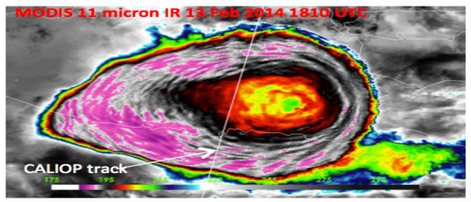
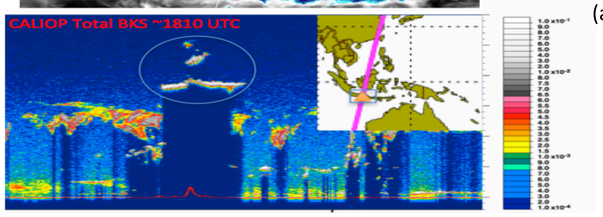
KLASH 2014: CALIPSO and in situ balloon measurements of the volcanic plume from Mt.Kelud; persistence of ash in the lower stratosphere

T. Duncan Fairlie[1], Jean-Paul Vernier[2], Terry Deshler[3], Katie Foster[3], Travis Knepp[2], Murali Natarajan[1], Kristopher Bedka[1], Stan Smith[3], Chip Trepte[1], Larry Thomason[1], and Frank. G Wienhold[4]

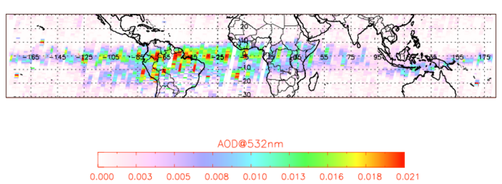
[1] NASA Langley Research Center, USA; [2] Science Systems and Applications, Inc., Hampton, USA; [3] University of Wyoming, Laramie, Wyoming, USA; [4] Swiss Federal Institute of Technology (ETHZ), Zurich, Switzerland

We show remote and in-situ observations that indicate the persistence of ash in a stratospheric volcanic plume following the eruption of the Mt. Kelud (Java) in February, 2014. Climate models typically assume stratospheric volcanic plumes to be purely sulfate. The initial eruption and subsequent dispersion of the plume in tropical latitudes were captured by the CALIPSO lidar. Initial depolarization measurements of ~0.3-0.4 indicated the presence of ash particles in the plume, while reduction of depolarization to ~0.1-0.2 in the following month was consistent with sulfate particle formation, but with a persistent ash component. In May 2014, we conducted a field campaign, based in Darwin, Australia. We made in-situ balloon-borne measurements of the Kelud volcanic plume to characterize particle size, optical properties, and volatile fraction of the aerosol. We conducted four flights of two-channel **Compact Optical Backscatter Aerosol Detector** (COBALD) backscatter sondes under small balloons, and a single flight of combined heated and unheated **U. Wyoming Optical Particle Counters (OPCs)** with COBALD under a large balloon. The observations show a double peak of backscatter in the vertical, and confirm the presence of larger non-volatile particles in the lower part of the plume.





The eruption of Mt. Kelud, 13 Feb., 2014: MODIS(Aqua) Brightness Temperature (11 micron), and CALIPSO total attenuated backscatter curtain showing main volcanic plume ~18-19 km altitude, extending as high as 26 km

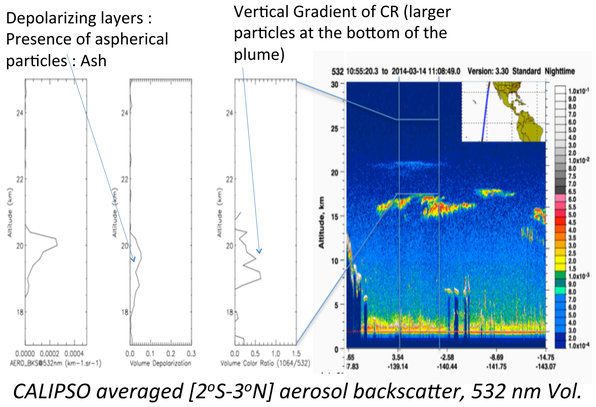


Map of AOD calculated between 18-21 km by accumulating CALIPSO observations of the Kelud volcanic cloud between 13 and 22 March 2014

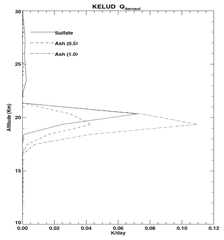
Volcanic ash detected a month after the eruption

Depolarizing layers : Presence of aspherical particles : Ash

Vertical Gradient of CR (larger particles at the bottom of the plume)



CALIPSO averaged [2°S-3°N] aerosol backscatter, 532 nm Vol. depo. and Col. Rat. (1064/532), 14 March, 2014.
Depolarization values of 0.05-0.1 at 18-21 km consistent with a mix of ash and sulfate .



Aerosol type	AOD	TOA ΔSW(W/m²)	TOA ΔLW(W/m²)	TOA RF(W/m²)	RF per unit AOD(W/m²)
Sulfate	0.0078	-0.338	-0.138	-0.200	-25.6
Ash (0.5 microns)	0.0045	-0.303	-0.076	-0.227	-50.4
Ash (1 micron)	0.0045	-0.321	-0.249	-0.072	-16.0

SW, LW radiative forcing (TOA) estimates show contributions from sulfate and ash components of the plume

Heating rate profiles calculated from the CALIPSO backscatter profiles shown above, for sulfate and ash components of the plume. Ash radii of 0.5 and 1 microns are shown. Lidar ratios of 70 (ash) and 50 sr-1 (sulfate) are assumed

KLASH deployment:

10-day balloon field experiment in **Darwin (Australia) May, 2014.** *Rapid Response*, with critical support from NASA HQ (Considine,Kaye), CALIPSO (Trepte), SAGE (Thomason), Australian BOM (Atkinson), CASA.

ETH COBALD Balloon Sonde

COBALD is designed to be flown on operational weather balloons. It uses two high power LEDs in the blue and the near IR and detects backscattered light from air molecules, aerosol or cloud droplets. Yields estimates of aerosol (or cloud) particle size and number density. For KLASH, COBALD integrated with an iMet sonde for data telemetry.

KLASH objectives

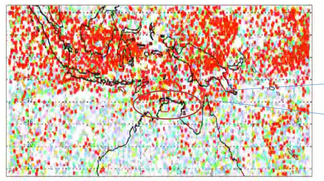
1. Establish aerosol size and sulfate/ash partitioning
2. Validate CALIPSO measurements
3. Derive optical parameters (lidar ratio, ash extinction), mass concentration (OPC), for use by CALIPSO, validation of other sensors, e.g. OMPS (Rault).
4. Provide radiative forcing estimates

KLASH flights

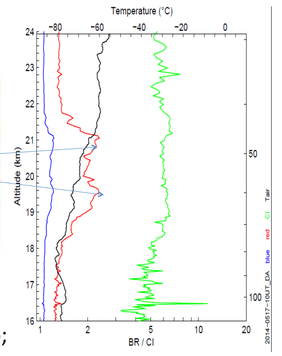
Four backscatter (COBALD) sondes flown under medium balloons. One combined heated and unheated OPCs flown with COBALD, under large balloon

Preliminary results: First COBALD flight (5/17)

Trajectory-mapped plume forecast
05/17 12 Z 21.30LT

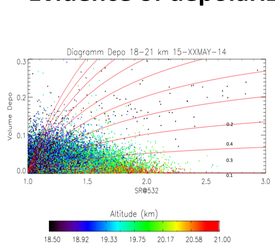


- Kelud Plume observed near 18-22 km
- Double peak in Scattering Ratio; later OPC flight indicates larger, non-volatile particles in lower of the 2 peaks.

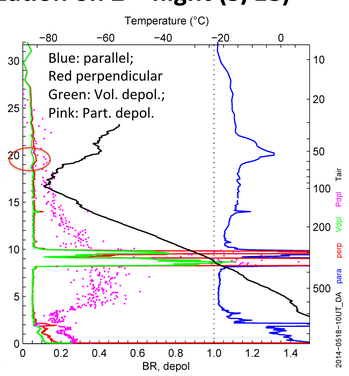


Red: 870 nm
Blue: 455 nm
Green: CR

Evidence of depolarization on 2nd flight (5/18)



CALIPSO: 10N-20S
15-24 May 2014



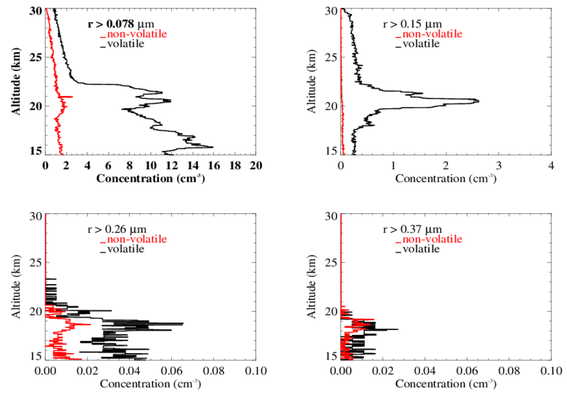
CALIPSO shows vertical gradient in depolarization indicating spherical particles at the top of the plume and aspherical below

Some increase in particle depolarization near 18 km, may indicate the presence of ash

The U. Wyoming Optical Particle Counter (OPC) is an *in situ* instrument which provides vertical profiles of size resolved aerosol concentration at 8 sizes. An additional OPC is used to obtain total aerosol population (CN). These measurements can be used to derive unimodal/bimodal lognormal size distributions to represent the measurements. A number of aerosol moments can then be calculated including aerosol extinction, volume, and surface area.

Preliminary OPC data: May 20, 2014

Volatile aerosol dominant for smallest particles



Confirmation of non-volatile ash particles 0.25-0.4 microns present in lower part of plume 18-20 km

Conclusions

KLASH was prepared in a short time with critical support from CALIPSO, SAGE groups, NASA HQ (D. Considine and J. Kaye)

Successfully sampled the Kelud plume at ~18-22 km and found evidence for ash particles, 3 months after the eruption

RF sensitivities to composition suggest that climate models may need to consider persistence of ash in stratospheric volcanic plumes, at least for months following an eruption

GEOS-5 simulations planned to test sensitivity to inclusion of ash in stratospheric volcanic plumes