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Use of inverse and ensemble modelling techniques for improved volcanic ash forecasts

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Introduction

Aim is to highlight ongoing research at the Australian Bureau of Meteorology focussed on improving volcanic ash forecasts by

- quantifying uncertainties in meteorological fields using ensembles
- improving the ash source term and quantifying uncertainties thereof using satellite observations

Will use the 13 February 2014 eruption of Kelut in Java, Indonesia, as a case study

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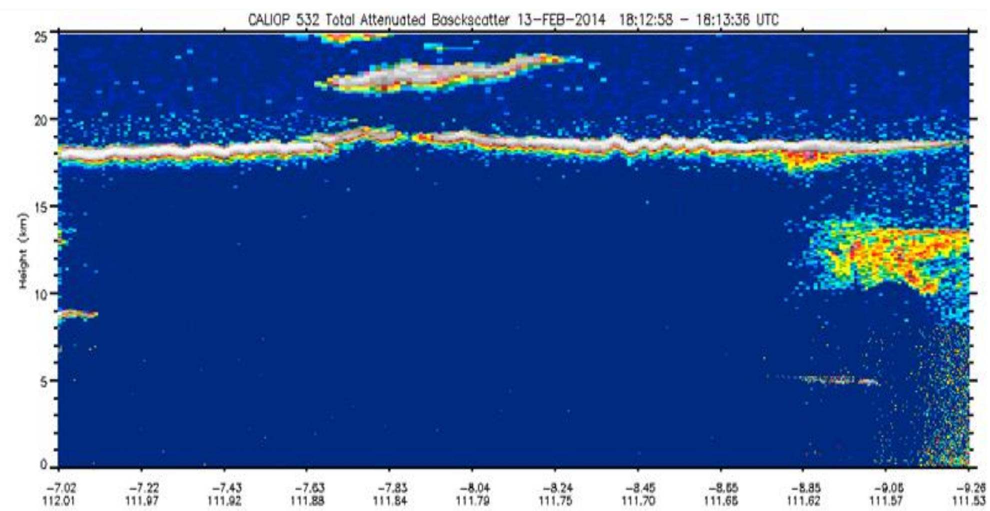
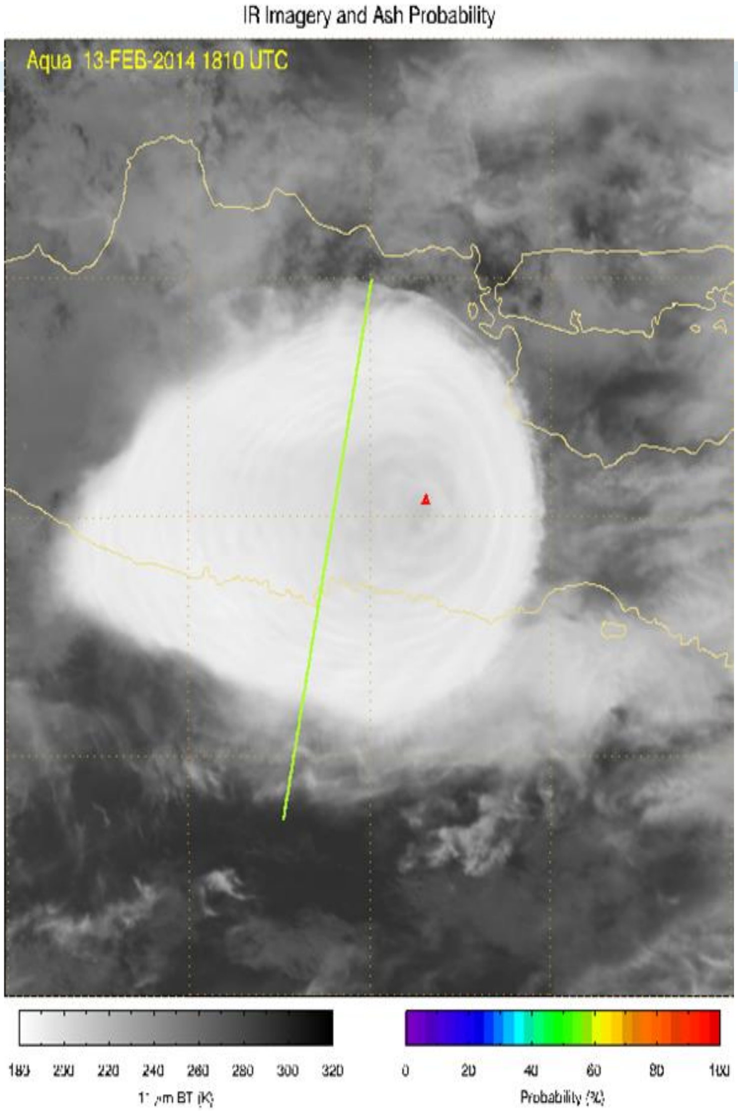
13 February 2014 Kelut eruption

Eruption commenced ~ 1600 UTC



- CALIPSO identifies ash at over 18 km with stratospheric ash reaching over 25 km
- How well can we forecast the locations of ash over 24 hours or so using meteorological ensembles?
- Can we deduce the ash profile using the MTSAT ash distribution alone?



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Dispersion ensemble prediction system

- Makes use of the Bureau's global ensemble model
  - Based on UK Met Office MOGREPS model
  - Employs ETKF and stochastic physics to generate perturbations
  - 24 ensemble members
- HYSPLIT run with each ensemble member to produce ensemble ash forecast
- Line source employed to 19 km

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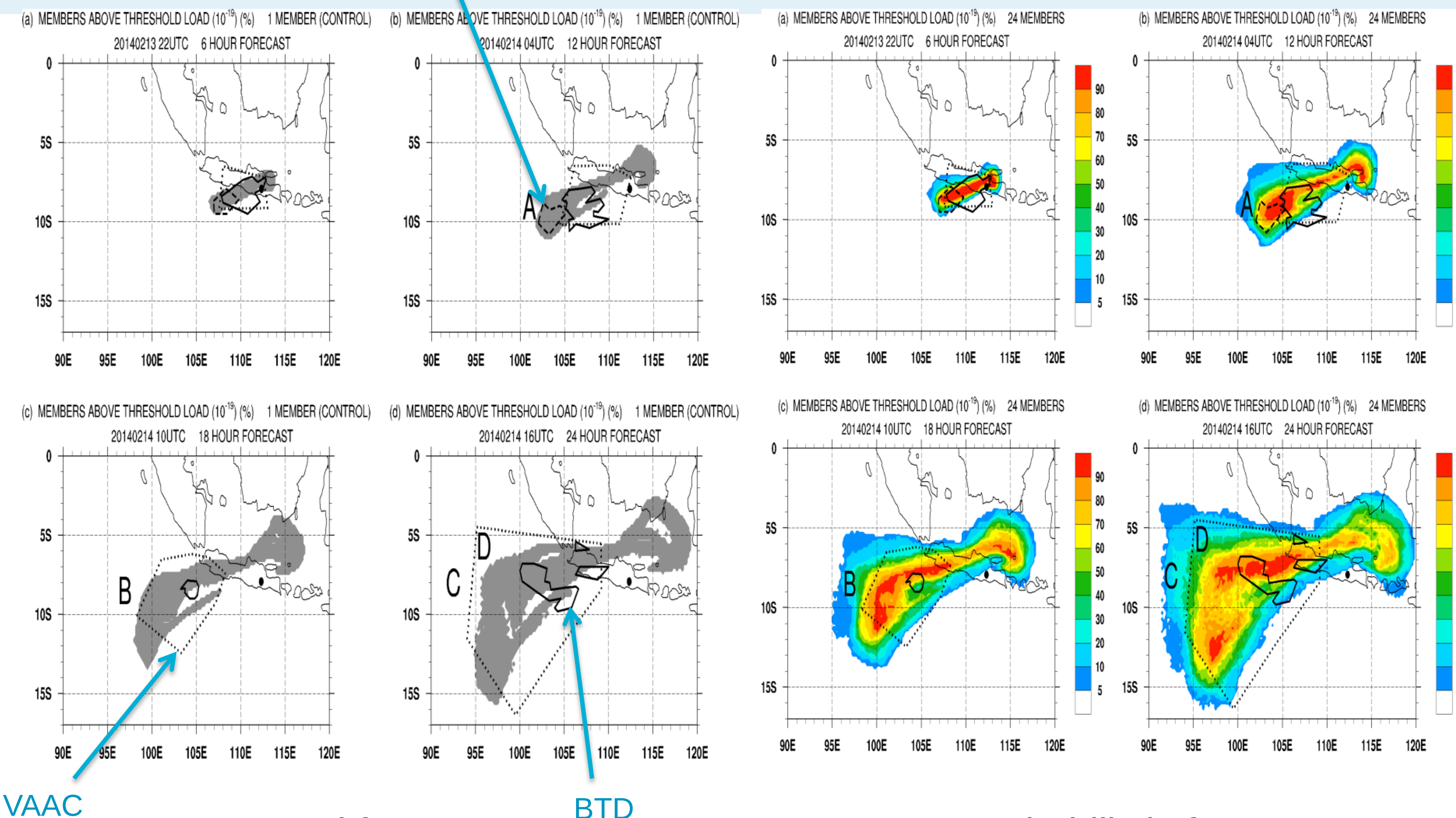
6-24 hour forecasts

Dare, R.A., D.H. Smith, and M.J. Naughton, 2015: Ensemble prediction of the dispersion of volcanic ash from the 13 February 2014 eruption of Kelut, Indonesia. Journal of Applied Meteorology and Climatology (accepted).



Control forecast

Probabilistic forecast

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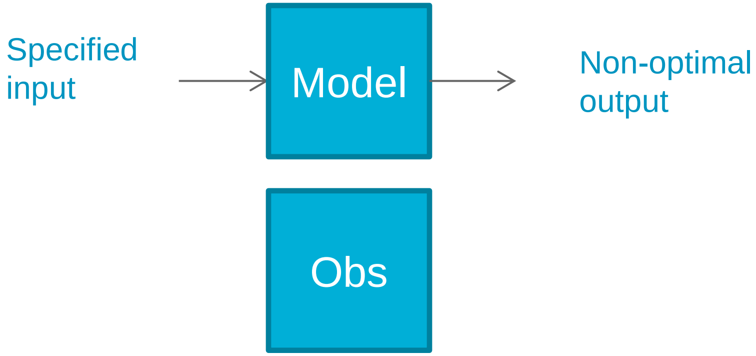
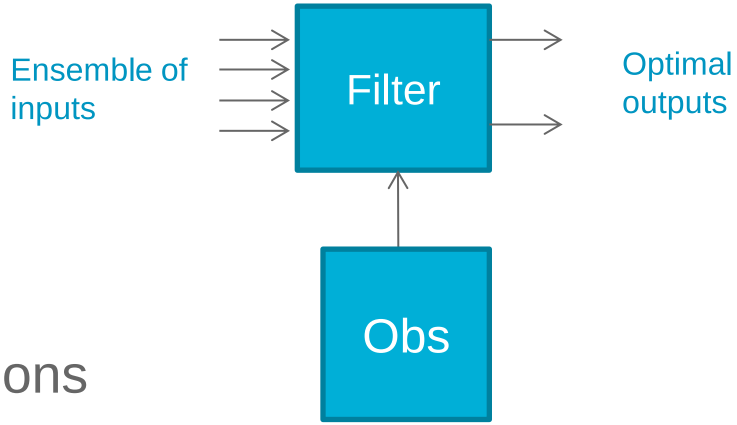
Inverse modelling approach for source term

OLD PARADIGM



NEW PARADIGM



In the new paradigm observations are directly integrated into the modelling process using an inverse model

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Inverse modelling algorithm

- A grid of all possible values of the model parameters (represented by **p**) is formed
- Pattern correlations are used as a measure of model agreement with observations for all gridded parameter values

$$r(\boldsymbol{p}) = \frac{\sum_{i=1}^{i=N}(x_i(\boldsymbol{p}) - \bar{x}(\boldsymbol{p}))(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{i=N}(x_i(\boldsymbol{p}) - \bar{x}(\boldsymbol{p}))^2}\sqrt{\sum_{i=1}^{i=N}(y_i - \bar{y})^2}}$$

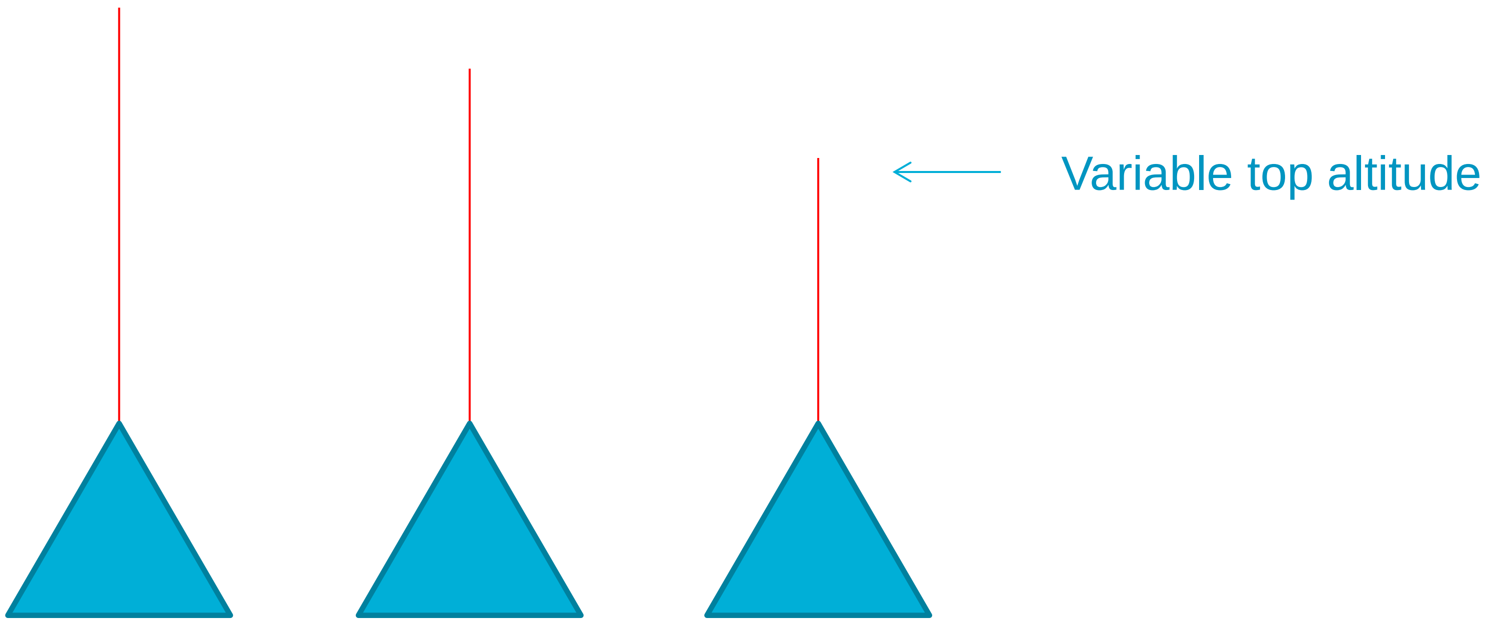
Model

Obs

- In the deterministic scheme, parameters yielding highest pattern correlations are chosen as the solution
- In the probabilistic scheme, parameters yielding pattern correlations above a specified threshold are chosen as members of the solution ensemble

Source top estimation

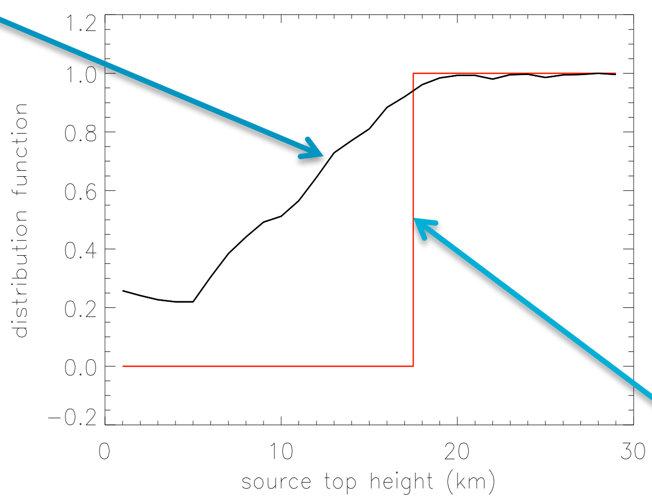
Line source extending from summit with uniform mass distribution



Inverse model results (source top)

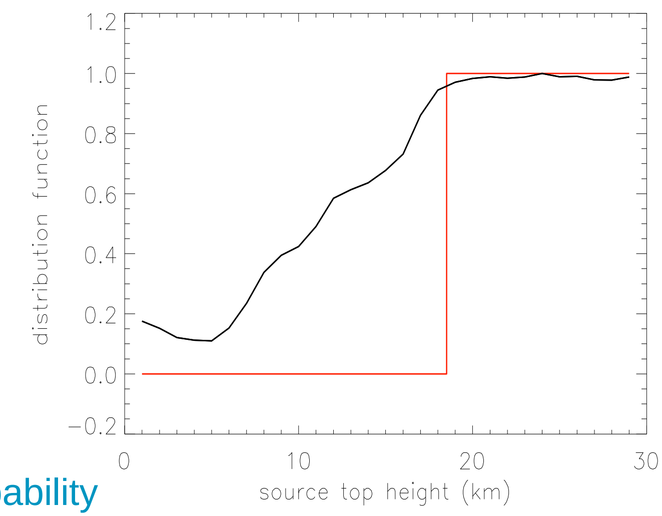
Time (UTC)	1630	1730	1830	1930	2030	2130	2230
Top altitude (km)	20.0	23.0	28.0	29.0	22.0	24.0	24.0
Pattern corr.	0.84	0.76	0.72	0.77	0.79	0.78	0.71

Scaled pattern correlation



1830 UTC analysis

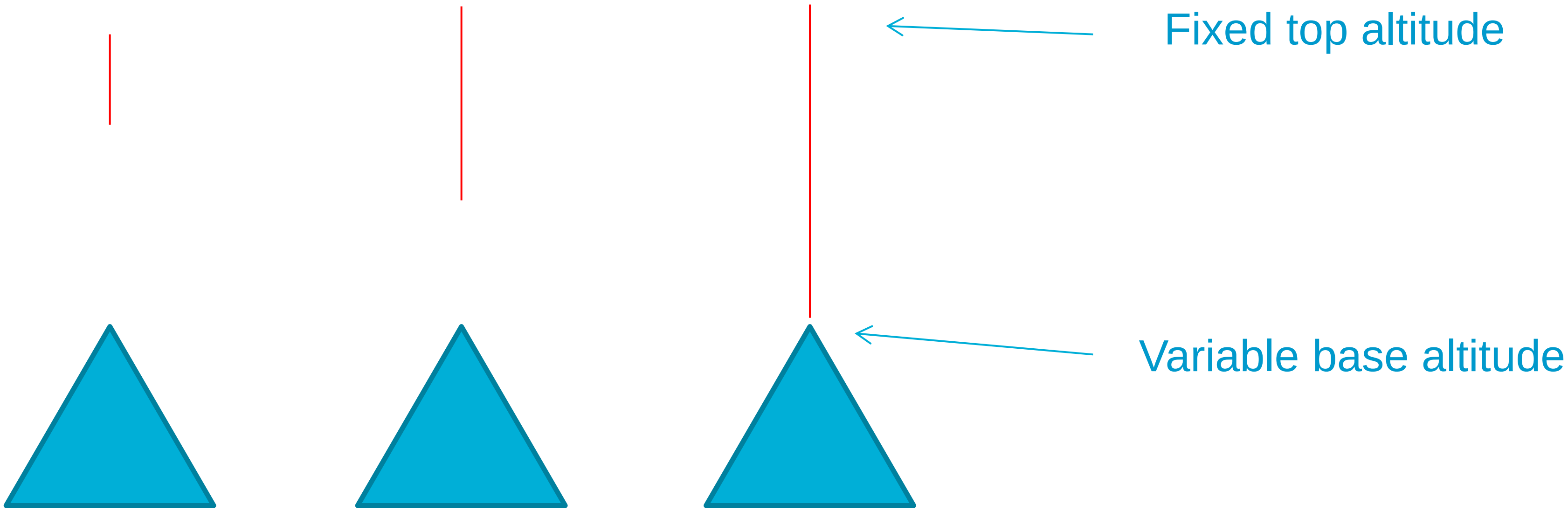
Discrete probability distribution



2230 UTC analysis

Source base estimation

Line source with non-uniform mass distribution



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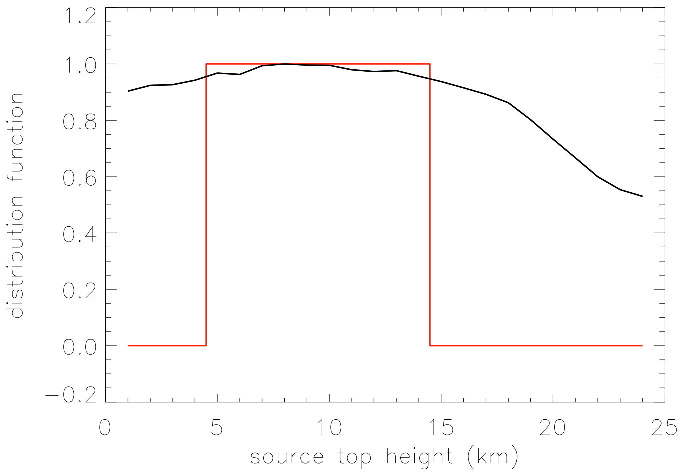
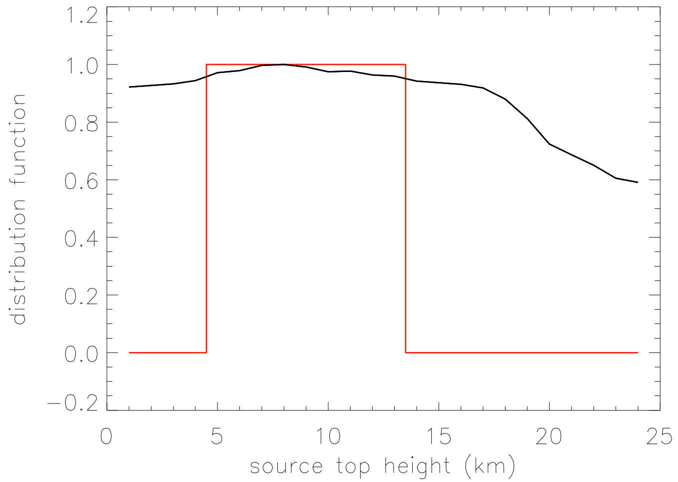
Using inverse model to infer source base altitude

Time (UTC)	1630	1730	1830	1930	2030	2130	2230
Bottom altitude (km)	6.0	6.0	8.0	7.0	7.0	7.0	8.0
Pattern corr.	0.88	0.78	0.78	0.82	0.82	0.81	0.75



1830 UTC analysis



2230 UTC analysis

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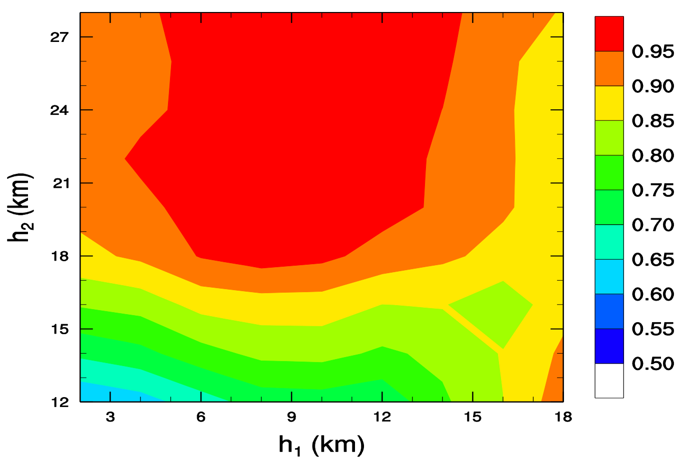
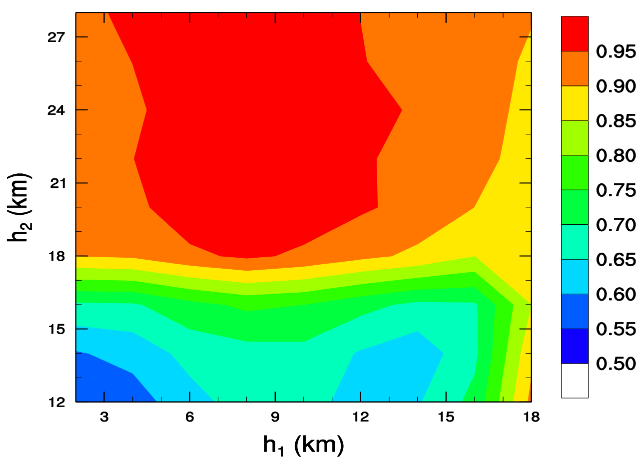
Two-dimensional inversion

Time (UTC)	1630	1730	1830	1930	2030	2130	2230
Base altitude (km)	8.0	6.0	8.0	6.0	6.0	8.0	8.0
Top altitude (km)	20.0	24.0	22.0	26.0	26.0	22.0	26.0
Pattern corr.	0.89	0.79	0.78	0.82	0.82	0.81	0.75

1830 UTC analysis

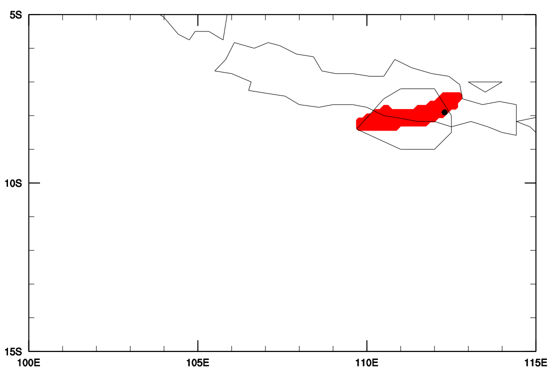


2230 UTC analysis

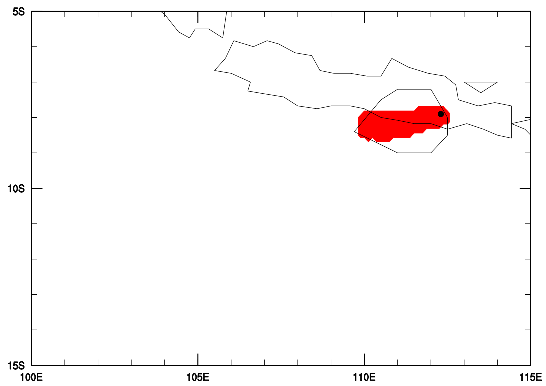


Umbrella cloud

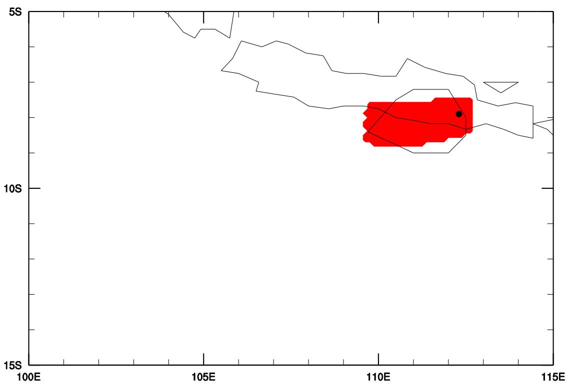
Line source

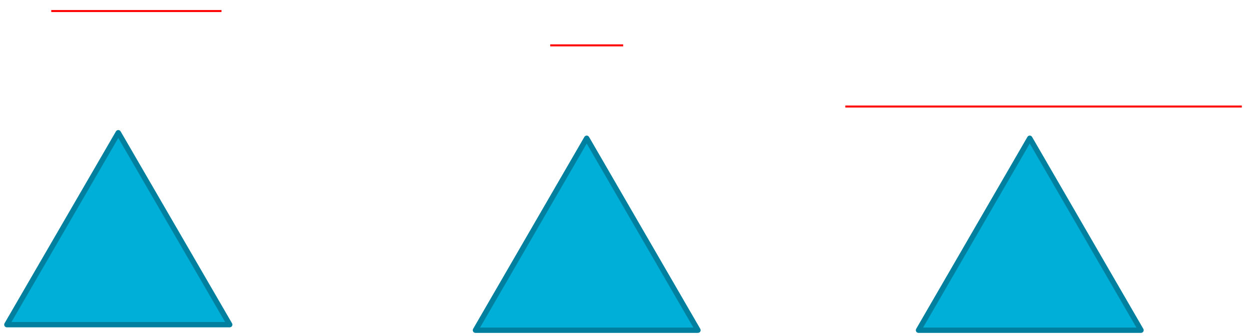


100 km 'disc'



200 km 'disc'

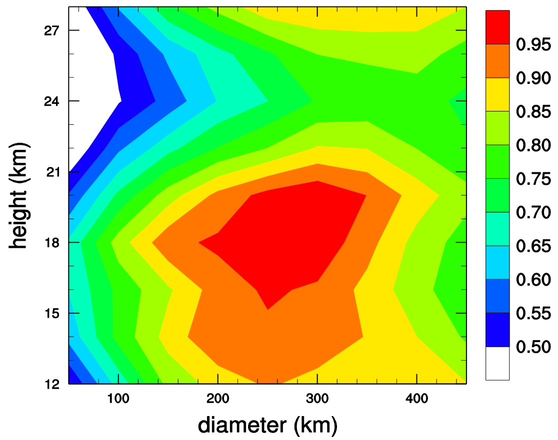




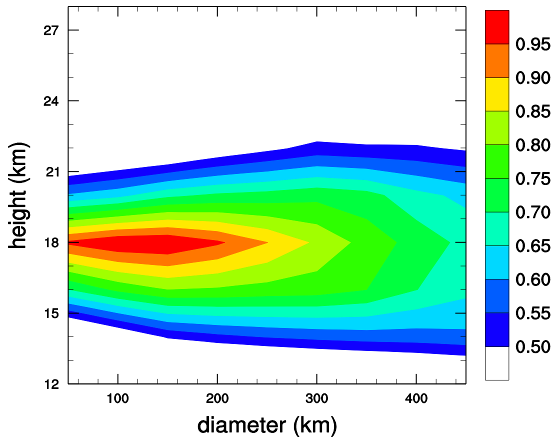
Vary source altitude and diameter

Umbrella cloud 2D inverse model

Time (UTC)	1630	1730	1830	1930	2030	2130	2230
altitude (km)	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Diam. (km)	100.0	250.0	250.0	250.0	250.0	200.0	150.0
Pattern corr.	0.82	0.84	0.83	0.80	0.87	0.83	0.74



1830 UTC



2230 UTC

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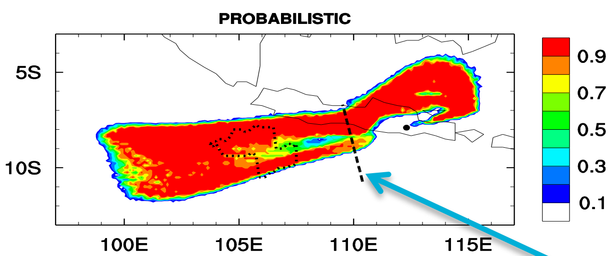
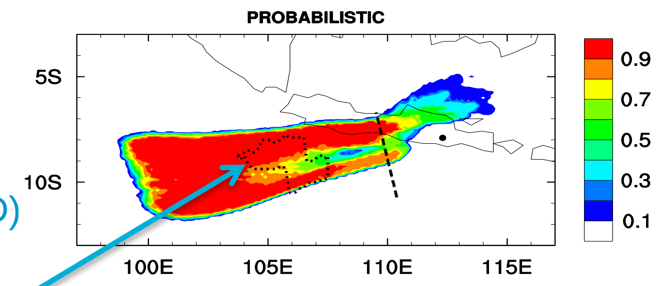
Ash forecasts (14/0630 UTC) from 13/1830 UTC analyses compared



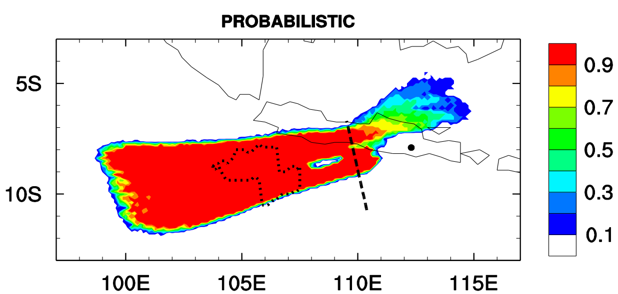
Uniform mass distribution (1D)

Non-uniform mass distribution (2D)



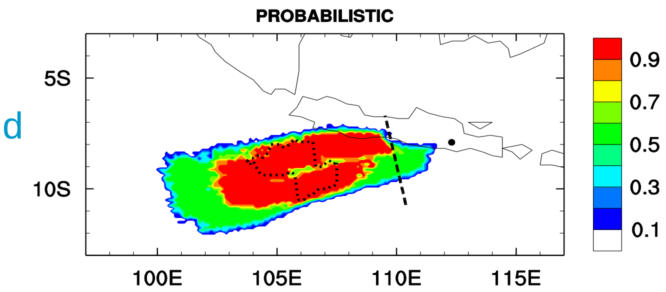
VOLCAT ash detection

CALIPSO track



Non-uniform Mass distribution (1D)

Umbrella cloud (2D)



Forecasts of ash probabilities at 14/0630 UTC based on different analyses at 13/1830 UTC

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Conclusion

- Have shown that the meteorological ensemble increases spread of ash forecasts, leading to better agreement with observations
- Have shown that top altitude of ash column can be estimated quite well with inverse model – generally > 20 km consistent with CALIPSO
- Have shown that low-altitude cut-off can also be estimated – generally about 6-8 km here – which is a crude model of non-uniform vertical emission rates
- Have shown that the inversions can be performed simultaneously i.e. 2D inversion
- Have shown that umbrella cloud span (diameter) may be estimated. Generally > 100 km in this case
- Have demonstrated the importance of quantifying uncertainties via a probabilistic description.

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Future work

- Integrate inverse modelling of source term with meteorological ensemble model
- Introduce continuous variations into emission profile by making use of VOLCAT mass loading retrievals
- Estimate optimal particle size distributions
- ETC

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Thank you…

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