

# CHARACTERISTICS OF VOLCANIC STRATOSPHERIC AEROSOL LAYER OBSERVED BY CALIOP AND GROUND BASED LIDAR AT EQUATORIAL ATMOSPHERE RADAR SITE

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## ABSTRACT

We investigated the relation between major tropical volcanic eruptions in the equatorial region and the stratospheric aerosol data, which have been collected by the ground based lidar observations at at Equatorial Atmosphere Radar site between 2004 and 2015 and the CALIOP observations in low latitude between 2006 and 2015. We found characteristic dynamic behavior of volcanic stratospheric aerosol layers over equatorial region.

## 1. INTRODUCTION

Stratospheric aerosols play important roles in climate regulation and atmospheric chemistry. Based on some satellite data, the stratospheric aerosol optical thickness (AOT) increased after 2000 as the result of a series of moderate but increasingly intense volcanic eruptions [1]. Table 1 shows a list of volcanic eruptions of VEI $\geq$ 4 in tropical region (Latitude $<$ 20) between 2002 and 2015.

Kelut (Kelud) volcano (7.9S, 112.3E) in the Java island of Indonesia erupted on 13 February 2014. The CALIOP observed that the eruption cloud reached 26km above sea level in the tropical stratosphere, but most of the plume remained at 19-20 km [2]. As the plume continued to move west over the Indian Ocean, it thinned and spread out, following local atmospheric circulation. Aerosol index returns show that much of the ash injected into the atmosphere was removed by three days after the eruption. Although most of the SO<sub>2</sub> was injected into the stratosphere, the total SO<sub>2</sub> mass measured was  $\sim$ 0.2 Tg (confirmed by multiple sensors including OMI, AIRS and IASI), making this eruption fairly modest in terms of SO<sub>2</sub> release [3].

In this paper, we report comparisons of lidar and radar observations of stratospheric aerosols and wind at Equatorial Atmosphere Radar (EAR) site in Kototabang (0.2S, 100.3E), Indonesia, and the CALIOP observations data.

Table 1. List of volcanic eruptions of VEI $\geq$ 4 in tropical region(Latitude $<$ 20) between 2002 and 2015.

Volcano	Date	Latitude	Longitude
Ruang	25-Sep-02	2.3N	125E
Reventador	3-Nov-02	0.1S	78W
Manam	28-Jan-05	4.1S	145E
Soufreiere Hills	20-May-06	16.7N	62W
Tavurvur	7-Oct-06	4.3S	152E
Merapi	4-Nov-10	7.5S	110E
Nabro	12-Jun-11	13.4N	42E
Kelut	13-Feb-14	7.9S	112E

## 2. LIDAR AND RADAR SYSTEM

We had constructed the lidar facility for survey of atmospheric structure from troposphere to lower thermosphere over Kototabang, Indonesia in the equatorial region [4]. The lidar system consists of the Mie and Raman lidars for tropospheric aerosol, water vapor and cloud measurements, the Rayleigh lidar for temperature measurements and the Resonance scattering lidar for metallic species density measurements. The most parts of this lidar system are remotely controlled via the Internet. The full lidar observations started from 2004. The routine observations of clouds and aerosol in the troposphere and stratosphere are continued now.

We have installed 532nm polarization lidar system for stratospheric aerosol monitoring in 2014. We used the nearest operational radiosonde data to calculate the atmospheric molecular density. The lidar backscattered signal was interactively normalized to unity around 27–32 km, where aerosol-free conditions could be assumed. The total linear depolarization ratio  $d$  is defined as

$$d = S / (P + S) \times 100(\%)$$

where P and S are the parallel and perpendicular components of the backscattered signals [5,6].

EAR is a large Doppler radar. It consists of 560 Yagi-antennas in a circular field of 110 m in diameter. It can observe winds and turbulence in the altitude range of 1.5 km to 25 km, and ionospheric irregularities at an altitude above 90 km.

### 3. RESULTS

Figure 1 shows time-height cross sections of scattering ratio and depolarization ratio observed by 532nm polarization lidar at Kototabang. Over Kototabang, stratospheric aerosol layers were observed on 28 February 2014 about 15 days after the eruption. The peak values of scattering ratio was 4 at 19 km and the values of depolarization ratio was 4% at 19 km. Non-spherical ash particles were probably included in the layers with sulfuric acid particles that were produced from SO<sub>2</sub> through chemical reactions. Non-spherical particles were also present in the lower region (13-17km) of the aerosol layer.

On 29 April 2014 (2 months after the eruption), the peak altitude of scattering ratio move upward to 21 km but the peak altitude of depolarization ratio was still at 19 km. Light spherical sulfuric acid particles should be moved upward by the upwelling tropical branch of the Brewer-Dobson circulation but the non-spherical ash should not be moved upward.

Figure 2 shows time-height cross sections of scattering ratio and depolarization ratio based on CALIOP observations over 1S-1N and 80-120E.

Figure 3 shows time-longitude cross sections of maximum scattering ratio based on CALIOP observations over 1S - 1N and 18 - 25km. Stratospheric aerosol cloud was spread in the longitude direction with the lapse of time on February. After March, westward movement is clearly seen. Aerosol should be carried by strong westward equatorial wind generated by QBO.

On 21-26 June 2014 (4 months after the eruption), aerosol transportation from the stratosphere to the troposphere. The peaked stratospheric aerosol layers could not be seen in July 2014. Figure 4 shows time-height cross sections of vertical wind velocity observed by EAR. Vertical resolution is 450m and time resolution is 11 days. In June, we can see down phase structure of vertical wind

between 16-18km generated by Kelvin-Helmholtz instability in the tropical tropopause layer[7].

### 4. CONCLUSION

We have observed 2014 Kelut volcanic stratospheric aerosol from 28 February 2014 at equatorial lidar site located in the Sumatra island of Indonesia. We observed the depolarization maximum to be up to 2km below the backscatter maximum in April 2014. We also observed the vertical transportation process of stratospheric aerosol to troposphere generated by equatorial Kelvin wave instability with lidar observations and radar vertical wind observations.

From CALIOP data, Kelut aerosol cloud movement by strong westward wind generated by QBO was clearly seen. Aerosol layer was spread in the longitude direction with the lapse of time.

As the SO<sub>2</sub> mass injected into the stratosphere by Kelut eruption is moderate, these observations are good example of transportation of materials from the equatorial stratosphere to the troposphere.

We have tried trajectory analysis, but the results did not match with CALIOP measurement. The causes is lack of radio sonde data in equatorial region.

There are advantages of high altitude resolution, high temporal resolution and high sensitive depolarization measurement in ground based lidar. On the other hand, satellite based lidar have not enough resolution and sensitivity, but there is advantage of global observation. Using combination of ground based lidar and satellite based lidars data, we can get valuable sample of equatorial stratospheric aerosol vertical and horizontal transportation.

### ACKNOWLEDGMENTS

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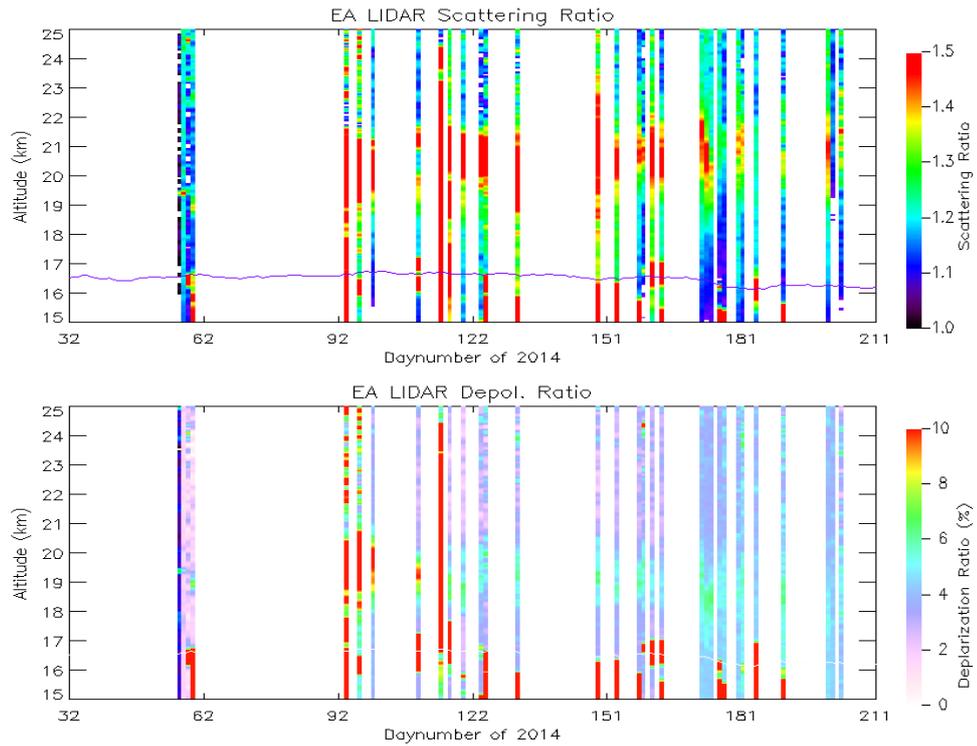


Figure 1 Time-height cross sections of scattering ratio and depolarization ratio observed by 532nm polarization lidar at Kototabang.

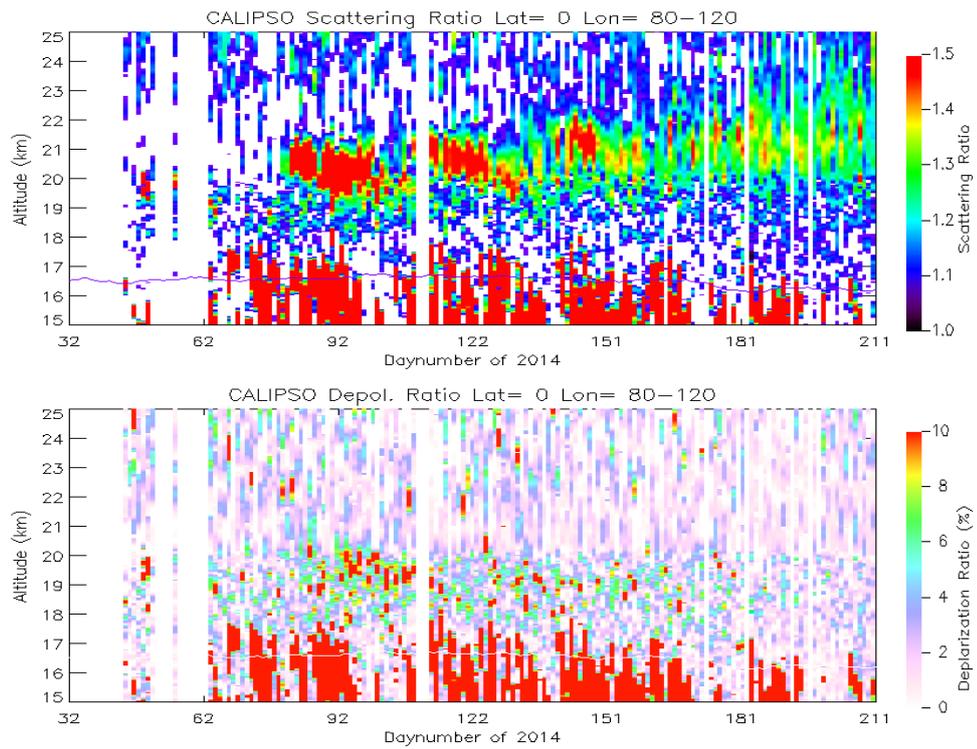


Figure 2 Time-height cross sections of scattering ratio and depolarization ratio based on CALIOP observations over 1S-1N and 80-120E.

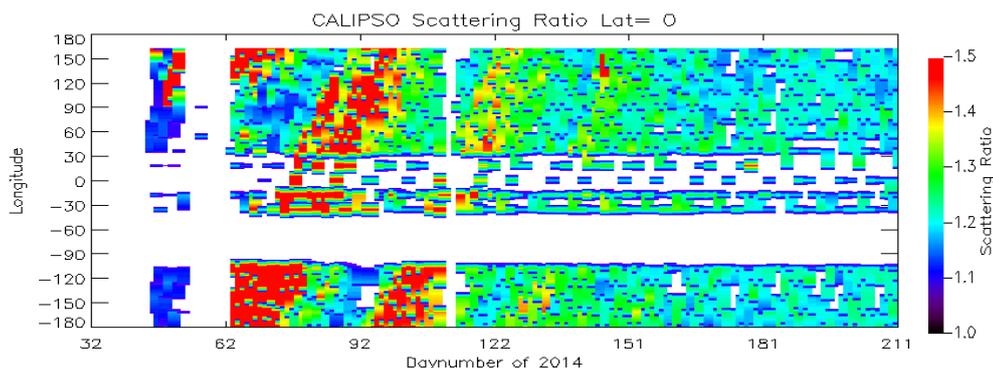


Figure 3 Time-longitude cross sections of maximum scattering ratio based on CALIOP observations over 1S-1N and 18-25km.

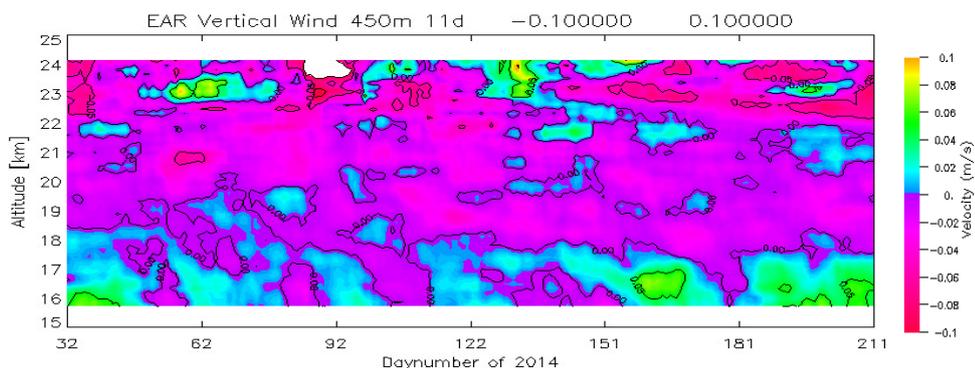


Figure 4 Time-height cross sections of vertical wind velocity observed by EAR. Vertical resolution is 450m and time resolution is 11 days.

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