Detection and Measurement of Stratospheric Aerosols in CALIPSO Satellite Data: Potential new Informants for Modeling Energy Exchange in the Earth-Atmosphere System

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Abstract

Tenuous aerosols resultant from wildfires, distant volcanic eruptions, Asian and Saharan dust storms play important roles in the Earth-Atmosphere system. Modeling of heat flux between the Earth and the atmosphere and health impacts of pollution are only two examples. Tenuous aerosols have been found to be transported around the entire Earth. Yet tenuous layers often go undetected in atmospheric lidar data.

The complexity of data situations in which atmospheric layers are recorded in lidar data, by themselves or interspersed with cloud layers of varying optical depths and at different altitudes, and in addition resultant from different background situations of daytime, night and dusk, often exceeds the capabilities of classic algorithms for atmospheric lidar data analysis and classification.

Tenuous aerosols are recorded in the low-level CALIOP data from NASA's CloudSat/CALIPSO mission, but especially stratospheric aerosol layers often escape detection and classification partly or entirely in the current CALIOP data analysis scheme. To solve this problem, we have developed the Density-Dimension Algorithm for atmospheric lidar data analysis (DDA-atmos), originally for the atmospheric data from ICESat-2, and adapted it to CALIOP data. In this talk, we present results from applications of the CALIOP-DDA-atmos to detection and classification of stratospheric aerosols from various sources. Notably, the DDA-atmos allows detection of extremely tenuous layers in presence of complex types of other cloud and aerosol layers across a large range of optical thicknesses.

The goal is to provide an algorithm that may be used to generate improved CALIOP data products in a future release. The resultant data product is expected to yield a data base that will include faint, subvisible atmospheric layers especially in the stratosphere and thus facilitate updated modeling of energy fluxes between the Earth and the atmosphere with reduced uncertainty.

Summary of Results

The CALIOP-DDA facilitates detection of faint stratospheric aerosols.

Comparison of CALIOP-DDA results to the current CALIOP detection and classification scheme indicates,

(1) detected layers include faint aerosols that escaped detection with the existing scheme or were only partly detected,

(2) layers detected with the existing algorithms are also detected with the CALIOP-DDA, and

(3) the spatial resolution of CALIOP-DDA detection results is the same as that of the highest, low-altitude data (334 m along-track and 30 m in height).

Final Result – Nighttime Example

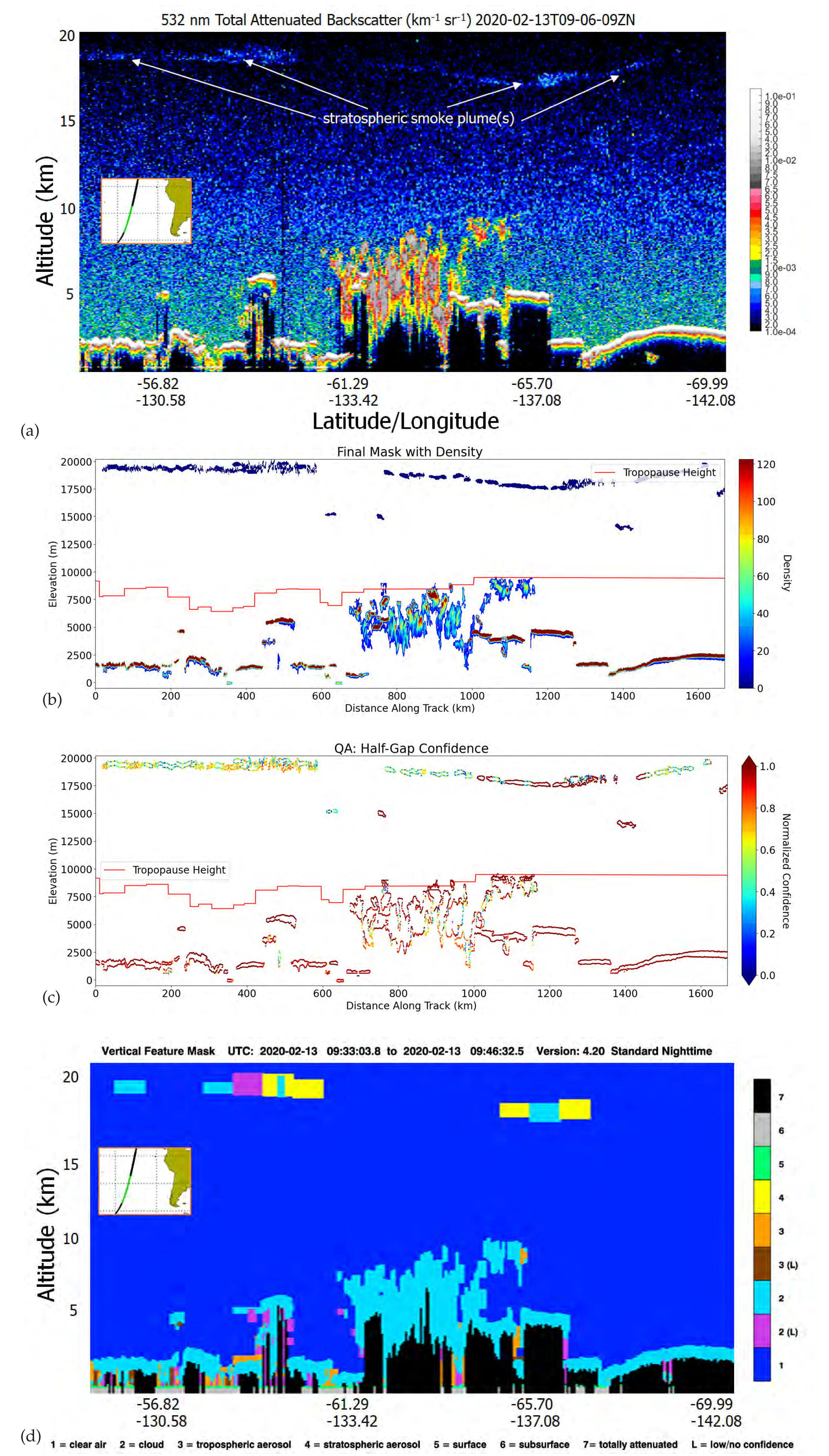

Figure 1. Demonstration of detection of faint stratospheric smoke plumes in CALIOP data v4 using the CALIOP-Density-Dimension Algorithm (CALIOP-DDA). The smoke plume is detected and reported at data-set resolution, although its signal in the total attenuated backscatter data is 2.5 orders of magnitude lower than that of cloud layers in the same data records. (a) 532nm total attenuated backscatter data. Inset: Data location. (b) Result of auto-adaptive layer detection using CALIOP-DDA. The dark-blue layer on top is the stratospheric smoke plume. Green color ranges - thin clouds. Red/orange color ranges: Optically thick clouds. Resolution of detected layers is 335m along-track/30m height (see, text). (c) Half-gap confidence of cloud and aerosol layer detection. (d) Current detection and classification capability given in the vertical feature mask of the CALIOP data product. Note along-track resolution is 80km along-track. Note the stratospheric smoke plume is partially detected, but largely missed and often misclassified.

Tropopause-split Concept

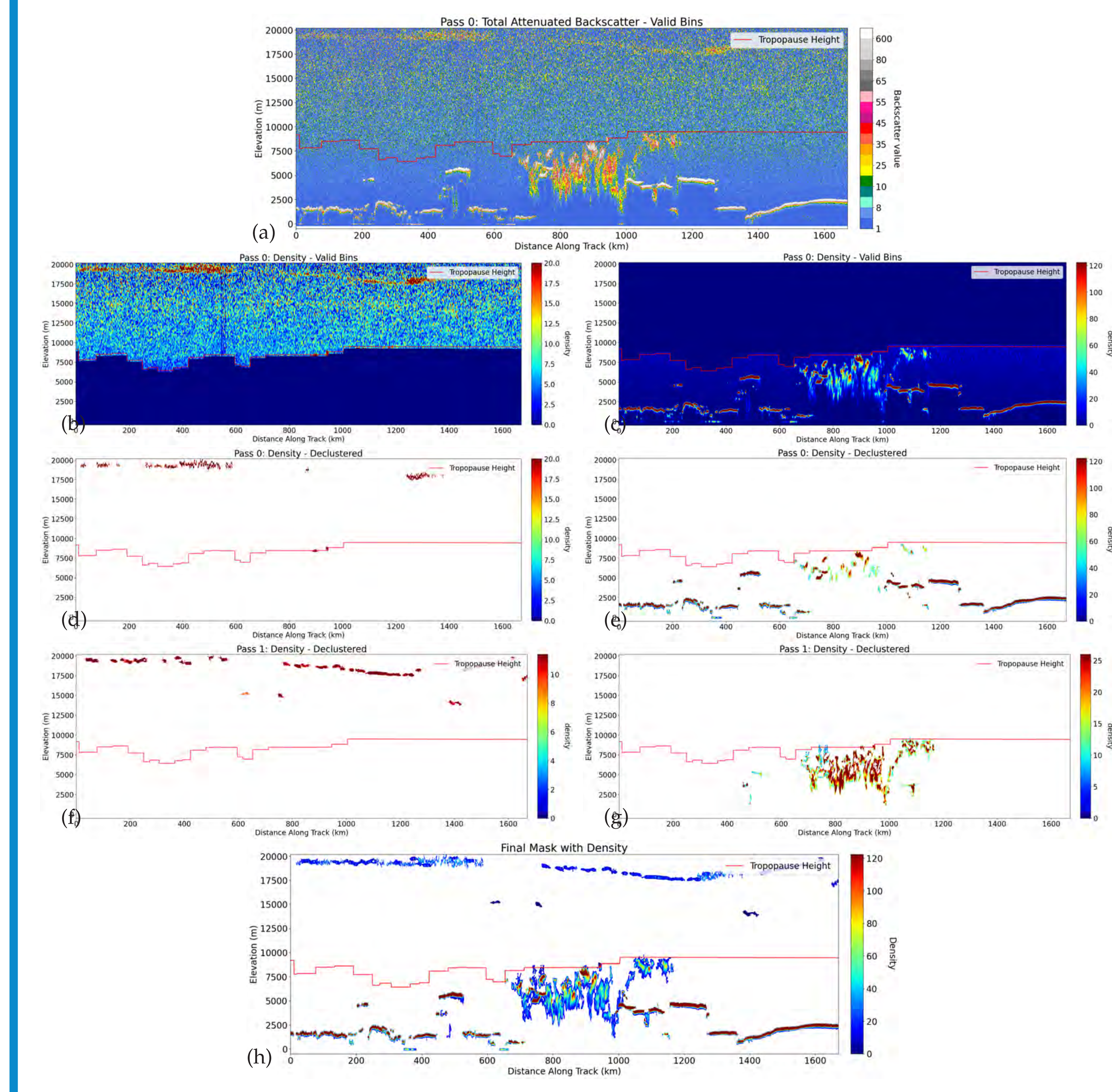

Figure 2. Experiment T1f. Nighttime full dataset. Parameter set T1. (a) Full NRB data, (b/c) Density Top/Bottom, (d/e) Decluster mask with density pass 1 Top/Bottom, (f/g) Decluster mask with density pass 2 Top/Bottom and (h) Final combined cloud mask with density.

Result: Faint aerosol layer (smoke plume) fully detected.

CALIOP-DDA Algorithm Steps

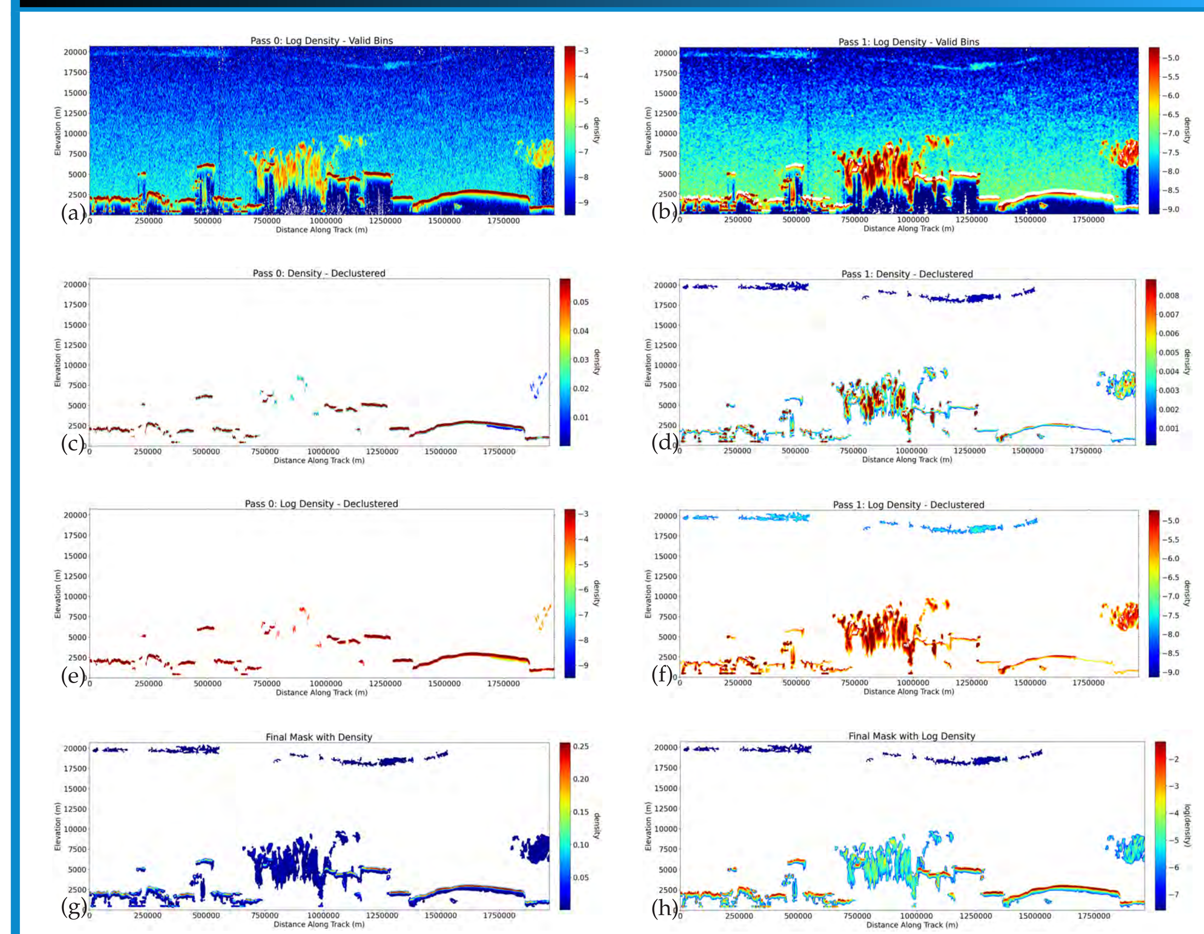

Figure 3. Stratospheric smoke plume example, DDA-steps. CALIOP Data. Prototype CALIOP-DDA. Figure highlighting the essential DDA steps. Log of density used for plotting to enhance visibility of layers across a range of backscatter values. Stratospheric smoke plume detected in presence of layers with 2.5 orders of magnitude larger backscatter values.

Daytime Example

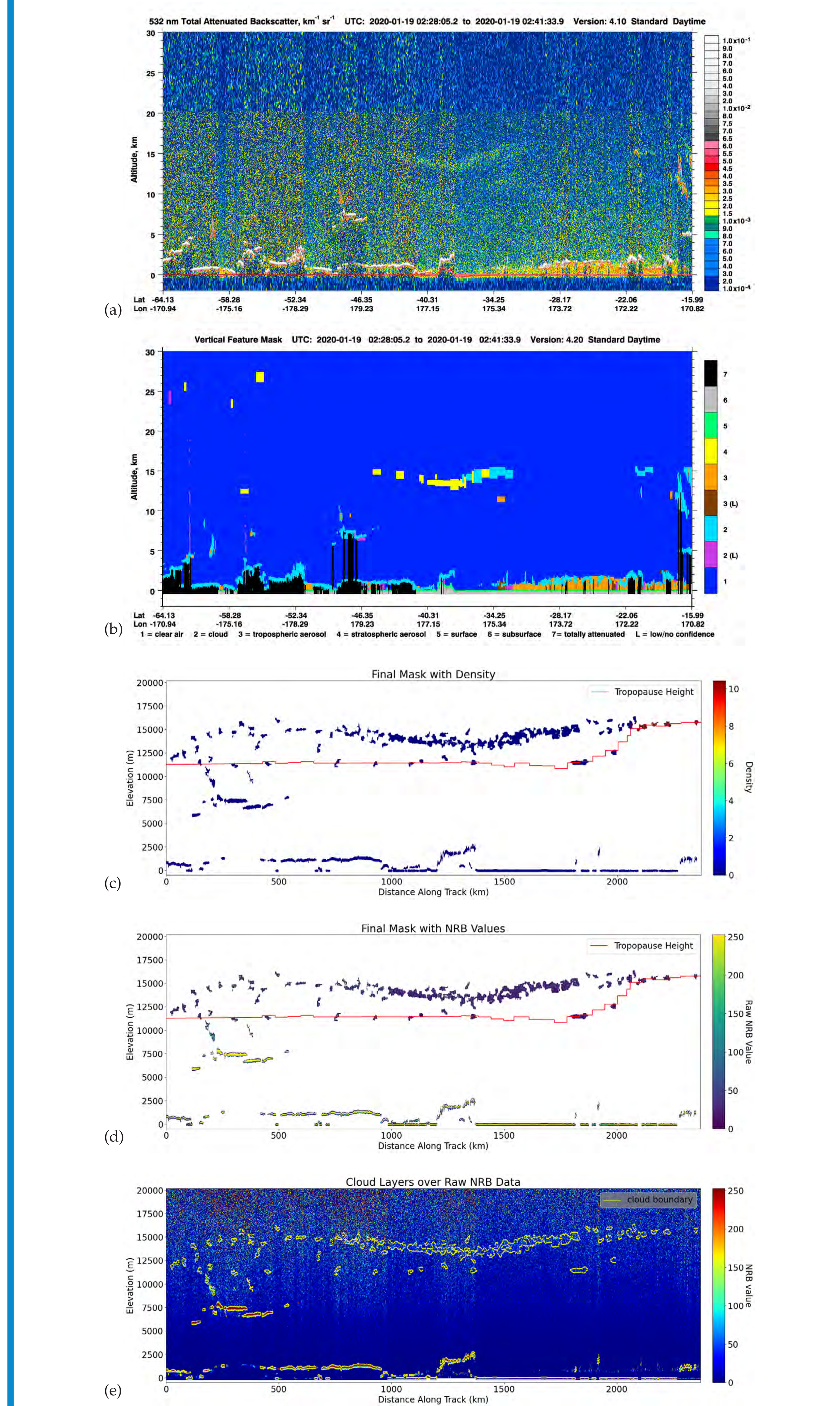

Figure 4. Stratospheric smoke plume from 2020 Australian wildfires. CALIOP Daytime data. 2020-01-19. Parameter set T3. (a) CALIOP radiometric backscatter 532T data set [put file name], (b) Result of CALIOP detection and classification. Vertical Feature Mask resultant from current CALIOP (c) Combined result, atmospheric layer mask over density field, (d) Combined result (top and bottom), atmospheric layer mask over radiometric backscatter and (e) Combined result, detected atmospheric layers (combined mask from runs 1 and 2) over radiometric backscatter.

DDA-Parameters

Run Name	s	a	c	t	T	m	L	q	Q	w	TF
T1-top	3,6	10,40	1	0.9, 1.0	0.0001	300,600	2	0.98,0.98	0.98,0.98	0.98,0.98	true
T1-bot	3,3	10,20	1	0.9, 1.0	5.0	300,600	2	0.98,0.95	0.98,0.8	0.98,0.95	true

Table 1. DDA parameters for tropopause split example. s - sigma, a - anisotropy, c - cutoff, t - threshold factor, T - threshold offset, m - clustersize, L - profile window size, q, Q, w - day-night-dusk quantiles, TF - trafo function applied

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Contact Info and References

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References:

[1] Herzfeld, U., Hayes, A., Palm, S., Hancock, D., Vaughan, M., & Barbieri, K. (2021). Detection and height measurement of tenuous clouds and blowing snow in ICESat-2 ATLAS data. Geophysical Research Letters, 48(17), doi: 10.1029/2021GL093473.