Aerosols and Cirrus Clouds over Hanoi, Vietnam: Comparison between satellite products and results derived from ground-based LIDAR measurements

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Abstract

In this paper, we present examples of aerosol and Cirrus cloud altitude profiles over Hanoi, Vietnam, measured with the ground LIDAR setup of the Institute of Physics. Comparisons are made to LIDAR data collected by the Calipso satellite of the NASA A-Train during its orbits over the Hanoi area. The height distributions for both surface aerosols and Cirrus clouds derived from ground and satellite observations are generally consistent, with distributions between 2km-3km, and 8km-15km respectively for aerosols and Cirrus clouds. Cirrus cloud locations inferred from an analysis of limb spectral radiances obtained by the SCIAMACHY satellite are also consistent with the LIDAR data.

Keywords: LIDAR, ground, satellite, aerosols, clouds, Cirrus, spectra

1. INTRODUCTION

LIDAR (Light Detection and Ranging) has been used over the years to determine atmospheric parameters and to characterize the time and spatial evolution of the atmospheric boundary layer, as well as to investigate the physical properties of the particulates, i.e., aerosols and clouds[1,2,3,7,8]. A multiwavelength LIDAR system has been developed at the Institute of Physics (IoP) of the Vietnam Academy of Science and Technology (VAST). The objective is to monitor the properties of aerosols and clouds over Hanoi, Vietnam. Our LIDAR system regularly collects backscattered signal at 1064 nm, 532 nm and Raman signal a 607 nm. From the LIDAR data, we can derive the vertical distribution of aerosol, the height of boundary layer as well as the total optical depth and LIDAR ratio. For cirrus clouds, the physical parameters of interest that can be measured with LIDAR are thickness, altitude and temperature of the cirrus clouds. These parameters will provide important information on the cirrus cloud's radiative properties[4,22]. Vietnam is located in the tropical region and the frequent appearance of cirrus clouds is expected. However, there is no prior detailed study of the cirrus clouds using remote sensing technique. This project presents the first comprehensive LIDAR based aerosol and cirrus cloud monitoring and analysis for Hanoi, Vietnam.

After a brief summary of our LIDAR setup and a short discussion of the typical signals obtained in Section 1, we shall present in Section 2 a comparison of several measurements of aerosols and Cirrus clouds from the IoP LIDAR with available data derived from the Calipso[5] satellite observations over Hanoi in 2011 and 2012. Finally in section 3, we show how spectral radiance data, such as data from the SCIAMACHY[6] satellite (European Space Agency), may be used in conjunction with the LIDAR data to further elucidate the distribution and properties of aerosols and clouds[9].

1.1 LIDAR setup at IoP

A compact LIDAR system has been developed for the present work at the Institute of Physics. The transmitter of the lidar system is based on the high power pulsed Nd: YAG laser Brilliant made by Quantel (France). The laser delivers a pulse energy of 180 mJ at 532 nm at a repetition rate of 10 Hz, and a pulse duration of 5 ns. The divergence of the laser beam is measured to be better than 1 mrad. The receiver is a 25 cm Cassegrain telescope (f/D = 10). To reduce the background light we limit the field of view of the telescope to 1.5 mrad during the lidar measurement[10]. Furthermore, to spectrally select the laser wavelength we use a high quality interference band pass filter of 3 nm. The backscattered light is detected using photomultiplier tube R7400U from Hamamatsu (Japan). The signal is then digitized using a high speed 12 – bit ADC sampling at 20 MSPS. That sampling rate defines our vertical resolution of 7.5 m. The schematics are illustrated in Figure 1.

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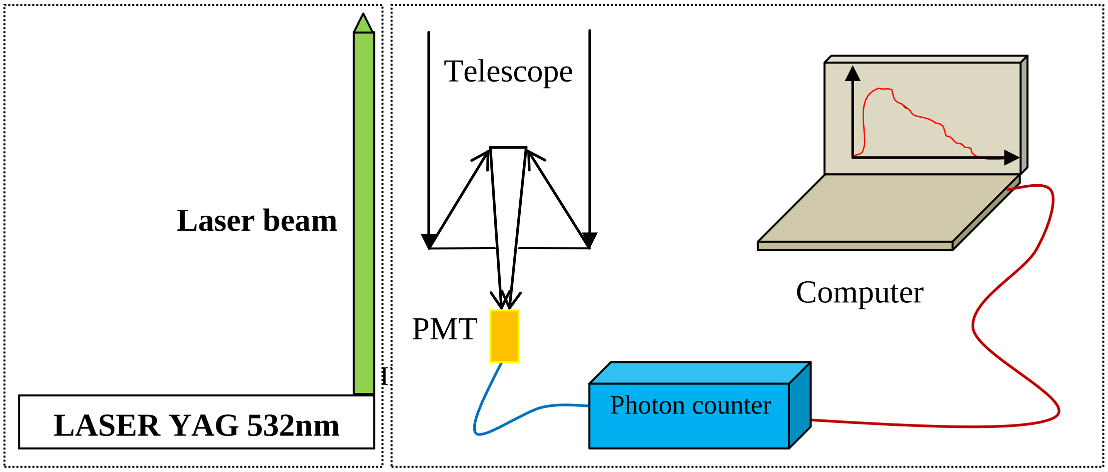


Figure 1. Schematics of the LIDAR system

1.2 LIDAR signals

A typical recorded LIDAR signal is shown in Figure 2, and an example of the time variation, due to the variations in particulate densities over Hanoi, is illustrated in Figure 3. Both figures show altitude distributions of the back scattered LIDAR intensity[23].

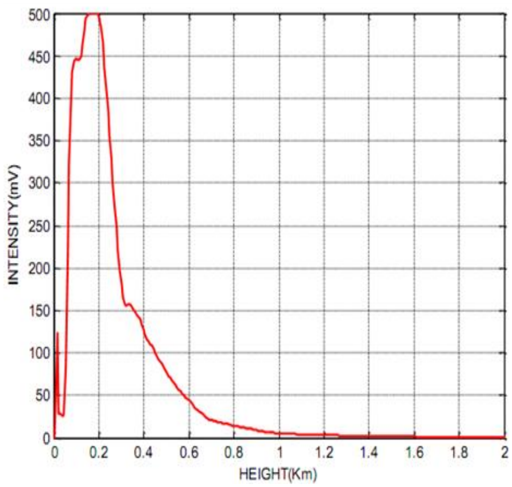


Figure 2. Lidar signal obtained at 8:00pm on 5/27/2011.

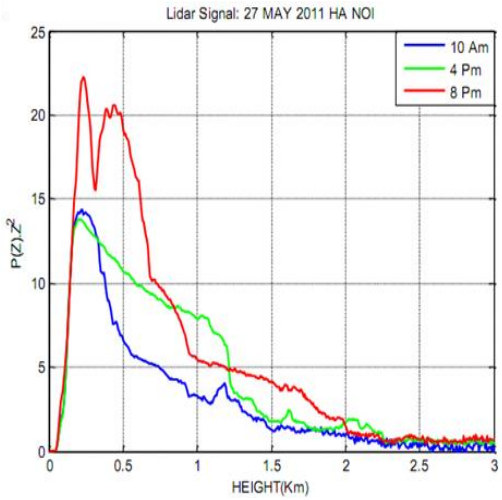


Figure 3: Height dependence of range corrected Lidar signal

An analysis of the particulates height distribution and their extinction properties is possible by realizing that the height distribution is composed by contributions from molecular and particulate scattering, as shown in Figure 4, where the logarithm of the range corrected LIDAR power is plotted versus height. The large signal below 1 km is due to scattering from the atmospheric boundary layer. Beyond the boundary layer, the photon count from aerosol or cloud scattering is observed above the background level due to contribution from atmospheric molecules.

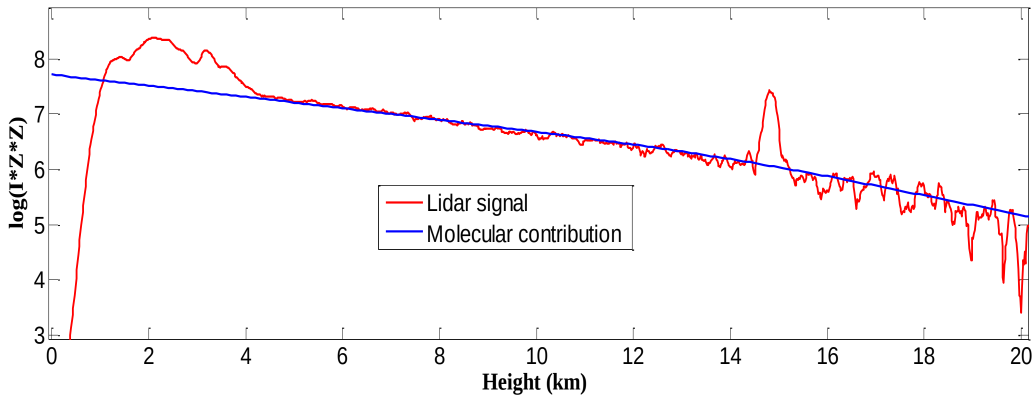


Figure 4. LIDAR signal from aerosols and clouds versus contribution from atmospheric molecules

By analyzing the LIDAR signal as shown in Figure 4, we can derive the height of boundary layer, the vertical distribution of the aerosol or cloud, as well as their extinction coefficients. The range corrected backscattered LIDAR power (**I.z^2**) has the same height distribution as the extinction coefficient[7,8]. In the following sections of this paper, we thus will compare our measured range corrected backscattered LIDAR power with extinction coefficients derived from satellite observations, where available.

In section 2, we present results from our observations of aerosols and Cirrus clouds over Hanoi in the years 2011 and 2012. Comparisons are made to available observations by the Calipso satellite aboard the A-Train in the days the constellation passed over Hanoi. We first give a brief introduction of the A-Train constellation.

1.3 A-Train Satellites

The 'A-train'[5] consists of a constellation of satellites that follow in close succession, each in a Sun-synchronous orbit 705 km above the ground. The satellites carry different instruments that collect data from which atmospheric products can be retrieved. The Caliop LIDAR aboard the Calipso satellite provides aerosol and cloud information along the orbits of the constellation. The sun-synchronous orbits for one day are illustrated in Figure 5. The orbits that overpass Hanoi, Vietnam (Lat ~21.05, Lon ~ 105.8) provide looks at aerosol and cloud conditions in the sky above the city.

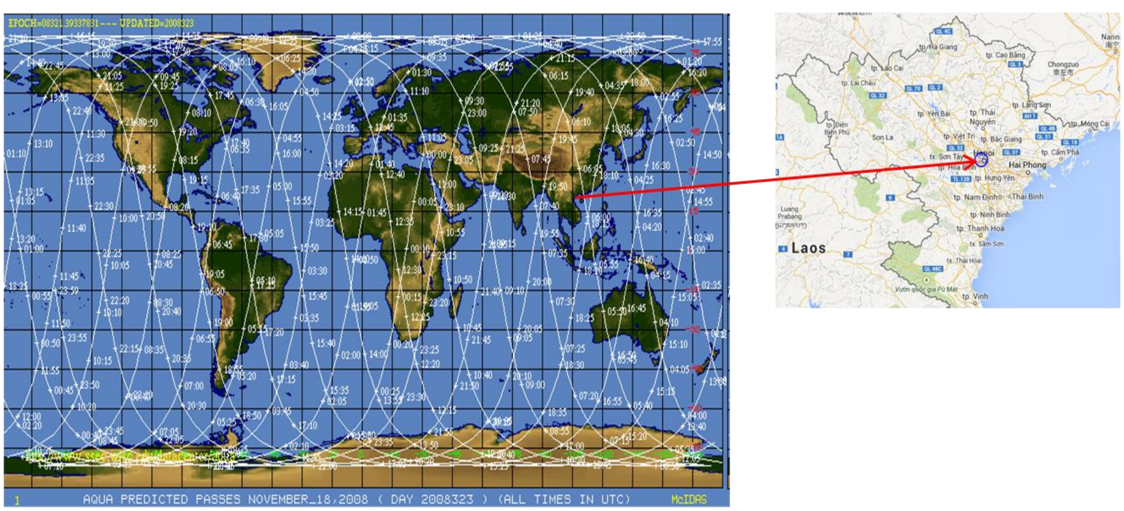


Figure 5. The A-Train satellite constellation sun-synchronous orbits for one day. The Hanoi region is indicated by the red arrow.

A close review of the A-Train orbits in the years 2011 and 2012 yields a series of orbits (labeled by date and GMT) when the constellation passes over Hanoi. Unfortunately, we found no exact time coincidence between IOP observations and Calipso data. Given the almost constant low cloud conditions over Hanoi, the IoP LIDAR can only reliably record aerosols and Cirrus clouds in sufficiently clear conditions. In addition, it should be pointed out that the Calipso Level 2 products which are being used for our comparisons are provisional data that still require further validation. Since the aerosols and cloud conditions also show great variability with time, as indicated for example in Figures 3 and 6, we are currently only able to make comparisons for some particular month of the year when possible, and draw general conclusions about the consistency of the two set of data, concerning the height distribution of aerosols or Cirrus clouds. The results are presented in the next section.

2. LIDAR OBSERVATIONS

2.1 Aerosols

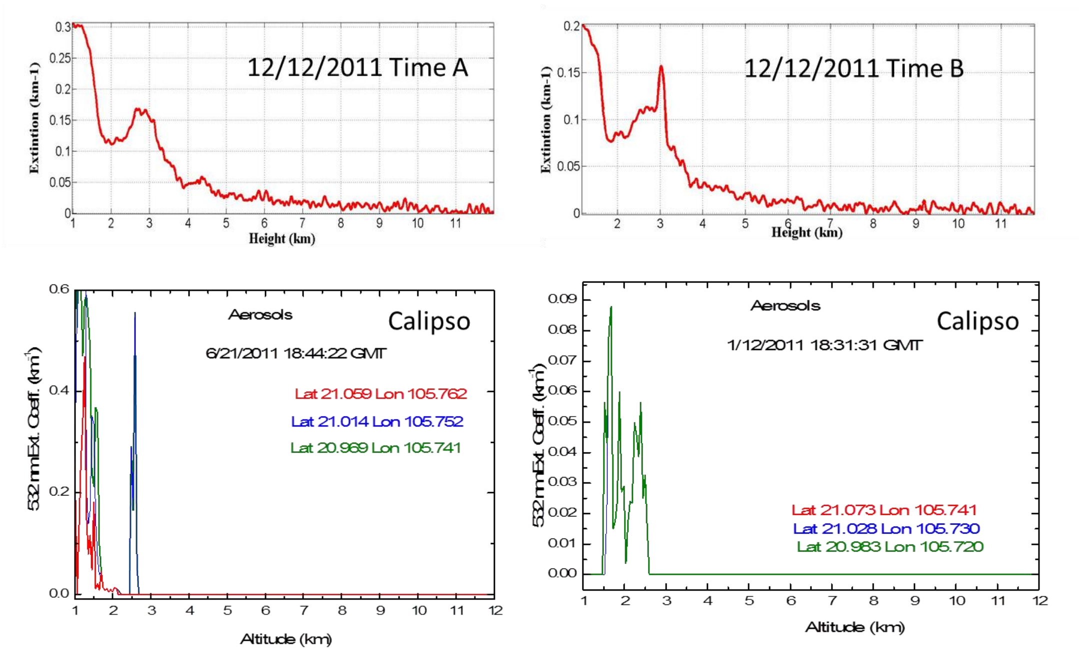


Figure 6. Extinction Coefficients derived from IoP ground LIDAR measurements at two different times of a day in 2011 (top panel) compared to examples of Calipso satellite derived values (bottom panel**)**

The time evolution of the surface aerosol layer measured by the Iop LIDAR can be observed in the top panel of Figure 6 in the changing shape of the signals between 2km and 3km at different times on Dec 12, 2011. Available Calipso observations of aerosols in 2011 are consistent in terms of height distribution over Hanoi, as illustrated by the examples in the bottom panel of Figure 6. Both data indicate presence of low altitude aerosol layers up to ~ 3km, while the magnitudes of the derived extinction coefficients can be different by up to several factors[11,12]. In general the height at the top of the surface aerosol layer measured by the IoP LIDAR is slighter larger.

2.2 CIRRUS Clouds

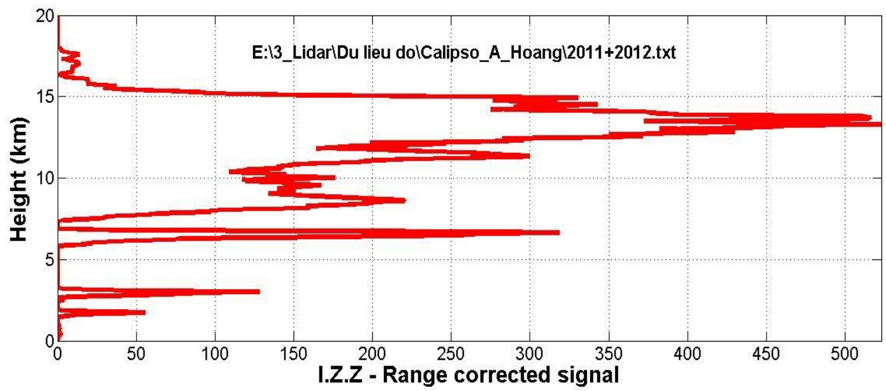


Figure 7. Averaged signal from observations made in 2011 and 2012 show Cirrus heights above Hanoi from 8 to 15km.

The averaged signal from LIDAR observations made at IoP in 2011 and 2012 is illustrated in Figure 7. Cirrus clouds can be seen to have distributions above Hanoi from 8 to 15km. These results are again consistent with the Calipso observations. For example, selected data collected in May-June of 2011, May and November of 2012 are shown for comparisons in Figures 8, 9 and 10, respectively.

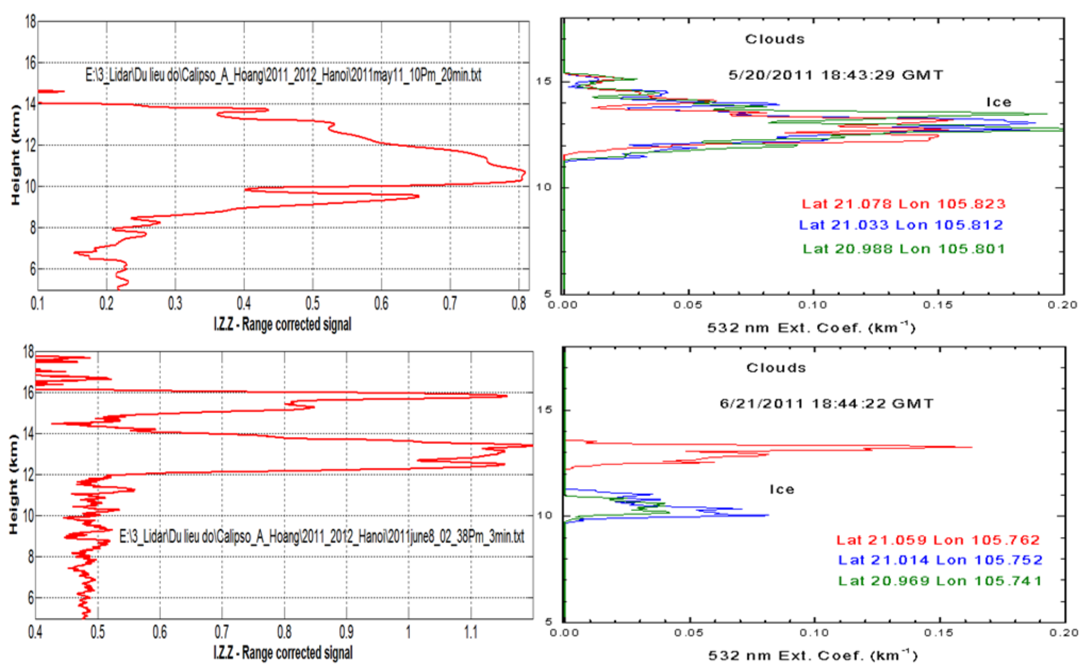


Figure 8. Comparison of Cirrus cloud profiles over Hanoi observed by IoP LIDAR (left) and Calipso satellite (right) in May and June 2011. May 2011(top), June 2011 (bottom). Both data show similar distributions of Cirrus clouds between 10km and 15km.

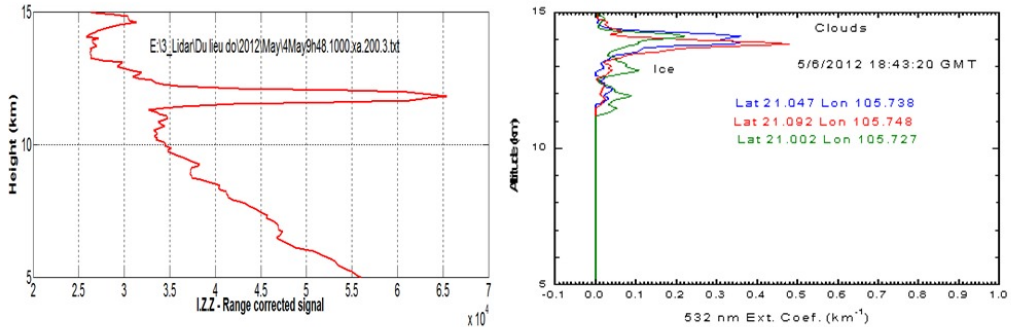


Figure 9. Comparison of Cirrus cloud profiles over Hanoi observed by IoP LIDAR (left) and Calipso satellite (right) in May 2012. Only one set of Calipso data over Hanoi is available in May 2012. The Cirrus cloud height observed by IoP is at ~ 12km on May 4, 2012, while the Calipso data show a layer at ~14km on May 6 2012[13-16].

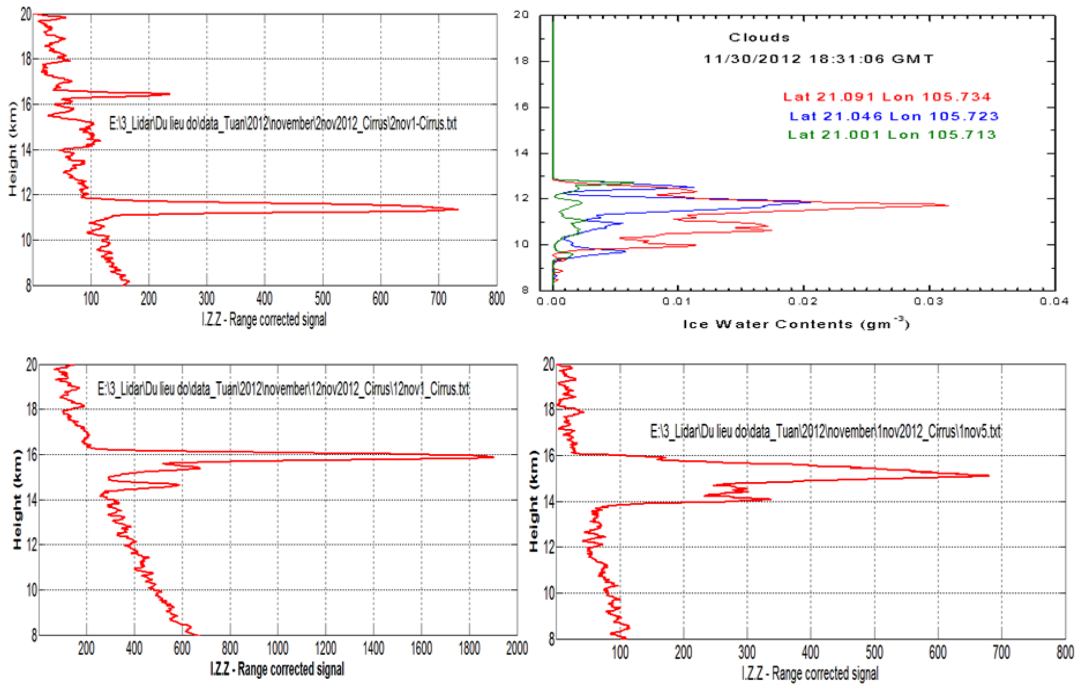
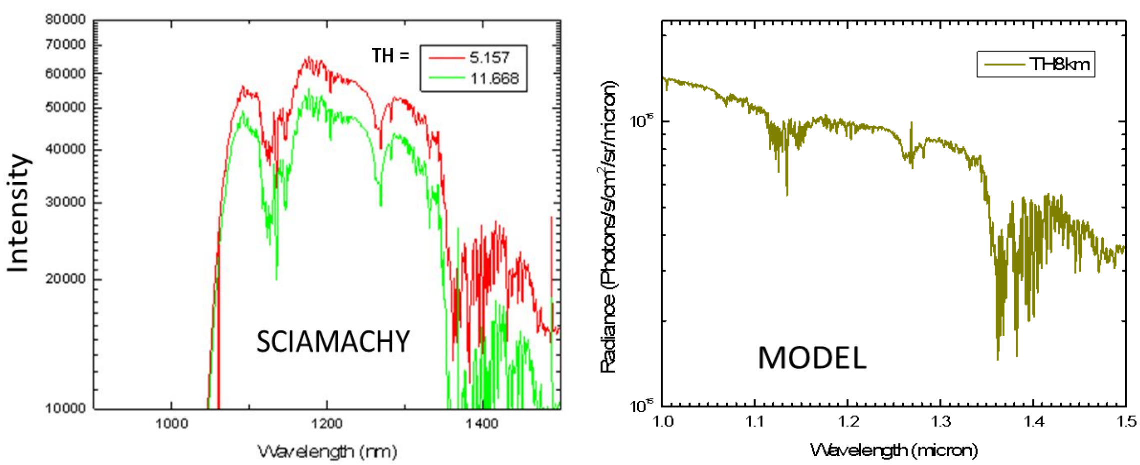


Figure 10. Comparison of Cirrus cloud profiles over Hanoi observed by IoP LIDAR (top left and bottom) and Calipso satellite (top right) in November 2012. Only one set of Calipso data over Hanoi is available in November 2012. During this period, the top Cirrus cloud altitude observed by the Iop LIDAR appears between 15km and 17km, at ~ 15km on Nov 1, ~ 16km on Nov 12, and slightly higher on Nov. 2, while the Calipso data show a layer at ~12km on Nov 30 2012. The IoP data on Nov 2 also shows a lower Cirrus layer at ~ 12km[17-21].

3. SPECTRAL RADIANCE OBSERVATIONS

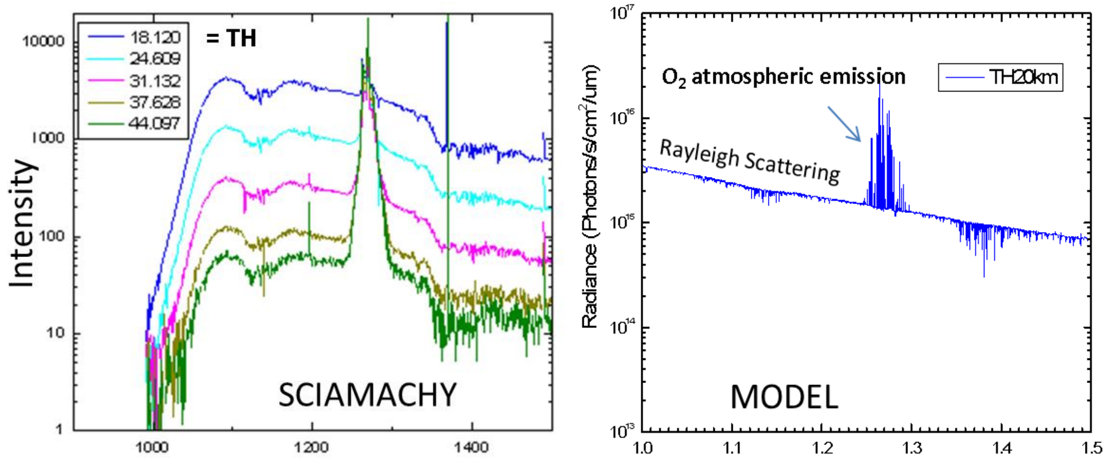
In this section we explore the possibility of validating the aerosol and cloud data retrieved by LIDAR measurements with spectral radiance observations. A set of data that can be used is the available limb spectra observed by the SCIAMACHY satellite (SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY)[6] from the European Space Agency. In a limb viewing mode, spectra are measured for a series of tangent heights (TH), i.e., a sequence of vertical steps, from low to high altitudes at the same latitude/longitude location. As it is likely for the lower altitude line of sight (LOS) to intersect clouds and thus give a different spectral signature from the higher altitude spectra, limb spectral radiances can be used to identify cloud presence and validate cloud properties retrieved by other techniques, such as LIDAR. The spectral radiances from SCIAMACHY observations of the atmosphere above Hanoi on May 5, 2011 are illustrated in Figures 11 and 12. The data at low and high tangent altitudes are shown in Figure 11a and 12a, respectively. These observations can be qualitatively interpreted by comparing to model calculated radiances. Shown in Figure 11b and 12b are the limb radiances for low (8km) and high tangent (20km) altitudes, calculated using a line-by-line spectral radiance code[24] developed at Spectral Sciences, Inc. The model calculations assume a Cirrus cloud layer around 10 km.

A comparison between Figure 11a and Figure 11b indicates consistency between the spectral radiances, suggesting cloud presence in the data at low altitudes; low tangent height (TH) limb data are dominated by solar scattering from clouds, attenuated by atmospheric transmission. On the other hand, the consistency between the spectral radiances seen in Figure 12a and Figure 12b shows that the high TH limb data are due to emission by atmospheric species in addition to molecular scattering. The observed spectra clearly shows the emission from the solar pumped O_2 atmospheric band at 1270 nm, a non thermal effect which is well reproduced by our radiance code. Note that the SCIAMACHY band filter function cuts off signal below 1000 nm.



(a) (b)

Figure 11. Limb spectral radiances at low tangent heights over Hanoi on May 5, 2011. (a) SCIAMACHY data (TH < 15km). (b) Model calculation (TH=8km).



(a) (b)

Figure 12. Limb spectral radiances at higher tangent heights over Hanoi on May 5, 2011. (a) SCIAMACHY data (TH > 15km). (b) Model calculation (TH=20km)

CONCLUSIONS

We have presented examples of aerosol and Cirrus cloud profiles over Hanoi recorded by the Institute of Physics LIDAR system. The data in 2011 and 2012 have been compared to Calipso satellite data during its overpasses of Hanoi. The aerosol and cloud conditions measured by the ground LIDAR system show great variability with time. The lack of exact coincidence in time and date with the Calipso measurements does not currently allow more than drawing the general conclusion that both sets of data yield consistent altitude distribution. We have also explored the use of limb spectral data to validate the altitudes of Cirrus clouds retrieved by the LIDAR observations. The SCIAMACHY limb spectral radiances over Hanoi were compared to model calculations and good agreement was obtained for scenarios with Cirrus cloud layers lying within the range retrieved by IoP and Calipso LIDAR data. These results suggest that limb radiances can be analyzed to locate the position of Cirrus clouds.

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