

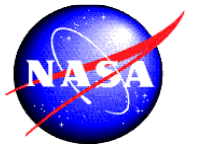
CALIPSO and What Comes Next

Dave Winker, Jason Tackett
NASA Langley Research Center, Hampton, VA

WLMLA, Sao Paolo, 9-12 April 2024



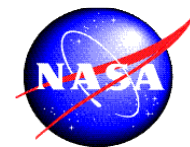
Quick CALIPSO Status



- Used last of propellant in 2019 (after leaving A-train)
- Satellite drifted eastward → decreasing solar array power
- Continued lidar operations in drifting orbit through the end of June 2023
- By August 2023, spacecraft had insufficient available power to fully support lidar operations
- Payload science operations terminated 1 August 2023
- Final engineering activities and satellite passivation completed during fall 2023
- Satellite turned off – 15 December 2023
- Satellite will re-enter the atmosphere in 2045 (TBD)



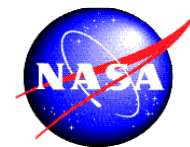
CALIPSO Timeline



- Launched in April 2006 for a 3-year prime mission
 - CALIPSO and CloudSat lower orbit, leave A-train
 - Orbits begin to precess eastward
 - Payload placed in Standby due to low power margins
 - Platform power decreased due to orbit precession
 - Test of primary laser:
 - Backup laser turned off
 - Primary laser restart
 - Science acquisition with primary laser
 - Science operations terminated
 - Engineering experiments
 - Spacecraft passivation, turned off
 - Satellite re-enters atmosphere
- mid-2018
- Sept-Oct 2022
- June 21, 2023
- June 28
- June 29-30
- August 1, 2023
- Sept-Nov 2023
- 15 Dec 2023
- ~ 2045



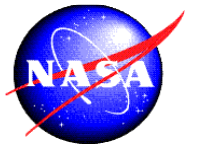
Data Product Status



- V4.5 Level 1/Level 2
 - Release completed in mid-2023
 - Highlights:
 - Column optical depths from surface returns (ODCOD)
 - Column optical depth above opaque water clouds (Hu et al 2007)
 - Improved retrieval of elevated smoke layers (SE Atlantic)
- Lidar Level 0
 - Raw profile data, before range corrections & calibration
 - To be released in HDF format: spring 2024 (?)
- Level 2 (or 3) sub-surface ocean product
 - To be released in mid-2024
- Version 5 (final version of data products)
 - Final code changes: Spring 2025
 - Final release, all data products: Summer/Fall 2025



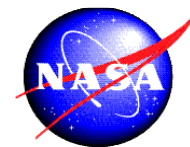
Release Schedule



<u>Data Product</u>	<u>Target Release Date</u>	<u>Notes/Dependencies</u>
V4.51 IIR L2	Summer 2023	Released October 2023
V1.00 Payload Inst. and Verification Block	Fall 2023	Final code changes underway
V1.00 CALIOP Level 0 – Public Format		Code finalized. Ready to being processing.
V2.00 CALIOP L2 Blowing Snow - Antarctica		Released February 2024
V1.00 CALIOP L2 Blowing Snow - Greenland		Released February 2024
V1.00 CALIOP Level 2 Ocean Product	Winter 2023	Algorithm development on-going, converting research to operational code.

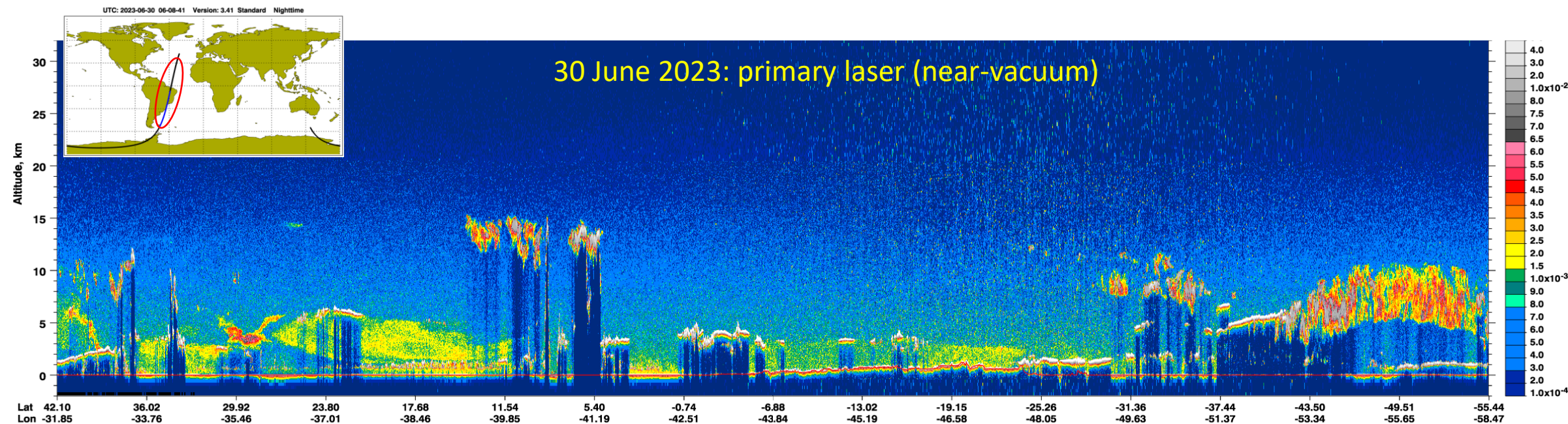
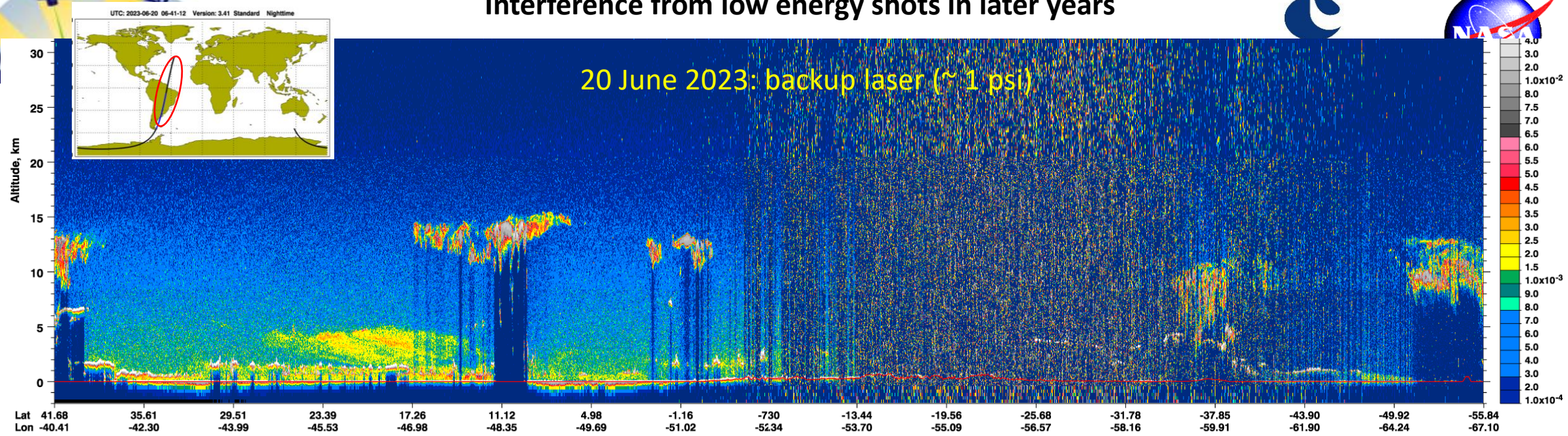


Release Schedule



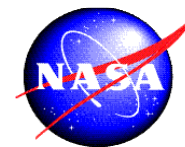
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V1.00 CALIOP L2 Blowing Snow - Greenland		Released February 2024
V1.00 CALIOP Level 2 Ocean Product	Spring 2024	Algorithm development on-going, converting research to operational code.
V5.00 CALIOP Level 1	Summer 2025	Start processing & ingest by Sept 2024.
V5.00 CALIOP Level 2		Follows V5.00 CALIOP Level 1
V5.00 IIR Level 2		Follows V5.00 CALIOP Level 2
V3.00 CALIOP L2 Blowing Snow - Antarctica		Follows V5.00 CALIOP Level 1 & Level 2
V2.00 CALIOP L2 Blowing Snow - Greenland		Follows V5.00 CALIOP Level 1 & Level 2
V5.00 CALIOP L3 – Tropospheric Aerosol		Follows V5.00 CALIOP Level 2
V2.00 CALIOP L3 – Stratospheric Aerosol		Follows V5.00 CALIOP Level 2
V2.00 CALIOP L3 – Ice Cloud		Follows V5.00 CALIOP Level 2
V2.00 CALIOP L3 – Cloud Occurrence		Follows V5.00 CALIOP Level 2
V2.00 CALIOP L3 – Cloud, GEWEX format		Follows V5.00 CALIOP Level 2
V2.00 IIR Level 3 – GEWEX format		Follows V5.00 CALIOP/IIR Level 2
V1.00 IIR Level 3		Follows V5.00 CALIOP/IIR Level 2

Interference from low energy shots in later years

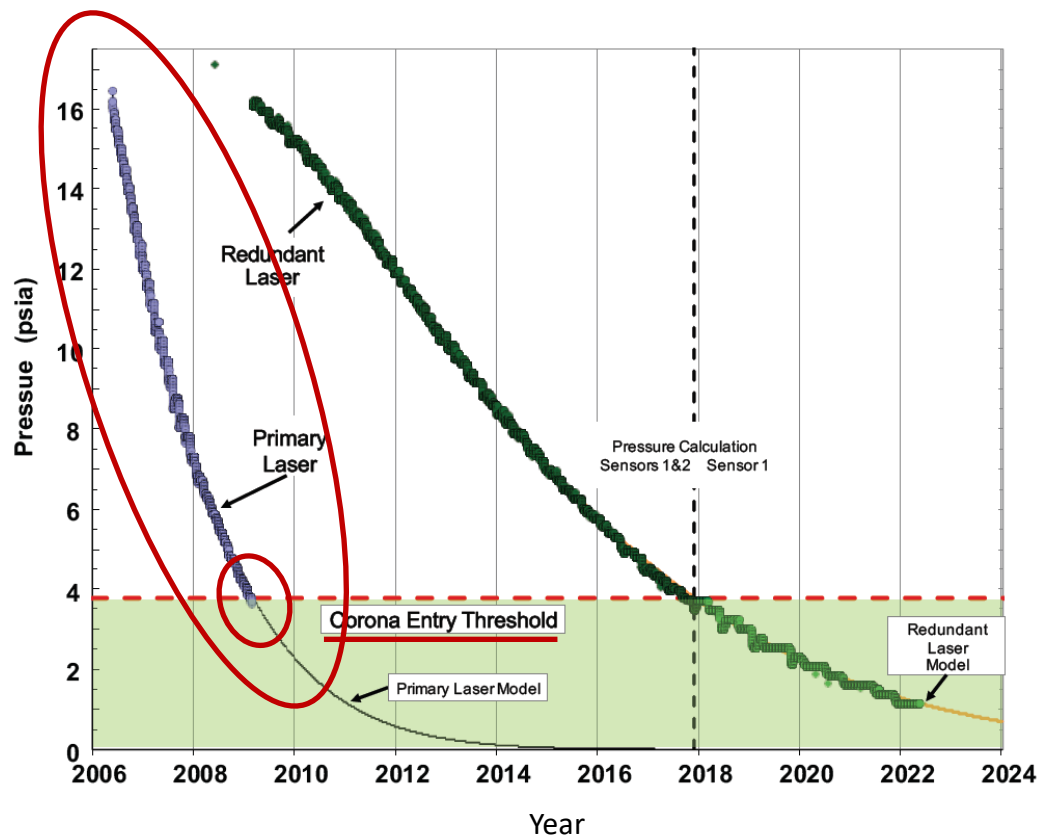




Origin of Low Energy Shots

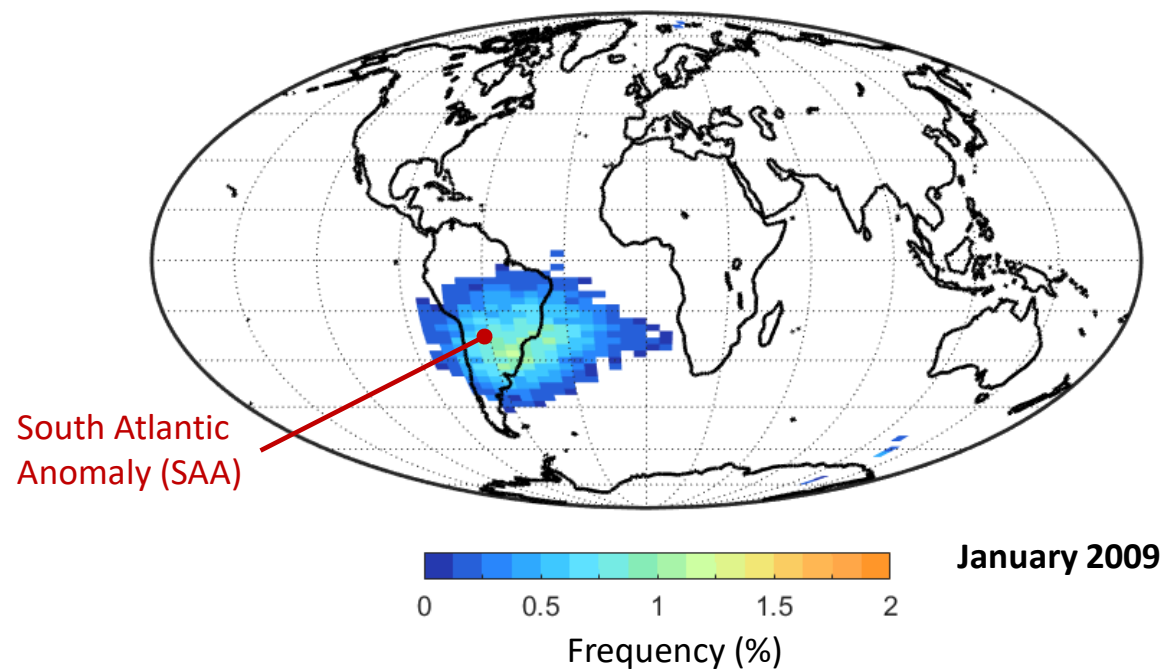


Laser Canister Pressure



Pressure losses in the primary laser canister allowed coronal arcing across the Q-switch, leading to low energy pulses.

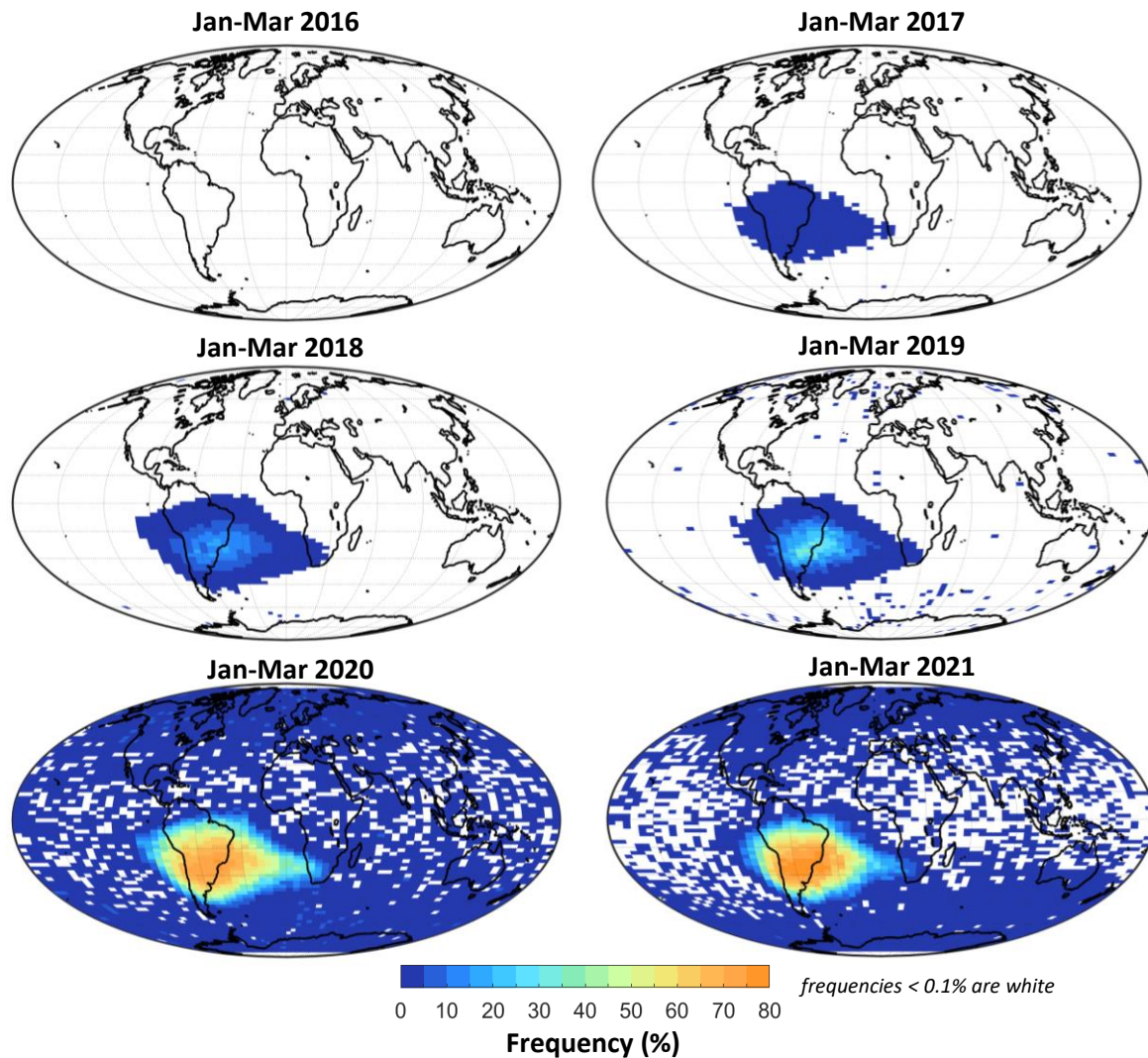
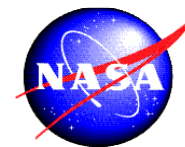
Pulses with $E_{532} < 10$ mJ



In 2009 the primary laser was deactivated.

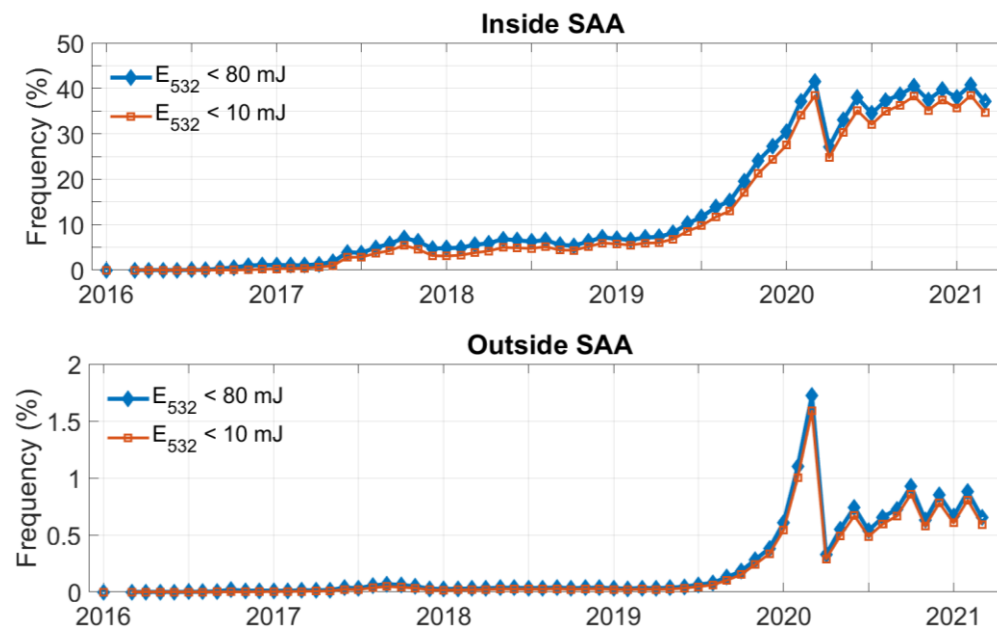


Evolution of Low Energy Laser Shots



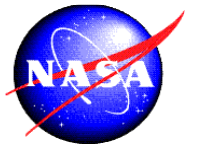
Early years – South America impacted starting in 2017

Mostly confined to SAA prior to 2022
Few shots with energy > 10 mJ but < 80 mJ



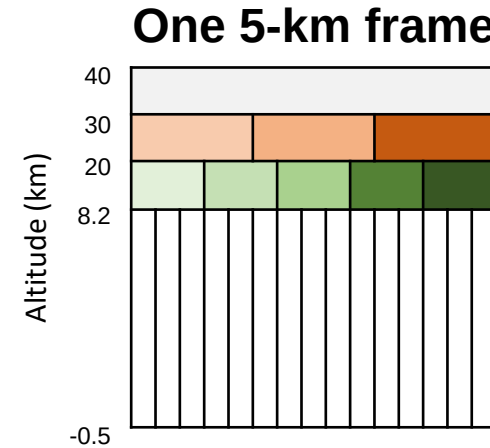


Level 2 Data Processing Fundamentals



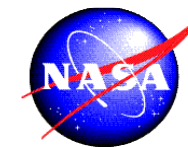
The basic data unit for Level 2 processing is a 15-shot “frame”

- Profiles above 8.2 km altitude are averaged before downlinking

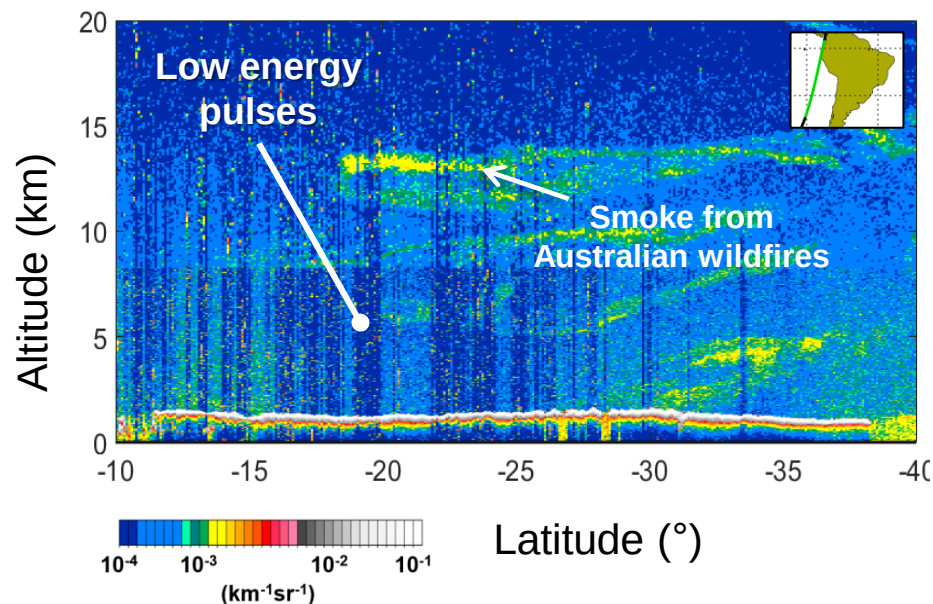




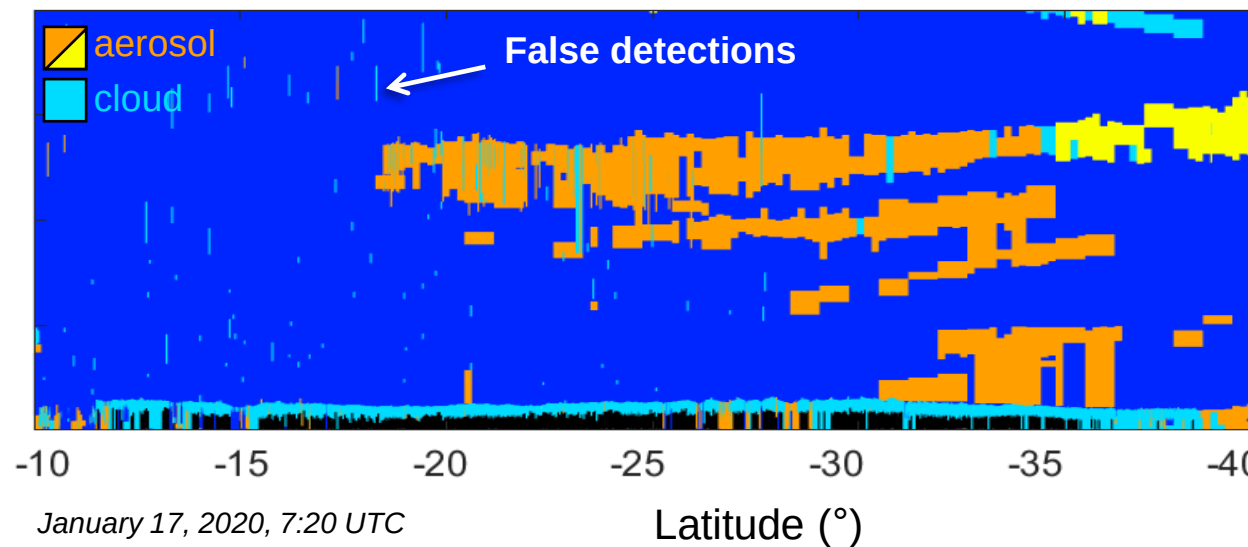
Impact of Low Energy Pulses



V4.1 Level 1 Attenuated Backscatter



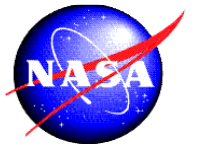
V4.5 Level 2 Feature Detection



Goal: mitigate the influence of low energy pulses on Level 1 calibration, Level 2 feature detection



Impacts on Calibration



Prior to Version 4.5:

532 nm nighttime calibration *is not* affected by low energy pulses.

- standard quality filters in algorithm mask out profiles with low energy

532 nm daytime calibration *is* affected:

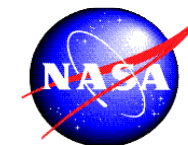
- Data used in calibration are averages across ± 52 consecutive granules, some passing through the SAA.
- Causes biased calibration coefficients and increased uncertainty.

Version 4.5 Level 1:

LEM implemented to reject data affected by low energy pulses from scattering ratios used for 532 nm daytime calibration

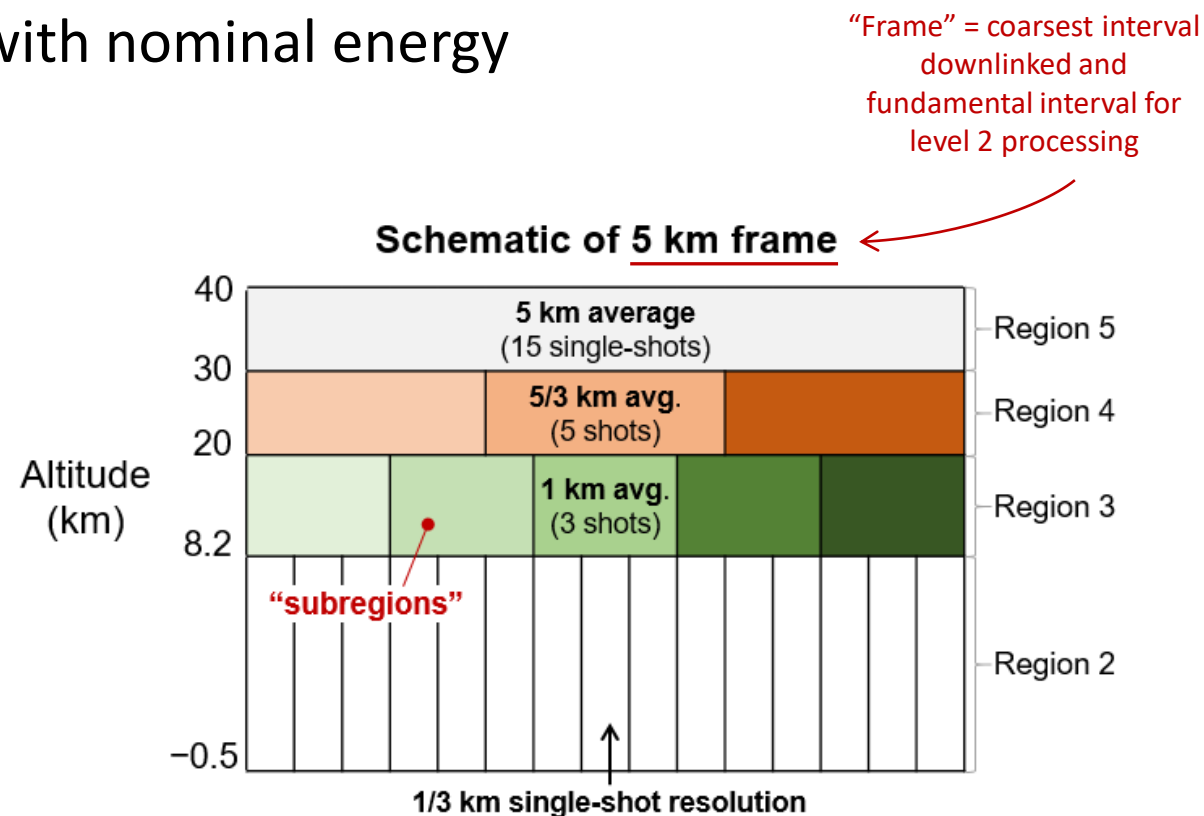
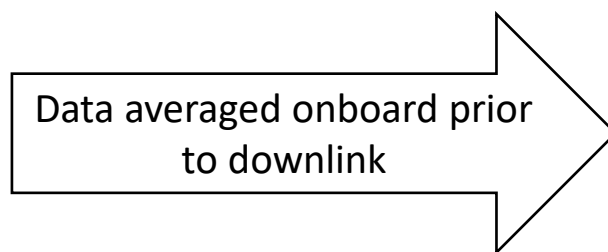
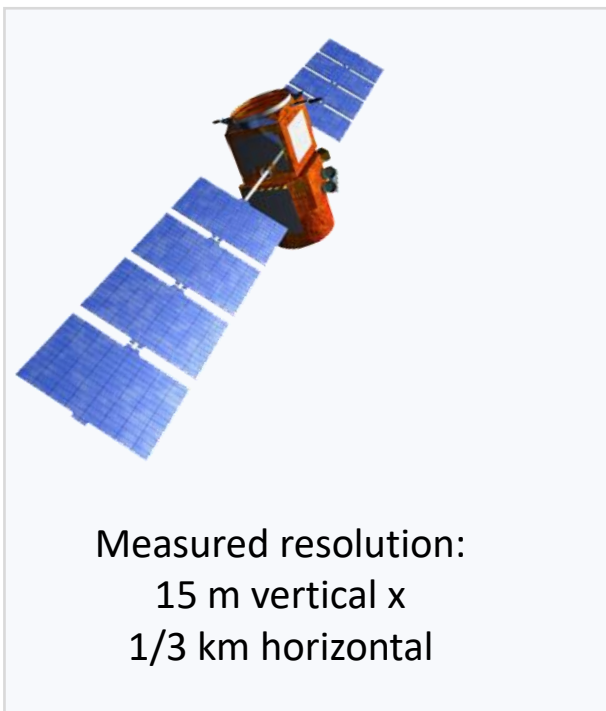


Low Energy Mitigation (LEM) Algorithm



A balance of two competing desires:

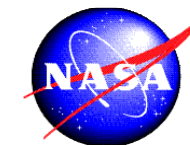
- Maintain science quality compared to data with nominal energy
- Minimize data rejection



LEM accounts for onboard averaging



LEM - Accounting for Onboard Averaging



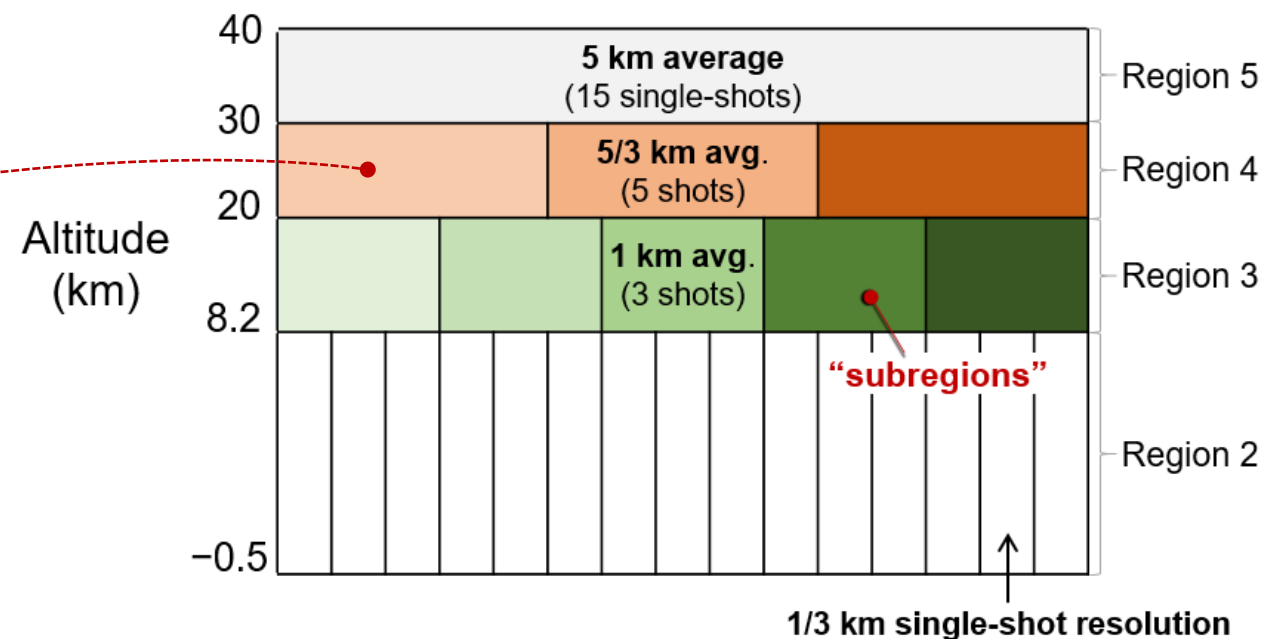
During calibration, the average signal is normalized by the average energy

$$\beta' = \left(\frac{r^2}{CG} \right) \frac{\bar{S}}{\bar{E}}$$

Energy normalization compensates for shots with low energy in the average...
but noise is increased

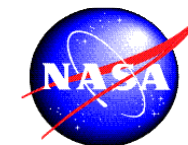
Therefore, *some* low energy shots can be tolerated in the averaged subregions of a frame.

Schematic of 5 km frame





LEM - Accounting for Onboard Averaging



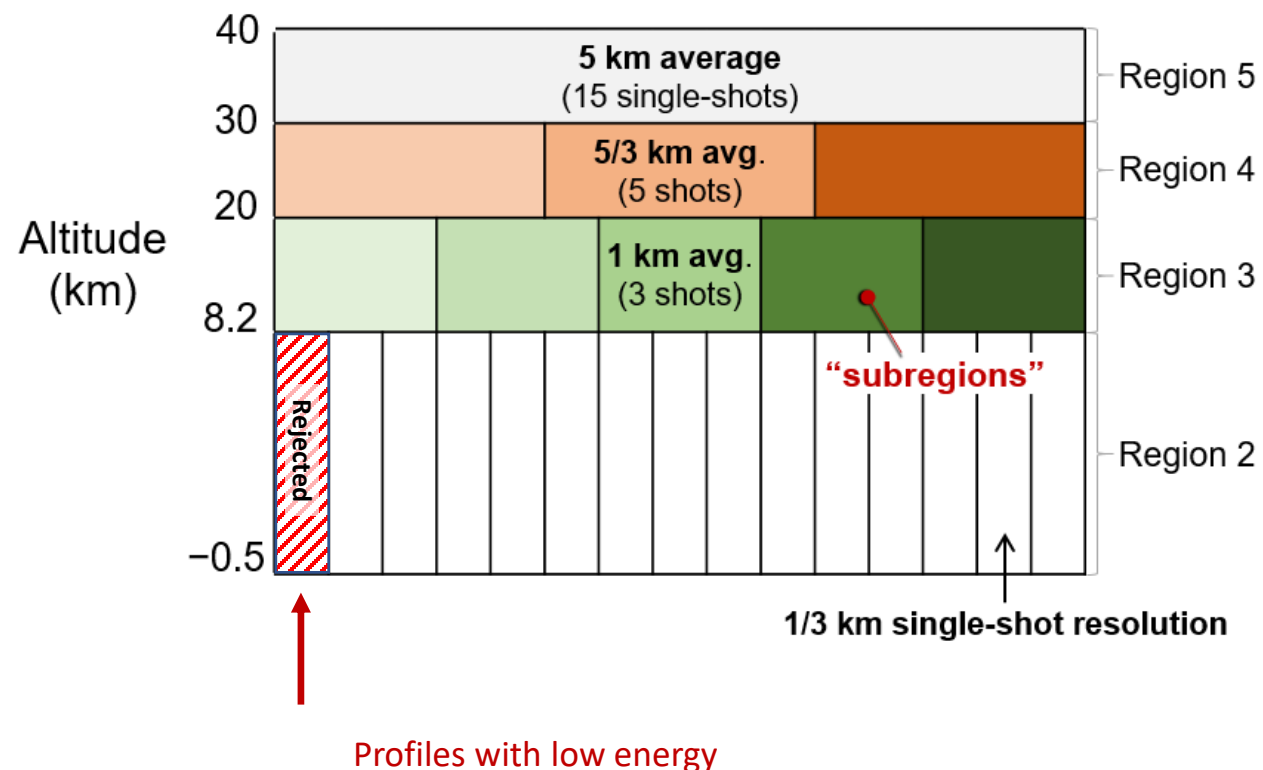
LEM requires each subregion in a frame to have minimum amount of profiles with nominal energy.

Example:

1 low energy pulse

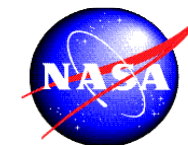
- Profile in single-shot resolution region rejected
- Remaining subregions accepted

Schematic of 5 km frame





LEM - Accounting for Onboard Averaging

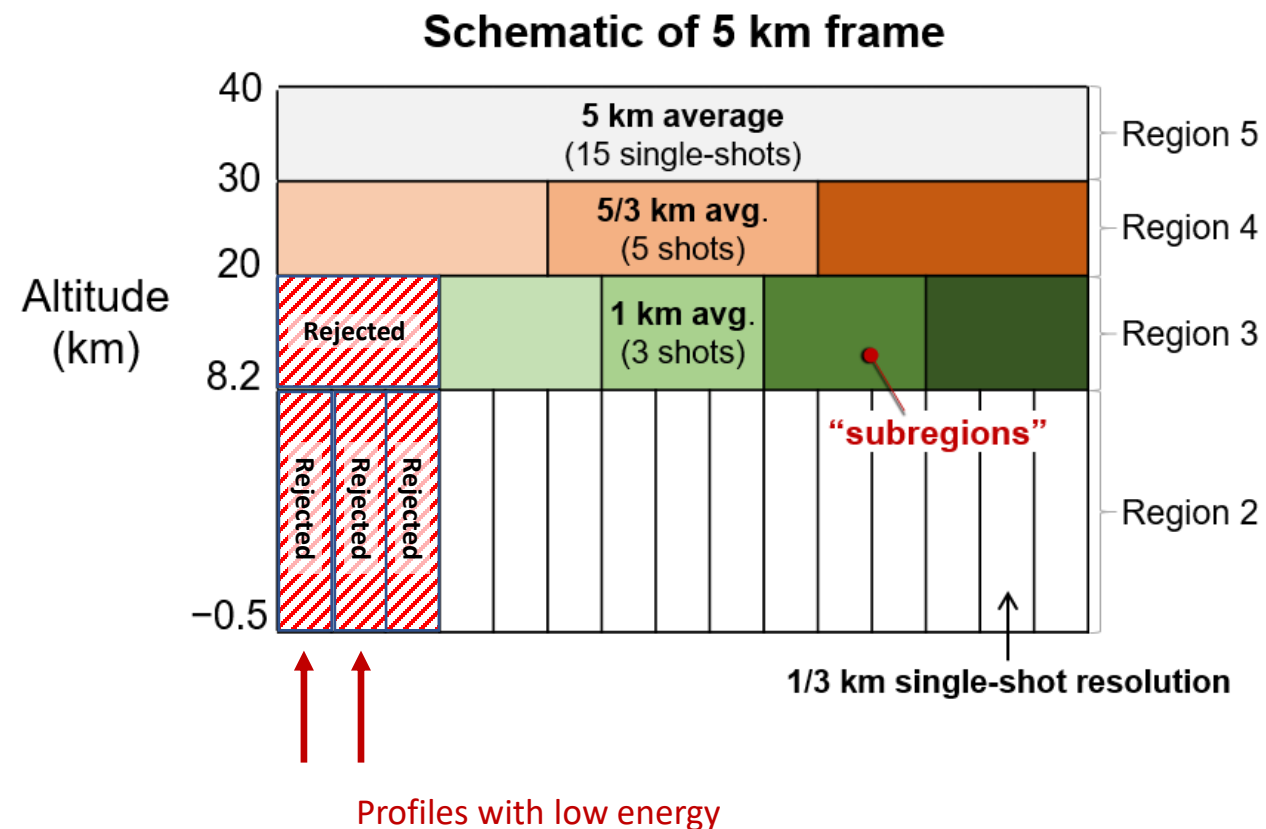


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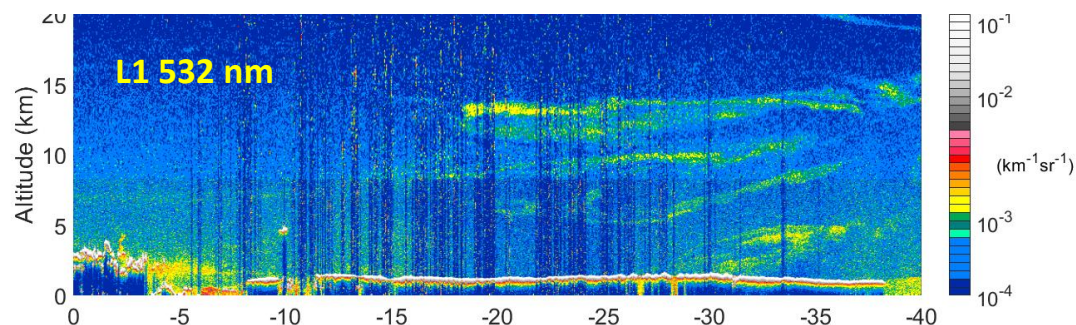
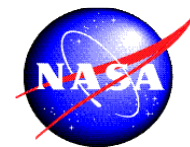
2 low energy pulses

- Profiles in single-shot resolution region rejected
- Region 3 average rejected

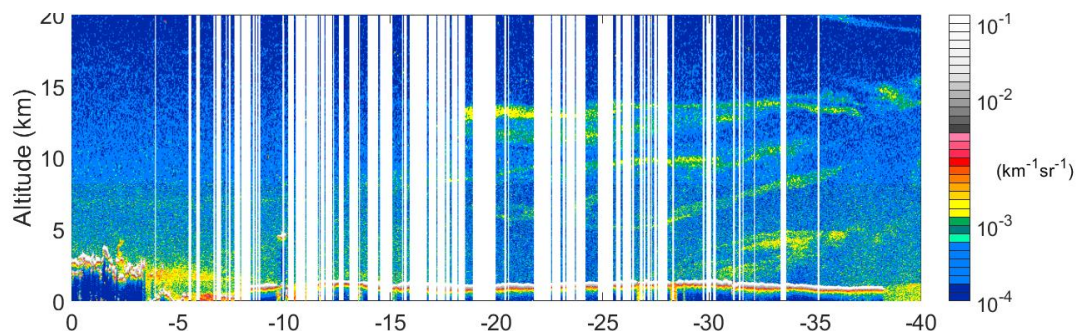




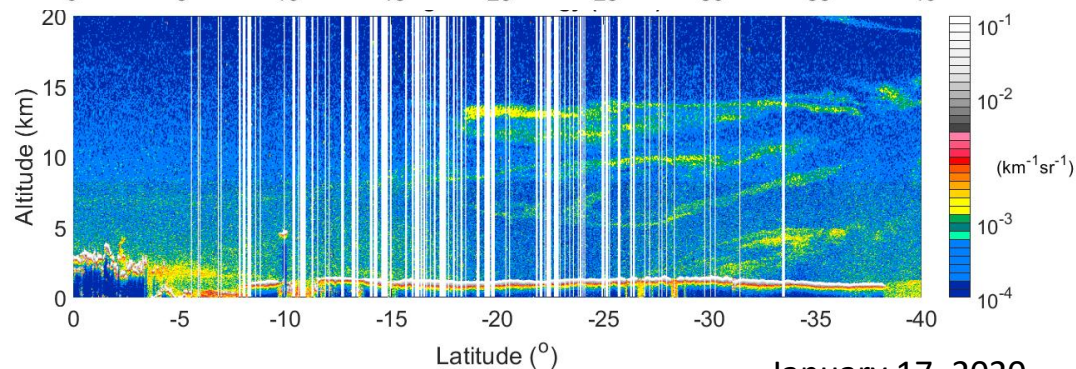
Improvement After Algorithm Applied



Black streaks are regions with low-energy pulses



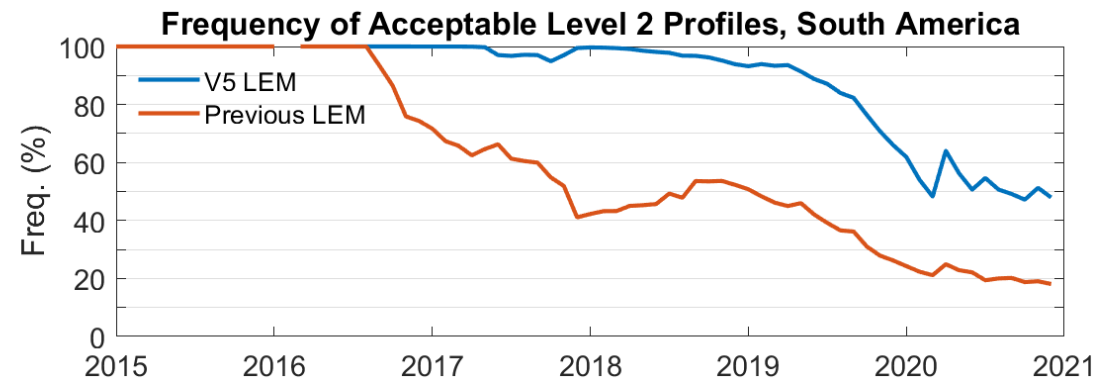
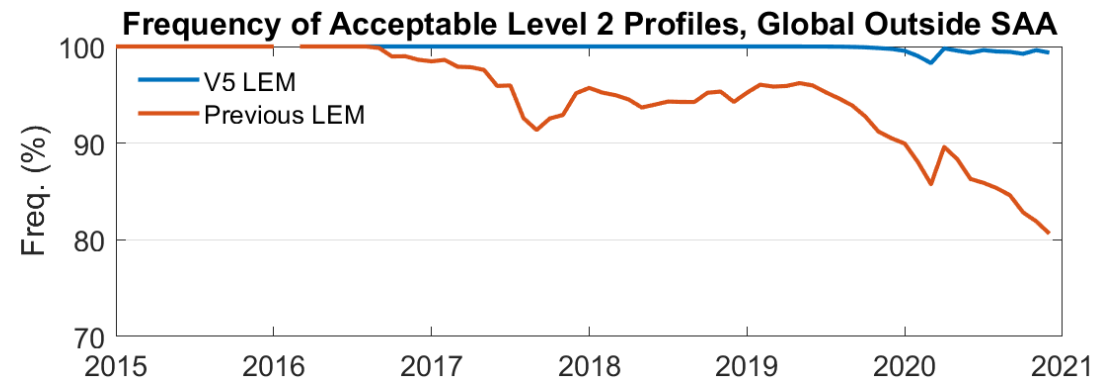
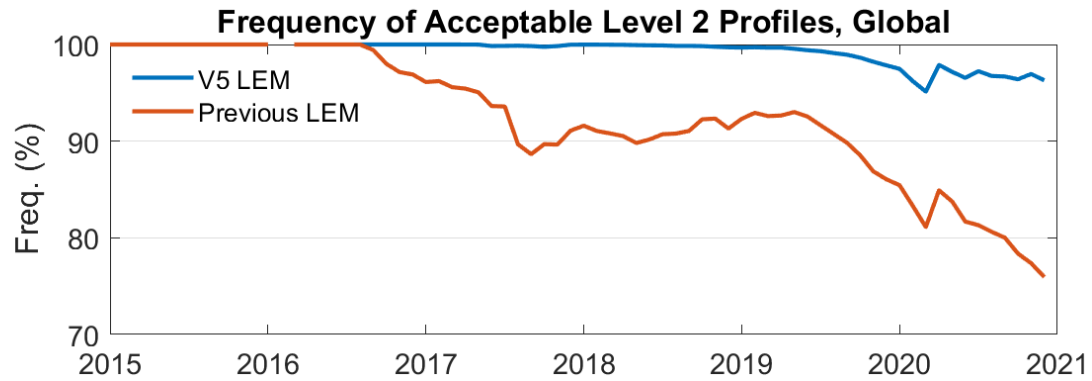
After masking out 80 km 'chunks' containing ≥ 1 low energy shot



After recovery of recoverable frames

Can recover quite a bit of data, even in the worst conditions

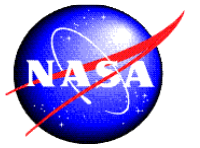
January 17, 2020



- LEM recovers majority of frames containing low energy pulses outside the SAA.
- Substantial frame loss occurs in the SAA.
- Globally, ~96% of frames will maintain nominal science quality for October 2021



Data Products Summary



- Version 5 development now underway
 - Implement LEM algorithm to reduce impacts of low energy laser shots
 - Convert format to netCDF or HDF-5
- Final processing and archival to be completed by August 2025
 - Processing and archival of the final versions will be phased based on product and scheduled to begin in September 2024, starting with Level 1 data
- All Version 5 data products will be moved into NASA's Earth Data Cloud and archived for "at least" 10 years
- CALIPSO science website
 - Will be preserved, and maintained by LaRC
 - www-calipso.larc.nasa.gov will move to a new URL
- Science documentation and code will be maintained by ASDC