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24. august 2015

Contribution of Arctic shipping to the atmospheric concentrations and deposition of pollutants in the Arctic

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3rd CRAICC-PEEX Workshop, DMI, 24-25 August 2015

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Danish Cooperation for Environment in the Arctic
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Outline

- Introduction
- Emission inventories
- CTM model calculations
- Conclusions

Introduction

- Navigation inside the Arctic is an important local emission source in the Arctic especially in the future due the expected increase of ships traffic

- This inventory provide emissions from Navigation North of 60N of SO_2, NO_x, CO, NMVOC, PM, BC, OC (organic carbon) and CO_2
- Black Carbon (BC) emissions are of particular interest because BC is a strong Short Lived Climate Forcer (SLFC) in the Arctic:
  - Radiative Forcing
  - Albedo Impacts
  - Cloud Impacts
- NO_x, CO, NMVOC can be important for Ozone which also is a SLCF

Emissions

Activity data for ships:

- Traffic data from the Danish Maritime Administration (DMA) based on sampled AIS data for the whole 2012
  - AIS (Automatic Information System): Transponder signals from ships with information about identity and position
  - High intensive traffic areas (coasts of Norway, Iceland, Faroe Islands and Baltic sea) covered by terrestrial base stations and AIS receivers
  - Outside these areas AIS data is gathered from two, sometimes three, polar orbital satellites, 20 min up to 2 hours between signals for each ships
- The AIS data is further processed by DMA into
  - Grid cell resolution: 0.5^o x 0.225^o long-lat
  - Average sailing speed and sailed distance per month in 2012
  - 14 ship types, 16 ship length categories

Emissions

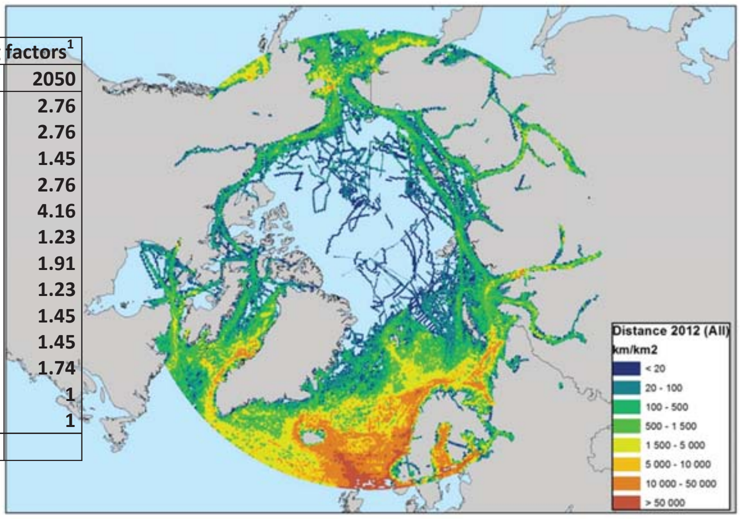
Activity data for ships, cont'

− Forecast years

- Traffic prognosis from International Maritime Organization (IMO)[1] is used to project 2012 traffic into 2020, 2030 and 2050

	Km x 10^3	Traffic scaling factors[1]		
Vessel type	2012	2020	2030	2050
Crude oil tanker	1496	1.42	1.83	2.76
Oil products & chemical tanker	9714	1.42	1.83	2.76
Ro-ro passenger ship[c]	14968	1.06	1.16	1.45
Gas tanker	888	1.42	1.83	2.76
Container ship	6858	1.26	1.83	4.16
General cargo ship	26916	1.02	1.08	1.23
Bulk carrier	4329	1.12	1.33	1.91
Ro-Ro cargo ship	3259	1.02	1.08	1.23
Passenger ship	9589	1.06	1.16	1.45
Fast ferry	273	1.06	1.16	1.45
Support ship	13715	1.19	1.37	1.74
Fishing ship	33491	1	1	1
Other ship	8039	1	1	1
All vessels	133535			

[1]Second IMO GHG Study 2009 (Buhaug et al. 2009)



Total sailing distance in 2012

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Emissions

Ship engine power

− Ship engine power functions as a function of ship type, ship length and sailing speed as well auxiliary engine power demand is also taken into account. Furthermore the ship engine power function are adjusted for improved ship energy efficiency in the forecast years according to the IMO Energy Efficiency Design Index scheme

− Fixed engine load factor (60 %) for fishing vessels, due to unprecise power-speed relation (COWI Tromsø, 2013)

Emissions

Emission factors

- The basis fuel consumption and emission factors, expressed in g/kWh, used are classified according to engine type, fuel type and engine production year
- Constant BC emission factor = 0,35 g/kg fuel (Corbett et al., 2010)
- Sulphur related PM mass varies with fuel S-%

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Emissions

- Engine work for the year X depends on ship type (S), fuel type (f), engine type (k), ship length (l), Power demand (P), Distance (D), speed (V) and EEDIf (Energy Efficiency Design Index factor):

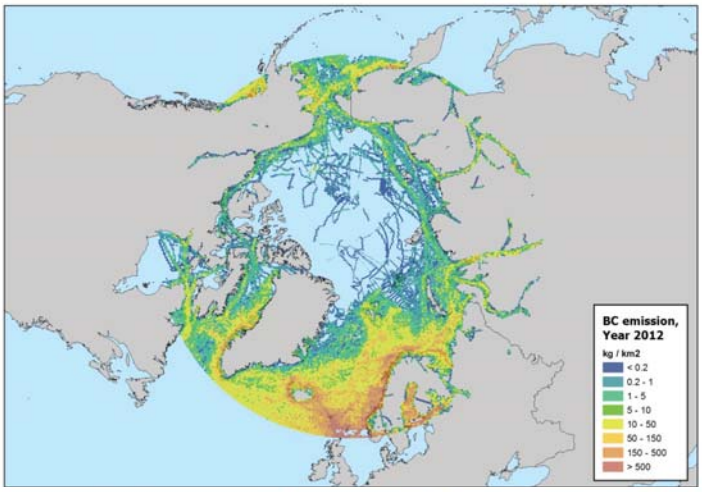
$$W_{S,f,k,l}(X) = P_{S,f,k,l} \cdot (100 - EEDIf_S(X)) / 100 \cdot D_{S,l}(X) / V_{S,l}$$

- Finally the fuel and emission calculations as function of Engine work (W) and Emission factors (EF) are calculated as:

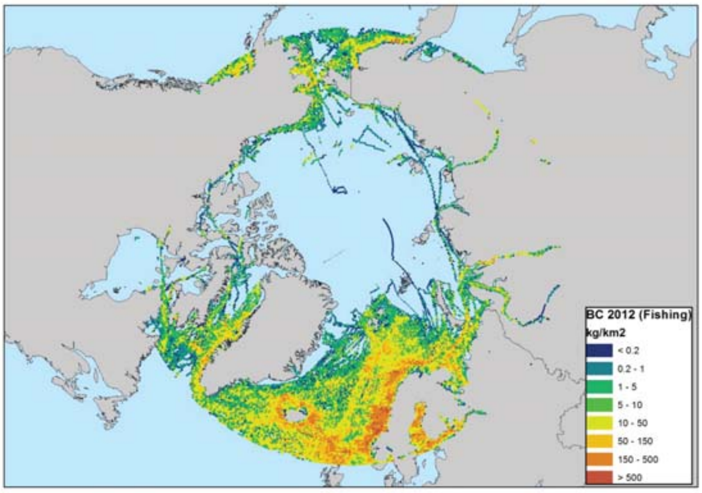
$$E_S(X) = \sum_{f,k,l} W_{S,f,k,l}(X) \cdot EF_{f,k}(X)$$

Example of spatial distribution of BC emissions

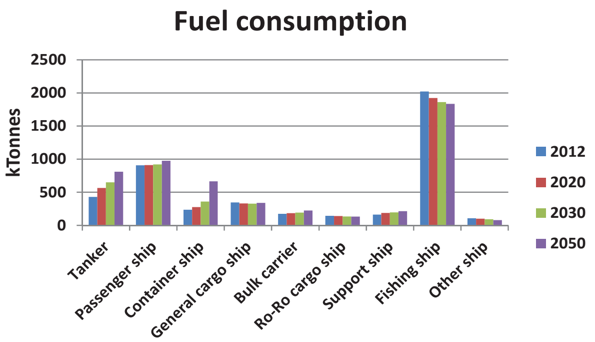
- The BC emissions from total navigation are shown on the upper figure

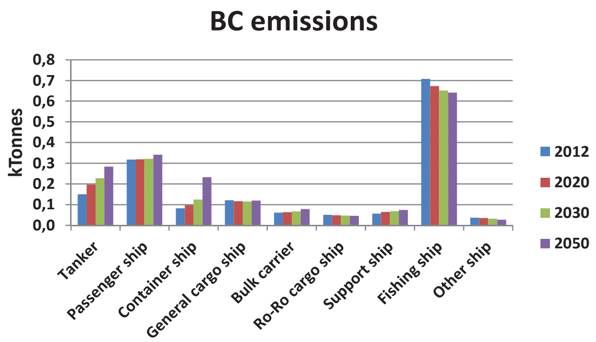


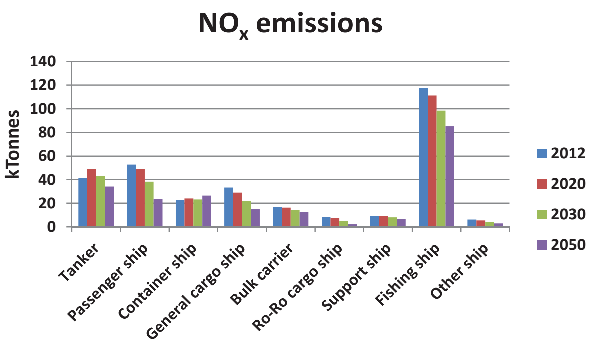
- The fishing activities and hence emissions (lower figure) are to a large extent coastal specific. The emissions are highest along the Norwegian coast, around the Faroe and Shetland Islands and around Iceland

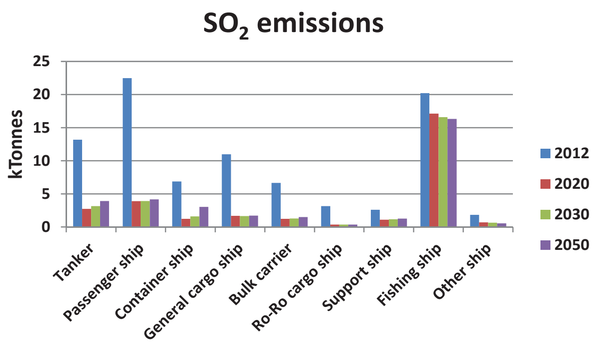


Fuel consumption and BC, NOx and SO2 emissions per ship type in 2012, 2020, 2030 and 2050

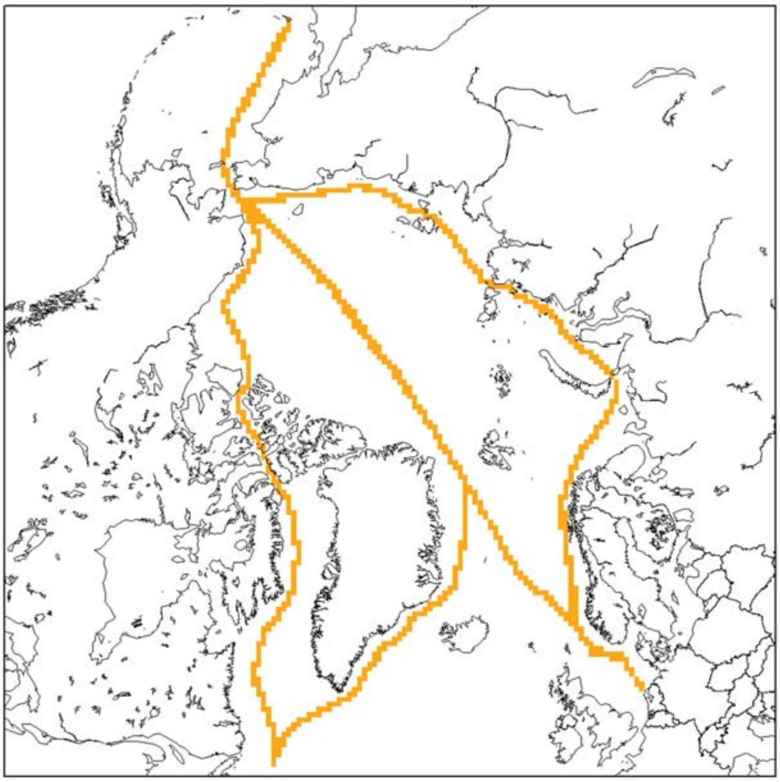








Emissions from polar diversion



- **Scenarios based on Corbett[1] with traffic diversion along polar routes due to less arctic sea ice in the future**
- **Our BAU scenario: 90 % more BC (and fuel) in the arctic area in 2050 due to polar traffic**
- **HiG scenario: 650 % more BC (and fuel) in the arctic area in 2050 due to polar traffic**

		Our study				Corbett HiG			
	Traffic	**2012**	**2020**	**2030**	**2050**	**2004**	**2020**	**2030**	**2050**
CO_2	**W/o diversion**	**14373**	**14653**	**15026**	**16747**	**4108**	**6372**	**8092**	**14370**
	Diversion routes		**5341**	**6213**	**14738**		**7007**	**19371**	**94237**
BC	**W/o diversion**	**1.58**	**1.62**	**1.66**	**1.84**	**0.45**	**0.70**	**0.88**	**1.57**
	Diversion routes		**0.58**	**0.68**	**1.61**		**0.76**	**2.11**	**10.29**

[1]Arctic shipping emissions inventories and future scenarios, Atmos. Chem. Phys., 10, 9689–9704

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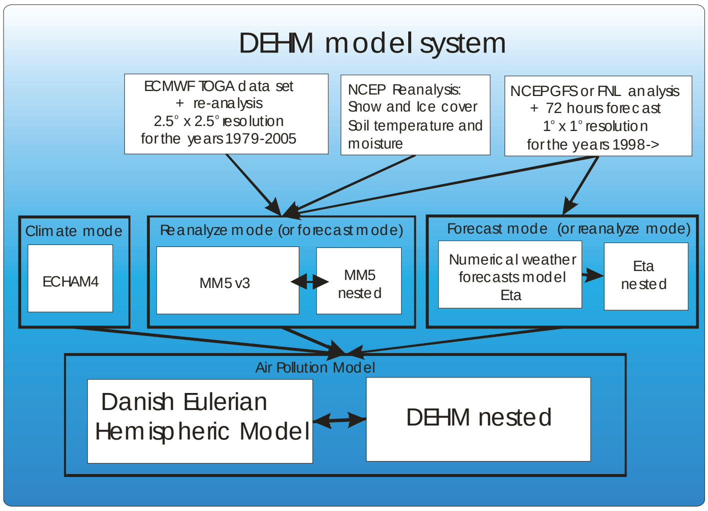
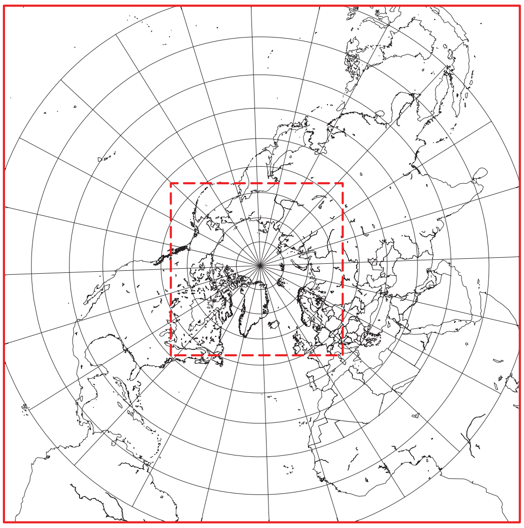
CTM model calculations

The Danish Eulerian Hemispheric Model (DEHM) System





150 km grid size for the hemispheric domain

50 km grid size for the Arctic domain

Modelled species

- 67 species totally
- 58 species in the ozone-NOx-VOC chemical scheme. Similar to the EMEP model chemistry.
- 2 sea salt fractions (coarse and fine)
- Mineral dust (coarse and fine)
- Primary organic aerosols (fine)
- 2 Black carbon (fine): fresh (hydrophobic) and aged (hydroscopic)

- Bulk representation of the PM species

Emissions in CTM

Basic run:

- RCP (0.5º x 0.5º) SO2, NOx, VOC, CO, NH3, OC, BC (2010)
- EMEP (50 km x 50 km for Europe) (SO2, NOx, VOC, CO, NH3, PM, (2011)
- GEIA (1º x 1º) (NH3, Soil NOx, NOx lightning)
- GFEDv3 biomass burning (0.5º x 0.5º) (2011)

- Global ship emissions from RCP + EMEP without emissions north of 60N

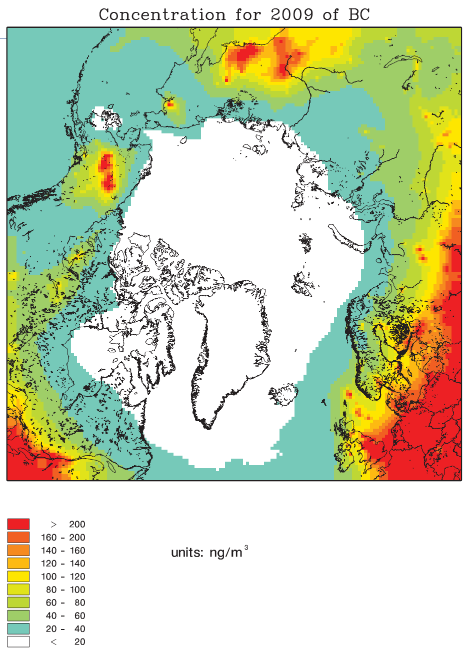
Arctic ships runs:

- Ship emissions from arctic ships (this study) + emissions based on Corbett's diversion (2012 and 2050BAU)

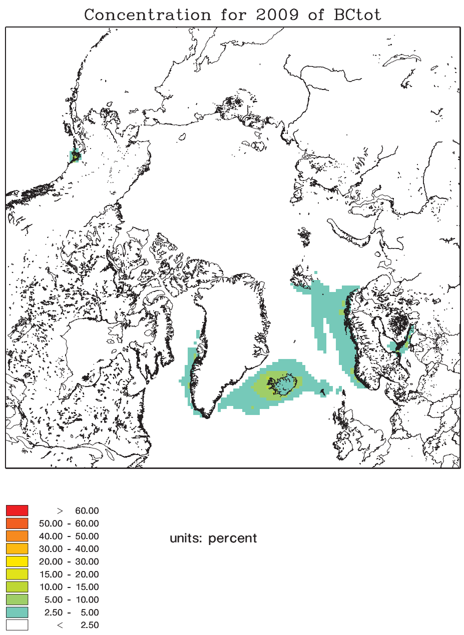
  or

- Corbett's ship emissions from arctic ships + diversions (2004 and 2050HiG)

BC concentrations with 2012 emissions

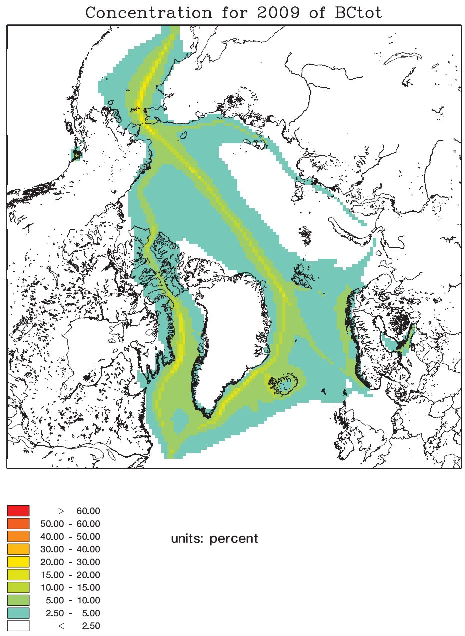


Total concentration without 2012 Arctic ships emissions



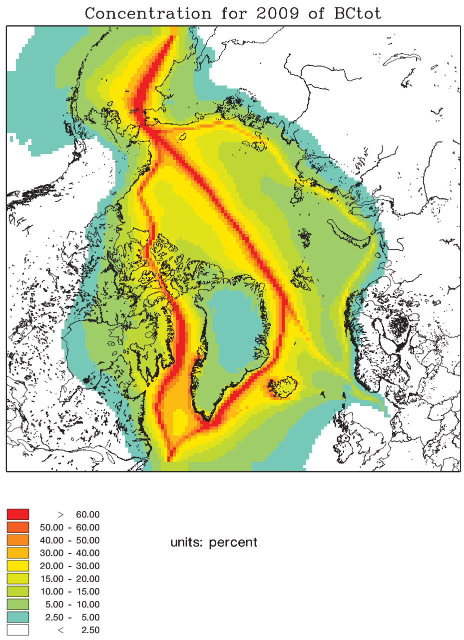
Additional contribution to BC concentration in % due to 2012 Arctic ships emissions

BC concentrations with 2050 emissions



Additional contribution to BC concentration in %

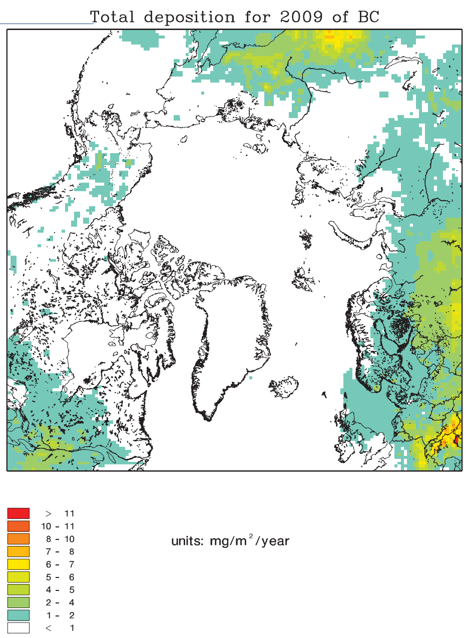
due to our 2050 Arctic ships emissions



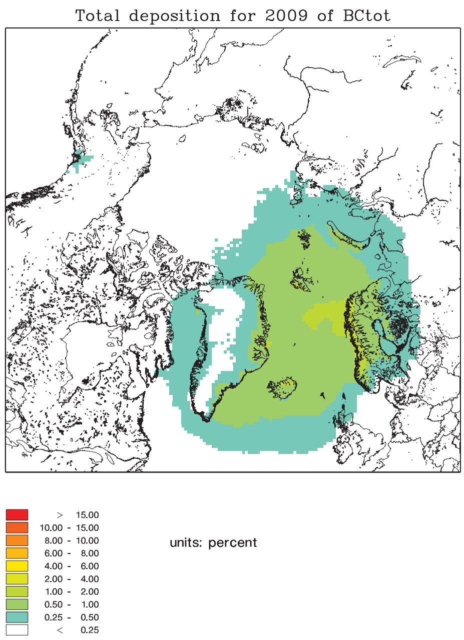
Additional contribution to BC concentration in %

due to Corbetts 2050 High Grow Arctic ships emissions

BC depositions with 2012 emissions



Total deposition without 2012 Arctic ships emissions



Additional contribution to BC deposition in %

due to 2012 Arctic ships emissions

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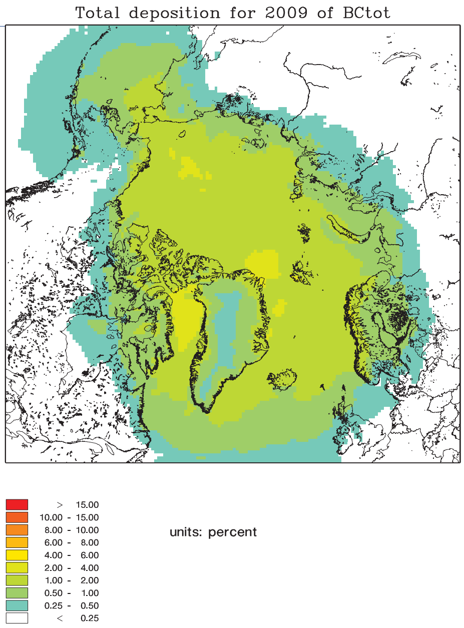
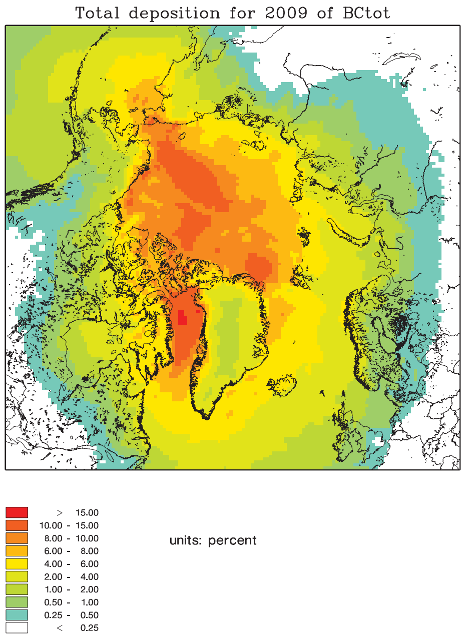
BC depositions with 2050 emissions



Additional contribution to BC deposition in %

due to our 2050 Arctic ships emissions



Additional contribution to BC deposition in %

due to Corbetts 2050 High Grow Arctic ships emissions

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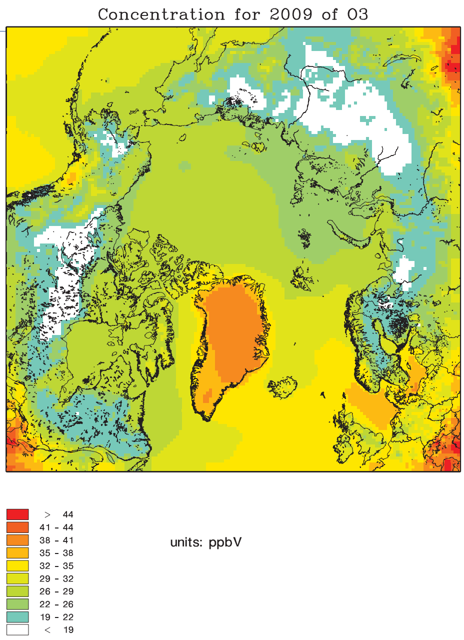
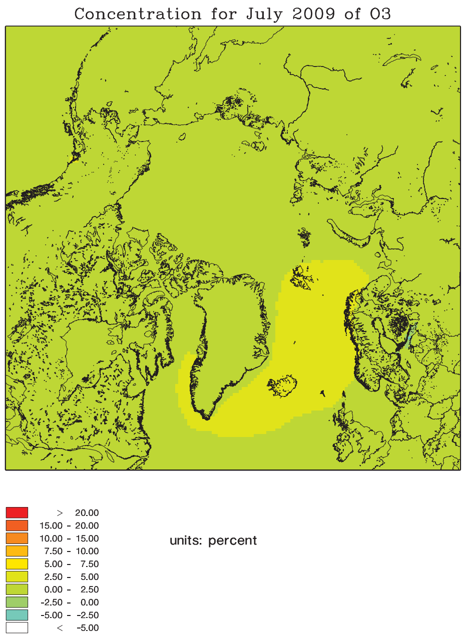
Summer Ozone concentrations with 2012 emissions



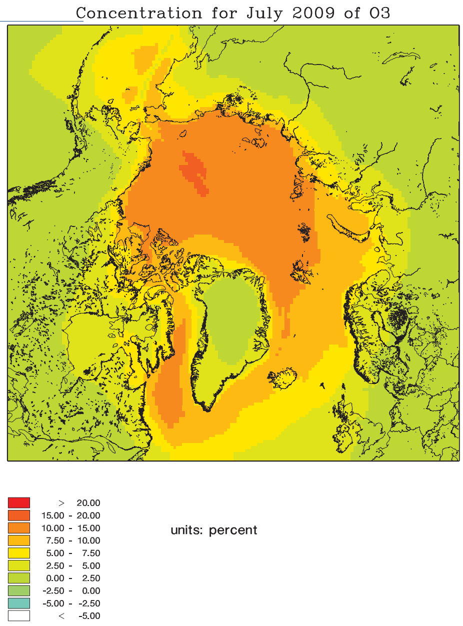
Ozone concentration without 2012 Arctic ships emissions



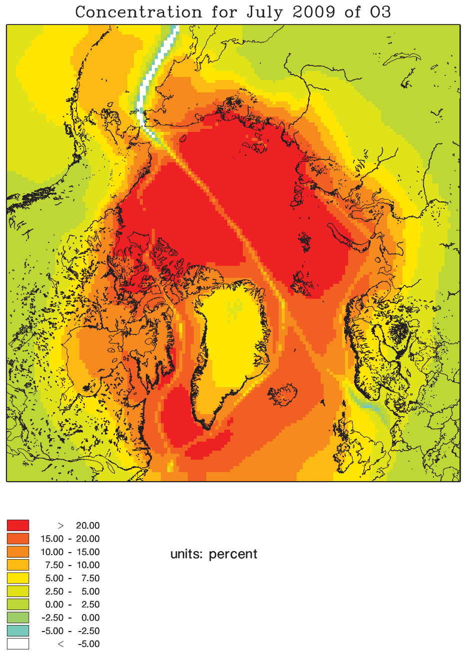
Additional contribution to Ozone concentration in %

due to 2012 Arctic ships emissions

Summer Ozone concentrations with 2050 emissions



Additional contribution to Ozone concentration in %
due to our 2050 Arctic ships emissions



Additional contribution to Ozone concentration in %
due to Corbetts 2050 High Grow Arctic ships emissions

Conclusion – emission inventory

- A detailed (0.5^ox0.225^o) emission inventory for the years 2012, 2020, 2030 and 2050 for ships in the Arctic has been constructed based on satellite and land based AIS data receivers, ship engine power functions, ship energy efficiency improvements and technology stratified emission factors
- Fishing ships (45 %) is the largest BC emission source in 2012, followed by passenger ships, tankers, general cargo and container ships
- Fishing ships is the most uncertain part of the inventory, due to a less certain power-speed relation
- Still, the estimates for fishing ships are a big step forward in knowledge; other inventories (e.g. Corbett et al.) are not gridded at all, and fishing activity data are estimates for the entire arctic area

- The total emissions of BC increase by 2, 4 and 16 % in 2020, 2030 and 2050 without polar diversion traffic. For 2050 alone, BC increases by 90 % with Corbetts polar diversion traffic BAU growth scenario and up to 650 % with Corbetts High Grow scenario.

Conclusion – CTM model calculations

- The model calculations shows that the contributions from ships without diverted traffic to BC, SO, and O3 concentrations and to BC deposition are low, especially from the current ships traffic, as a mean for the whole Arctic, but locally BC contributions reach up to 20 % as around Iceland.
- The model results also show that the diverted traffic highly influences the concentrations and the deposition of BC in the Arctic in the future. Although the average summertime contributions from navigation to the concentration and depositions of BC and Ozone remain moderate (1-5%) for our inventory in 2050, the navigation contributions become very visible for BC (> 80 %) along the polar routes, while the O3 (> 10 %) and BC deposition (> 5 %) contributions get highest over the oceans east of Greenland and in High Arctic.
- For the environmentally worst case HiG scenario become both the yearly average and especially the summertime concentrations of BC and Ozone and BC depositions much higher in 2050. Especially the high forecasted values for BC sea-ice deposition close to the Polar routes are of main concern due to the decrease in the albedo in turn enhancing the melting of sea-ice

More information

Winther, M., Christensen, J. H., Plejdrup, M. S., Ravn, E. S., Eriksson, Ó. F., and Kristensen, H. O. (2014): Emission inventories for ships in the Arctic based on satellite sampled AIS data, Atmospheric Environment, 91, 1-14.

The gridded Arctic ship emissions inventory are available from: http:/envs.au.dk/ArcticShipEmissions

Acknowledgement

The present work has been funded by the Danish Environmental Protection Agency as part of the environmental support program DANCEA – Danish Cooperation for Environment in the Arctic. The authors are solely responsible for all results and conclusions presented in the report and do not necessarily reflect the position of the Danish Environmental Protection Agency.

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Thank you for your attention!