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	2016
Project Title:	FLEXPART transport simulations and inverse modelling of atmospheric components
Computer Project Account:	SPNOFLEX
Principal Investigator(s):	Espen Sollum
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, Espen Sollum
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	3292	50000	60300.25
Data storage capacity	(Gbytes)	150	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)

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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

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

1. Using ECMWF fields to identify source term of Chernobyl 30 years after
2. Inverse modelling of methane in the northern high latitudes
3. Comparison between FLEXPART-NorESM/CAM and FLEXPART-ECMWF
4. Examining release of methane from Arctic sea bed west of Svalbard during summer 2014

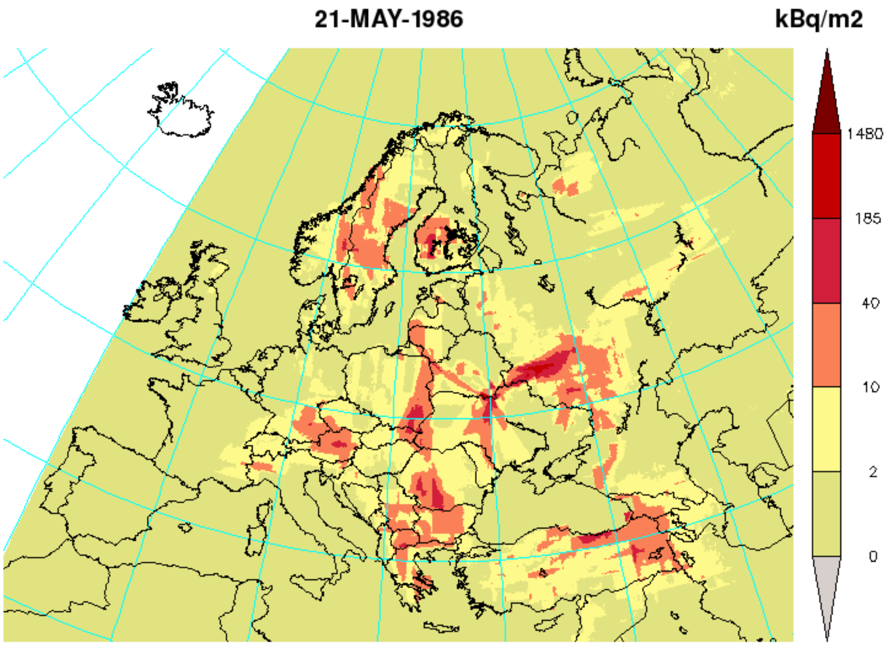
1) Using ECMWF fields to identify source term of Chernobyl 30 years after

N. Evangeliou

We used the Lagrangian particle dispersion model FLEXPART (Stohl et al., 1998; Stohl et al., 2005) to simulate transport and deposition of radionuclides. The model was originally developed for calculating the dispersion of radioactive material from nuclear emergencies, but has since been used for many other applications as well. Nuclear emergency applications include simulations of the transport of radioactive materials from NPPs and other facilities (Andreev et al., 1998; Wotawa et al., 2010) or from nuclear bomb tests (Becker et al., 2010). FLEXPART is also operationally used at the CTBTO (Comprehensive Nuclear Test Ban Treaty Organisation) for atmospheric backtracking and at the Central Institute for Meteorology and Geodynamics of Austria for emergency response.

We used ERA-40, which is an ECMWF re-analysis of the global atmosphere and surface conditions for 45-years (1957–2002) at a 125 km resolution (ECMWF, 2016a). Furthermore, we used ERA-Interim, which is a global atmospheric reanalysis from 1979, continuously updated in real time. The system includes a 4-dimensional variational analysis (4D-Var) with a 12-hour analysis window. The spatial resolution of the data set is approximately 80 km on 60 vertical levels from the surface up to 0.1 hPa (ECMWF, 2016b).

The different wind fields give a complete different shape of deposition (**Fig. 1**) that affects the inversion substantially. Therefore, it was decided that both winds would be used for the inversion. The study is still ongoing in the frame of the project STRADI (Source-Term Determination of Radionuclide Releases by Inverse Atmospheric Dispersion Modelling) of the Czech-Norwegian Research Programme (project ID: 7F14287).



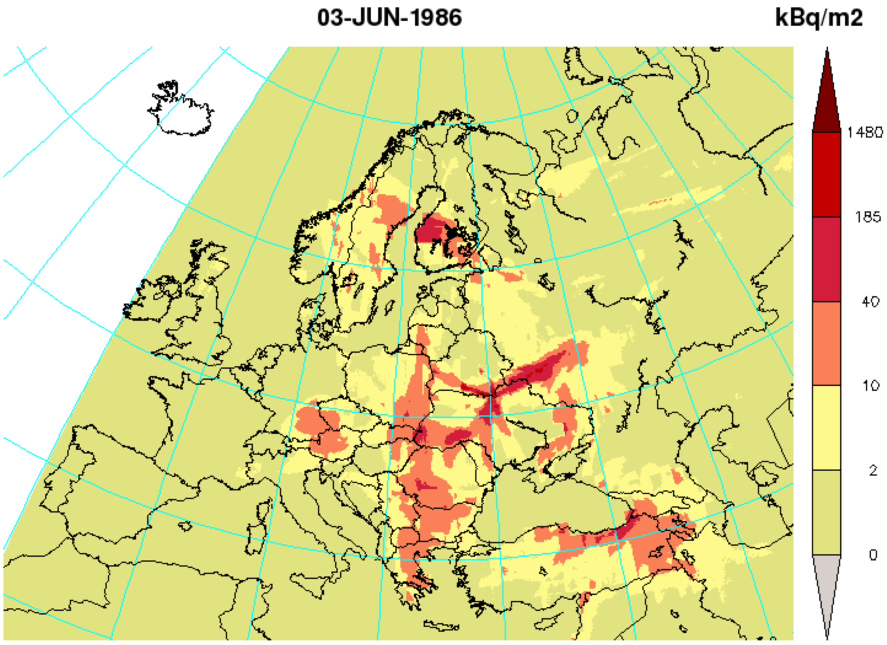


Fig. 1. Total deposition of 137Cs after the Chernobyl accident using ERA-40 and ERA-interim winds from ECMWF.

References

Stohl, A., Hittenberger, M., and Wotawa, G.: Validation of the Lagrangian particle dispersion model FLEXPART against large scale tracer experiment data, Atmos. Environ., 32, 4245–4264, 1998.

Stohl, A., Forster, C., Frank, A., Seibert, P., and Wotawa, G.: Technical note: The Lagrangian particle dispersion model FLEXPART version 6.2., Atmos. Chem. Phys., 5, 2461–2474, doi:10.5194/acp-5-2461-2005, 2005.

Andreev, I., Hittenberger, M., Hofer, P., Kromp-Kolb, H., Kromp, W., Seibert, P., andWotawa, G.: Risks due to beyond design base accidents of nuclear power plants in Europe – the methodology of Riskmap, J. Hazard. Mater., 61, 257–262, 1998.

Wotawa, G., Becker, A., Kalinowski, M., Saey, P., Tuma, M., and Z¨ahringer, M.: Computation and analysis of the global distribution of the radioxenon isotope 133133 based on emissions from nuclear power plants and radioisotope production faclities and its relevance for the verification of the Nuclear-Test-Ban treaty, Pure Appl. Geophys., 167, 541–557, 2010.

Becker, A., Wotawa, G., Ringbom, A., and Saey, P. R. J.: Backtracking of noble gas measurements taken in the aftermath of the announced October 2006 event in North Korea by means of PTS methods in nuclear source estimation and reconstruction, Pure Appl. Geophys., 167, 581–599, 2010.

ECMWF: ERA-40, daily fields, available at: http://apps.ecmwf.int/datasets/data/era40-daily/levtype=sfc/, 2016a.

ECMWF: ERA-Interim, daily fields, available at: http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/, 2016b.

2) *Inverse modelling of methane in the northern high latitudes*

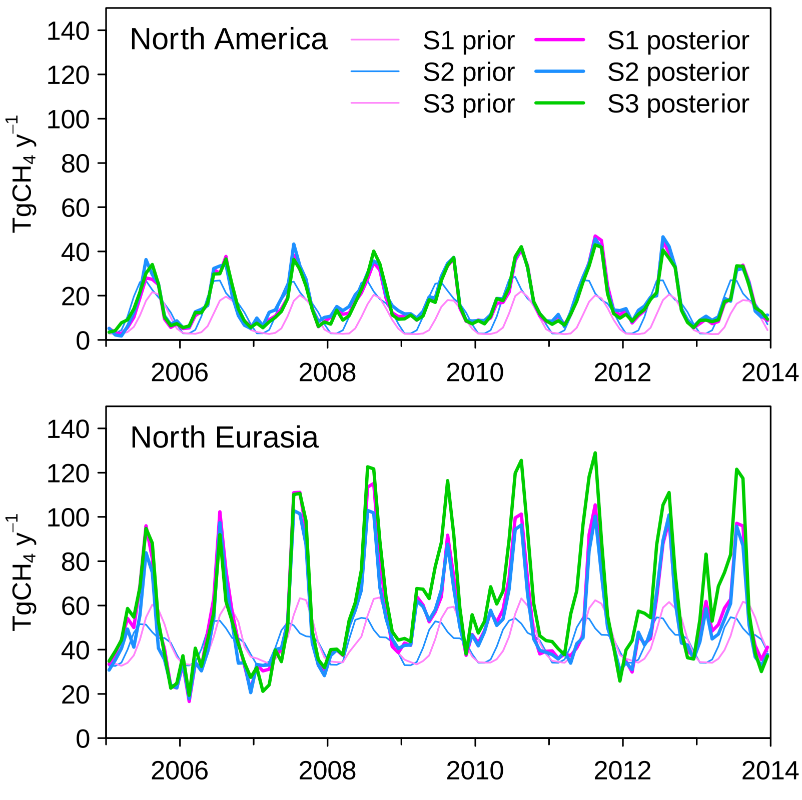
R. L. Thompson

Methane (CH_4) is the second most important anthropogenic greenhouse gas after CO_2. Atmospheric CH_4 increased from pre-industrial concentrations of around 722 ppb (parts-per-billion) to 1773 ppb in the late 1990s and then remained approximately stable until the mid 2000s. However, since 2007 atmospheric CH_4 has begun to increase again. The reasons for the stabilization and subsequent increase are likely to be a combination of changes in anthropogenic emissions such as from fossil fuels, as well as natural wetland sources. Moreover, anomalously high temperatures in the Arctic in 2007 are thought to have resulted in higher emissions and also to have contributed the high growth rate of CH_4 in the same year (Dlugokencky et al. 2009; Bousquet et al. 2011; Rigby et al. 2008). In recent decades, the high latitudes have warmed substantially with temperatures in the Arctic increasing at an average rate of 0.38°C per decade (Chylek et al. 2009) and the changing climate may have a considerable impact on CH_4 sources (Bridgham et al. 2013).

We have estimated CH_4 fluxes for the high northern latitudes (>50°N) from 2005 to 2013 using a Bayesian atmospheric inversion (Thompson and Stohl, 2014). The inversion incorporates observations from 17 in-situ and 5 discrete-sample sites across northern North America and northern Eurasia. Atmospheric transport is based on the Lagrangian particle dispersion model, FLEXPART, run with ECMWF Era-interim (EI) meteorological analyses. EI data was chosen over the higher resolution operational data owing to its long-term consistency. Emissions were optimized monthly and on a spatial grid of variable resolution (from 1°×1° to 8°×8°). Background concentrations were estimated by coupling FLEXPART to monthly global 2-D fields of CH_4 concentration from a bivariate interpolation of smoothed data from the NOAA ESRL network.

Our inversion finds a CH_4 source from the high northern latitudes of 80.9 to 82.5 Tg y^{-1}, constituting ~15% of the global total. For northern North America, we estimate a mean source of 16.6 to 17.9 Tg y^{-1}, which is dominated by fluxes in the Hudson Bay Lowlands and western Canada, specifically, the region of Alberta. For northern Eurasia, we find a mean source of 52.2 to 55.5 Tg y^{-1}, with a strong contribution from fluxes in the Western Siberian Lowlands for which we estimate a source of 19.3 to 19.9 Tg y^{-1}. Over the 9-year inversion period, we find significant year-to-year variations in the fluxes, which in northern North America and, specifically, in the Hudson Bay Lowlands appears to be driven at least in part by soil temperature, while in the Western Siberian Lowlands, the variability is more dependent on soil moisture.

Figure 1: Monthly area integrated fluxes (units Tg CH_4 y^{-1}) for northern North America and North Eurasia (both for the region north of 50°N). Shown are the results for three case studies, S1 and S2 use different prior fluxes, while S3 is uses a subset of the observations, which are quasi-continuous throughout the inversion period.



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Szopa, S., Yver, C., Viovy, N. and Ciais, P.: Source attribution of the changes in atmospheric methane for 2006 - 2008, Atmos. Chem. Phys, 11(8), 3689-3700, doi:10.5194/acp-11-3689-2011, 2011.
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Chylek, P., Folland, C. K., Lesins, G., Dubey, M. K. and Wang, M.: Arctic air temperature change amplification and the Atlantic Multidecadal Oscillation, Geophys. Res. Lett, 36(14), L14801, doi:10.1029/2009gl038777, 2009.
Dlugokencky, E. J., Bruhwiler, L., White, J. W. C., Emmons, L. K., Novelli, P. C., Montzka, S. A., Masarie, K. A., Lang, P. M., Crotwell, A. M., Miller, J. B. and Gatti, L. V.: Observational constraints on recent increases in the atmospheric CH4 burden, Geophys. Res. Lett, 36(18), L18803, doi:10.1029/2009gl039780, 2009.
Rigby, M., Prinn, R. G., Fraser, P. J., Simmonds, P. G., Langenfelds, R. L., Huang, J., Cunnold, D. M., Steele, L. P., Krummel, P. B., Weiss, R. F., O'Doherty, S., Salameh, P. K., Wang, H. J., Harth, C. M., Mühle, J. and Porter, L. W.: Renewed growth of atmospheric methane, Geophys. Res. Lett., 35(22), doi:10.1029/2008gl036037, 2008.
Thompson, R. L. and Stohl, A.: FLEXINVERT: an atmospheric Bayesian inversion framework for determining surface fluxes of trace species using an optimized grid, Geosci. Mod. Devel., 7, 2223-2242, doi:10.5194/gmd-7-2223-2014, 2014.

3) Comparison between FLEXPART-NorESM/CAM and FLEXPART-ECMW

M. Cassiani

Cassiani et al. (2016) presented a comparison between FLEXPART-NorESM/CAM and FLEXPART-ECMWF driven by ERA-Interim meteorology. This test also compares indirectly the climatologies of meteorological variables in NorESM (Norwegian Earth System Model) and ERA-Interim that are important for driving FLEXPART. The comparison considered one of the most common applications of global-scale Lagrangian particle models, the modelling of retroplumes. The figure below show the results obtained for the conserved tracer and for four stations at polar latitudes for JJA. The patterns for the averaged residence time of all the stations are very similar between FLEXPART-ECMWF and FLEXPART-NorESM/CAM, with extremely consistent differences between release locations.

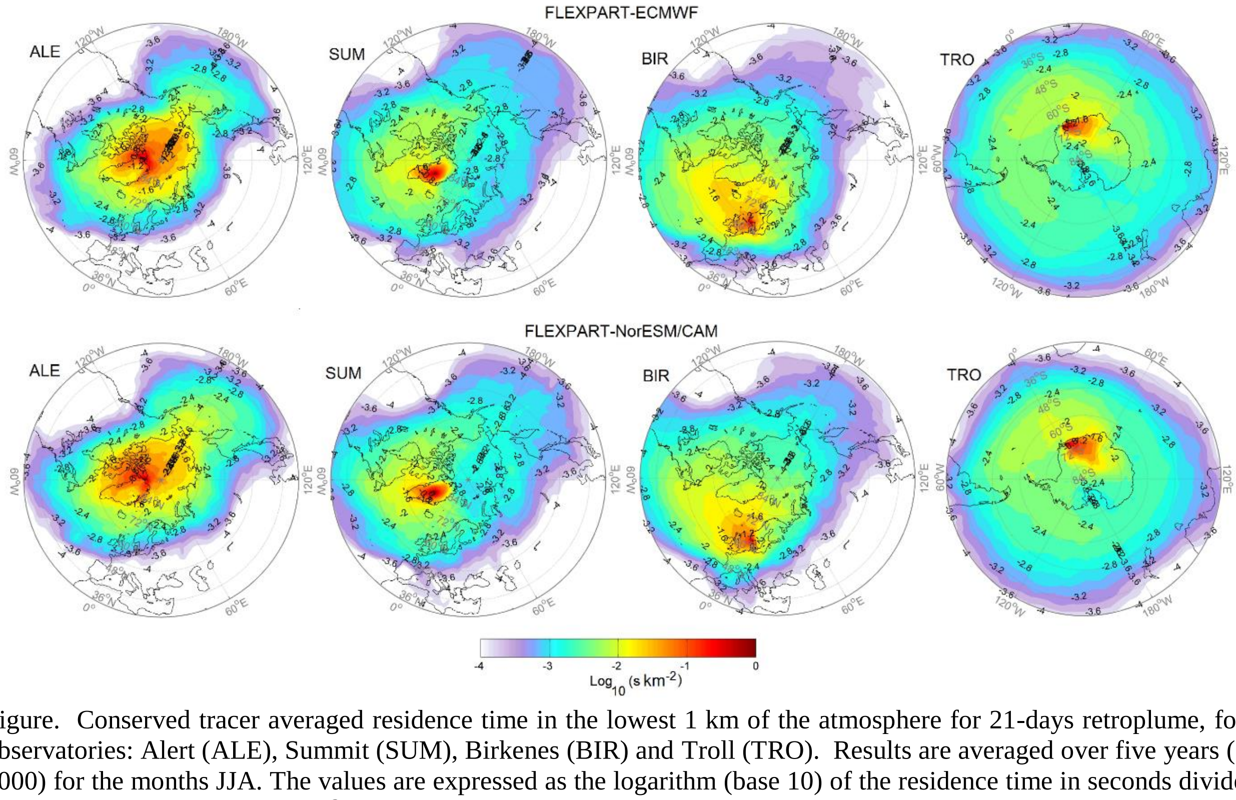

Figure. Conserved tracer averaged residence time in the lowest 1 km of the atmosphere for 21-days retroplume, for four observatories: Alert (ALE), Summit (SUM), Birkenes (BIR) and Troll (TRO). Results are averaged over five years (1995-2000) for the months JJA. The values are expressed as the logarithm (base 10) of the residence time in seconds divided for the surface of the grid cell in km^2.

Reference

Cassiani, M., Stohl, A., Olivié, D., Seland, Ø., Bethke, I., Pisso, I., and Iversen, T.: The off-line Lagrangian particle model FLEXPART-NorESM/CAM (V1): model description and comparisons with the on-line NorESM transport scheme and with the reference FLEXPART model, Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-86, in review, 2016.

4) Extensive release of methane from Arctic sea bed west of Svalbard during summer 2014

I. Pisso

Methane stored in the seabed in the form of hydrates can decompose in a warming ocean and has the potential to reach the atmosphere in bubbles or through flux of CH4 dissolved in the ocean water. To assess the atmospheric impact of oceanic emissions from the area west of Svalbard we utilized a set of measurements collected with a research aircraft, a ship and at the Zeppelin Observatory and flexpart to identify potential CH4 emission areas. We found small differences between the CH4 mixing ratios measured upwind and downwind of the potential emission areas during the campaign, suggesting that oceanic CH4 emissions produce, at most, modest atmospheric signals in this case study. By taking into account measurement and sampling uncertainties and by determining the sensitivity of the measured mixing ratios to potential oceanic emissions, we provide quantitative upper limits for the CH4 fluxes in the potential emission areas.

List of publications/reports from the project with complete references

1. Thompson, R. L., Stohl, A., Zhou, L. X., Dlugokencky, E., Fukuyama, Y., Tohjima, Y., Kim, S. -Y., Lee, H., Nisbet, E. G. and Fisher, R. E.: Methane emissions in East Asia for 2000-2011 estimated using an atmospheric Bayesian inversion, Journal of Geophysical Research: Atmospheres, doi:10.1002/2014JD022394, 2015
2. Evangeliou, N., Hamburger T., Talerko N., Zibtsev S., Bondar Yu., Stohl A., Balkanski Y., Mousseau T. A., Møller A. P. (2016), Reconstructing the Chernobyl Nuclear Power Plant (CNPP) accident 30 years after. A unique database of air concentration and deposition measurements over Europe. Environmental Pollution, accepted, DOI: 10.1016/j.envpol.2016.05.030
3. C. Lund Myhre, B. Ferré, S. M. Platt, A. Silyakova, O. Hermansen, G. Allen, I. Pisso, N. Schmidbauer, A.Stohl, J.Pitt, P.Jansson, J.Greinert, C. Percival, A.M.Fjaeraa, S.J.O’Shea, M. Gallagher, M.LeBreton, K.N.Bower, S.J.B.Bauguitt, S.Dalsøren, S. Vadakkepuliyambatta, R. E. Fisher, E.G.Nisbet, D.Lowry, G.Myhre, J.A.Pyle, M.Cain, and J. Mienert: Extensive release of methane from Arctic sea bed west of Svalbard during summer 2014 does not influence the atmosphere, Geophys. Res. Lett., 43, 4624–4631, doi:10.1002/2016GL068999.
4. Cassiani, M., Stohl, A., Olivié, D., Seland, Ø., Bethke, I., Pisso, I., and Iversen, T.: The off-line Lagrangian particle model FLEXPART-NorESM/CAM (V1): model description and comparisons with the on-line NorESM transport scheme and with the reference FLEXPART model, Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-86, in review, 2016

Summary of plans for the continuation of the project

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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.