Stratospheric volcanic ash emissions from the 13 February 2014 Kelut eruption

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WMO, Seventh International Volcanic Ash Workshop, Anchorage, Alaska, 19-23 October 2015

Kelut (Kelud)

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

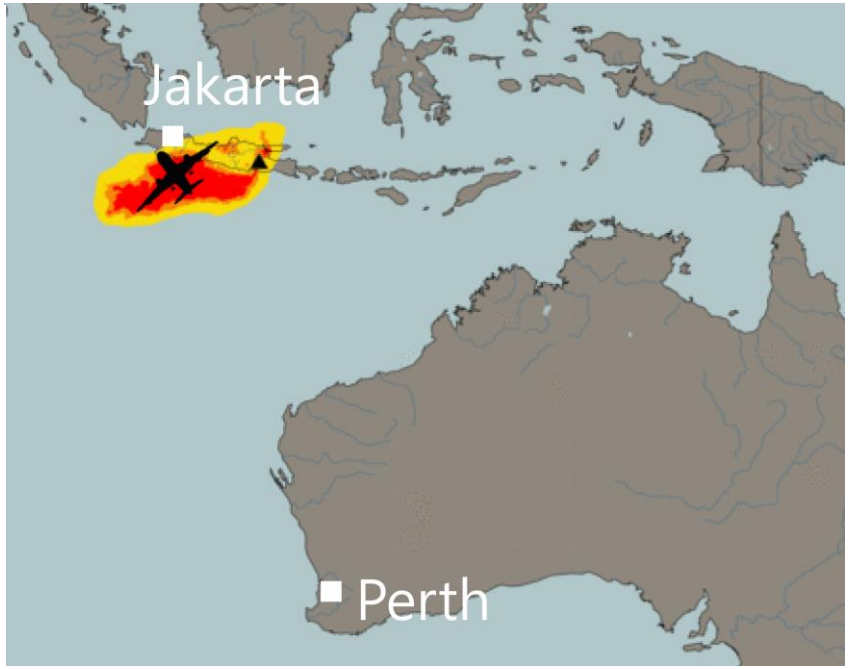
Major eruption duration
~ 6 hours

Emissions
SO_2 and ash plumes to ~26 km

Aircraft encounter

Commercial flight from Perth to Jakarta

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



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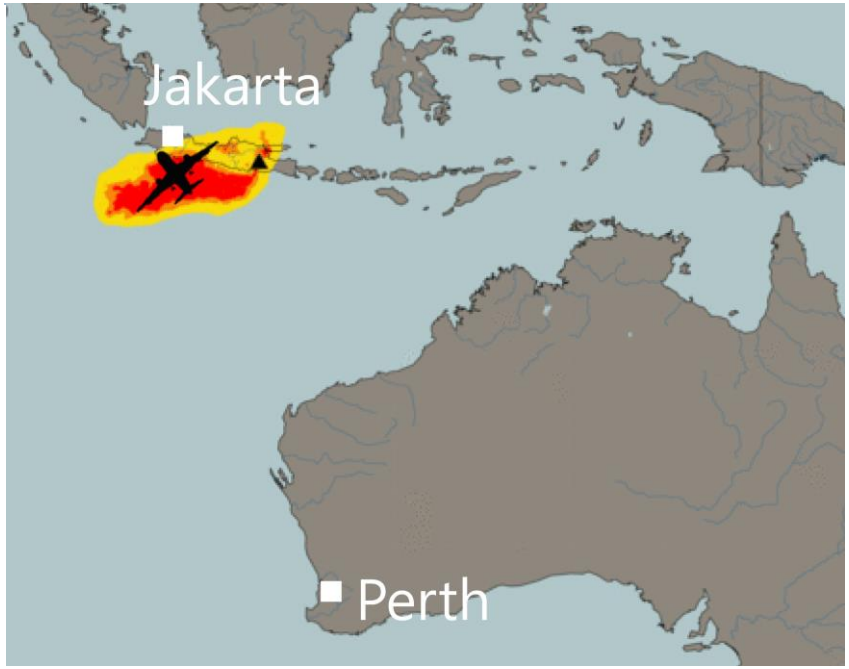
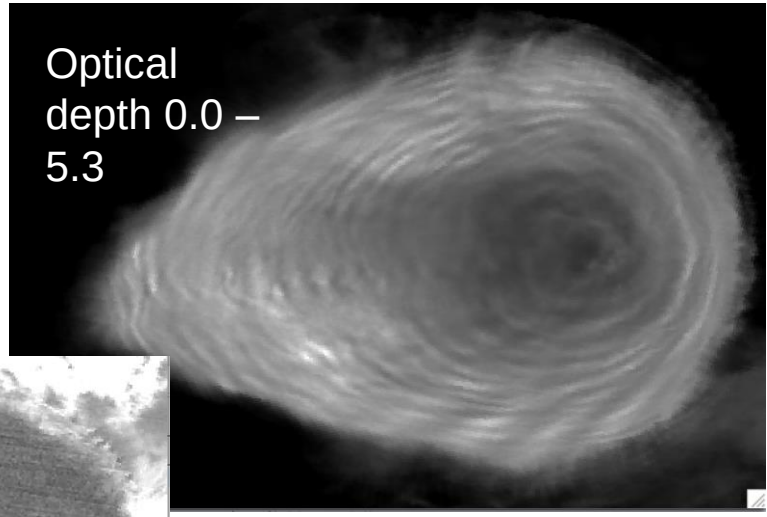
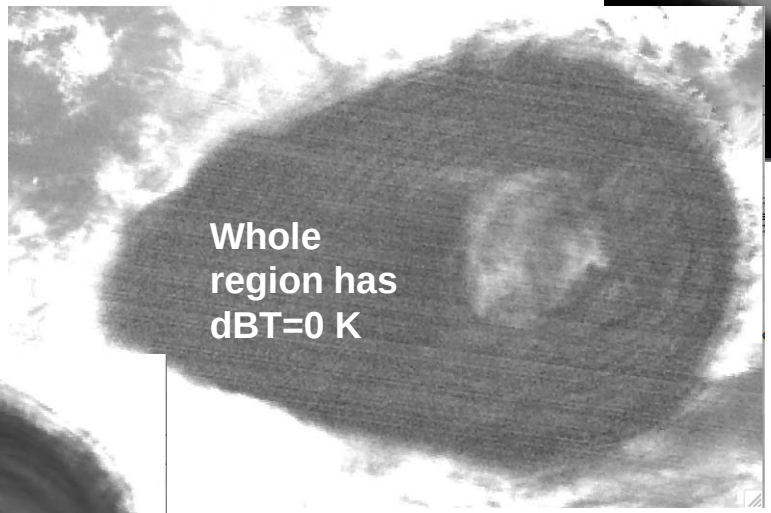


Satellite ash retrievals troublesome

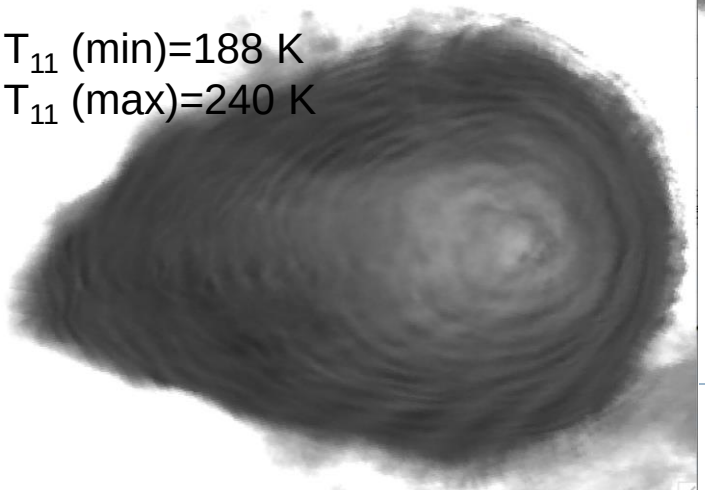
Can inverse and dispersion modelling help in estimating the concentrations of ash that the aircraft encountered?

Satellite observations of the umbrella cloud

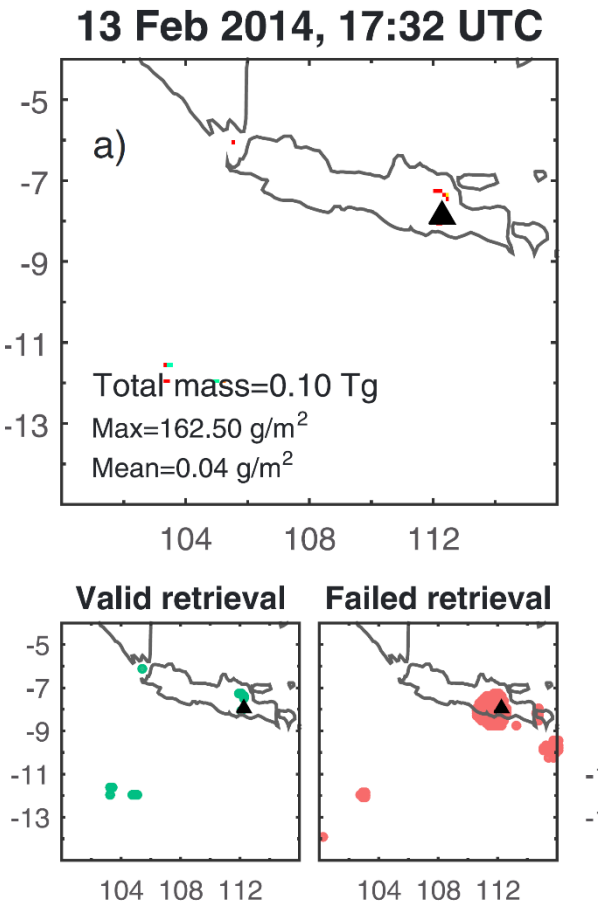




T_{11} (min)=188 K
T_{11} (max)=240 K



Satellite ash retrievals from MTSAT



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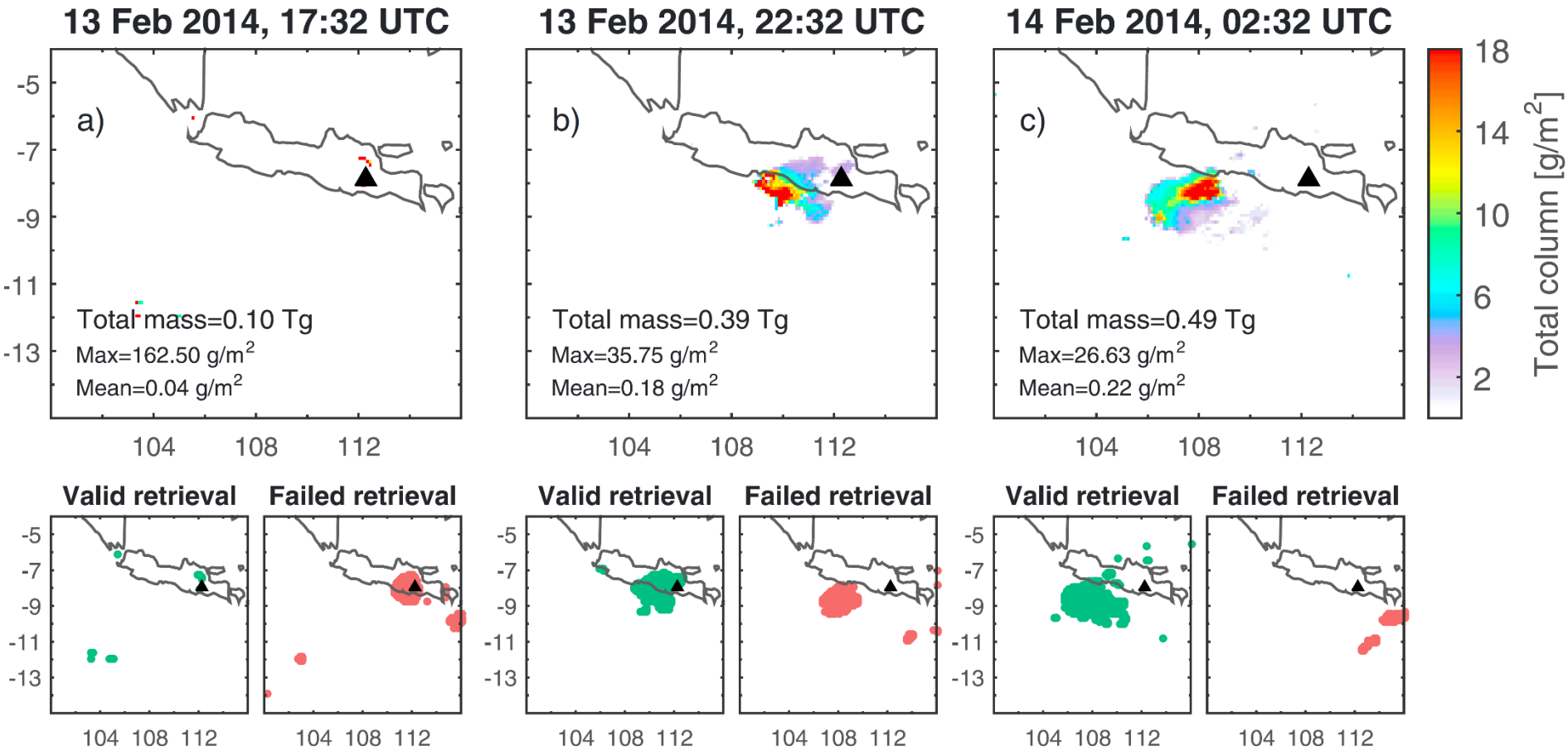

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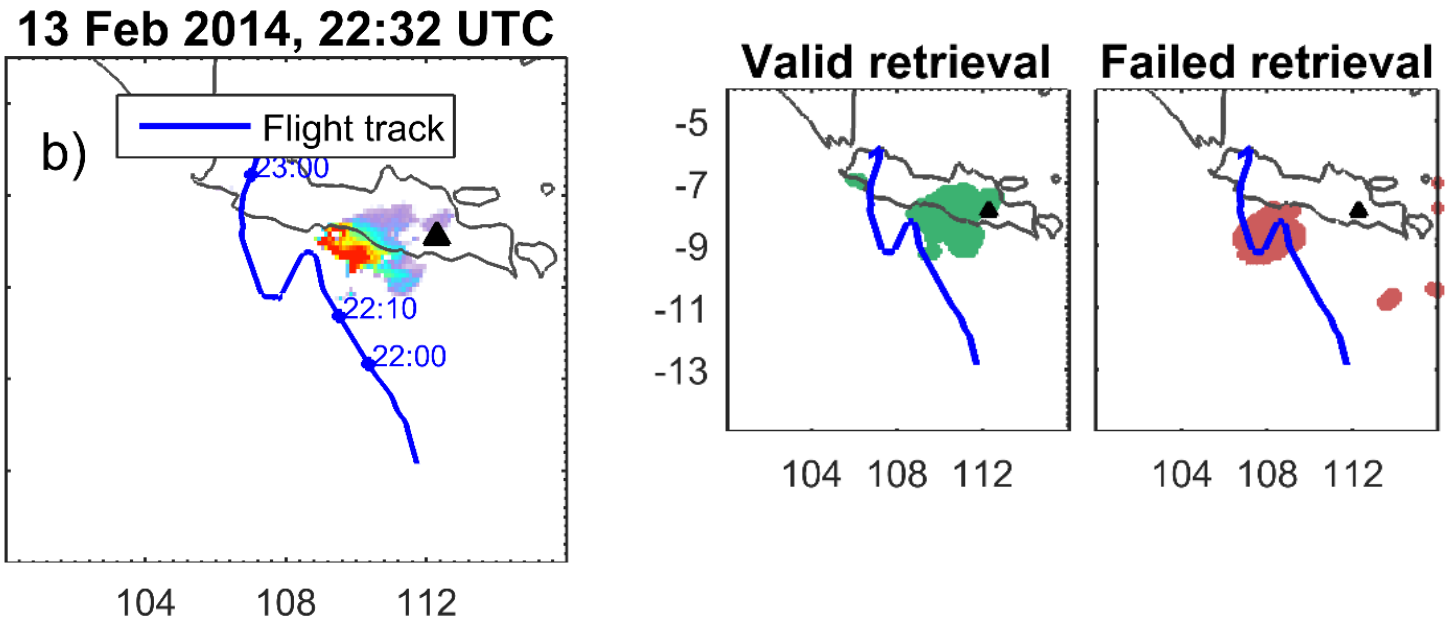
Aircraft encounter “seen” from MTSAT



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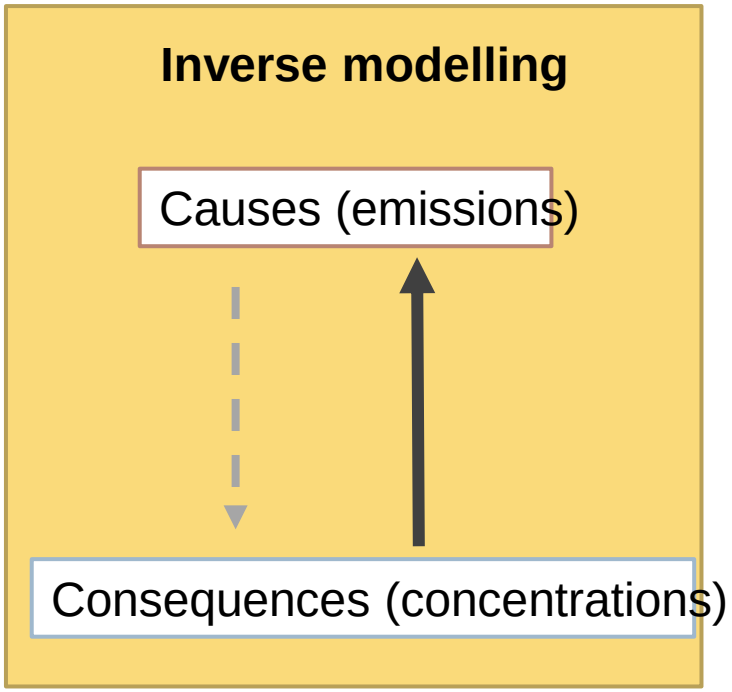
Can modelling help?

Dispersion modelling is crusially 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?

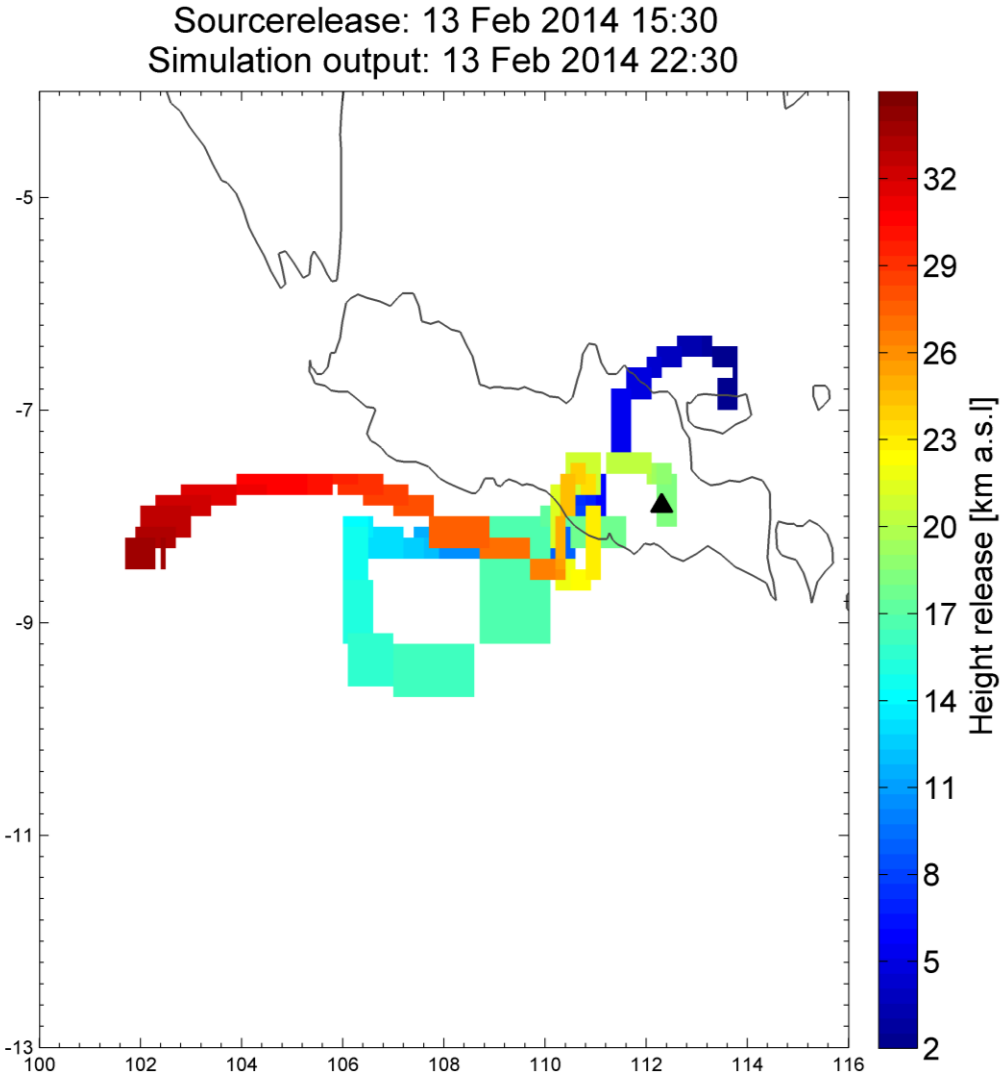


Source term inversion:

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

$$\mathbf{M}\ \mathbf{x} = \mathbf{y^o}$$

Unknown source

M: Model sensitivities (g/m^2)

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

$\mathbf{y^o}$: Satellite observations (g/m^2)

One-hourly MTSAT ash mass loading retrievals

Flags: valid/failed retrieval

Eckhardt, S., A. J. Prata, P. Seibert, K. Stebel, and A. Stohl (2008), Estimation of the vertical profile of sulfur dioxide injection in the atmos-

Source term inversion:
Combining model, satellite and a priori

$$\mathbf{M}(\mathbf{x} - \mathbf{x}^{\mathbf{a}}) \approx \mathbf{y}^{\mathbf{o}} - \mathbf{M}\mathbf{x}^{\mathbf{a}}$$

Unknown source

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]
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$\mathbf{y}^{\mathbf{o}}$: Satellite observations (g/m²)

One-hourly MTSAT ash mass loading retrievals

Flags: valid/failed retrieval

***$\mathbf{x}^{\mathbf{a}}$**: a priori*

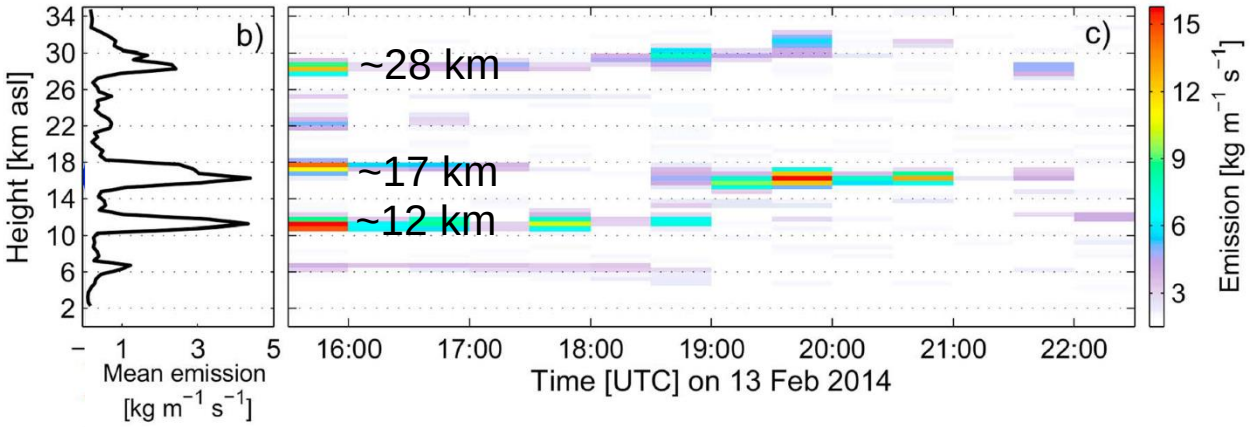
1.5 Tg fine ash (from "poor-mans inversion")

Distributed uniformly in time and height.

Very large uncertainty

Eckhardt, S., A. J. Prata, P. Seibert, K. Stebel, and A. Stohl (2008), Estimation of the vertical profile of sulfur dioxide injection in the atmos-

Satellite-constrained *fine ash* source term



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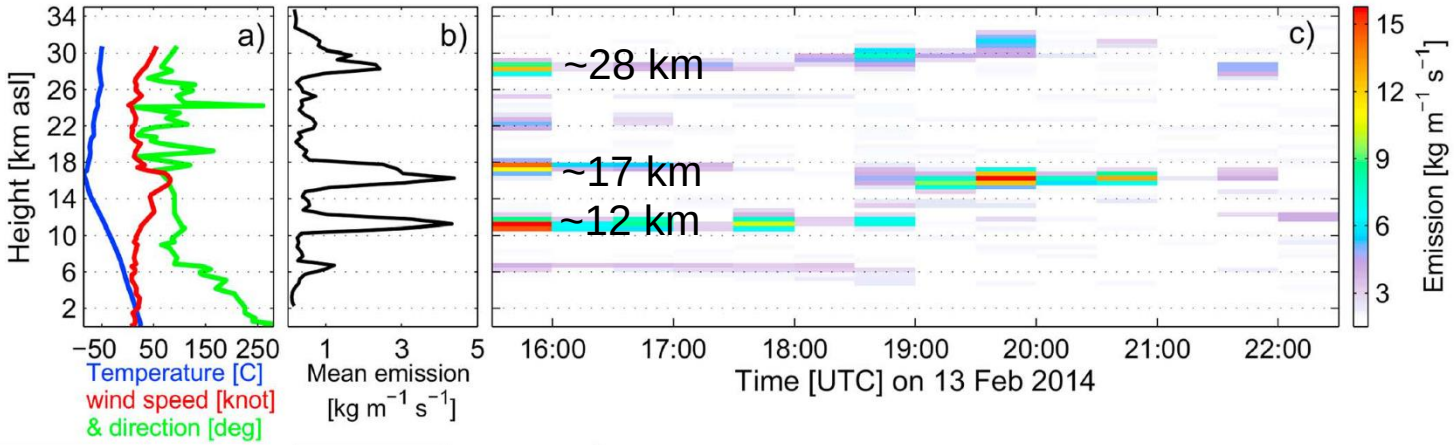

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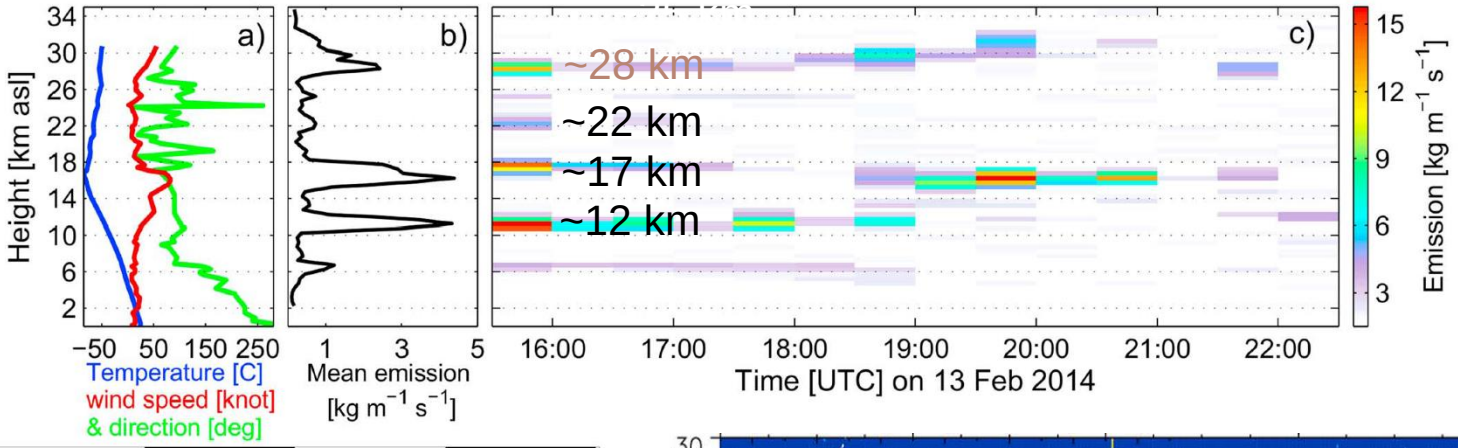
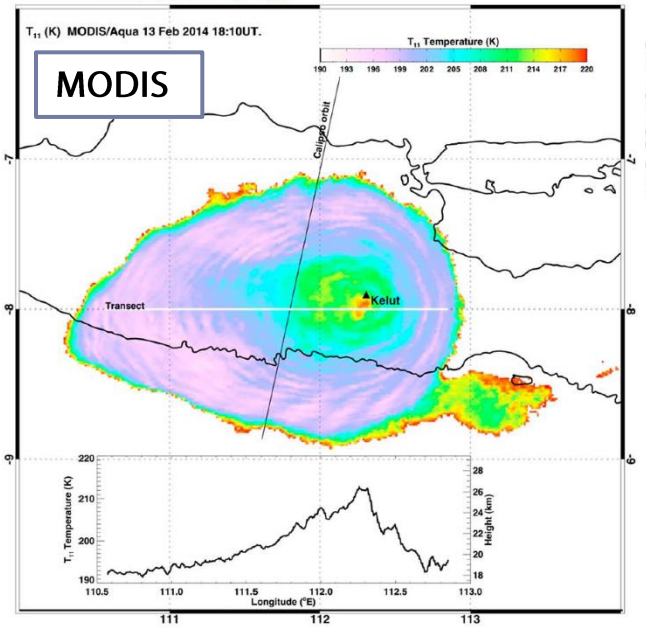
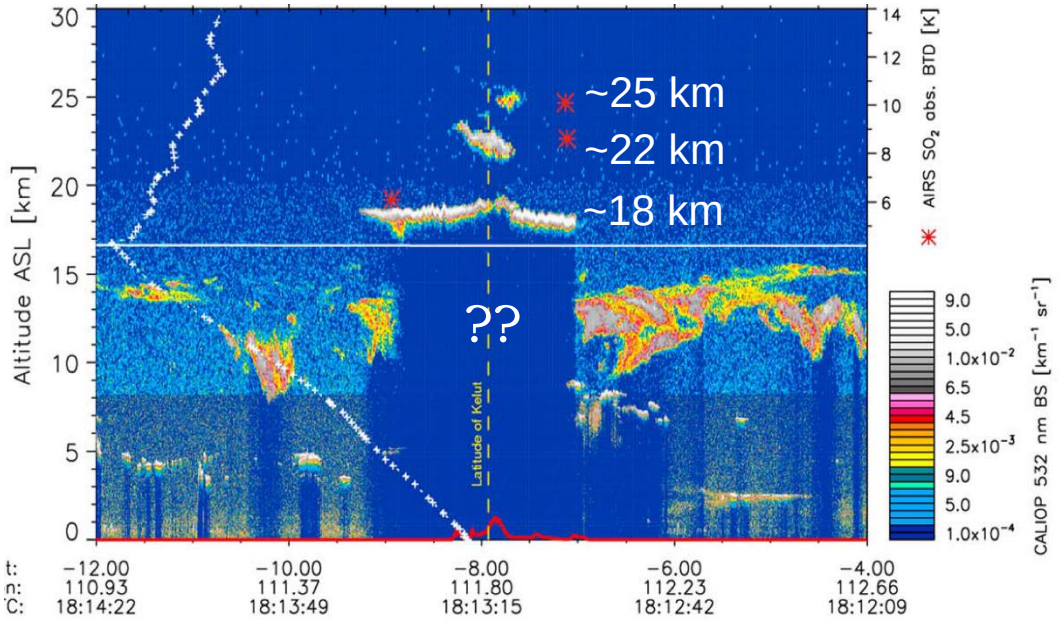
Comparison to CALIOP







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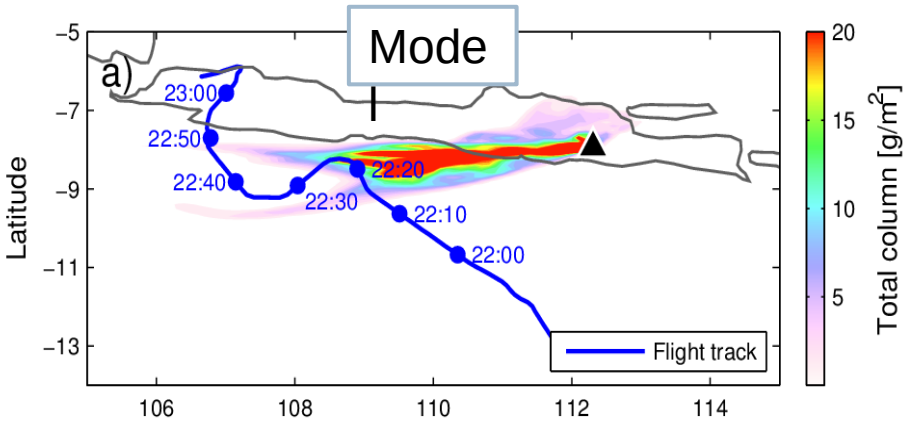
Modelling the aircraft encounter



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

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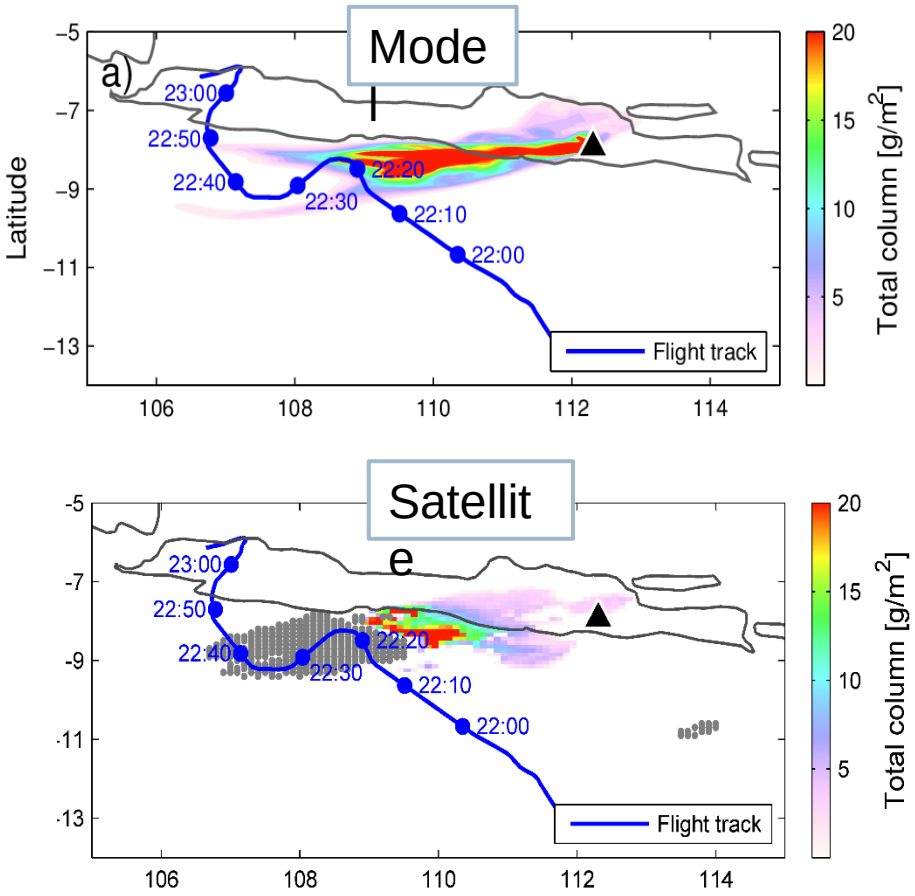

The inversion locates some ash in the western part only because this ash was observed elsewhere at a later time.

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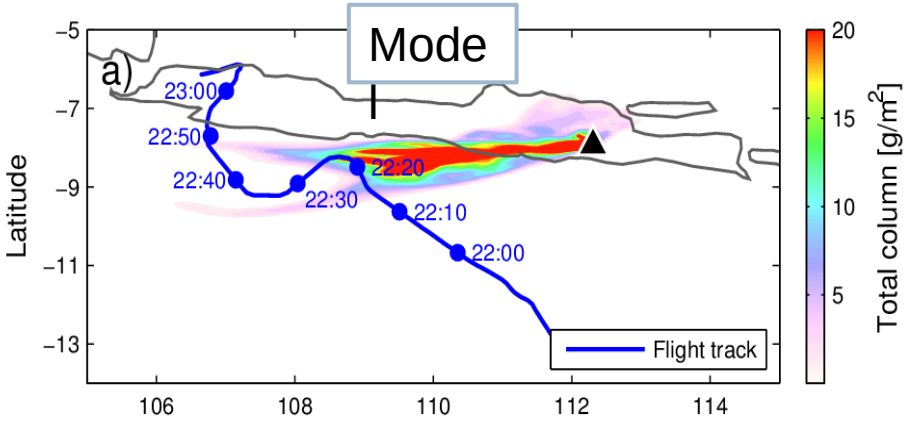

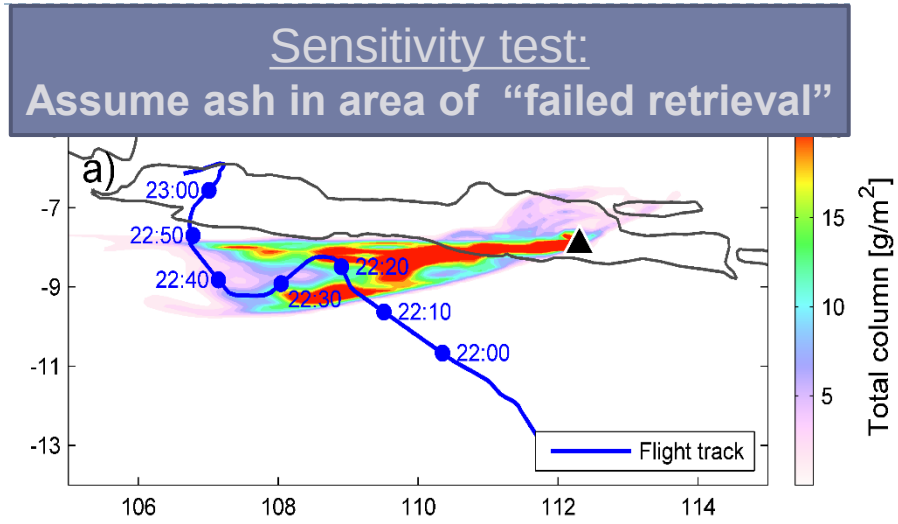

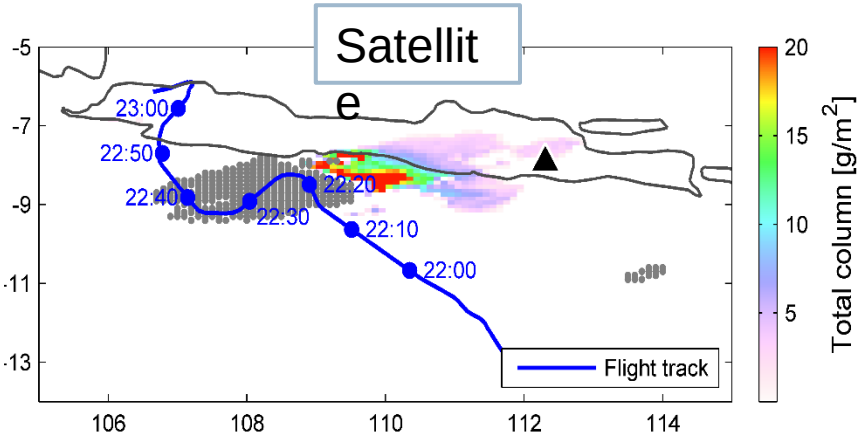

Other sensitivity tests for the inversion:

- Different amounts of satellite data
- Start and end time of assumed emission time period
- Assumed uncertainties
- Assumed ash particle size distribution

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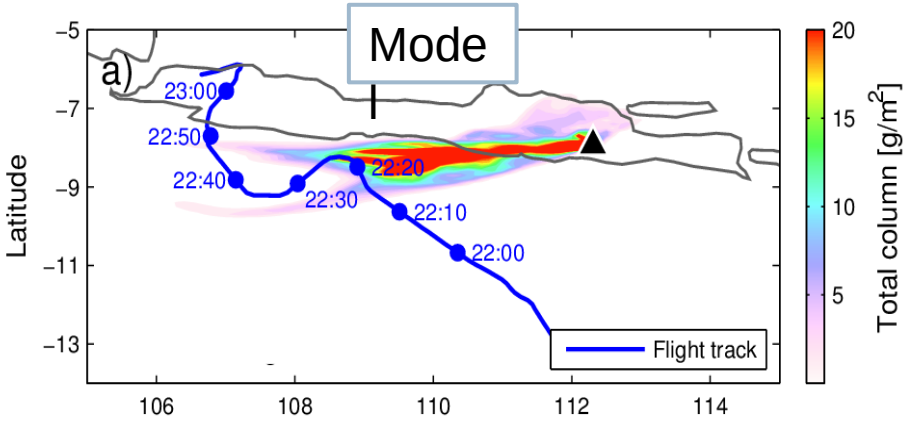

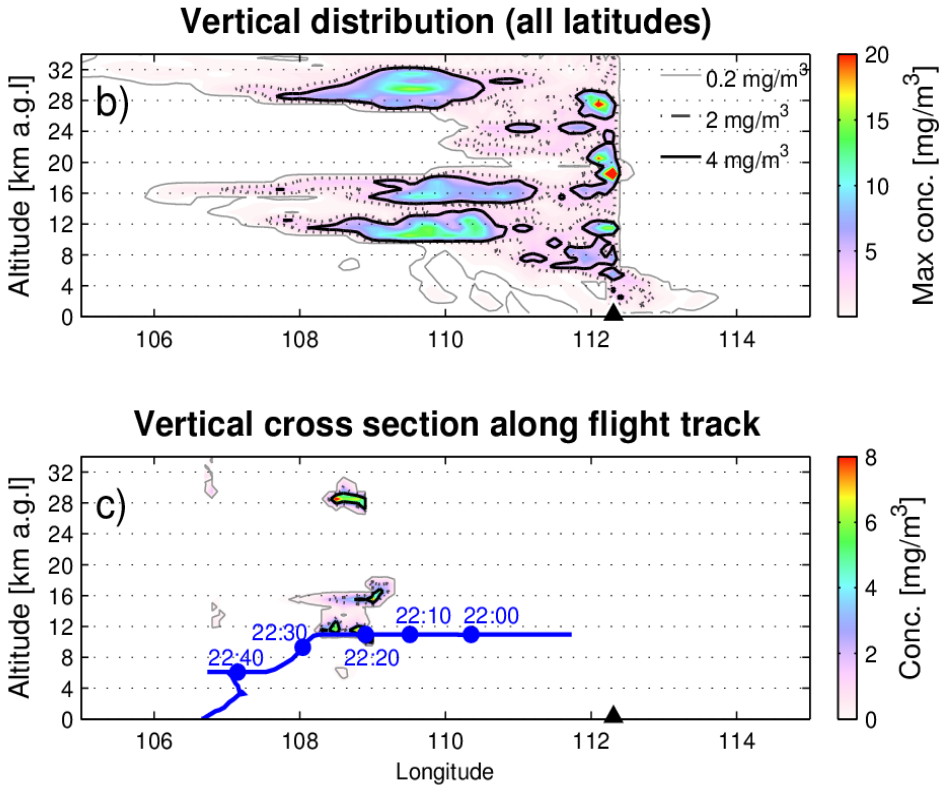

Modelling suggests that **the aircraft flew below the main ash cloud**

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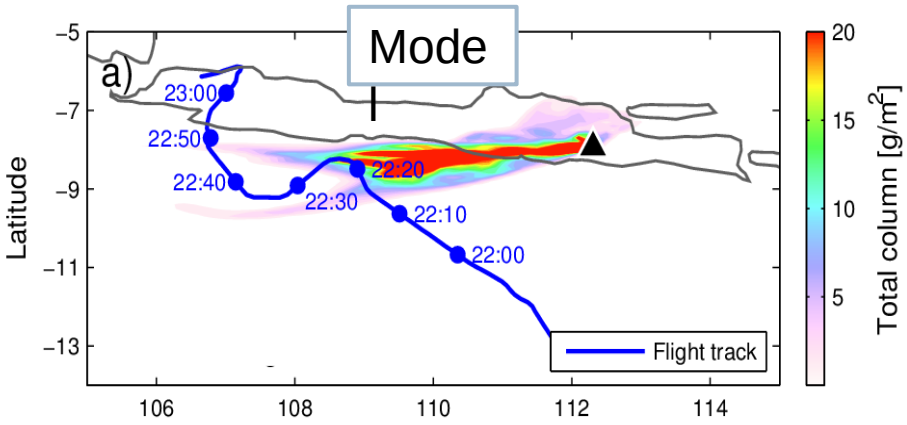

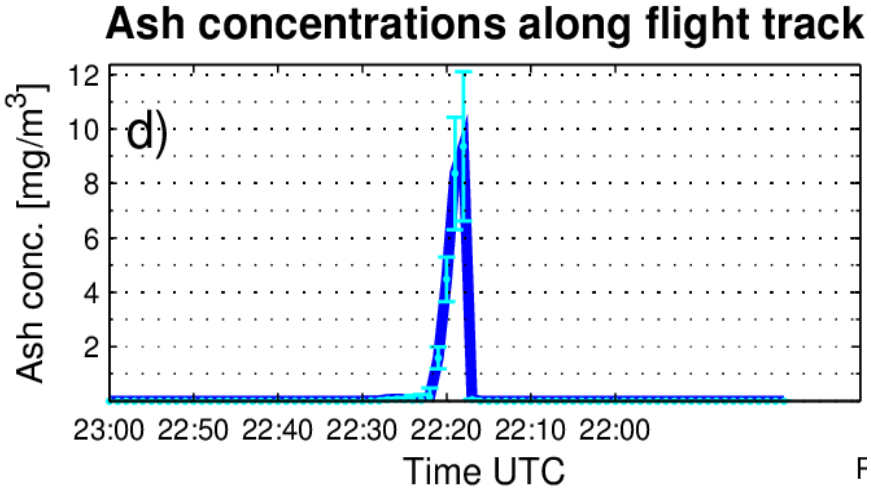

Modelling suggests the aircraft flew in areas with **ash concentrations up to 9-12 mg/m^3 over a period of 10-12 min**

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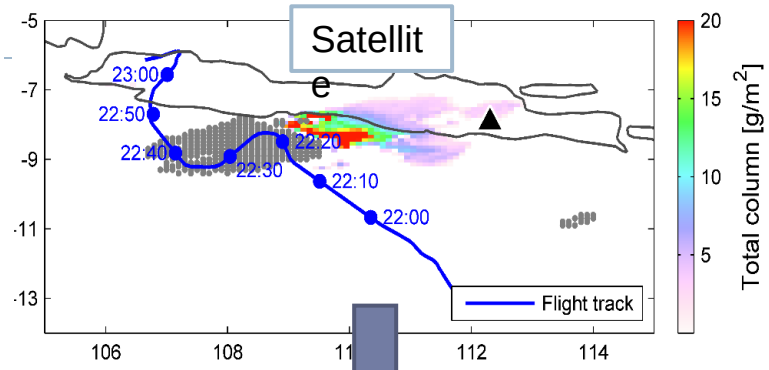
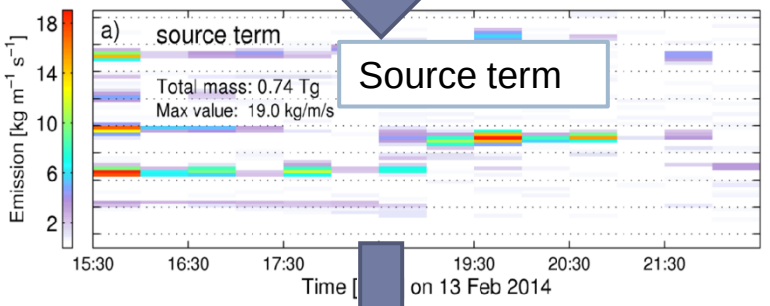
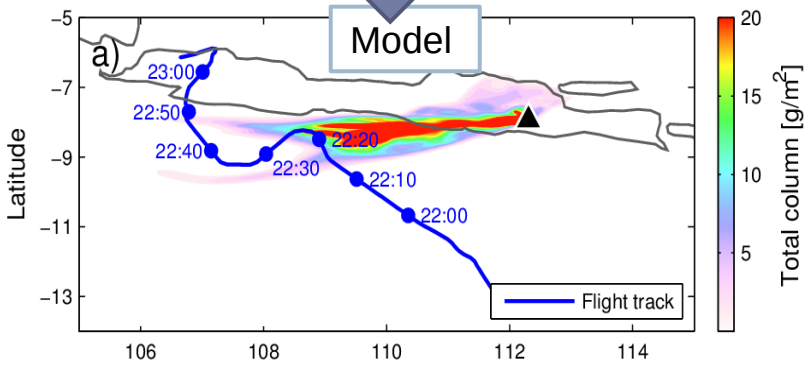
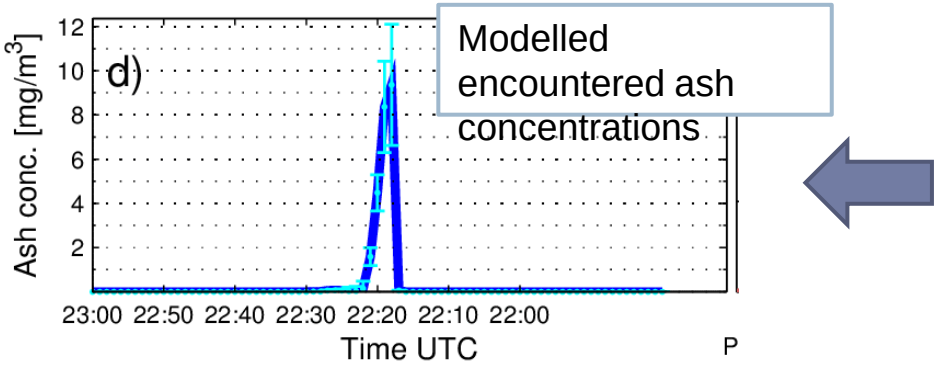
Key point

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









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SAMFERDSELSDEPARTEMENTET

AVINOR

Thank you

esa

Universität Bremen
BCKU
INGV
Met NILU
SAVAA
Support to Aviation for Volcanic Ash Avoidance
esa

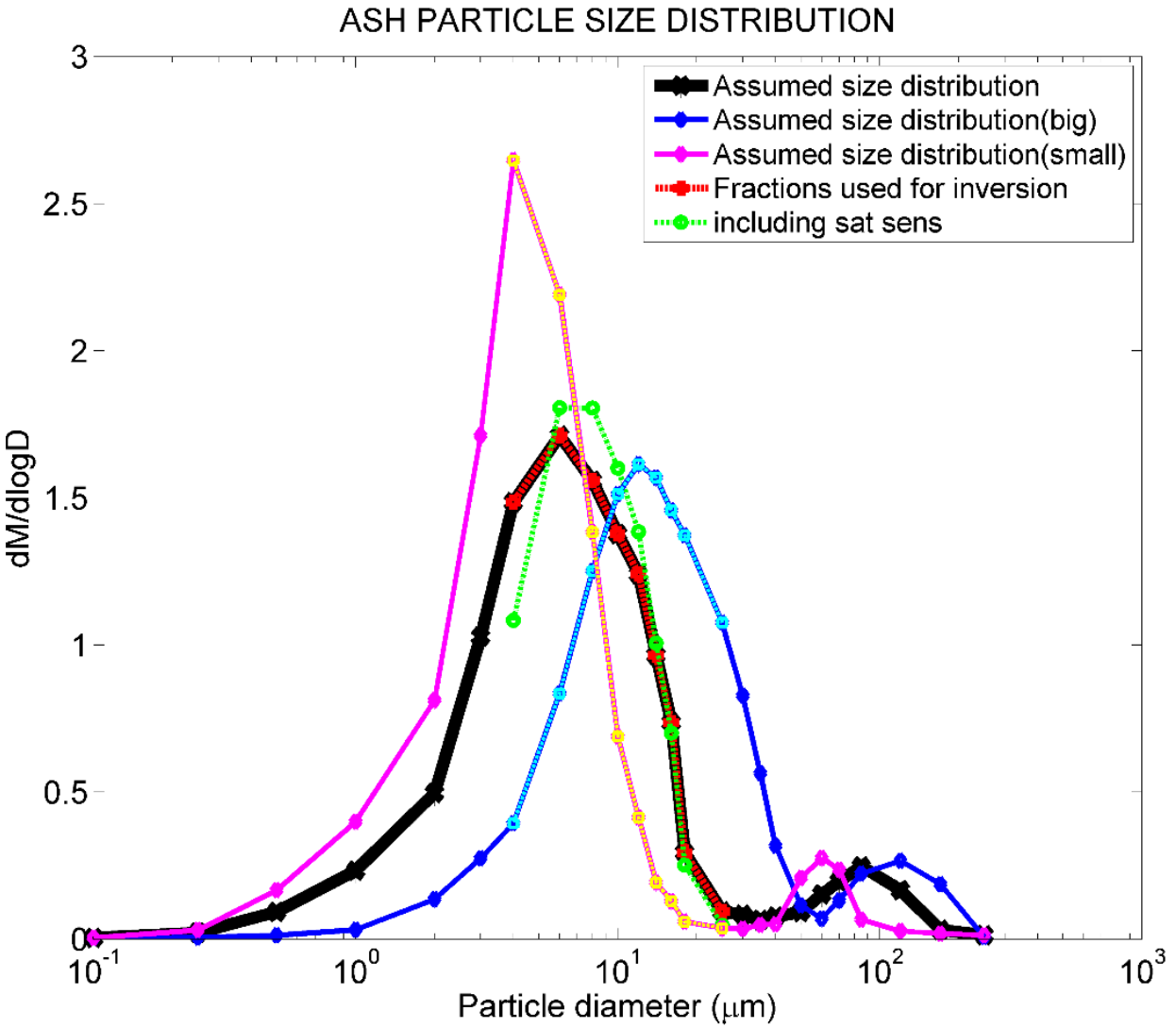
vast
volcanic ash strategic initiative team

? Questions

Contact: nik@nilu.no

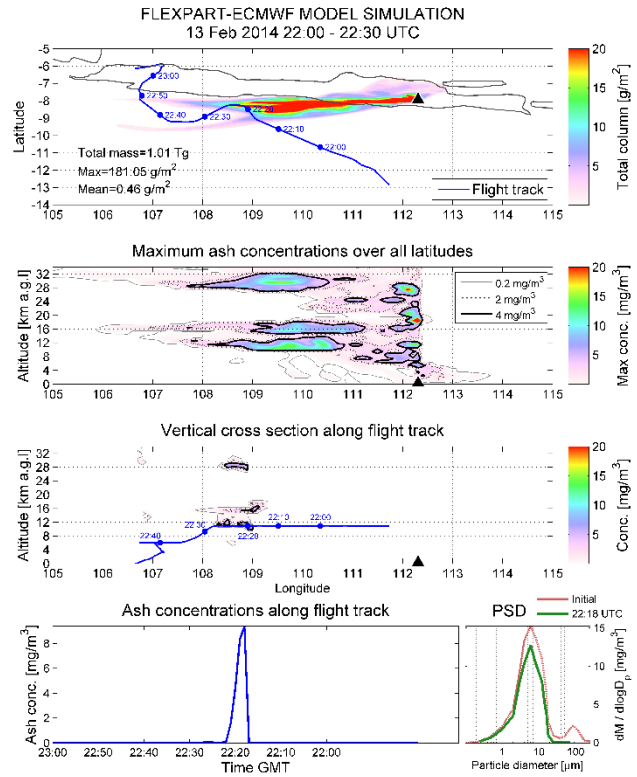
Additional slides

Sensitivity to assumed particle size distribution

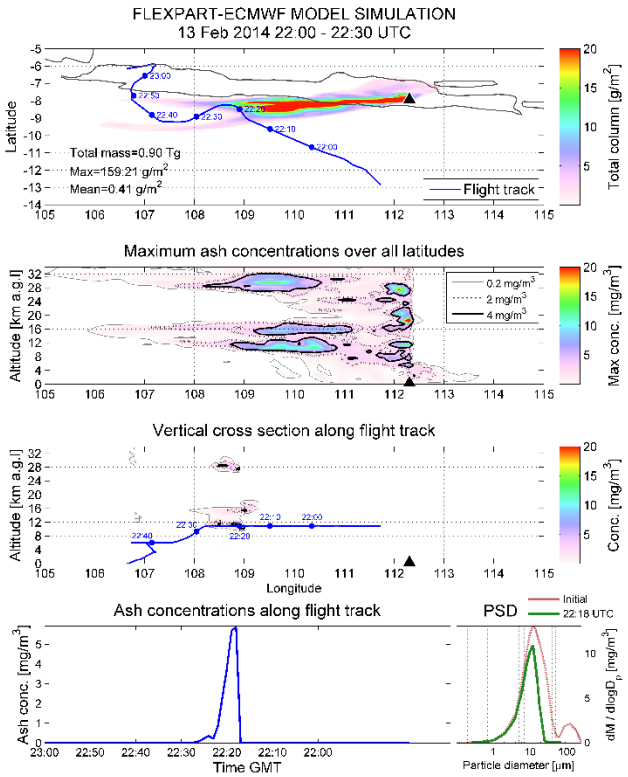


Sensitivity to assumed particle size distribution

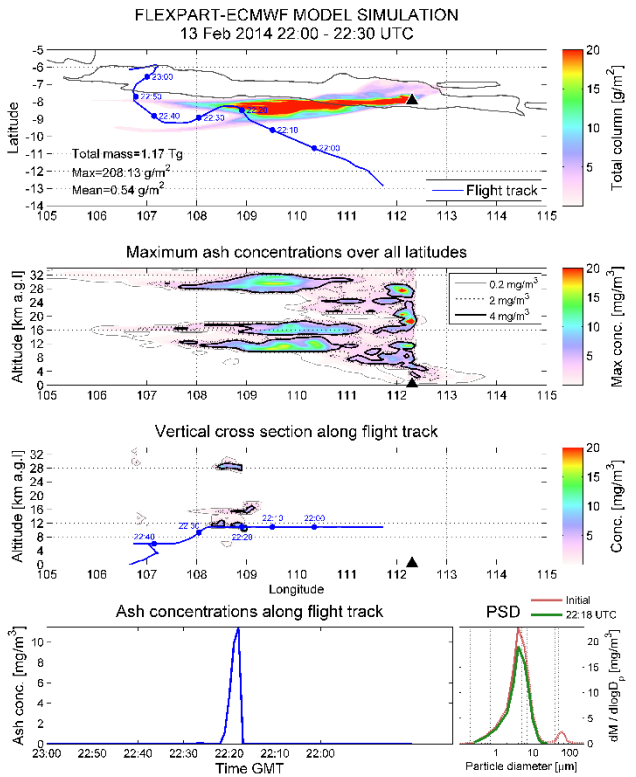
DEFAULT PSD



BIG PSD



SMALL PSD



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 adjusements 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