Stratospheric volcanic ash emissions from the 13 February 2014 Kelut eruption

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Kelut (Kelud)

Eruption onset
13 February 2014 22:50 LT (15:50 UTC)

Major eruption duration
~ 6 hours

Emissions
SO$_2$ and ash plumes to ~26 km
Aircraft encounter

Commercial flight from Perth to Jakarta

- Took off from Perth **02:25** LT
- Encountered the ash cloud around **05:10** LT
- Landed safely in Jakarta **05:50** LT
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Satellite ash retrievals troublesome

Can inverse and dispersion modelling help in estimating the concentrations of ash that the aircraft encountered?
Satellite observations of the umbrella cloud

Whole region has $dBT=0$ K

$T_{11} \text{ (min)}=188$ K
$T_{11} \text{ (max)}=240$ K

Optical depth 0.0 – 5.3
Satellite ash retrievals from MTSAT

13 Feb 2014, 17:32 UTC

Total mass = 0.10 Tg
Max = 162.50 g/m²
Mean = 0.04 g/m²

Valid retrieval
Failed retrieval

Satellite ash retrievals from MTSAT

13 Feb 2014, 17:32 UTC

Total mass = 0.10 Tg
Max = 162.50 g/m²
Mean = 0.04 g/m²

13 Feb 2014, 22:32 UTC

Total mass = 0.39 Tg
Max = 35.75 g/m²
Mean = 0.18 g/m²

14 Feb 2014, 02:32 UTC

Total mass = 0.49 Tg
Max = 26.63 g/m²
Mean = 0.22 g/m²

Aircraft encounter “seen” from MTSAT

Can modelling help?

Dispersion modelling is crucially dependent on the source term!

Estimate ash source term using inverse modelling; find the emissions that make the modelled ash clouds in best possible agreement with satellite observations!

If satellite retrievals cannot see the ash cloud – how can the source term be estimated and modelling reveal it?
Source term inversion:
Transport is dependent on altitude of emission

FLEXPART dispersion model run on one-hourly ECMWF NWP data

Emissions of ash
- every 500 m [2-35 km a.s.l]
- every 30 min
Source term inversion: Combining model, satellite and a priori

\[ M x = y^o \]

**M**: Model sensitivities (g/m²)
FLEXPART dispersion model run on one-hourly ECMWF NWP data

**Unknown source**

Emissions of ash
- every 500 m [2-35 km a.s.l.]
- every 30 min

**y^o**: Satellite observations (g/m²)
One-hourly MTSAT ash mass loading retrievals
Flags: valid/failed retrieval

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Source term inversion: Combining model, satellite and a priori

\[ M(x - x^a) \approx y^o - Mx^a \]

- **M**: Model sensitivities (g/m²)
  - FLEXPART dispersion model run on one-hourly ECMWF NWP data
  - Emissions of ash
    - every 500 m [2-35 km a.s.l]
    - every 30 min

- **y^o**: Satellite observations (g/m²)
  - One-hourly MTSAT ash mass loading retrievals
  - Flags: valid/failed retrieval

- **x^a**: a priori
  - 1.5 Tg fine ash (from “poor-mans inversion”)
  - Distributed uniformly in time and height.
  - Very large uncertainty

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Satellite-constrained *fine ash* source term

Satellite-constrained *fine ash* source term
Comparison to CALIOP

Modelling the aircraft encounter

Fine ash source term → Extend the particle size distribution and the related mass eruption rate to include smaller/larger particles than what is inverted for (i.e. observed by satellite).

Modelling the aircraft encounter

The inversion locates some ash in the western part only because this ash was observed elsewhere at a later time.

Modelling the aircraft encounter

Sensitivity test:
Assume ash in area of “failed retrieval”

Other sensitivity tests for the inversion:
- Different amounts of satellite data
- Start and end time of assumed emission time period
- Assumed uncertainties
- Assumed ash particle size distribution

Modelling the aircraft encounter

Modelling suggests that the aircraft flew below the main ash cloud.

Modelling suggests the aircraft flew in areas with **ash concentrations up to 9-12 mg/m$^3$** over a period of **10-12 min**.
**Key point**

The method of combining satellite retrievals and transport modeling gives information that *cannot be obtained using either data source alone!*

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Thank you

Questions

Contact: nik@nilu.no
Additional slides
Sensitivity to assumed particle size distribution
Sensitivity to assumed particle size distribution
Some limitations of inverse modelling

- Relies on the “quality” of the satellite data or other constraining data
- Characterizing the uncertainties related to the three inputs are challenging
- Assumes normally distributed uncorrelated errors
- Some subjective adjustments might be needed
- Implicitly assumes that the uncertainty of the volcanic cloud modeling is dominated by the uncertainty of the source term
- As the volcanic cloud gets transported further from the source, this assumption could be violated due to errors in meteorology and/or model parametrizations
- Combining data assimilation and source term inversions could be helpful