Observation of high load of stratospheric aerosols over Hampton-USA- 2011

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ABSTRACT

Lidar observations from the Hampton University observatory (37.02°N, 76.33°W) show an unexpected stratospheric aerosol layer between 17 to 18 km altitude on 14, 18 and 20 July 2011, and 01 and 02 August. This layer is related to the June 2011 Nabro volcanic eruption. Thirty-five-day backtrajectories from 20 July show the transport of stratospheric layers from Africa to Hampton at 17.5 km. The CALIPSO daytime overpass on 21 July, 338 km from Hampton confirms a stratospheric layer at approximately the same height.

Retrieved vertical profiles of aerosol extinction and backscatter coefficient are used to confirm the existence of aerosol layers at stratospheric heights and to determine their optical properties. The backscatter and extinction coefficients of these stratospheric aerosols are obtained using the Klett method and an estimated lidar ratio. A backscatter ratio at 1064 nm exceeding a threshold value of 3.5 in the stratosphere is considered a stratospheric aerosol layer. The aerosol optical thickness of this layer is compared to the integrated aerosol optical thickness of the lowest 3km of the troposphere.

1. INTRODUCTION

The stratosphere is usually characterized by very low aerosol content concentrated between 17 and 25 km in the Junge layer. However, significant deviation from this baseline can strongly affect atmospheric properties [1]. Aircraft, balloon sounding and satellite observations of the stratospheric aerosol determined its global characteristics. Layers of stratospheric aerosol have been shown to extend from just above tropopause to about 30km. The extinction ratio (ratio of aerosol extinction to molecular extinction) at 1.02 µm varies between 2 and 6 as the aerosol undergoes seasonal variation [2-5]. High optical depths caused by stratospheric aerosol loading affect climate, while the significant injection of sulfate aerosols into the stratosphere affect atmospheric chemistry [1, 6]. These effects are further compounded by the long life time of aerosols in the stratosphere. After a volcanic eruption, they can remain in the stratosphere for several years. Previous eruptions such as Pinatubo in 1991 show that the transport of aerosols in the stratosphere happens slowly [5, 7]. Pinatubo was also the first eruption in which stratospheric aerosol characteristics were studied using lidar [8]. These aerosols can act as cloud condensation nuclei and may influence cloud properties in the upper troposphere. The combination of Hampton University (HU) lidar observations and the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) transport model can relate the stratospheric aerosol layer to the Nabro eruption.

High levels of particle backscattering and extinction coefficient of stratospheric aerosols were measured at Hampton University, Virginia, USA on 14, 18 and 20 July 2011. The HU lidar has not observed major aerosol loading concentration this high in stratosphere in the 3 years preceding this event.

The unusually high concentration of aerosols was observed at heights above 16 km over a series of days by the HU lidar and further verified by CALIOP data. This increase in stratospheric aerosol loading was observed some days after the eruption, and the layer was exceptionally strong on 20 July 2011.

The University of Maryland, Baltimore County (UMBC) also observed this high level of aerosol loading related to Nabro volcanic ash from the June 2011 eruption. Since February 2009, UMBC and the HU lidar monitor aerosols in the troposphere and stratosphere on a routine basis as part of the CREST Lidar Network (CLN) [9]. Further Northern Hemisphere observations of a stratospheric aerosol layer between 12 and 19 km related to the Nabro eruption were reported by The Meteorological Observatory in Hohenpeissenberg (Germany), Evora (Portugal), Ukraine and Russia.

With consideration for the retrieved aerosol properties, regional observations and backtrajectory analysis, these aerosols observed over Hampton can be traced back to Nabro in Eritrea, Africa with a high degree of certainty.

2. MEASUREMENT AND DATA PROCESSING

The HU lidar operates at 1064, 532 and 355 nm using a Nd:YAG laser with a repetition rate of 20 Hz. Under normal operation each measurement consists of a 100s

(2000 shots) average. However, for the purposes of this study, only elastic retrievals at 1064nm are presented.

Here we will discuss and present the method used to define the aerosol layer in a case study of 20 July 2011. The aerosol extinction and backscatter coefficients have been calculated using the Klett method [10, 11] and an estimated lidar ratio. We have observed stratospheric aerosol at 1064 nm, producing a vertical profile of the range corrected signal, backscatter and extinction coefficients and backscatter ratio. However, the 355 nm noise level is higher than the backscatter of the stratospheric layer and is omitted in this study. Wandinger et al. show that aerosol characteristics can be retrieved with 10 to 40% relative error at 355 nm[12].

3. CASE STUDY OF 20 JULY 2011

The stratospheric aerosol layer was observed over the course of multiple days during July and August 2011. The results of 20 July 2011 are presented. In this section we present the range-corrected elastic backscatter signal, aerosol backscatter coefficient, aerosol extinction coefficient and aerosol optical thickness measured on 20 July 2011. The lidar measurement starts at 10:32 and continues until 15:40 local time.

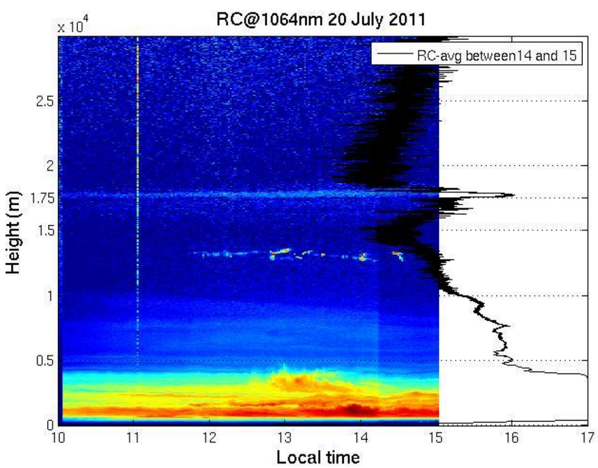

Figure 1. The range-corrected elastic backscatter signal measured on 20 July 2011 between 10:38 and 15:00 local time. The black line is the average of range-corrected signal between 14:00 and 15:00.

An unexpected increase in the 1064 nm range corrected backscatter signal was observed in the stratosphere between 17 and 18km (Figure 1). The strongest signal in the stratospheric layers is observed between 17.3 km and 17.8km with the maximum backscatter measured at 17.5km. A cloud layer has also been observed between 12700 and 13600m.

The backscatter and extinction coefficients at 1064nm have also been determined. The retrieved stratospheric aerosol backscatter and extinction coefficients using the Klett method is shown in Figures 2 and 3.

Figure 2 shows the temporal evolution of extinction coefficient profiles at 1064 nm (a_{1064}) using the Klett method with an appropriately chosen lidar ratio of LR=50 sr at 1064 nm[13]. The stratospheric aerosols have an extinction coefficient in the range of $2.8e10^{-6}$. The maximum extinction coefficients in the stratosphere are observed at an altitude range between 17.3 and 18.3 km.

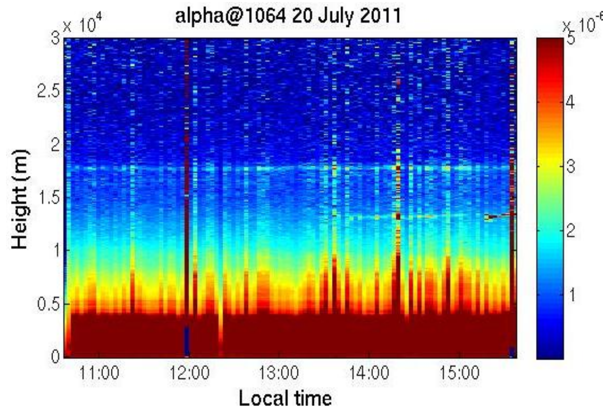

Figure 2. Evolution of extinction coefficient profiles at 1064 (a_{1064}) using the Klett method.

Figure 3 shows the evolution of total backscatter coefficient profiles at 1064nm (β_{1064}) using the Klett method with the estimated lidar ratio at 1064nm. The maximum aerosol backscatter coefficient for this stratospheric aerosol layer is observed at 17500km.

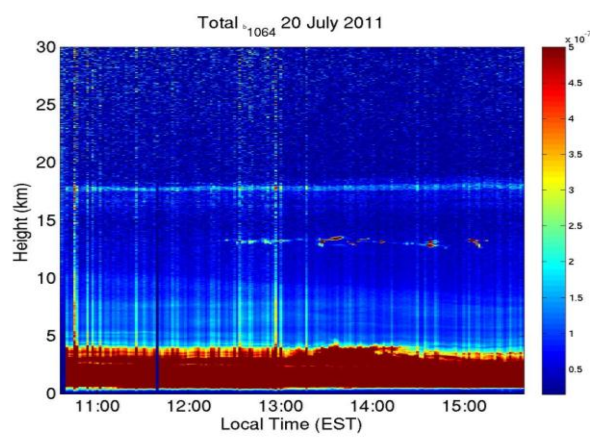

Figure 3. Backscatter coefficient of aerosol at 1064 nm. Vertical resolution is 7.5m.

Figure 4 shows the total attenuated backscatter at 532 nm measured by CALIOP. The distance between the CALIPSO overpass and Hampton observatory on 21 July is over 300km. CALIOP observes the stratospheric aerosol layers between 16 and 18 km, confirming the stratospheric layer observed by the HU lidar.

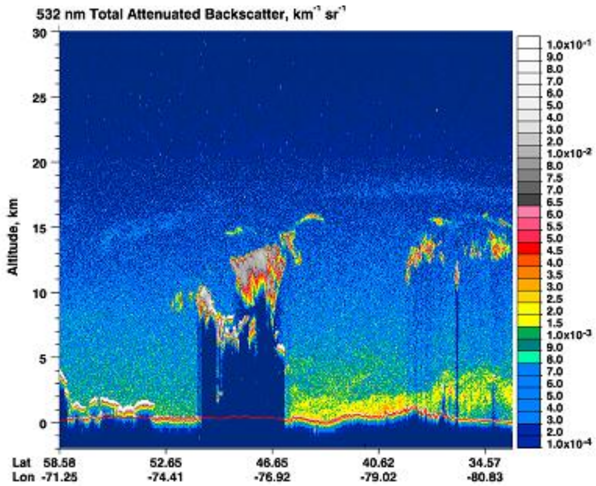

Figure 4. CALIPSO-images of total attenuated backscatter coefficient at a distance of 338 km from the Hampton observatory on 21 July

The vertical profile of aerosol backscatter and extinction coefficients at 1064 is shown in Figure 5. The retrieved extinction and backscatter coefficient have been averaged between 11:00 and 11:30 local time to reduce noise. An increase in extinction coefficient and backscatter of stratospheric aerosol layer is observed between 15.3 and 18.3 km. but the highest value of backscatter and extinction coefficient occurs at 17500m.

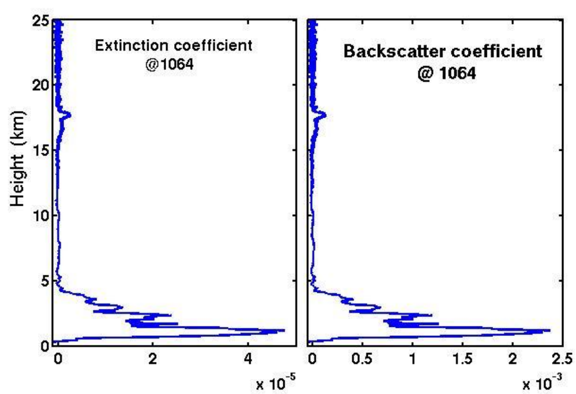

Figure 5. A vertical profile of averaged backscatter and extinction coefficient of aerosols at 1064 between 11 and 11:30.

The backscatter ratio (BSR) is the ratio of the total backscatter to molecular backscatter. Figure 6 shows the time series of height-dependent backscatter ratio. The retrieved BSR profiles are only used to define the existence of aerosol layers within the stratosphere wherever the BSR_{1064} exceeded a threshold value of BSR=3.5. This threshold is defined as the sum of the boundary condition and the error of BSR (+0.5 and -0.5). The BSR is divided by the molecular background signal between 10 and 11 km when there are no clouds present.

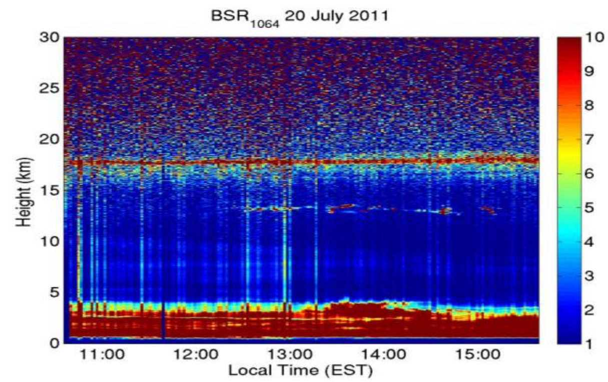

Figure 6. Backscatter ratio (BSR) at 1064 nm. A BSR > 3.5 in the stratosphere is used to identify stratospheric aerosol layers.

Since the layers are stable in optical thickness and altitude the hourly average of aerosol optical thickness (AOT) has been calculated. AOT is a parameter used to quantify stratospheric aerosol climate forcing.

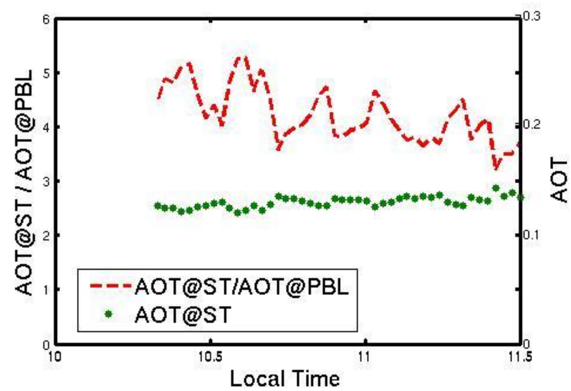

Figure 7. The AOT of the stratospheric layer (green line, right y-axis) and a ratio of the AOT of the stratospheric layer to the AOT of the boundary layer (blue line, left y-axis)

Figure 7 shows the calculated AOT for the stratospheric layer between 17.3 and 18 km (black line) and the ratio of stratospheric AOT value to the AOT below 3km. This altitude is used as an approximation for the top of boundary layer which contains most of the tropospheric aerosols. The observed AOT of the stratospheric layer is stable and varies less than 10%. The optical thickness of the stratospheric layer is about 15% of total optical thickness.

Figure 8 shows the 35-day backtrajectories for the airmass at 17.5 km generated by HYSPLIT. The observed trajectories associated with the layer trace back to Eritrea, indicating its relation to the June

African eruption. The thirty-five-day back-trajectories are calculated from 20 July at 12 UTC.

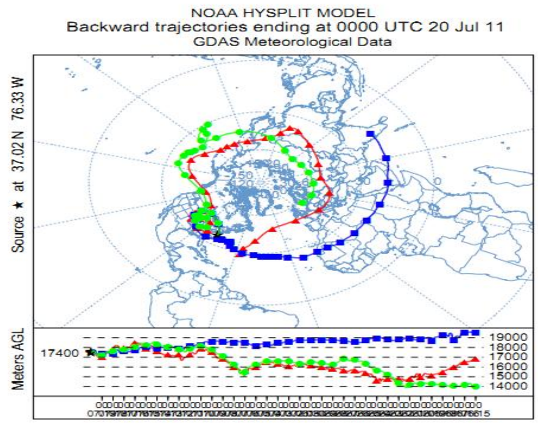

Figure 8. Thirty five day of back-trajectories calculated using HYSPLIT model 20 July 2011.

4. SUMMARY

We performed Lidar observations over Hampton, VA, USA that allow for the retrieval of aerosol extinction and backscatter coefficients and aerosol optical properties. Stratospheric aerosols are known to have long life times. Such aerosols resulting from major volcanic eruptions can persist at significant concentrations for several years with an e-folding time of about 1 year [7]. The first appearance of the stratospheric layer observed over Hampton by the HU lidar is likely 14 July. Backtrajectories for the stratospheric layer at 17.5 km on 20 July suggest the layer originated from the June 2011 Nabro volcanic eruption. Observations by lidar show the stratospheric layer between 16 and 18 km on 20 July. Multiple observations over different days show stratospheric aerosols in July, August and September, all of which appear to be related to the Nabro eruption aerosol layer, corroborating the long life of these aerosols and their transport.

5. ACKNOWLEDGEMENT

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