NWP Ensembles for Volcanic Ash Plume Forecasting

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Outline

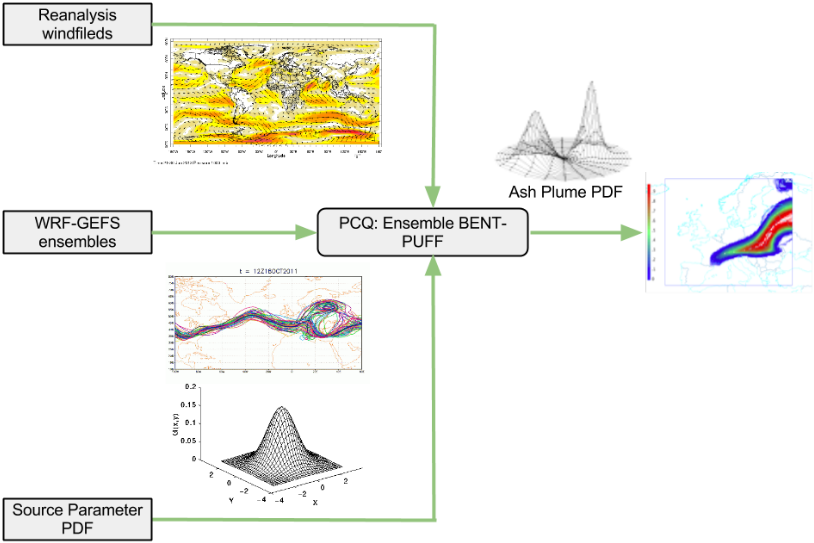
Introduction

* http://bowshooter.blogspot.com/2010/05/iceland-volcano-eruption-of.html

- Deal with complex physics.
- Sparse observations - one cannot build a forecast based only on observations.
- To supplement the lack of observations we used mathematical models of advection and dispersion.
- These models require input data on source conditions such as eruption plume height, as well as the windfield.

The problem

- The ash clouds extend over large areas and can travel thousands of kilometers from the source volcano, disrupting air traffic and posing a significant hazard to air travel.
- Windfields along with source parameters (vent radius, vent velocity, mean grain size and grain size variance) represent major sources for uncertainties in ash transport and dispersion simulations.
- The volcanic source inputs are usually not well constrained - uncertainty in the inputs is needed to make probabilistic predictions.
- For windfields, ensemble methods are considered to be an effective way to estimate the probability density function of future states of the atmosphere.


Reanalysis windfileds
WRF-GEFS ensembles
Source Parameter PDF
PCQ: Ensemble BENT-PUFF
Ash Plume PDF
t = 12Z16OCT2011
G(x,y)
X
Y

GEFS ensemble

GEFS ensembles account for uncertainty in initial conditions using breeding vectors approach [a]. Breeding method is based on the idea that the analysis that we get out of the data assimilation cycle will accumulate growing errors when it is recycled from one data assimilation cycle to the next.

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[a] Toth, Z. and Kalnay, E. (1997) Ensemble forecasting at NCEP and the breeding method. Mon. Wea. Rev., 126, 3292-3302

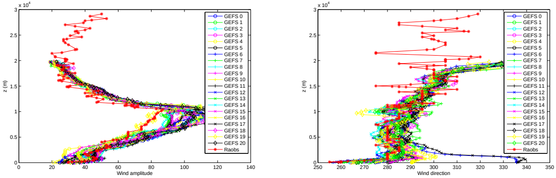
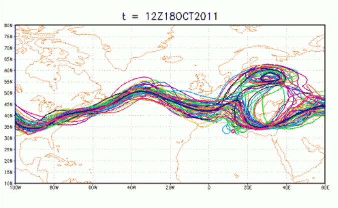


Figure : a) Wind amplitude in knots, lat 60.13 and lon -1.18, April 17 2010 00Z b)Wind direction in deg, lat 60.13 and lon -1.18, April 17 2010 00Z

GEFS ensemble - cont

The NCEP GEFS ensembles consists of 21 members and is run 4 times daily (0000, 0600, 1200, and 1800 UTC) out to 384-h (16 day) lead time. The underlying model for the GEFS is the NCEP Global Forecasting System (GFS), a high-resolution spectral atmospheric model run 4 times daily at the Environmental Modeling Center.



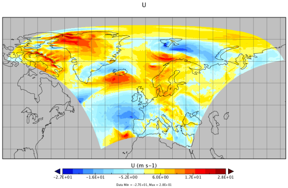
Ensemble spaghetti plot courtesy of http://www.pandowae.de/en/projects/block

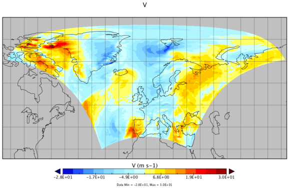
We are using the ensemble members produced four times daily, at 0000, 0600, 1200, and 1800 UTC, starting 0000 UTC April 14 to 0000 UTC April 18 at 1°latitude by 1°longitude grid.

WRF

Weather Research and Forecast (WRF) model is a numerical weather prediction system, used to forecast the wind speed.

- The model domain is centered on the location of the Eyjafjallajökull vent (63.63 °N and 19.63 °S) with dimensions of 230 × 230 horizontal grids points with spacing of 27 km, 29 pressure levels (1000-100 hPa, excluding the surface) and it comprises most of Europe.





The existence of stochastic forecast products is a great advantage relative to a situation with a deterministic modeling system where a single realization of the future state of the atmosphere is produced, and the forecaster must trust his instincts and guess the best value of the state.

Probabilistic forecast - cont

The probability of having ash at a specific height is given by:

$$P(h) = \int_{\Omega} P(h|W)p(W)dW \approx \frac{1}{N_W}\sum_{i=1}^{N_W} P(h|W_i)$$

Expected value of the height:

$$E[h] = \int hP(h)dh = \int h(\theta, W)\left(\int P(h|W)p(W)dW\right)dh$$
$$= \int\int h(\theta, W)P(h|W)p(W)dWdh = \sum_{i=1}^{N_W} w_i \sum_{q=1}^{N_{CUT}} w_q h(\theta_q, W_i)$$

were w_i are the weights associated with the wind ensemble, while w_q are the obtained from using gPC expansion [1].

[1] Bursik, M.I. et al. (2012) Estimation and propagation of volcanic source parameter uncertainty in an ash transport and dispersal model: application to the Eyjafjallajökull plume of 14 - 16 April 2010, Bull. Volc.

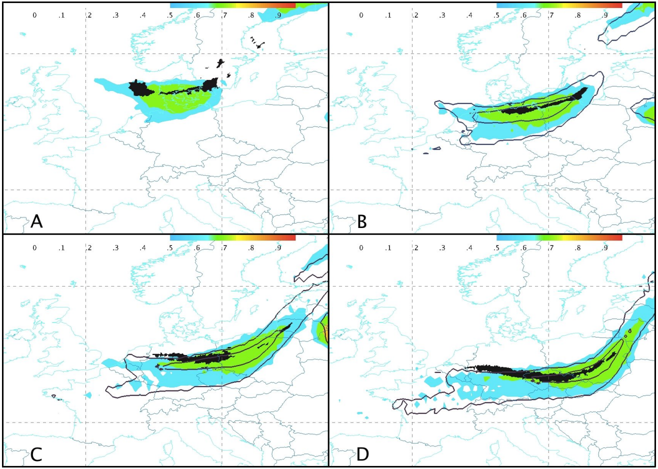


Figure : Probability of having airborne ash when accounting for source parameters only (solid color), source parameters and windfield variability (probability contour) and corresponding satellite image at different times (black color), (a) 0000 UTC April 16, (b) 0006 UTC April 16, (c) 0012 UTC April 16, and (d) 0018 UTC April 16

	Skills			
	Brier score	Reliability	Resolution	Uncertainty
Model 1	0.3225	0.3216	5.617e-05	0.002537
Model 2	0.2048	0.2036	3.881e-05	0.003253

Table : Skills of model 1 and model 2

	Measures		
	RMSE	Pearson coeff	Dice coeff
Model 1	0.5675316	-0.2020078	0.01481481
Model 2	0.4478977	-0.1550349	0.01646844

Table : Measures of model 1 and model 2

Skills and measures

Brier Score

$$BS = \frac{1}{T}\sum_i (f_i - o_i)^2 = \tag{1}$$

$$= \underbrace{\frac{1}{T}\sum_i n_i(f_i - \bar{o}_i)^2}_{Reliability} - \underbrace{\frac{1}{T}\sum_i n_i(\bar{o}_i - \bar{o})^2}_{Resolution} + \underbrace{\bar{o}(1-\bar{o})}_{Uncertainty}$$

Since Brier score is a measure of error, smaller values are better.
Reliability - ideally, this measure should be zero.
Resolution - larger values are best.
Uncertainty - there is no ideal or better value.

Skills and measures

Root mean squared error (RMSE)

$$RMSE = \sqrt{\frac{1}{T}\sum_{i=1}^{T}(f_i - o_i)^2} \quad (2)$$

Pearson Correlation Coefficient

$$r = \frac{\sum_i^T (f_i - \bar{f})(o_i - \bar{o})}{\sqrt{\sum (f_i - \bar{f})^2}\sqrt{\sum (o_i - \bar{o})^2}} \quad (3)$$

Dice similarity coefficient (DSC)

$$DSC(A,B) = 2(A \cap B)/(A + B) \quad (4)$$

Conclusions

- We account for the variability of the windfields in a volcanic ash cloud transport and dispersion model.
- Using WRF wind ensemble we are trying to capture the dependency on initial conditions that can lead to large differences in the forecasts.
- Output uncertainty due to uncertain input parameters is determined with a polynomial chaos quadrature-based sampling of the multidimensional puff input vector space.
- The results of comparing WRF forecast with Reanalysis suggest that the winds play a small role in the uncertainty quantification.
- This work was supported by AFOSR grant number FA9550-11-1-0336 and NSF-IDR CMMI grant number 1131074.