RA 2: Clouds, aerosols, turbulence and climate

Bolin Centre Climate Science course

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2021-03-08

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Lecture outline

- Clouds and Aerosols in the Atmosphere
  - Aerosols in the present-day climate system
  - Our understanding of clouds in the current climate
  - Aerosols, clouds and climate change

- Some examples of research conducted within RA 2
  - Using satellites and models to understand clouds and aerosols
  - Arctic research on aerosols and clouds

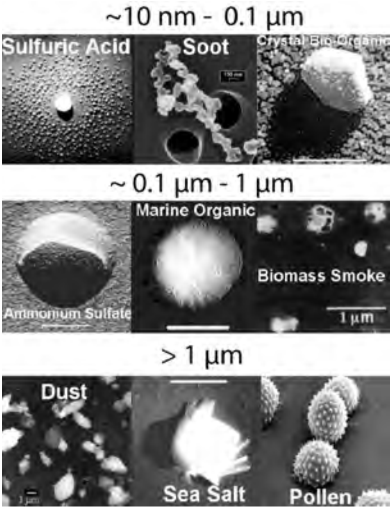
What are aerosols?

Definition

An aerosol is a suspension of solid or liquid particles in a gas

	Continuous phase	Dispersed phase
Aerosol	Gaseous	Liquid/solid
Hydrosol	Liquid	Liquid/solid
Foam	Liquid/solid	Gaseous

- Large variation in size, shape, lifetime and chemical composition.



What are aerosols?

$\rightarrow$ There is no strict scientific classification of aerosols.

Bioaerosol Aerosol of biological origin (viruses, pollen, bacteria, fungal spores and their fragments).

Cloud Visible aerosol with defined boundaries.

Dust Solids formed by disintegration processes (crushing, grinding, blasting, drilling etc.), natural source, generally larger size (1μm to $>$ 100μm), usually irregular.

Fumes Solids produced by physicochemical reactions (e.g., combustion, sublimation, distillation), small in size ($<$ 1μm), term also refers to noxious vapour components.

What are aerosols?

Haze A visibility reducing aerosol.

Smoke Solid or liquid aerosol due to incomplete combustion or condensation of supersaturated vapors, mostly $< 1\mu$m.

Mist and fog Suspension of liquid droplets, formed by condensation of supersaturated vapours, nebulizers, spraying or bubbling, larger in size ($> 1\mu$m).

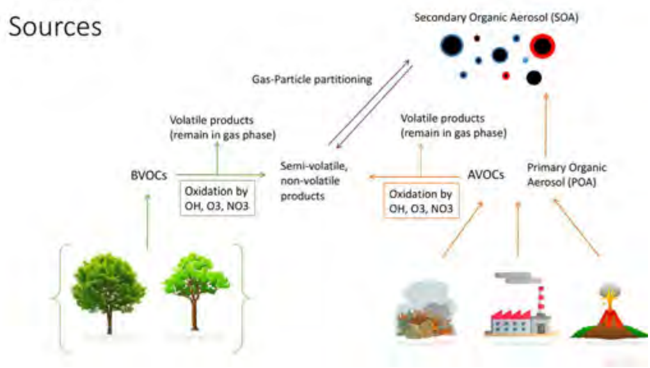
Smog $=$ smoke $+$ fog, term for visible pollution, consisting of solid or liquid particles, created partially by the action of sun light on vapours, includes the vapours, usually below 1 - 2 μm.

Natural and anthropogenic sources of aerosols

Examples

Desert dust, sea spray, volcanic emissions, emissions from forests, forest fires, industry emissions, car or ship emissions, etc.,

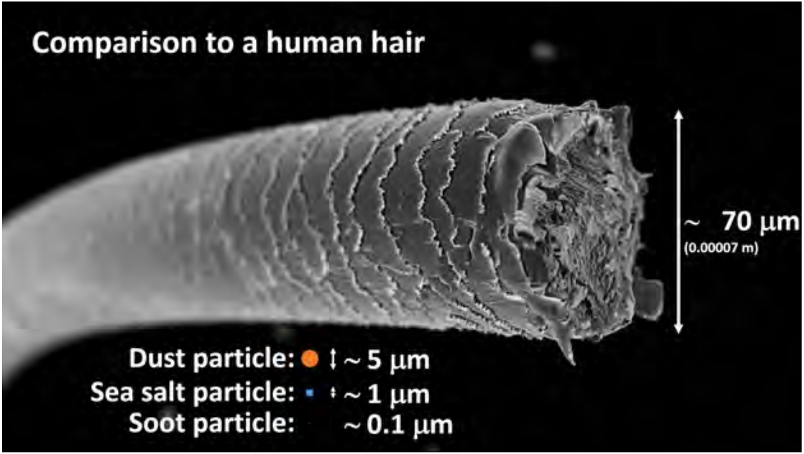
Natural and anthropogenic sources of aerosols



Credit: Gabriela Saavedra

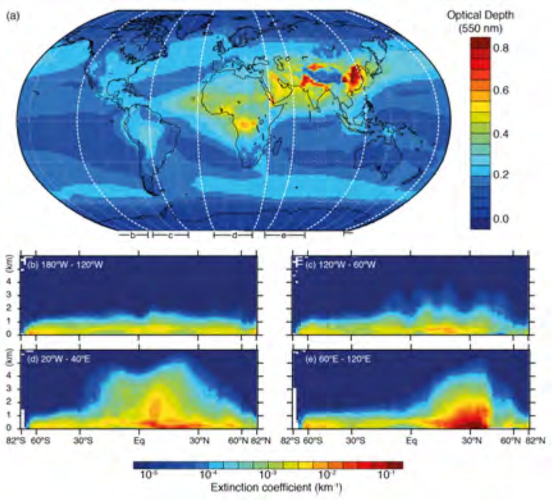
- **Primary atmospheric aerosols** are particulates directly emitted into the atmosphere.
- **Secondary atmospheric aerosols** are particulates formed in the atmosphere by gas-to-particles conversion processes.

Natural and anthropogenic sources of aerosols



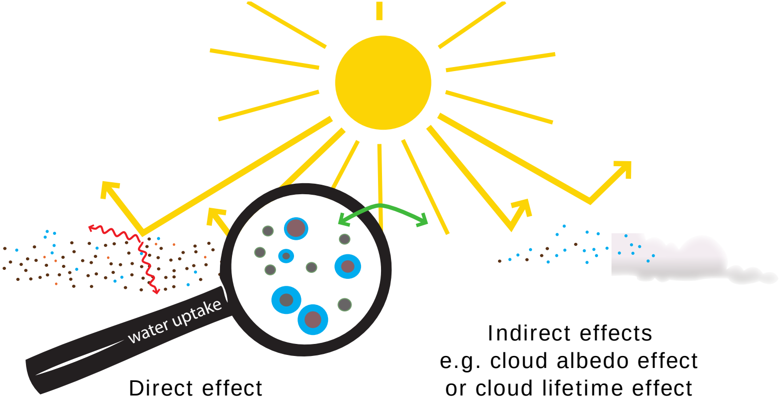
Credit: Paul Zieger, ACES, SU

Natural and anthropogenic sources of aerosols



Credit: IPCC, 2013

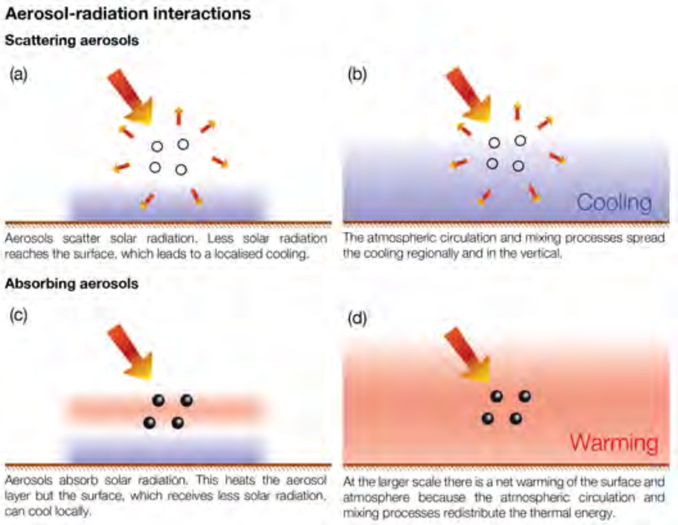
The role of aerosols in Earth's climate



Credit: Paul Zieger, ACES, SU

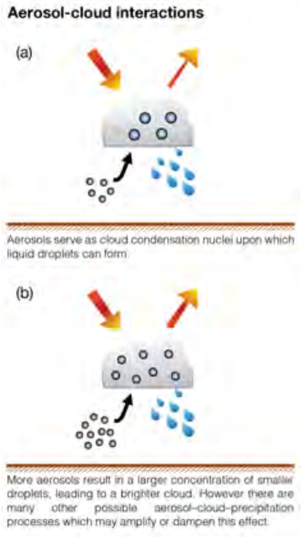
- Aerosols scatter and absorb solar radiation and are important for cloud formation.

The role of aerosols in Earth's climate



Credit: IPCC, 2013

The role of aerosols in Earth's climate



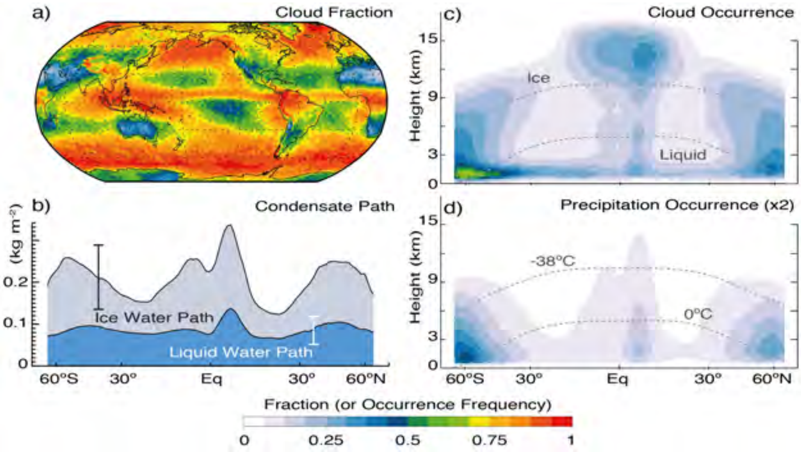
Credit: IPCC, 2013

- Aerosols serve as condensation and ice nucleation sites, on which cloud droplets and ice particles can form.
- $\uparrow$ aerosol particles, $\uparrow$ smaller liquid droplets, $\uparrow$ reflection solar radiation.
- Many other pathways for aerosol–cloud interactions, particularly in ice-or mixed liquid and ice-clouds, where phase changes between liquid and ice water are sensitive to aerosol concentrations and properties.

Clouds

- To form a cloud, air must cool or moisten until it is sufficiently supersaturated to activate some of the available condensation or freezing nuclei.
- Clouds may be composed of liquid water (possibly supercooled), ice or both (mixed phase).
- The nucleated cloud particles are initially very small, but grow by vapour deposition.
- If and when some of the droplets or ice particles become large enough, these will fall out of the cloud as precipitation.
- Clouds cover roughly two thirds of the globe.

Clouds



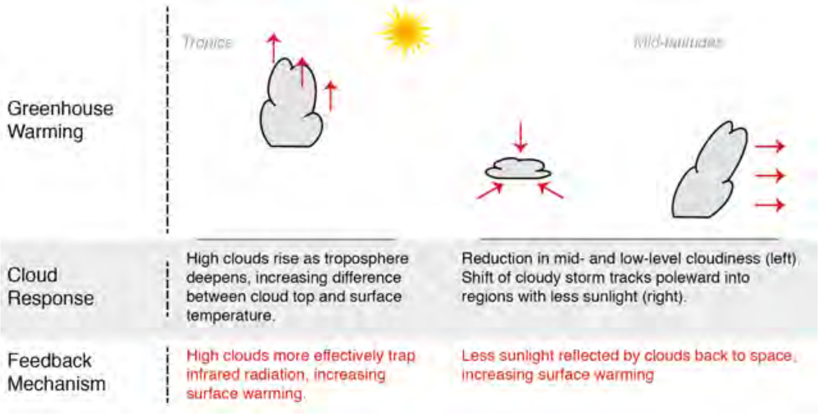
Credit: IPCC, 2013

Clouds

Clouds impact surface temperature in 3 ways:

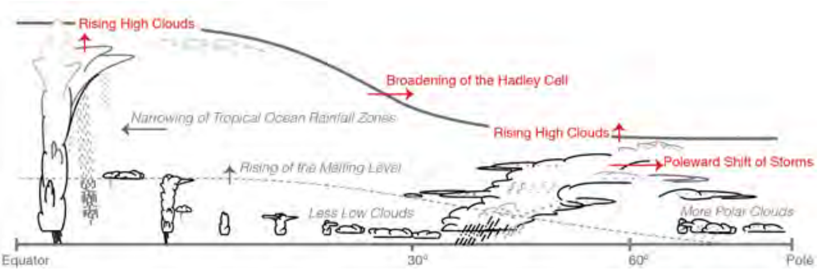
- They reflect sunlight from their topside (albedo)
- Through the “greenhouse effect” - they absorb and re-radiate thermal radiation.
- They reflect back down the thermal radiation emitted from Earth’s surface.

Clouds



Credit: IPCC, 2013

Clouds

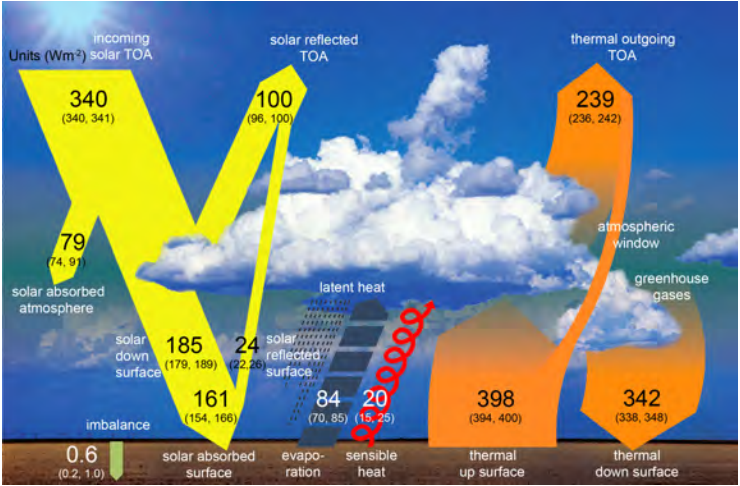


Credit: IPCC, 2013

Cloud feedbacks:

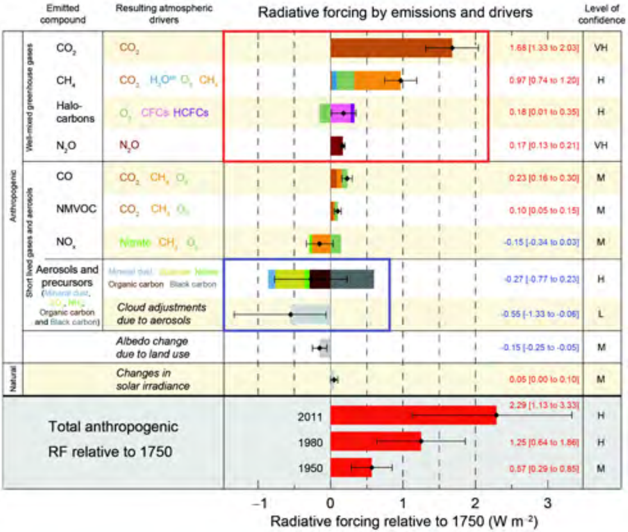
- Changes in high-level cloud altitude and amount.
- Effects of hydrological cycle and storm track changes on cloud systems.
- Changes in low-level cloud amount.
- Microphysically induced opacity (optical depth) changes
- Changes in high-latitude clouds.

The role of aerosols in Earth's climate



Credit: IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*

Uncertainty associated with aerosols and clouds



Credit: IPCC, 2013

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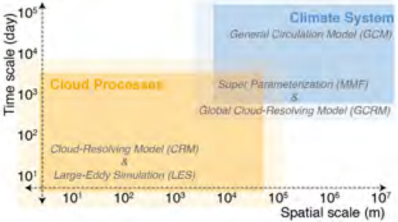
Challenges related to aerosols, clouds and climate

Models have to parameterise *sub-gridscale* processes such as:

- Turbulence
- Cumulus convection
- Microphysical processes
- Radiative transfer
- Cloud amount (including vertical overlap between different grid levels)
- Sub-gridscale transport of aerosol and chemical species

As such many cloud processes are unrealistic in current GCMs $\rightarrow$ cloud response to climate change remains highly uncertain.



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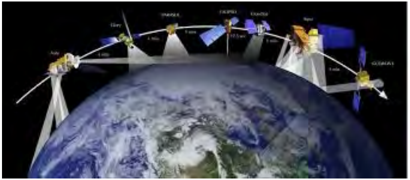
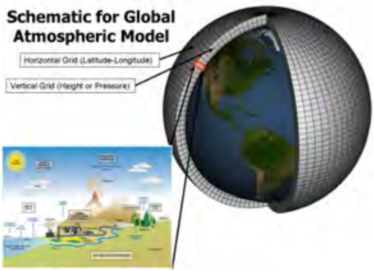
Research conducted within RA2

- Some examples of research conducted within RA 2
  - Using satellites and models to understand clouds and aerosols
  - Arctic research on aerosols and clouds

Using satellites and models to understand clouds and aerosols

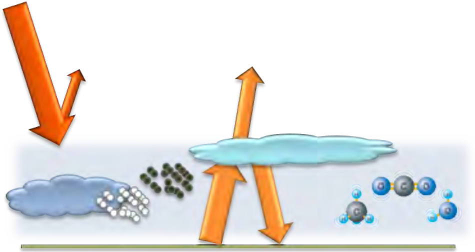


Credit: NASA



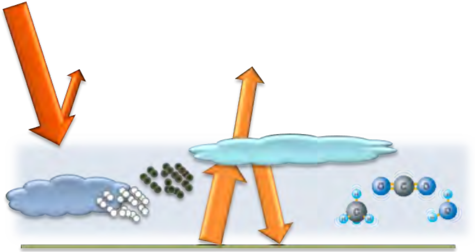
Credit: NASA

Example 1: cloud albedo (reflectivity)



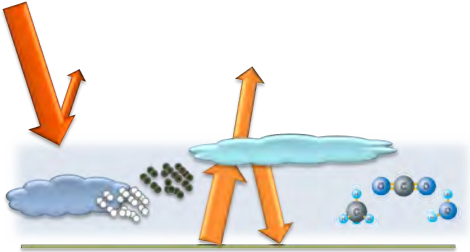
- How reflective are clouds and how do they impact the Earth's radiative balance?
- Frida Bender *et al.* developed a method for quantifying cloud albedo such as from stratocumulus cloud decks.

Example1 : cloud albedo (reflectivity)



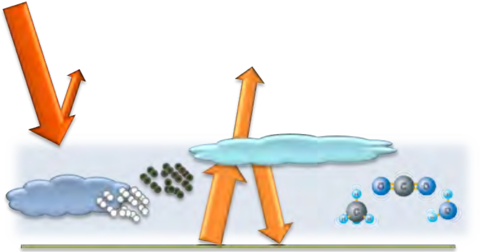
- They observed that models over-estimate cloud-brightening due to aerosols leading to overestimated aerosol cooling and overestimated climate sensitivity.
- In models, microphysical aerosol-cloud interactions propagate to the larger scale while in the real world these aerosol-cloud interactions are hidden or overridden by other factors. Models fail to capture this!

Example 2: vertical distribution of absorbing aerosol



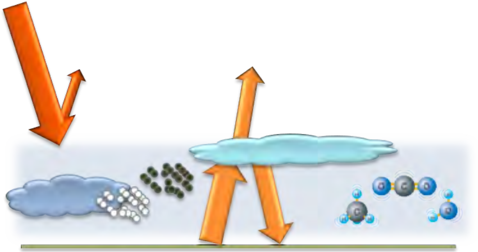
- The location of aerosols in relation to clouds is important in terms of their radiative affect and cloud interaction.
- Frida Bender *et al.* observed that models underestimate aerosol absorption above clouds which leads to overestimates of aerosol cooling.

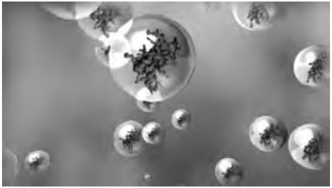
Example 2: vertical distribution of absorbing aerosol



- To probe this further Frida Bender *et al.* obtained in-situ data using UAV’s and combined this with satellite data.
- They are using this data to test and improve models.

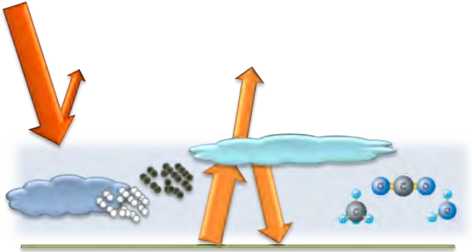
Example 3: cloud droplet number concentration

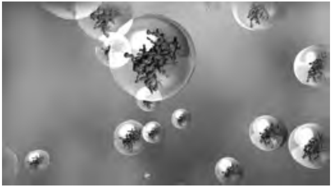




- The representation of cloud droplet number concentration is a another problem in models. This quantity is central to aerosol-cloud interactions.
- It is difficult to measure and difficult to model.
- Frida Bender *et al.* have combined and contrasted modelled and observed CDNC.

Example 3: cloud droplet number concentration



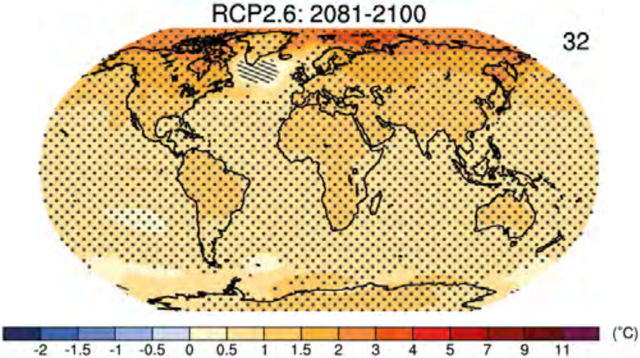


- They observed that sulphate aerosols can be used as a proxy for CDNC to simplify representation in models.
- They also observed that models overestimate the effect of aerosol on cloud life-time.
- This is yet another example of how microphysical effects are buffered and blurred on climatologically relevant timescales illustrating how hard it is to represent subgrid-sacle processes in models.

Arctic research on aerosols and clouds

View from Zeppelin observatory, Svalbard (26 April 2006). Credit: Ann-Christine Engvall

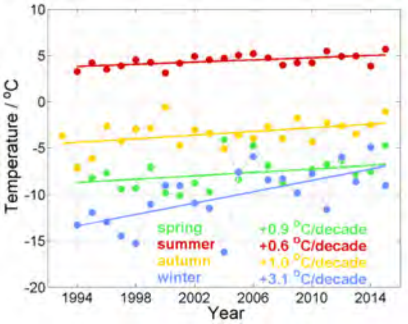
Arctic research on aerosols and clouds



Credit: IPCC, 2013

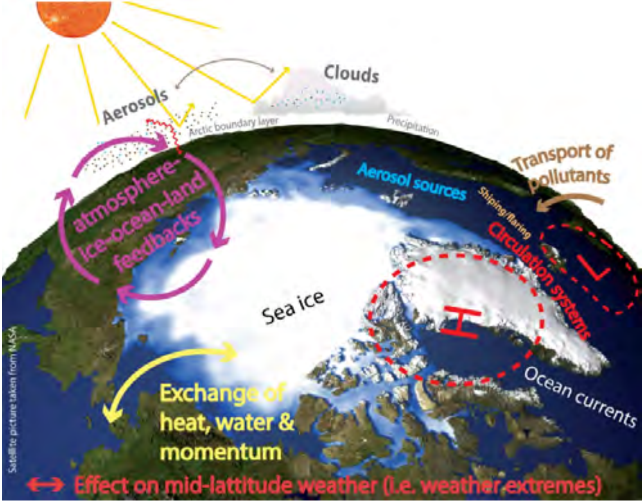
- Arctic amplification → Arctic is warming at double the rate of lower latitudes.

Arctic research on aerosols and clouds



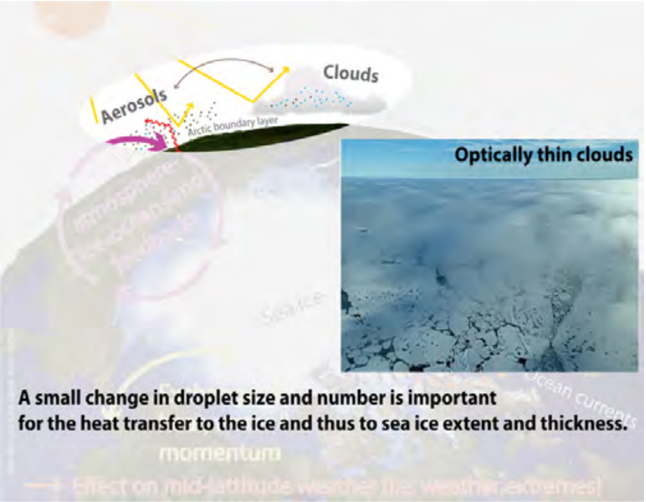
- Seasonal mean surface air temperatures at Ny-Ålesund.
- Most changes occur in winter.
- Why?
- Might aerosols and clouds be involved?

Arctic research on aerosols and clouds



Credit: Paul Zieger, ACES, SU

Arctic research on aerosols and clouds



Credit: Paul Zieger, ACES, SU

Arctic research on aerosols and clouds

Research questions:

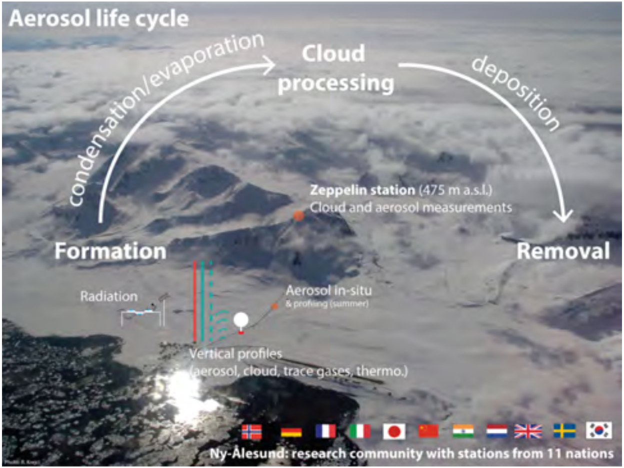
- What are the **main sources** of cloud condensation (CCN) and ice nuclei (IN) in the Arctic?
- How important are **locally sourced** CCN/IN relative to **long-range transported** CCN/IN in the Arctic?
- What are the **properties** of cloud condensation and ice nuclei of low-altitude clouds or fog in the Arctic?
- How important are particles with **biogenic origin**?
- What is the **annual cycle** of microphysical properties of CCN in the Arctic?

Arctic research on aerosols and clouds

- Long-term continuous measurements from **Zeppelin observatory (ZEP)** in Ny-Ålesund on Svalbard.
- MOCCHA campaign within the **Arctic Ocean 2018 expedition (AO18)** to the North pole on board I/B *Oden* (August - September 2018)

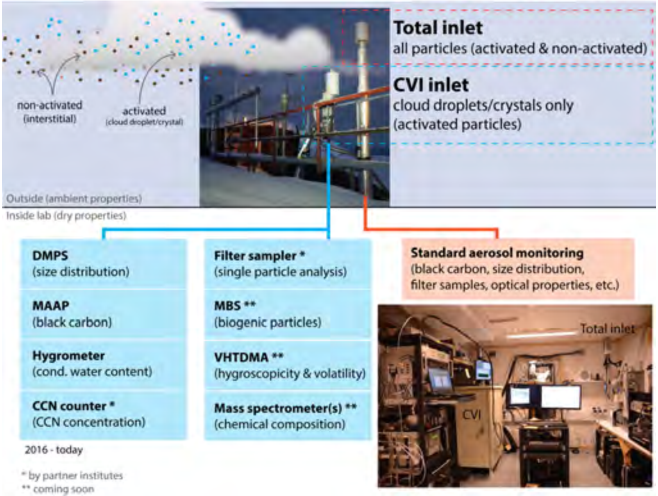
Zeppelin observatory

A perfect location to study Arctic aerosols and clouds



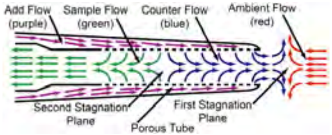
Credit: Radek Krejci and Paul Zieger, ACES, SU

Zeppelin observatory

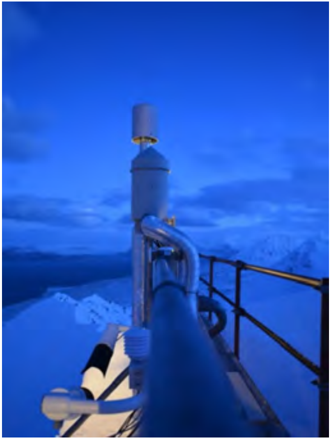


Credit: Paul Zieger, ACES, SU

Zeppelin observatory - Counterflow virtual impactor



Credit: Brechtel manual



Samples only cloud droplets and ice crystals

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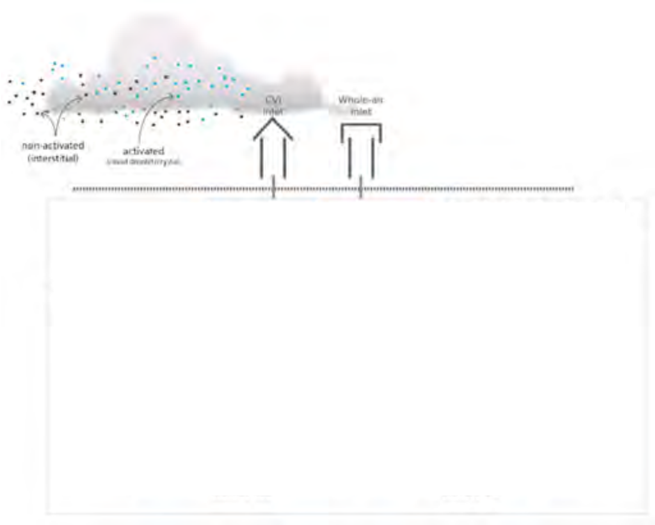
Zepperlin observatory - Counterflow virtual impactor



Credit: Paul Zieger, ACES, SU

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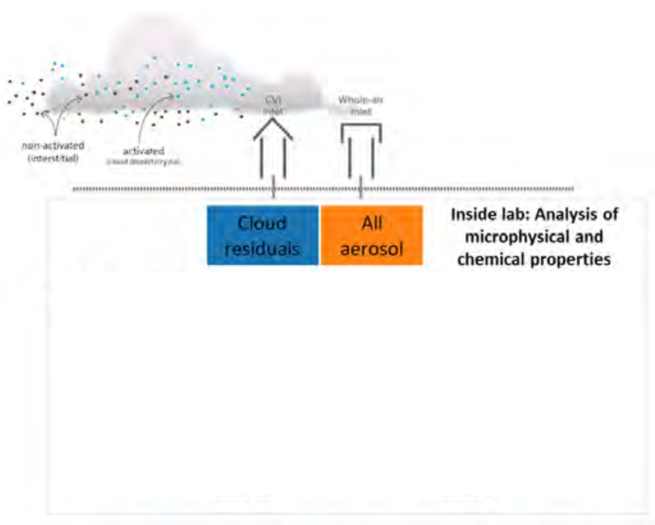

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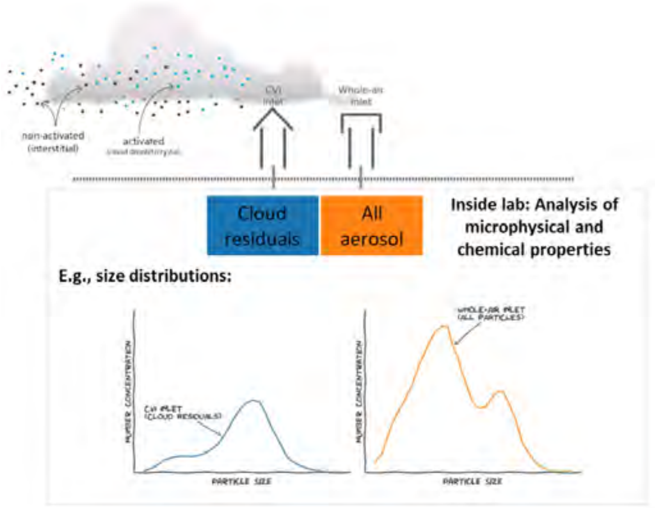

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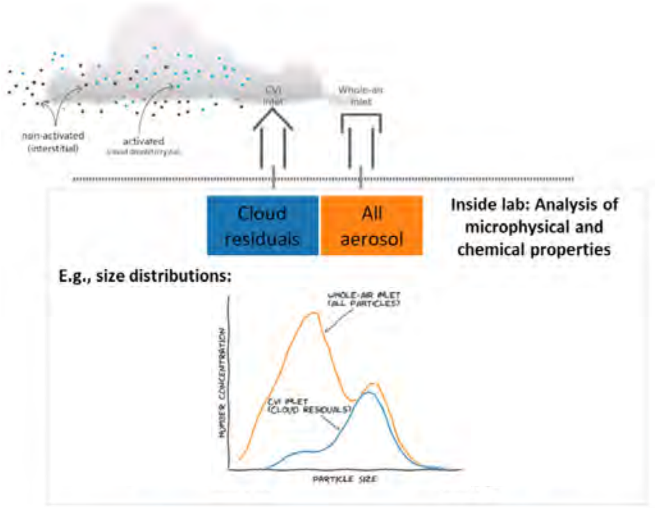
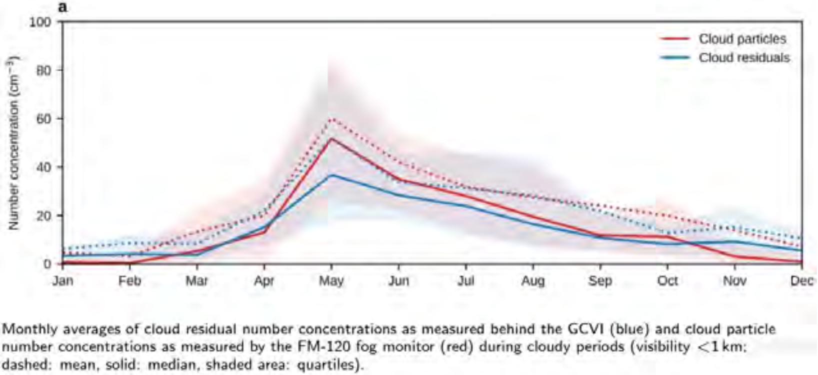


Credit: Paul Zieger, ACES, SU

Zeppelin observatory - cloud residuals



Monthly averages of cloud residual number concentrations as measured behind the GCVI (blue) and cloud particle number concentrations as measured by the FM-120 fog monitor (red) during cloudy periods (visibility <1 km; dashed: mean, solid: median, shaded area: quartiles).

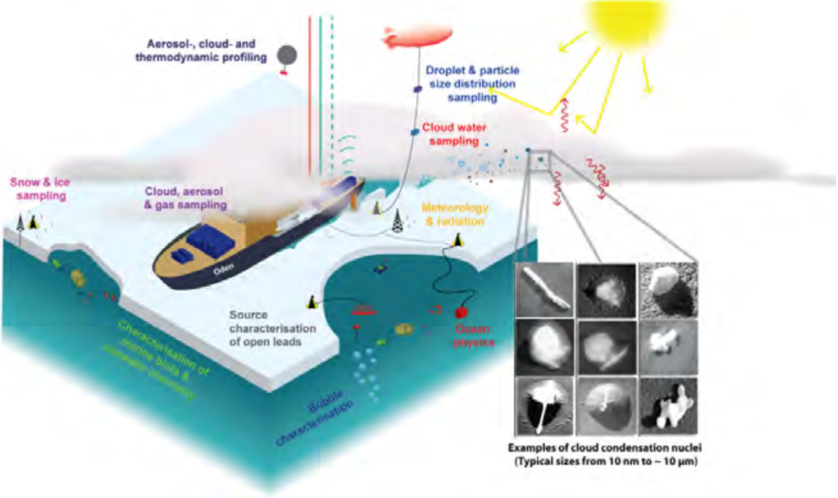
Credit: Paul Zieger, ACES, SU

- Cloud residuals follow the typical seasonal cycle of Arctic aerosol (max in spring and summer, min in late autumn and winter)
- The same dataset has highlighted that sub-100nm particles may also be important as cloud nuclei.

Arctic Ocean expedition 2018

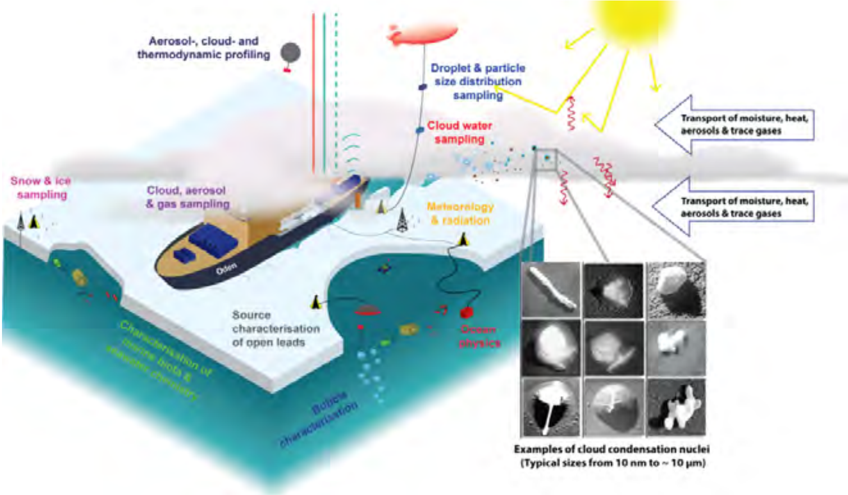
I/B *Oden* with the TROPOS balloon during the ice drift

Arctic Ocean expedition 2018



- Theme: Microbial life in the ocean and ice and how it is connected to cloud formation.

Arctic Ocean expedition 2018



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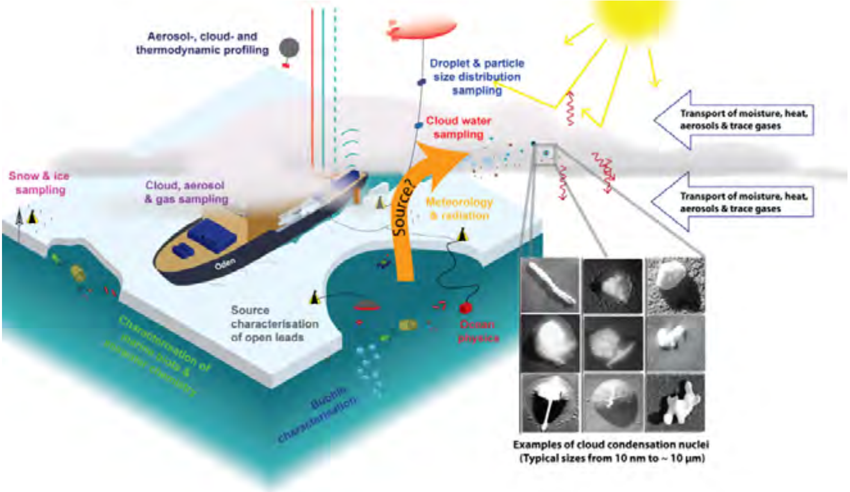

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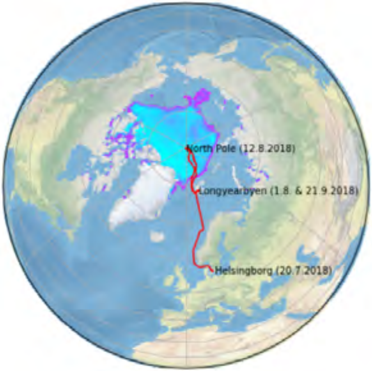
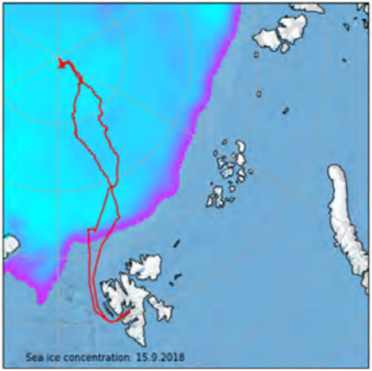
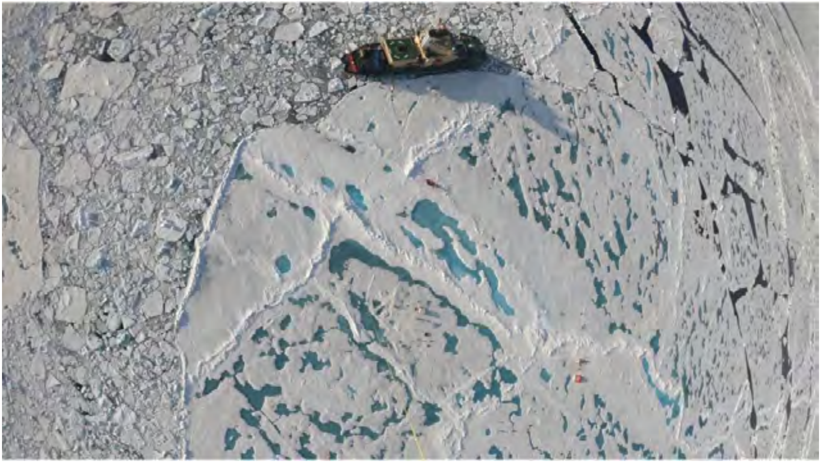




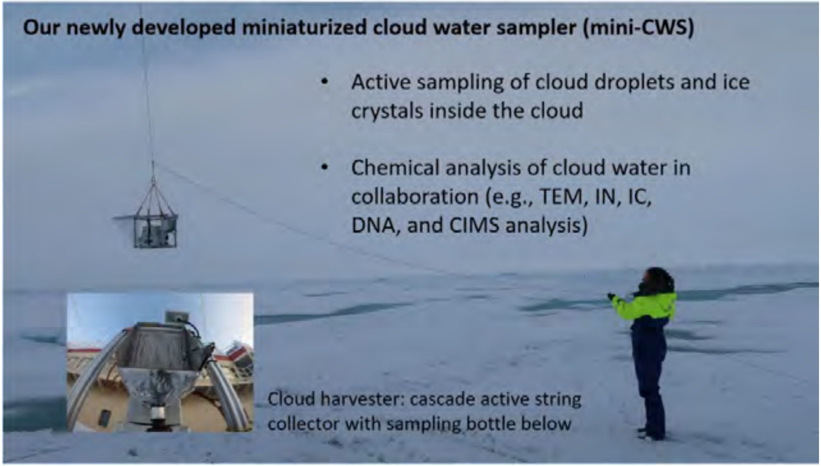
Arctic Ocean expedition 2018



Credit: Paul Zieger, ACES, SU

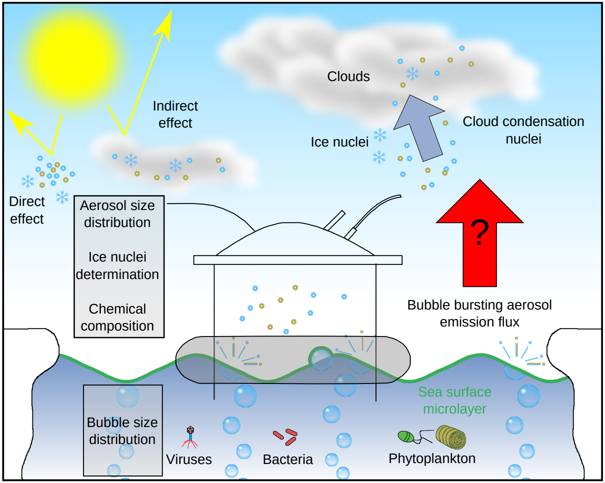
Arctic Ocean expedition 2018

Arctic Ocean expedition 2018



- Direct sampling of cloud water using a helikite.

Arctic Ocean expedition 2018

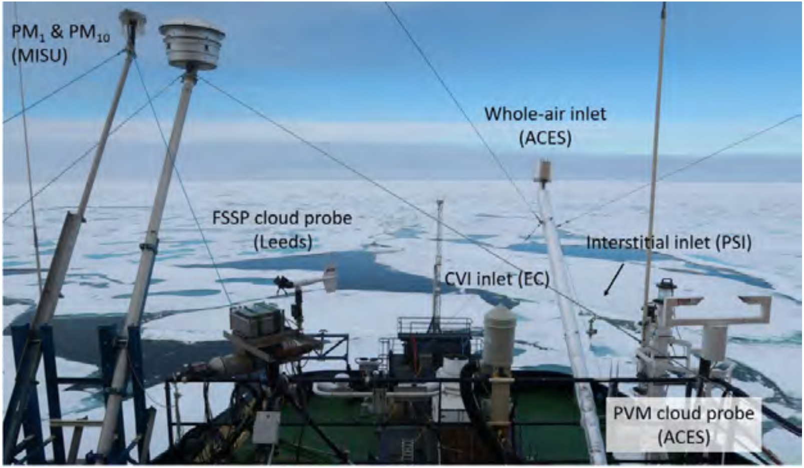


- A major goal was to quantify the flux of particles entering the atmosphere from leads in the ice.

Arctic Ocean expedition 2018

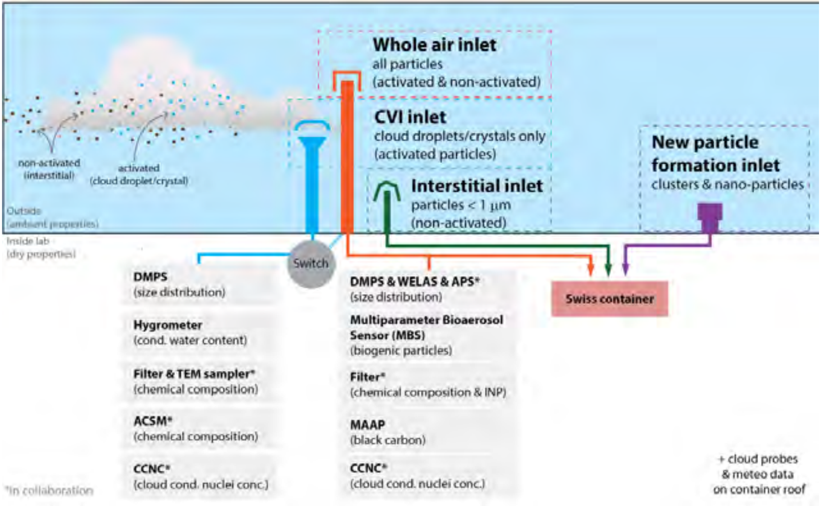
- To achieve this we deployed a floating aerosol flux chamber.

Arctic Ocean expedition 2018



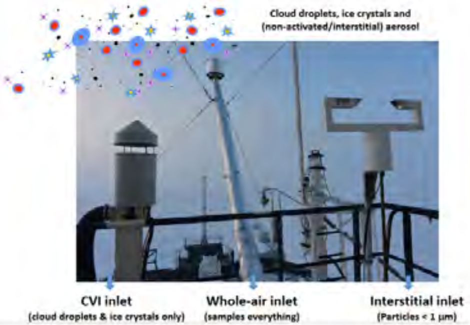
- Sampling the ambient aerosol in the region required a suite of aerosol and cloud inlets.

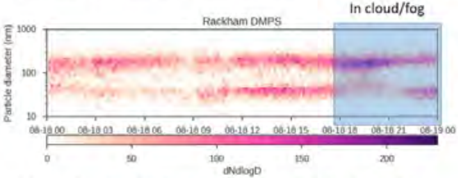
Arctic Ocean expedition 2018



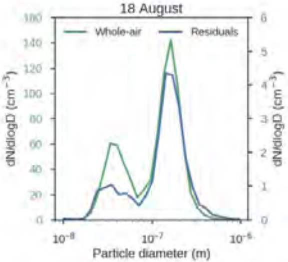
Credit: Paul Zieger, ACES, SU

Arctic Ocean expedition 2018





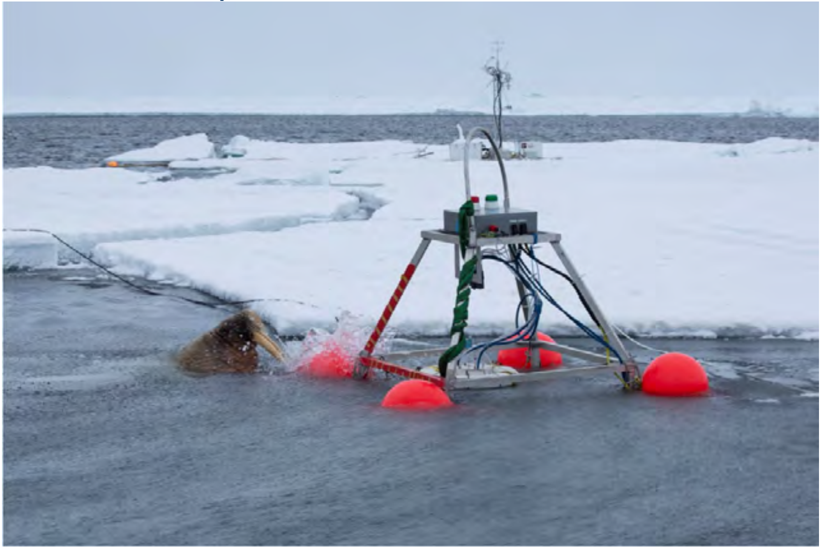
Particle number size distribution (DMPS1 on whole-air inlet).



Particle number size distribution whole-air inlet (DMPS1) + CVI inlet (DMPS2). Not corrected by CVI sampling efficiency.

Credit: Paul Zieger, ACES, SU

Arctic Ocean expedition 2018



Credit: Karin Alfredsson

Arctic Ocean expedition 2018

Credit: Lars Lehnert