Arctic shipping activities and possible consequences for the regional climate

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Greenhouse gases

Carbon dioxide, Ozone, Methane, Water vapor: Carbon dioxide is primarily emitted by combustion processes of fossil fuels and modern fuels such as biomass.

Climate impact

Greenhouse gases directly absorb the terrestrial thermal radiation which is emitted from the earth and by this they heat up the atmosphere: CO_2 is the major player and its concentration has been increasing dramatically since the beginning of the industrialization.

Atmospheric Particles

Aerosol particles:

Aerosol particles are solid and /or liquid particles substantially larger than atoms and ordinary molecules (1 nm) suspended in air.

Size range

Ultrafine, fine and coarse particles:

Nucleation mode range:	1 nm - 20 nm
Aitken mode range:	20 nm - 100 nm
Accumulation mode range:	100 nm - 1 µm
Coarse mode range:	1 µm - 10 µm and larger

Direct emissions

Natural: E.g. desert dust particles or sea spray particles from oceans
Anthropogenic: Mostly by incomplete combustion processes

Indirect emissions

Natural and Anthropogenic: Condensation and nucleation of precursors

Climate impact

- **Direct Aerosol Effect:** aerosol particles scatter (e.g. sulfate particles) and absorb (e.g. black carbon particles) the incoming solar radiation and can thus contribute to global warming or cooling

  ► In the Arctic this effect may contribute substantially different because of the originally high surface albedo

- **Indirect Aerosol Effect:** aerosol particles serve as cloud condensation nuclei and ice nuclei for the formation of clouds and fog which reflect solar radiation and thus contribute to global cooling at our latitudes

  ► In the Arctic such clouds can contribute to global warming when they appear during the polar night and absorb and reemit infrared radiation which is emitted by the earth

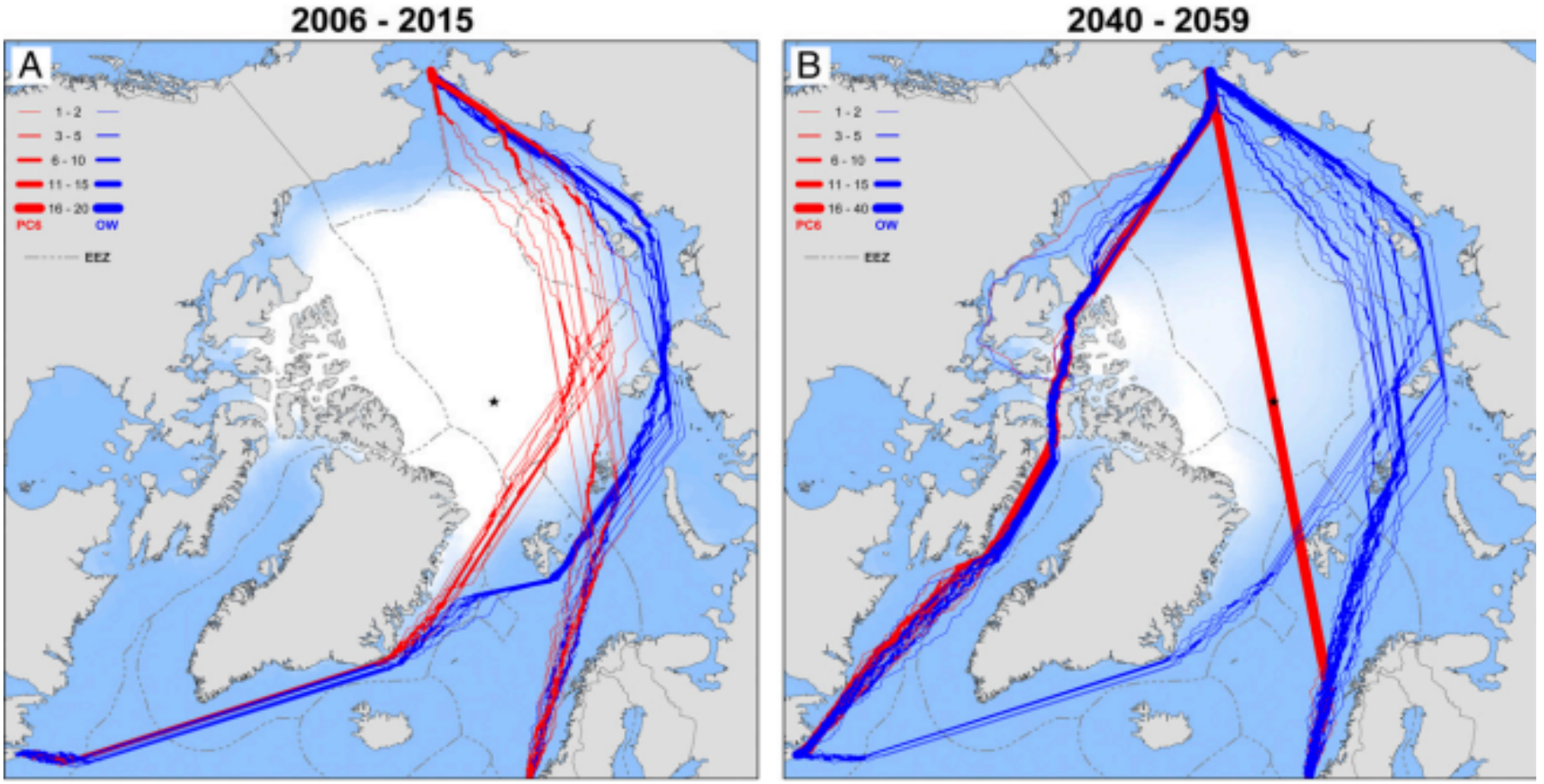
- **Semi-direct aerosol effect:** Black Carbon (BC) can be deposited on snow and ice-covered surfaces and thus change the surface albedo leading to warming of the surface area followed by enhanced melting

Long-range transport

- Every year long-range transported air masses from Eurasia or Canada reach the high Arctic introducing gaseous and particulate pollution to this highly sensitive area.
- The phenomen observed in the Arctic is called Arctic haze and may have a substantial influence on the radiation budget of the Arctic area impacting on climate.

Local emissions

- Anthropogenic sources of gaseous and particulate matter in the high Arctic are scarce at the moment – how will that process in the future?
- The lengthening of the open-water season has led to new industrial developments, including oil and gas activities and a rising number of large maritime vessels.
- The ships transit either the Northern Sea Route over the Russian Arctic from Europe, or the Northwest Passage through the Canadian Arctic from the Atlantic.
- Growing Arctic ship traffic will bring with air pollution that has the potential to accelerate climate change in the world's northern areas.
- Growing oil and gas activities may contribute to this problem as well.



Simulated shipping routes in September through the Arctic in the near future and the mid-21th century, taking into account the changing ice conditions. Blue lines represent open water ships and red lines represent ice reinforced ships (Smith and Stephenson, 2013).

Ship emissions

- Emissions from ships include CO_2, NOx, SO_2, organic vapours and black carbon.
- Recent studies indicate that today emissions of CO_2, NOx and SO_2 by ships correspond to about 2-3%, 10-15% and 4-9% of the global anthropogenic emissions, respectively.

Ship emissions

- **Organic vapours and SO_2: these emissions can form fresh new particles on the nanometer scale after some oxidation processes.**

  ► Freshly emitted particles may grow to substantial sizes via condensational processes and then they can efficiently absorb and / or scatter incoming solar radiation (direct aerososl effect) and can be involved in cloud processes (indirect aerosol effect).

- **Black carbon aerosol: these particles are primary emitted and are originally on the nanometer scale of a few tens or hundreds of nm in size.**

  ► Black carbon particles (BC) can also contribute to the direct and indirect aerosol effect and in addition they can be deposited on snow and ice covered surfaces (semi-direct aerosol effect).

Flaring and venting

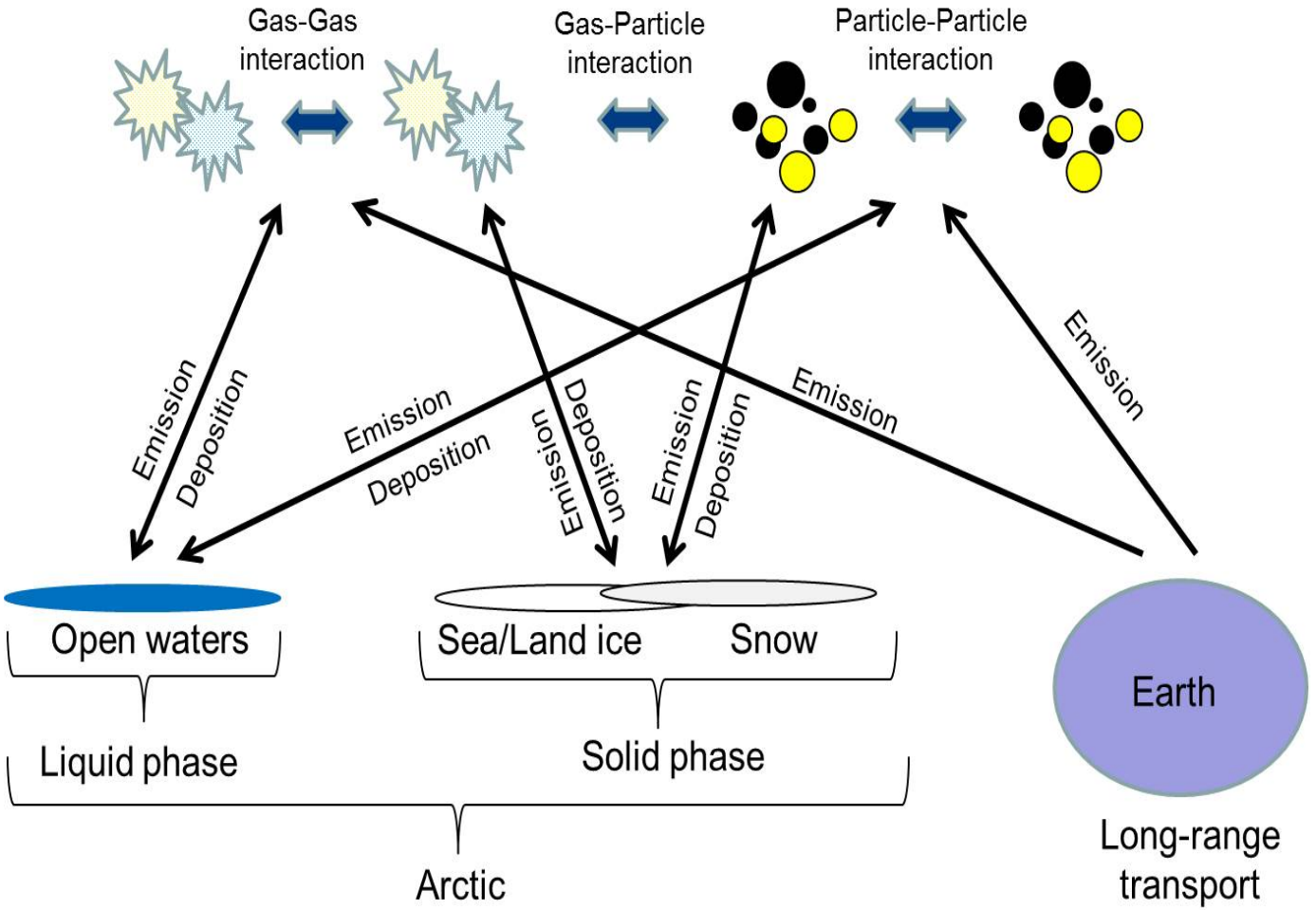
- Flaring and venting of natural gas often occur as part of the oil and gas production process. Flaring is the burning of natural gas in an open flame and venting is the direct release of natural gas into the atmosphere.
- In the context of global greenhouse gas emissions, emissions from venting and flaring represent 4% of anthropogenic CH_4 emissions.

Emissions from flaring and venting

- **In venting, CH_4 is released directly into the atmosphere as a greenhouse gas.**
- **Flaring mainly produces CO_2 and water as waste products of combustion.**
- **The combustion process during flaring is often incomplete which can result in emissions of CO, NO, unburned hydrocarbons, particulate matter including black carbon (BC), and volatile organic carbon (VOCs).**

Atmospheric Interactions

Offshore activities



Special case “The Arctic”: Climate forcing estimates

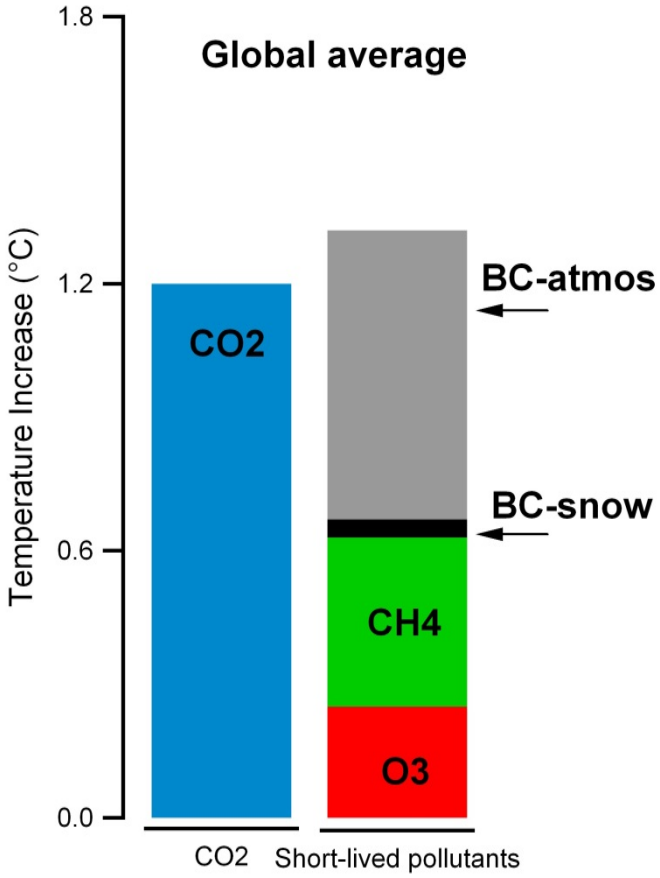
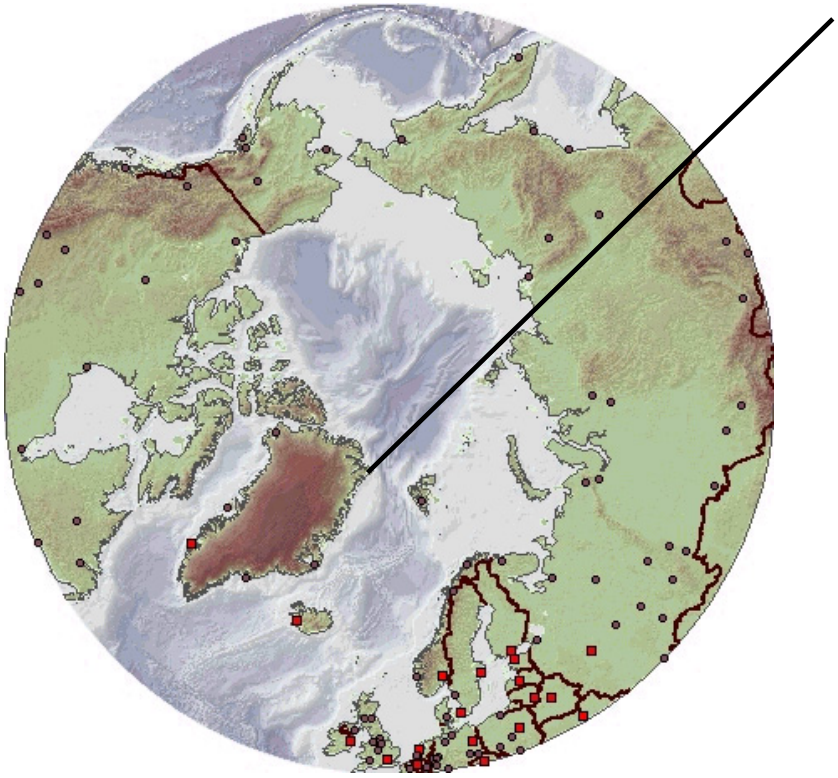
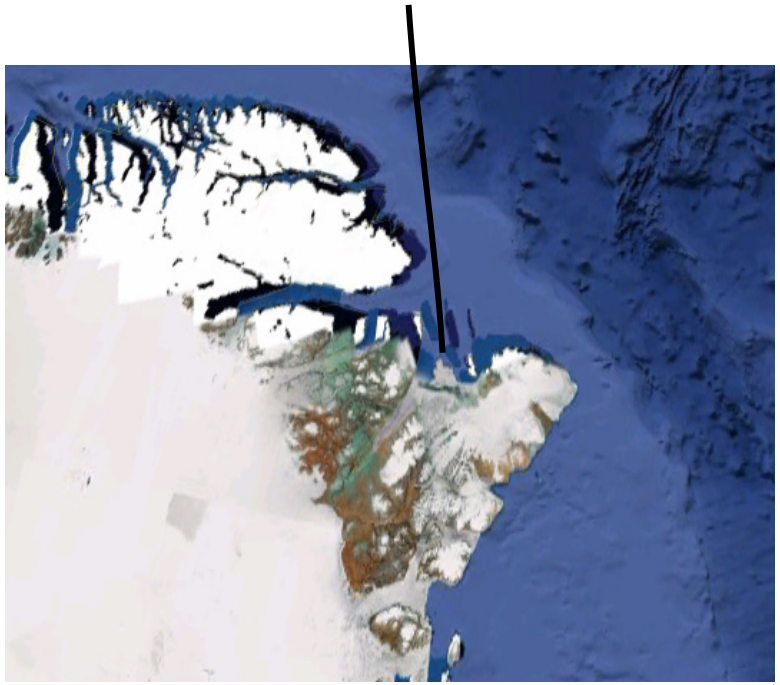


Figure 1: Yearly mean temperature increase by CO2 and short-lived climate forcers compared to the level before industrialization. Global values are based on IPCC (2007). Arctic values are based on Quinn et al. (2007).

Arctic environments: Villum Research Station (VRS) Station Nord, Greenland 81° 36'N 16°39' W

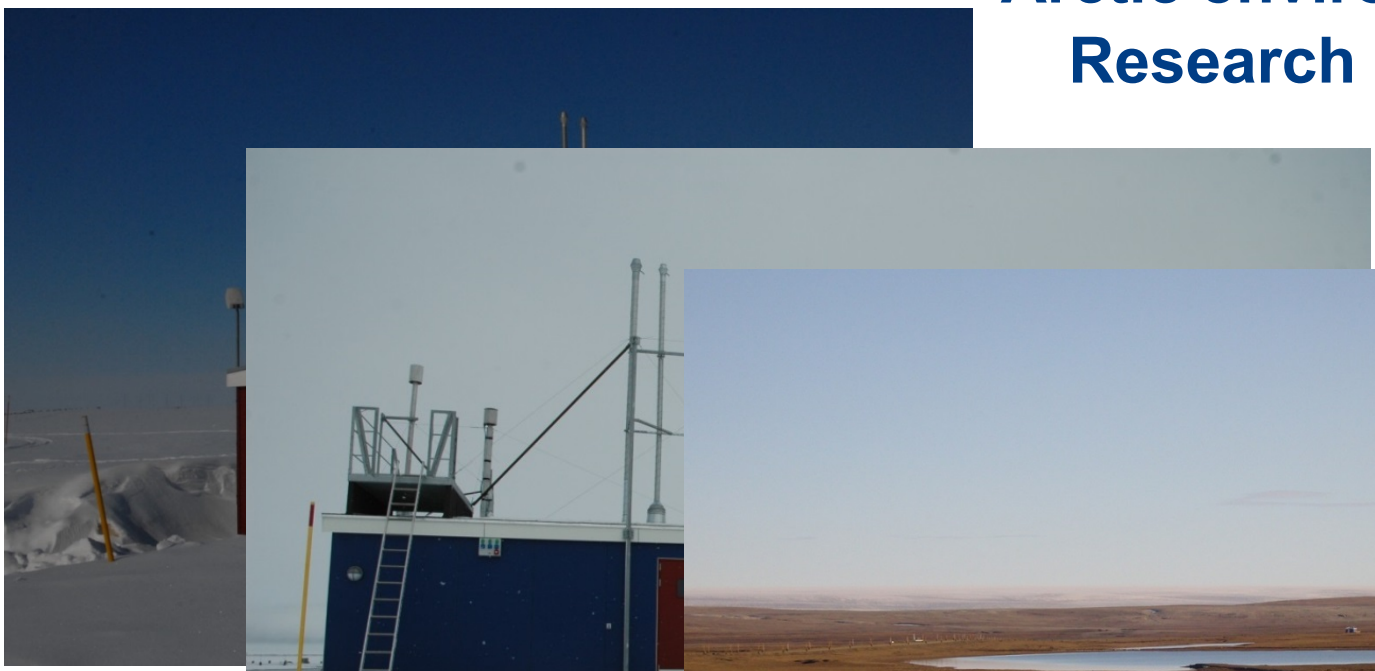




- Base Station (fixed ground station)
- Mobile Station (mobile ground station)
- Air Station (UAVs, balloons, remote sensing)

Andreas Massling Copenhagen, August 2015

Arctic environments: Villum Research Station (VRS)



Drinking lake

Meteorology (by AU-ENVS and DMI)

- T, RH
- WD, WS (Sonic)
- Precipitation (electronic sensor)
- Radiation

Other (by AU-ENVS and DMI)

- Snow depth

Modelling (by AU-ENVS)

- COPREM (COnstrained Physical REceptor Model) and PMF (Positive Matrix Factorization) for source apportionment
- DEHM (Danish Eulerian Hemispheric Model) for estimate of various gas phase and particle compounds

Gasses (by AU-ENVS)

- Ozone, Gaseous Elemental Mercury (GEM), NOx, CO, CH_4, CO_2, H_2
- Fluxes of mercury fractions (Gaseous Elementary Mercury GEM, Total Atmospheric Mercury TAM)

Remote sensing (DTU-RISØ)

- Ceilometer measurements for boundary layer height

Chemistry (by AU-ENVS and AU-Chem) – weekly time resolution

- Filter-Pack Sampler (Inorganics: Elements (ICP-MS); SO_4^{2-}, NO_3^-, NH_4^+ (IC))
- High Volume Sampler (Carbonaceous: EC/OC, Thermo-optical method and Identification of organo sulfates)
- High Volume Sampler (POPs)

Chemistry (by AU-ENVS) – campaignwise

- BC investigation in snow samples
- Chemical speciation of aerosols using a SP-TOF-MS
- Speciation of gas phase compounds using a PTR-TOF-MS

Particle physics (by AU-ENVS) – daily data

- Particle number size distribution (10 - 900nm, SMPS)
- Particle number size distribution (0.5 - 32µm, OPC)
- Absorption coefficient / Black carbon mass concentration (MAAP)
- Scattering coefficient at three wavelengths (Nephelometer)

Particle physics (by AU-ENVS) – campaignwise in future

- CCN activity of submicrometer aerosol (CCN counter)
- Hygroscopicity of submicrometer aerosol (HTDMA system)

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