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Automated Detection and Characterization of Meteor Trails in Dual-Wavelength Sodium and Potassium LIDAR Spectrogram Data Using Unsupervised Machine Learning

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An unsupervised machine learning framework was developed to detect and characterize meteor trails in dual-wavelength resonance LIDAR spectrograms from simultaneous sodium (589 nm) and potassium (770 nm) channels (N=175, 256×256×2). An autoencoder compressed each spectrogram into a latent representation, reduced via global average pooling to a (175, 32) feature vector. Two clustering approaches were compared: standard Hierarchical (Agglomerative) Clustering applied directly to the feature vectors, and a hybrid SOM–Hierarchical method clustering SOM-projected prototypes. K=3 was selected via Elbow and Silhouette analysis, consistent with known background, sporadic, and meteor-trail layer structures. Both methods separated the data into three physically interpretable clusters based on signal intensity and spectral-altitudinal characteristics (PCA, t-SNE). Direct Hierarchical clustering outperformed SOM–Hierarchical clustering (Silhouette Score: 0.4745 vs. 0.4290; Davies–Bouldin Index: 0.7502 vs. 0.8120), indicating superior capture of mesospheric structure. The SOM achieved strong topology preservation (quantization error 0.004, topographic error 0.00). Autoencoder reconstructions preserved dominant layer dynamics and transient meteor-trail signatures. These results demonstrate feasibility of fully unsupervised, label-free classification of atmospheric LIDAR signals for meteor trail detection.

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