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Two-dimensional Simulation of Aerosol−Cloud Profile

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Abstract

Developments of algorithm and computer graphics simulation are important to distinguish between aerosols and clouds in remote sensing data and images. The distribution of aerosols and clouds are need to be distinguishable in order to study their interactions with one another and identify both affecting factors towards Earth's climate stability. The objective of this paper is to expand the current work done in building new algorithm and simulation method to differentiate aerosols and clouds in spaceborne lidar data and images using image processing and computer graphics software, PCI Geomatica 10.1 and SCION Image. The new algorithm and simulation that has developed showed good results and clarify the vertical distribution of aerosols and clouds in the atmosphere. Plot profiles of clouds on both days showed higher pixel values than aerosols. Aerosols have been found consistently to have higher mean at altitude 0−5 km and 15−20 km on both days.

Keywords: Simulation, Algorithm, Image Processing, Remote Sensing

1. Image Processing and Lidar

1.1 Computer graphics and image processing

Advancement in computer graphics and image processing give benefits in many educational and research fields including remote sensing. One of the main challenges in remote sensing is to distinguish between aerosols and clouds in the measured data and captured images. The issue on global climate change has revealed that clouds can have a significant cause on the Earth's climate and that one of the most uncertain aspects in their formation and ultimate dissipation is the influence by aerosols (Spichtinger and Cziczo, 2008). Researchers have applied computer graphics techniques of simulating clouds. Kajiya and Von Herzen generated cloud data sets for their ray tracing algorithm (Kajiya and Von Herzen, 1984), Dobashi used a simple cellular machine model of cloud structure to animate clouds offline (Dobashi et al., 2000) and Miyazaki extended this to use a coupled map lattice model based on atmospheric fluid dynamics (Miyazaki et al., 2001). Simulation on aerosol behaviour in an atmosphere containing saturated vapour has been performed by Klejenak and Mavko (Kljenak and Mavko, 2002). Other researchers have done numerical simulation of dust aerosols optical properties (Wiegner et al., 2009). Hoose et al. have performed a global simulation of aerosol processing in clouds (Hoose et al., 2008).

1.2 Lidar

Light Detection and Ranging (LIDAR) is a remote sensing system used to collect atmospheric data. Lidar has been used in optical remote sensing technique to study atmospheric particulate and gas pollutants over half of the century (Grant, 1987; Killinger and Menyuk, 1987; Killinger and Mooradian, 1983; Measures, 1984). Lidar has the ability to measure remotely atmospheric aerosols (Carswell, 1983; Fiocco and Smullin, 1963). Remote sensing of atmosphere applying Lidar technique depends on backscattering light of particles. Lidar produces radiation electromagnetic and compute radiation backward scattered (Dakin and Brown, 2006). The launched of space borne LIDAR satellite, Cloud-Aerosol Lidar and Infrared Pathfinder Satellite (CALIPSO) in early 2005 has provide the prospect to obtain the relevant data that essential to study the distribution of clouds and aerosols and its impact to the atmosphere. CALIPSO is orbiting at 705 km height from Earth's surface and in 98° inclination orbit. It has ability to provide daily maps of aerosols and clouds distribution globally (Winker et al., 2003).

CALIPSO used Nd:YAG based lidar system consist three main instruments at the CALIPSO payload which are the Cloud-Aerosol LIDAR with Orthogonal Polarization (CALIOP), an Imaging Infrared Radiometer (IIR), and a moderate spatial resolution Wide-Field Camera (WFC) (Weimer, 2004).

The Lidar equation is shown as below:

$$P_r(r) = \frac{C_N E_o \exp\left\{-2\int_h^z \sigma(r')\, dr'\right\}\beta(r)}{r^2} + P_{bg}$$

Where:

R	=	distance between scattered location and lidar (m)
H	=	lidar height
Pr(r)	=	power signal that returned of distance z (m)
σ(r)	=	atmospheric extinction coefficient (m^{-1})
β(r)	=	atmospheric backscatter coefficient (m^{-1} sr^{-1})
Pbg	=	background light power
CNE_o	=	system constant

The objective of this paper is to use our developed algorithm in EASI Modeling and perform 2D simulation on CALIPSO Total Attenuated Backscatter (TAB) images over Malaysia. We compare 2D simulation images with TAB data and perform further analysis on the aerosols and clouds density trend. We used image processing software and computer graphics software, PCI Geomatica 10.1 and SCION Image® (Fig. 1). PCI Geomatica 10.1 is been used to find the digital number of the CALIPSO TAB images and also as a platform to perform 2D simulation using our developed algorithm in EASI modelling. For further analysis, SCION Image® is been applied to carry out measurement and plot profiles of aerosols and clouds from 2D simulation images. These steps are important in order to get aerosols and clouds density trend vertically in the atmosphere.

2. Algorithm, EASI and SCION

In this study we used CALIPSO data and images on 4 January and 5 February 2009. We selected these two dates because CALIPSO has overpassed the study area, Malaysia during both days. The images showed the color–modulated profiles of Total Attenuated Backscatter (TAB) of the region that has been measured by CALIPSO (Fig. 2). The color coding scheme applied in CALIPSO TAB image which red represents strong returns from clouds and from surface. Yellows and greens represent weak cloud and strong aerosol scattering, blues represent weak aerosol and molecular scattering (Winker, 2007). The drawback of the CALIPSO TAB images was that the distribution of aerosols and clouds are not differentiated clearly. Research has been done to distinguish between aerosols and clouds using 2D simulation by EASI modelling. The digital number (DN) of aerosols and clouds have been determined using PCI Geomatica 10.1 (Table 1 and Table 2). By utilizing the DN values, we developed two algorithms using EASI modelling in PCI Geomatica 10.1. Two raster layers have been created for aerosols and clouds simulation respectively. The CALIPSO TAB images are then being simulated using EASI modelling by applying the algorithm below for aerosols and clouds. The simulation images are view in pseudocolor.

Algorithm for aerosols:

if (%1=255 AND %2=255 AND %3=0) or (%1=255 and %2=212 and %3=0) or (%1=255 AND %2=127 AND %3=0) or (%1=255 AND %2=170 AND %3=0) then %5=0 else%5=1

endif

Algorithm for clouds:

if (%1=255 AND %2= 255 AND %3=255) or (%1=253 AND %2=253 AND %3=253) or (%1=180 AND %2= 180 AND %3=180) or (%1=225 AND %2=225 AND %3=225) or (%1=245 AND %2= 245 AND %3=245) or (%1=240 AND %2=240 AND %3=240) or (%1=155 AND %2= 155 AND %3=155) or (%1=235 AND %2= 235 AND %3=235) or (%1=249 AND %2= 249 AND %3=249) or (%1=100 AND %2= 100 AND %3=100) or (%1=70 AND %2= 70 AND %3=70) or (%1=130 AND %2= 130 AND %3=130) or (%1=200 AND %2=200 AND %3=200) or (%1=242 AND %2=242 AND %3=242) then %4=0 else%4=1

endif

while %1 is a red layer, %2 is a green layer, % 3 is a blue layer and %4 and %5 are new added layers. After the simulations using EASI modelling, the aerosols and clouds profile successfully separated and viewed in different images. Then we plot TAB data from the ground until 20 km altitude. The data are being plotted in the multiple 1km range. We decided to plot within this height from the ground because we could observe that most of aerosols and clouds are located in this range. Above this height, no clouds are observed and the numbers of aerosols are decreasing. The 2D simulations of aerosols and clouds are further analyzed using SCION Image®. The objective of this analysis is to see the density trend of aerosols and clouds across the study area. The x−axis represents the length of the study area on the 2D simulation image and the y−axis represents the density in the pixel values unit at the study area.

3. Results and Discussion

There were highly dense aerosols which located within 17.93 N and 99.55 E to 8.00 N to 101 E where the distribution of the aerosols reaching 3 km height. Several locations showed dense profiles of aerosols within 5 km height from the ground. Obviously we could notice that most of the aerosols are tropospheric aerosols that located from the ground to about 20 km height. Other researches have revealed that aerosols are mostly confined to lower altitudes (De Tomasi et al., 2002). Region in Asia is considered as the region where the emission of anthropogenic aerosols which are the main contributors to tropospheric aerosols are rapidly increases (Muruyama, 1999).

Aerosols also can be observed at the surrounding edge of the clouds which explained their role in clouds condensation. Aerosols can act as nuclei on which water condenses to form cloud droplets at super saturations lower than those needed for homogeneous water nucleation (Cruz and Pandis, 1997). It has been confirmed that the indirect effect of aerosols that play sufficient role as cloud condensation nuclei (Mukai et al., 2003). A few groups of clouds were distributed at altitude 10 to 15 km at 11.82N and 100.91 E to −12.62 S to 106.18 E. On 5 February 2009, numerous clouds located at 10 to 15 km height within 5 N and 101.9 E to −11.08 S and 105.8 E. Maxima in the cloud-top altitude distribution mainly occurred in the upper troposphere, between 12 and 15 km and in the lower troposphere, below about 4 km.

From the 2D simulation of EASI modelling, the distribution of aerosols and clouds can be located more precisely. The 2D simulation images demonstrate agreeable results with TAB plotted values. The plotted graph of TAB showed that the locations of clouds have higher values of TAB than aerosols. The low altitude clouds showed higher TAB values than high altitude clouds.

Aerosols and clouds plot profiles from SCION Image® showed the density trend of aerosols and clouds respectively. This plot profiles are analyzed from EASI modelling images within 0 to 15 km height. In default, brighter areas in the images will have lower pixel values. The locations which have denser aerosols and clouds represents by darker areas in the simulation images. The denser areas have higher pixel values than the less dense area. We can see that for aerosols and clouds profile on 4 January 2009, the highest pixel value for aerosol is 234.04 and for cloud is 255. On 5 February 2009, the highest pixel value for aerosol is 244.11 and for cloud is 255. This means that clouds have higher density than aerosols.

The measurement using SCION Image® is done on the 2D simulation images of aerosols and clouds over the study area on the both days. The range of measurement has been set in 5 km such as 0−5 km, 5−10 km, 10−15 km and 15 to 20 km height. It can be noticed that the higher mean of aerosols are obtained at altitude 0−5 km and 15−20 km for both days. The highest mean of aerosols for both days are similar those were at the upper troposphere (15−20 km). In contrast, the higher mean of clouds are not linked on both days. The highest mean on 4 January 2009 is at 15−20 km while on 5 February 2009, the highest mean is at 5−10 km height.

The proposed simulation algorithm can be applied exclusively to the TAB images from space borne satellite, CALIPSO. If we want to apply this algorithm to other backscatter image, such as ground-based LIDAR, we have to change the numbers in the brackets of this algorithm to the RGB values of aerosols and clouds in the image that have been used. This algorithm can be reliably discerning clouds from aerosols because it follows the essential characteristic of clouds which have higher backscatter values than aerosols. The further analysis using SCION Image® proves the consistency of the proposed algorithm.

4. Conclusion

The 2D simulation of aerosols−clouds vertical profiles have been successfully obtained using EASI modelling. The aerosol-cloud vertical profiles have been distinguished and the distributions become clearer than before. It is noted that most of the aerosols over Malaysia for both days are tropospheric aerosols. The distributions of clouds are observed mostly at 5−6 km and 10−15 km height. Further analysis using SCION Image® on 2D simulation images have showed the density trend of aerosols and clouds. This new method of analyses using new algorithms with image processing and computer graphics software have provided an option for researchers to analyze the atmospheric backscatter data and images captured by space borne sensors.

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Table 1. The digital number for aerosols. The classification is based on the digital number (DN) of the weak backscatter colour.

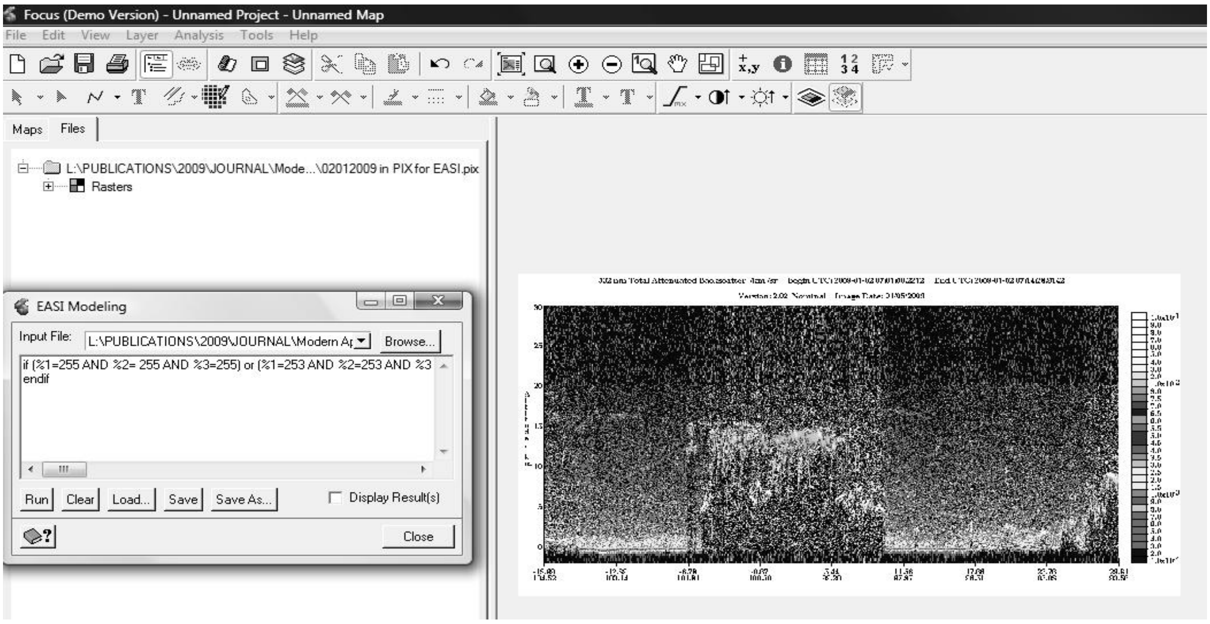
Red	Green	Blue
255	255	0
255	212	0
255	127	0
255	170	0

Table 2. The DN for clouds. The classification is based on the digital number (DN) of the strong backscatter color

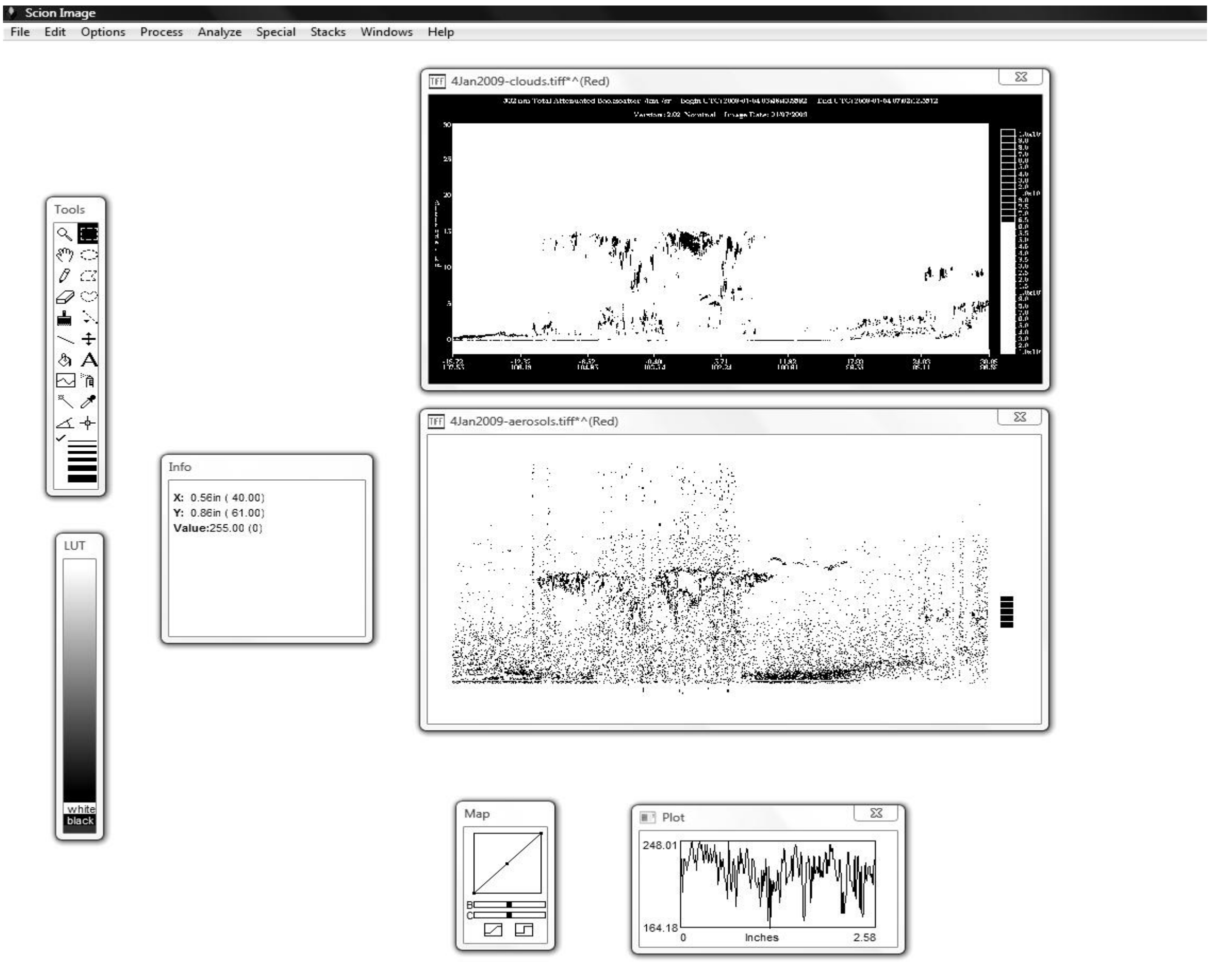
Red	Green	Blue
255	255	255
253	253	253
249	249	249
245	245	245
242	242	242
240	240	240
235	235	235
225	225	225
200	200	200
180	180	180
155	155	155
130	130	130
100	100	100
70	70	70

Table 3. The measurement using SCION Image® on the 2D simulation images of the study area. The higher mean of aerosols are obtained at altitude 0−5 km and 15−20 km for both days. The highest mean of aerosols for both days are related those were at the upper troposphere (15−20 km). On the contrary, the higher mean of clouds are not concurrent on both days

Altitude	Measurement	Value			
		Aerosol		Cloud	
		4 Jan 2009	5 Feb 2009	4 Jan 2009	5 Feb 2009
0-5km	Pixels	1984	1998	2520	2436
	Mean	209.55	202.5	251.07	242.07
	Std Dev	97.38	102.88	31.36	55.84
5-10km	Pixels	1590	1998	2520	2436
	Mean	230.24	231.99	245.42	253.96
	Std Dev	75.36	72.92	48.39	16.24
10-15km	Pixels	1457	1998	2520	2436
	Mean	212.46	218.39	236.86	228.52
	Std Dev	94.87	89.24	64.53	77.64
15-20km	Pixels	946	1998	2520	2436
	Mean	244.53	234.79	251.17	237.38
	Std Dev	50.53	68.76	30.96	64.55



(a)



(b)

Figure 1. Image processing and computer graphics software used (a) PCI Geomatica 10.1 and (b) SCION Image®. PCI Geomatica 10.1 is used as a platform to apply the algorithm at the original lidar image. The 2D simulation images of aerosol and cloud are developed here. SCION Image® is used to analyze the 2D simulation image.

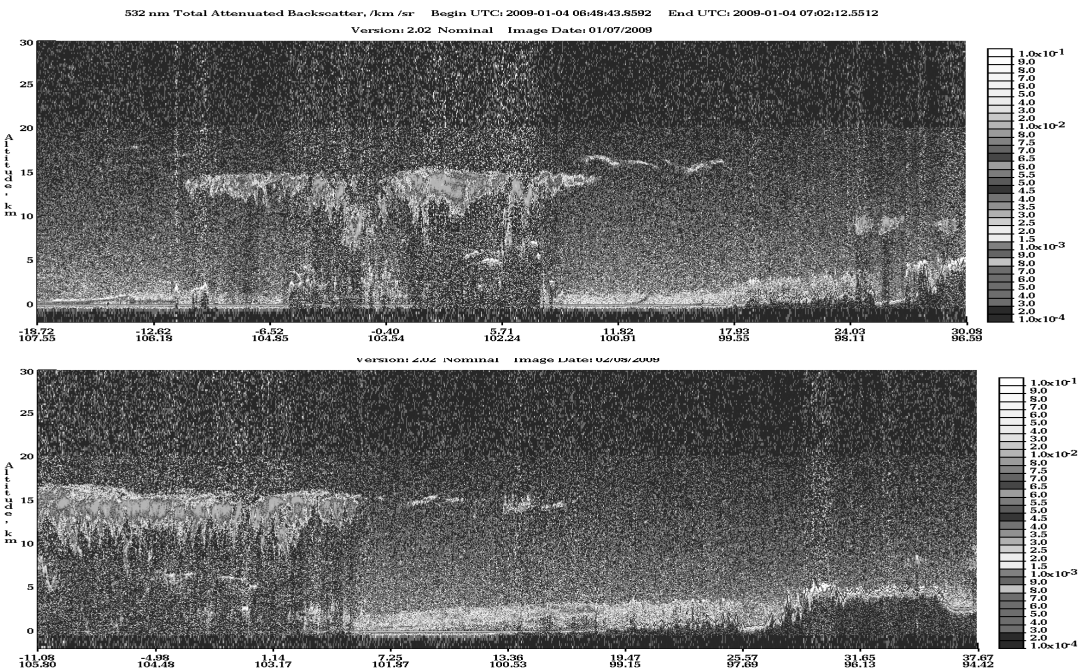
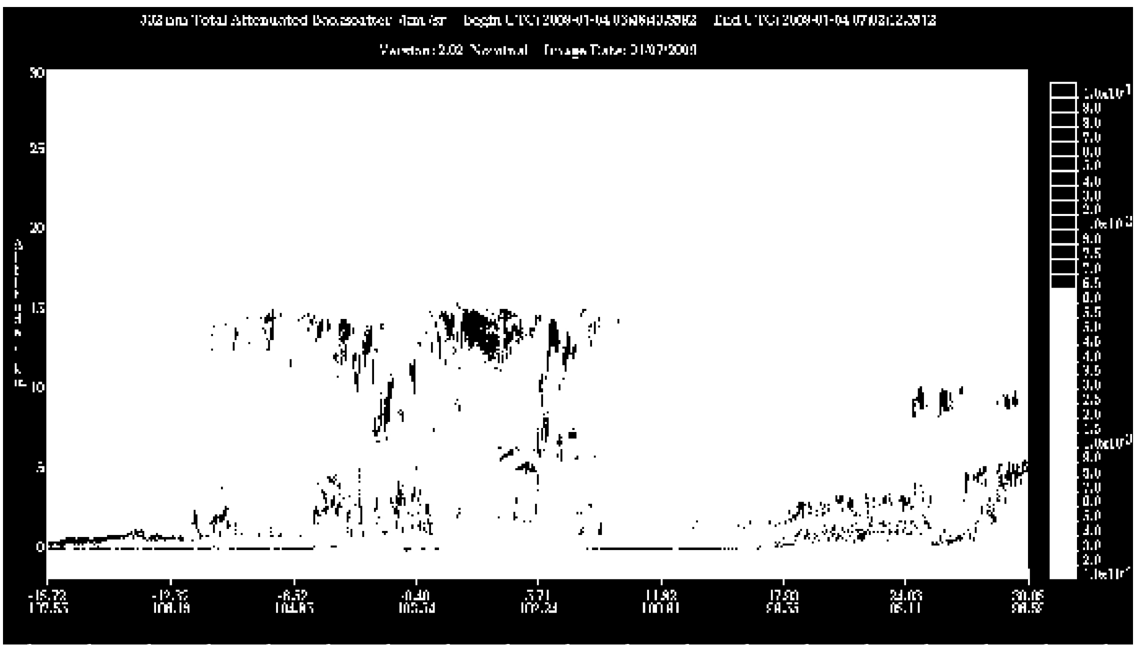
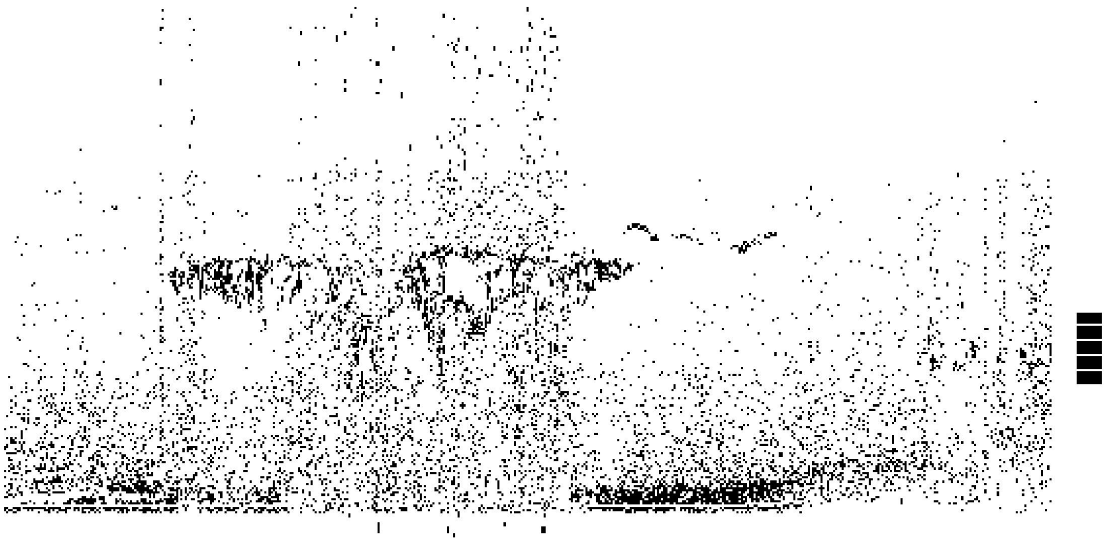


Figure 2. Total Attenuated Backscatter on (a) 4 January 2009 and (b) 5 February 2009. The intensity of the backscatter values are shown at the key-colour beside the image which read as the increment of intensity is from the bottom to the higher colour at the key colour.

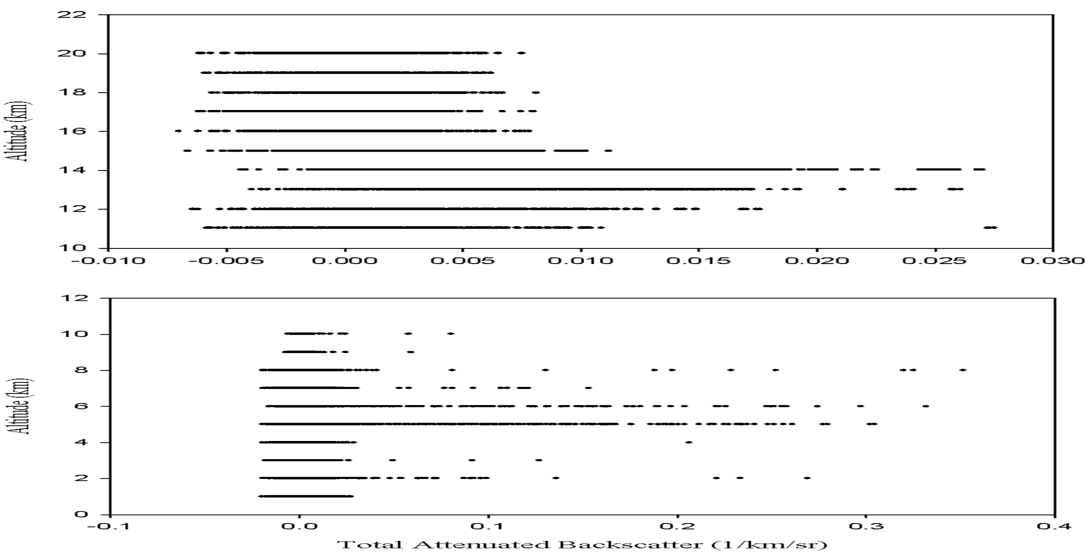
(a)



(b)



(c)



(d)

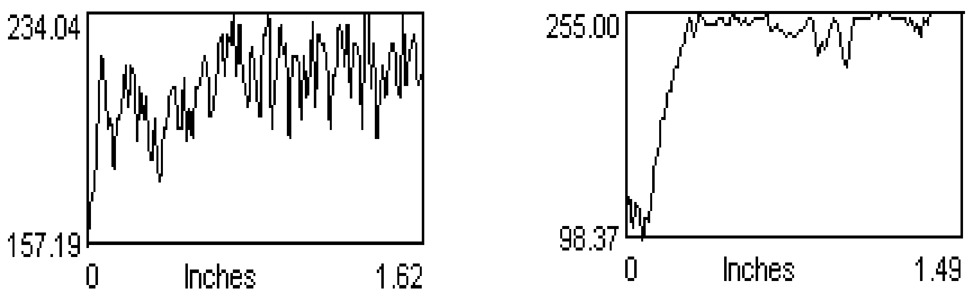
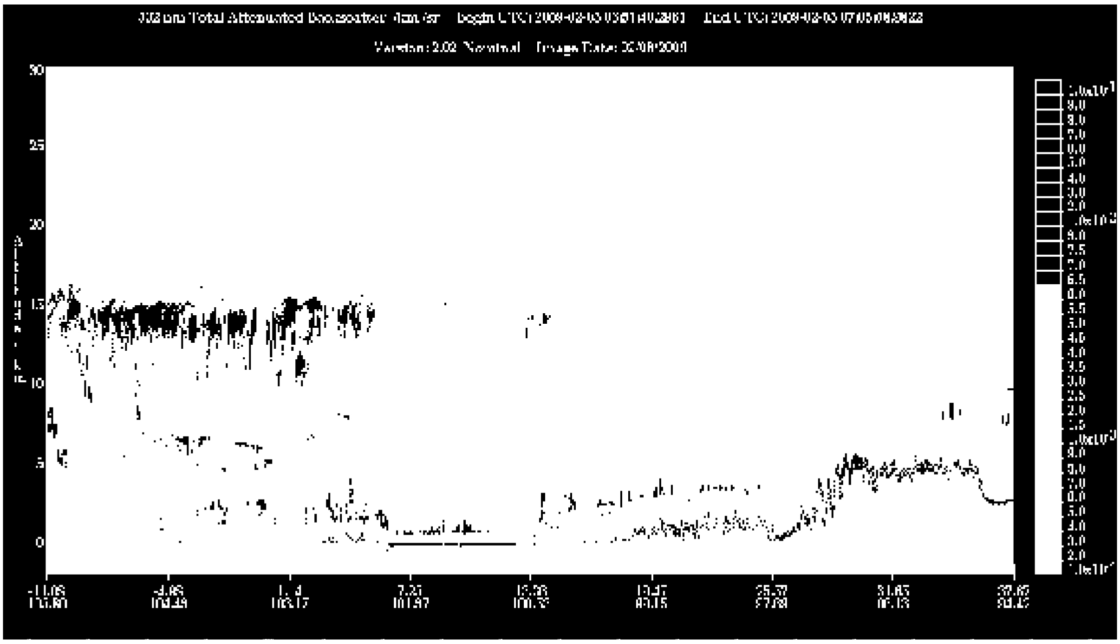
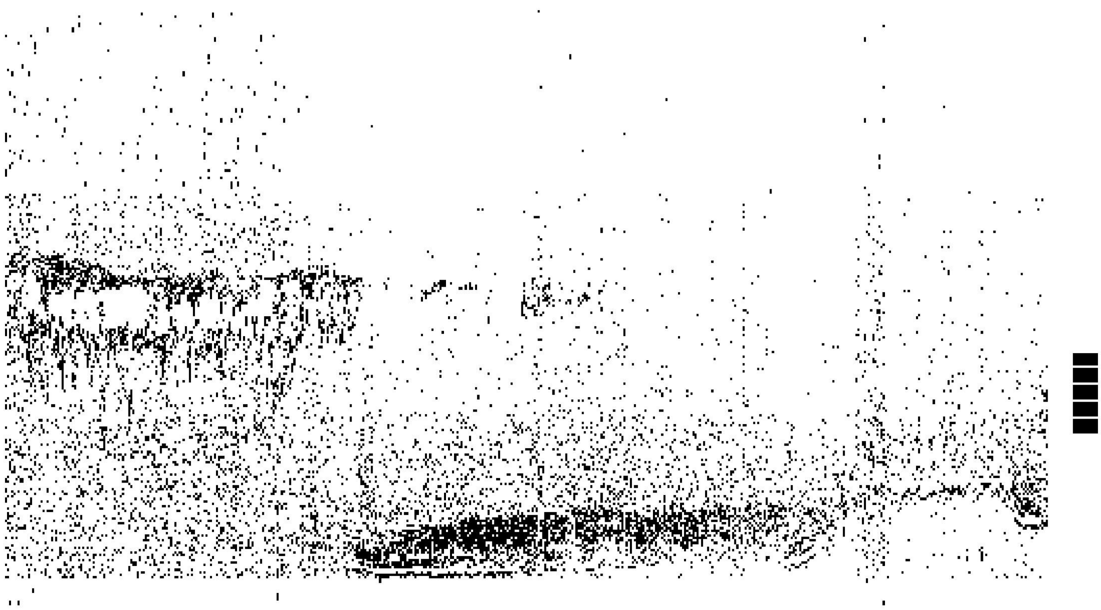


Figure 3. Images on 4 January 2009 (a) Simulation image of clouds (b) Simulation image of aerosols (c) TAB profiles from 0 to 20 km height and (d) SCION Image® of aerosols (left) and clouds (right). The aerosol-cloud profile, total attenuated backscatter and intensity analysis are being studied simultaneously.

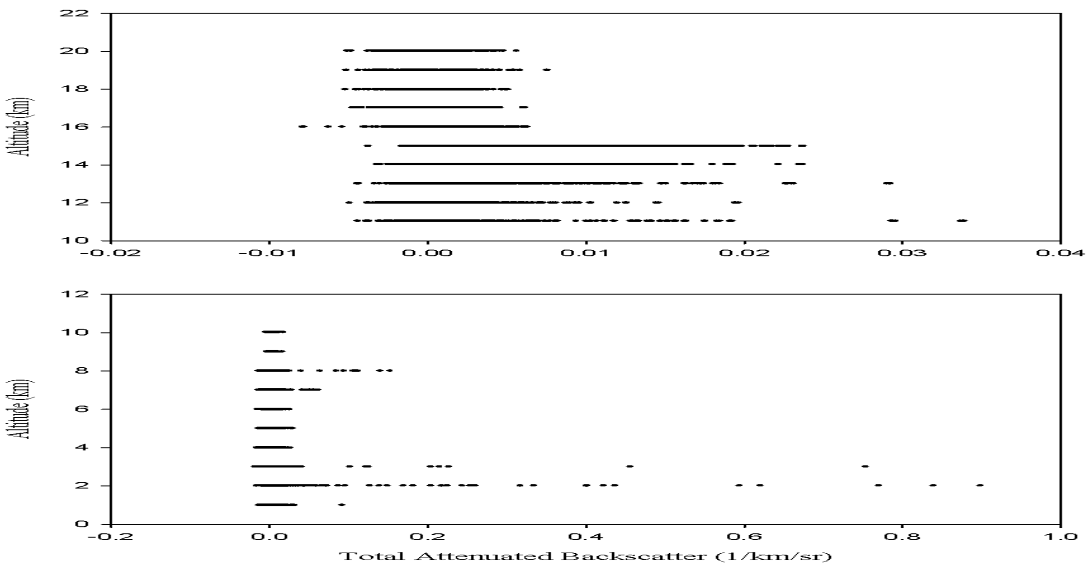
(a)



(b)



(c)



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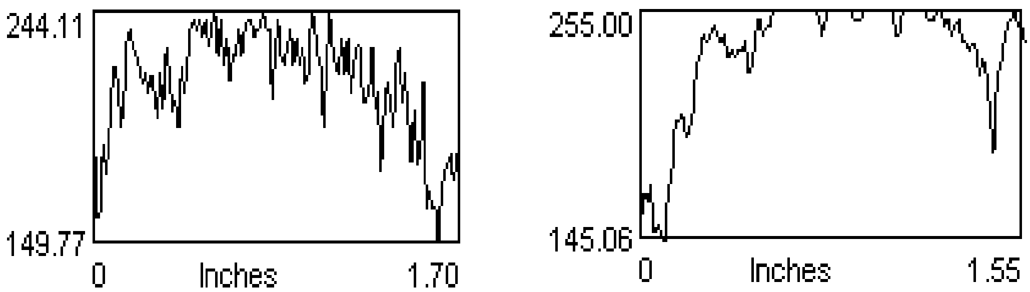

Figure 4. Images on 5 February 2009 (a) Simulation image of clouds (b) Simulation image of aerosols (c) TAB profiles from 0 to 20 km height and (d) SCION Image® of aerosols (left) and clouds (right). The aerosol-cloud profile, total attenuated backscatter and intensity analysis are being studied simultaneously