SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2015
Project Title:	FLEXPART transport simulations and inverse modelling of atmospheric components
Computer Project Account:	SPNOFLEX
Principal Investigator(s):	Nina Iren Kristiansen
Affiliation:	NILU- Norwegian Institute for Air Research
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Sabine Eckhardt, Massimo Cassiani, Rona Thompson, Thomas Hamburger, Henrik Grythe, Ignacio Pisso, Arve Kylling, Andreas Stohl
Start date of the project:	2015
Expected end date:	2017

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	50000		50000	3292
Data storage capacity	(Gbytes)	150		150	150

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 any)

(20 lines max)

……………………………………………………………………………………………………

Summary of results of the current year (from July of previous year to June of current year)

This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

3 main topics within our research have used and analysed ECMWF data in the previous year:

1. Modelled and measured distribution of short-lived climate forcers (SLCFs) in the Arctic
2. Source term inversions of the Kelut-2014 eruption
3. Black Carbon (BC) calculations in the frame of the SLICFONIA project

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

1. *Modelled and measured distribution of short-lived climate forcers (SLCFs) in the Arctic*

FLEXPART model simulations run on ECMWF meteorological data were included in a model-intercomparison studying short-lived climate forcers (SLCFs) in the Arctic. The model data were compared to SLCF measurements at several Arctic surface sites from the years 2008-2009. Model results were taken from the suite of AMAP and ECLIPSE (see www.eclipse.no) models which have performed simulations for the years 2008-2009 using a consistent set of emission inventories (ECLIPSE V4a). Inter-model differences in the simulated distributions of aerosols are thus only due to differences in meteorological input data (or modelled climate realization in case of free-running GCMs), resolution, numerical schemes and model physics and chemistry.

Measurements throughout the Arctic have repeatedly shown that aerosol concentrations (including BC and sulfate) near the surface peak in winter/early spring – the phenomenon is known as Arctic Haze – and are lowest in early autumn. At the five sites with continuous EBC monitoring, the EBC concentrations are comparable, with monthly median values of about 20-80 ng m^{-3} in late winter/early spring and of less than 10 ng m^{-3} in summer/early autumn (see **Fig. 1**). The seasonality is least strong at the southernmost site, Pallas, where the summer concentrations are about twice as high as at the other sites, reflecting a decrease of the seasonal minimum with latitude. While the aerosol concentrations in the Arctic during late winter/early spring are comparable to remote regions further south, the concentrations in summer/early autumn are lower because of the effective cleansing of the atmosphere. The highest EBC concentrations were observed in January (Alert), February (Barrow), March (Pallas) or April (Zeppelin, Station Nord), with no clear relationship between time of the maximum and latitude; however, the maximum occurred earlier at the two North American sites than at the other sites.

The models capture the Arctic BC concentrations with variable success (**Fig. 1**). There is clear progress since earlier studies, where most models produced a wrong seasonality and systematically under-predicted the Arctic Haze concentrations. In this study, most models capture the much higher concentrations in winter/spring compared to summer/autumn, and some models can approximately reproduce the concentrations reached during the Arctic Haze season. However, there is still a surprising variability between individual models, with seasonal median values varying by about an order of magnitude both in spring and summer even when excluding the most extreme models (see **Table 1**). Some models still under-predict the high BC concentrations during the Arctic Haze season and over-predict the low concentrations in summer. Also, the model deficiencies get worse with increasing latitude. For instance, at the northernmost site, Alert (82.5°N), all models under-predict concentrations for the full duration of the Arctic Haze season from January until April.

Table 1. Model overview

Model Name	Model Type[1]	Horizontal/vertical	Meteorological fields	Years simulated/temporal resol. output	Reference
FLEXPART	LPDM	-	ECMWF	2008,2009 3h	Stohl et al. (2005)
OsloCTM2	CT	2.8°x2.8°, 60L	ECMWF Reanalysis	2008, 2009	Guenther et al. (1995), Myhre et al. (2009), Skeie et al. (2011)
NORESM	CCM	1.9°x2.5°, 26L	Internal	2008,2009	Kirkevåg et al. (2013), Bentsen et al. (2013)
TM4	CT	2°x3°, 34L	ECMWF ERA-interim	2008, 2009 24h	Myriokefalitakis et al., (2011); Kanakidou et al., (2012); Daskalakis et al,(2014)
ECHAM6	CCM	1.8° x 1.8°, 31L	ECMWF Reanalysis	2009	Stevens et al. (2013), Zhang et al (2012)
SMHI-MATCH	CT	.57°x.75°, 38L	ECMWF	2008,2009	Andersson et al. (2007), Robertson et al. (1999)
CanAM4.2/PAM	CCM	2.8°x2.8°, 49L	Nudged to ECMWF temp.and winds	2008, 2009	Von Salzen et al (2013), von Salzen (2006)
DEHM	CT	150km <60° N 50km >60°N, 29L	NCEP	2008,2009	Christensen (1997), Brandt et al. (2012)
CAM5.2	CCM	0.9°x1.12°, 30L	Internal, SST presc.	2008,2009	Liu et al. (2012), Wang et al. (2013), Flanner et al. (2009)
WRF-Chem	CT	0.75°x0.75°, 38L	Nudged to FNL	2009	Grell et al. (2005), Zeveri et al. (1999), Zeveri et al. (2008)

[1] Chemistry transport model (CT), Lagrangian particle dispersion model (LPDM), chemistry climate model (CCM)

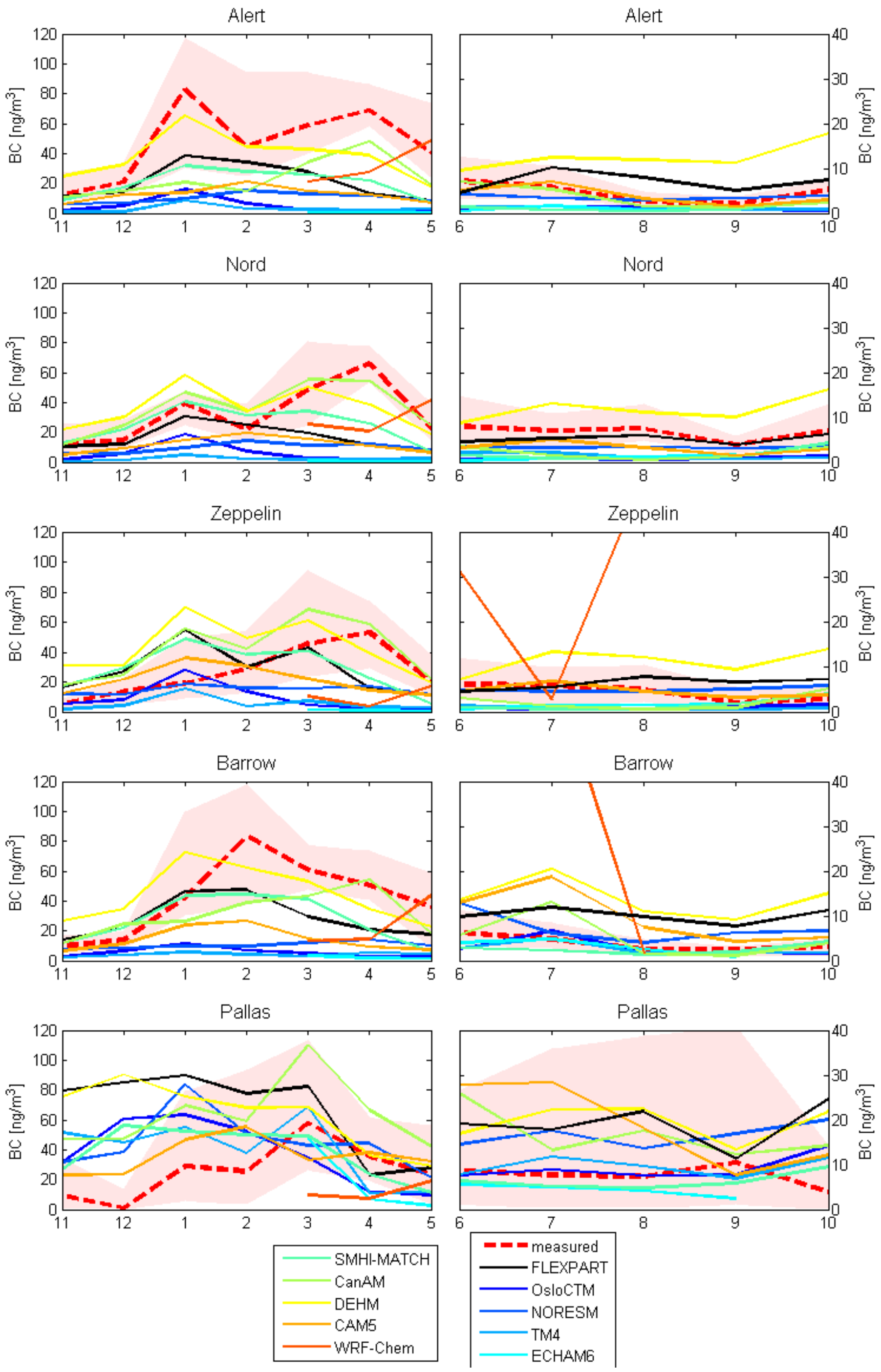

Figure 1. Seasonal variation of observed equivalent and modelled BC concentrations at five stations for winter/spring (left column, months shown on x-axis) and summer/fall (right column, notice different scale for BC between left and right panels). The red dashed line is the observed median, the light red shaded areas indicate the range from the 25th to the 75th percentile. Different colored lines show the modelled monthly median values.

Reference:

Eckhardt et al : Current model capabilities for simulating black carbon and sulfate concentrations in the Arctic atmosphere: a multi-model evaluation using a comprehensive measurement data set, Atmos. Chem. Phys. Discuss., 15, 10425-10477, doi:10.5194/acpd-15-10425-2015, 2015.

2. Source term inversions of the Kelut-2014 eruption

Kristiansen et al. (2015) used an inversion method to estimate the source term for ash from the Kelut (Java, Indonesia) eruption in February 2014. 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 driven with high-resolution (0.1° × 0.1°) 1-hourly ECMWF analysis data, was used to simulate the transport of ash 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 the Geostationary IR satellite data from Japan's second Multifunctional Transport Satellite (MTSAT 2) acquired at hourly intervals. 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.

Mount Kelut (Indonesia) erupted explosively around 15:50 UT on 13 February 2014 sending ash and gases into the stratosphere. Satellite ash retrievals and dispersion transport modeling were combined within an inversion framework to estimate the volcanic ash source term and to study ash transport. The estimated source term suggests that most of the ash was injected to altitudes of 16–17 km, in agreement with space-based lidar data. Modeled ash concentrations along the flight track of a commercial aircraft that encountered the ash cloud indicate that it flew under the main ash cloud and encountered maximum ash concentrations of 9±3 mg m−3, mean concentrations of 2±1 mg m−3 over a period of 10–11 min of the flight (**Fig. 2**) , giving a dosage of 1.2±0.3 g s m−3. Satellite data could not be used directly to observe the ash cloud encountered by the aircraft, whereas inverse modeling revealed its presence. 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.

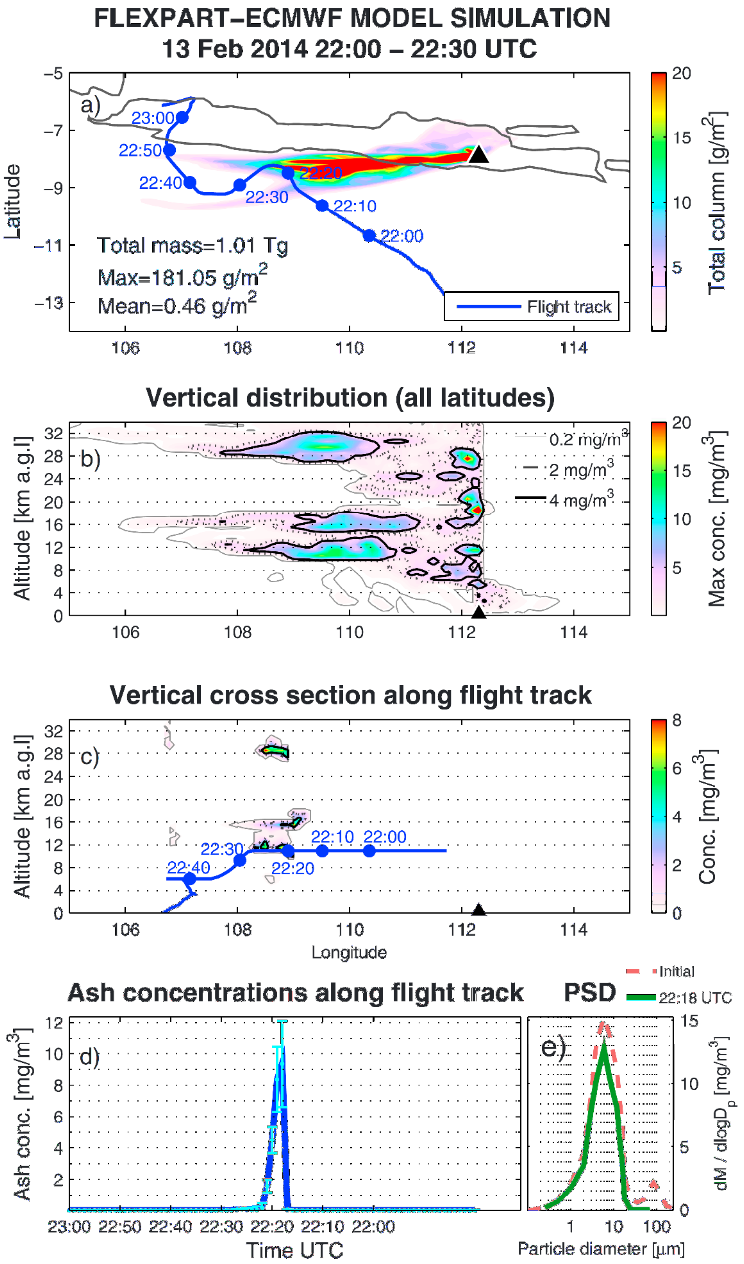

Figure 2. Modeled ash clouds: (a) FLEXPART-modeled total ash columns of fine ash. The model is driven with high-resolution (0.1° × 0.1°) 1-hourly ECMWF analysis data . The blue line is the flight track of the aircraft that encountered the ash cloud, and the Kelut volcano is marked by a black triangle. (b) Modeled vertical distribution of fine ash (the maximum concentrations across all latitudes are shown), (c) modeled vertical cross section along the flight track, (d) modeled ash concentrations, with error bars (turquoise), along the flight track, and (e) the modeled ash PSD at the time of the maximum modeled ash concentration along the flight track at 22:18 UTC and released at the source (initial).

Reference:

Kristiansen, N. I., A. J. Prata, A. Stohl and S. A. Carn (2015): Stratospheric volcanic ash emissions from the 13 February 2014 Kelut eruption, Geophys. Res. Lett., 42, doi:10.1002/2014GL062307.

3.Black Carbon (BC) calculations in the frame of the SLICFONIA project

Calculated emission sensitivity of BC using the FLEXPART model nudged with ECMWF ERA Interim are estimated for the Arctic environment (**Fig. 3**). Five stations located in the Arctic (Nord, Alert, Barrow, Tiksi and Zeppelin marked in blue) have been used for the year 2010. Total sensitivity has been averaged for June 2010 in the figure shown below. The results have been obtained for the SLICFONIA (Emissions of Short-Lived Climate Forcers near and in the Arctic) project (web: https://ch02120.wordpress.com).

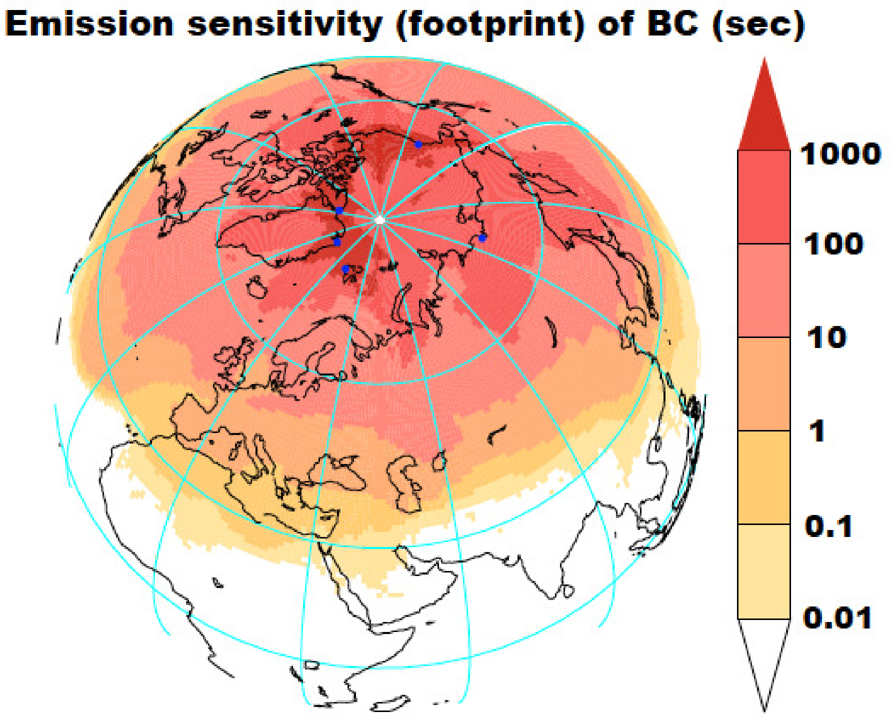

Figure 3. Average "footprint" of BC over the Arctic for June 2010.

For justification of the currently known sources of BC in the Northern Hemisphere, the results are compared with real-time observations for 2010 from the five Arctic stations. ECLIPSE (Evaluating the CLimate and Air Quality ImPacts of ShortlivEd Pollutants) project emission dataset described in Klimont et al. (2013) and available through the ECLIPSE project website (http://eclipse.nilu.no) upon request were used for the calculation of surface concentrations of BC. The anthropogenic component of the emission dataset used in this work has been developed with the GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model (Amann, 2011, see http://gains.iiasa.ac.at). The results are shown in **Fig. 4**.

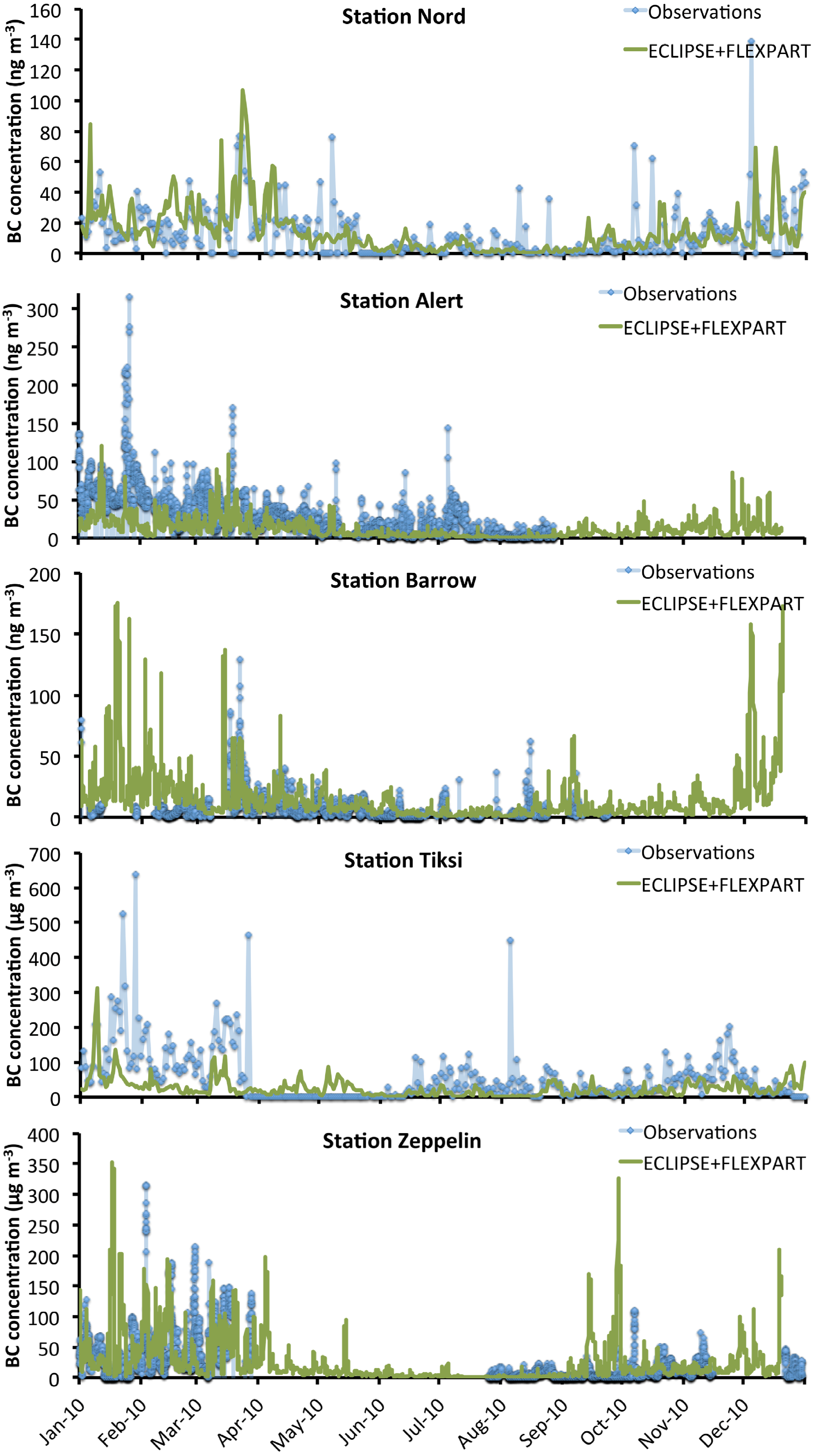

Figure 4: Comparison of observed and modelled BC concentrations at five stations in the Arctic. The FLEXPART model simulations are driven with ECMWF ERA-Interim data.

References

Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., Klimont, Z., Nguyen, B., Posch, M., Rafaj, P., Sander, R., Schöpp, W., Wagner, F., and Winiwarter, W.: Cost-effective control of air quality and greenhouse gases in Europe: modeling and policy applications, Environ. Mod. Software, 26, 1489–1501, doi:10.1016/j.envsoft.2011.07.012, 2011.

Klimont, Z., Kupiainen, K., Heyes, Ch., Purohit, P., Cofala, J., Rafaj, P., and Schoepp, W.: Global anthropogenic emissions of particulate matter, in preparation, 2013.

List of publications/reports from the project with complete references

1. **Kristiansen**, N. I., A. J. Prata, A. Stohl and S. A. Carn (2015): Stratospheric volcanic ash emissions from the 13 February 2014 Kelut eruption, Geophys. Res. Lett., 42, doi:10.1002/2014GL062307.
2. **Cassiani**, M., A. Stohl, and J. Brioude (2015): Lagrangian stochastic modeling of dispersion in the convective boundary layer with skewed turbulence conditions and a vertical density gradient: Formulation and implementation in the FLEXPART model. Accepted by Bound.-Layer Met. 154, 367-390, doi: 10.1007/s10546-014-9976-5.
3. **Thompson**, R. L., and A. Stohl (2014): FLEXINVERT: an atmospheric Bayesian inversion framework for determining surface fluxes of trace species using an optimized grid. Geophys. Mod. Dev. 7, 2223-2242, doi:10.5194/gmd-7-2223-2014
4. **Kylling**, A., N. Kristiansen, A. Stohl, R. Buras-Schnell, C. Emde, and J. Gasteiger (2015): A model sensitivity study of the impact of clouds on satellite detection and retrieval of volcan-ic ash. Atmos. Meas. Techn. 8, 1935-1949, doi:10.5194/amt-8-1935-2015
5. **Eckhardt**, S., Quennehen, B., Olivié, D. J. L., Berntsen, T. K., Cherian, R., Christensen, J. H., Collins, W., Crepinsek, S., Daskalakis, N., Flanner, M., Herber, A., Heyes, C., Hodnebrog, Ø., Huang, L., Kanakidou, M., Klimont, Z., Langner, J., Law, K. S., Massling, A., Myriokefalitakis, S., Nielsen, I. E., Nøjgaard, J. K., Quaas, J., Quinn, P. K., Raut, J.-C., Rumbold, S. T., Schulz, M., Skeie, R. B., Skov, H., Lund, M. T., Uttal, T., von Salzen, K., Mahmood, R., and Stohl, A.: Current model capabilities for simulating black carbon and sulfate concentrations in the Arctic atmosphere: a multi-model evaluation using a comprehensive measurement data set, Atmos. Chem. Phys. Discuss., 15, 10425-10477, doi:10.5194/acpd-15-10425-2015, 2015.

Summary of plans for the continuation of the project

(10 lines max)

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.