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	July 2014 – June 2015
Project Title:	Modelling of chemistry-climate interactions
Computer Project Account:	SPNOKRIS
Principal Investigator(s):	Prof. Jon Egill Kristjansson
Affiliation:	Department of Geosciences, University of Oslo
Name of ECMWF scientist(s) collaborating to the project (if applicable)	N / A
Start date of the project:	26 March 2012
Expected end date:	31 Dec 2014

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)				
Data storage capacity	(Gbytes)				

Summary of project objectives

(10 lines max)

The overall objective of the project is to assist us in our modelling of various aspects of chemistry-climate interactions. We run the IFS model to produce meteorological input data for the off-line Chemical Transport Model *Oslo CTM3*, which is used to calculate the distribution and changes in chemically and radiatively active atmospheric compounds. These calculations are used in the EU projects ECLIPSE, ECATS and REACT4C, as well as in the international networks AeroCom and ACCMIP. We also need ECMWF reanalysis data for our high-resolution simulations of aerosol-climate and aerosol-cloud interactions using WRF-CHEM, in connection with the nationally funded projects AERO-CLO-WV, EarthClim and CRYO-MET. The objective of these studies is a better understanding and quantification of the role of aerosols in the climate system. Furthermore, we use ECMWF reanalysis data for studies of mesoscale weather phenomena, such as polar lows.

Summary of problems encountered (if any)

(20 lines max)

None.

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

a) Simulated and observed surface energy budget at Svalbard

A high resolution, one-year simulation of the atmosphere and surface conditions at the Svalbard archipelago has been performed with the Weather Research and Forecasting model, and compared with measurements of all components of the surface energy balance (Aas et al., 2015). As lateral boundary conditions, we use the ERA-Interim reanalysis, downloaded with 0.5° horizontal resolution and 6 h time steps. The model is set up with three one-way nested domains, with 9, 3, and 1 km horizontal grid spacing (Fig. 1a). In the vertical, we use 35 terrain-following layers, with 7 layers in the lowermost 1 km of the atmosphere.

For surface air temperature, a good agreement between model and observations was found across the archipelago. High correlations were also found for daily averaged surface energy fluxes within the different seasons. For the four radiation components correlation was above 0.5 in all seasons (mostly above 0.9), whereas for the sensible and latent heat fluxes it varied between 0.3 and 0.8. However, underestimation of cloud-cover or cloud optical thickness led to seasonal biases in incoming short- and long-wave radiation of up to 30%. During summer (Fig. 1b), this was mainly a result of distinct days when the model erroneously simulated cloud free conditions, whereas during winter, it seemed to be more related to an underestimation of cloud optical thickness rather than of the frequency of clouds. In addition to biases in radiation and corresponding overestimation of sensible and latent heat fluxes, the model initially overestimated the average Bowen ratio by a factor six. With two physically based model modifications related to frozen ground hydrology, this was reduced to twice the observed value due to more realistic simulation of soil moisture. The ground/snow heat flux was mostly in agreement with observations over the length of a season, but with considerable underestimation of short time variability when a thick snow pack was present.

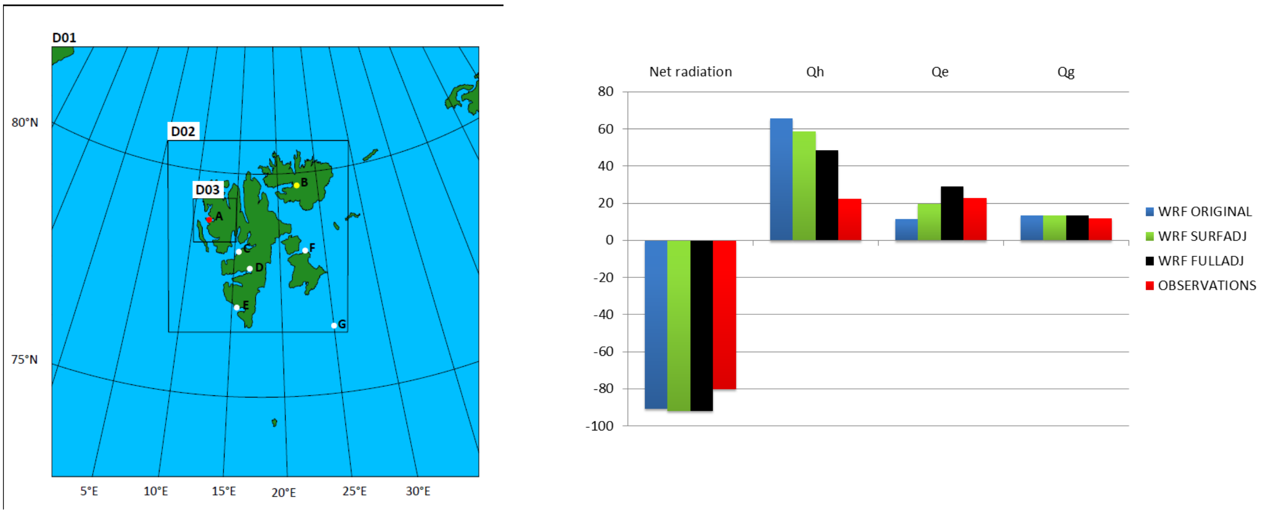

Figure 1: a) Map of WRF-domains with 9x9 km resolution (D01), 3x3 km resolution (D02) and 1x1 km resolution (D03), with the measurement sites marked as white dots. A: Bayelva/Ny-Ålesund, B: Austfonna, C: Svalbard Lufthavn, D: Sveagruva, E: Hornsund, F: Edgeøya and G: Hopen;
b) Average surface energy budget (W m^{-2}) during the summer period (July and August) from the original WRF model (blue), modified surface runoff simulation (green), modified surface and underground runoff simulation (black) and measurements (red). Q_h denotes sensible heat flux, Q_e latent heat flux and Q_g flux into the soil. From Aas et al. (2015).

b) Relative dispersion in the atmosphere from reanalysis winds

The dispersion of pairs of synthetic particles, advected with ECMWF winds, is examined (Graff et al., 2015). The particles were deployed at three latitudes and on three potential temperature surfaces in both hemispheres (Fig.2). Separation statistics are calculated and evaluated in relation to 2D turbulence theory and to Eulerian structure functions calculated directly from the wind data.

At the smallest sampled scales (100–1000 km), the pair-separation velocities are correlated, and the dispersion is laterally isotropic, at least at the higher latitudes. At larger scales, the dispersion is zonally anisotropic, and the pair velocities are uncorrelated. In all cases, the dispersion grows exponentially in time, and the second-order Eulerian structure functions consistently increase as separation squared. This implies nonlocal dispersion, which occurs with energy spectra at least as steep as K^{-3}.

Regional variations are seen in the parameters however. The *e*-folding times and the maximum scales for exponential growth are significantly larger on the 430-K surface than on the 315-K surface, and the dispersion is anisotropic at low latitudes, even at the smallest scales. Therefore, 2D homogeneous turbulence theory is applicable at best at subdeformation scales at the higher latitudes.

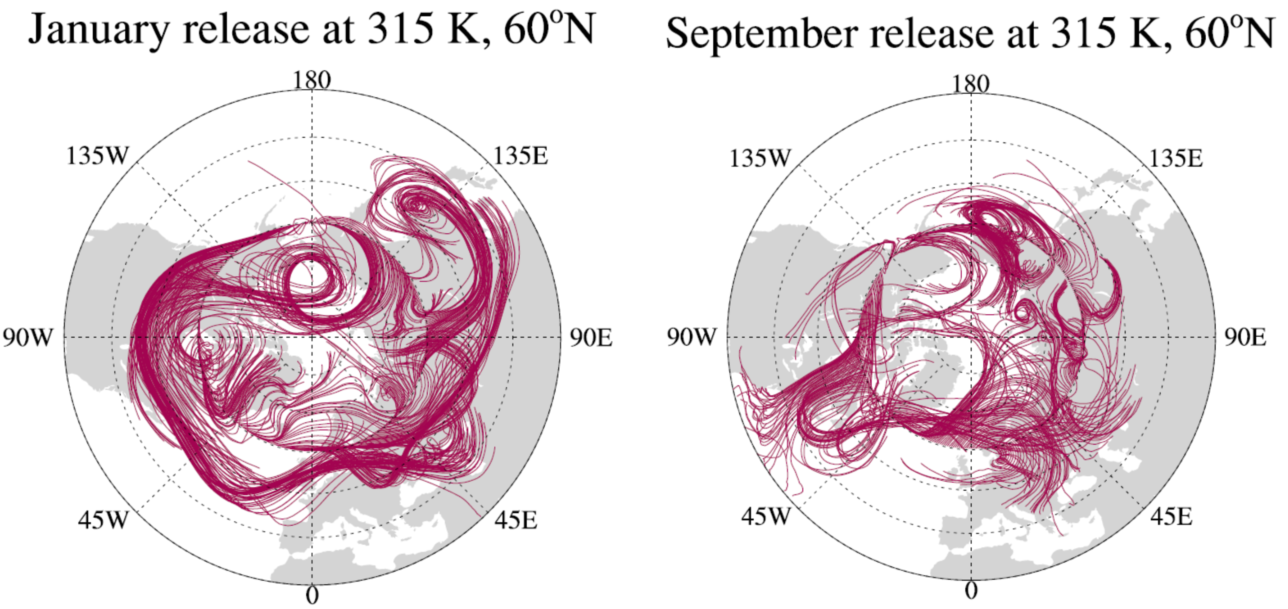

Figure 2: Trajectories of 360 (out of 1440) particles deployed in 1991 in: (left) January at 315 K and 60°N, (right) September at 315 K and 60°N. For clarity, we only show the positions for the first 4 days after deployment. Note that the minimum latitude is 30°N in both panels. From Graff et al. (2015).

c) Sensitivity of regional European boreal climate to changes in surface properties from vegetation perturbations

Amplified warming at high latitudes over the past few decades has led to changes in the boreal and Arctic climate system such as structural changes in high-latitude ecosystems and soil moisture properties. These changes trigger land–atmosphere feedbacks through altered energy partitioning in response to changes in albedo and surface water fluxes. Local-scale changes in the Arctic and boreal zones may propagate to affect large-scale climatic features. In this study, MODIS land surface data are used with the Weather Research and Forecasting model (WRF V3.5.1) and the Noah land surface model (LSM), in a series of experiments to investigate the sensitivity of the overlying atmosphere to perturbations in the structural vegetation in the northern European boreal ecosystem. Emphasis is placed on surface energy partitioning and near-surface atmospheric variables, and their response to observed and anticipated land cover changes.
We find that perturbations simulating northward migration of evergreen needle leaf forest into tundra regions (Ex1) cause an increase in latent rather than sensible heat fluxes during the summer season. Shrub expansion in tundra areas has only small effects on surface fluxes. Perturbations simulating the northward migration of mixed forest across the present southern border of the boreal forest (Ex2), have largely opposite effects on the summer latent heat flux, i.e., they lead to a decrease and act to moderate the overall mean regional effects of structural vegetation changes on the near-surface atmosphere.

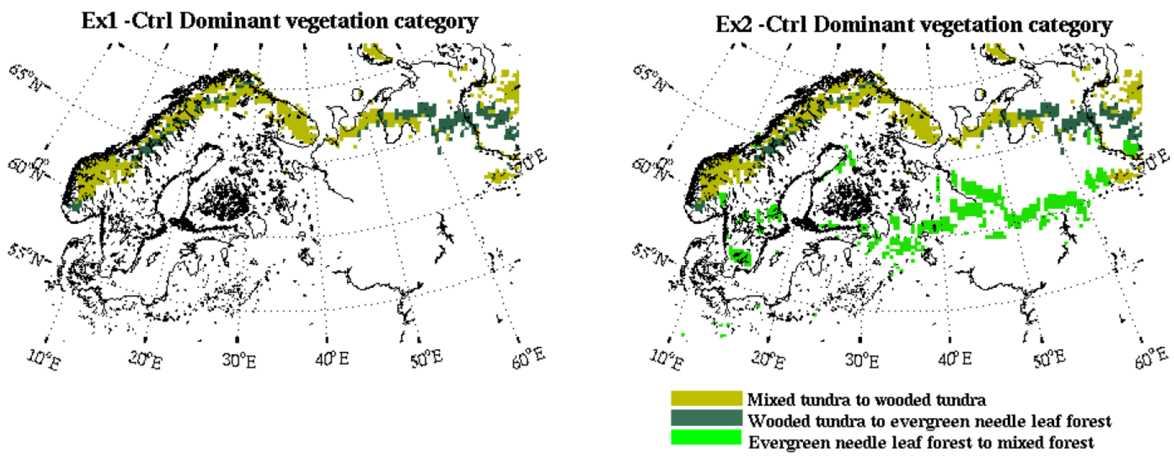

Figure 3: Changes in dominant vegetation category as compared to the control simulation for Ex 1 (left panel) and Ex 2 (right panel). The olive-green color represents areas where the dominant category is changed from mixed tundra to wooded tundra to represent shrub expansion. Light green represents areas where mixed forest has taken over evergreen needleleaf forest (only Ex 2).

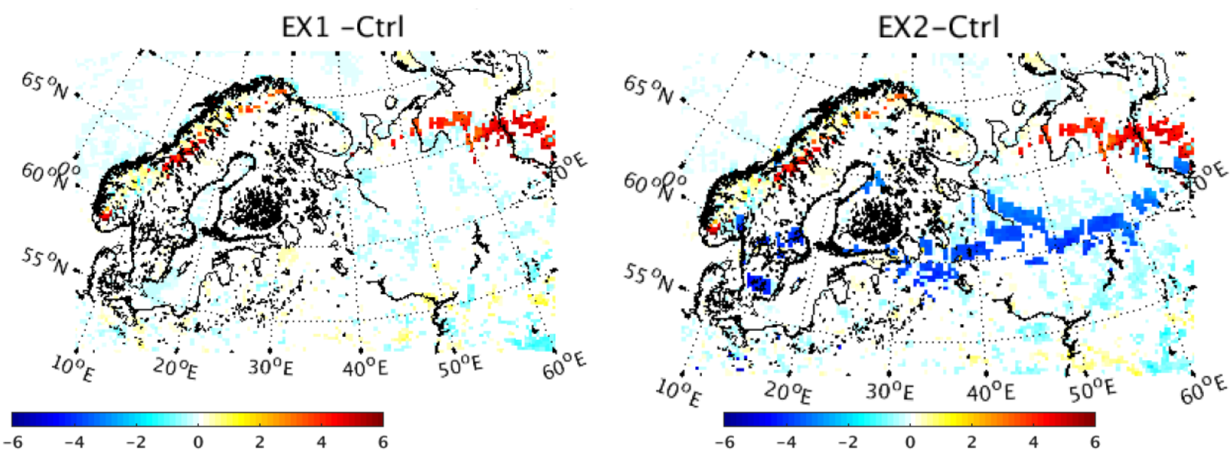

Figure 4: Changes in 10-year average latent heat flux, as compared to the control simulation (only showing significant results at the 95% confidence level). From Rydsaa et al. (2015).

d) Is there a positive feedback between Arctic stratus and Arctic sea ice changes?

The influence of diminishing sea ice and increased aerosol number concentration on low clouds over the Beaufort Sea, north of Canada and Alaska, has been investigated by use of the Weather Research and Forecasting (WRF) model (Kristiansen, 2015). The model was run for the five first days of September 2012, of which the discussion focuses on days 1 and 5. The first day is basically an off-line run, representing near instantaneous changes in clouds and radiation due to ice removal and aerosol number concentration increase, whereas by day five the atmosphere has had time to adapt to the changes that were imposed at the start of the first day.
The near-instantaneous changes as a consequence of removal of sea ice were negative in upward shortwave radiation (SW) at the top of the atmosphere (TOA) due to decreased surface albedo. There were also signs of new clouds forming, indicated by an increase in liquid water path (LWP) of 15 g/m^2. As the atmosphere adapts to the changed sea ice extent, increased precipitation release dominates over increased moisture supply from the open ocean, leading to an average decrease in LWP, -2.3 g/m^2. The average change in downward longwave flux (LW) for the domain was -0.15 W/m^2.
The near-instantaneous changes following an increase in aerosol number concentration are increases in LWP and cloud droplet number concentration (CDNC), as well as a decrease in cloud droplet size. These more numerous and smaller droplets increase the albedo of the clouds, known as the first indirect effect. The increase in LWP indicates that the clouds are also denser, which is known as the second indirect effect. Both these effects reduce the downward SW at the surface, giving a change of -9.2 W/m^2. As the atmosphere has had time to adapt, the cooling effect from reduced downward SW is evident in the surface temperature and heat fluxes, which decrease.
In this study, initially high LWP (40-300 g/m^2) weakens the enhancement of LW flux down at the surface, since the clouds are sometimes saturated with respect to LW, and the SW change therefore dominates the response to sea ice decrease and aerosol number concentration increase. The proposed positive feedback between changes in Arctic stratus and changes in Arctic sea ice extent is not confirmed by this study.

e) Timescales of surface-to-tropopause transport in the tropics, using Flexpart

The timescales of transport from the surface to the tropical tropopause layer (TTL) have been studied using the Lagrangian transport model Flexpart (Wærsted, 2015). The model was driven by the ERA-Interim reanalysis from the European Center for Medium-Range Weather Forecasts (ECMWF). Trajectories were released each month in the period 1 June 2002 - 1 May 2013 at 15 km and 17 km altitude over the whole tropics and simulated 90 days backward in time. The age of air at 15 km and 17 km relative to the last contact with the boundary layer (BL) was computed using a constant BL-height of 1 km above sea level.
The aim of the study was to give a detailed description of the tropospheric age of air in the TTL, mainly motivated by the importance of transport timescales for the entry of short-lived compounds to the stratosphere.
Several sensitivity studies were carried out. The most important of these concerned the sensitivity to the use of the convection scheme in Flexpart. In the run without the convection scheme, the median age at 15 km was 17 day longer, and at 17 km 25 days longer, than in the runs using the convection scheme. In particular, the fraction of the air at 17 km younger than 10 days decreased by an order of magnitude, from 11.1 % to 0.9 %.
For 30°S - 30°N as a whole, the median age was 26 days at 15 km and 50 days at 17 km. A seasonal cycle in the age was found at both altitudes. The seasonal cycle was most pronounced at 17 km, where the median age varied by ~14 days during the year, being highest in August and lowest in May. At both altitudes, the air was younger near the main convective areas in the tropics, such as the Intertropical Convergence Zone (ITCZ), with less young air approaching the subtropics. The air was particularly young above the tropical western Pacific; the median age there was only 16 days at 15 km and 30 days at 17 km. The air at both 15 km and 17 km was found to originate from the BL above the main convective regions in the tropics. In particular, the West and Central Pacific stood for 40-50 % of the BL-origins.
The age decreased over the period, both at 15 km and 17 km. The decrease in the annual median age during 2003-2012 was 2.0 days per decade at 15 km and 9.7 days per decade at 17 km (for 30°S - 30°N). Much of this decrease appeared to have taken place around 2009. Interannual variability in the age above the tropical Pacific in December-February (DJF) was found to be related to the El Niño-Southern Oscillation (ENSO). The air was younger above the Pacific during El Niño and older during La Niña conditions. A shift in the BL-origins above the Pacific Ocean, eastward in El Niño and westward in La Niña, was also found.

List of publications/reports from the project with complete references

Aas, K. S., T. K. Berntsen, J. Boike, B. Etzelmüller, J. E. Kristjánsson, M. Maturilli, T. V. Schuler, F. Stordal, and S. Westermann, 2015: A comparison between simulated and observed surface energy balance at the Svalbard archipelago. *J. Appl. Met. Clim.*, 54, 1102-1119.

Graff, L. S., S. Guttu, and J. H. LaCasce, 2015: Relative dispersion in the atmosphere from reanalysis winds. *J. Atmos. Sci.*, 72, 2769-2785.

Kristiansen, M. F., 2015: Is there a positive feedback between Arctic stratus and Arctic sea ice changes? *Master's thesis*, Department of Geosciences, University of Oslo, 95 pp.

Rydsaa, J. H., L. Tallaksen, and F. Stordal, 2015: Sensitivity of the regional European boreal climate to changes in surface properties resulting from structural vegetation perturbations. *Biogeosciences*, 12, 3071-3087.

Wærsted, E. G., 2015: Timescales of surface-to-tropopause transport in the tropics, using Flexpart. *Master's thesis*, Department of Geosciences, University of Oslo, 75 pp.

Summary of plans for the continuation of the project

(10 lines max)

The research effort will be pursued further, but the project will not be continued because we are now able to access all the ERA data that we need without having a special project at ECMWF. As for number crunching and storage, the Norwegian national supercomputing programme (NOTUR) currently provides adequate resources to meet our needs.