

# Assembling a High Energy Pulse Lidar (HEPL) System: Preliminary Results from an Astronomical Site in the Central Himalayan Region

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An indigenously designed High Energy Pulse LIDAR (HEPL) system was re-integrated and installed at ARIES, Nainital, for probing the atmosphere and to analyse the Mie scatterers. After the characterization of the Photomultiplier tube and Discriminator, about 50 quality checked valid measurements were investigated. Reasonably good signals were obtained upto ~2.5 km for 30 m altitude resolution, ~5 km for 150 m, and ~8 km for 300 m resolutions in the vertical, which were utilized to investigate the aerosol and cloud profiles. The system was able to capture the clouds at various altitudes under different atmospheric conditions. Elevated aerosol layers were also detected at about 3 and 3.5 km over the observation site. Such unique measurements from the data void complex Himalayan terrain highlight the need for continuous monitoring of the aerosol loading caused by transport of pollutants from continental locations and far-off distances that affect the air quality and Himalayan glaciers as well.

**Keywords:** Lidar; CALIPSO; Vertical mixing; Aerosols; Clouds

## 1 Introduction

The Himalayan region is topographically complex, consisting of fragile mountains and a delicate ecosystem that is very susceptible to climatic change<sup>1</sup>. This region frequently witnesses extreme weather events in terms of cloud bursts, heavy rainfall, flash floods and landslides *etc.*<sup>2,3</sup> and is exposed to the transport of pollutants from continental as well as long-range sources in the form of dust storms and occasional elevated aerosol layers<sup>4-6</sup>. These aerosols are ubiquitous in the Earth's atmosphere predominantly arising from anthropogenic sources such as fossil fuel combustion, industrial emission, biomass burning *etc.*, and natural sources like sea salt spray, wind-blown dust and volcanic ash which subsequently act as pollutants in the atmosphere. They have the potential to influence global as well as regional climate by altering the available solar radiation at the Earth's surface, re-distributing the Earth-atmosphere energy budget, and changing the cloud microphysics, consequently, the hydrological cycles<sup>5,7-9</sup>.

Additionally, aerosols have a pronounced effect on visibility and are found to degrade astronomical observations over ARIES Nainital, in addition to the air quality of the pristine environment across the

central Himalaya<sup>10,11</sup>. These microscopic particles of the particulate matter, scatter and absorb light, thereby often lead to degraded seeing conditions. The presence of aerosols introduces scattering of starlight, diminishing image sharpness and resolution<sup>5,10</sup>. Therefore, a comprehensive understanding of aerosol characteristics and their distribution is vital for improving astronomical observations and enhancing image quality in the Himalayan region.

In addition to the presence of aerosols, clouds also have a significant impact on both atmospheric dynamics and astronomical observations. They influence the Earth's energy balance, radiative transfer, and hydrological cycle. In the field of astronomy, clouds can obstruct celestial objects and degrade the quality of astronomical images. LIDAR based observations play a crucial role in the study of clouds, providing valuable information about their vertical structure, optical properties, and phase characteristics. Ground-based LIDAR systems are particularly useful in determining cloud height, distribution, and thickness, which are important for parameterizing clouds in atmospheric models<sup>12,13</sup>. Space borne LIDAR missions, such as CALIPSO, is used for cloud studies, however, it is crucial to note that surface observations also play a vital role in validating and complementing space-based measurements<sup>13,14</sup>.

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Numerous surface based measurements have been reported from a few locations in the Himalayan region<sup>4-6,15,16</sup>, on particulate matter, black carbon aerosols, and clouds, proving the profound impact on the Himalayan ecosystems, regional air quality with seasonal features. However, the study on the influence of long-range transport of aerosols or dust is limited or nearly non-existent. Studies on the vertical profiling on the aerosol is very important to understand the mixing of the pollutants higher up in the atmosphere as most instruments used for the measurements of aerosols provide the concentration and size distribution at surface level<sup>4,14,17</sup>. LIDAR is an essential tool to probe the atmosphere in the vertical and to capture the vertical mixing and distribution of the aerosols above ground<sup>4,14,17-21</sup>. LIDAR for atmospheric studies, in general, transmits high energy pulsed laser beam vertically into the atmosphere and the backscattered light is received using a telescope (receiver). By measuring the scattering and attenuation experienced by the incident laser pulse, one can investigate the properties of the scatterers located in the atmosphere. The time delay between the transmit pulse and the backscattered signal gives the altitude information, while the signal strength is proportional to the amount of scatterers at that particular altitude. The backscattered signal detected by a LIDAR system can be well described by the LIDAR equation<sup>17,22</sup>.

Considering the importance of studying aerosols and clouds, and their impact on astronomical observations, we have made functional a LIDAR system namely

High Energy Pulse LIDAR (HEPL) preferably to study the entire free troposphere, and to study the vertical distribution of aerosol in the boundary layer. Here, we are presenting the preliminary observations made with HEPL. Section 2 provides the details on site and the LIDAR system, section 3 deals with the preliminary results and need of the ground-based observations with such unique devices.

## 2 Material and Methodology

### 2.1 Study Site

The observational site Aryabhata Research Institute of Observational Sciences (ARIES) located over the Manora Peak (29°22' N, 79°27', 1900m, AMSL) in the Shivalik range of foothills of central Himalaya and at about 2 km aerial distance from the city of Nainital. The variation of topography around the site, as shown in Fig. 1, exhibits sharp fluctuations at a sub-kilometer scale. This site is a major center for conducting the observations related to the atmospheric sciences and astronomy and plays a crucial role in advancing scientific knowledge in these fields. Due to its distant and pristine location, Manora Peak has provided an ideal environment for conducting such crucial observations with minimal anthropogenic influences. Despite its remote location, over time, the increasing aerosols loading in the region has begun to affect the scientific observations. Additionally, Nainital is a tourist place and particularly in summer it attracts a huge number of tourists leading to the significant surge in commercial activities and subsequently affects the air quality of the region<sup>5,11</sup>.

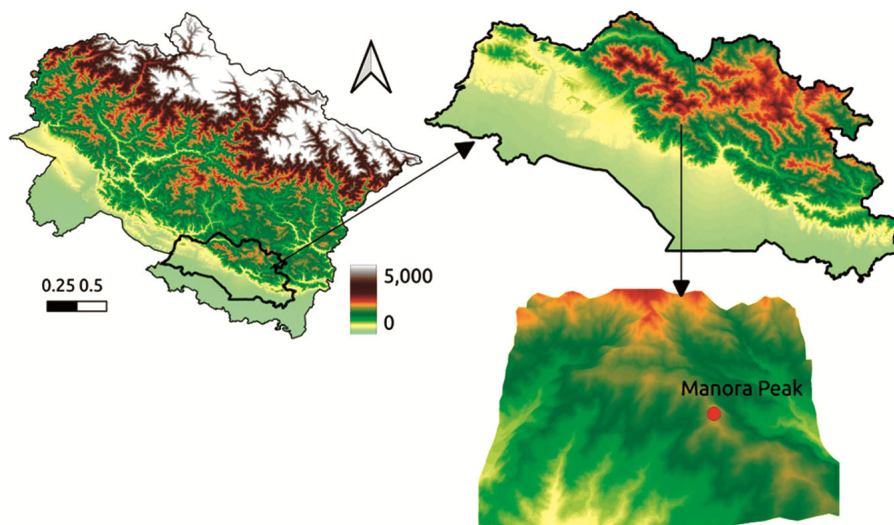


Fig. 1 — Topographical map around the observational site Manora Peak and its geolocation shown as Uttarakhand province (left panel) zoomed area Nainital and (right-top), and topography image of Manora Peak (red dot) and its surroundings (right-bottom).

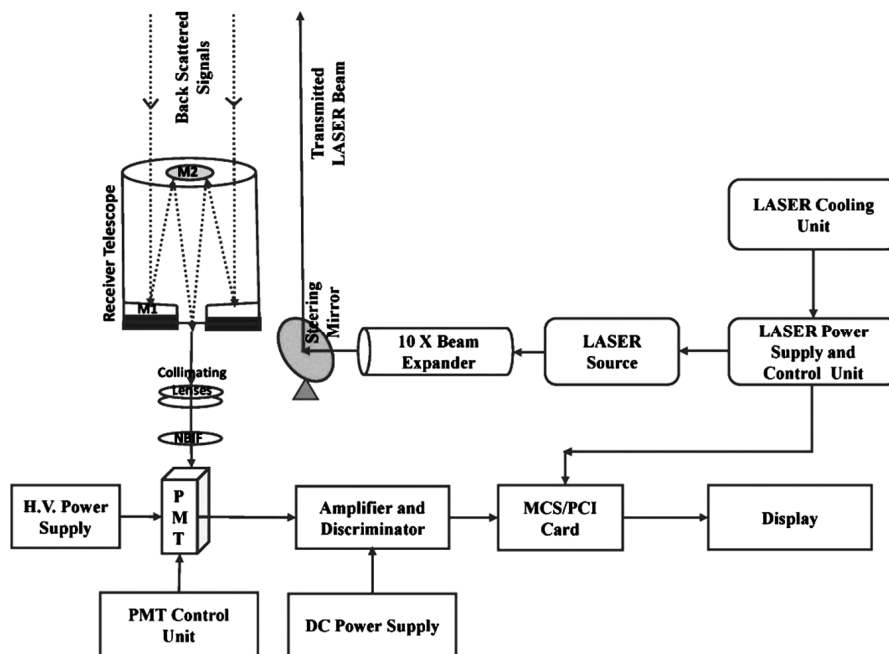


Fig. 2 — Block diagram of High Energy Pulse LIDAR system, displaying various components and subsystems of the in-house arrangement.

Table 1 — HEPL system specifications

Transmitter	
Laser	Pulsed, Nd: YAG
Wavelength (nm)	532
Maximum pulse energy (mJ)	750
Pulse width (ns)	7
Pulse repetition frequency (Hz)	30
Laser beam divergence (mrad)	0.1 with 10x beam expander
Receiver optics	
Telescope	Classical Cassegrain
Primary/Secondary diameter	380 mm/123 mm
Focal ratio	f/15
Field of View (mrad)	6
Complete overlap	300 m
Detector	Photomultiplier (Electron Tubes 9863/350-B)
Data acquisition	
Type	Computer based multi-channel scaler (MCS) plug-in card
MCS counting rate (MHz)	150 (max)
Dwell time (selectable)	100 ns to 1300 seconds
Scan length	4 – 64K bins settable
Integration time (s)	250 (typical)

## 2.2 HEPL-Block diagram and write up

The indigenously developed High Energy Pulse LIDAR system has been installed at ARIES, Manora Peak (29°22' N, 79°27', 1900m, AMSL), Nainital, Uttarakhand. Fig. 2 shows the block diagram of HEPL system, and its major technical specifications are given in Table 1.

It uses a flash lamp pumped High-Energy, water-cooled LASER at 532 nm with pulse repetition frequency of 30 Hz. The output beam of 9 mm diameter is being expanded to 90 mm using a 10X beam expander. The back-scattered signal is received using a 380 mm diameter Cassegrain telescope. The back-end optics comprises the collimating lenses and narrowband interference filter. The Photomultiplier Tube (PMT) having 51 mm input aperture is used to convert the received backscattered signal into electrical pulse corresponding to the incident photon. This electrical pulse is being amplified and identified using Ortec make 1 GHz amplifier and discriminator. The output of discriminator is being fed to the Ortec make MCS/PCI card for data processing and acquisition purpose. The MCS/PCI card records the counting rate of events as a function of time in its digital memory till the end of the preselected dwell time.

## 2.3 Observations and data

The High Energy Pulse LIDAR was operated at 532 nm wavelength with 750 milli Joule power at different pulse widths (PW) - 200 ns, 1  $\mu$ s, and 2  $\mu$ s, during November 2020 - December 2021. Observations during this period were intermittent, and under various atmospheric conditions starting from twilight hours to midnight, to investigate the vertical structure and optical properties of the aerosol layers and clouds. The details of the observations made are provided in Fig. 3.

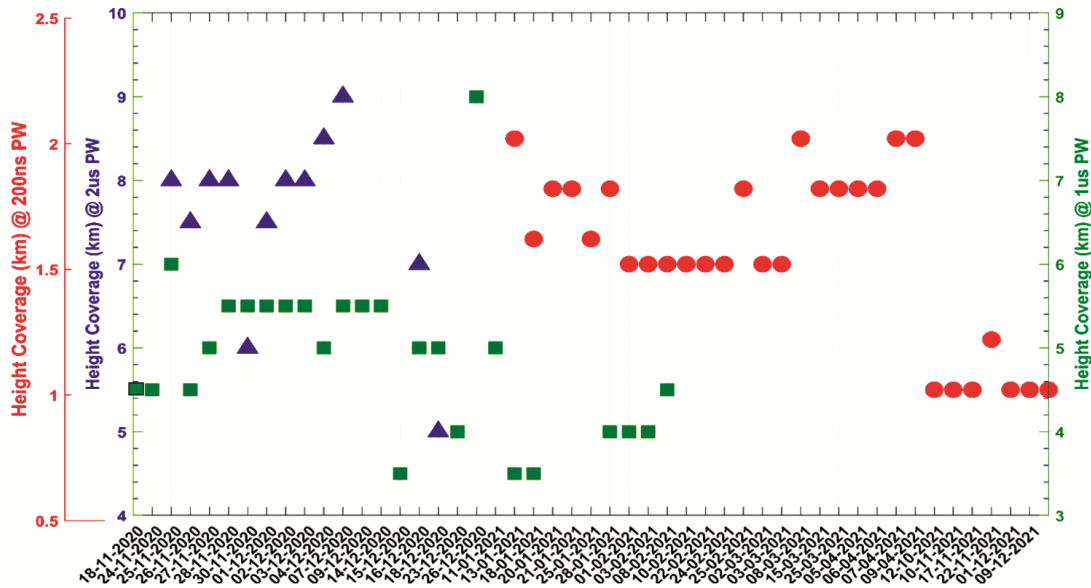


Fig. 3 — Observation Day vs height coverage at 200ns, 1 $\mu$ s, and 2 $\mu$ s pulse width (PW).

Data collected under different combinations during 18 November 2020 - 9 December 2021 showed the variations in height coverage range of the measurement. As evident from Fig. 3, the narrow laser beam *i.e.*, 200 ns pulse enabled observation with high resolution and short dead zones but less height coverage ( $\sim 2$  km), while the observation with wide laser beam *i.e.* 1  $\mu$ s, and 2  $\mu$ s pulse widths demonstrated good height coverage (up to 8-9 km), however, both have their own relevance at the pristine and strategic study site. Observations at high pulse width (PW) are generally preferred when maximum height coverage is desired. High-resolution observations over the tropospheric-free site provides valuable information on the aerosol masses and transport sources. Similarly, low-resolution study is best suited for boundary layer evolution and associated mechanisms.

The system is made operational in November 2020, and till 22nd December 2021, scientific observations were taken for 49 nights: (Details of Observations: November 2020: 06 nights, December 2020: 11 nights, January 2021: 07 nights, February 2021: 07 nights, March 2021: 05 nights, April 2021: 04 nights, October 2021: 03 nights, November 2021: 03 nights, and December 2021: 03 nights). These observations with different height coverage with aforementioned PW are summarized in Fig. 3. Further, night observations with height resolution of 30 m were initiated from 13th January 2021 and continued till December 2021.

### 3 Results and Discussion

#### 3.1 Overview

In the process of making the HEPL operational, the system was tested for various user defined specifications, in order to optimize the functionalities of various subsystems and quality of the measurements. This intensive exercise resulted into a total of 64 fairly good vertical profiles including 43 aerosol profile cases under clear sky conditions (at 1  $\mu$ s & 200 ns (Fig. 4(a,b)) and 21 cloud detection cases (Fig. 4(c)) during the period of study and the profiles were captured between 300 m (overlap height) and 10 km. The most probable occurrence of aerosol concentration was observed between surface and to about 4 km with the signature of occasional elevated layers at about 3 to 3.5 km. However, 200 ns pulse provides a better picture of the local boundary layer whereas 1  $\mu$ s can provide reliable profiles up to 6 km in the vertical.

Major sources for higher aerosols loading during November as depicted by the higher backscatter photon counts could be associated with the crop residue burning over north Indian subcontinent that get transported over the mountainous region of Himalaya<sup>23,24</sup>. During the pre-monsoon seasons, the region experiences the episodic dust storm and degraded the air quality by enhanced dust loading through long range transport. Such events are investigated in earlier studies<sup>5,6</sup>. Additionally, the observations during the cloudy days as depicted in Fig. 4(c) shows that this LIDAR system can detect the low-level cloud. Intense dense layer of the cloud layer

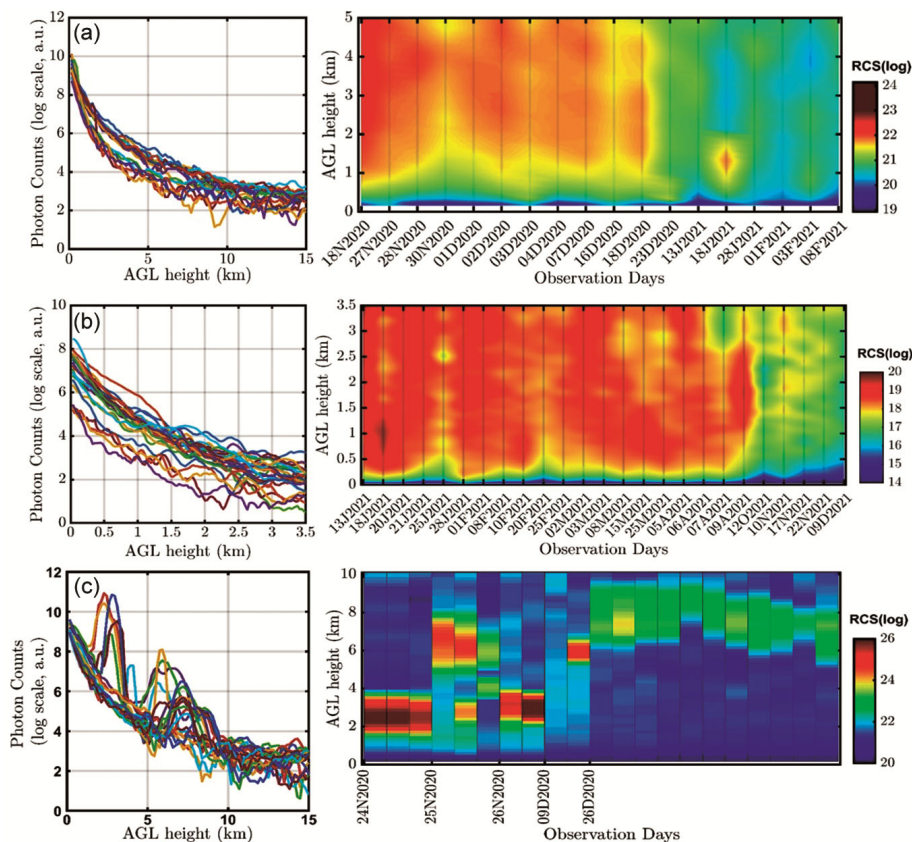


Fig. 4 — Averaged photon counts and RCS profiles for the (a) clear-sky observation at  $1\mu\text{s}$  pulse width during 18 November 2020 - 03 February 2021, (b) clear-sky observation at 200 ns pulse width during 13 January 2021 - 09 December 2021, (c) observation under cloudy conditions during 24 November 2020 - 26 December 2020 at  $1\mu\text{s}$  pulse width.

(about 2 km) resulted in the higher photon counts of about  $10^{12}$  as compared to the background atmospheric column. This system also detects the high-altitude cirrus cloud present at higher altitude about 8-10 km from the surface.

Further, the CALIPSO satellite-based vertical profile of backscatter coefficient at 532 nm is plotted for the coinciding passes with the clear-sky observations by considering 50 km radius around the site. The vertical profile of backscattering coefficient at 532 nm is used from CALIPSO Level-2 aerosols profile (CAL\_LID\_L2\_05KMAPRO-STANDARD-V4-20) and aerosols subtypes (CAL\_LID\_L2\_VFM-STANDARD-V4-20) products<sup>25</sup>. The evaluation of the CALIPSO products over the site has been carried out in the previous studies<sup>14,22</sup> and demonstrated that the satellite products are generally in good agreement with the ground observations on the vertical distribution of the aerosols. Fig. 5 show that the backscatter coefficient profiles of December and January months confined in the lower altitude below 3 km in presence of the calm and near-neutral atmospheric conditions<sup>26</sup> that strongly inhibit the

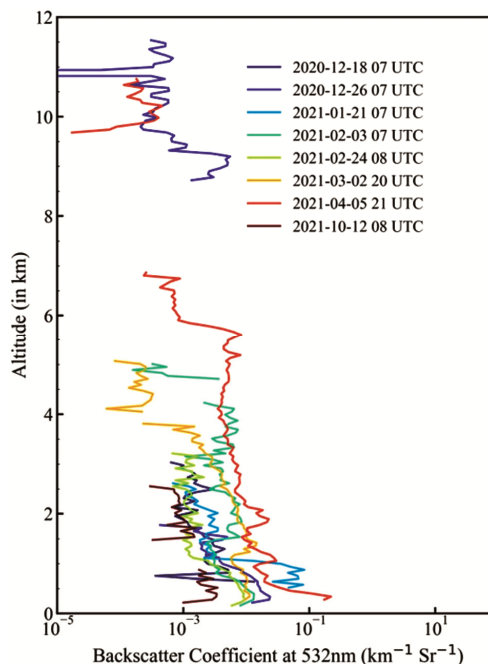


Fig. 5 — Backscatter coefficient from CALIPSO for the clear sky days. These profiles are based on the suggested nearby passes.

vertical mixing of pollutants. These shallow mixing of pollutants cases are well captured by the HEPL system. While the profiles with the higher backscatter coefficients ( $\sim 10^3$ ) are observed during March and April month.

### 3.2 Cloud observations

During the vertical profiling of the atmosphere at various occasions HEPL is found to detect the presence of low, middle, and high-level clouds, which are basically the stationary or sometimes moving patches of clouds present in nearly clear sky conditions. However, at the same time, the aerosol

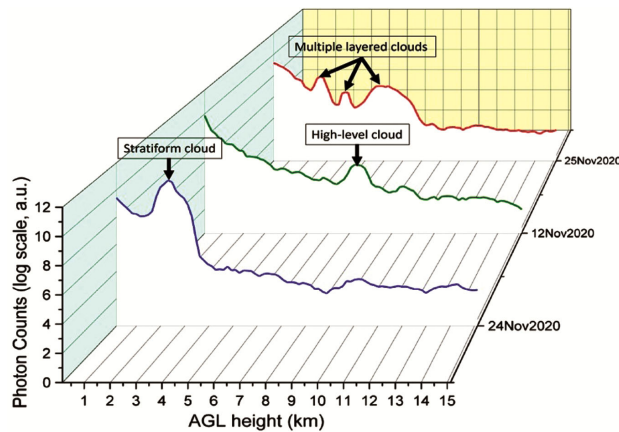


Fig. 6 — Vertical profile of photon counts from LIDAR for different cloud types including low-level layer cloud (stratiform), high-level layered cloud (Cirrus) and multi-layer clouds.

profile is observed up to about 3 km vertical resolutions as seen in the Fig. 4(c). This ensures the functionality and the response of the system to various atmospheric conditions, which requires further measurements in different seasons over a year to yield the better science output.

By maintaining a manual logbook of the observations, three different cloudy profiles detected by the HEPL system are plotted in Fig. 6 including low altitude stratiform cloud (24 November 2020), high level cirrus cloud layer (12 November 2020) and multiple layered clouds (25 November 2020). This also confirmed the reliability of the LIDAR observations in terms of the detecting clouds layer while longer observations along with the sky-imager observations need to support this finding and classifying the cloud layers. Ground-based observations could be utilized to improve the satellite products. Further, the presence of very thin layer of high-altitude clouds (generally cirrus) on 26 December 2020 is selected based on the observation logbook over the site. The vertical profile of the photon counts and range corrected signal from the HEPL system as shown in the Fig. 7 (upper panel) depicts this cloud layer. The feature flags and aerosols subtype based on the CALIPSO, classified this layer as clouds and aerosols. This finding highlights the importance of ground-based observations in improving the satellite products over this region.

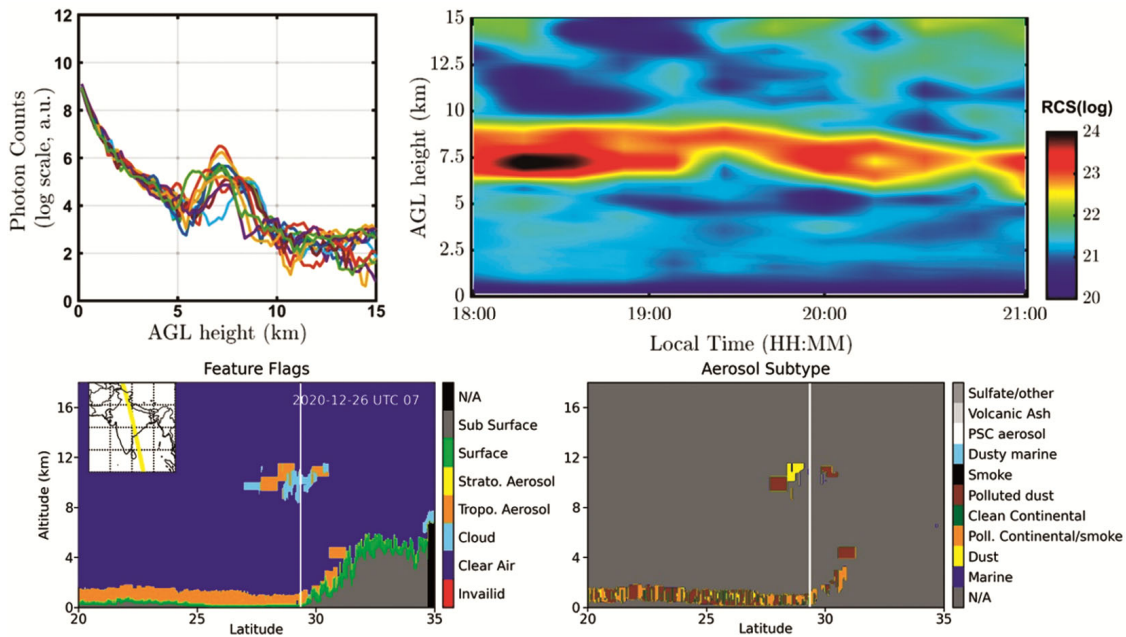


Fig. 7 — LIDAR Observation of Cirrus Cloud at an Altitude above 6 km over the Site (upper panel). Photon counts and colour shading depict the temporal variations in the cloud layer. The lower panel displays feature flags and aerosol subtypes obtained from the CALIPSO satellite on 26th December 2020.

#### 4 Conclusion

The installation and re-integration of the indigenously designed High Energy Pulse LIDAR (HEPL) system at ARIES, Nainital, have enabled insightful observations of aerosols, with a specific focus on Mie Mode operation. Further, efforts are being made for operating the system in Rayleigh scatterers. Since November 2020 to January 2022, the HEPL system primarily operated in Mie mode, conducting intermittent nocturnal observations. Higher aerosol loading was detected in the lower troposphere (<4 km), indicating the vertical mixing through boundary layer processes and orographic influences.

Observations carried out with varying pulse widths demonstrated that a 200 ns pulse provides a clearer depiction of the above ground mixing within lower most region upto about 2.5km, while a 1 $\mu$ s pulse can offer reliable profiles up to  $\sim$  5 km vertical. Vertical atmospheric profiling on different occasions revealed the presence of low, middle, and high-level clouds. These clouds are essentially stationary or occasionally moving patches found in mostly clear sky conditions. Such observations could enhance cloud classification, supporting existing satellite products like CALIPSO, within the region. Further measurements across different seasons throughout the year are necessary to yield more comprehensive scientific outcomes.

Overall, aerosols and cloud presence strongly affect astronomical observations conducted over this site, and these LIDAR observations can be utilized for both atmospheric profiling and astronomical seeing studies across the data void region of the central Himalaya.

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