Properties (and open questions) of Arctic Haze observed by lidar in Ny-Alesund, Spitsbergen

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Outline:

What is Arctic Haze?

The site and the (aerosol) remote instruments of Ny-Ålesund

Properties of Arctic Haze:

- optical properties, from optical to microphysical properties,
- hygroscopicity

Open Questions:

- Closure ("overestimation"?), pollution pathways

Next steps:

- MOSAiC (pathways), AC3: radiation & clouds
What do we know about Arctic Haze:
Can reduce visibility
Composition: sulfates, organics, few metals, (Ny-Ålesund) sea spray, little BC
(Udisti 2016, Tunved 2013)

Origin: mostly anthropogenic (Quinn 2007), but also forest fires (Warneke, 2009)
mixing state: turns into internal mixture during aging (Hara 2003)
Size: around 0.2µm diameter (Tunved 2013)
Max AOD due to size not due to concentration!

Photo:
Extreme event, agricultural flaming May 2006
(Stohl 2006)
Arctic Haze in spring: because particles are larger, have larger scattering efficiency

Max. aerosol number concentration in summer due to marine aerosol
Scattering efficiency, Mie theory:

Size parameter:

\[ x = \frac{2 \pi r}{\lambda} \]

x = 1 for \( \lambda = 355\text{nm} \)
means:
\( r = 56\text{nm} \)

Arctic aerosol is generally small and at the edge of visibility!
Typical AOD values from Toledano 2012 Atmos. Environm.

Spitsbergen

- Spring: Arctic-AOD > N-European-AOD
- No Haze in Scandinavia
- No „easy“ direct pollution transport from Europe

Scandinavia

- Contrary: Eckhardt 2003 (Flextra, CO Tracer) „NAO + facilitates transport into Arctic“

Aerosol may have different pollution pathways than trace gases!
Spring AOD decreases over time
→ annual run of AOD becomes flatter
2009 was last polluted year
Generally high variability

Median, 25% and 75% percentile

AOD- Evolution in Ny-Ålesund, monthly means

S. Graßl 2019, Masterthesis
Ferrero et al, ACP 2016: vertical profiles of aerosol
Tethered balloons with particle counters

a) const. aerosol load – (but convection seldom)
b) More aerosol higher up – advection!
c) More aerosol close to ground (sources?)
d) Difference Aitken vs. Accumulation, strange temp. profile
division: „circulation of the atmosphere“:
Runs climate models: global, regional (future: local)
For improved understanding of physical and meteorological processes
Chemistry of the stratosphere, operate AWIPEV (Koldewey-) station on
Spitsbergen

European Arctic warm: Gulf stream, Westspitsbergen current
Spitsbergen treaty 1920
Ny-Ålesund, 78.9°N, 11.9°O – one of the northernmost settlements:

Coal mining until 1963
Today science village (I, D, No, Sk, J, Cn, Kor, …)
(+): cheap and quick accessible, comfortable
(-): warm for the Arctic, mountains introduce „micrometeorology“
(?) testbed for future
Observatory
78°55'25"N, 011°55'21"E

Balloon launch facility
The peculiarities of Spitsbergen:

DJF temperature trend at 850hPa using ERA-Interim 1996-2016
“center of wintertime warming“ Dahlke & Maturilli, 2017:
¼ of warming due to more efficient advection from Atlantic

Maturilli 2015: strong winter warming also in our data (BSRN, surface)

Annual average temp (April 18 – March 19):
-3°C

West Coast Spitsbergen is transition between N Atlantic and Arctic.
May become „more Atlantic“ in future
Koldewey (AWIPEV Station):

2004 united with frech IPEV

Different projects:
- Biology
- Permafrost
- Atmospheric research

Automatic stations (T, rh, wind, radiation, cloud altitude) regular balloon launches, Eddy covariance; Remote sensing
Jan 2019: winter-campaign

Tonight!!!!
Tue, 21. Jan
17:30
KARL: Koldewey Aerosol Raman Lidar

Backscatter ($\beta$) @ 355nm, 532nm, 1064nm
Extinction ($\alpha$) @ 355nm, 532nm
Depolarisation ($\delta$) @ 355nm, 532nm
Water vapor (mr) @ 407nm, 660nm

Spectra 290 /50 Laser (10W / colour)
70cm mirror
Fov: 1 …. 4 mrad
Licel transients, Hamamatsu PMTs
Overlap > 700m
Tropo- & stratosphere
Challenges with extinction in lidars:

Regardless of extinction profile in atmosphere: impact on lidar profile is infinitely differentiable

$$\exp \left( -2 \int_{z_0}^{z} \alpha(\hat{z}) \, d\hat{z} \right)$$
Extinction in a lidar:

\[ P_r(z) = C_r \rho(z) \frac{1}{z^2} \exp(-\int_0^z \alpha_{le}(\hat{z}) + \alpha_{lr}(\hat{z}) \, d\hat{z}) \cdot [O(z)] \]

Do not smooth or fit your lidar profile !!

Instead you can calculate a “layer-integrated” extinction \((z_{bottom} \rightarrow z_{top})\)

\[ P_r(z_t) = C_r \rho(z_r) \frac{1}{z_r^2} \exp(-\int_{z_b}^{z_t} \alpha \, dz) \cdot \exp(-\int_{z_b}^{z_t} \alpha \, dz) \]

If the derivative \(\frac{\partial}{\partial z}\) harms, avoid it

Or make a statistic from unsmoothed lidar data
(first calculation, then averaging)
What does an aerosol lidar deliver:

extensive quantities (dependent on aerosol number concentration):

backscatter (concentration, size, shape, refractive index)
extinction (concentration, size, shape, refractive index)!

Intensive quantities (not dependent on aerosol number concentration)

depolarisation $\delta = \frac{\beta_1}{\beta_0}$ (shape) [dipole moment]

colour ratio $\text{CR} = \frac{\beta_{\lambda 1}}{\beta_{\lambda 2}}$ (size) [$\beta \sim \lambda^4 \ -4 < \lambda < 0$]

lidar ratio $\text{LR}(\lambda) = \frac{a_{\text{aer}}}{\beta_{\text{aer}}}$ (index of refraction, size, shape)

Knowledge of $\delta$, CR, LR allows a robust classification of aerosol type (dust, smoke, sea salt, cirrus…)

→ it’s about getting the intensive quantities!
Ny–Alesund: backscatter @ 532nm during 2013
optically detectable aerosol disappears from ground up during season

AOD from photometer shows max. in April
Annual cycle in Lidar ratio? Data from 2013

Generally:

LR355 < LR532

\[ LR = \frac{\alpha_{aer}}{\beta_{aer}} \]
Intensive quantity: aerosol depolarisation (shape)

Particles more spherical outside haze season! (Mie better)
Intensive quantity: color ratio (size)

Size more uniform in Feb??
More uniform in low altitudes

- 800m – 1500m
- 1500m – 2500m
- 2500m – 3500m
- 3500m – 5000m
- 5000m – 7000m

colour ratio during spring

backscatter @ 532nm [m^{-1}sr^{-1}] × 10^{-7}

colour ratio 532 / 1064

small
large

Feb
Mar
Apr
May
Mixing state of aerosol:

Sort aerosol for size and shape: still very inhomogeneous LR:

Chemistry unrelated to size and shape

On scale 30m/10min no individual soot, sulphate, crust ... particles

Color ratio, depol. ratio both intensive quantities
Inverting lidar data:

Aim: estimate size distribution \( n(r) \) \((r_{\text{eff}}, \sigma, N_0)\) and refractive index \( m \) from lidar data
Assume spherical particles, Mie theory, efficiencies \( Q_{\text{ext/\beta}} \) are known
\( \rightarrow \) set of Fredholm integral equations for extinction & backscatter

\[
\alpha(\lambda) = \int_{R_{\text{min}}}^{R_{\text{max}}} Q_{\text{ext}}(\lambda, r, m) \pi r^2 n(r) \, dr \\
\beta(\lambda) = \int_{R_{\text{min}}}^{R_{\text{max}}} Q_{\pi}(\lambda, r, m) \pi r^2 n(r) \, dr
\]

Retrieval of \( n(r) \) from \( Q, \alpha, \beta \) is an ill-posed Problem
At least 2 \( \alpha \), 3\( \beta \) needed

But:
Lidar is only able to retrieve aerosol in accumulation mode: 0.1\( \mu \) < \( r \) < 1.2\( \mu \)
Lidar offers: backscatter and extinction. The refractive index depends on: scattering and absorption. Hence: from lidar alone an index of refraction is difficult to obtain. “Stripes” like this in the probability distribution do occur frequently.
Example case of Arctic haze:

Why variation in the backscatter? Just fluctuation in number concentration or also in size and refractive index?
Lidar and contemporary radiosonde: hygroscopic growth?

In-situ define scattering enhancement factor \( f(\text{rh}) = (1-\text{rh})^{-\gamma} \)
Question: apply this to \( \beta \) (instead of \( \sigma \))?
Assumption: all lidar data in a given time / height should belong to „same event“

Backscatter (532nm) vs Rel. Humidity of Water 700-1500m

- \( \beta \)
- \( \beta_{\text{non-valid}} \)
- \( \gamma_1 = 0.3 \)
- \( \gamma_2 = 0.6 \)
- \( \gamma_3 = 1.0 \)
- \( \gamma_4 = 1.3 \)
Open questions:
1. Does remote sensing overestimates extinction?

Tesche et al. 2014 ACP:
Calipso_extinction > in-situ
(Zeppelin station)

(what was NOT published in)
Lisok, 2016 Atm. Environm:
KARL_extinction > in-situ
(Gruvebadet station)
And extinction at ground, 1km, 2km altitude not correlated
Deviations also at rh =50%

Needs to be clarified during MOSAiC:
Less orography!
Open questions:
2. Pollution pathways

Graßl, 2019: Flextra with ERA-interim

Low AOD (April 2013) high AOD

5 days trajectories too short
Reanalysis products show large differences
Slightly higher AOD from Siberia
Sea ice as reduced sinks?

High aerosol load due to sources and sinks

Sea ice: dry, stable BL less vertical mixing, longer aer. life-time

Best conditions for aerosol transport:
Air over source regions in BL with enough wind speed
Ascend of the air (higher wind speed, 5 days, less precipitation)
Advection over sea ice

MOSAiC: coordinated observations with surrounding stations needed
MOSAiC: 
**Multidisciplinary Drifting Observatory for the Study of Arctic Climate**

- September 2019 – September 2020
- Largest Arctic research expedition ever
- 5 icebreakers
- More than 60 institutes
- 17 nations
- ~300 scientists in the central Arctic

Goal:
To improve the understanding and model representation of coupled atmosphere-ice-ocean-ecosystem-biogeochemistry processes
Atmospheric research: Similar instrumentation on ship and AWIPEV: Pollution transport
Atmospheric observations during MOSAiC

13 stations with year long monitoring program + 2 AWI planes

Transparency from Marco Zanatta
Several ground stations for meteorology and aerosol in-situ
AC3 and PAMARCMiP 2018:

Persistent layer of aerosol in 5-7km

Polar5 flight-track towards Station Nord

Ny-Ålesund, Spitsbergen

Compare remote sensing to in-situ

Calculate radiative forcing
Arctic Haze consists of small particles
Max. extinction in spring due to slightly larger particles
Effective pollution pathways unknown: MOSAiC
Weakly depolarizing particles with moderate LR, chem. „internal mixed“ on 10min / 30m scale
Maybe in-situ underestimates extinction
A theory is short, concise and complete and is believed by nobody except of its inventor.

Observational data are noisy, strange and incomplete and are believed by everybody except of the one who measured them.

Thank you for your attention!
### Available aerosol measurements during MOSAiC

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Platforms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AEROSOL BASIC</strong></td>
<td></td>
</tr>
<tr>
<td>Total number concentration</td>
<td>Detected</td>
</tr>
<tr>
<td>Total mass concentration</td>
<td>Not observed</td>
</tr>
<tr>
<td>Number size distribution</td>
<td>To be confirmed</td>
</tr>
<tr>
<td>Scattering</td>
<td>No Info</td>
</tr>
<tr>
<td>Absorption (direct measurement)</td>
<td>No Info</td>
</tr>
<tr>
<td>Cloud condensation nuclei</td>
<td>No Info</td>
</tr>
<tr>
<td>ChemistryOnline</td>
<td>No Info</td>
</tr>
<tr>
<td>EC/OC</td>
<td>No Info</td>
</tr>
<tr>
<td><strong>OTHER</strong></td>
<td></td>
</tr>
<tr>
<td>Refractory black carbon</td>
<td>Detected</td>
</tr>
<tr>
<td>Hygroscopicity (HTDMA)</td>
<td>Detected</td>
</tr>
<tr>
<td>In-situ cloud activation (CVI or interstitial)</td>
<td>Detected</td>
</tr>
<tr>
<td>INP (online-offline)</td>
<td>Detected</td>
</tr>
<tr>
<td>Wet scattering</td>
<td>Detected</td>
</tr>
<tr>
<td>Cloud residual size distribution</td>
<td>Detected</td>
</tr>
<tr>
<td>Cloud residual BC</td>
<td>Detected</td>
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<tr>
<td>Cloud residual composition</td>
<td>Detected</td>
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<td>Cloud liquid water content</td>
<td>Detected</td>
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<td>Droplet size distribution</td>
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<tr>
<td>CCN on cloud residuals</td>
<td>Detected</td>
</tr>
<tr>
<td>Aerosol ion spectrometer (NAIS)</td>
<td>Detected</td>
</tr>
<tr>
<td>Single particle BC both in aerosol and cloud residuals</td>
<td>Detected</td>
</tr>
<tr>
<td>Bioaerosol single particle (MBS) both in aerosols and cloud residuals</td>
<td>Detected</td>
</tr>
</tbody>
</table>
Aerosol measurements:

Can be
direct ↔ indirect (physical model / other quantities needed)

Can be
In situ ↔ remote sensing
DMPS, Filter, (OPC) “what is the optical impact of the aerosol”
“What aerosol is there”

In situ and remote sensing must not match closely:
Shape of aerosol?
Index of refraction?
General scattering theory missing!
For spherical particles: Mie

“closure experiments”

Note: prefer direct measurements
f(cause) → effect always given; f^{-1}(effect) → cause ??
KARL:
Koldewey Aerosol Raman Lidar
Since 2001
Aerosol and water vapor
199? – 2008 also a lidar for
stratospheric ozone
Spring AOD decreases over time
→ annual run of AOD becomes flatter
2009 was last polluted year
Generally high variability
Principles and equation:

elastic:

\[ P_e (z) = C_e \beta (z) \frac{1}{z^2} \exp \left( -2 \int_0^Z \alpha_{le} (\hat{z}) \, d\hat{z} \right) \cdot [O(z)] \]

\[ \beta^{\text{tot}} = \beta^{\text{Ray}} + \beta^{\text{aer}} \]

\[ \alpha^{\text{tot}} = \alpha^{\text{Ray}} + \alpha^{\text{aer}} \]

\( P \): return power [MHz]
\( \beta \): backscatter \([\text{m}^{-1}\text{sr}^{-1}]\)
\( \alpha \): extinction \([\text{m}^{-1}]\)
\( O \): overlap function
\( C \): lidar constant (laser power, optics: transmission, PMT efficiency \(\ldots\))

Raman –scattering, inelastic \(\lambda_{\text{elastic}} \rightarrow \lambda_{\text{Raman}}\)

\[ P_r (z) = C_r \rho (z) \frac{1}{z^2} \exp \left( -\int_0^Z \alpha_{le} (\hat{z}) + \alpha_{lr} (\hat{z}) \, d\hat{z} \right) \cdot [O(z)] \]

\( \rho \): air density, Raman scattering at nitrogen molecules

Extinction principally challenging!

It all depends on SNR
In total: 2 equations for \( \alpha, \beta \)
Without Raman effect: 1 equation, 2 unknowns

If the green 532nm light is emitted into the atmosphere the strongest Raman return occurs at 607nm (Stokes from \(N_2\)), \(N_2\) is proportional to air number density

\[
P^{607\text{nm}}(z) = \hat{C} \cdot \frac{1}{z^2} \rho(z) \cdot \exp\left(-\int_0^z \alpha^{532} + \alpha^{607} \, d\hat{z}\right)
\]

As with photometer assume \(A : \alpha_{\text{Aer}}^{532} = \alpha_{\text{Aer}}^{607} \cdot (532\text{nm/607nm})\hat{A}\)

\(\Rightarrow\) equation for \(\alpha^{532}\) but noisy

\[
P^{607\text{nm}}(z) = \hat{C} \cdot \frac{1}{z^2} \rho(z) \cdot \exp\left(-\int_0^z f \cdot \alpha^{532}(\hat{z}) \, d\hat{z}\right)
\]

does \(f\) depend on \(z\)?
Evaluation of lidar data:

If Raman channel is available and looks trustful:

a) Solve Raman lidar equation for extinction
b) Use this extinction to solve the elastic lidar equation for backscatter

If Raman channel is not available:

Estimate a Lidar Ratio $LR(\lambda) = \frac{\alpha^{aer}}{\beta^{aer}}$

Bring elastic lidar equation in form of Bernoulli Differential equation and solve it for the backscatter

You need (always): 1) air density profile

2) boundary condition $\beta^{tot}(z_{ref}) = (1+\varepsilon) \cdot \beta^{Ray}(z_{ref})$

\[
P_r(z) = C_r \rho(z) \frac{1}{z^2} \exp(-\int_0^z f \cdot \alpha_{\lambda e}(\hat{z}) \, d\hat{z}) \cdot [O(z)]
\]

\[
P_e(z) = C_e \beta(z) \frac{1}{z^2} \exp(-2 \int_0^z (\alpha^{Ray} + LR \cdot \beta^{Aer}) \cdot [O(z)]
\]
Extinction in a lidar:

\[ P_r(z) = C_r \rho(z) \frac{1}{z^2} \exp(-\int_0^z \alpha_\lambda_e(\hat{z}) + \alpha_\lambda_r(\hat{z}) \, d\hat{z}) \cdot [O(z)] \]

Do not smooth or fit your lidar profile!!

Instead you can calculate a “layer-integrated” extinction \((z_{\text{bottom}} \rightarrow z_{\text{top}})\)

\[ P_r(z_t) = C_r \rho(z_r) \frac{1}{z_r^2} \exp(-\int_0^{z_b} \alpha \, dz) \cdot \exp(-\int_{z_b}^{z_t} \alpha \, dz) \]

\[ P_r(z_b) = \frac{z_b^2}{C_r \rho(z_b)} \]

If the derivative \(\partial / \partial z\) harms, avoid it.

Or make a statistic from unsmoothed lidar data (first calculation, then averaging)
Elastic: $\sim \beta(z)$
Raman: $\sim \rho(z)$ – no cloud spikes but extinction

How do lidar signals look like?
Shortcomings of lidar data:

Phase function missing: only info around $\Phi = 180^\circ$

overlap: boundary layer difficult

Refractive index challenging: $m = m_{\text{real}} + i \cdot m_{\text{imag}}$

$m_{\text{real}} \sim$ scattering $m_{\text{imag}} \sim$ absorption

but we only have $\beta, \alpha$

Weak absorption $\rightarrow \omega$ insecure

Only trustful info for accumulation mode:

Aitken: interaction too small

giant mode: Mie efficiency becomes flat

\[ \alpha = \frac{2 \pi r}{\lambda} \leftrightarrow r = \frac{\alpha \lambda}{2 \pi} \]

\[ \alpha \in [1 \ldots 12], \lambda = 0.5 \mu \rightarrow r \in \left[\frac{1}{4\pi} \ldots \frac{3}{\pi}\right] \mu \]

conclusion: aerosol, cloud particles
Results Haze season 2013:

Most polluted March / April
Principally more backscatter close to ground
Haze season starts close to the ground and lasts longer in higher altitude
LR might have an annual cycle with lower values early in the season and closer to the ground
During the haze period the particles are more irregular in shape
Below 850m time consuming overlapp corrections with Ceilometer required

Since 2011: Vaisala CL51

Calibrate Ceilo with KARL (Klett) in about 1.5km on clear, stable day
Assume Ceilo measured true results (@910nm)
Assume Å, LR(z)
→ calculate missing overlapp of KARL

SNR(Ceilo) moderate
Definition “aerosol closure”:

1) Closure on microphysics (locally)
2) Closure on radiative impact (column)

1) Bring together different sensors (with different weaknesses and assumptions) in a common evaluation scheme until
   a) a consistent set of assumptions & properties is found
   b) a clear gap / mismatch has been identified
   best: homogeneous aerosol (composition, mixing state)
   dry, stable atmosphere, spherical particles
   problems: scattering theory (who does not depend on that, entirely?)
   refractive index & shape, espec. when heterogeneous particles, hysteresis of rh …
   at the end of a successful closure we have a match between “what is there” and its optical impact
2) understand the relation between microphysics and optical properties for the whole column and include integrating values as AOD, radiation values and the resulting forcing by a radiative transfer model
   problems: air-borne in-situ measurements for validation
   At the end: knowledge of RF of aerosol, depending on meteorology
Comparison in-situ, remote sensing

Flight pattern of P5 on April 4, 2009

Red: AMALI lidar, downward looking

Blue: sunphotometer
Extinction from AOD\(z_1\) – AOD\(z_2\)

So we have:
Backscatter from lidar
Extinction: from lidar and from photometer
1st comparison in situ to lidar, case April 4, 2009

Extinction in photometer(s) smaller than in lidar, cause:? Optical systems insensitive below 80nm So, accum. mode: basically log-normal distribution
Summary

Lidar active remote sensing, give height resolved information on many parameters. Aerosol: backscatter, extinction & depolarisation

→ allows (sometimes) estimation of size distribution & refractive index in accumulation mode

Is handicapped in Aitken mode
can easily see giant mode, clouds

Should be compared to ground-based in-situ data:
Is the aerosol in the column / free troposphere the same as on ground?

Has typical resolution of minutes / 10m
Arctic Haze: spring-time „air pollution“

Arctic Haze:
Sulfates, soot, …
Small particels, but they can scatter light

Max. in spring but large year to year variability
Sandra is analysing it:
Motivation:

Warum interessieren wir uns für das Klima der Polargebiete? Telekonnektion der Atmosphäre! Korrelation der Abweichung meteor. Größen auf Skalen bis 10000km

Eine wärmere, eisarme Arktis könnte die Wahrscheinlichkeit kalter Winter in gemäßigten Breiten erhöhen

„Arktische Oszillation“
warum? Rückkopplungen „Feedbacks“
Ursache → Effekt (der) → Ursache verstärkt → (stärkerer) Effekt …

Eis-Albedo Rückkopplung

2014: Pithan, Mauritsen (MPI-Hamburg)
Arktische Verstärkung nur durch Temperaturreffekte
(generell) Strahlungsbilanz:

Sehr verschiedene Prozesse, Subtraktion, Addition von ähnlichen Größen

Wolken wichtig!

Es gibt Eis- und Wasserwolken

Absorbierte Energie > 0 → Erwärmung
Aerosole:
Alle festen oder flüssigen Teilchen in Atmosphäre als Träergas:

Wüstenstaub
(Sahara, Gobi)

Biologisch:
Bakterien, Viren,
Pollen

Waldbrände

anthropogen

weiterhin:
Seesalz, Vulknstaub,

„sekundärem Aerosol“, aus reaktiven Gasen gebildet

Durchmesser: 10nm -10μm
(Sedimentationsgeschwindigkeit ~ r²)

Ganz unterschiedliche Form, Größe und Chemie
Ohne Aerosole kein Niederschlag!

Betrachten kleine Wassertröpfchen:

Haben hohe Oberflächenspannung → haben höheren Sättigungsdampfdruck als große Tropfen
Tröpfchen verdunsten – Tropfen wachsen „Kelvineffekt“

In reiner Luft bräuchte man eine Übersättigung von 450% bis sich aus Wasserdampf stabile Tröpfchen bilden

Aerosole stellen Oberfläche zur Verfügung, an der sich Wassermoleküle anlagern können

„Oberflächenspannung aufrecht zu erhalten, kostet Energie, Natur will das vermeiden“
Aerosole beeinflussen Strahlungsbilanz:

direkt (Streuung, Absorption – abhängig von Albedo) oder indirekt (Wolkenbildung, deren Lebensdauer, Helligkeit) „forcing“

Aerosole ändern ständig Durchmesser und chem. Zusammensetzung Verschwinden aus Atmosphäre durch Niederschlag, Sedimentation
Consider an aerosol cloud:

a) External mixing

- Soot
- Mineral dust
- Sulphate

Chemically external mixture: most particles have one chemical composition

b) Internal mixing:

Internal mixing: most particles have heterogeneous composition

Aging:
Due to Brownian motion coagulation, more internal mixture
But also new particle formation due to SO₂, O₃ und UV radiation
Problems with climate …

Deficiencies in physics:
Aerosol: scattering properties (shape, size, index of refraction!), interaction with clouds
Clouds: size, altitude, phase (IN), life-time, precipitation, brightness
“nothing known”
Turbulence
(origin of) long-scale variations, circulation pattern
Dependence on external forcing: sun, cosmic rays, sea ice, ocean

Deficiencies in description:
Non-sufficient horizontal and vertical resolution: parameterization
Reifen & Toumi, GRL 2009: “non-stationarity of climate feedbacks” …
→ models which are good in one period might be inferior at other times

Principal challenges:
Collins: Climate Dynamics 2002: critical dependence on initial conditions, is chaotic system
→ still no predictability beyond seasonal scale
Introduction III: where does the aerosol come from?

Method: take all AOD data Ny Alesund from 1998 – 2008 where air trajectories came from same origin in 850hPa, 700hPa, 500hPa (ECMWF)
Remove all aerosol events of known origin (mainly forest fire / agricul. flaming)

Cluster 1 Eastern Arctic/ Siberia
  2 Beaufortsea
  3 Western Russia
  4 North-East Canada

Cluster 5 Europe
  6 central Arctic
  7 local
  8 Greenland
Most aerosol from Beaufortsea, Eastern or central Arctic, least from Europe, Greenland
Spring: annual max and max of variations between clusters
Europe: rapid / (direct) transport associated with cloud formation (no photometer observation and/or wet scavenging)

Where does aerosol come from?
Measurements in central and Russian Arctic required!
Follow pollution plumes with aircraft/satellites over several days
Downwind of emission comparable to Greenhouse gases

Assumptions the similar? → results similar

Hence: clouds, aerosol!
The headache caused by aerosol:

Challenges:
Various types
Non-uniform distribution
Properties change with meteorology (hysteresis)
RF also dependent on ground
Chemically mixture: intern or extern

Remote sensing:
Measures optical parameters, then estimates (overall) size distribution, (overall) shape and effective RI
In-situ measurements:
Get size distribution, chemical composition (almost) directly, then estimates scattering properties

In situ & remote sensing must not agree
Twomey effect: smaller cloud particles have less absorption, more scattering (polluted clouds are whiter) higher albedo, larger life-time

Pincus & Baker: cloud thickness and cloud top altitude increase with concentration of CCN
Why aerosol in the Arctic?

Arctic relatively clean: AOD(550nm): 0.05 – 0.1
But climatological sensitive environment (“polar amplification”)
Many different aerosol processes:
- in atmosphere (scattering, absorption: “dimming”)
- on ground: decrease of albedo “darkening”

Polar amplification:
(from IPCC)
ΔT (2071 – 2100) –
(1961 – 1990)
Reason: feedbacks
(e.g. ice – albedo)

Challenges:
Seasonality: albedo, solar incident angle
Aerosol: (inter-annual) variability
LIDAR
(Light Detection and Ranging)

Active remote sensing: information on altitude by time delay and c

- Laser pulses
- Telescopes (beam-widening, recording)
- Dichroic mirror
- Photomultiplier tube
- Transient recorder

Diagram:

[Diagram of LIDAR system, including laser, telescopes, dichroic mirror, photomultiplier tube, and transient recorder]