SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	FLEXPART transport simulations of volcanic ash clouds and gas tracer for the Norwegian community Earth System Model
Computer Project Account:	SPNOFLEX
Start Year - End Year :	2012 - 2014
Principal Investigator(s)	Nina Iren Kristiansen
Affiliation/Address:	NILU- Norwegian Institute for Air Research
Other Researchers (Name/Affiliation):	Sabine Eckhardt, Andreas Stohl, Massimo Cassiani, Rona Thompson, Thomas Hamburger, Henrik Grythe, Ignacio Pisso, Arve Kylling All at NILU.

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The Lagrangian particle dispersion model FLEXPART is run on ECMWF data to explore the transport and dispersion of various atmospheric constituents from greenhouse gases, aerosols like black carbon to volcanic ash released during eruptions. The model is used with various inversion techniques to infer emission estimates of many atmospheric compounds. This helps improving transport simulations of these substances and to understand their contribution and effects on the climate system.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

……

……

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

No problems and we got all information and help we needed.

Summary of results

(This section should comprise up to 10 pages and can be replaced by a short summary plus an existing scientific report on the project.)

A range of topics have been studied within our project with the use of ECMWF data:

1. Source term estimates and transport simulations of the Eyjafjallajökull
2. Estimates of radioactive emissions from the Fukushima accident
3. Simulated satellite images of the Eyjafjallajökull volcanic ash cloud
4. Estimates of methane emissions in East Asia
5. Modelling the Arctic Haze phenomenon
6. Analysis of variability in atmospheric methane in the Arctic
7. Impact of meteorological clouds on detection and retrieval of volcanic ash during the Eyjafjallajokull 2010 eruption: A modelling study.
8. Source term inversions of the Grimsvötn-2011 eruption
9. Atmospheric transport in historical climate and future climate scenarios is studied from coupling of the NorESM model with FLEXPART

Short summaries of these studies are given below with reference to scientific papers/reports/projects.

1. Source term estimates and transport simulations of the Eyjafjallajökull volcanic ash cloud

Volcanic ash constitutes a serious threat to aviation. The 2010-eruption of Eyjafjallajökull volcano on Iceland led to a costly shutdown of air space across Europe. Observations (particularly from satellites) and model simulations aid in situations with volcanic ash intersecting air routes. Due to the highly variable nature of volcanic eruptions and the strong variability in the emissions of ash and gases, there is a need to estimate the emission variability in order to perform accurate simulations of the spread and particularly the concentrations of volcanic ash in air space. There is also a need to perform simulations using several models to evaluate the differences that may occur in the simulations, and to determine the models' capability of simulating volcanic ash clouds and their concentrations.

An inversion method was already applied to determine the emissions of ash from the Eyjafjallajökull eruption, and the temporal and vertical variations (*Stohl et al*., 2011). Now, two different dispersion models (FLEXPART and NAME), run on different meteorological input data (ECMWF, GFS and UK MetOffice UM model) have been used as a small ensemble of model simulations for the volcanic ash transport from the 2010 Eyjafjallajökull eruption. Analyses of these simulations against observations have been published in a peer-reviewed paper (*Kristiansen et al*., 2012). The model simulations use different emissions of ash from the volcano. Simple emissions profiles are used (a priori and "uniform") as well as the inversion-based emission estimates (a posteriori). The simulations show different shapes and mass loadings of the ash clouds over the North Sea on 17 May 2010 (Figure 1.1). The FLEXPART ECMWF-based a posteriori simulation (Figure 1.1, bottom middle) seems to be in better agreement with the satellite observations (Figure 1.1, top left). This simulation especially captures the thin filament of the ash cloud along the coast of the Netherlands which FLEXPART-GFS and NAME do not simulate as well probably due to the meteorology driving the models. Two research aircraft (BAe-146 and Falcon) performed in-situ measurements of the ash clouds (flight tracks shown by colored lines in Figure 1.1). The measured ash concentrations (Figure 1.2) show distinct peaks when the aircraft descended into the ash clouds. The main peaks of the observations are captured by the models (Figure 1.2), and a posteriori concentrations are generally within the uncertainty of the measurements. The better agreement for FLEXPART-ECMWF to the in-situ observations confirms the presence of the ash filament along the Netherlands as observed also by the SEVIRI satellite instrument (Figure 1.1, top left). A more thorough statistical analysis of measured to modeled ash concentrations was also performed by *Kristiansen et al.* (2012).

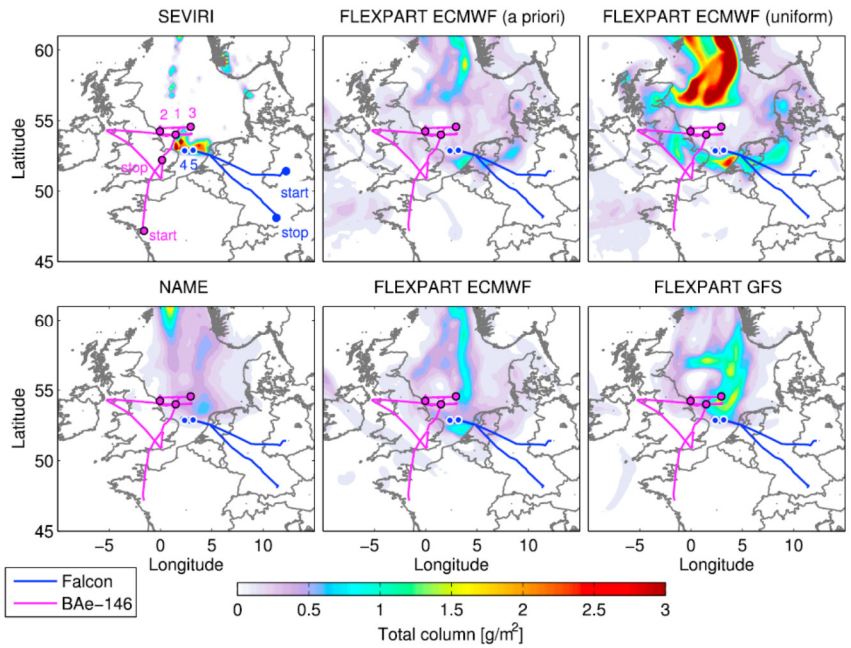

Figure 1.1. *Observed and modeled clouds of volcanic ash on 17 May 2010. Model simulations are using different emissions of ash from the volcano.* ***(top left)*** *retrieved ash columns from the SEVIRI satellite instrument,* ***(top middle and right)*** *modeled ash clouds as simulated by FLEXPART run on ECMWF meteorology,* ***(bottom left)*** *modeled total ash columns from the NAME model run on MetUM meteorology,* ***(bottom middle)*** *modeled ash clouds from the FLEXPART model run on ECMWF and* ***(bottom right)*** *GFS meteorology. The magenta and blue lines indicate the flight track of two research aircraft (BAe-146 and Falcon) performing in-situ measurements within the ash clouds.*

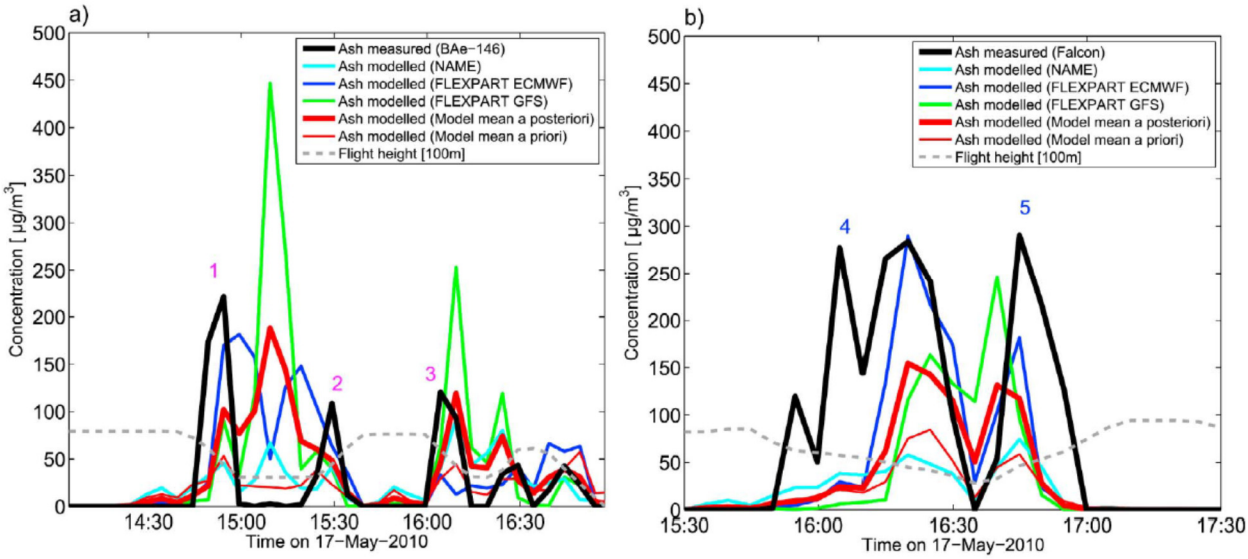

Figure 1.2. *Measured and modeled concentrations of volcanic ash on 17 May 2010. The black thick lines are the measured ash concentrations from the two research aircraft (BAe-146 and Falcon) which the flight tracks are shown in Figure 1.1. The blue lines shows the modeled ash concentrations from the FLEXPART simulation run on ECMWF input.*

2. Estimates of radioactive emissions from the Fukushima accident

The March-2011 accident at the Fukushima Dai-Ichi nuclear power plant, emissions of radioactive material are determined with an inversion method (*Stohl et al.*, 2012). Caesium-137 (^{137}Cs) is a radionuclide of particular concern during nuclear accidents, because it is emitted in large amounts and is of significant health impact.

To determine the radionuclide emissions as a function of height and time from 11 March until 20 April, a first guess of release rates (a priori) was made based on fuel inventories and documented accident events at the site. This first guess was subsequently improved by inverse modeling, which combined it with the results of an atmospheric transport model, FLEXPART (run on ECMWF and GFS meteorology), and measurement data from several dozen stations in Japan, North America and other regions. Both atmospheric activity concentration measurements were used as well as measurements of bulk deposition. For ^{137}Cs, the inversion results gave a total emission of 36.6 (20.1–53.1) PBq, or about 43% of the estimated Chernobyl emission. The results (**Figure 2.1**) indicated that ^{137}Cs emissions peaked on 14–15 March but were generally high from 12 until 19 March, when they suddenly dropped by orders of magnitude at the time when spraying of water on the spent fuel pool of unit 4 started confirming that the spraying was an effective countermeasure.

FLEXPART model simulations were used to explore the main dispersion and deposition patterns of the radioactive cloud, both regionally for Japan as well as for the entire Northern Hemisphere. The agreement of model results (both using a priori and a posteriori emissions) with measurement data was better with GFS data than with ECMWF data. The fact that this was also found for a different radionuclides (xenon-133) which is not affected by wet scavenging, shows that GFS-FLEXPART captured the general transport better than ECMWF-FLEXPART. Furthermore, the wet scavenging of ^{137}Cs was much stronger with ECMWF data than with the GFS data, causing a strong underestimation of ^{137}Cs concentrations at sites in North America and Europe. The ECMWF-based simulations were mainly used as ensemble members in the inversion to quantify the model uncertainties.

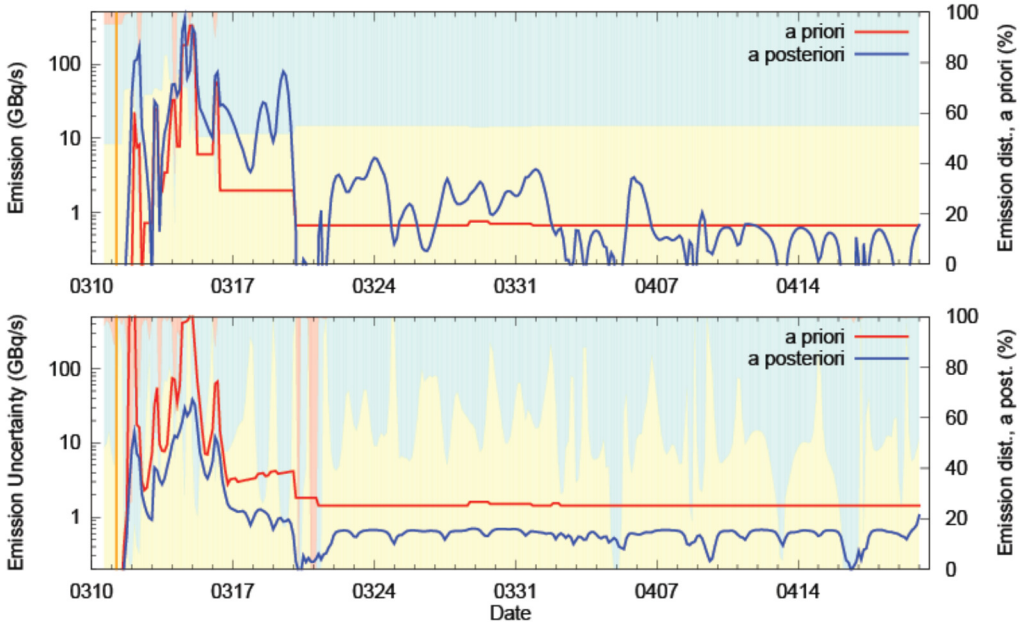

Figure 2.1. *Emissions of ^{137}Cs used a priori (red line) and obtained a posteriori by the inversion (blue line) (upper panel), as well as associated uncertainties (lower panel). The vertical distribution of the emissions over the three layers, with scale on the right hand side, is shown by the background colors (0–50 m, light yellow; 50-300 m; light turquoise, 300-1000 m, light red) for the a priori emissions (upper panel) and the a posteriori emissions (lower panel). The orange vertical line indicates the time of the earthquake, when the nuclear power station lost its electric power and uncontrolled release started.*

3. Simulated satellite images of the Eyjafjallajökull volcanic ash cloud

Infrared satellite images are widely and successfully used to detect and follow atmospheric ash from erupting volcanoes. **Kylling et al. (2013)** describe a new radiative transfer model framework for the simulation of infrared radiances, which can be compared directly with satellite images (**Figure 3.1**).

This can be helpful to get insight into the processes that affect the satellite retrievals. As input to the radiative transfer model, the distribution of ash is provided by simulations with the FLEXPART Lagrangian particle dispersion model, meteorological cloud information is adopted from the ECMWF analysis and the radiative transfer modelling is performed with the MYSTIC 3-D radiative transfer model. The model framework was used to study an episode during the Eyjafjallajökull eruption in 2010. It was found that to detect ash by the reverse absorption retrieval technique, accurate representation of the ash particle size distribution was required. Detailed investigation of individual pixels displayed the radiative effects of various combinations of ash, liquid water and ice clouds. In order to be clearly detectable, the ash clouds need to be located at some distance above other clouds. If ash clouds are mixed with water clouds or are located only slightly above water clouds, detection of the ash becomes difficult. Simulations were also made using the so-called independent pixel approximation (IPA) instead of the fully 3-D radiative transfer modelling. In the two simulations, different clouds (or different parts of the clouds) or the ground were effectively emitting radiation towards the instrument, thus causing differences in the brightness temperature of up to ± 25 K. The presented model framework is useful for further studies of the processes that affect satellite imagery and may be used to test both new and existing ash retrieval algorithms.

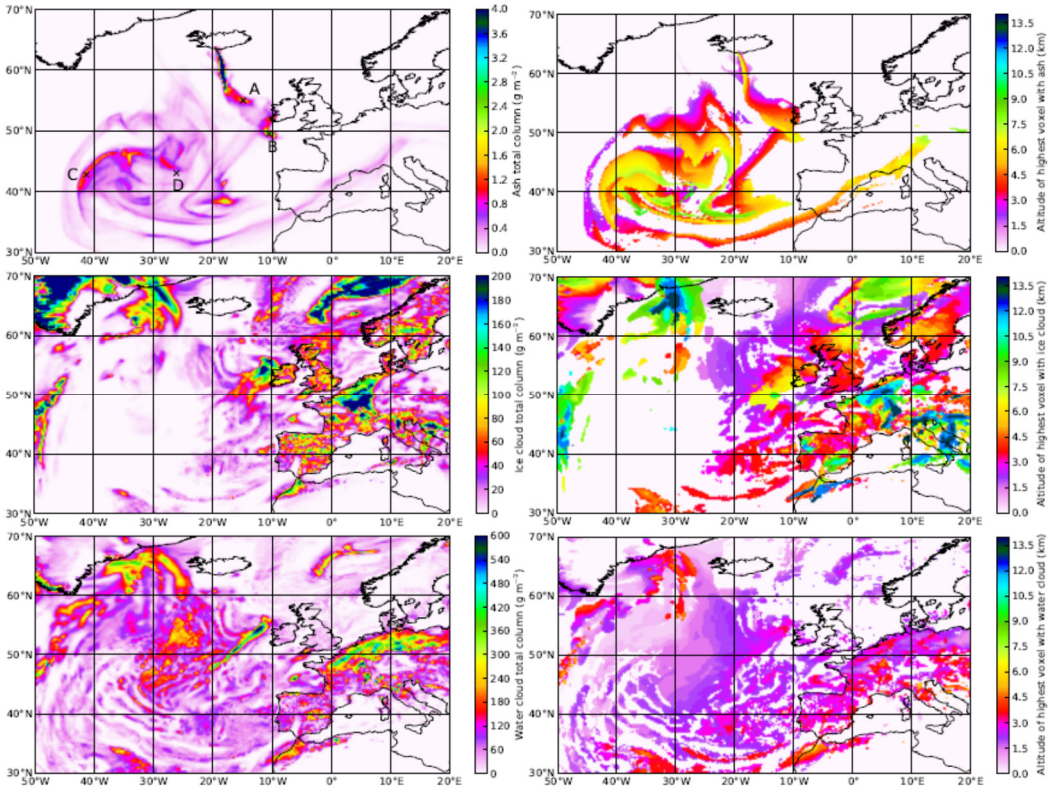

Figure 3.1: *Left column: the total column density of the ash as simulated by FLEXPART (top panel), ice (middle panel) and water (bottom panel) clouds from* ***ECMWF****. Right column: the altitude of the highest pixel with ash concentration above 0.1 mgm−3 (top panel), ice above 10 mgm−3 (middle panel), and water above 50 mgm−3 (bottom panel).*

4. Estimates of methane emissions in East Asia

Methane (CH_4) is currently the second most important long-lived anthropogenic GHG. South and East Asia are particularly important regions for CH_4 emissions globally, owing to especially strong sources from rice cultivation and wetlands. Top-down estimates of CH_4 emissions from these regions have hitherto been from inversion studies using coarse global transport models. However, owing to the paucity of atmospheric observations and the low spatial resolution of the global models, these estimates are associated with considerable uncertainties. In order to improve estimates of CH_4 emissions from East Asia, we used a Bayesian inversion approach with transport modelled by the Lagrangian particle

dispersion model, FLEXPART. FLEXPART provides the source-receptor relationships, that is, the description of how changes in fluxes are related to changes in concentrations at the measurement sites. For this study, back-trajectories of 20-days were calculated using wind fields from ECMWF ERA-interim. We coupled FLEXPART to output from a global circulation model (LMDZ-v4) to calculate the influence of variability in the background concentrations.

Emissions of CH_4 were estimated for the year 2009. This year was chosen as it coincides with the start of measurements in China from 4 new sites: Long Feng Shan (LFS), Shang Dian Zi (SDZ), Mt Waliguan (WLG), and Lin An (LAN), all operated by the Chinese Academy of Meteorological Sciences. Without these measurements, East Asia, and particularly, China would be poorly constrained. In addition to these sites, measurements were used from the NOAA CCGG, AGAGE, NIES, JMA, and KMA networks. In total, 33 sites were used globally, of which 15 are in the East Asia domain. Emissions of CH_4 were solved for globally but with a nested (fine resolution) grid between 9°N to 54°N and 72°E to 153°E. Inside the nested domain, grid cells are either 3°×3° or 1°×1°, while outside the domain the grid cells are 9°×9°. The inversion was solved globally in order to account for the influence of emissions outside the domain on the observed concentrations. The background concentration (estimated by coupling FLEXPART to CH_4 concentration fields from LMDZ-v4) was also optimized. For the prior estimate of CH_4 emissions, we compiled emission estimates from wetlands (LPJ DGVM model), geological seeps and volcanoes, biomass burning (GFED-v3), wild ruminants, termites, soils and anthropogenic sources (EDGAR-v4.1). Our prior had a total global emission of 579 Tg CH_4 y^{-1}.

Figure 4.1 shows the posterior CH_4 emissions and the difference in emissions (posterior – prior) for the East Asia domain. We found considerably higher (relative to the prior) emissions in eastern China, particularly in the provinces of Beijing, Hebei, Tianjin, Zhejiang, Fujian and Jiangxi, while lower emissions were found in the regions immediately west of these provinces. Lower emissions were found in Bangladesh, Myanmar, Thailand and Cambodia, however, there was little error reduction for these regions.

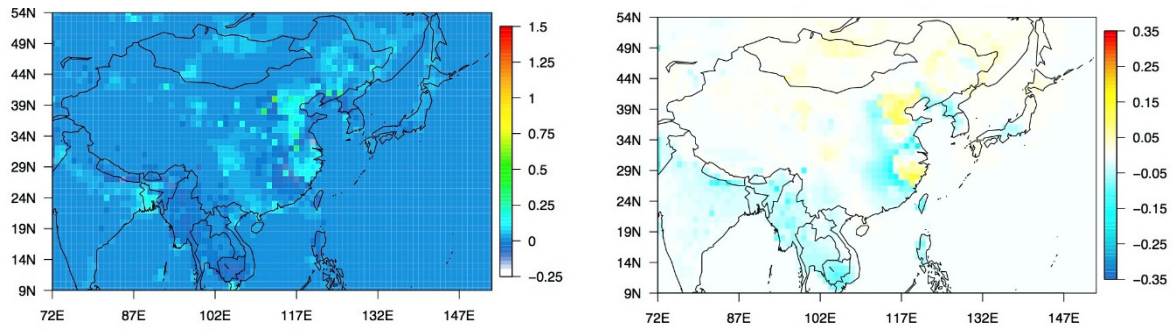

Figure 4.1. *Posterior emissions of CH_4 (units of $gCH_4\ m^{-2}\ y^{-1}$) (upper panel) and the difference in emissions (posteriori-prior) (lower panel).*

5. Modelling the Arctic Haze phenomenon

Arctic Haze is a seasonal phenomenon with high concentrations of accumulation-mode aerosols occurring in the Arctic in winter and early spring. Chemistry transport models and climate chemistry models struggle to reproduce this phenomenon, and this has recently prompted changes in aerosol removal schemes to remedy the modelling problems.

Stohl et al. (2013) show that shortcomings in current emission data sets are at least as important. They performed a 3 yr model simulation of black carbon (BC) with the Lagrangian particle dispersion model FLEXPART driven using three-hourly operational meteorological analyses from the European Centre for Medium-Range Weather Forecasts (ECMWF) with 91 model levels and a horizontal resolution of 1◦×1◦. The model was driven with a new emission data set which includes emissions

from gas flaring (**Figure 5.1**). While gas flaring was estimated to contribute less than 3 % of global BC emissions in this data set, flaring dominated the estimated BC emissions in the Arctic (north of 66◦ N). Putting these emissions into the model, they found that flaring contributed 42 % to the annual mean BC surface concentrations in the Arctic. In March, flaring even accounts for 52 % of all Arctic BC near the surface. Most of the flaring BC remains close to the surface in the Arctic, so that the flaring contribution to BC in the middle and upper troposphere was small. Another important factor determining simulated BC concentrations was the seasonal variation of BC emissions from domestic combustion. They calculated daily domestic combustion emissions using the heating degree day (HDD) concept based on ambient air temperature and compare results from model simulations using emissions with daily, monthly and annual time resolution. In January, the Arctic-mean surface concentrations of BC due to domestic combustion emissions were 150 % higher when using daily emissions than when using annually constant emissions. While there were concentration reductions in summer, they were smaller than the winter increases, leading to a systematic increase of annual mean Arctic BC surface concentrations due to domestic combustion by 68 % when using daily emissions. A large part (93 %) of this systematic increase could be captured also when using monthly emissions; the increase was compensated by a decreased BC burden at lower latitudes.

In a comparison with BC measurements at six Arctic stations, they found that using daily-varying domestic combustion emissions and introducing gas flaring emissions lead to large improvements of the simulated Arctic BC, both in terms of mean concentration levels and simulated seasonality. Case studies based on BC and carbon monoxide (CO) measurements from the Zeppelin observatory appeared to confirm flaring as an important BC source that could produce pollution plumes in the Arctic with a high BC/CO enhancement ratio, as expected for this source type. The results suggest that it may not be “vertical transport that is too strong or scavenging rates that are too low” and “opposite biases in these processes” in the Arctic and elsewhere in current aerosol models, as suggested in a recent review article, but missing emission sources and lacking time resolution of the emission data that are causing opposite model biases in simulated BC concentrations in the Arctic and in the mid-latitudes.

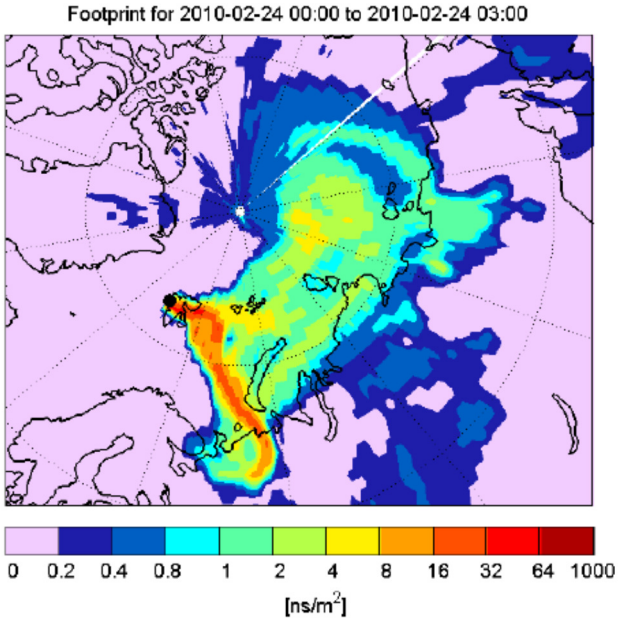

Figure 5.1. *Map of the footprint emission sensitivity simulated by FLEXPART with ECMWF data of the BC aerosol tracer, for the air mass arriving at the Zeppelin station between 00:00 and 03:00UTC on 24 February 2010. The Zeppelin station is marked with a black dot.The FLEXPART footprint emission sensitivity is high above the gas flaring region but the retroplume did not extend over any other major BC source region.*

6. Analysis of variability in atmospheric methane in the Arctic

Methane (CH4) is an important greenhouse gas (GHG) contributing 0.5 Wm-2 to radiative forcing. Since 2006, the atmospheric CH4 growth rate has increased again after fluctuating around zero for circa one decade. This change has been attributed to increased anthropogenic emissions but also to emissions from natural wetlands as a response to climate forcing. At least 25% of the wetland response in 2007 is likely from the high northern latitudes (Bousquet et al., 2011). In this study, we have analysed the causes in inter-annual variability in atmospheric CH4 mole fractions and its growth rate from 5 sites in the Arctic with long-term records (circa 10 years or more).

We found that the growth rates at the 5 sites deviated significantly from the global mean growth rate. To understand the cause of the Arctic variability in growth rate we examined the influence of transport versus emission variability. Using ECMWF ERA-interim data in the Lagrangian Particle Dispersion model, FLEXPART, we have analysed the influence of atmospheric transport to the sites: Barrow in Alaska, Zeppelin in Svalbard, and Pallas in Finland for the period 2001 to 2012. This was done by calculating 3-hourly backwards-in-time trajectories, which were followed for 20 days, and calculating the residence time of virtual particles in the surface layer to determine spatio-temporal patterns the site footprints. We then used k-means cluster analysis to group the transport patterns and determine changes in occurrence frequency of these patterns over the study period. We found that there was an anomaly in transport in 2007, a particularly warm year in the Arctic, but no significant anomalies in other years nor any evidence of a trend (Thompson et al., 2014). On the other hand, we found a significant positive correlation of the growth rate at Zeppelin, Pallas and Barrow with summer mean temperature area-weighted for the region of Western Siberia (for Zeppelin and Pallas) and Northern Canada and Alaska (for Barrow), both regions with large wetland extents. This suggests that surface temperature is an important factor driving wetland emissions of CH4 in the Arctic on large-scales and which has an influence on the atmospheric variability. This study was published in 2014.

References

Bousquet et al., Source attribution of the changes in atmospheric methane for 2006-2008, Atmos. Chem. Phys., 11, 3689-3700, 2011.
Thompson et al., Analysis of variability in atmospheric methane in the Arctic, Geophysical Research Abstracts, 16, EGU2014-10405, 2014.

7. Impact of meteorological clouds on detection and retrieval of volcanic ash during the Eyjafjallajokull 2010 eruption: A modelling study.

Volcanic ash is commonly detected by infrared detectors in space using variations of the reverse absorption technique, which explores the brightness temperature difference between the 10.8 and 12.0 micrometer regions of the thermal spectrum. Several factors affect the infrared detection and retrieval of volcanic ash, including the altitude (temperature) of the ash cloud, the surface temperature, and particle density, size distribution and shape. In addition the presence of ice and/or liquid water clouds may change the brightness temperature difference and affect the retrieval of ash cloud mass loading.

The effect of ice and liquid water clouds on detection and retrieval of volcanic ash may not readily be estimated based on experimental methods. This is due to the inherent problem in comparing overcast and cloudless cases and the need for in-situ ice and liquid water cloud information together with volcanic ash cloud information. Thus a model-based approach was adopted based on simulated 10.8 and 12.0 micrometre Spinning Enhanced Visible and Infrared Imager (SEVIRI) images representing the Eyjafjallajokull 2010 eruption. SEVIRI images were simulated by the MYSTIC 3-D radiative transfer model which was run within the libRadtran model framework (Mayer and Kylling, 2005). Input to the simulations were:
(i) Ash concentrations calculated by the Flexpart dispersion model (Stohl et al., 2011). The ash concentration was calculated with a horizontal resolution of 0.25 times 0.25 degrees and a vertical resolution of 250 m for 25 particle size classes with radii in the range 0.125-125 micrometer.

(ii) Liquid water and ice clouds from European Center Medium-Range Weather Forecasting (ECMWF) analysis data. The horizontal resolution is 0.25 times 0.25 degress and in the vertical data are provided at 91 model levels. The ECMWF data were interpolated to the Flexpart resolution (Kylling et al., 2013).
(iii) Surface and atmospheric temperatures were taken from ECMWF analysis.

From the simulate images the ash mass loading may be estimated assuming the ash composition and hence the extinction efficiency and density is known, and estimates of the ash cloud optical depth and effective radius are available. The ash cloud optical depth and effective radius were retrieved using a modification of the Bayesian optimal estimation technique. Simulated SEVIRI brightness temperatures at 10.8 and 12.0 micrometre were the ``observational" input to the retrieval. Surface and ash cloud temperatures, needed for the retrieval, were estimated from the 12.0 micrometre images. LibRadtran was used as the forward model (Mayer and Kylling, 2005). Ash mass loading retrieved from simulated images are shown in Figure 7.1a and 7.1b. The retrieval based on cloudless simulated images (Figure 7.1a) resembles the Flexpart ash distribution used as input. Including ECMWF meteorological clouds causes both over- and under-estimates of the ash mass loading (Figure 7.1b and 7.1c).

Conclusions
* SEVIRI IR images have been simulated for the complete Eyjafjallajokull 2010 eruption.
* Meteorological clouds were included using data from ECMWF.
* The presence of meteorological clouds mostly led to identification of fewer ash affected pixels. However, for some cases more ash pixels were identified in the presence of meteorological clouds.
* Dispersed and thinned ash cloud are most likely to go undetected.
* Meteorological clouds implied that ash mass loading was often overestimated.
* The results suggest that a two-layer retrieval is needed to further improve ash mass loading estimates.

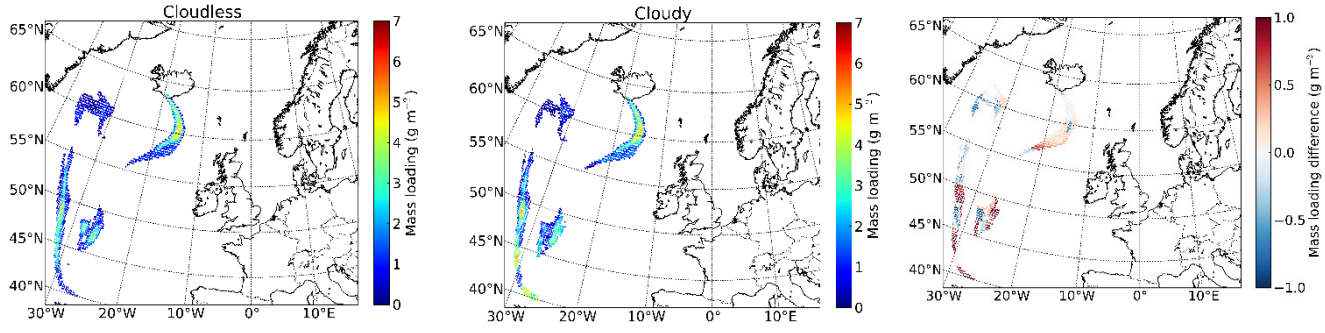

Figure 7.1: a) The ash mass loading retrieved from cloudless simulated SEVIRI images. b) The ash mass loading retrieved from simulated SEVIRI images including meteorological clouds. c) *The difference between the ash mass loading retrieved from the cloudy and cloudless simulations. All data representative for 1800 UTC, 8 May, 2010.*

References
Mayer, B., and A. Kylling, Technical note: the libRadtran software package for radiative transfer calculations-description and examples of use, Atmos. Chem. Phys., 5, 1855-1877, 2005.
Kylling, A. and Buras, R. and Eckhardt, S. and Emde, C. and Mayer, B. and Stohl, A., Simulation of SEVIRI infrared channels: a case study from the Eyjafjallajokull April/May 2010 eruption, AtmosphericMeasurement Techniques, 6, 649-660, doi: 10.5194/amt-6-649-2013, 2013.
Stohl, A., et al. (2011) Determination of time- and height-resolved volcanic ash emissions for quantitative ash dispersion modeling: The 2010 Eyjafjallajokull eruption, Atmos. Chem. Phys., 11, 4333-4351, doi:10.5194/acp-11-4333-2011.

8. Source term inversions of the Grimsvötn-2011 eruption

Moxnes (2014) used an inversion method to estimate the source terms for SO_2 and ash from the Grímsvötn eruption in May 2011. The method takes input from a dispersion model and satellite observations as well as several a priori source estimates. The Lagrangian particle dispersion model, FLEXPART, run on two different meteorological analysis data sets (ECMWF and GFS), was used to simulate the transport of ash and SO_2 emitted by the eruption. Simulations were carried out for a large number of emission times and altitudes above the volcano where the particles were released and subsequently tracked in the model atmosphere. Modelled total atmospheric columns from the various emission times and altitudes were compared with satellite observations from two different satellite instruments (IASI and SEVIRI). The misfit between the observations and the model results was minimized by making a linear combination of the emissions from the different times and altitudes. In this way, a source term for the volcanic emissions was obtained. The inversion method was performed for SO_2 and ash separately. The inverted source terms for Grímsvötn (Figure 8.1) showed that the SO_2 was emitted mostly to high altitudes (from 8-12 km) over a period of about 21 hours (21 May 21 UTC to 22 May 18 UTC). The ash was emitted mostly to low altitudes (below 5 km) in several emission pulses during roughly 51 hours over the time period 21 May 12 UTC to 23 May 15 UTC. Some ash was also emitted to higher altitudes together with the SO_2. FLEXPART forward simulations using ECMWF data were performed using the inverted source terms for ash and SO2 to examine the similarities and differences in the subsequent transport patterns of the two substances. The transport simulations showed that the SO_2 was transported mostly north-westward and the ash mostly south-eastward. This corresponded well with independent satellite observations from GOME-2 and SCIAMACHY (for SO_2) and measured aerosol mass concentrations at different surface stations in Scandinavia (for ash). The study demonstrated that the inversion method, in this case, was able to distinguish between emissions and transport of SO_2 and ash. The method is useful for improving the forecasts of ash and SO_2 in case of volcanic eruptions, which will aid aviation and help evaluate any potential climate impacts.

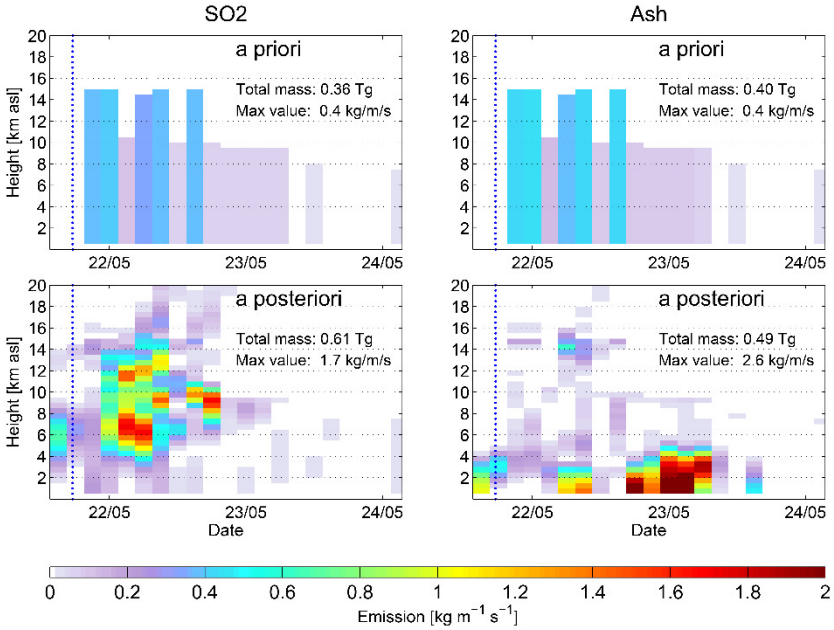

Figure 8.1: Volcanic source terms for the Grimsvötn 2011 eruption as estimated with the inversion method for SO_2 (left) and ash (right). The source terms have been estimated using an inverse modelling framework which takes input from FLEXPART run on ECMWF meteorological data.

9. Atmospheric transport in historical climate and future climate scenarios is studied from coupling of the NorESM model with FLEXPART

During the EarthClim project (http://folk.uib.no/ngfhd/EarthClim/Publications/publications.html) the Norwegian Earth System Model (NorESM, e.g. Bentsen et al. 2013) has been coupled with the FLEXPART Lagrangian stochastic particle model. This modelling system allows the study of Atmospheric transport characteristics in future climate scenarios, taking advantage of the unique diagnostic possibility offered by a fully Lagrangian approach. Daily based, 30 days backward in time, simulations have been performed for the years 1990 to 2070 for several measurement stations in the arctic and Antarctic. This allows investigating the variability of transport patterns to the Polar Regions in the future climate scenario. The historical part of these simulations will be compared during the EVA project (http://www.bjerknes.uib.no/pages.asp?kat=187&lang=2) to similar simulations performed using the FLEXPART model driven by ECMWF meteorological data. In addition, the transport of moisture towards Northern Europe within the NorESM climate model will be investigated for selected periods and for the historical periods, it will be compared to the transport of moisture obtained from ECMWF meteorological data. In both cases an established water source diagnostic (Stohl anpd James, 2004) based on the FLEXPART model will be used.

References

Bentsen, M., Bethke, I., Debernard, J. B., Iversen, T., Kirkevåg, A., Seland, Ø. Drange, H., Roelandt, C., Seierstad, I. A., Hoose, C., and Kristjansson, J. E. (2013): The Norwegian Earth System Model, NorESM1-M - Part 1: Description and basic evaluation of the physical climate, Geosci. Model Dev., 6, 687-720, doi:10.5194/gmd-6-687-2013.

Stohl, A; James, P. A (2004): Lagrangian analysis of the atmospheric branch of the global water cycle. part I: Method description, validation, and demonstration for the August 2002 flooding in central Europe.JOURNAL OF HYDROMETEOROLOGY 5, 656-678

List of publications/reports from the project with complete references

1. **Stohl**, A., Prata, A. J., Eckhardt, S., Clarisse, L., Durant, A., Henne, S., Kristiansen, N. I., Minikin, A.,Schumann, U., Seibert, P., Stebel, K., Thomas, H. E., Thorsteinsson, T., Tørseth, K., and Weinzierl, B.: Determination of time- and height-resolved volcanic ash emissions and their use for quantitative ash dispersion modeling: the 2010 Eyjafjallajökull eruption, Atmos. Chem. Phys., 11, 4333-4351, doi:10.5194/acp-11-4333-2011, 2011
2. **Kristiansen**, N. I., A. Stohl, F. Prata, N. Bukowiecki, H. Dacre, S. Eckhardt, S. Henne, M. Hort, B. Johnson, F. Marenco, B. Neininger, O. Reitebuch, P. Seibert, D. Thomson, H. Webster, B. Weinzierl (2012), Performance assessment of a volcanic ash transport model mini-ensemble used for inverse modelling of the 2010 Eyjafjallajökull eruption, Journal of Geophysical Research, 117, D00U11, doi:10.1029/2011JD016844.
3. **Stohl**, A., P. Seibert, G. Wotawa, D. Arnold, J. F. Burkhart, S. Eckhardt, C. Tapia, A. Vargas, and T. J. Yasunari (2012), Xenon-133 and caesium-137 releases into the atmosphere from the Fukushima Dai-ichi nuclear power plant: determination of the source term, atmospheric dispersion, and deposition, Atmospheric Chemistry and Physics, 12(5), 2313-2343, doi:10.5194/acp-12-2313-2012.
4. **Kylling**, A., Buras, R., Eckhardt, S., Emde, C., Mayer, B., and Stohl, A.: Simulation of SEVIRI infrared channels: a case study from the Eyjafjallajökull April/May 2010 eruption, Atmos. Meas. Tech., 6, 649-660, doi:10.5194/amt-6-649-2013, 2013.
5. **Moxnes**, E.: Estimating the sulphur dioxide and ash emissions from the Grímsvötn 2011 volcanic eruption and simulating their transport across Northern Europe, Master Thesis in Geosciences, Faculty of Mathematics and Natural Sciences, University of Oslo, 1 June, 2013
6. **Stohl**, A., Klimont, Z., Eckhardt, S., and Kupiainen, K.: Why models struggle to capture Arctic Haze: the underestimated role of gas flaring and domestic combustion emissions, Atmos. Chem. Phys. Discuss., 13, 9567-9613, doi:10.5194/acpd-13-9567-2013, 2013.
7. **Thompson**, R., A. Stohl, Report for the project Sources of Greenhouse Gases in East Asia (SOGG-EA) financed by the Norwegian Research Council under the framework NORKLIMA, project number 193774, June 2013Thompson et al. (2014), Analysis of variability in atmospheric methane in the Arctic, Geophysical Research Abstracts, 16, EGU2014-10405, 2014
8. **A. Kylling** (2014), Impact of meteorological clouds on detection of volcanic ash during the Eyjafjallajökull 2010 eruption: A modelling study, Geophysical Research Abstracts, 16, EGU2014-2943, 2014

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

ECMWF data will be continued to be used within the various inversion frameworks for estimating greenhouse gas emissions, radionuclide emissions and volcanic emissions, and subsequent FLEXPART transport simulations using the inverted sources. Historical transport simulations with FLEXPART using ECMWF data will be compared with transport simulations using input from the NorESM model, particularly moisture transport will be investigated.

The continuing activities are linked to the follow-up SPNOFLEX project:
FLEXPART transport simulations and inverse modelling of atmospheric components