9.3 GENERATION AND VALIDATION OF IMPROVED ICESAT-2 ATMOSPHERIC DATA PRODUCTS

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NASA's Ice, Cloud, and Land Elevation Satellite (ICESat-2) is primarily designed for altimetry measurements but also provides atmospheric data. However, extracting atmospheric data from ICESat-2 is challenging due to limitations as shown in Figure 1 such as being a single-wavelength instrument, lacking depolarization measurement capability, and having a high repetition rate with low pulse energy, which leads to folding or aliasing effects. Deep learning, specifically Convolutional Neural Networks (CNN), has been used to address these challenges and generate improved atmospheric data products.

In our previous work, we demonstrated that the CNN method exhibits improved performance in areas where traditional feature detection and cloud-aerosol discrimination algorithms struggle, such as resolving boundaries between adjacent layers and detecting clouds obscured within aerosol layers at fine resolution (Oladipo et al., 2024). Validation of the CNN model against other space-based or ground-based observations, such as Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data, is essential to confirm its robustness and reliability. CALIPSO's Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) provides high-resolution vertical profiles of clouds and aerosols, making it a valuable independent data source for validation (Getzewich et al., 2018; Kar et al., 2018; Kim et al., 2018).

To validate the CNN model, orbit crossing points between ICESat-2 and CALIPSO were identified, and data from both instruments were collected within a narrow time window of 50 seconds. A total of 38 data coincidences were identified for quantitative and qualitative analyses.

The current ICESat-2 algorithm uses the Density Dimension Algorithm (DDA) to detect layers, operating in two passes with different kernel sizes to detect thick and thin layers (Herzfeld et al., 2021; Palm et al., 2022; Palm et al., 2021).

The input data for the CNN U-Net model included a month's worth of ICESat-2 data (November 2018), consisting of calibrated attenuated backscatter, altitude, and relative humidity. The CNN model performs two tasks: detecting the presence of a layer and classifying it as either cloud or aerosol. The study compares ICESat-2 Advanced Topographic Laser Altimeter System (ATLAS) ATL09 layer detection and Cloud Aerosol Discrimination CAD retrievals, CNN layer detection and CAD retrievals, and CALIPSO layer detection and CAD retrievals. Confusion matrices were generated to compare the results, including CALIPSO layer detection and CAD retrievals versus CNN layer detection and CAD retrievals, as well as ICESat-2 layer detection and CAD retrievals versus CNN layer detection and CAD.

Figure 2 shows a comparison of ICESat-2 input data, CALIPSO input data, ICESat-2 ATL09, CNN, and CALIPSO layer detection and classification retrievals. Panel A in Figure 2 shows the input data (ICESat-2 532 nm profiles of calibrated attenuated backscatter) used for layer detection and classification. Panel B in Figure 2 shows the retrieved information from the ICESat-2 ATL09 layer-finding and classification algorithm. Panel C shows the retrieved information from the CNN layer-finding and classification algorithm. Panel D shows the input data (CALIPSO 532 nm profiles of total attenuated backscatter) used for layer detection and classification. Panel E in Figure 2 shows the retrieved information from the CALIPSO layer-finding and classification algorithm.

The CNN model demonstrated high-resolution layer detection, close to the native resolution of ICESat-2 data. There was high agreement between the CNN and ICESat-2 ATL09 algorithms in terms of layer detection, but differences were observed in aerosol classification.

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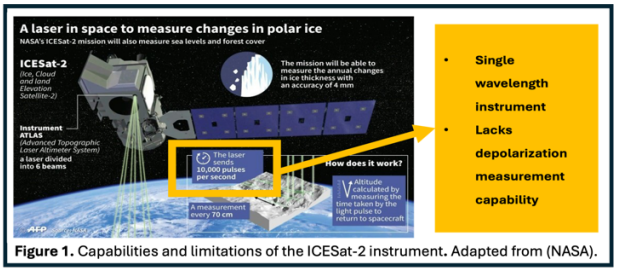


Figure 1. Capabilities and limitations of the ICESat-2 instrument. Adapted from (NASA).

The CNN model, operating on a pixel-by-pixel basis, achieved high-resolution feature detection, resolving boundaries between different layers and identifying features embedded within other features. In contrast, the ICESat-2 ATL09 algorithm performs columnar or blocky classification, leading to differences in aerosol classification.

The overall goal of this work is to develop new research products for ICESat-2 using deep learning, enabling future capabilities for onboard processing and minimal latency in data input for aerosol, cloud, and air quality models.

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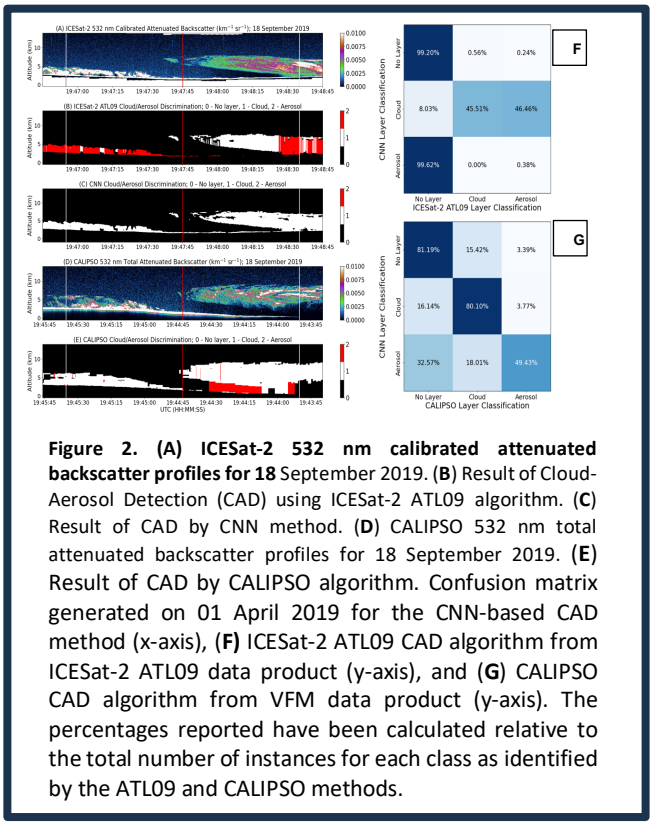


Figure 2. (A) ICESat-2 532 nm calibrated attenuated backscatter profiles for 18 September 2019. (**B**) Result of Cloud-Aerosol Detection (CAD) using ICESat-2 ATL09 algorithm. (**C**) Result of CAD by CNN method. (**D**) CALIPSO 532 nm total attenuated backscatter profiles for 18 September 2019. (**E**) Result of CAD by CALIPSO algorithm. Confusion matrix generated on 01 April 2019 for the CNN-based CAD method (x-axis), (**F**) ICESat-2 ATL09 CAD algorithm from ICESat-2 ATL09 data product (y-axis), and (**G**) CALIPSO CAD algorithm from VFM data product (y-axis). The percentages reported have been calculated relative to the total number of instances for each class as identified by the ATL09 and CALIPSO methods.