Black carbon measurements in the air and clouds at Zeppelin Observatory (AC/BC)

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With our main scientific collaborators:
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Polar Night Week 2019, January 15 2019

What are black carbon (BC) aerosols and why do we study them?

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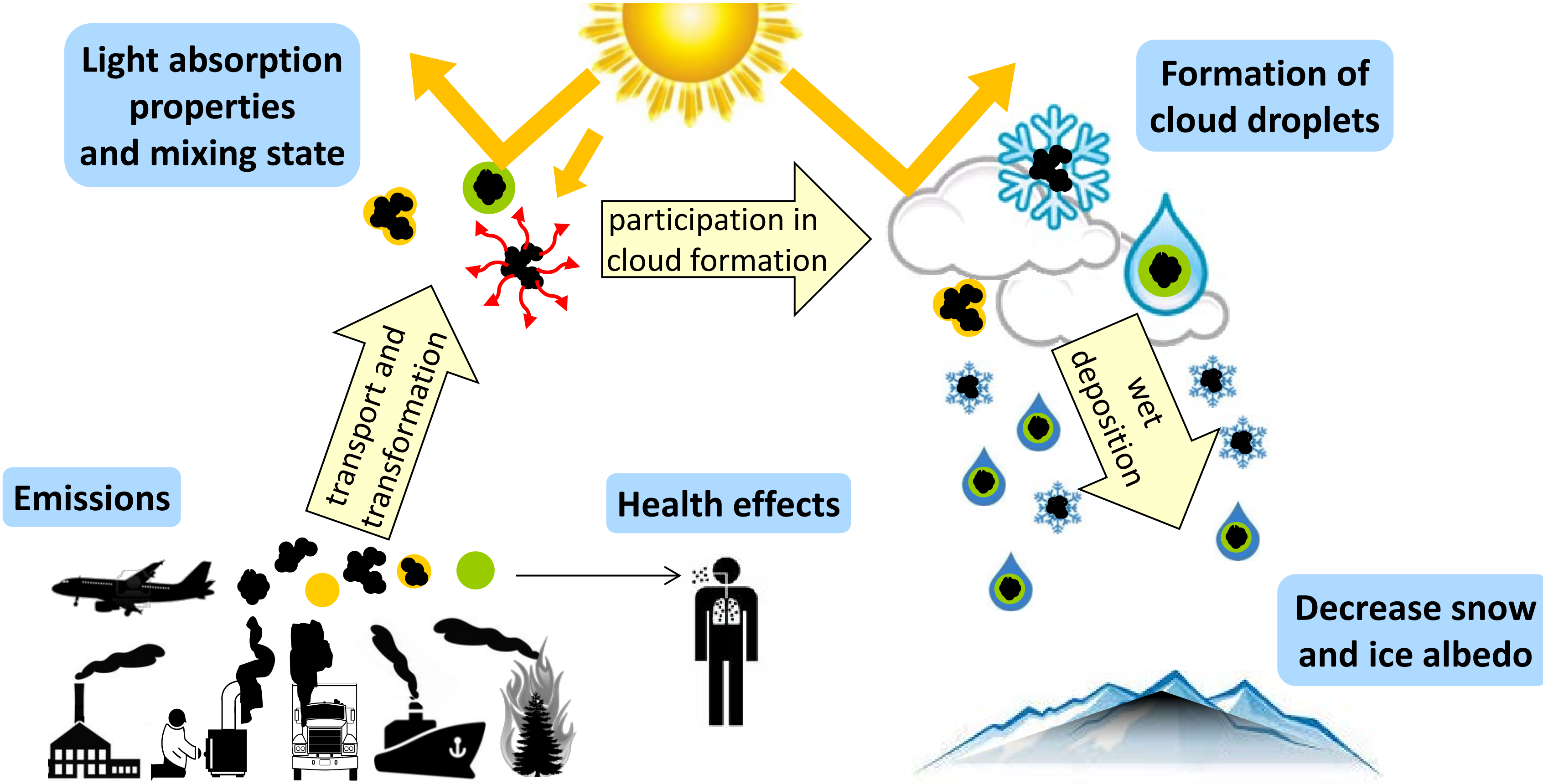

Atmospheric aerosols are small particles suspended in the Earth's atmosphere. ***Black carbon (BC)*** particles are a type of atmospheric aerosol with important environmental impacts → the AC/BC project is motivated by the impacts that BC has on Arctic climate change.

Estimates of the climate impact of BC aerosols are highly uncertain

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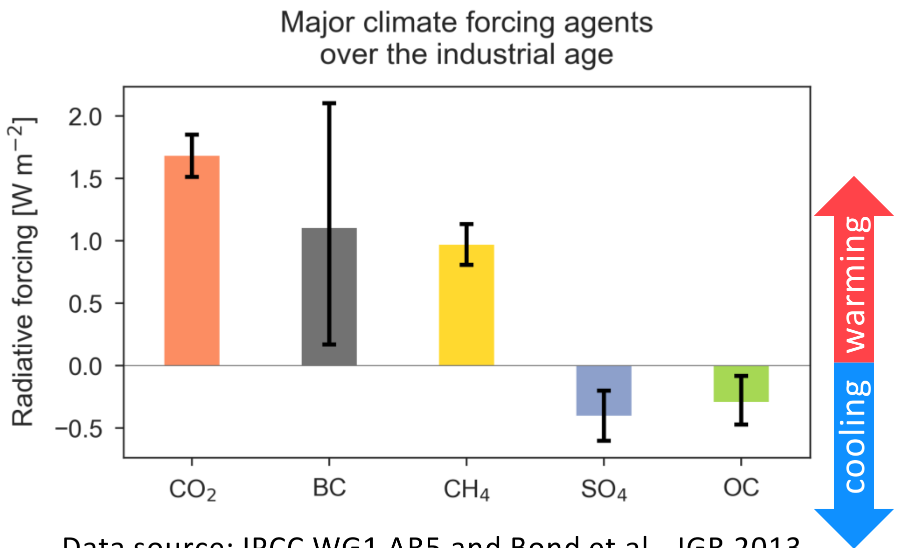


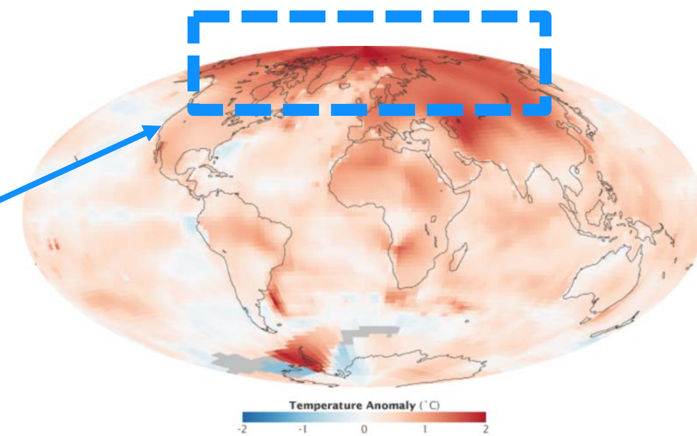
Data source: IPCC WG1 AR5 and Bond et al., JGR 2013

Radiative forcing is a measure of the atmospheric energy imbalance caused by a specific process/species over the industrial age.

→ BC radiative forcing is particularly uncertain…

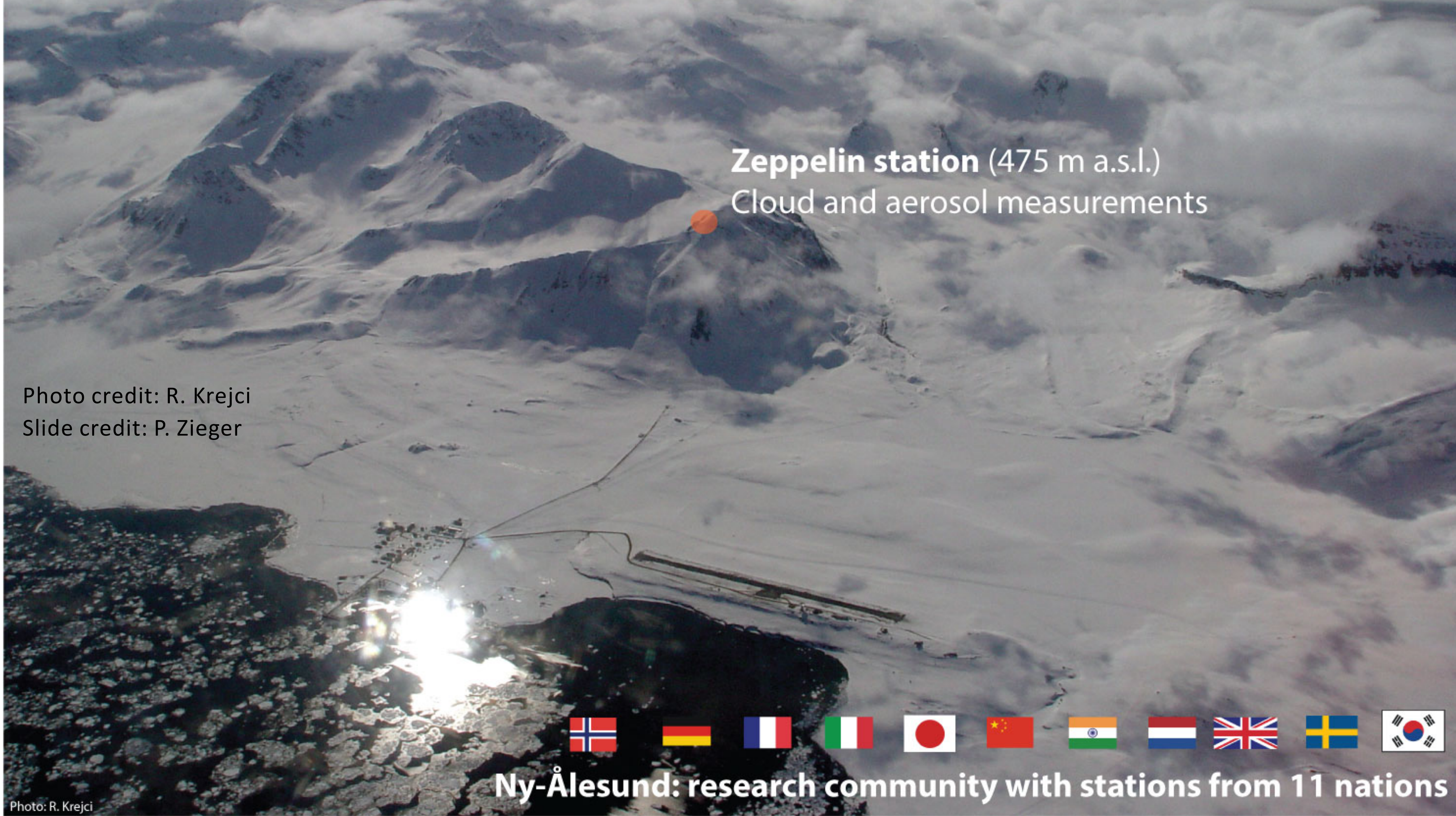
… particularly in the Arctic due to the surface albedo effect (dark material depositing on bright snow)

What role has BC played in Arctic amplification?



NASA image by Robert Simmon based on GISS surface temperature analysis data including ship and buoy data from the Hadley Centre

Targeted observations of BC concentrations and properties in Arctic air and clouds are required to challenge models that simulate BC climate effects: **Zeppelin Observatory, Svalbard is uniquely situated and equipped for this purpose**



Historical (and ongoing) BC measurements at Zeppelin Observatory

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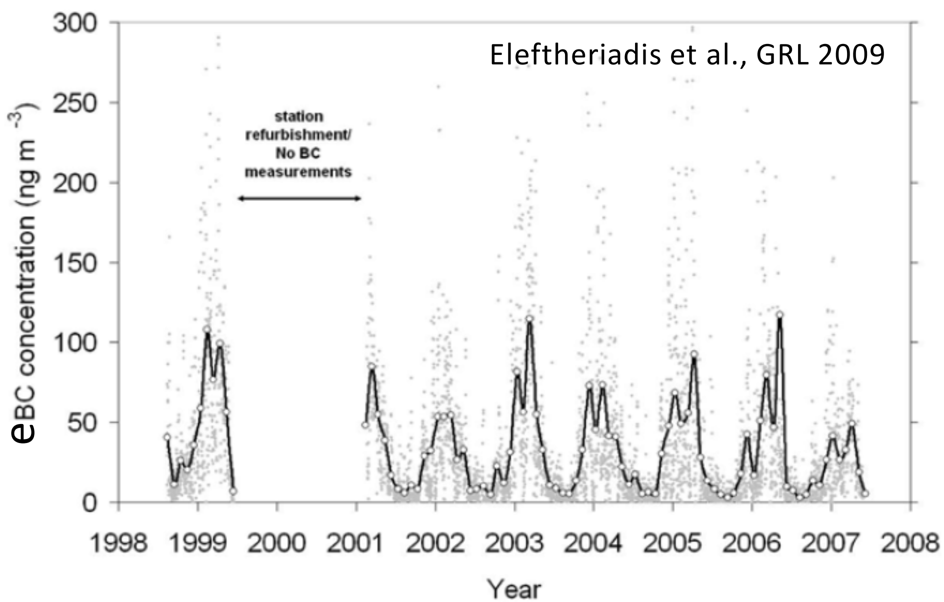
In the air

Traditional method of measuring light attenuation by particles accumulated on a filter (Rosen et al., Appl. Opt. 1978), termed 'equivalent BC' (eBC). Several instruments used over the years (Aethalometer, PSAP, COSMOS).

Result: strong seasonal cycle of eBC concentrations in the air



… ongoing

What about in the clouds?

1 early measurement of the fraction of BC that makes it into cloud, new measurements being made now by SU.

Season	EC (nmol m^{-3})
winter	
< 1990	5.5
90–92	7.78
M/V	1.42
INT/OOC	0.23
σ [%]	14
summer	
< 1990	0.38
90–91	0.89
M/V	2.35
INT/OOC	0.19
σ [%]	14

Heintzenberg and Leck, TellusB 1994

Issues with the previous measurements

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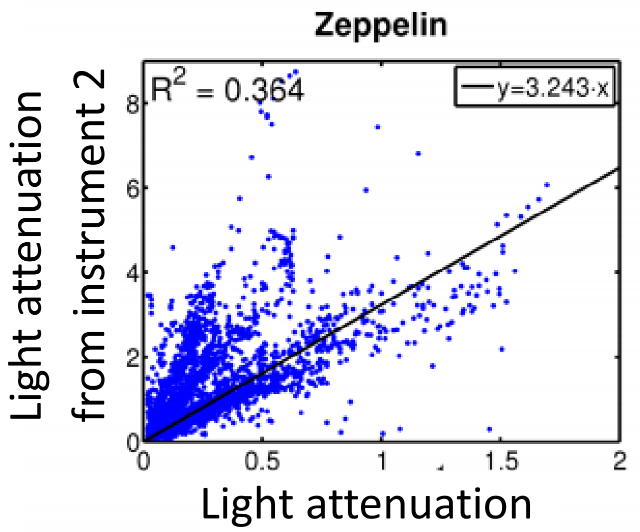

Traditional eBC 'filter-based' methods are subject to **large measurement uncertainties and systematic biases.**

E.g. comparison of 2 eBC monitors (PSAP & Aethalomenter) at Zeppelin from 2012 – 2014 (Schmeisser et al., ACP 2018)

Measurements of eBC levels are a good start but the climate impacts of BC also depend on particle size and mixing state → **complete BC characterization required**

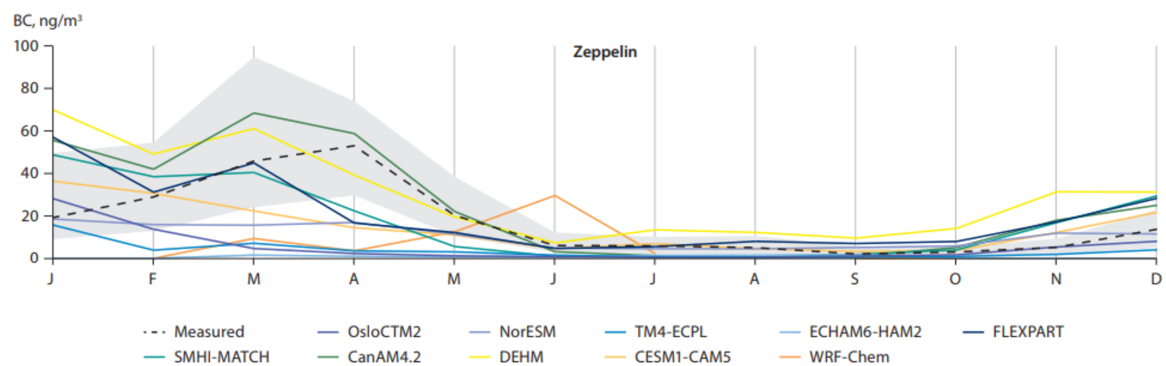

Figure 8.2 Seasonal variation in observed and modeled equivalent black carbon (eBC) concentrations for the years 2008 and 2009 at four stations. The black dashed line is the observed median, the light shaded area indicates the range between the 25th and 75th percentiles. Different colored lines show the modeled monthly median values.

AMAP Assessment 2015: Black carbon and ozone as Arctic climate forcers

A new generation of BC measurements

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The single particle soot photometer 'SP2' (Schwarz et al., JGR 2006; Stephens et al., Appl. Opt. 2003)

- Measures individual particles by the method of Laser Induced Incandescence → **extremely sensitive**
- **More complete characterization of BC**: concentrations, size distributions and mixing state
- 'Research-grade' instrument → **not plug and play**

...introducing the newest member of the SP2 family

The new, simplified 'extended range' SP2-XR:

- Most of the above but much simpler to operate → **remote, long-term SP2 measurements are now feasible for the first time**

PAUL SCHERRER INSTITUT PSI

AC/BC project outline

LABORATORY OF ATMOSPHERIC CHEMISTRY

AC/BC
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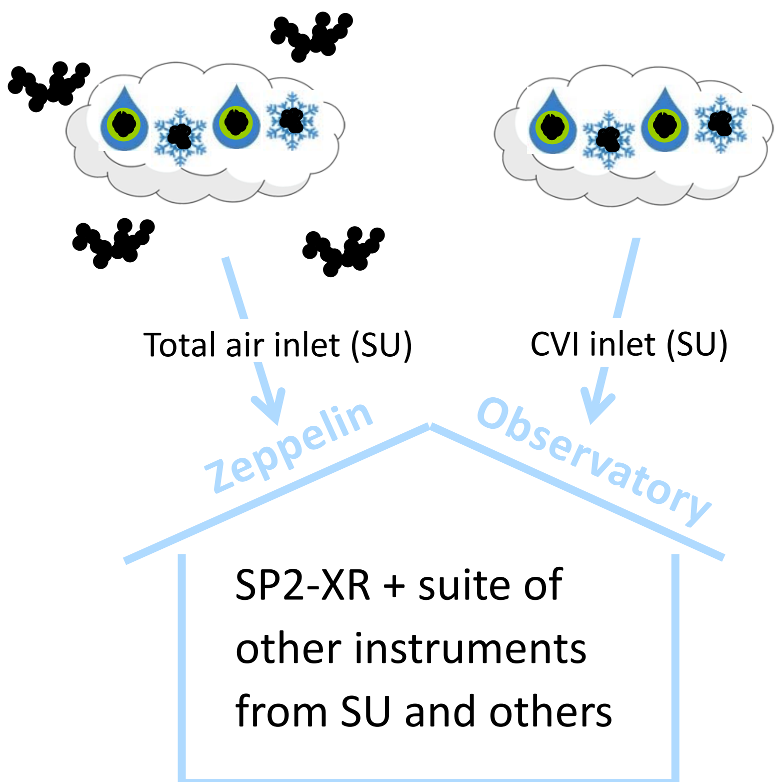
Goal: 1 full year of SP2-XR measurements at Zeppelin Observatory from March 2019 to March 2020



How: 5 trips to Zeppelin Observatory (4 in 2018, 1 in 2019) of 1 – 2 weeks length to perform regular calibrations and instrument maintenance. (Total 63 access days, 28 of which will be funded by the SIOS access grant)

The resulting dataset:

1 year's worth of measurements of:

- BC concentrations, size distributions and mixing state
- The fraction of BC in low-level Artic clouds (scavenging fraction) as a function of cloud supersaturation and BC properties

To be made freely available through e.g. the SIOS data management system

! Check out posters from Paul Zieger and the SU team in the hall for further details on CVI-related measurements !

Expected outcomes

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These measurements will allow us and others:

– To assess the accuracy of the routine eBC mass concentration measurements performed at Zeppelin Observatory over a full year

– To determine a set of seasonally-resolved values for the constant (‘mass absorption cross section’) used to convert light attenuation measurements to eBC concentrations in order to minimize systematic biases

– To examine the seasonal variability in BC properties (concentrations, size distributions, and mixing state) at Zeppelin Observatory

– (Potentially) to identify the main sources contributing to the BC measured in the lower atmosphere over Svalbard throughout the year (local vs remote?)

– To use the co-located BC scavenging fraction and supersaturation measurements for low-level Arctic clouds to test climate model simulations of BC-cloud interactions

– To assess the suitability of the SP2-XR as a routine monitoring instrument

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Backup slides

An example of what is to come: BC scavenging fractions

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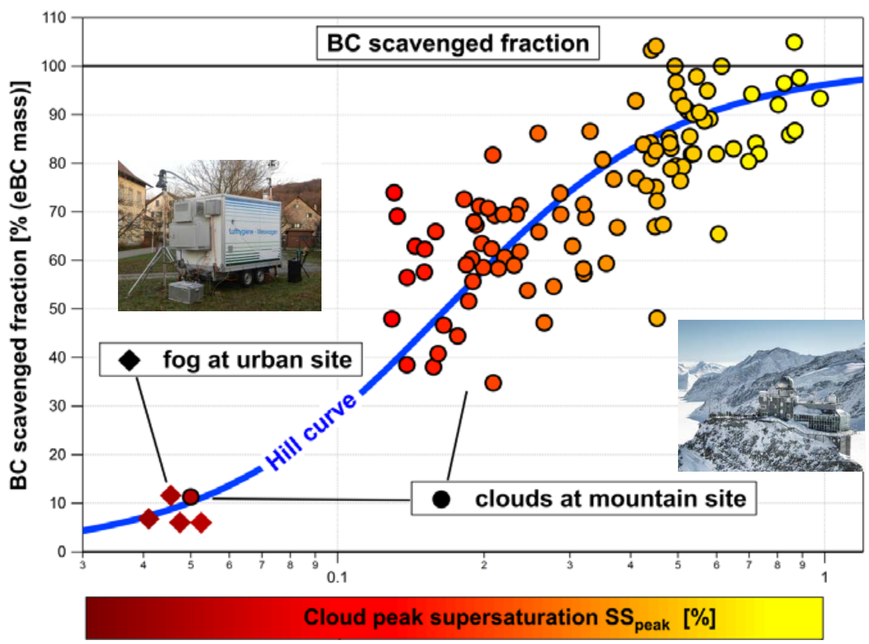
Combined measurements of BC scavenging fractions and supersaturations in clouds are very scarce anywhere in the world…not just in the Arctic → **a very unique dataset**

Recent measurements from the PSI group show BC mass scavenging is driven mainly by supersaturation, and modulated by BC size distribution and mixing state.

How will this play out for low-level Arctic clouds fed by a mix of local and long-range transported BC?



Motos et al., ACPD, 2018

Problems with the existing measurements

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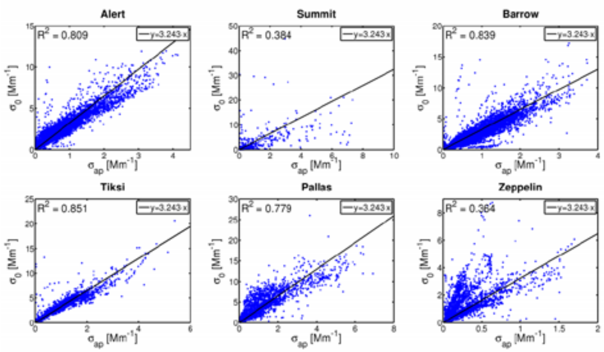
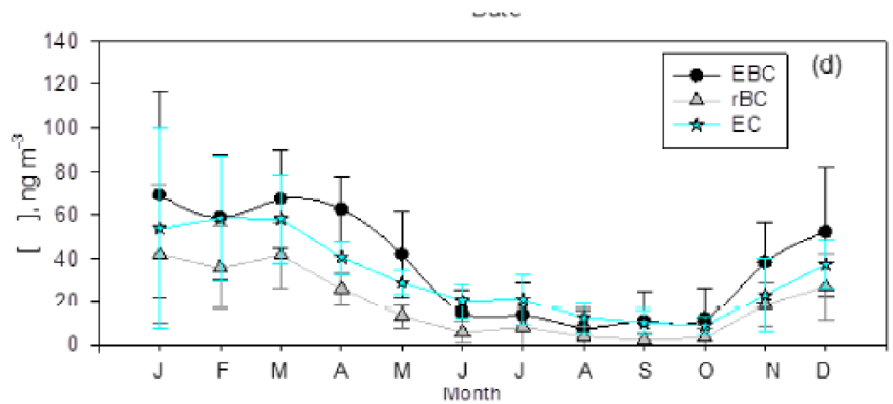
Comparison of Aethalometer and Reference Absorption Instrument

Figure S1 shows comparison of the absorption coefficients from the Aethalometer (σ_0) and reference absorption instrument (σ_{ap}). Generally, the absorption coefficients from the different instruments compare well at each station. ALT, TIK and BRW show the best agreement between the instruments.



Schmeisser et al., ACP 2018



Sharma et al., ACP 2017

eBC definition including MAC value. Subject to random erro (filter-based) and systematic b (choice of incorrect MAC value

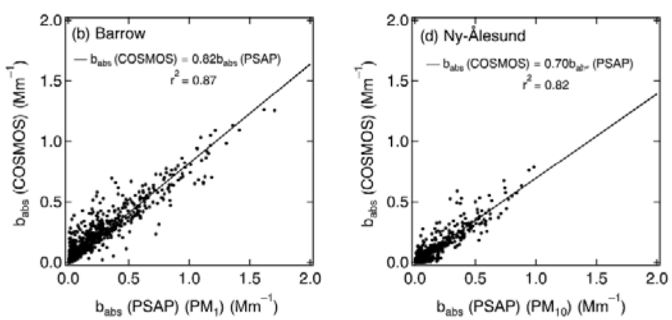


Figure 9. Scatterplots between daily mean (a) b_{abs} (PSAP) for PM_1 and b_{abs} (PSAP) for PM_{10} and between daily mean b_{abs} (COSMOS) and b_{abs} (PSAP) for (b) PM_1 and (c) PM_{10} at Barrow during 2012–2015. (d) Scatterplot between daily mean b_{abs} (COSMOS) and b_{abs} (PSAP) for PM_{10} at Ny-Ålesund during 2012–2014.

Sinha et al., JGR 2017

AMAP report 2015:
"Intercomparisons of d
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snow are urgently need
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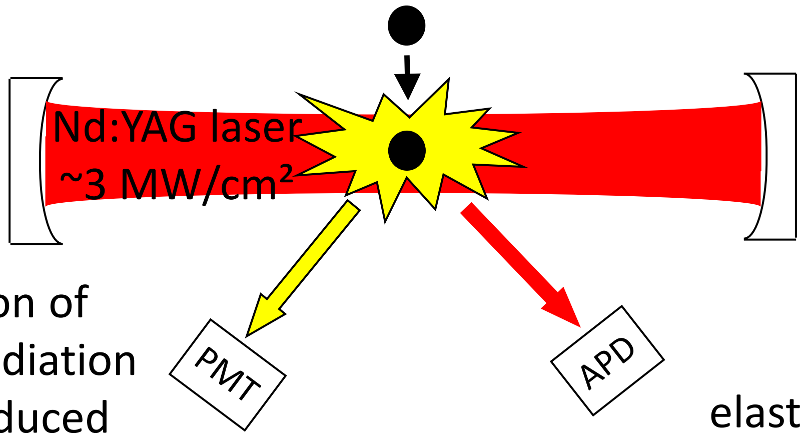
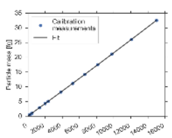
Our weapon of choice

Single particle soot photometer (SP2)

rBC ⇒ refractory BC



Detection of thermal radiation (Laser Induced Incandescence)



External calibration against a BC standard

rBC mass

rBC mass concentrations

Material density of BC

rBC mass equivalent diameter

rBC size distributions

Detection of elastically scattered light

Optical calibration and model

Optical particle diameter

Coating thickness and/or rBC volume fraction