Black Carbon in the Arctic, how well is it captured by models?

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Summary

The concentrations of black carbon (BC) and other aerosols in the Arctic are characterized by high values in late winter and spring (so-called Arctic Haze) and low values in summer. Models have long been struggling to capture this seasonality and especially the high concentrations associated with Arctic Haze. We evaluate BC concentrations from eleven different models driven with the same emission inventory against a comprehensive pan-Arctic measurement data set over a time period of two years (2008-2009). The set of models consisted of one Lagrangian particle dispersion model, four chemistry-transport models (CTMs), one atmospheric chemistry-weather forecast model and five chemistry-climate models (CCMs), of which two were nudged to meteorological analyses and three were running freely. The measurement data set consisted of surface measurements of equivalent BC (eBC) from five stations (Alert, Barrow, Pallas, Tiksi and Zeppelin), elemental carbon (EC) from Station Nord and Alert and aircraft measurements of refractory BC (rBC) from six different campaigns. We find that the models generally captured the measured eBC/rBC concentrations quite well, compared to past comparisons. However, the aerosol seasonality at the surface is still too weak in most models. Concentrations of eBC averaged over three surface sites are underestimated in winter/spring in all but one model, whereas concentrations in summer are overestimated in the model mean (by 88% and 44% for July-September), but with over- as well as underestimates present in individual models. The most pronounced eBC underestimates, not included in the above multi-site average, are found for the station Tiksi in Siberia where the measured annual mean eBC concentration is three times higher than the average annual mean for all other stations. This suggests an underestimate of BC sources in Russia in the emission inventory used. Based on the campaign data, biomass burning was identified as another cause of the modelling problems.

Motivation

Aerosols such as black carbon (BC) are likely to increase climate warming. In addition to atmospheric radiative forcing, deposition of absorbing aerosols on snow or ice reduces the albedo and can thus induce faster melting and efficient surface warming. The highly reflective surfaces of snow and ice as well as strong feedback processes make the Arctic a region of particular interest for aerosol research.

Models have for a long time struggled to capture the distribution of aerosols in the Arctic (Shindell et al., 2008; Koch et al., 2009). The concentrations of BC during the Arctic Haze season in particular were underestimated, in some cases by more than an order of magnitude (Shindell et al., 2008), whereas summer concentrations were sometimes overestimated. The simulated aerosol seasonality is strongly dependent on the model treatment of aerosol removal processes. For instance, changes in the calculation of aerosol microphysical properties, size distribution and removal can change simulated concentrations by more than an order of magnitude in remote regions such as the Arctic and the calculated Arctic BC mass concentrations are very sensitive to parameterizations of BC aging (conversion from hydrophobic to hydrophilic properties) and wet scavenging.

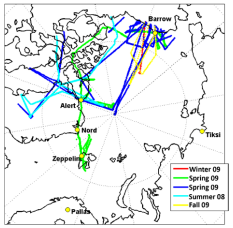


Figure 1. Map showing the locations of the measurement stations (yellow circles) and the flight tracks north of 70°N of all aircraft campaigns used in this study. Aircraft data were from the HIPPO (winter 2009 and fall 2009), ARCTAS (spring and summer 2008), ARCPAC (spring 2008) and PAMARCMiP (spring 2009) campaigns.

Table 1. Model overview

Model Name	Model Type[1]	Horizontal/vertical resolution	Meteorological fields	Periods simulated / output temporal resolution
FLEXPART	LPDM	Met. Input data: 1° x1°/92L	ECMWF Operational Analyses	2008-2009 3h
OsloCTM2	CTM	2.8°x2.8°, 60L	ECMWF Operational Analyses	2008-2009 3h
NorESM	CCM	1.9°x2.5°, 26L	Internal, observed SST prescribed	2008-2009 3h
TM4-ECPL	CTM	2°x3°, 34L	ECMWF ERA-interim	2008-2009 24h
ECHAM6-HAM2	ACM	1.8°x1.8°, 31L	ECMWF Reanalysis	March-August, 2008, 1h
SMHI-MATCH	CTM	0.57°x0.75°, 38L	ECMWF – ERA-Interim	2008, 2009 1h
CanAM4.2	ACM	2.8°x2.8°, 49L	Nudged to ECMWF temp and winds	2008-2009 3h
DEHM	CTM	150km <60°, 50km >60°N, 29L	NCEP	2008-2009 3h
CESM1/CAM5.2	CCM	1.9°x2.5°, 30L	Internal, observed SST prescribed	2008-2009 1h
WRF-Chem	CTM	100kmx100km 38L	Nudged to FNL	March-August 2008 3h
HadGEM3	CCM	1.9°x1.3°, 63L	ECMWF ERA-interim	March-June, November 2008, January, May and November 2009 3h

[1]Chemistry transport model (CTM), Lagrangian-particle-dispersion-model (LPDM), chemistry climate model (CCM), aerosol chemistry model (ACM)

Emissions

All models made use of an identical emission dataset, the ECLIPSE (Evaluating the Climate and Air Quality Impacts of Short-Lived Pollutants) emission inventory version V4. The ECLIPSE inventory was created using the GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model, which provides emissions of long-lived greenhouse gases and shorter-lived species in a consistent framework. The emission data can be downloaded at eclipse.nilu.no.

Models

We show results of 11 different models, whose main characteristics and references are summarized in Table 1.

Observed and simulated BC seasonality at Arctic surface measurement stations

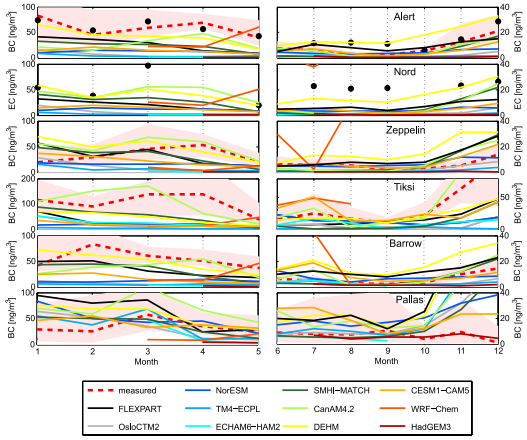


Figure 2 Monthly median observed eBC/EC and modeled BC concentrations for the stations (from top) Alert, Nord, Zeppelin, Tiksi, Barrow and Pallas, for late winter/spring (left column) and summer/fall (right column). The red dashed lines connect the observed median eBC values, The black dots are the EC concentrations.

The eBC mass concentrations at the three sites (Fig 1) in the western Arctic (Alert, Barrow, Pallas) are quite comparable to those at Zeppelin station, with monthly median values of about 20-80 ng/m3 in late winter/early spring and of less than 10 ng/m3 in summer/early fall (see Fig. 2). One exception is EC measured at Station Nord, which in summer is higher than eBC measured at the other sites. At Alert, where both eBC and EC data are available, EC values in summer are also somewhat higher than eBC values (although lower than the Station Nord EC values), probably due to systematic differences in measurement techniques.

At the Tiksi station, which is closer to the main source regions of Arctic BC in high-latitude Eurasia (Hirdman et al., 2010), higher monthly median eBC values were measured (more than 100 ng / m3 in winter/spring, about 20-40 ng /m3 in summer) and the annual mean (81 ng/m3) is 2.5 times higher than the average for the other stations (31 ng/m3). The seasonality of measured eBC is strongest at Alert where the summer concentrations are very low, but the winter/spring concentrations are similar to the other sites in the western Arctic.

Vertical Profiles

For spring 2008, the aggregate plots for BC (Fig. 3) show that nearly all models underestimate the measured rBC concentrations both at low and high altitudes. The measured median rBC mass concentrations at low (high) altitudes were about a factor two (three) lower than for the spring 2008 campaigns. Most models also simulated lower median BC concentrations than a year earlier, but the modeled reductions were less pronounced than the measured ones and, thus, about half of the models under- and the other half overestimated the measured median values. The vertical gradient of measured BC was also different in 2008 and in 2009. While in spring 2008, the concentrations above 3 km were higher than those below, the opposite was true in spring 2009, likely because of the weaker biomass burning influence in 2009.The HIPPO campaign in fall 2009 was conducted about one month after the seasonal minimum at most surface sites and measured very low rBC mass concentrations, which is consistent with the surface observations.

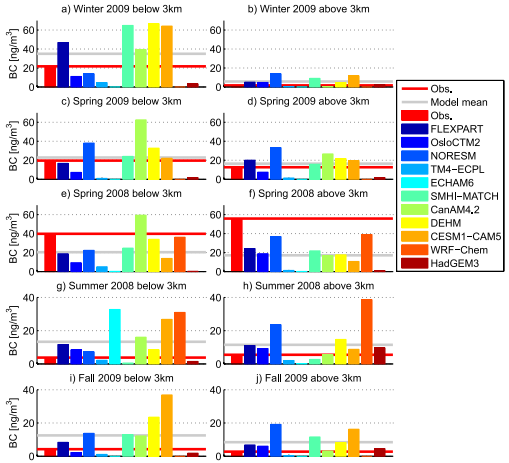
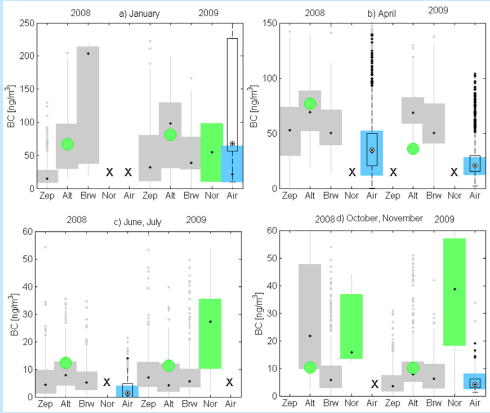


Figure 3: Median observed rBC and modeled BC mass concentrations for the winter 2009 HIPPO (a, b) spring 2009 PAMARCMiP (c-d) spring 2008 ARCTAS/ ARCPAC (e-f) summer 2008 ARCTAS (g-h) and the fall 2009 HIPPO (i-j) aircraft campaigns. The red bar and the red horizontal line show the observations, the other colored bars the various models, the grey line shows the mean value of all model medians. Results are shown separately for measurements below 3 km (left panels) and above 3 km (right panels).

Conclusions

- The simulation of BC concentrations in the Arctic has improved compared to earlier studies (e.g. Shindell et al., 2008; Koch et al., 2009). For instance, our model-mean underestimate of Arctic eBC at Barrow and Alert is about a factor of 2, compared to one order of magnitude reported in Shindell et al. (2008). Nevertheless, the aerosol seasonality at the surface is still too weak in most models.
- For the aircraft campaigns, the models overestimated measured rBC during all seasons except for spring and throughout the depth of the troposphere. In spring 2009, no overestimate was found, and in spring 2008 the models underestimated both The largest eBC underestimates are found for the station Tiksi, which is closest to potential Russian source regions and where the annual mean eBC concentration is three times higher than the average annual mean for all other stations. This suggests an underestimate of BC sources in Russia in the emission inventory used, even though this inventory contains gas flaring as an important BC source there.

How consistent are the aircraft campaigns and the station measurements?



eBC [ng/m³] measured at the stations Zeppelin (Zep), Alert (Alt), and Barrow (Brw) (grey bars), EC measured at Alert and Station Nord (Nord) (green dots and bars) and rBC [ng/m³] measured by aircraft (Air).

Acknowledgements

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no 282688 – ECLIPSE. Some of the work was conducted for and funded by the Arctic Monitoring and Assessment Programme (AMAP).

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PP 04/2015 SEC