Surface-atmosphere exchange of aerosol particles in the high Arctic – Results from ASCOS

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Objective

We report experimental results of the Arctic Summer Cloud-Ocean Study ASCOS investigating processes controlling the atmospheric heat balance in the pack ice region of the high Arctic with a special focus on the origin of aerosol particles and their relevance for cloud formation. The surface-atmosphere exchange of aerosol particles was studied at the edge of an ice floe using direct eddy covariance measurements and gradient measurements in the lowest two meters of the boundary layer.

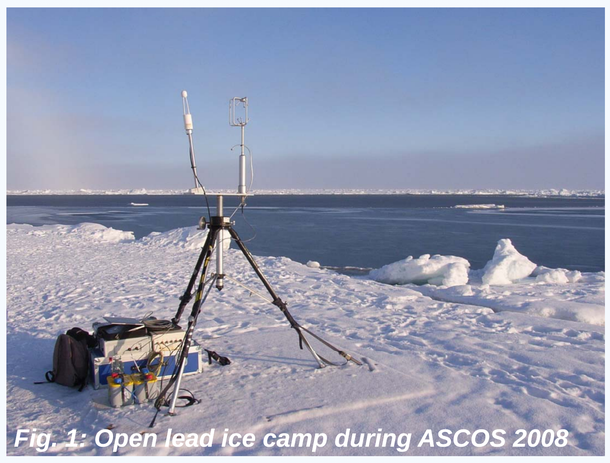

Fig. 1: Open lead ice camp during ASCOS 2008

Introduction

In order to understand aerosol-cloud-climate interactions in the high Arctic, the relevant sources and sinks of particles must be identified. With regard to particle sources, it has been suggested that local particle production may play a role in the Arctic (e.g. Leck and Bigg, 1999). It has been hypothesized that bubble bursting in the open waters of the Arctic creates airborne aerosol particles. The bubbles rise under quiescent waters between the ice floes, and upon fragmentation at the water surface, generate nanometer-sized droplets enriched in the composition of the surface film through which they broke (Bigg and Leck, 2008). During the Arctic Summer Cloud-Ocean Study (ASCOS) in 2008, local particle emission from open leads was studied by various methods.

Experimental Setup

Particle number concentrations were measured at small height intervals above open lead and snow surfaces on an ice floe drifting in the Arctic Ocean between 87°N 01°W and 87.5°N 11°W (Fig. 2), and aerosol number fluxes were directly measured by eddy covariance close to the edge of the ice floe. Depending on the wind direction, the footprint of these measurements was influenced by open leads or by ice and snow surfaces.

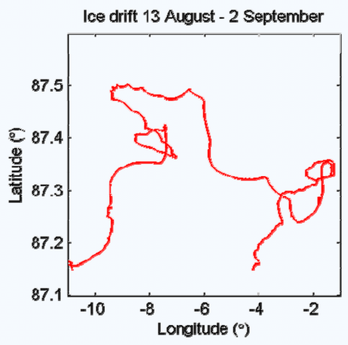

Fig. 2: Drift path of ice floe

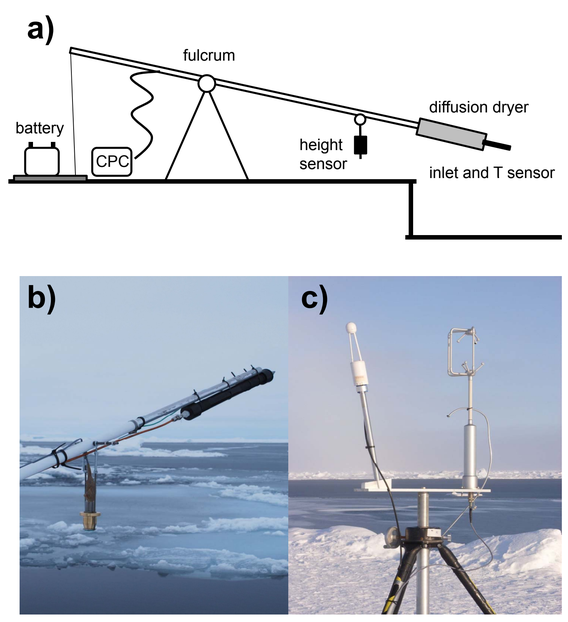

Fig. 3: Different measurement setups

Measurement

A “gradient pole”, a 3 m-rod positioned on a tripod holding a diffusion dryer, a copper sampling line, a thermo-couple, and an ultrasound height sensor, was used to measure the temperature and the particle concentration at various heights above the surface (cf. Fig. 3a, b; Orsini et al., *submitted*). In addition, aerosol number fluxes were directly measured by eddy covariance using a sonic anemometer and a conden-sation particle counter (cf. Fig. 3c).

Data analysis

The aerosol inlet and the tip of the thermocouple were manually moved in the lowest two meters above the surface, and fixed at different heights for typically 20 s (cf. height measurement in Figs. 4c and 5c). Fig. 4a clearly shows higher temperatures at lower heights, i.e. a negative temperature gradient. In Fig. 5 a, a similar trend can be seen for particle number concentrations in the first half of the measurement period. However, after a wind shift and freeze-up of the open lead surface around 21:10 UTC, the number concentration gradient disappears. Meso-scale variations of the corresponding temperature and particle number measurements were removed (Fig. 4b) before median values of the temperature and the particle number concentration were calculated at different heights.

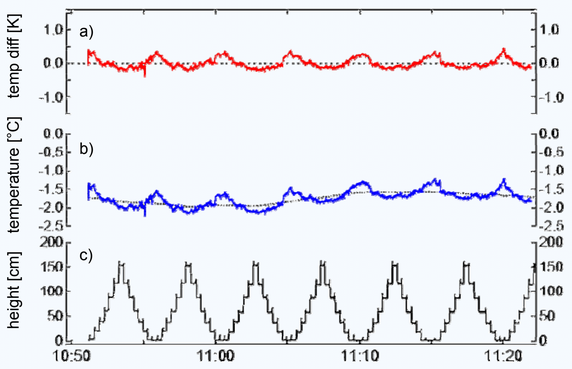

Fig. 4: Temperature gradients, August 31, 2008

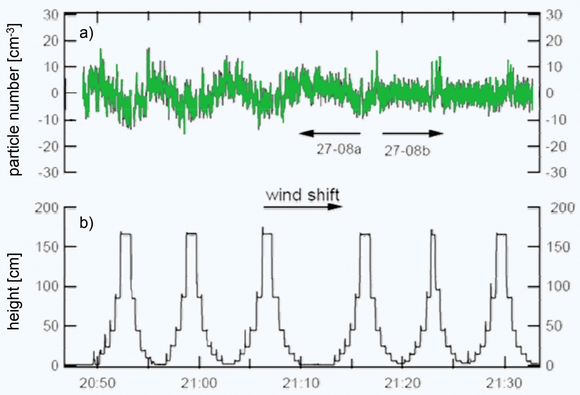

Fig. 5: Particle gradients, August 27, 2008

Flux Results

Under near-neutral conditions, basic flux-profile relationships were used to estimate the sensible heat flux F_h and the aerosol number flux F_c from the gradient measurements of temperature t and particle concen-tration c in different heights z:

$$t_2 - t_1 = -\frac{F_h}{u_* \kappa} \ln\left(\frac{z_2}{z_1}\right) \quad \text{[Eq. I]}$$

$$c_2 - c_1 = -\frac{F_c}{u_* \kappa} \ln\left(\frac{z_2}{z_1}\right) \quad \text{[Eq. II]}$$

where u*, the friction velocity, and κ, the von-Karman constant. Fig. 6 shows the particle number gradient on August 28, 2008 (diamonds), the logarithmic concentration profile fitted according to Eq. II, and the concentration profile corresponding to the aerosol number flux measured by eddy covariance. The particle deposition velocities are 0.29 mm s^{-1} vs. 0.58 mm s^{-1}.

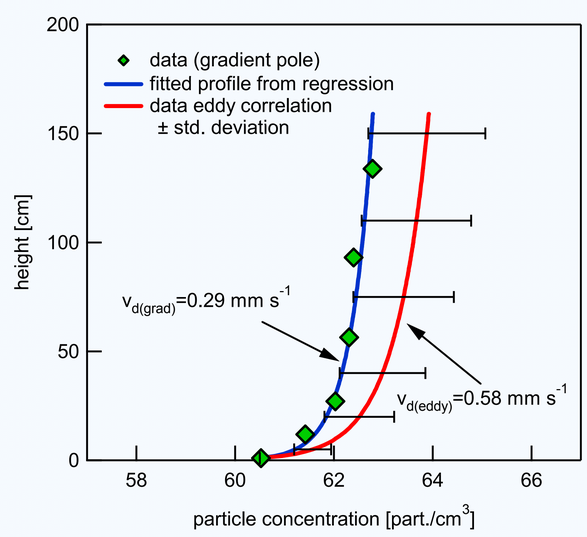

Fig. 6: Particle number logarithmic profile

Table 1: Particle number gradients and deposition velocities

Date 2008	avg. conc.	Trend Δ Part.cm^{-3}m^{-1}	F_c (u*κ)$^{-1}$ - (slope)	R^2 -	F_c 10^6 m^{-2} s^{-1}	$v_{d\,(grad)}$ mm s^{-1}	$v_{d(eddy)}$ mm s^{-1}	comment
Over Lead								
26/08	71.2	(+0.9)	1.07E-01	0.62	4.28E-03	-0.06	-0.09	weak fetch over lead
27/08a	55.3	+5.8	1.29E+00	0.79	5.14E-02	-0.93	-0.44	fetch over lead, before freezeup
27/08b	42.5	none	(2.35E-02)	0.01	--	--	-0.05	fetch over lead, after freezeup
29/08	56.7	none	(-4.76E-02)	0.16	--	--	0.00	slush and ice on lead
31/08a	8.6	none	(1.90E-03)	0.01	--	--	0.35	fetch over frozen lead
01/09	7.9	none	(-6.50E-03)	0.14	--	--	--	frozen lead, cold
Over Snow								
24/08	72.4	-4.5	-9.74E-01	0.77	-3.89E-02	0.53	0.54	first run, near ship, 2 profiles
28/08	61.9	-2.0	-4.54E-01	0.98	-1.82E-02	0.29	0.58	light wind, fetch over snow
30/08	22.3	(-0.5)	-7.12E-02	0.75	-2.85E-03	0.13	-8.02	sun breaks/flurries
31/08b	8.51	(+0.3)	4.73E-02	0.73	1.89E-03	-0.22	0.28	light fog (high variance)

In Table 1, the deposition velocities v_d derived from gradient measurements on various days are compared with deposition velocities directly measured by eddy covariance. On four occasions, particle number gradients were not detectable (27/08b, 29/08, 31/08a, 01/09) There are two particle source cases over the lead before freeze-up and two sink cases over the snow surface (24/08 and 28/08). The low R^2 value on 24/08 is likely due to the low number of data points since only two profiles were measured with the gradient pole. For the transitional day 27/08 when the lead froze, v_d(eddy) also indicates a transition in the same direction as data collected with the gradient pole. A change in v_d(eddy) from -0.44 to -0.05 is consistent with the shutdown of a particle source at the lead, indicated by a change in v_d(grad) from -0.93 to no detectable profile.

Conclusions

A simple “gradient pole” was successfully deployed in the Arctic pack ice to measure temperature and particle number concentration gradients and derive heat and aerosol fluxes. The snow surfaces behaved in general as particle sinks with deposition velocities ranging from 0.13 to 0.53 mm s^{-1} (gradient method), and from 0.28 to 0.58 mm s^{-1} (eddy covariance). Over the open lead, weak particle emission was observed and confirmed by both methods. No convincing aerosol gradients of any sort were detected over the frozen lead. These findings support the hypothesis that open leads can act as local particle sources in the high Arctic. However, the observed particle fluxes alone cannot explain the observed changes in particle number concentration.

REFERENCES
Leck, C., and Bigg, E.K. (1999) Geophys. Res. Lett., 23, 3577–3581.
Bigg, E.K., and Leck, C. (2008) *J. Geophys. Res.*, *113 (D1),* 1209, doi:10.1029/2007JD009078.
Orsini, D., Held, A., Vaattovaara, P., and Tjernström, M., submitted to the *Journal of Applied Meteorology and Climatology.*

ACKNOWLEDGEMENTS
This work is part of ASCOS (the Arctic Summer Cloud-Ocean Study). ASCOS was made possible by funding from the Knut and Alice Wallenberg Foundation and the DAMOCLES European Union 6th Framework Integrated Research Project. The Swedish Polar Research Secretariat (SPRS) provided access to the icebreaker Oden and logistical support. We are grateful to Michael Tjernström for co-planning and co-coordinating ASCOS, to the SPRS logistics staff and to Oden's captain Mattias Peterson and his crew. ASCOS is an IPY project under the AICI-IPY umbrella and is an endorsed SOLAS project.