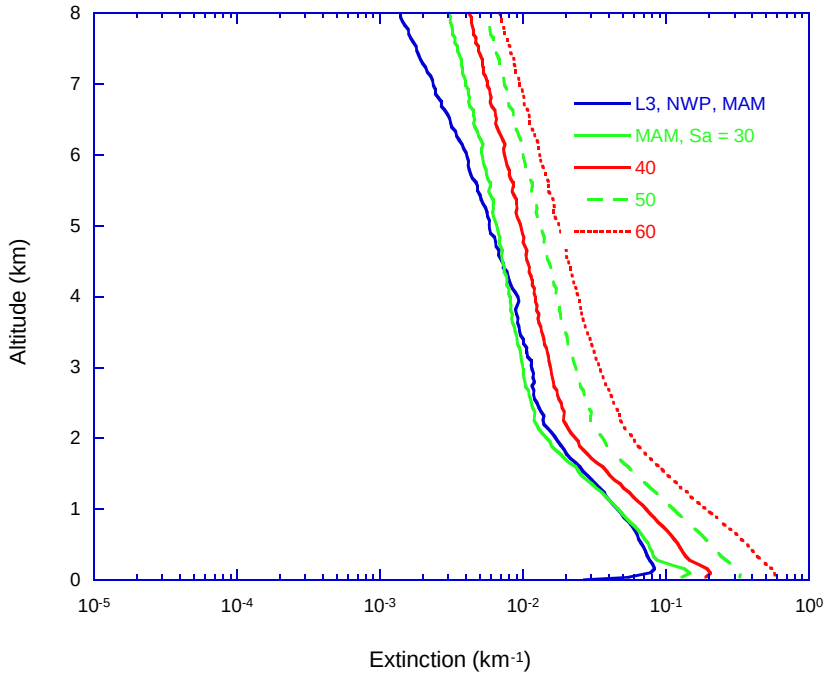
Profile Validation



Standard Retrieval vs. Full-Column



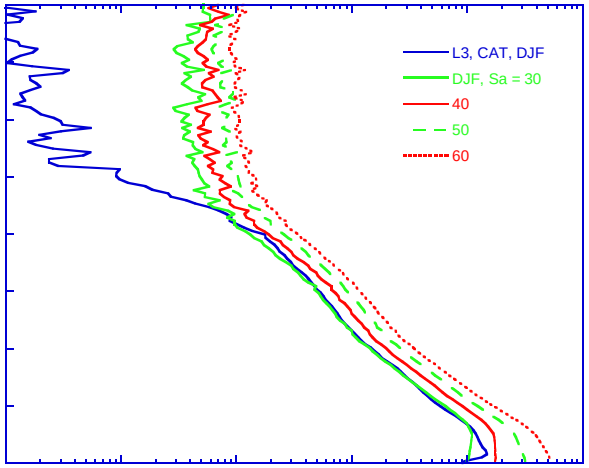
South Pacific (SON)



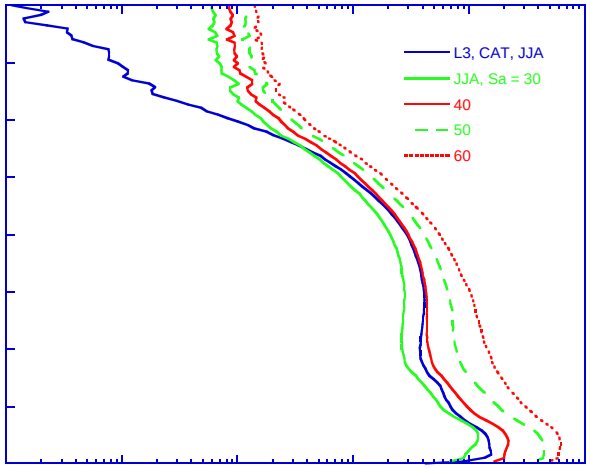
Northwest Pacific (MAM)

(Winker et al., ACP, 2013)

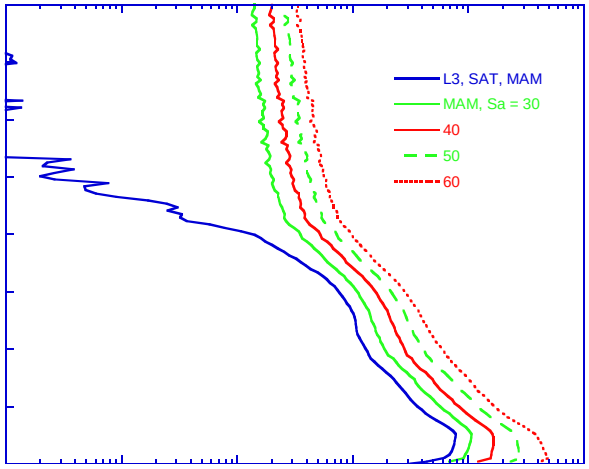
CAT, DJF



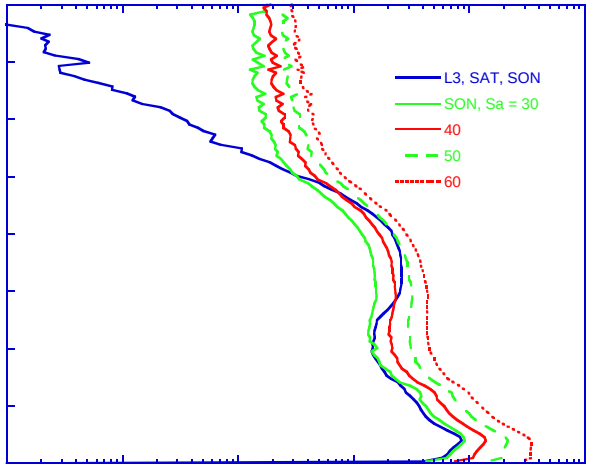
CAT, JJA



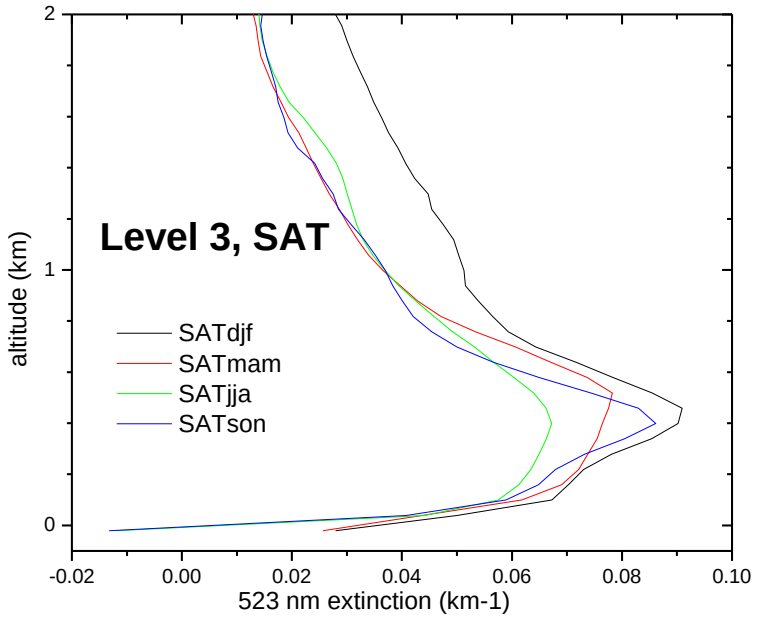
SAT, MAM

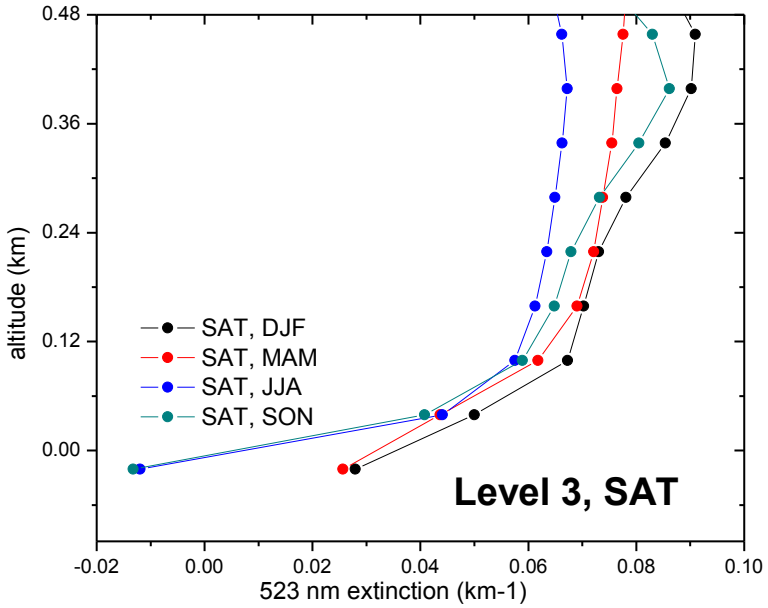


SAT, SON



Near-surface Extinction Decrease





- Over ocean, negative spikes are sometimes found at -20 m or +10 m
  - Should be part of the surface return
- Affects only the lowest two range bins
- Will be mitigated in next version of Level 3 aerosol product

Version 4 Level 1

532 nm Calibration

V3 night: backscatter signal normalized to model atmosphere, 30-34 km

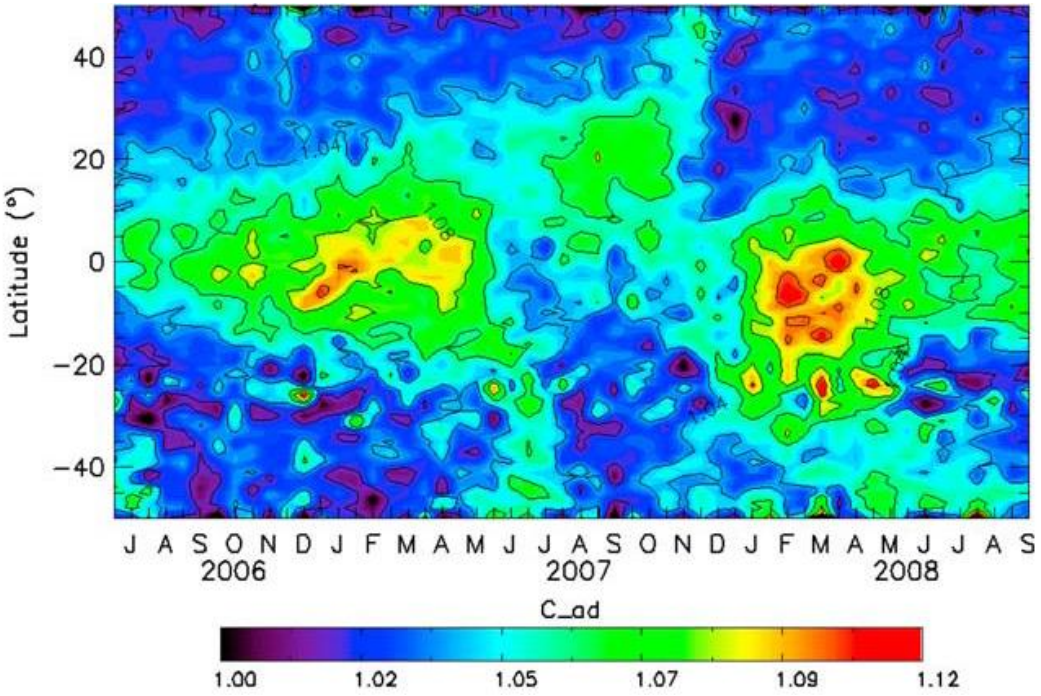
V3 day: daytime normalized to nighttime, 8-12 km

Version 3

- Aerosol at 30 - 34 km, mostly tropical, biases 532 nm night calibration
- Day-night calibration biases

Version 4

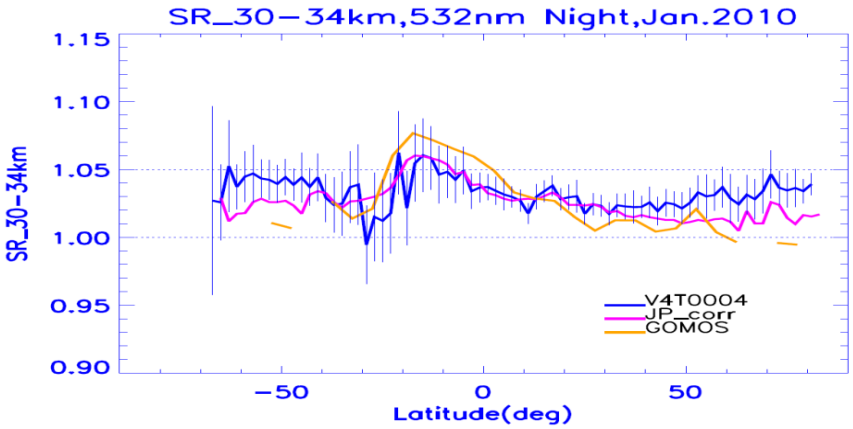
- Night calibration region raised to 36 - 39 km
- Day calibration region raised above tropopause
- Average over multiple orbits

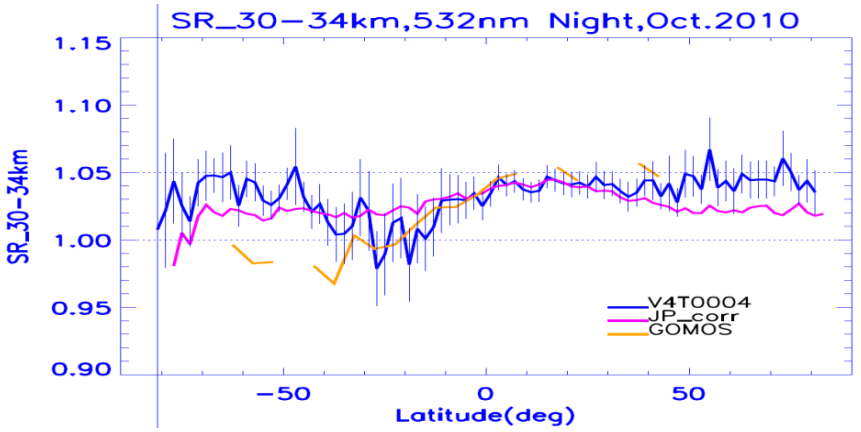


(Vernier, et al., JGR, 2009)

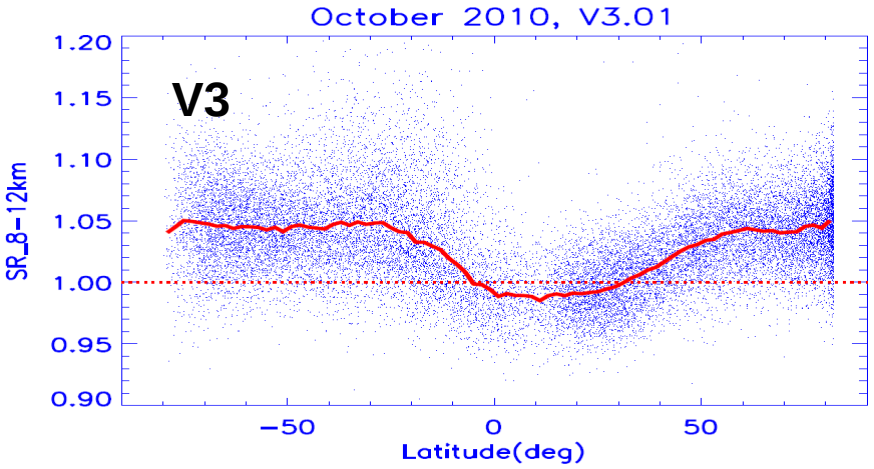
532 nm Night: V4 Performance

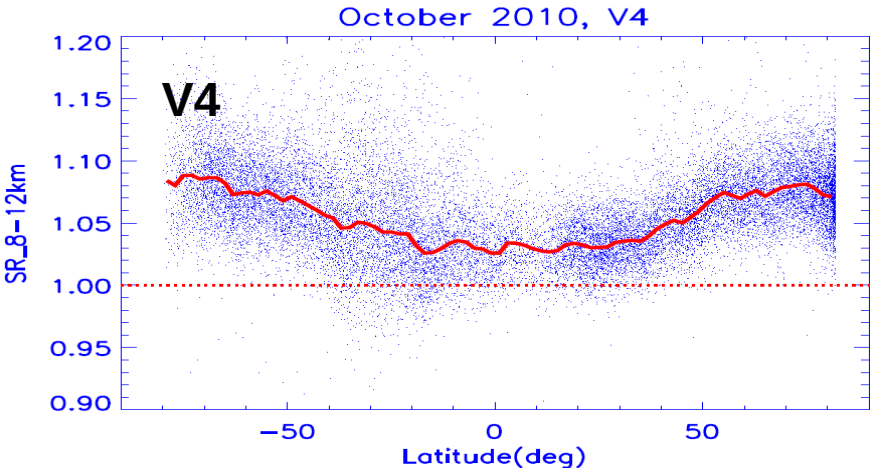
V4: 30-34 km scattering ratios (SR) consistent with Vernier (2009) and GOMOS



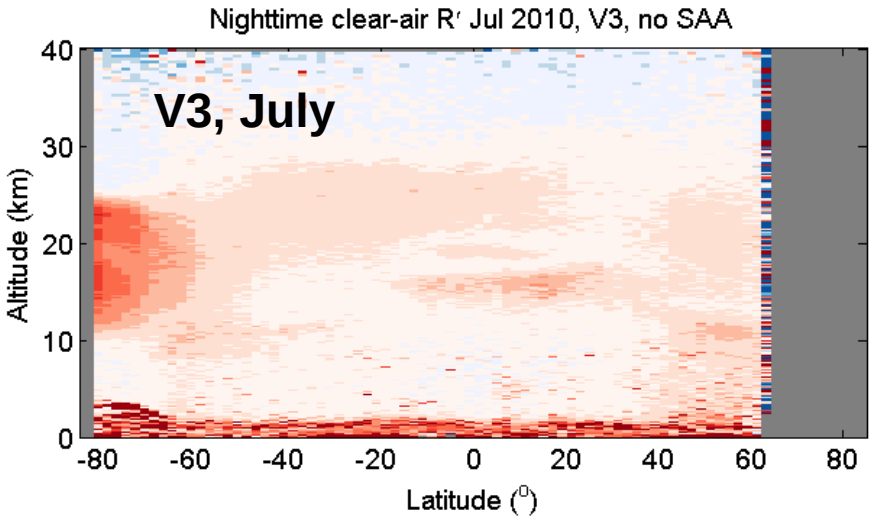


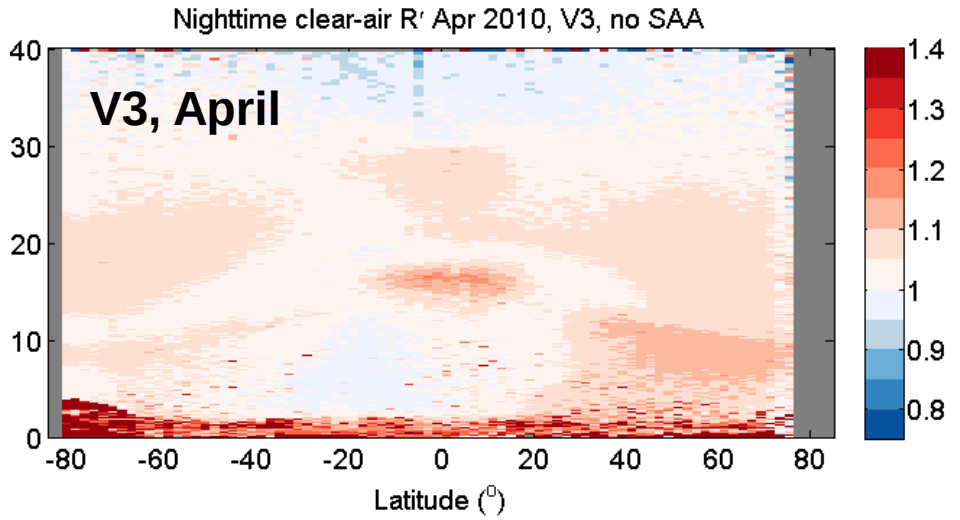
clear air 8-12 km: **V3)** SR < 1 in tropics (non-physical). **V4)** SR > 1 for all seasons

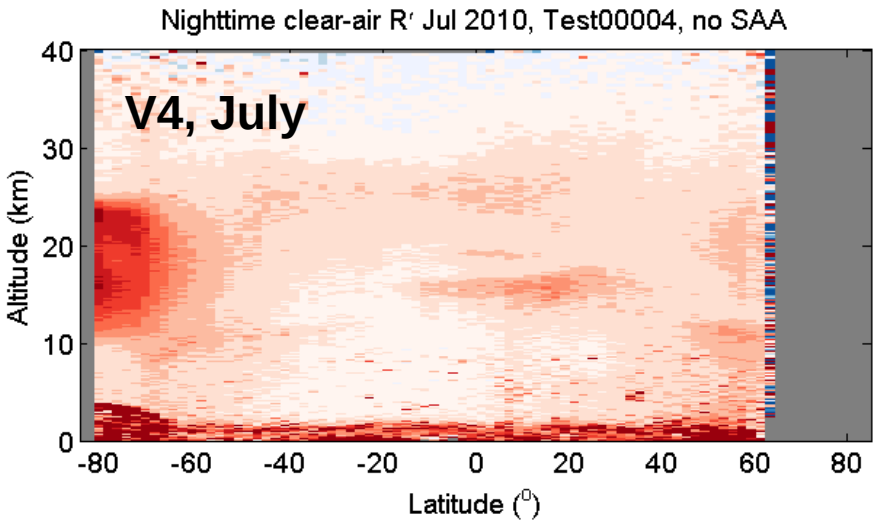


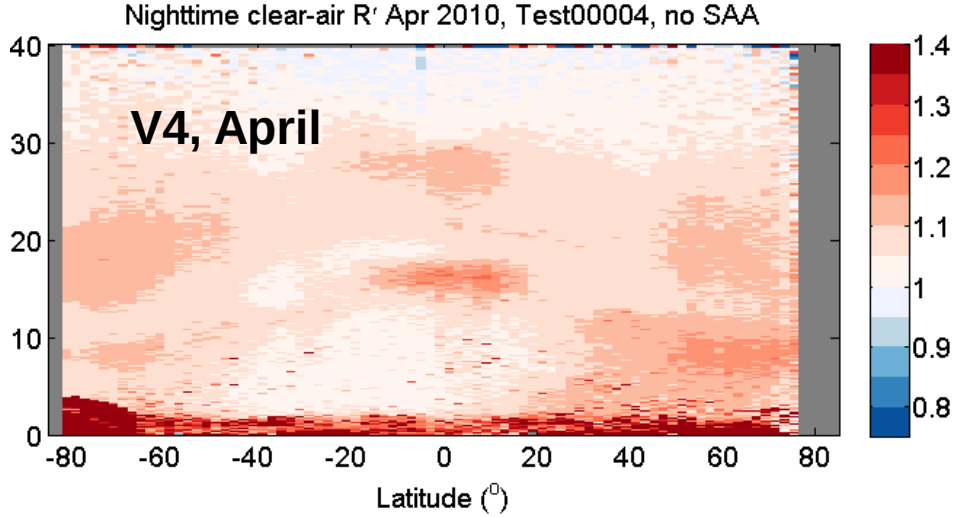


532 nm SR of background aerosol using V3 aerosol/cloud mask

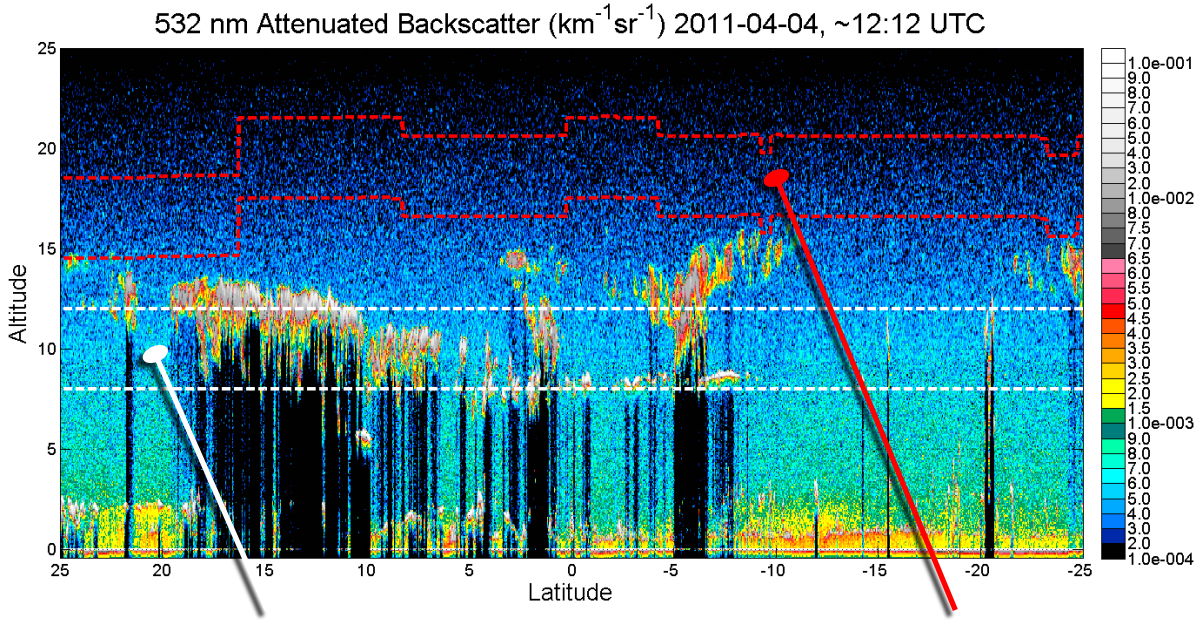








V4 532 nm Daytime Calibration



V3 "clear air" search region: 8 - 12 km

V4 "clear air" search region, varies with tropopause height

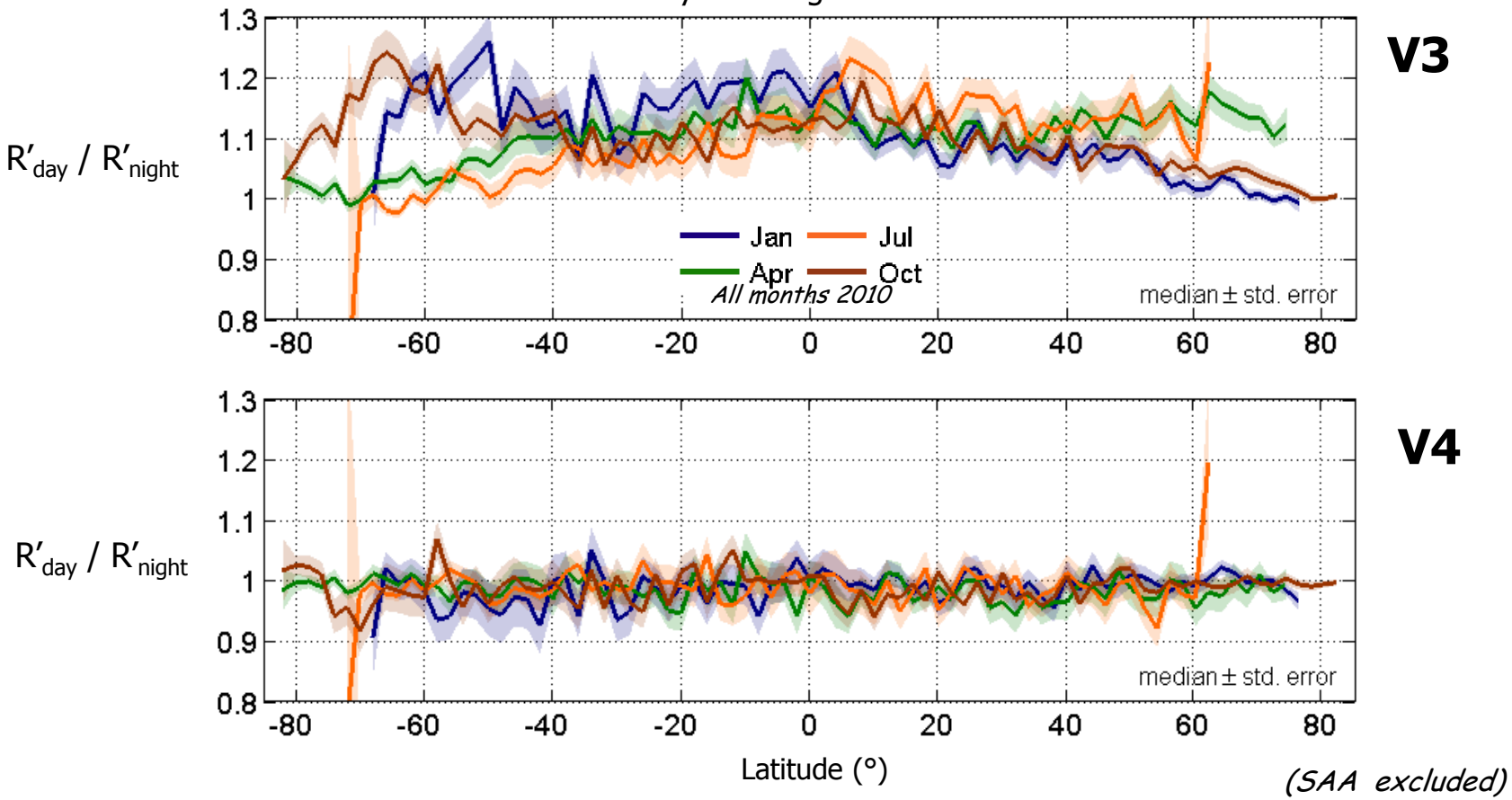
Calibration Transfer Region moved from 8-12 km to:

2 -6 km above θ = 400 K

Higher altitude gives better sampling

Day/Night Scattering Ratios Agree Better in V4

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

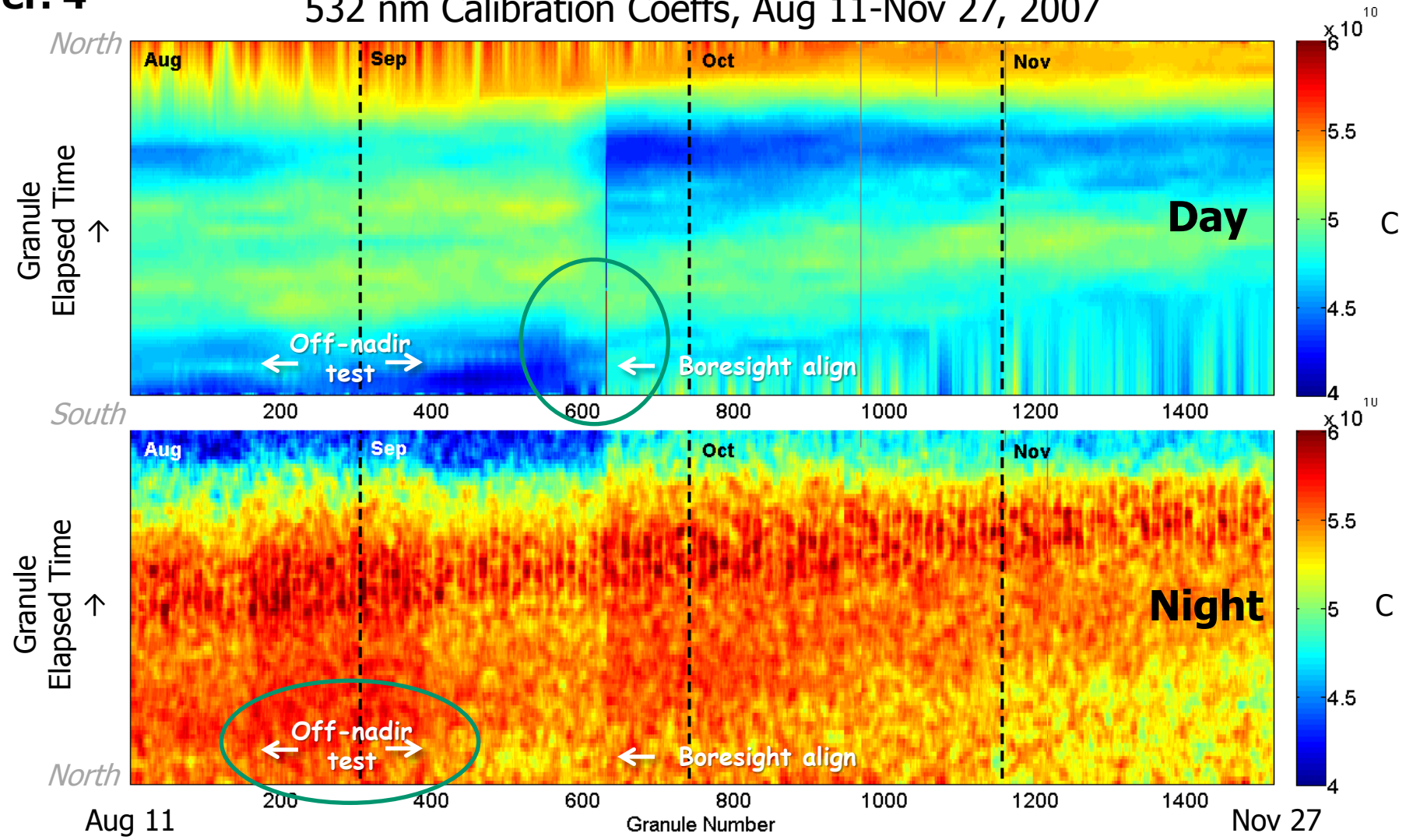


(SAA excluded)

Algorithm Accounts Correctly for Instrument Changes

Ver. 4

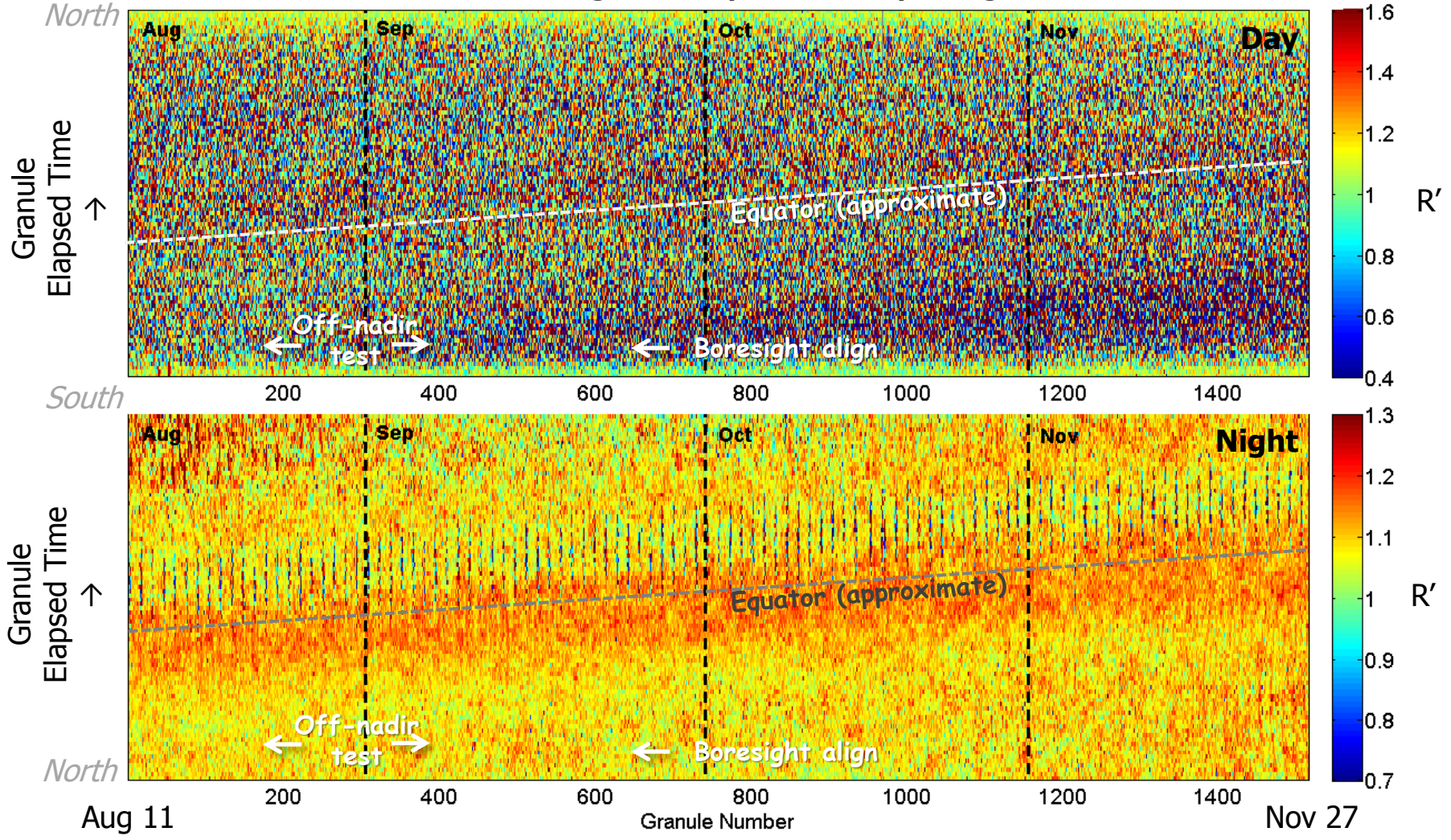
532 nm Calibration Coeffs, Aug 11-Nov 27, 2007



Algorithm Accounts Correctly for Instrument Changes

Ver. 4

532 nm Clear-air Scattering Ratio (24-30 km), Aug 11-Nov 27, 2007



1064 nm Calibration

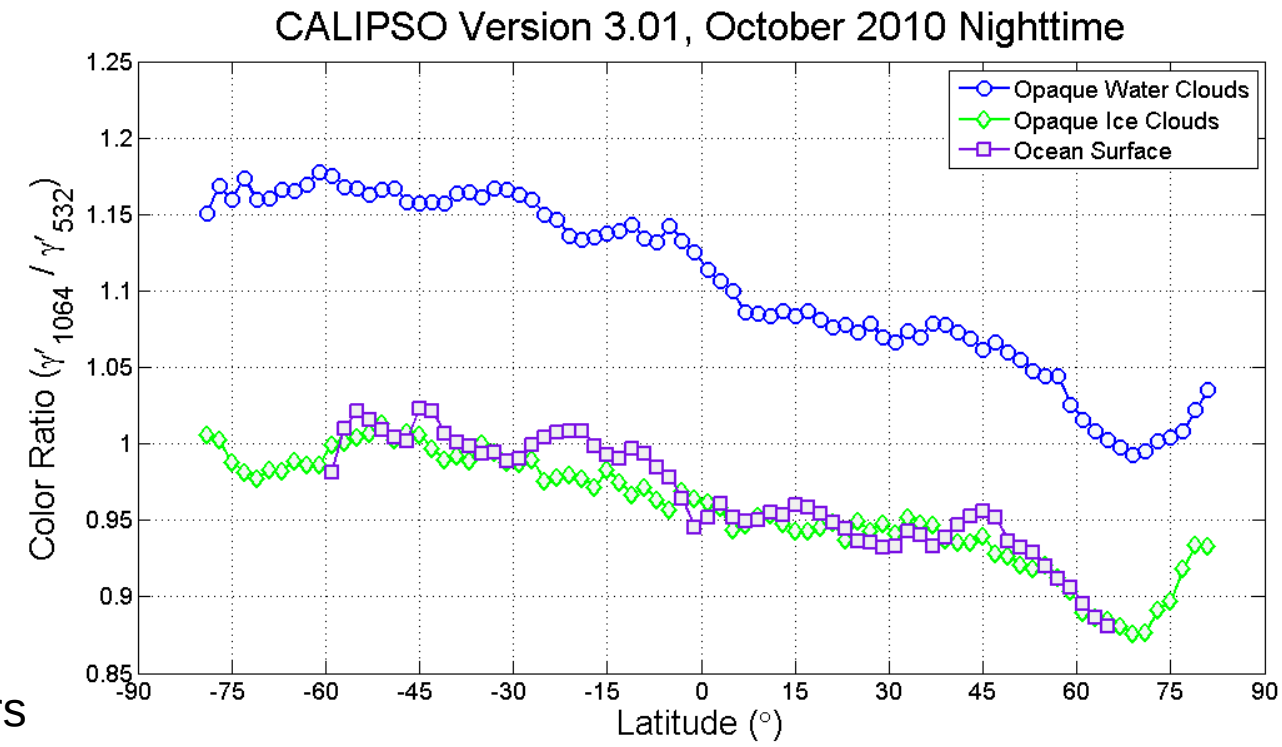
1064 nm calibration: normalized to 532 nm cirrus returns assuming $\chi = 1$

Version 3

1064 nm channel shows large latitudinal biases in calibration

Version 4

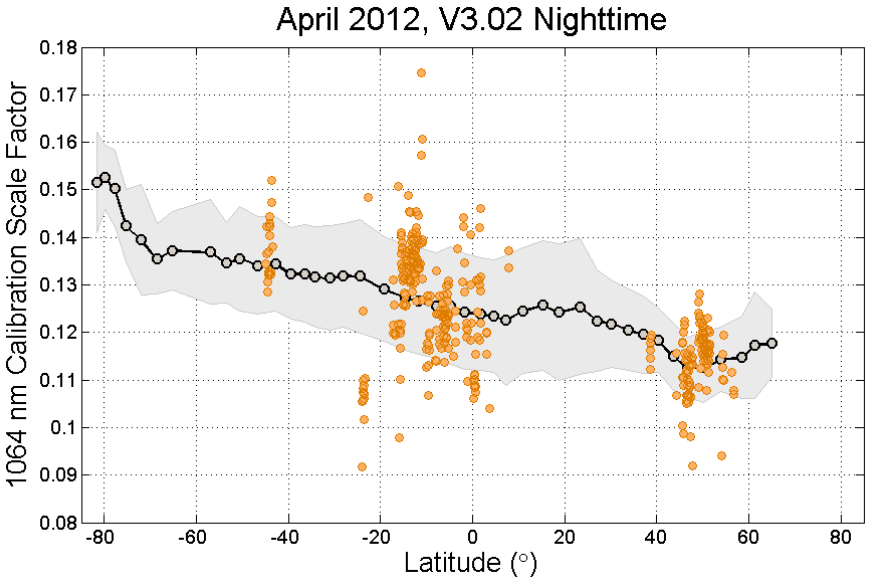
1) Improved selection of "calibration clouds"
2) Improved sampling
3) Calibration scale factors now computed as function of latitude

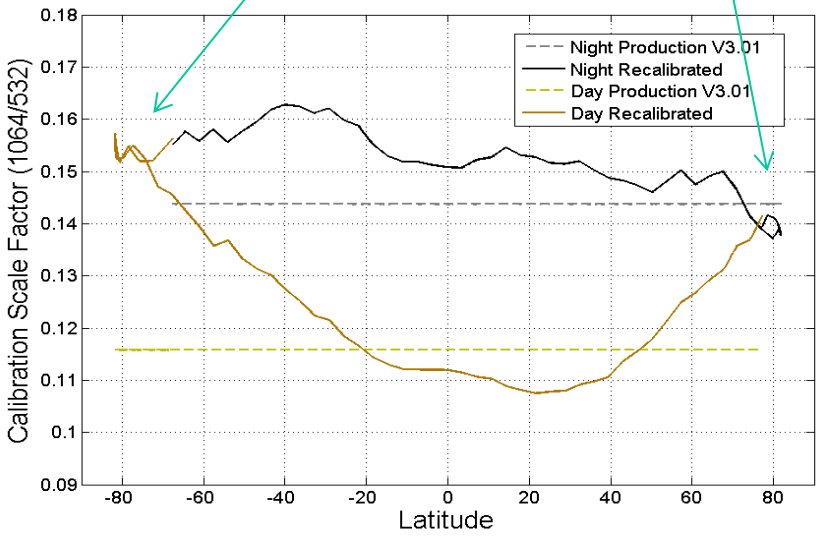


Similar latitudinal trends in color ratio from water clouds, ice clouds and ocean surface

Now as Function of Latitudinal

Continuity of V4 calibration scale factors between night and day





V3: Orbit-average calibration computed, represented by a single coefficient

V4: Calibration applied as a function of latitude, requires averaging over multiple granules

Improved Cloud Selection in V4

Optically thin clouds

VERSION 3

8.2 km < Z < 17.0 km

R′ > 50

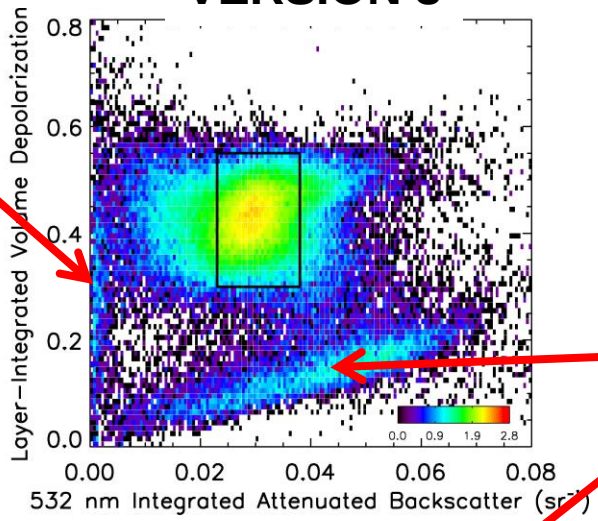
VERSION 4

T_{mid} < -35°

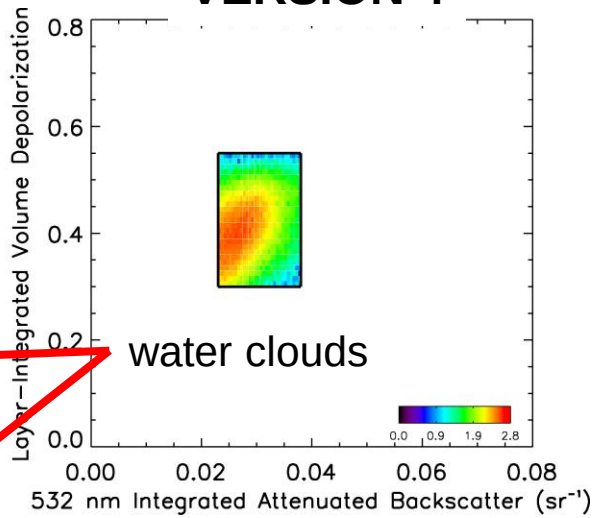
0.30 < δ < 0.55

0.023 < γ′ < 0.038

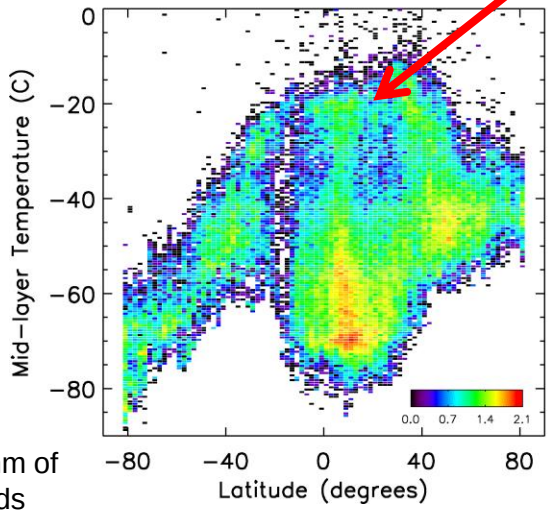
VERSION 3

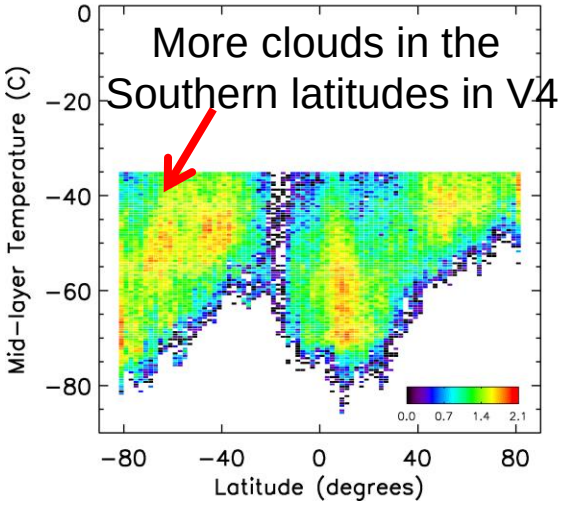


VERSION 4



water clouds





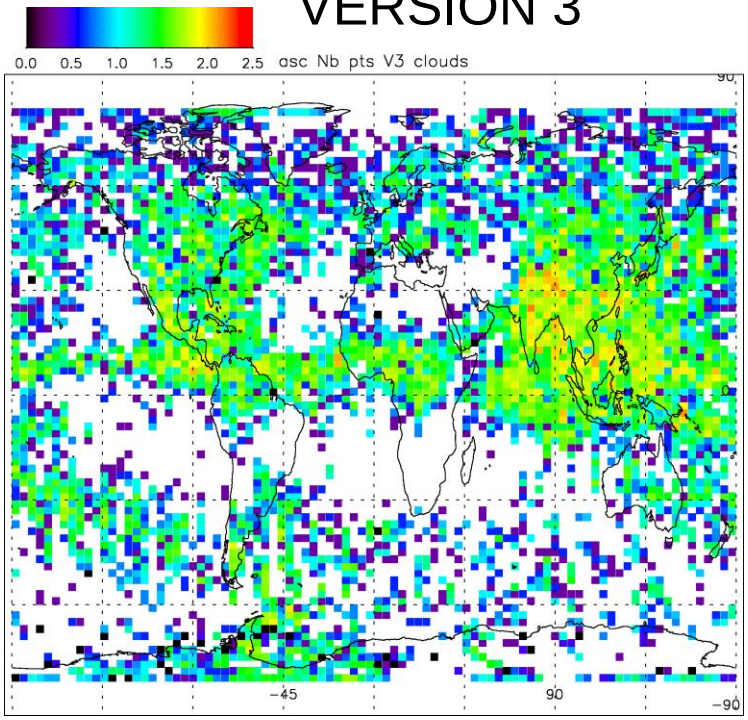
More clouds in the Southern latitudes in V4

Color Code is the decimal logarithm of the number of calibration clouds

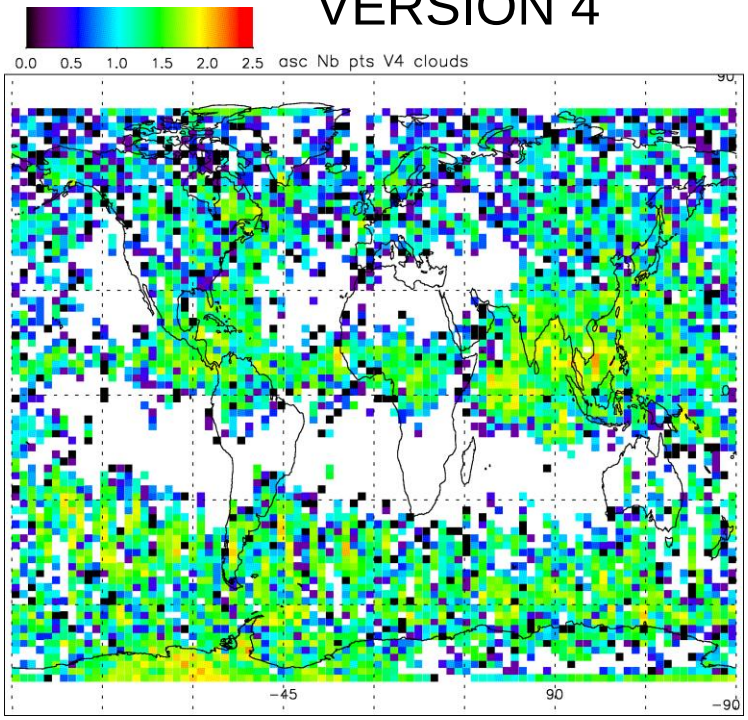
Increased Sampling in V4

Number of Calibration Clouds, July 2010, day orbits

VERSION 3



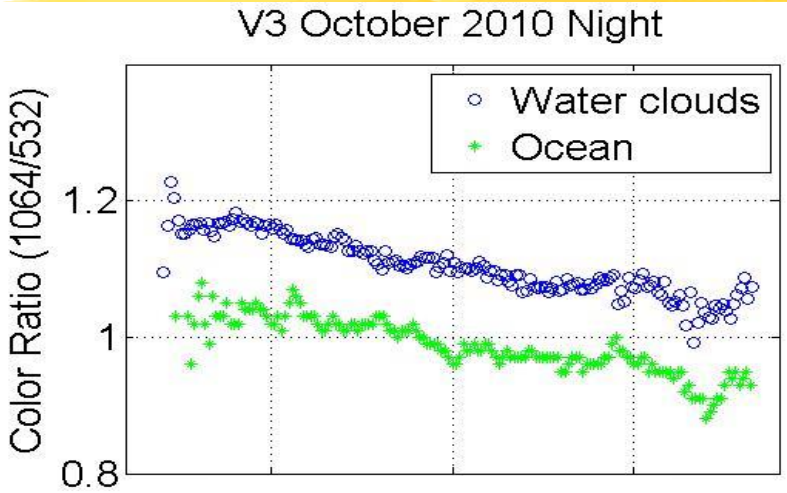
VERSION 4

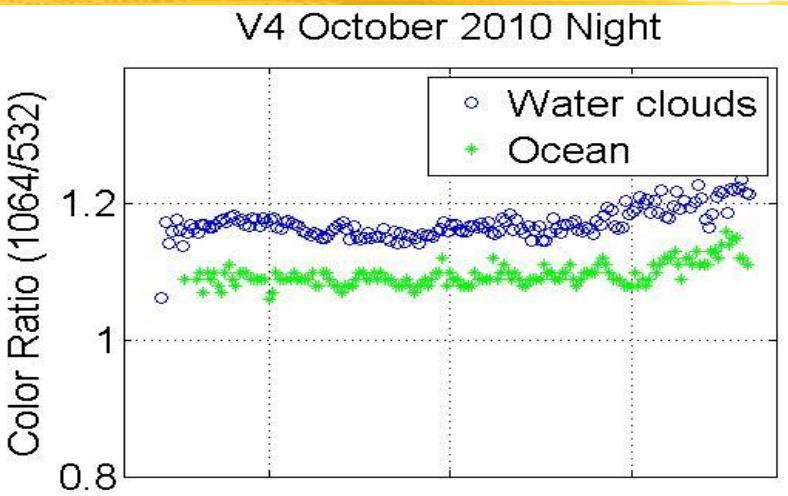


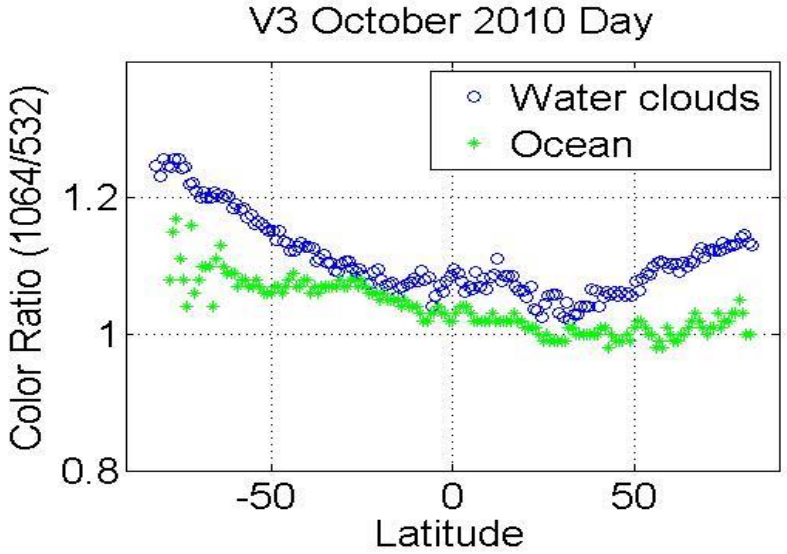
Decimal logarithm of the number of calibration clouds

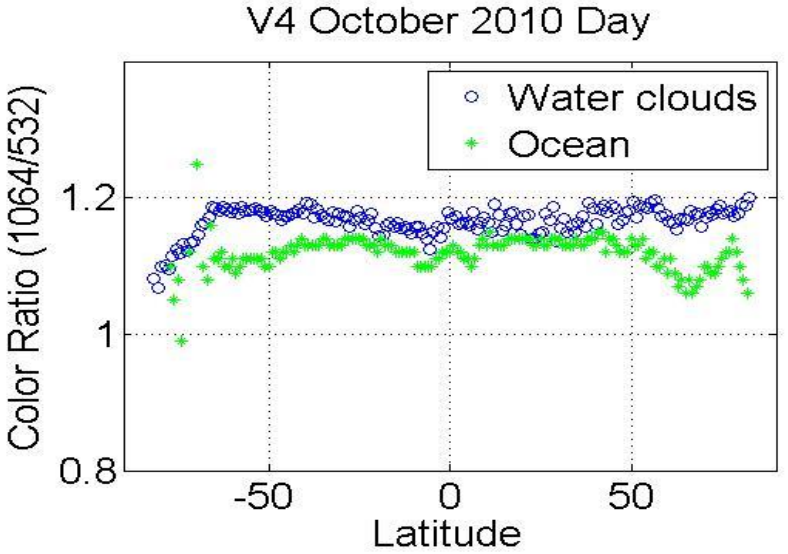
Revised cloud selection scheme improves sampling in V4, reducing both random and systematic errors

Cirrus Color Ratio Trend: V3 vs V4









Latitudinal slope reduced in V4

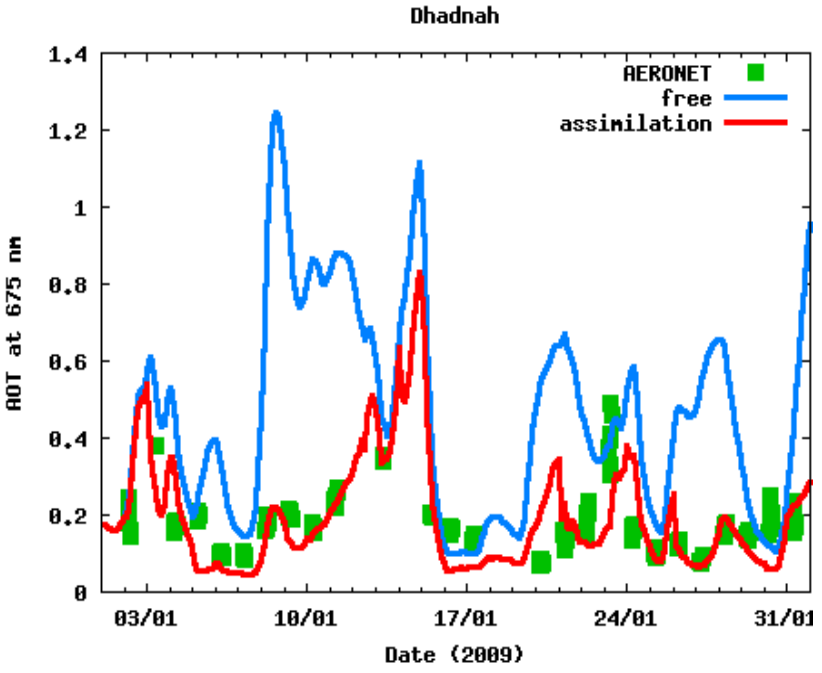
Level 1 Status

- Processing of Version 4 to begin next month
- Processing of full mission expected to continue through mid-2014
  - Contingent on availability of new GMAO met data
- Production of Version 3 Level 1 and Level 2 will continue as-is until V4 Level 2 becomes available

A few assimilation examples

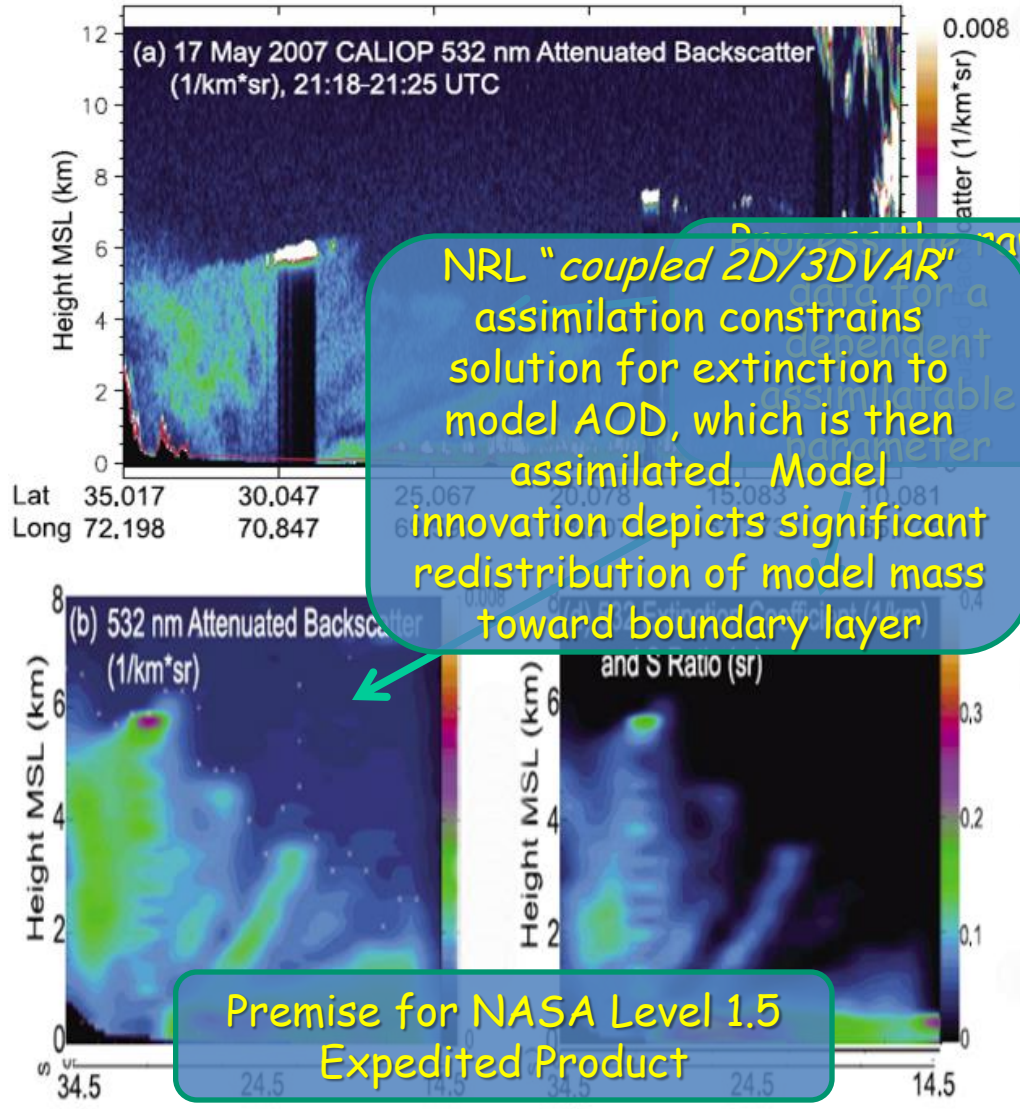
Assimilation Experiment: Tokyo U.

- CALIOP nighttime Level 1 profiles assimilated into global aerosol transport model
  - SPRINTARS driven by MIROC
  - Local Ensemble Transform Kalman filter assimilation scheme
  - Assimilation observation operator assumes single scattering, treats dust as spheroids
- Improves agreement with AERONET *AOD* at Dhadnah
  - Decreases dust in free troposphere
  - Increases dust loading in PBL



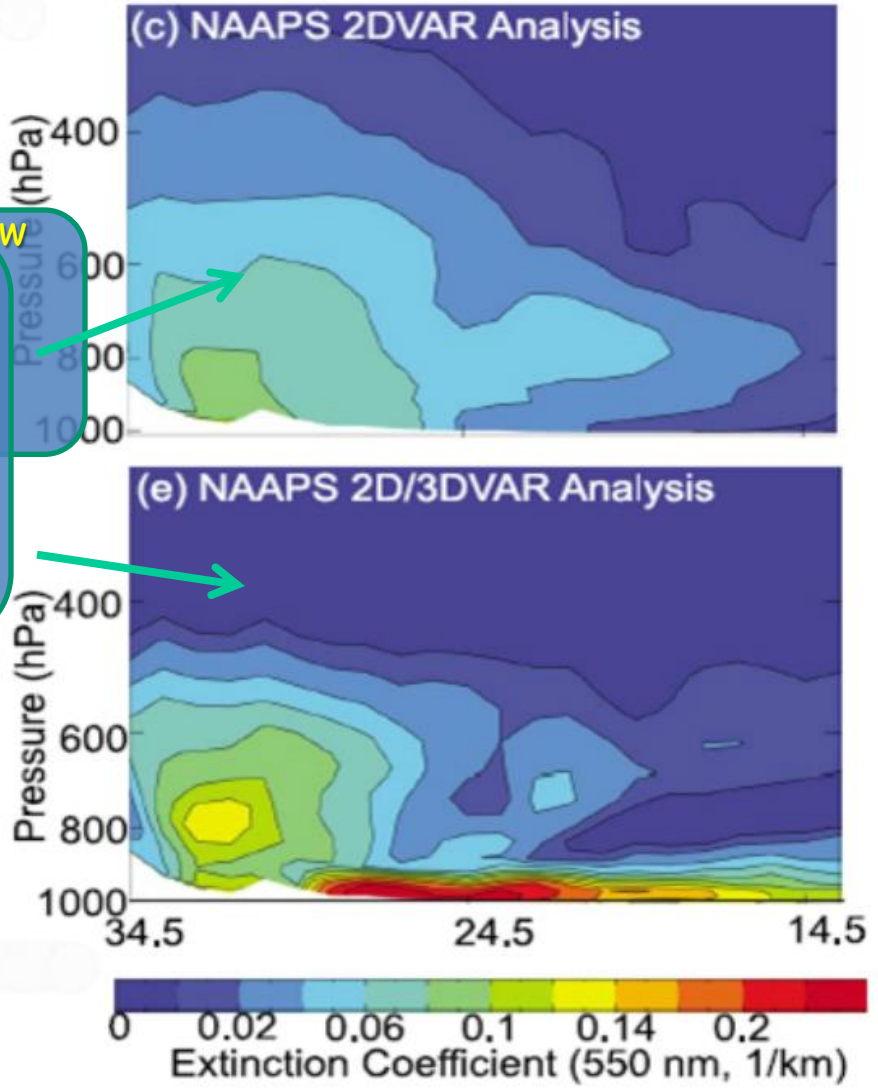
Nick Schutgens & Eiji Oikawa, Tokyo U.

NRL: Processing Paradigm
(James Campbell)

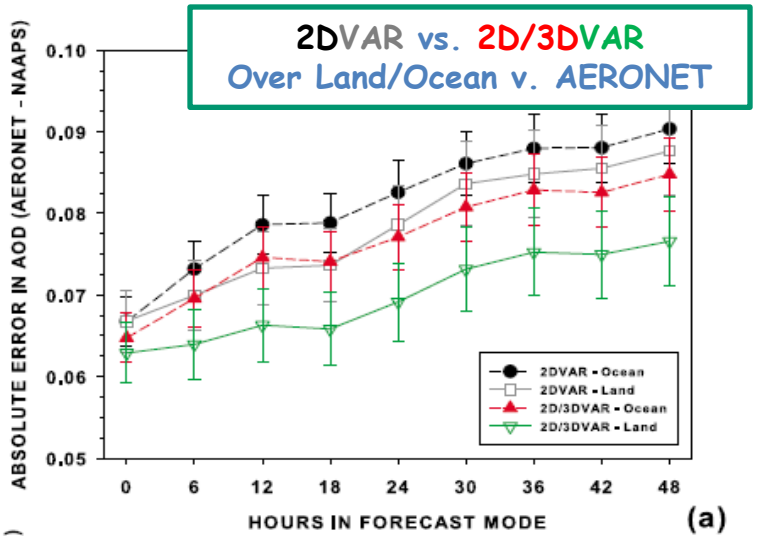


NRL "*coupled 2D/3DVAR*" assimilation constrains solution for extinction to model AOD, which is then assimilated. Model innovation depicts significant redistribution of model mass toward boundary layer

Premise for NASA Level 1.5 Expedited Product

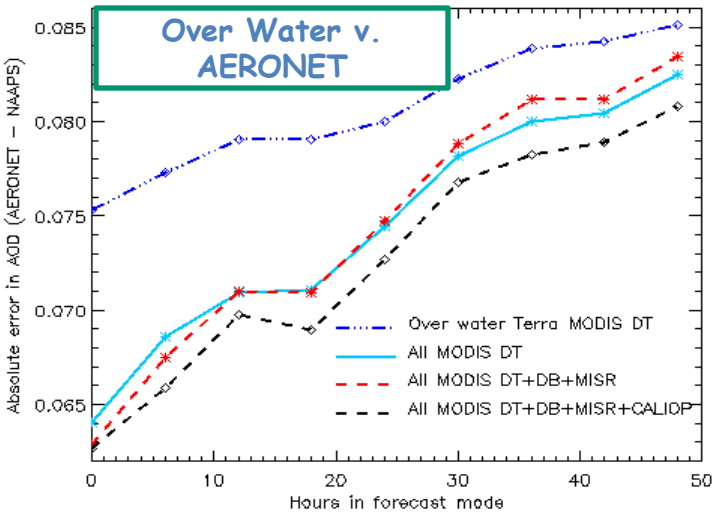


NRL: Performance Evaluation



- Since coupled 2D/3DVAR is constrained by 2DVAR prior for AOD, particle mass is conserved.
- We see little skill improvement at 00-hr analysis, but increasing skill through forecast
- By redistributing model mass with CALIOP, forecast AODs improve downwind
- Greater improvement over land where passive sensors experience difficulties

- New paper by *Zhang et al.* describes sequential improvement to NAAPS AOD v. AERONET with each satellite dataset added to assimilation
- CALIOP datasets represent 1/100th of potential *x, y* spatial data volume of MODIS/MISR, yet produce significant improvement through forecast.
- Will only improve further with future multi-satellite lidar arrays and ensemble DA



Product Plans

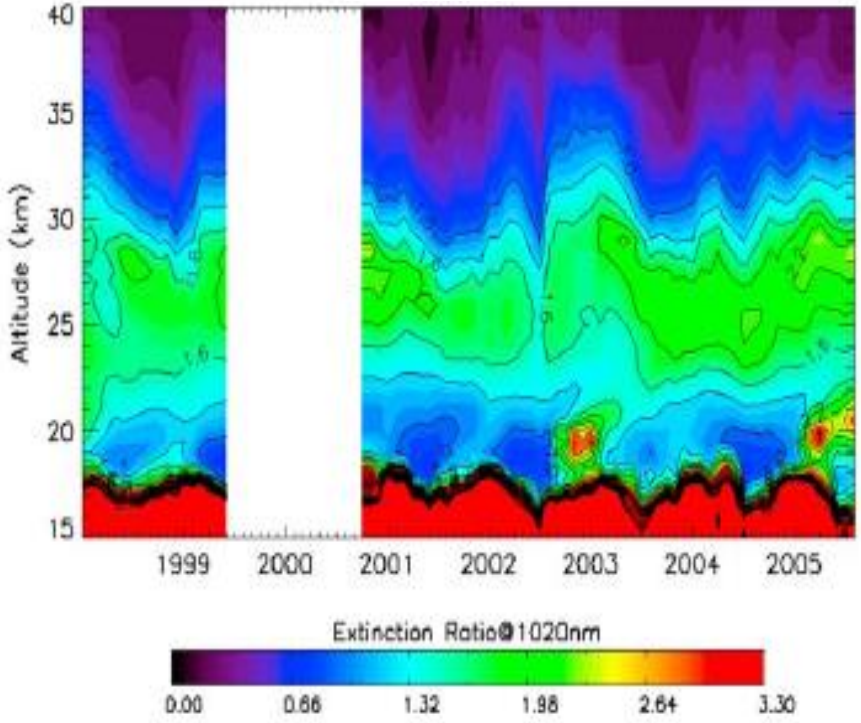
Near-term Plans

- V4L1 production to begin next month
  - Schedule contingent on availability of new GMAO met data
  - Next step in validation is evaluation of new Level 2 products
- Release of a Level 2 PSC product is imminent
- Level 3 Aerosol product
  - β-version currently available
  - An improved "Provisional" release scheduled for early 2014
  - Change grid to 2°x 2° ??
- Stratospheric product in development– built on V4 L1
- A Level 1.5 "re-analysis" product is being considered
  - Product of current Level 1.5 NRT will continue, based on V3

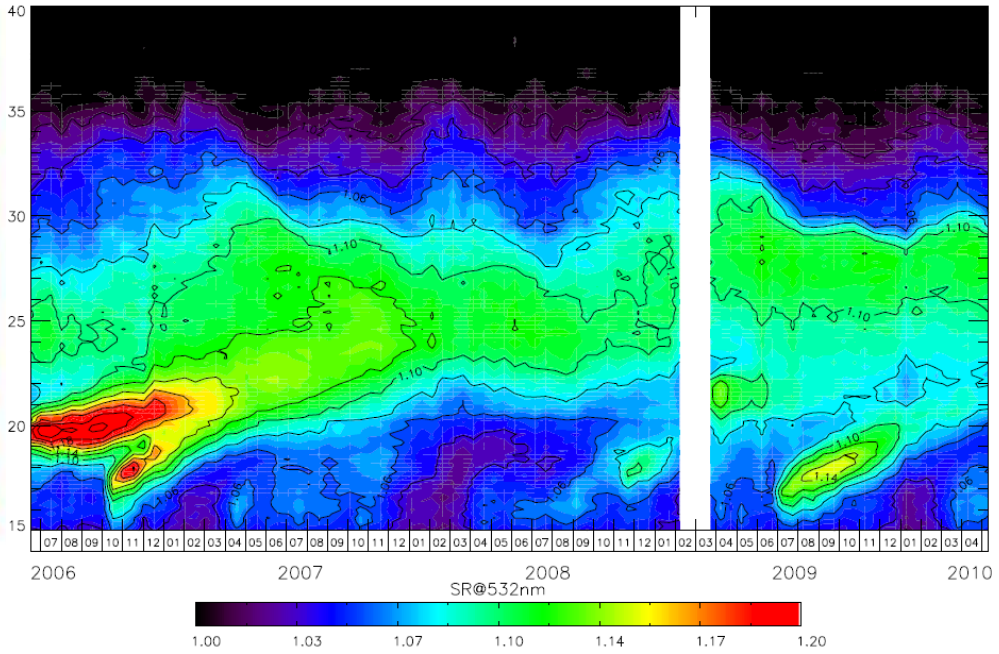
New Products
Stratospheric Aerosol

- CALIOP has been able to extend the multi-decade SAGE climatology
- Developed as a research product, will be refined and released next year as an official CALIPSO data product
  - Proposed grid: 5 x 20 degs x 360 m, tropopause to 40 km
  - Monthly files

SAGE II



CALIOP



Longer Term Plans

- Version 4 Level 2 in development
  - Once V4 Level 1 is in production, focus shifts to Level 2
  - Will be used for higher-level validation of V4 Level 1
- Level 3 cloud product
  - Based on V4 Level 2
- Level 3 aerosol product
  - Will be updated when V4 Level 2 is available

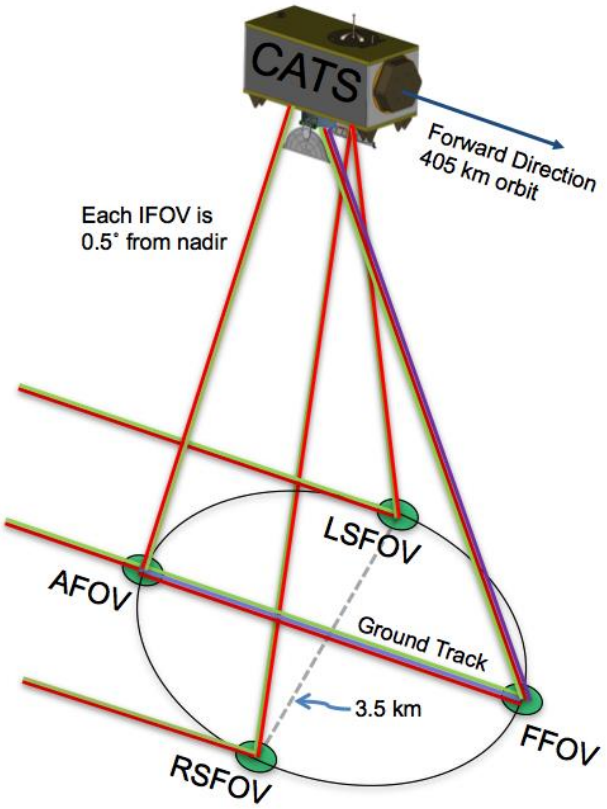
Other Activities

- OCO-2
  - Will fly in A-train ahead of CALIPSO
  - Launch: summer 2014
  - CALIOP data will be used to evaluate OCO-2 retrievals
  - Aerosol absorption retrieval in development
    - ✓ combines CALIOP with OCO-2 O_2 A-band radiances ($\Delta\lambda$ = 0.05 nm)

- CATS-ISS
  - To be operated on ISS JEM platform
  - Launch: June 2014 on H-2
  - CALIPSO team will produce CALIPSO-like product from CATS mode 1 data
  - OCO-3 also planned for ISS JEM

SPARE

CATS Configuration



Two non-identical Nd:YAG lasers:

- **1064/532**
- **1064/532/355**
- **1-2 mJ, 5 kHz pulse rate**

Receiver:

- **3-λ elastic backscatter**
- **532 HSRL mode**
- **Depol at all three wavelengths**
- **Range resolution: 60 meters**
- **Redundant optical chains → four footprints**

Six different operating modes:

Science Mode	Laser	Wavelength (nm)							IFOV			
		1064		532			355					
		||	⊥	||	⊥	HSRL	||	⊥	LSFOV	RSFOV	FFOV	AFOV
1	1	X	X	X	X				X	X		
2	2a	X	X	X		X						X
3	2b	X	X	X	X		X	X			X	
4	2c	X	X	X	X				X			
5	2c	X	X	X	X					X		
6	2c	X	X	X	X						X	