Application of the Density Dimension Algorithm for Atmosphere (DDA-Atmos) to ICESat-2 and CALIPSO Satellite LiDAR Observations

Camden Opfer[1], Ute Herzfeld[1], Thomas Trantow[1], Mark Vaughan[2], Stephen Palm[3], Kathleen A Powell[2], Eric Rodriguez[1], Kieran Stone[1]

[1]University of Colorado, Boulder: Department of Electrical, Computer, & Energy Engineering, [2]NASA Langley Research Center, [3]NASA Goddard Space Flight Center

Key Points

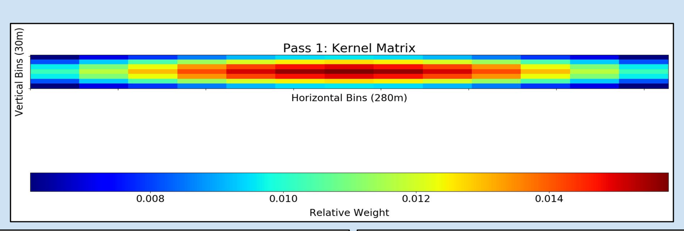
- The ICESat-2 and CALIPSO's LiDAR instruments provide 18 years (and counting) of continuous radiative backscatter
- The density dimension algorithm for atmosphere (DDA-Atmos) is an established approach to maximize cloud and aerosol detection in ICESat-2 data
- Density-n and smooth pass allow the DDA-Atmos to effectively identify dust layers despite their dispersed nature, and to distinguish between clouds and aerosols
- The DDA-CALIPSO has been developed to apply the same fundamental algorithmic approach to CALIPSO data
- A tropopause split allows for more effective detection of high altitude, tenuous layers by the DDA-CALIPSO

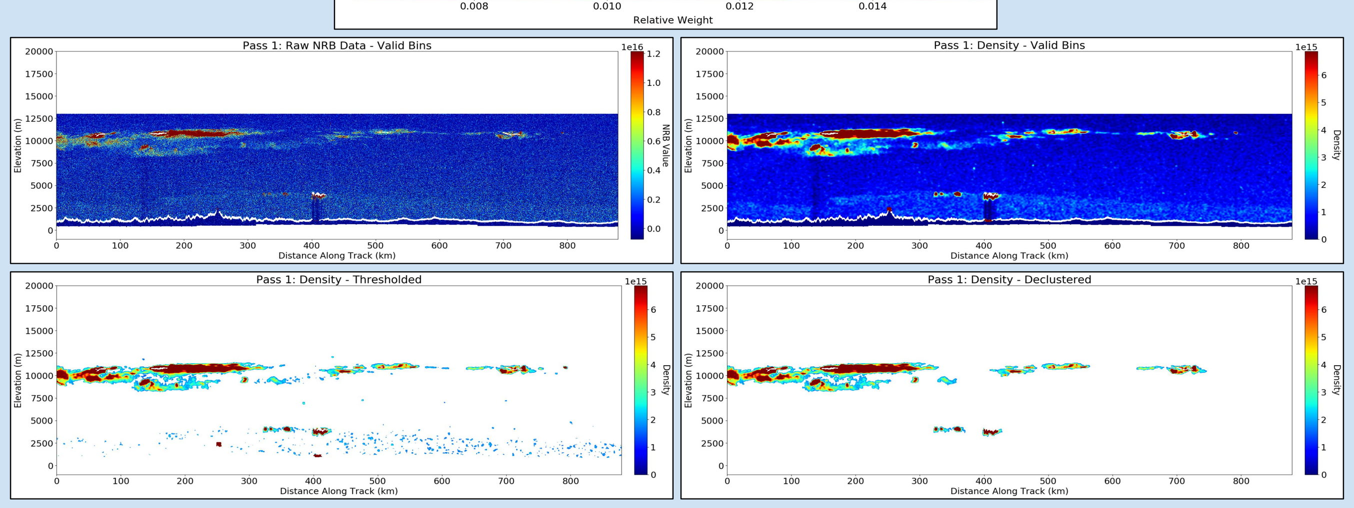
Density Dimension Algorithm

The DDA-Atmos is an algorithm which identifies cloud and aerosol layers in normalized radiative backscatter data. First, a gaussian radial basis function is applied to find the density of returns, allowing for easier determination of signal from noise..

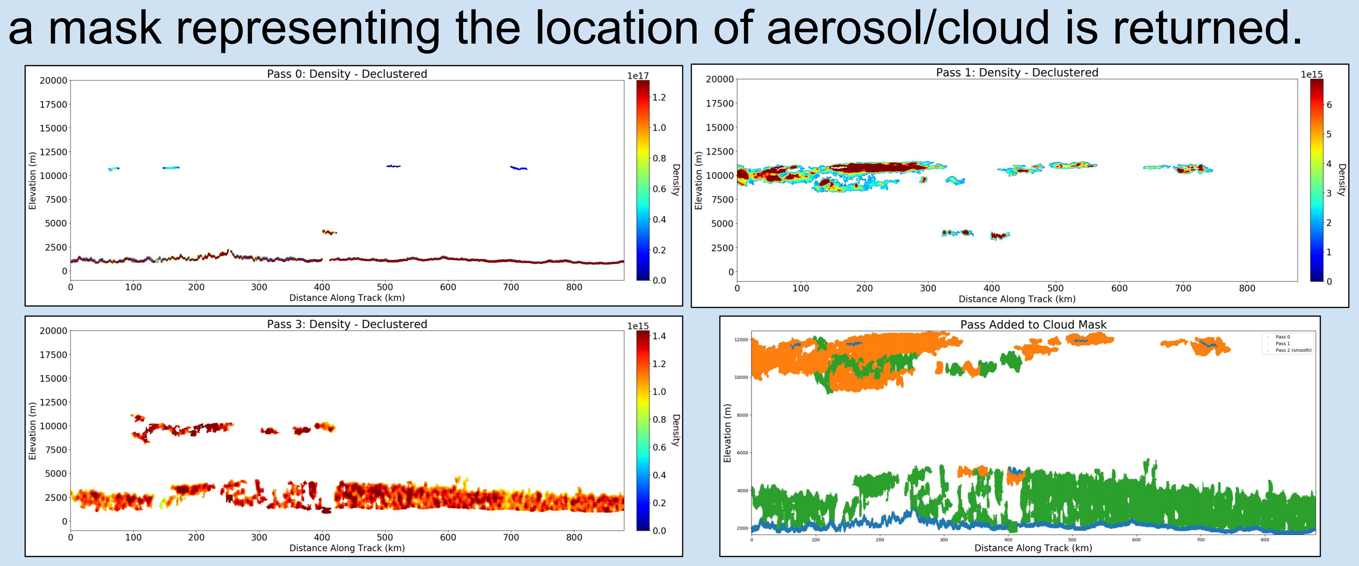
$$\Phi(r) = \exp\left[-\left(\frac{r}{\sqrt{2}s}\right)^2\right] \quad r \text{ distance, } s \text{ data values}$$

Next, thresholding is applied, identifying bins with greater photon return density as potential cloud/aerosol. A declustering algorithm is used to remove isolated bins which passed thresholding. This avoids non-physical, overly small layers being detected.





This process is repeated at least twice so that more tenuous layers (which initially blend in with noise) can be found. Finally, a mask representing the location of aerosol/cloud is returned.



Background: CALIPSO and ICESat-2

CALIPSO

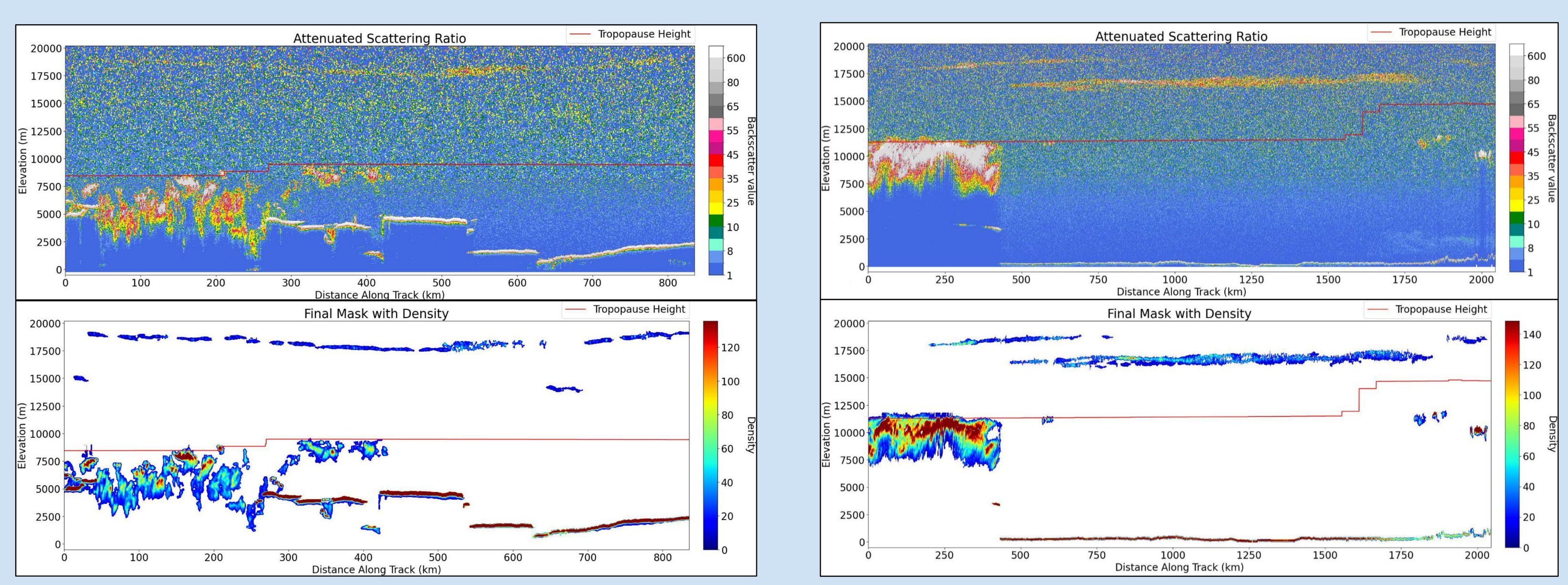
A mission lasting from April 2006 to December 2023, the NASA-CNES CALIPSO satellite carried the CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) instrument, which operated at both 532 and 1064*nm*. Radiative backscatter was provided at variable spatial resolution up to an altitude of 40*km*.

ICESat-2

Launched in September 2018, NASA's ICESat-2 satellite carries a 532nm, multi-beam, photon-counting LiDAR called ATLAS (the Advanced Topographic Laser Altimeter System). This provides radiative backscatter at a 280*m* horizontal and 30*m* vertical resolution to a maximum altitude of 14*km*.

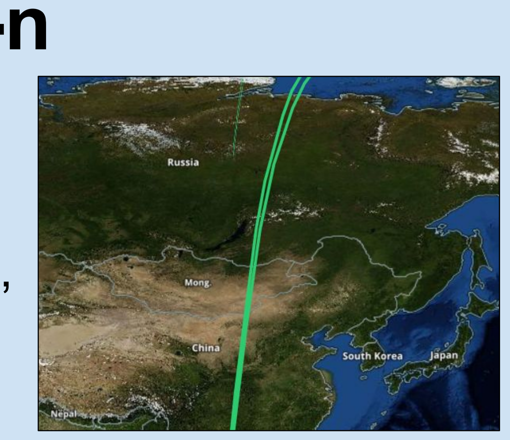
CALIPSO: Tropopause Split

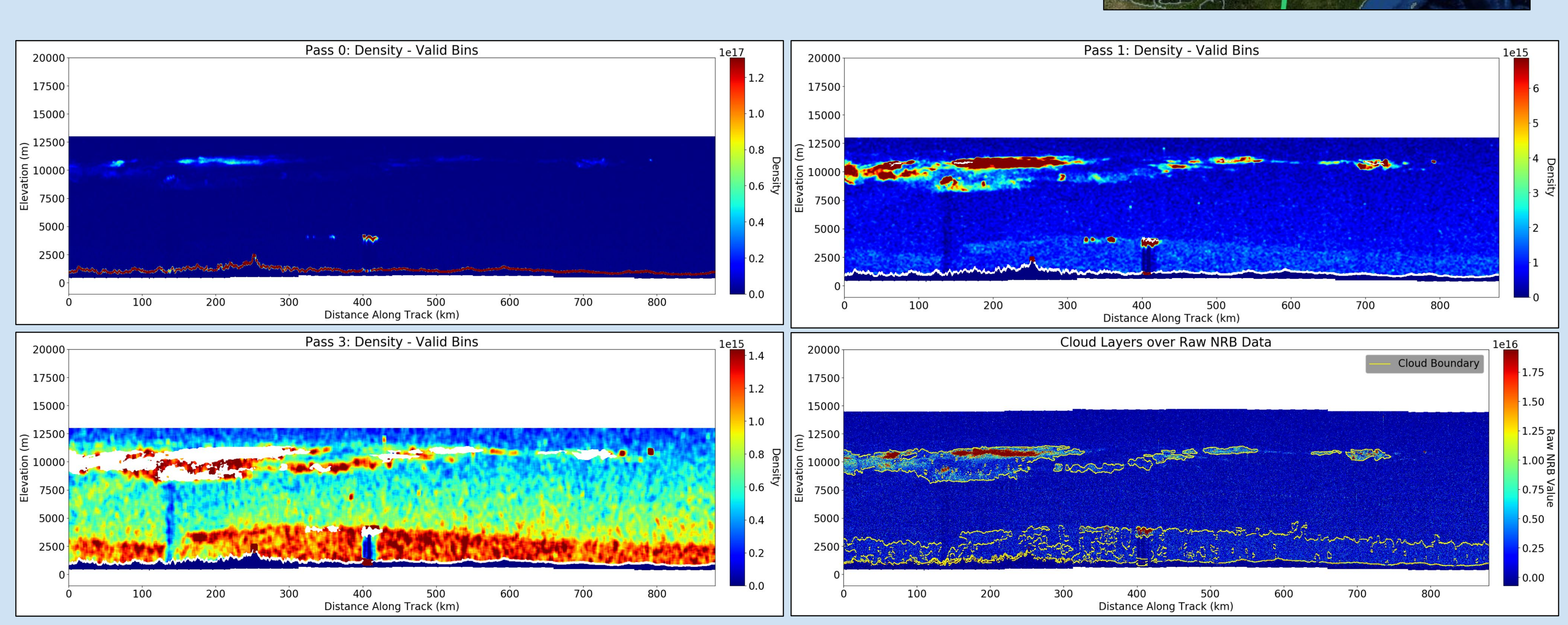
After implementing the DDA for CALIPSO, which has a greater vertical extent of data, it has been found that separate passes of the DDA above and below the tropopause accounts for the different physical properties (most notably optical thickness) across this boundary. The DDA-CALIPSO can be run on either total attenuated backscatter (TAB) or attenuated scattering ratio (ASR), which each have distinct changes in their characteristics at the tropopause.



ICESat-2: Density-n

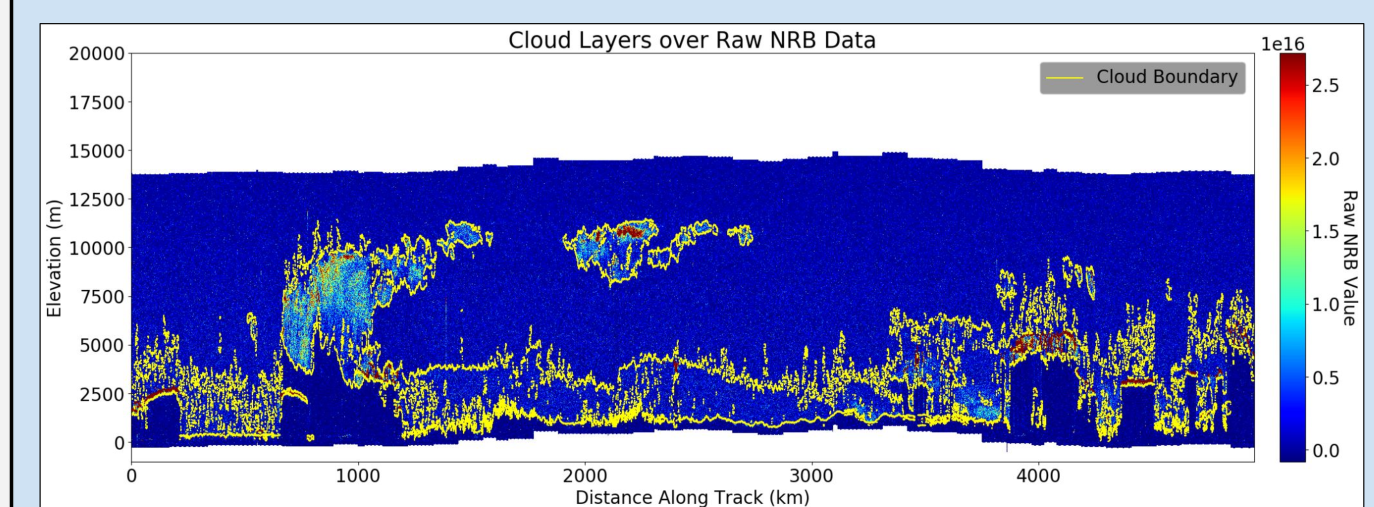
By running the DDA-Atmos more than twice (an arbitrary n times), more subtle atmospheric layers can be detected. Algorithm parameters are tuned for each pass so they detect progressively more tenuous layers, permitting rudimentary distinction between clouds (optically thicker and detected earlier) and aerosols.

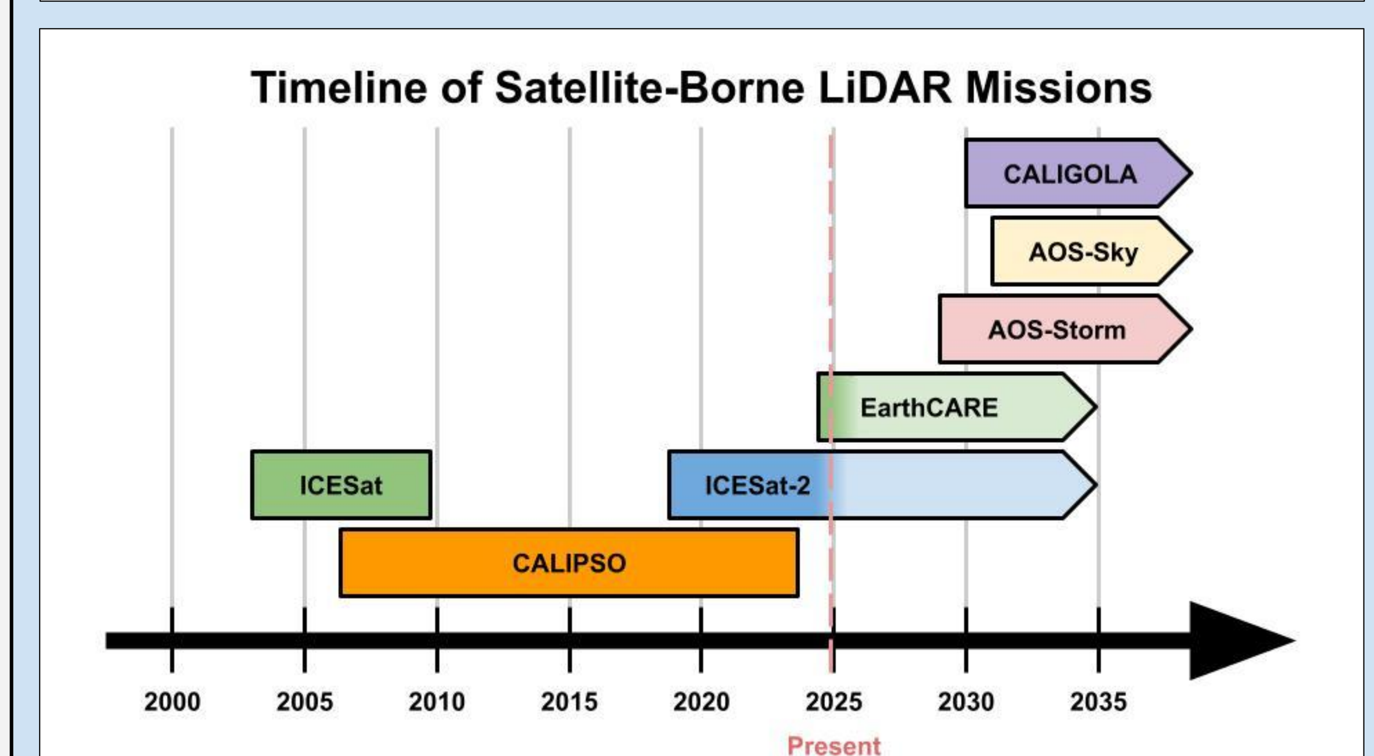




Conclusions

The DDA-Atmos is effective at identifying cloud and aerosol layers in both ICESat-2 and CALIPSO atmospheric LiDAR products, providing a cohesive understanding of the vertical and spatial distribution of these layers. This includes effective detection of optically thin clouds and aerosols, which are difficult to find, but have notable weather and climate impacts.





A key advantage of using the same underlying algorithm to analyze output from both CALIPSO and ICESat-2 is the continuous, rich data record from 2006 and into the future that these satellites provide. The DDA-Atmos also holds promise for analyzing the data of future satellite missions, such as the ESA-JAXA collaboration EarthCare.

Acknowledgements

work supported by NASA Earth Sciences (ICESat-2-project and CloudSat/ CALIPSO Science Team award, PI U.C.Herzfeld).

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.

[2] Herzfeld, U., Trantow, T., Vaughan, M., Palm, S., Opfer, C., & Rodriguez, E. (2024).High-Resolution Detection of Stratospheric Aerosolsin CALIPSO Atmospheric Lidar Data Facilitated by the CALIOP-Density-Dimension Algorithm, doi: 10.36227/techrxiv.173221125.51829367/v1.

Contact

Camden Opfer: camden.opfer@colorado.edu
Dr. Ute Herzfeld: ute.herzfeld@colorado.edu