Environment Canada Environnement Canada

Canada

Observations of aerosol effects on the microphysics and radiative properties of Arctic liquid-phase clouds

Michael Earle,[1] Peter Liu,[1] J. Water Strapp,[1] Alla Zelenyuk,[2] Dan Imre,[3] Greg McFarquhar,[4] Nicole Shantz,[1] W. Richard Leaitch,[1] Mikhail Ovchinnikov,[2] and Steve Ghan[2]

[1] Environment Canada, [2] Pacific Northwest National Laboratory, [3] Imre Consulting, [4] University of Illinois

ASR Science Team Meeting
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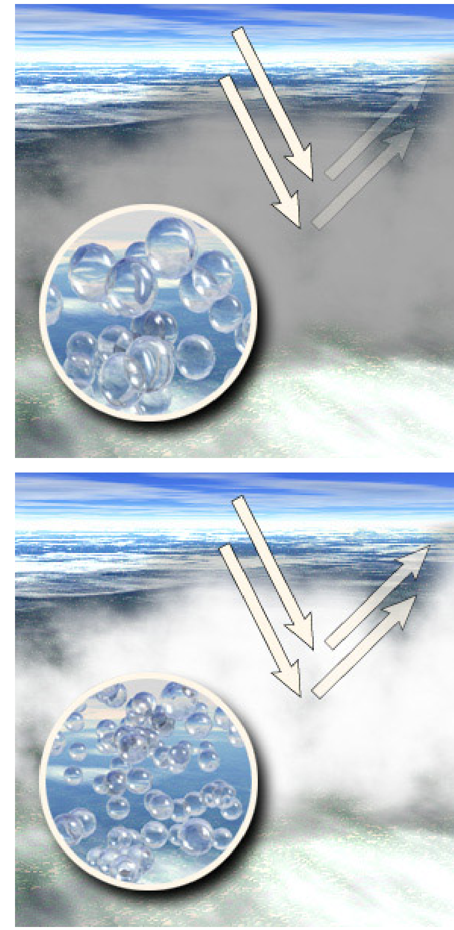
ASR Atmospheric System Research

Introduction

- Aerosol indirect effects: influence of increasing cloud condensation nucleus (CCN) concentrations
  - 1st : Smaller droplets, higher albedo
  - 2nd: Precipitation inhibition, extended cloud lifetimes
- Cloud microphysical and radiative properties
  - Droplet size: effective radius (*Re*)
  - Related to cloud optical depth (τ) and albedo (*A*)
- Droplet activation: CCN ability, dynamics
  - Aerosol physicochemical properties; updraft velocity
- Key climate system process, uncertainty
  - Requirement for studies in Arctic

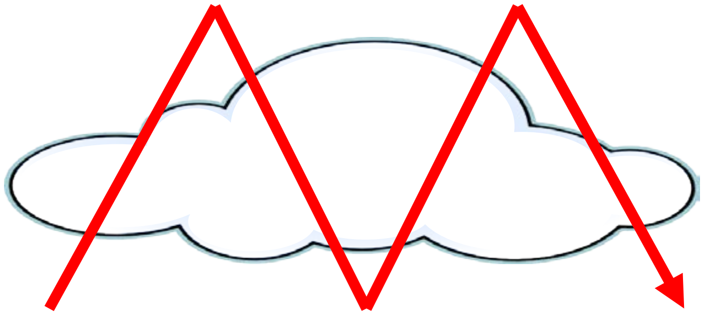


Aerosol indirect effects in liquid clouds (Credit: NASA)

Approach

National Research Council of Canada (NRC) Convair-580

- Indirect and Semi-Direct Aerosol Campaign (ISDAC)
  - Barrow, Alaska – April 2008
- Predominantly liquid clouds
  - April 8, 26, 27 - clean conditions; ‘golden’ cases
  - April 19,20 - biomass burning (BB); polluted conditions



- Part 1: Cloud microphysical and radiative properties
  - Vertical profiles through cloud in clean (30 profiles) and polluted (12 profiles) conditions

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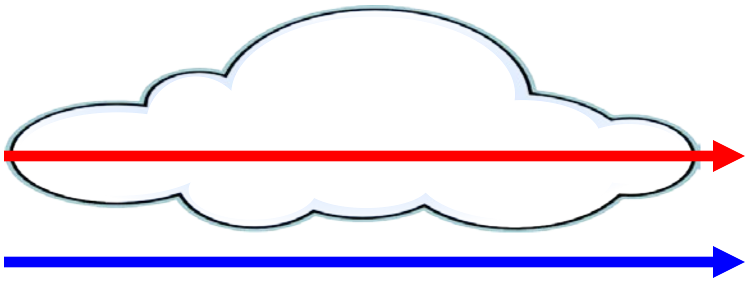


- Part 2: Droplet activation
  - Horizontal flight legs in- (droplets) and below-cloud (aerosols)
  - Droplet closure analysis for clean and polluted cases

Aircraft instrumentation

In-cloud measurements

- Cloud droplet number concentration (N_d)
  - Cloud Droplet Probe (CDP; 2 to 50 µm)
  - Forward – Scattering Spectrometer Probe (FSSP-100; size range ~ 3 to 45 µm)
- Vertical velocity
  - Rosemount 858 gust probe

Below – cloud aerosol measurements

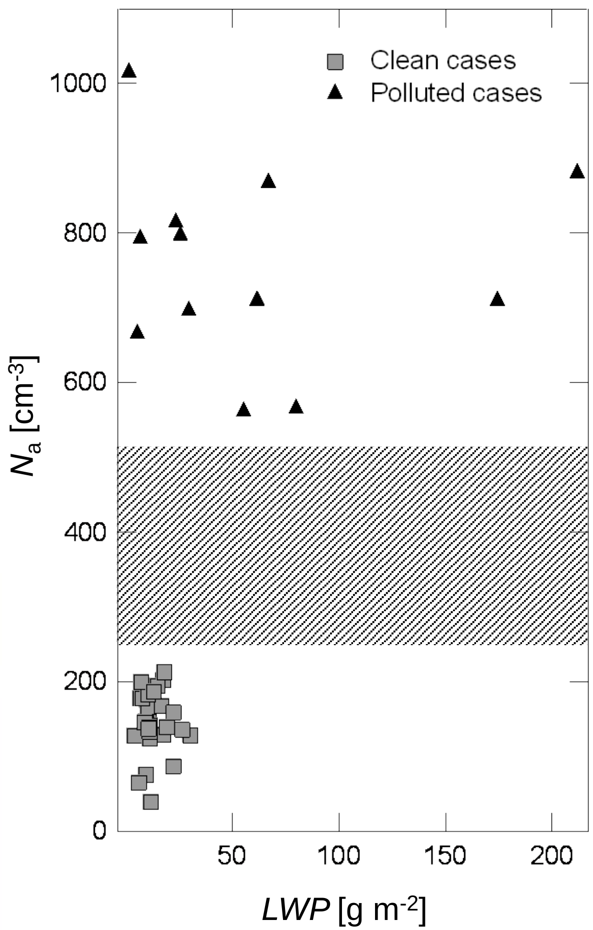
- Aerosol particle number concentration (N_a)
  - Passive Cavity Aerosol Spectrometer Probe (PCASP-100X; size range ~ 0.1 to 3 µm)
  - FSSP-300 (Size range ~ 0.3 to 20 µm)
- Size-distributed particle concentration, composition
  - Single-particle mass spectrometer (SPLAT II)

Canister-mounted FSSP probes (top) and view of SPLAT II from Convair-580 interior (right)

Analysis

Part 1: cloud microphysical and radiative properties

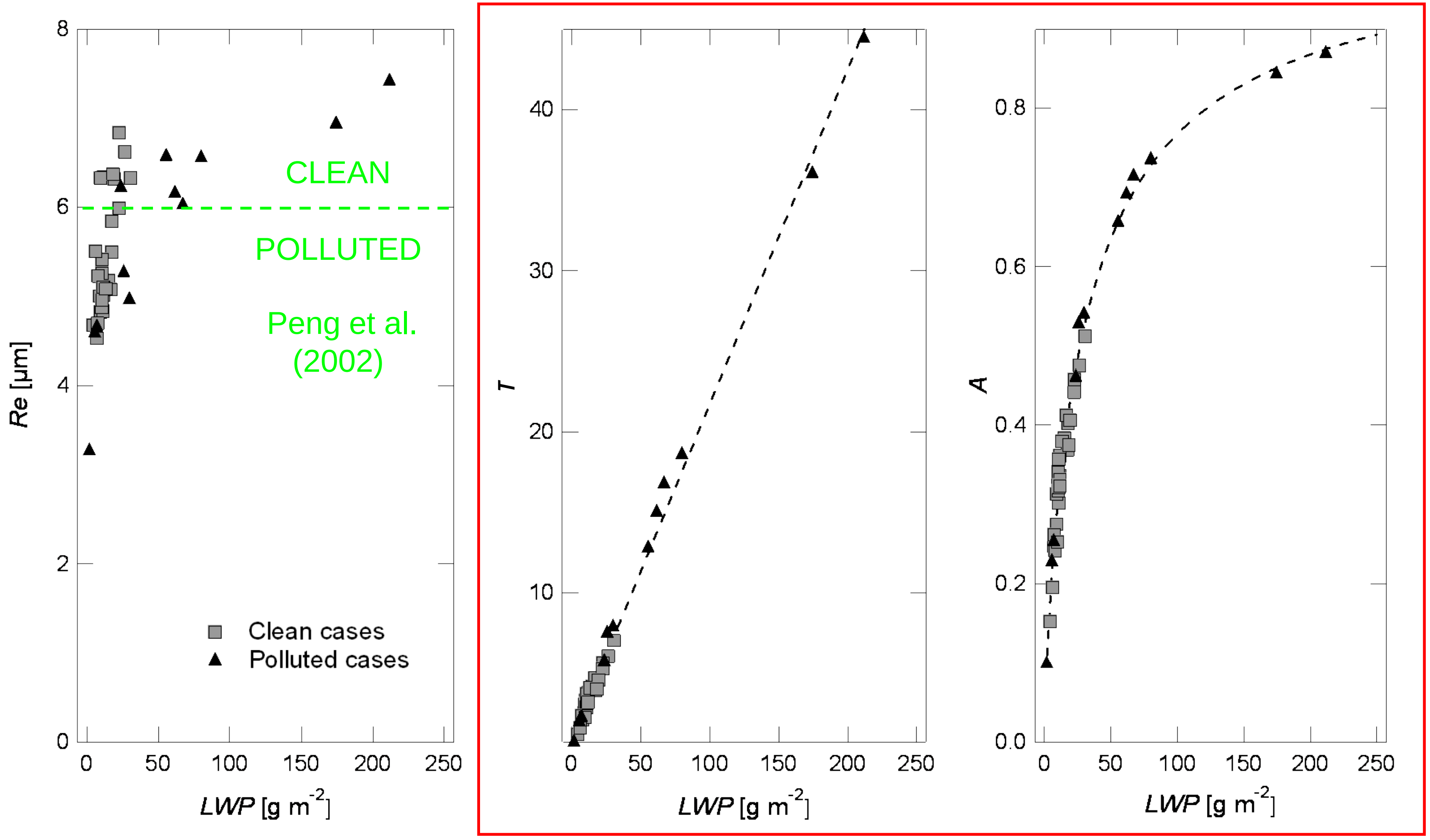
Comparison: clean and polluted cases



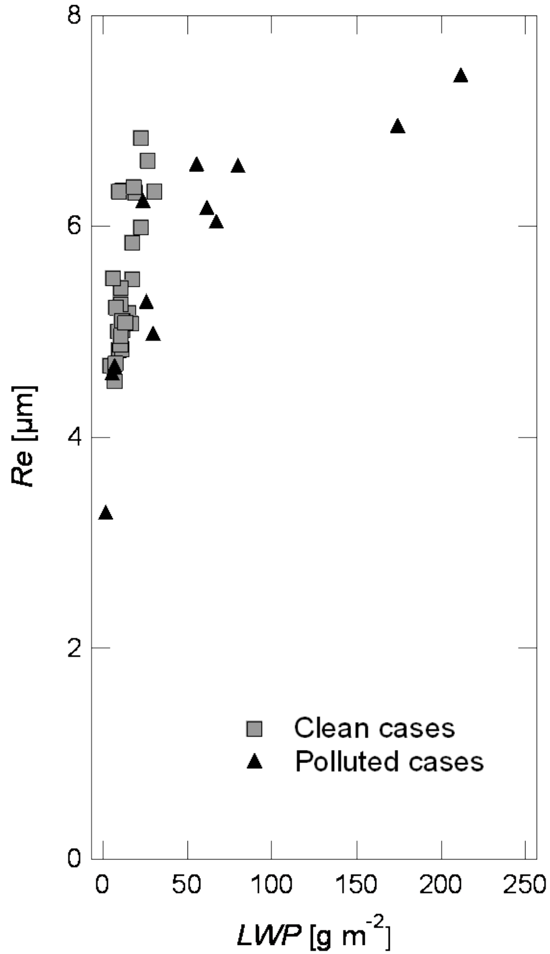
Parameter	Clean	Polluted
N_a, cm^{-3}	147 ± 41	756 ± 132
N_d, cm^{-3}	136 ± 31	304 ± 81
Activated fraction	0.96	0.41
T, °C	-12.9 ± 1.1	-7.5 ± 1.1
LWC, g m^{-3}	0.07 ± 0.02	0.16 ± 0.11
H_c, m	180 ± 43	296 ± 64
LWP, g m^{-2}	13.4 ± 6.1	61.9 ± 66.8
Re, µm	5.4 ± 0.7	5.7 ± 1.2
τ	3.60 ± 0.30	14.13 ± 13.64
A	0.34 ± 0.08	0.55 ± 0.25

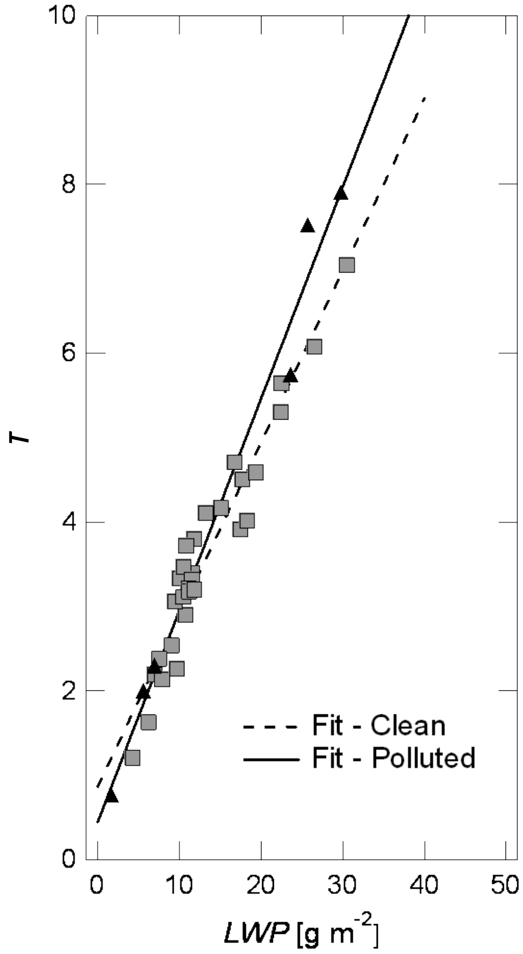
Average properties and standard deviations for all cases

First indirect effect



First indirect effect

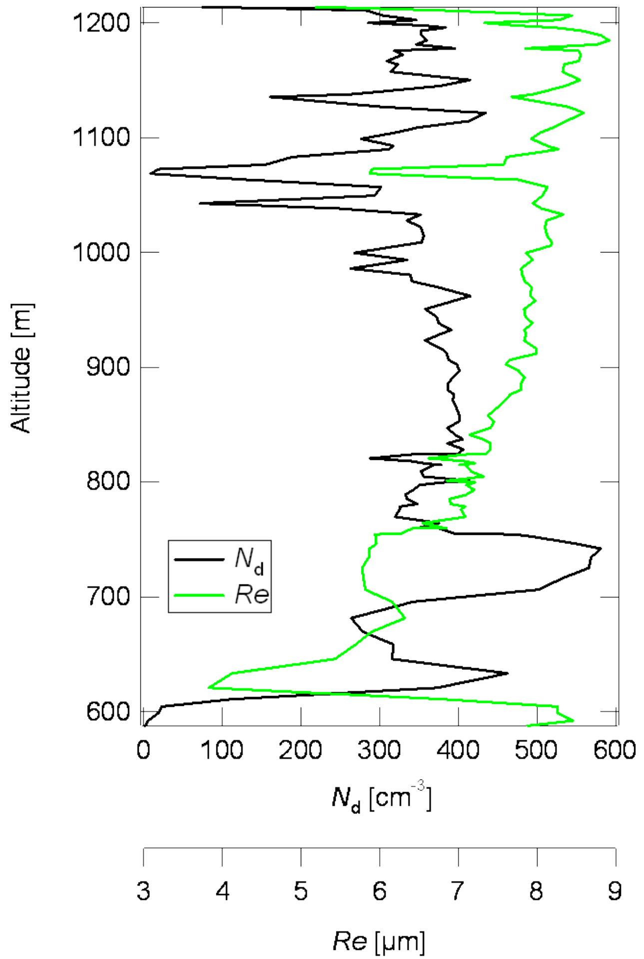




- Focus on range of comparable *LWP*
  - *LWP* < 50 g m^{-2}
- Steeper *τ* – *LWP* relationship for polluted points
- Implies presence of more numerous, smaller droplets
- Reflected in *Re*
  - Clean: 5.4 ± 0.7 µm
  - Polluted: 4.8 ± 1.0 µm

Second indirect effect

- Correlation between higher N_a and higher *LWP* in-cloud – polluted cases
- Enhanced *LWP* prior to precipitation onset in polluted environments (L'Ecuyer et al., 2009)
  - Clouds more vertically-developed
- Assess precipitation formation in terms of *Re*
  - Threshold value ~ 10 – 14 µm (e.g. Gerber, 1996; Hudson and Yum, 2002)
- **Polluted cases** – higher N_d keeps droplet sizes sufficiently small to inhibit drizzle formation by collision-coalescence
- Clean cases – lower *LWC* (colder conditions) limits droplet growth to sizes below drizzle threshold



Polluted case: April 20 (flight 26)

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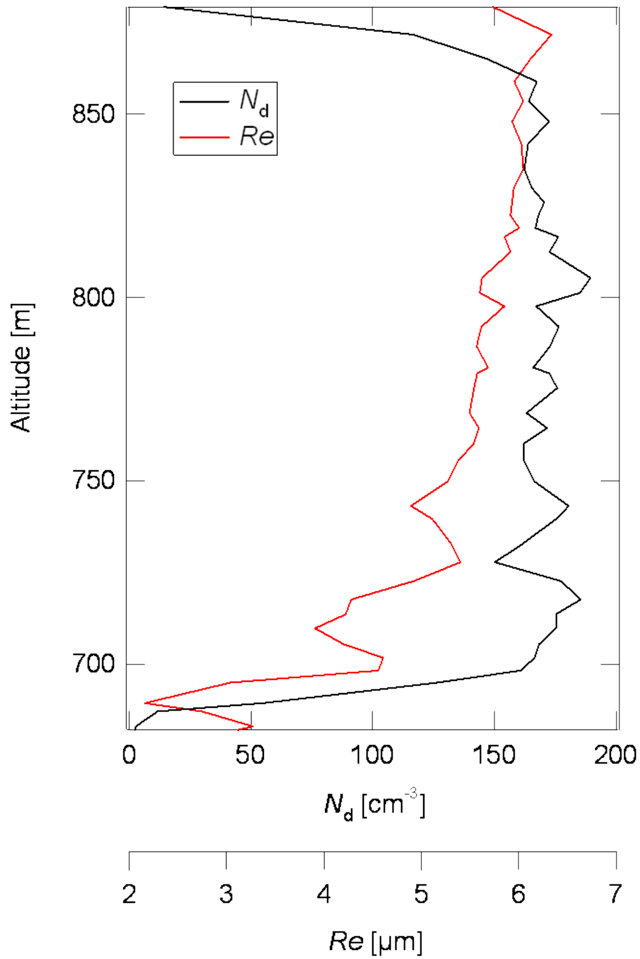
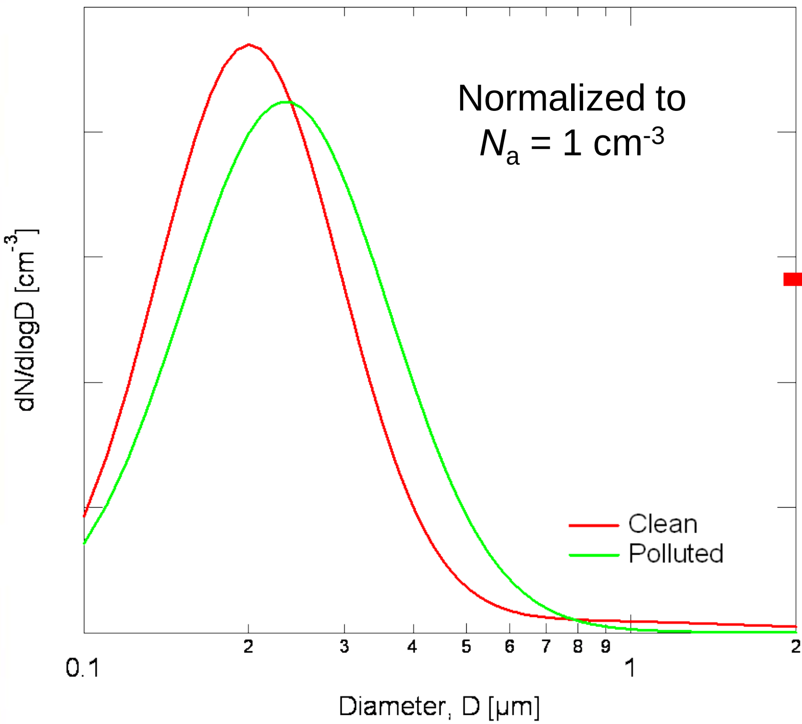


Clean case: April 27 (flight 31)

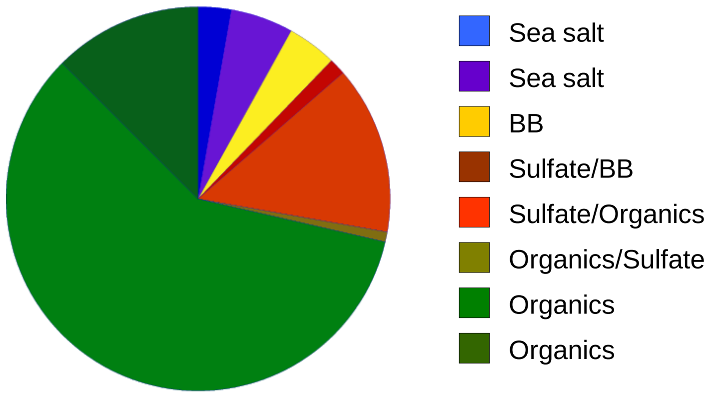
Analysis

Part 2: droplet activation

Aerosol physicochemical properties



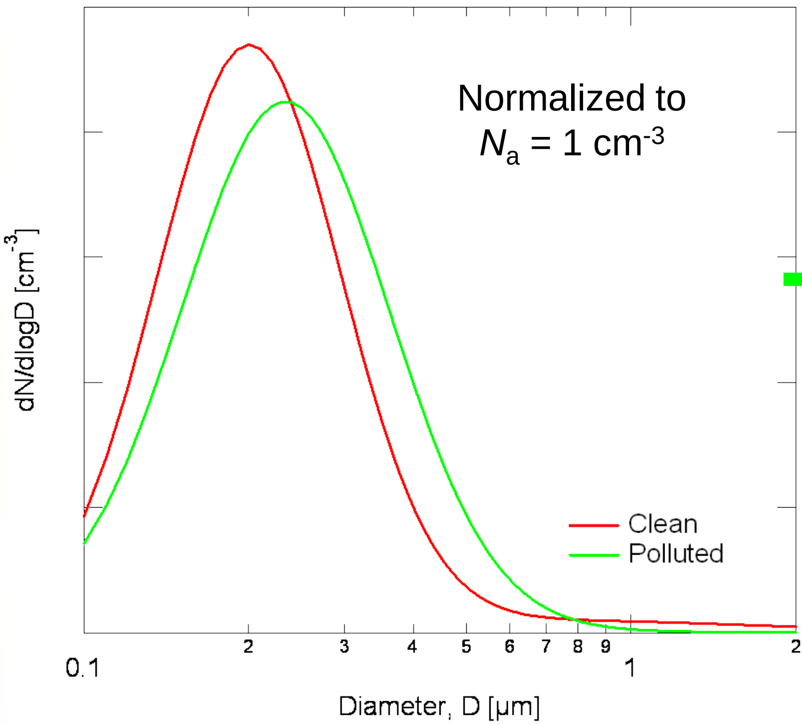
- Aerosol particle size distribution and bulk composition below-cloud



Clean case: April 27 (ISDAC flight 31)

- Mode diameter ~ 0.20 μm
- Predominantly organics
- Mixing with sulphate, BB

Aerosol physicochemical properties



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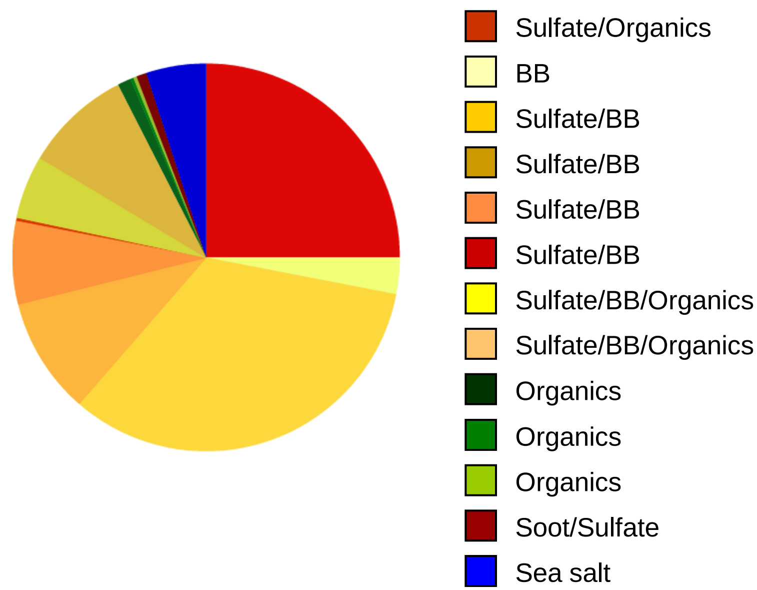
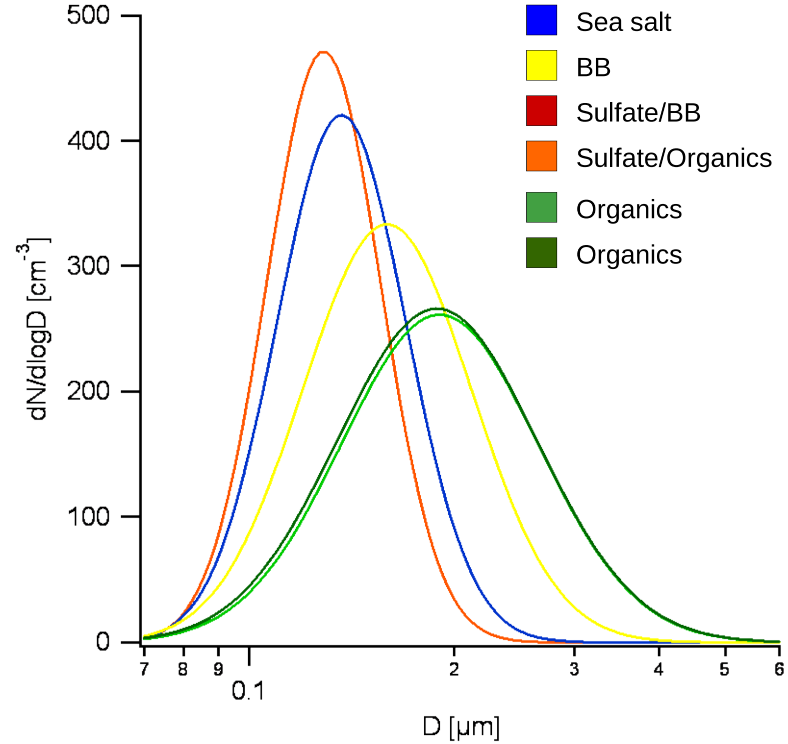


Polluted case: April 20 (ISDAC flight 26)

- Mode diameter ~ 0.24 μm
- Predominantly BB components
- Mixing with sulphate, organics

Droplet closure analysis

- Adiabatic parcel model simulations
- Updraft velocity: standard deviation of gust velocity PDF, σ_ω (e.g. Peng et al., 2005; Fountoukis et al., 2007)
- Hygroscopicity parameter, κ (Petters and Kreidenweis, 2007)
  - Internal / external mixtures
- Results: in polluted cases, activation more sensitive to updraft velocity
  - Lower activated fraction
- Lower max. supersaturation
  - Activation limited to larger and/or more hygroscopic particles
- Implications for *Re*



Size-distributed aerosol particle composition from SPLAT II for clean case on April 27 (flight 31)

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Clean case: April 27 2008

Mixing state	Updraft velocity [cm s^{-1}]	% Difference N_d
Internal (κ = 0.3)	(0.6 – 1) σ_ω	8 %
External	(0.7 – 1) σ_ω	13 -14 %

Polluted case: April 20 2008

Mixing state	Updraft velocity [cm s^{-1}]	% Difference N_d
Internal (κ = 0.3)	(0.4 – 0.5) σ_ω	4 %
External	0.5 σ_ω	3 %

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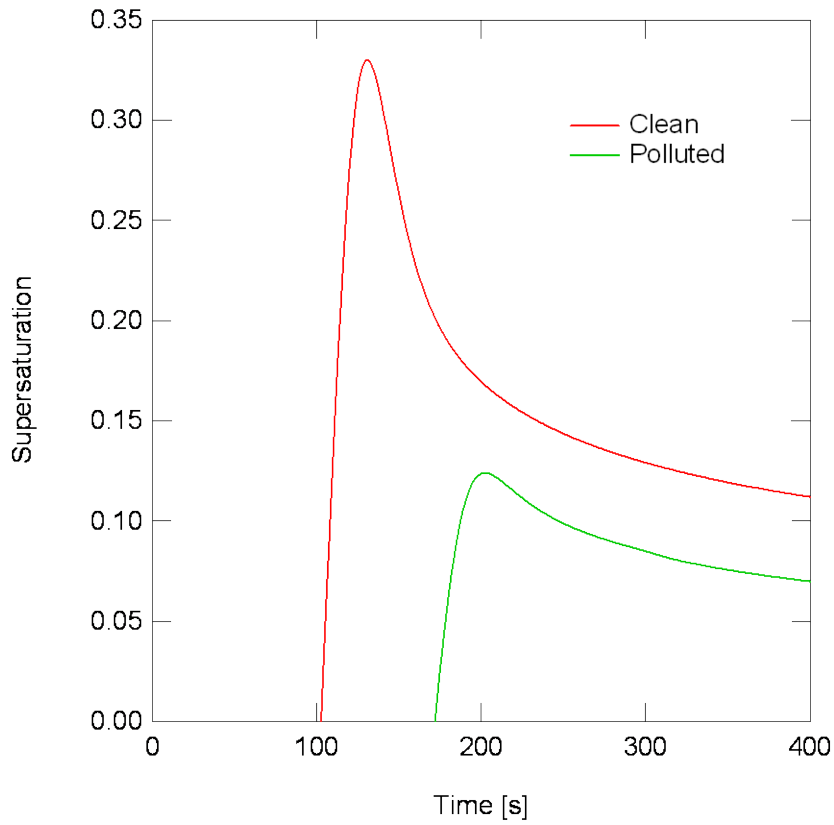

Development of supersaturation in parcel model simulations for clean and polluted cases

Summary

- Vertical profiles through (predominantly liquid-phase) Arctic clouds in clean and polluted conditions
- Polluted cases: higher N_a, N_d, *LWP*, *Re*
  - Roles of temperature, dynamics, aerosol physicochemical properties
- Some evidence of first indirect effect for $LWP < 50$ g m^{-2}
- Evidence for precipitation suppression – second indirect effect
  - Polluted cases: higher N_d limits droplet growth
  - Clean cases: lower *LWC* limits droplet growth
- Droplet closure analysis
  - Polluted cases more sensitive to updraft velocity
  - Preferential activation of larger and/or more hygroscopic particles
  - Future work: toward characteristic updraft velocities for activation in Arctic clouds

Acknowledgements

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- **Collaborators, instrument PIs, support staff**