CALIPSO characterization of volcanic aerosol properties and developed tools


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The CALIPSO Mission

CALIPSO Mission results from a NASA-CNES collaboration

CALIPSO Platform has been launched in April 2006 and is operational since then

Operational products are delivered by LaRC

http://eosweb.larc.nasa.gov/PRODOCS/calipso/table_calipso.html
browse images

http://www-calipso.larc.nasa.gov/products/lidar/browse_images

that are also available from the mirror site in France at ICARE

http://www.icare.univ-lille1.fr/calipso/
The CALIPSO Mission

It is the advantage of the CALIPSO platform to combine a 2-wavelength Cloud and Aerosol Lidar with Orthogonal Polarization (CALIOP) and a 3-band Infrared Imaging Radiometer (IIR) to provide accurately co-located observations directly exploitable for the detection and characterization of cloud and aerosol properties.

CALIPSO is furthermore a mission of the A-Train, allowing further combinations with other instruments (AIRS, CloudSat, MODIS, OMI, Parasol …) - N. Krotov’s talk yesterday-
Volcanic plumes in the atmosphere may contain sulfur gases (SO2, H2S, …), H2SO4 droplets and solid material (silicates, sulphates, …).

Such plumes present specific spectral signatures in the IR and also induce large depolarization of light in the visible due to scattering by non-spherical solid mineral particles.

LIDAR observations allow identification from depolarization and color ratio (but may be ambiguous), precise altitude determination, and extinction.

IR measurements allow identification from BTDs, optical depths and microphysical properties.

Interest of CALIPSO
The CALIPSO Data

Research satellite, but faster procedure in place since 2012

CALIPSO V3 data are now available in less than 24 h due to a faster processing using climatological atmospheric parameters.

Expedited quick-looks and expedited data (level 1 and level 2, CALIOP and IIR) are first available.

Final processing is performed within a week or so using GMAO data.
The CALIPSO Data

http://www-calipso.larc.nasa.gov/products/lidar/browse_images
The CALIPSO Data

http://www-calipso.larc.nasa.gov/products/lidar/browse_images
No specific data identified for volcanoes, needs to be extracted
CALIOP OBSERVATIONS
AFTER APRIL Eyjafjallajökull ERUPTION

Analysis conducted over April

Unvaluable information on vertical Localisation showing large Heterogeneity (patchy structure)

But 16 days repeat cycle
Estimate of Mass concentration $M$ of ash (lidar alone)

Is done assuming

$M = K \alpha$

Where $\alpha$ is the extinction coefficient derived by lidar

→ Large uncertainty on $K$ ( >50%)

→ and on $\alpha$ due to possible mixing of particles (ash and other non-mineral particles) and lidar inversion (lidar ratio)

Overall uncertainty on $K$ estimated to be a factor $> 2$

Thin layers: can be a few hundred meters
The ash plume transport after Puyehue Cordon-Caulle eruption

Large quantities of ash particles transported at high altitude (10 -12 km) at 40 S circulated round the globe up to Australia/New Zealand causing great trouble

→ Volcanic cloud from CALIOP cross-sections and trajectories from LaRC transport model

Vernier et al., JAMC, 2013
The ash plume transport after Puyehue-Cordon Caulle eruption

Large quantities of ash particles transported at high altitude (10 -12 km) at 40 S

- Separation of ice and ash particles using color ratio (aging)
- Estimate ash contribution from depolarization

Vernier et al., JAMC, 2013
ALagrangian model forced by CALIPSO observations

Data analysis using CALIOP data fed into LaRC transport model (Fairlie et al., 2009)

Vernier et al., JAMC, 2013
Include more CALIPSO Data
Back to the Eyjafjallajökull
Better Plume Characterization

- Altitude of the plume
- Optical parameters
- Microphysical (size and composition)

for transport analysis (small scale), radiative impact and risk for air traffic.

WHAT WE CAN USE

- CALIOP/IIR operational V3 L2 data (structure, extinction, emissivities and optical depths)

- CALIPSO/CloudSat AODs using lidar signal return on clouds (Hu et al, 2007) and radar/lidar ocean surface (Josset et al., 2008, 2009) - joint CNES-NASA SODA product at ICARE-

→ Determination of aerosol lidar ratio
May, 6

May, 7

May, 8

May, 9

SEVIRI/MSG (13:00 UTC)

EUMETSAT
The volcano plume extent is detected by the IIR using 10-12 BTDs according to a conservative threshold lower than the cloud reference used in the a posteriori analysis.
Optical depths larger than 2
Close to the source at 532 and 1064 nm
No spectral dependence (532/1064 nm)
→ Larger amount of big particles

Error on SODA AOD < 0.05
Error on IR AAOD ~0.05 to 0.1

Lidar ratio of 50 sr-1 after multiple scattering correction (corresponds to ash)

Use for better assessment of mass from Vis AOD

1K error is possible for the cloud reference (change of cloud top, opacity)
MICROPHYSICAL PROPERTIES DERIVED FROM MIE CALCULATIONS IN the 8.7-10.6-12 µm bands with andesite (Pollack et al., 1973). 10.6-12 µm give ash properties, 8.7-12 µm differences may infer the presence of SO2, H2SO4

→ GOOD AGREEMENT (within the error bars) between the three bands for May 6.

In regions # 1, 2 De ~5.5 µm
In region # 3 : De ~ 4.5 µm (smaller error)
→ Contribution of other particles in the accumulation mode will increase the visible OD but Contribution negligible when less than 1/20 of the OD in the accumulation mode Consistent with a large Angström coefficient (close to 1) and large depolarization (> 35 %) → different from Puyehue-Cordon Caulle

→ Possible to use Vis OD using direct lidar retrieval or or IR Abs OD with layer structure

The mass concentration estimate in the plume is

\[ M = \frac{2}{3} \rho \alpha D_e \]

Writing \( M = k \alpha \) emphasizes the importance of the size \( D_e \) and type of particles \( \rho \)

→ From CALIOP (OD, a) and IIR (OD, De), peak value is \( M \sim 7 \text{ mg/m}^3 \) for May 6, in the denser part (vis extinction above 2 km\(^{-1}\) e.g; \( V < 2 \text{ km} \))
Cloud/aerosols discrimination requires to use Lidar + IIR.

**EYJAFJALLAJOKULL ERUPTION**

*07 MAY 2010 03:20 UTC*

BTD > 0

$\Delta \varepsilon > 0$, $< 0$, $<< 0$

MSG 03h30

Volcano

Cloud/aerosols discrimination requires to use Lidar + IIR.

IIR volcanic ash index

**Δε10-12**
De = 4.2 µm

De = 5.2 µm

OD8/OD12 in worse agreement than for May 6 ➔ additional absorbing species, Biases due to lower cloud layer …

LARGE Abs ODs observed in region #3 ➔ Large mass concentrations
14/06/11: Nabro eruption (Eritrea)

First model initialisation on both SO$_2$ as seen by IASI and simple oxidation scheme: takes too much time to reconstruct realistic field.

Second model initialisation on two weeks CALIOP averaged data (15-30 June).

CALIOP plume position from 01st to 16th of July.
Model setup

- Grid resolution: 0.5° - Global Stratosphere
- Semi-lagrangian advection step: 1h – regrid every 6h
- CALIOP expedited data resolution: 1° - 1km - 17/18km average
- Backscatter ratio sequential assimilation – Control variable: Number concentration
- 75 size bins geometrically spread from 0.01µm to 10µm
  - Large number of bins needed to accurately model the backscatter coefficient

Simulation from June 25th to September 20th  – 405K
Assumption: After one month, SO$_2$ oxidation is complete – only H$_2$SO$_4$ is accounted for
Upon initialisation, uniform volcanic bimodal size distribution (taken from Deshler et al., 2003)
CALIPSO allows to characterize critical parameters of volcanic plume

- Combined Lidar/IIR observations can be used to better identify particle properties (altitude of injection, type of material, microphysical and radiative properties).
- Importance of visible and IR ODs, color ratio, depolarization to address composition in fine and coarse modes and plume aging/mixing

We have explored combined Lidar/IIR analysis methods to overcome problems linked to multilayered atmospheric structure (aerosols over clouds) and AOD retrievals (direct analysis in the IR). Accurate Abs ODs can be retrieved (accuracy better than 10% for absODs of 0.5 or Vis OD=1)

The optical properties of the plume in the IR and effective diameter allows to derive more accurate mass concentrations linked to mineral particles, and possible occurrence of absorbing species. Determination however depends on size distribution used.
Localized valuable information available, further improve data quality

Extend available CALIPSO parameters to forecast evolution as small scale using advection models constrained with observations.

Results from systematic analysis to be included in a new product dedicated to volcanic plume?

Accessible information in V4 ...
Ex: Maps and files of ash localisation on tracks, altitude, time, tbd, ...

Any specific need? Please contact us!