Improving volcanic ash forecasting at the Bureau

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plus

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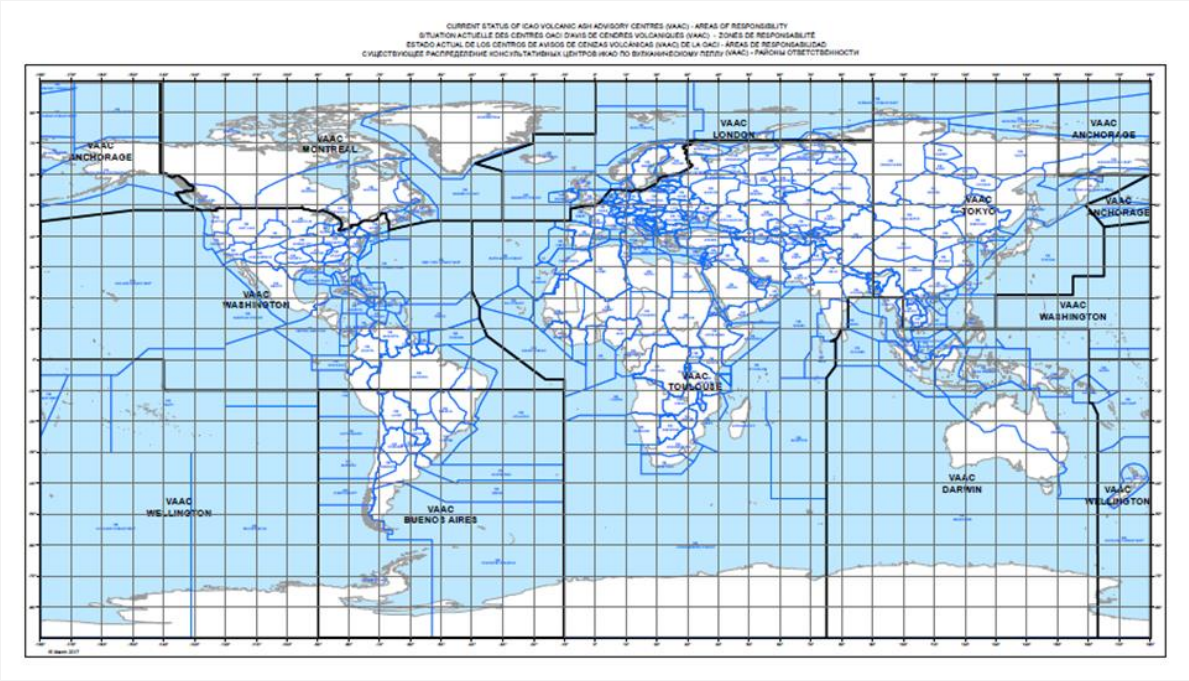
Motivation

- Volcanic Ash is dangerous to aircraft
  - Eyjafjallajökull 2010 re-emphasized impacts
- Volcanic Ash Advisory Centres (VAAC)
- Some 'dosage' of volcanic ash is safe
- Aviation Industry wants
  - Timely detections of eruptions/ash cloud
  - 4-d characteristics (x, y, z, t) of VA cloud
  - Amount of ash in cloud (quantitative)
  - Uncertainty information
- Initial quantitative advice in 2023, mandatory in 2026 (pending approval from MET panel)
- These are hard problems…volcanoes sporadic, few *in situ* observations of ash amounts, many large uncertainties, much variance

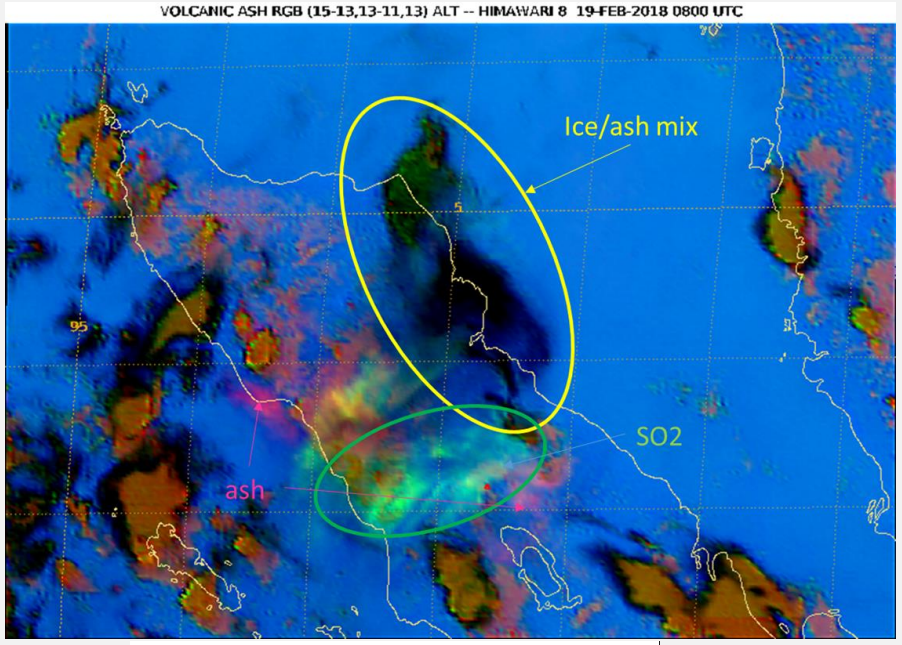


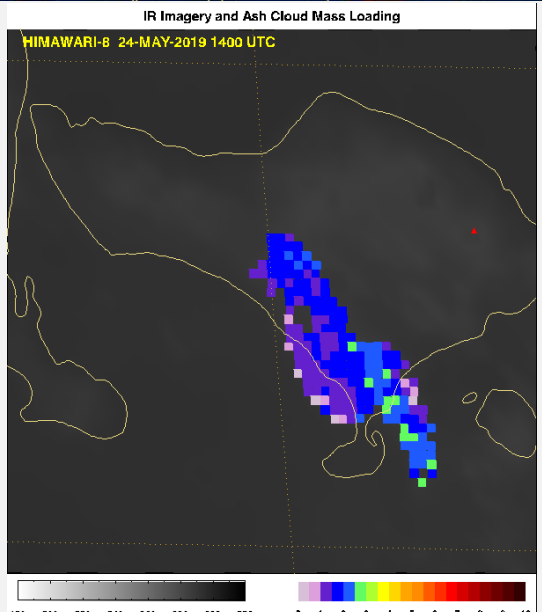
Proposed Concentration Thresholds for Ash

Threshold	Ash Concentration range (mg / m3)
Very Low	< 0.2
Low	0.2-2.0
Medium	2.0-5.0
High	5.0-10.0
Very High	> 10.0

Detecting and characterizing eruptions

- Satellite data is key element required to detect volcanic eruptions in time manner
- RGB composite imagery crucial
- In some circumstances, quantitative retrievals are possible
  - Cloud height, Mass loading, Particle size
- NOAA VOLCAT package currently being implemented
  - State of art automated detection and retrievals
- Significant uncertainties remain in retrievals
- **A key parameter for the modelling and prediction is the height of the volcanic plume**





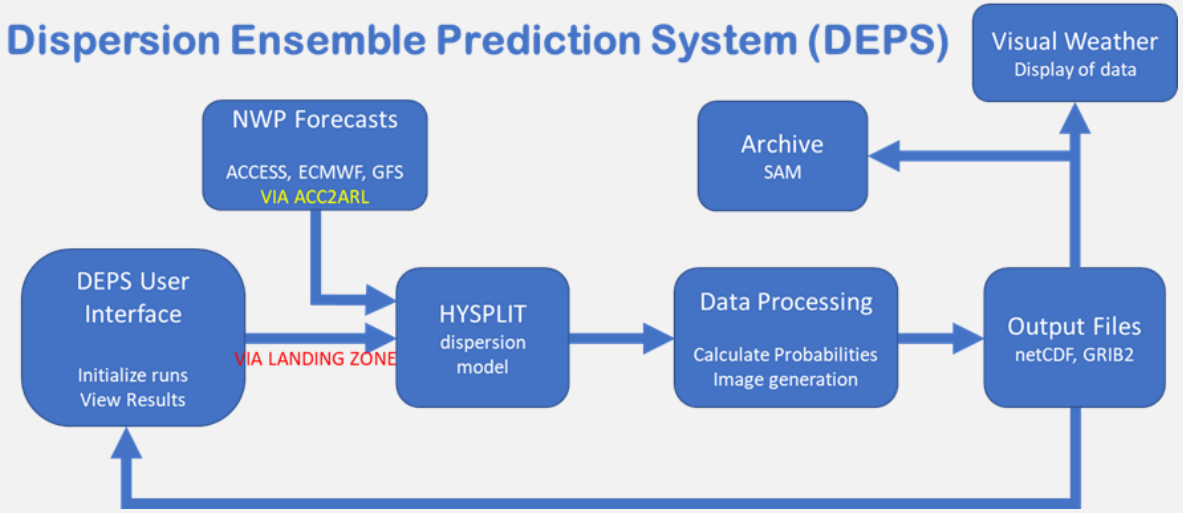
Dispersion Ensemble Prediction System

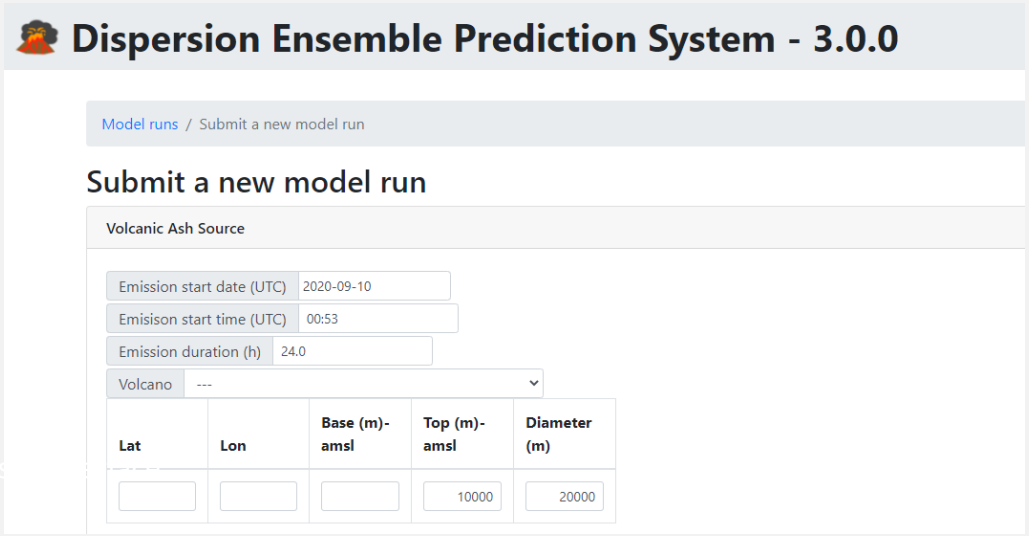
A ensemble-based dispersion model for real-time prediction of volcanic ash plumes. Captures **meteorological** uncertainty.

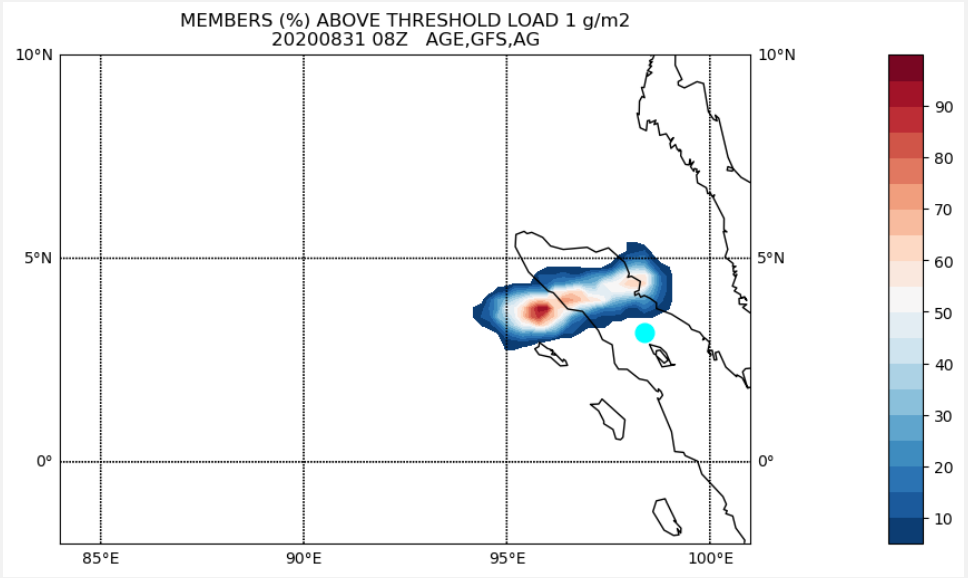
Primarily based on ACCESS GE3 (36 members)

Formally Operationalized in May 2020

It's the first operational system of its type in the world







Example Result – Sinabung (N Sumatra) 31 August 2020

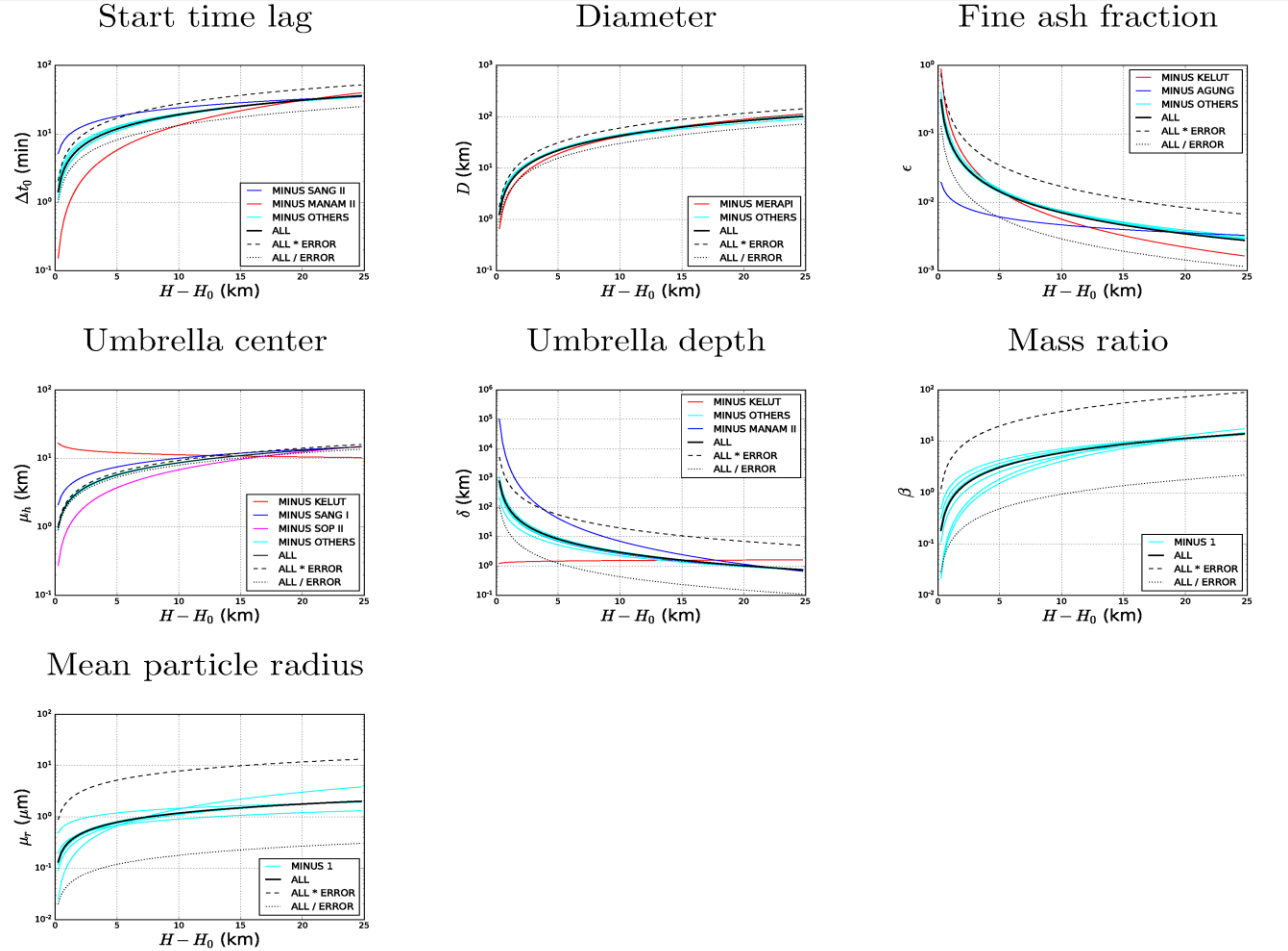
DEPS 2 – Improving DEPS with observations

- The most significant source of uncertainty in volcanic ash forecasting lies in identifying the characteristics of the source term
  - How high is plume? How much ash is there? How deep is the plume?
  - Even when there is a measurement, there is still a great deal of uncertainty

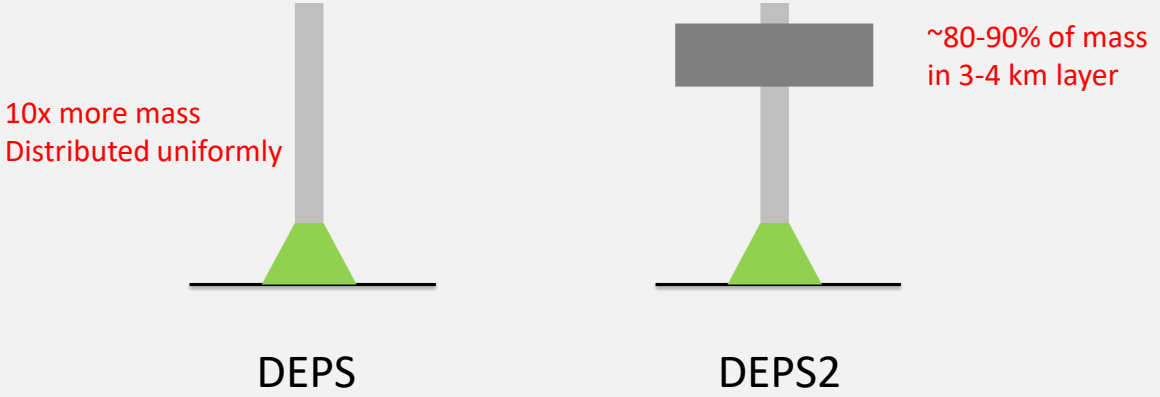
- DEPS 2 is more sophisticated in that it uses observations of the ash cloud in conjunction with many dispersion model simulations to identify the set of model parameters/ensemble members that give the best match to the observation.
  - Data assimilation algorithm
  - Observations: VAAC polygons and/or quantitative satellite retrievals

- DEPS 2 also changes the way the eruption is initialized in the model
  - In standard practice (and DEPS), eruption is treated as uniform column

Defining the source term



- Quantitative retrievals from 14 eruptions combined with inverse modelling to identify 'best' parameters
- From these cases, use regression to identify power law fits as function of eruption height
- Estimation of error magnitudes and correlations (error covariance matrix)
- Use to construct analysis ensemble members



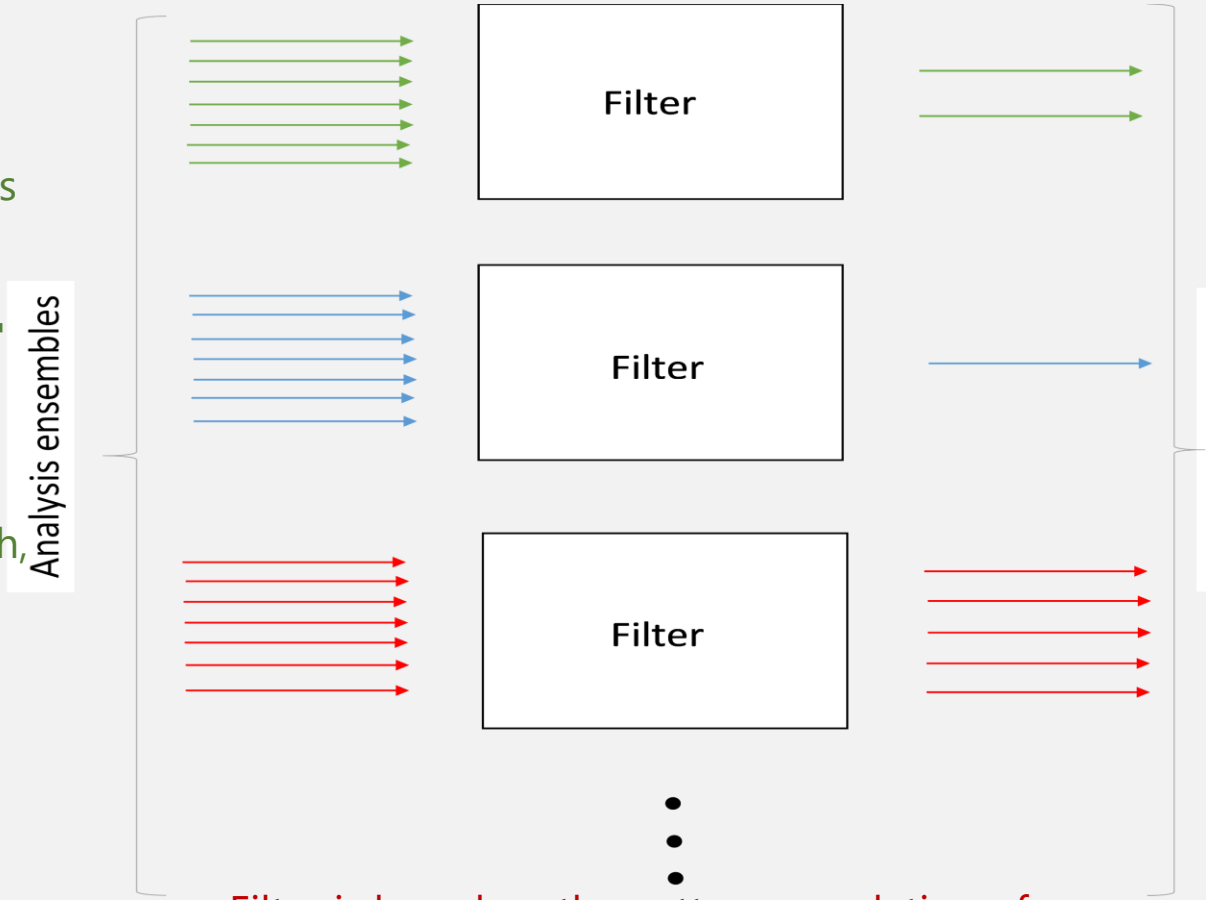
Schematic for data assimilation algorithm

Analysis ensembles consist of met ensemble members and source term ensemble members

Filtering done in batches rather than over whole analysis 'super' ensemble to ameliorate filter degeneracy

Perhaps 100 members per batch, with maybe 40 batches equals ~4000 simulations in analysis phase

Short simulations…3-6 hours



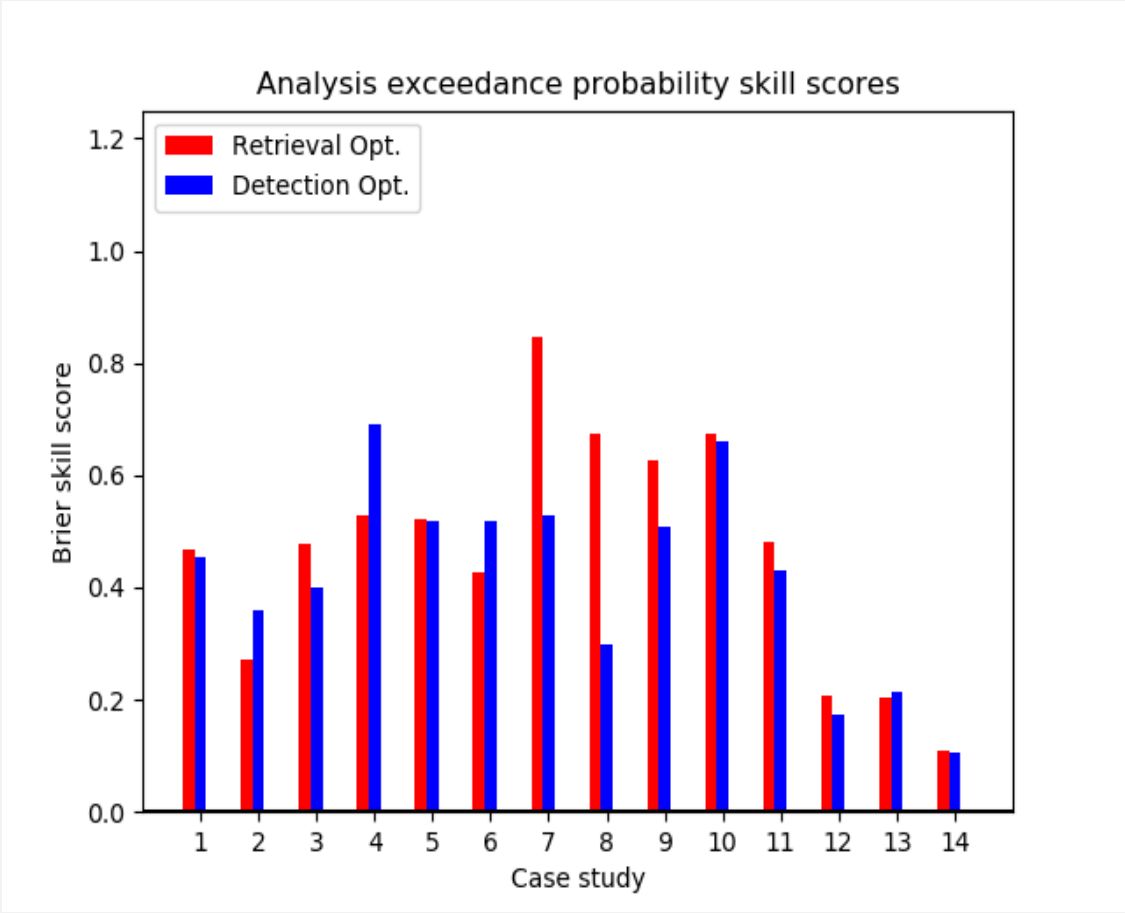
Filter is based on the pattern correlation of ensemble member output with the input observation(s)

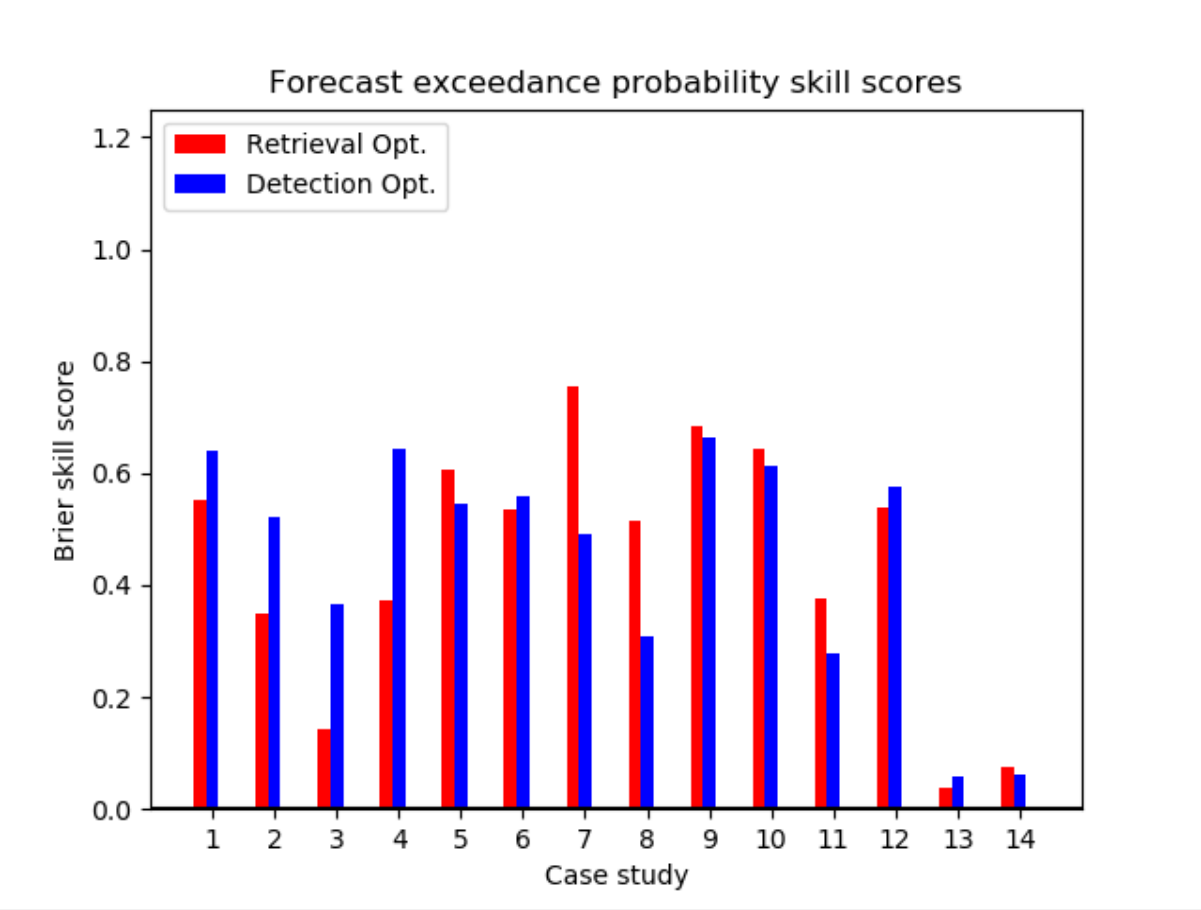
Forecast ensemble composed of members which pass through filter (i.e. the best performing ones)

Typically, about 2/3 of analysis ensembles filtered out

These ensemble members make up the final forecast ensemble

Overall performance





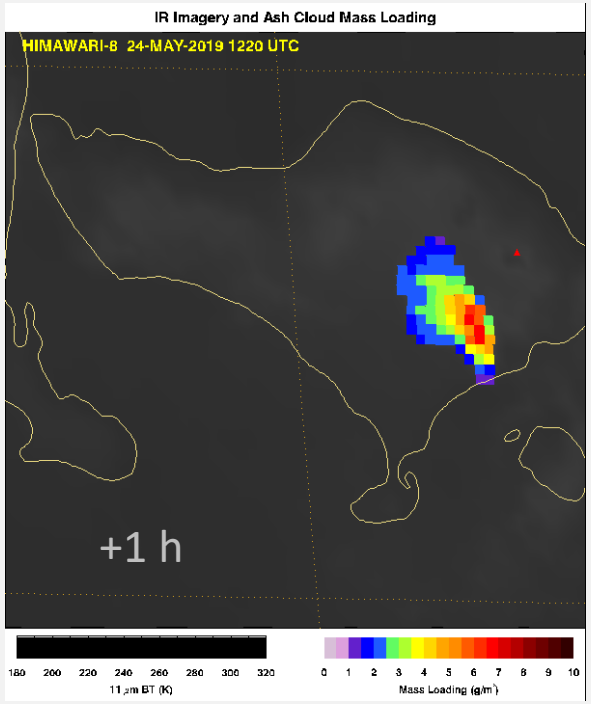
Improved forecast skill in all case studies relative to reference ('status quo') runs

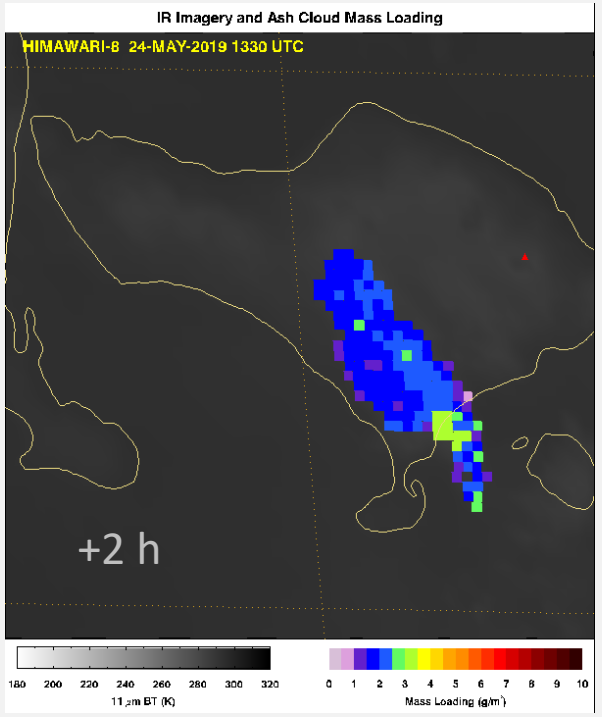
Agung, May 2019

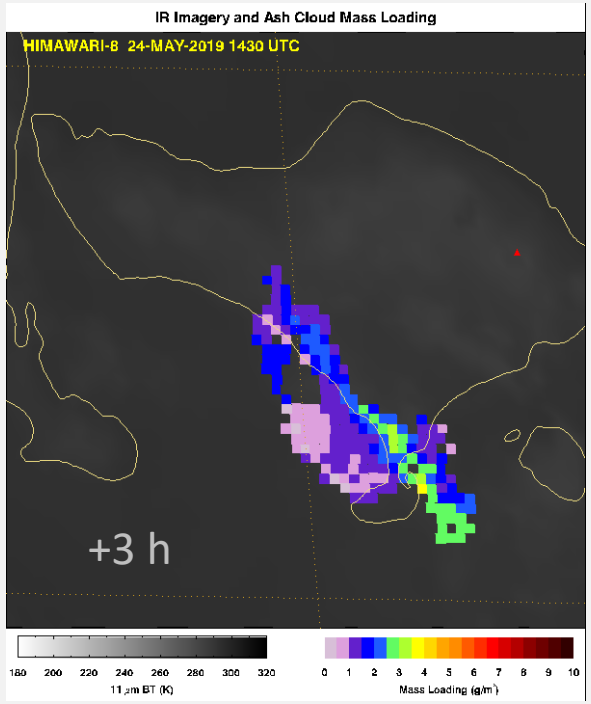
Small eruption of Agung, 24 May 19
- Reported height: FL150 (4.6 km)
- A few aviation impacts

Stunning photos of the Volcano Mount Agung erupting. Picture: BackGrid. Source: BackGrid. From: www.news.com.au

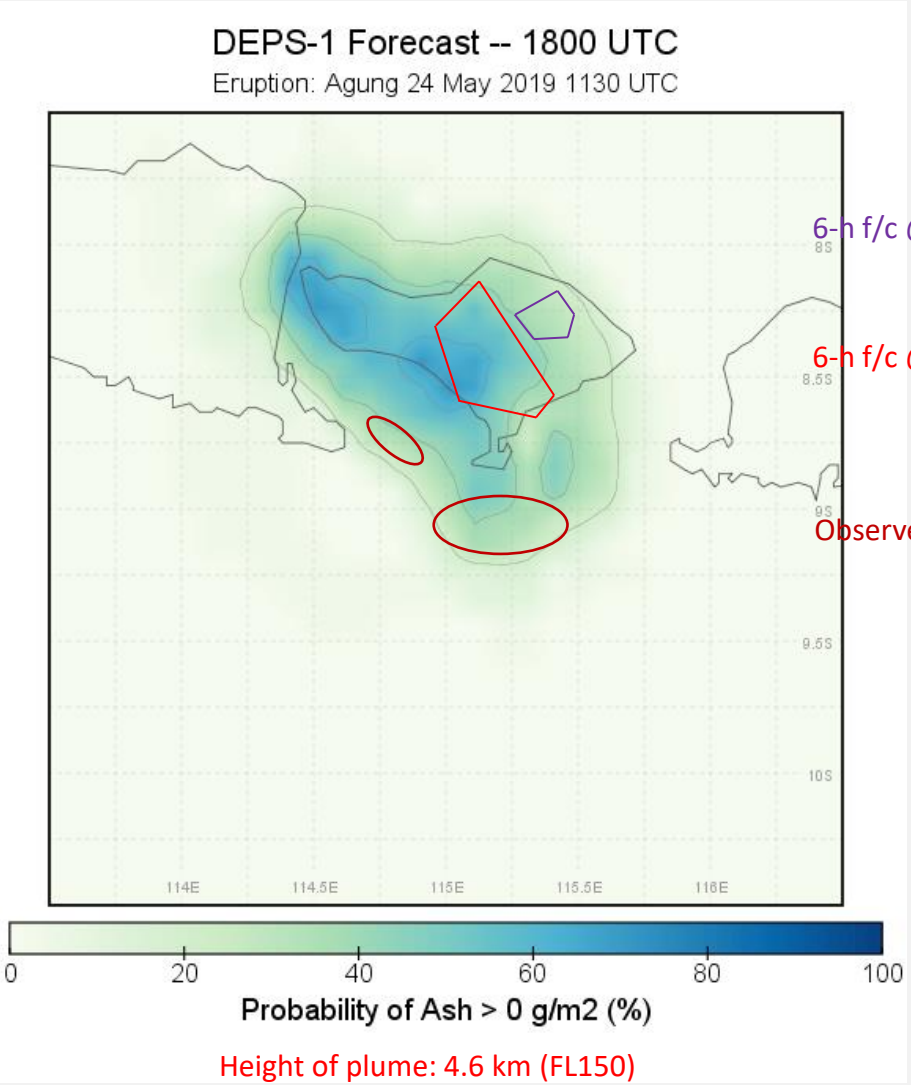
Mass Load retrievals from VOLCAT







DEPS vs DEPS2

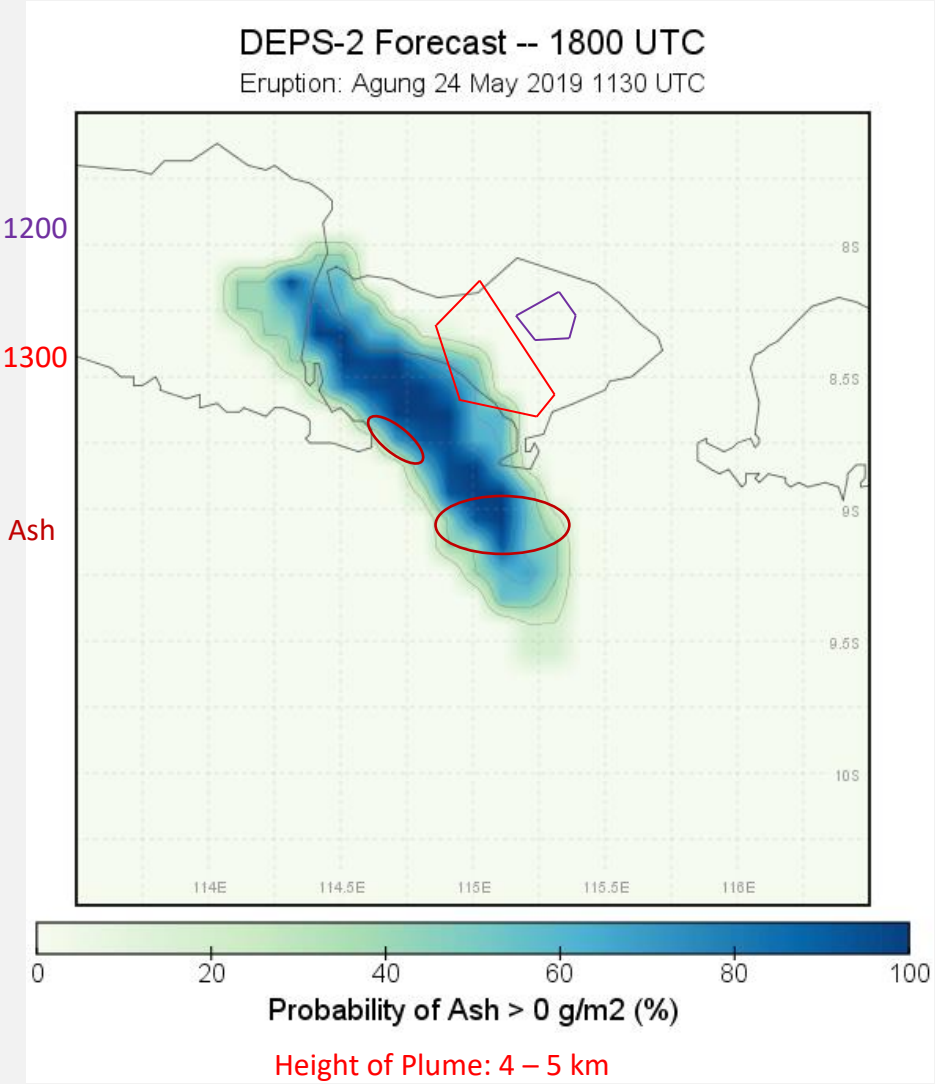


Height of plume: 4.6 km (FL150)

6-h f/c @ 1200

6-h f/c @ 1300

Observed Ash



Height of Plume: 4 – 5 km

Concluding remarks

- Other associated research efforts
  - Optimizing the particle size distribution (R Dare)
  - Multi-threaded version of HYSPLIT dispersion model (T Pugh)

- This work represents a significant enhancement of our ability to semi-confidently make quantitative ash predictions
  - Uncertainty remains high in how much ash there actually is in these clouds. What are satellite retrievals not seeing?
  - Verification in real-time cases to build trust
  - How confidently can we meet the required criteria?

- Implementation
  - Target is operationalization by June 2021
  - Dev version working, software maturity process underway
  - Where to run? HPC architecture?