Comprehensive Study of Cloud Characteristics over a High Altitude Station - Leh, India using Ground-Based Lidar and Satellite Observations

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Abstract

A rise of approximately 1°C in global average temperature is influencing sea surface temperature, sea-level, intensity of storms, frequency and severity of hydro-meteorological extreme events. Such effects are comparatively more pronounced in tropical and sub-tropical zones, wherein Leh-Ladakh region of Indian subcontinent, is peculiar and characterized by extreme weather conditions. The present work unravels the cloud characteristics over the Leh region using ground-based ceilometer lidar (3255 m above mean sea level), remote-sensing, and reanalysis data sets for one-year (September 2022–August 2023). Variations in cloud base height (CBH) was observed with lidar, enabling the measurement of CBH up to three distinct layers, designated as CBH1, CBH2, and CBH3, respectively. This study reveals distinct seasonal and altitudinal variations in CBH, with cloud occurrence frequencies peaking during the pre-monsoon (67.94%) and monsoon (98%) seasons, reflecting the onset and active phases of the Indian summer monsoon. Month of July was recorded with the highest prevalence of multi-layered clouds (84.03%), which includes triple-layered clouds (CBH3, 42.13%) dominating over double-layered (CBH2, 25.98%) and single-layered (CBH1, 15.92%) clouds. Seasonal analysis showed a dominance of mid-level clouds (~3–6 km, 77.53%), while high-level clouds (~6–18 km, 4.43%) were less frequent. Altostratus and altocumulus clouds were particularly prominent across all seasons, with their variability linked to topographic and climatic factors. The ceilometer's high-resolution measurements captured the temporal dynamics of CBH, which aligned with satellite and reanalysis data, demonstrating the value of ground-based instruments in complementing remote sensing technologies. These findings provide valuable insights into cloud dynamics and their role in extreme weather events such as cloudbursts and intense rainfall, which are increasingly frequent in the Himalayan region. By improving our understanding of cloud–precipitation interactions, this study offers critical information for enhancing weather forecasting, informing rainfall prediction models, and supporting climate adaptation strategies in climatically vulnerable high-altitude regions.