Operational source term estimation and ensemble prediction for the Grimsvoetn 2011 event

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Background

In the year 2010 the eruption of the Icelandic volcano Eyjafjallajökul injected huge amounts of ash into the atmosphere, leading to a shut-down of European airspace for several days. This led to an economical damage of around 5 million Euros. The significant economical damage as well as the increased public perception induced the ESA-funded international project VAST (Volcanic Ash Strategic Initiative Team) with the aim of the demonstration of an operational ash monitoring and prediction service. Two main issues are a realistic *source term estimation* in case of volcanic eruptions and the *estimation of forecast uncertainty* in the resulting dispersion calculations due to the forecast uncertainty in the meteorological input data.

A corresponding result is depicted in the following for a first test case, the eruption of the Grimsvoetn volcano on Iceland in May 2011.

Source term inversion

Basics and aims

- Determination of ash- and/or SO2-emissions from volcanos, which are not immediately measurable.
- A correct source term is absolutely necessary. It is the most decisive factor in an atmospheric dispersion calculation.
- The desired source term is the one, which yields a minimum deviation between model and (satellite) observations under certain constraints (e.g. model pyhsics).

Literatur: E. D. Moxnes (2013): Estimating the sulphur dioxide and ash emissions from the Grimsvötn 2011 volcanic eruption and simulating their transport across Northern Europe, Master Thesis, University of Oslo.

Methods

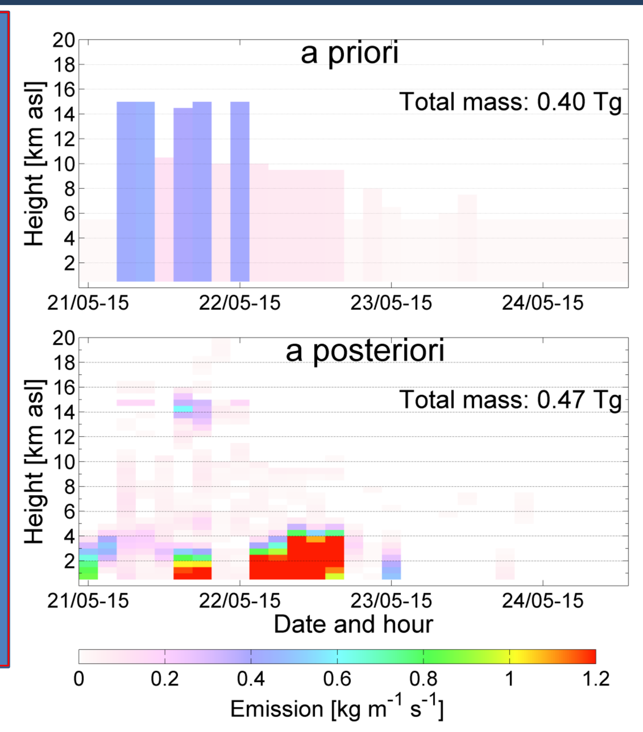
Source-Receptor-Sensitivities (M) from model runs for different regular time and height intervals with unit emissions.

Scaling of the unit emissions with an **a priori source term** (xa), which is estimated according to empiric rules (e.g. Mastin et al., 2009), independent observations and eruption models (PLUMERIA, Mastin, 2007).

Comparison of model output summed over the atmospheric column with **satellite observations** (yo) from the same time slot with identical spatial and temporal resolution.

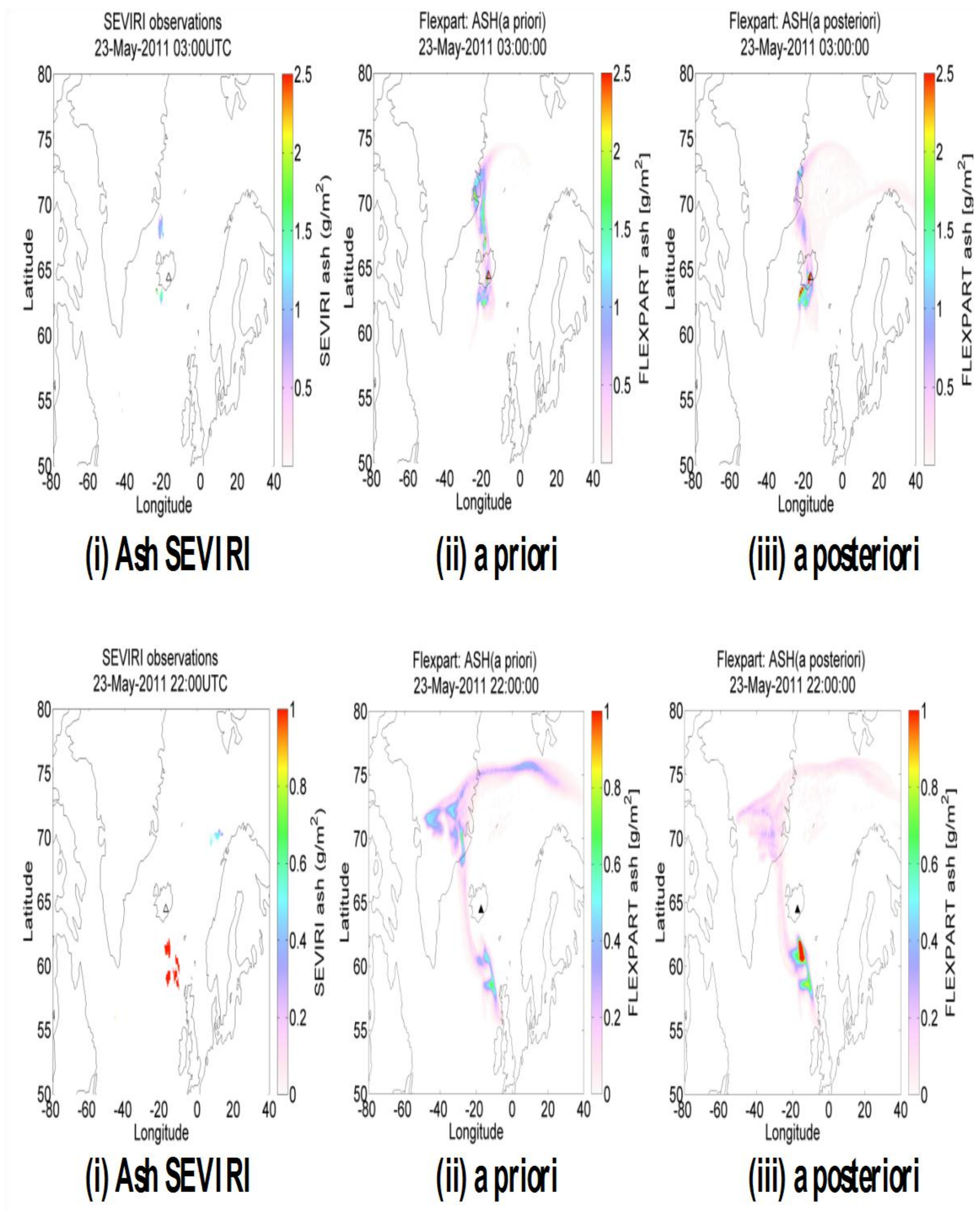
(Subjective) **estimation of the error** in the a priori (**σ**x, ~50%), in the satellite observations (~E-3kg/m2) and in the disperison model (~1E-2 kg/m2), whereat the latter two get combined (**σ**o, errors added).

Analytical solution of the problem for the desired source **x**: **M(x-xa) = yo – Mxa** under consideration of regularisation terms (Tikhnov, smoothing of vertical profiles).



A posteriori time-height distribution of emitted fine ash (<25 µm) [kgm-1s-1] using ECMWF input data for the dispersion model FLEXPART and IASI ash satellite data (from polar orbiting METOP-A)
Emissions mainly below 4km!

A priori and a posteriori as model input



*Comparison of (i) ash **SEVIRI** satellite observations, which are used as input for the inversion, (ii) FLEXPART- simulations using the a priori source term and (iii) FLEXPART-simulations using the a posteriori source term for two time steps: 23. May 2011 02-03 UTC (upper row) and 23. May 2011 21-22 UTC (lower row), plots from Moxnes (2013).*

Multi-Input-Single-Model-Ensemble

Basics and aims

- Enabling of **operational** FLEXPART ash ensemble dispersion calculations.
- Therefore one needs a reduction of the 50 ensemble members through the use of clustering technics.
- So we have to analyze, whether there is a strong linkage between some selected meteorological input variables and FLEXPART concentration fields.
- In that case one can choose members for a reduced ensemble via ensemble clustering, which is based only on information from the selected meteorological input.
- Challenge: Finding the suitable meteorological variables and an appropriate clustering algorithm.

Literatur: R. Klonner (2013): Clustering ECMWF ENS ensemble predictions to optimise FLEXPART plume dispersion ensembles, Master Thesis, University of Vienna.

Methods

First Guess: Global FLEXPART-simulation with the operational ECMWF-run, to determine the area affected by the ash cloud.

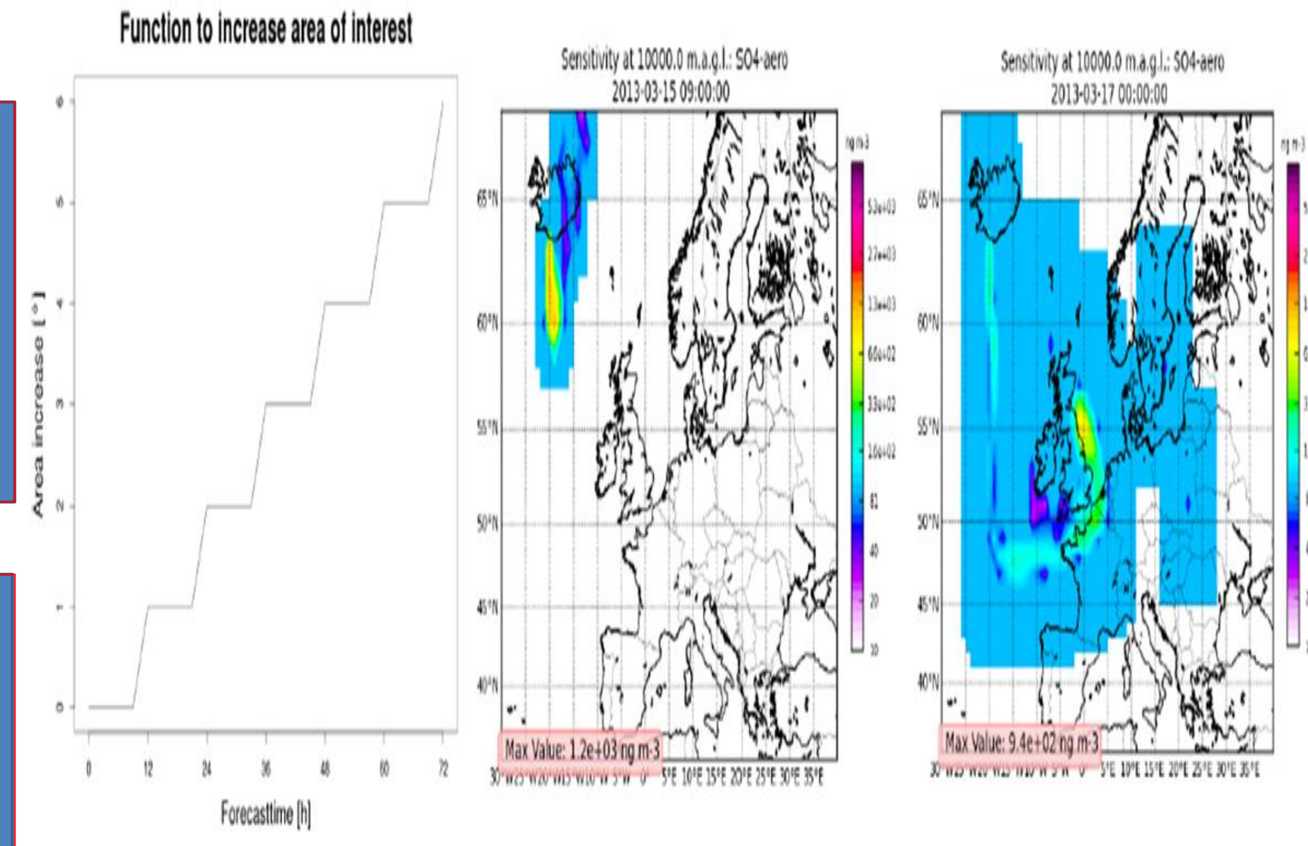
Masking of the affected area:
- Only those grid points of the meteorological field shall be considered in clustering, which can influence the ash cloud.
- The mask has to change with time according to the First Guess.
- An additional are has to be added for considering the variation in the 50 ensemble members.

Hierarchic (Ward's Method) and non-hierarchic (K-means, Partitioning Around Medoids) clustering-methods

Decisive variables:
- Horizontal wind field (u,v) for the transport
- Precipitation (lsp and cp) for wet deposition
- Conclusion: Use of u and v on pressure levels (e.g. 250 hPa ~ 12km ~ cruising altitude) for the clustering.

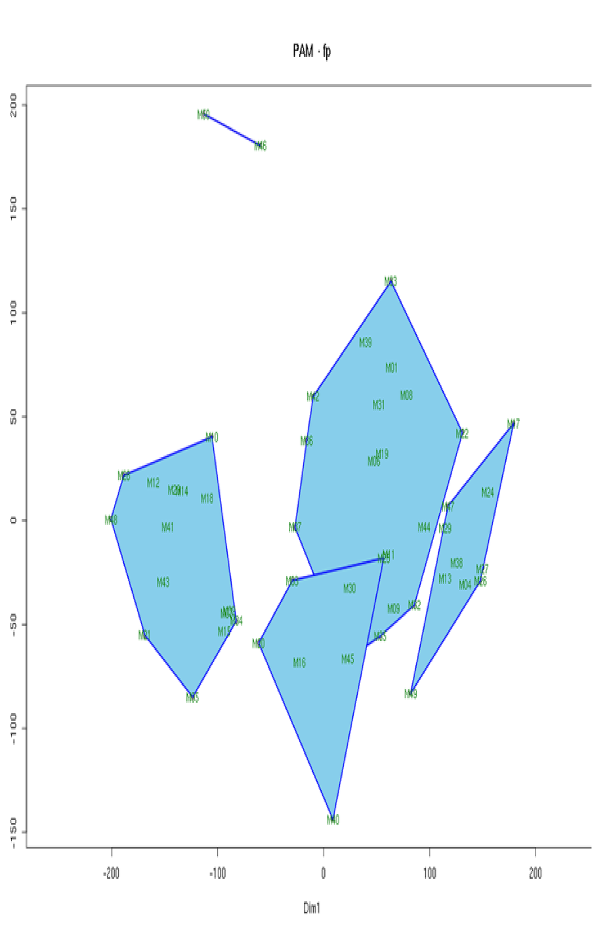
Precipitation plays a minor role in that layer.

~ 5 representative members (if strong horizontal forcing is present)

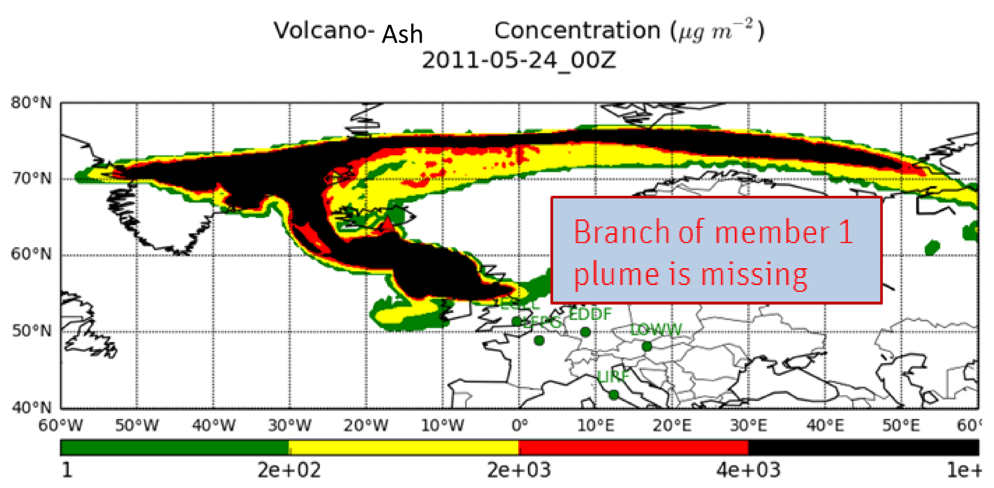


Example for the step wise increase of the area of uncertainty as function of forecast time.

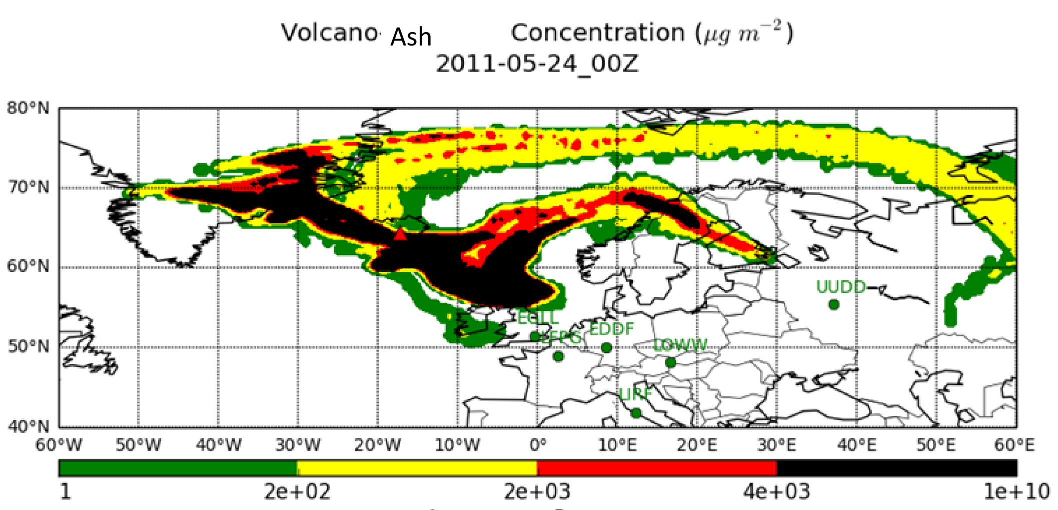
Multi-Input-Single-Model-Ensemble results



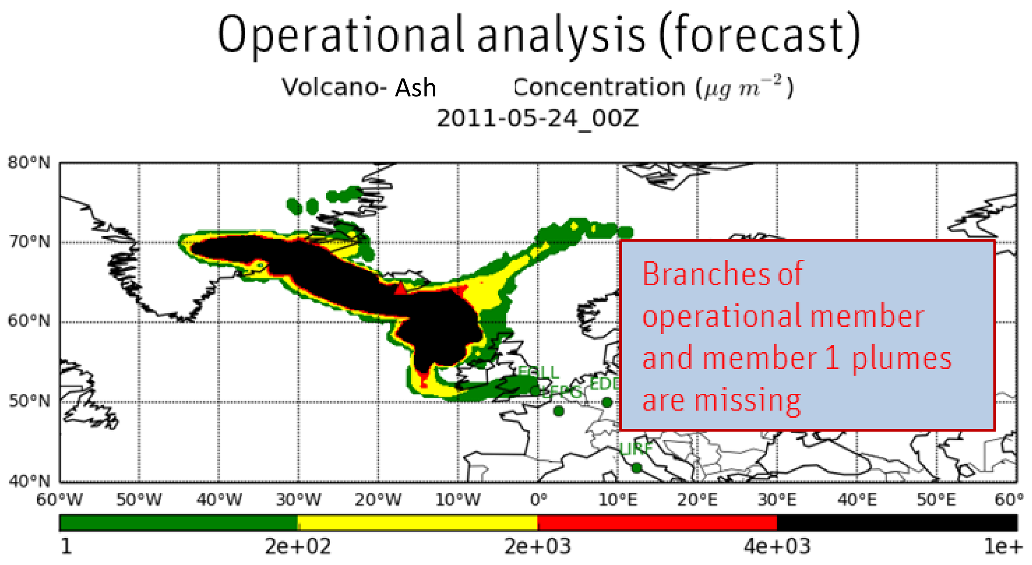
Depiction of the 5 clusters for the Grimsvoetn case via multidimensional scaling which represents a high dimensional data matrix of dissimilarities in a lower dimensional space (here 2D) through eigen analysis.



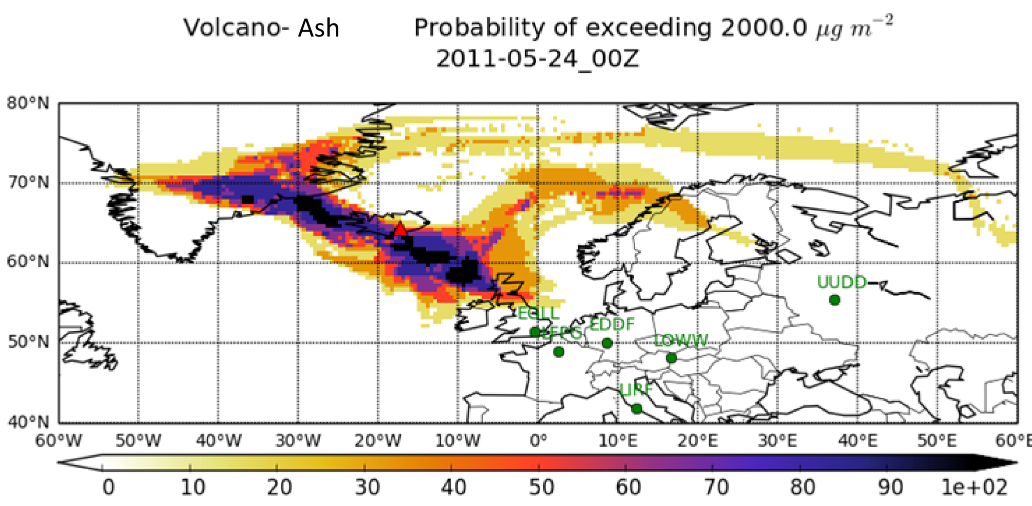
Operational analysis (forecast)



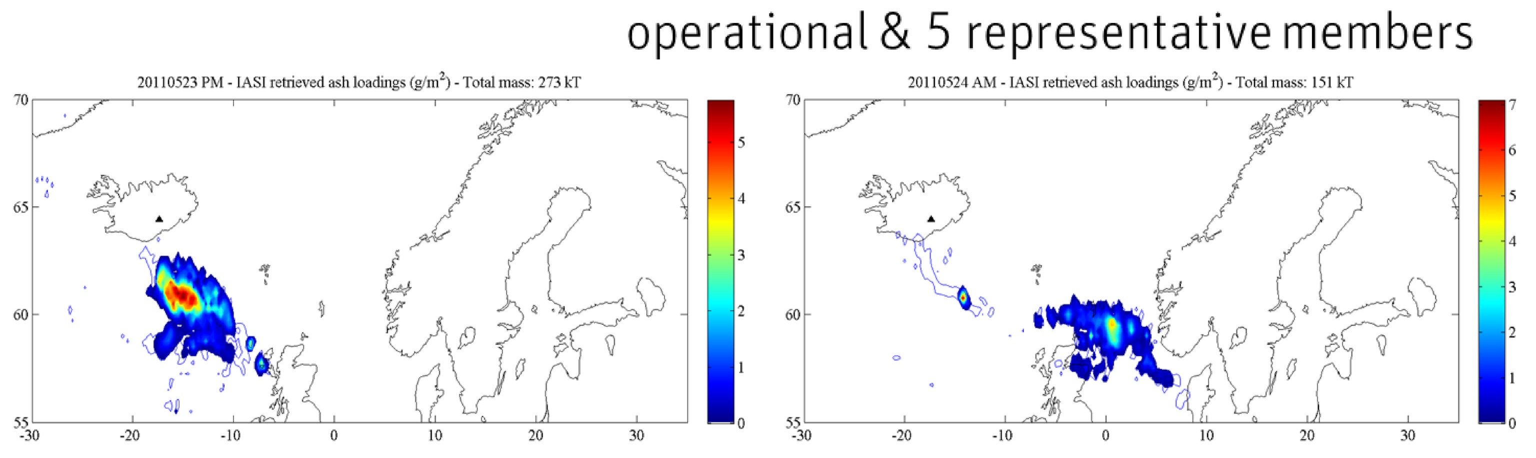
Member 1 forecast



Member 2 forecast



Probability of exceedance forecast using operational & 5 representative members



Total column loadings 72 hours after the eruption of Grimsvoetn: Operational run, one representative run similar to the operational run, another representative run different to the operational run as well as a combination (probability plot) of the five representative members and the operational run. Further, two IASI retrievals at comparable time steps.

Conclusions

- From IASI/SEVIRI-satellite observations of volcanic ash, with the dispersion model FLEXPART and an a priori source term an a posteriori source term for the Grimsvoetn eruption 2011 can be estimated. This source term shows that the ash mainly was emitted to altitudes up to 4 km. Whereas the precise height-time structure in the apriori is of limited significance, the starting time of the eruption is indeed relevant.
- Since the SEVIRI-instrument is located on board of a geostationary satellite (MetOp-A), a lot of information becomes available within very short time (observations every 15 min). An operational inversion is feasible and is currently implemented at ZAMG.
- With regard to a multi-input-ensembles a reasonable link between u- and v- wind fields and FLEXPART-concentrations in the case of moderate to strong horizontal forcing can be established. Thus five representative members out of the total of 50 ECMWF-EPS-members can be selected with the help of the wind field only, which reflect the total ensemble spread sufficently and which can be used as input for FLEXPART.
- It would be operational not feasible to cluster the concentrations for all 50 ensemble members. An operational implementation at ZAMG of the approach presented is in progress.
- Both examined research areas help to estimate the area affected by volcanic ash more realistically and to avoid unnecessary shut-downs of the air traffic.