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

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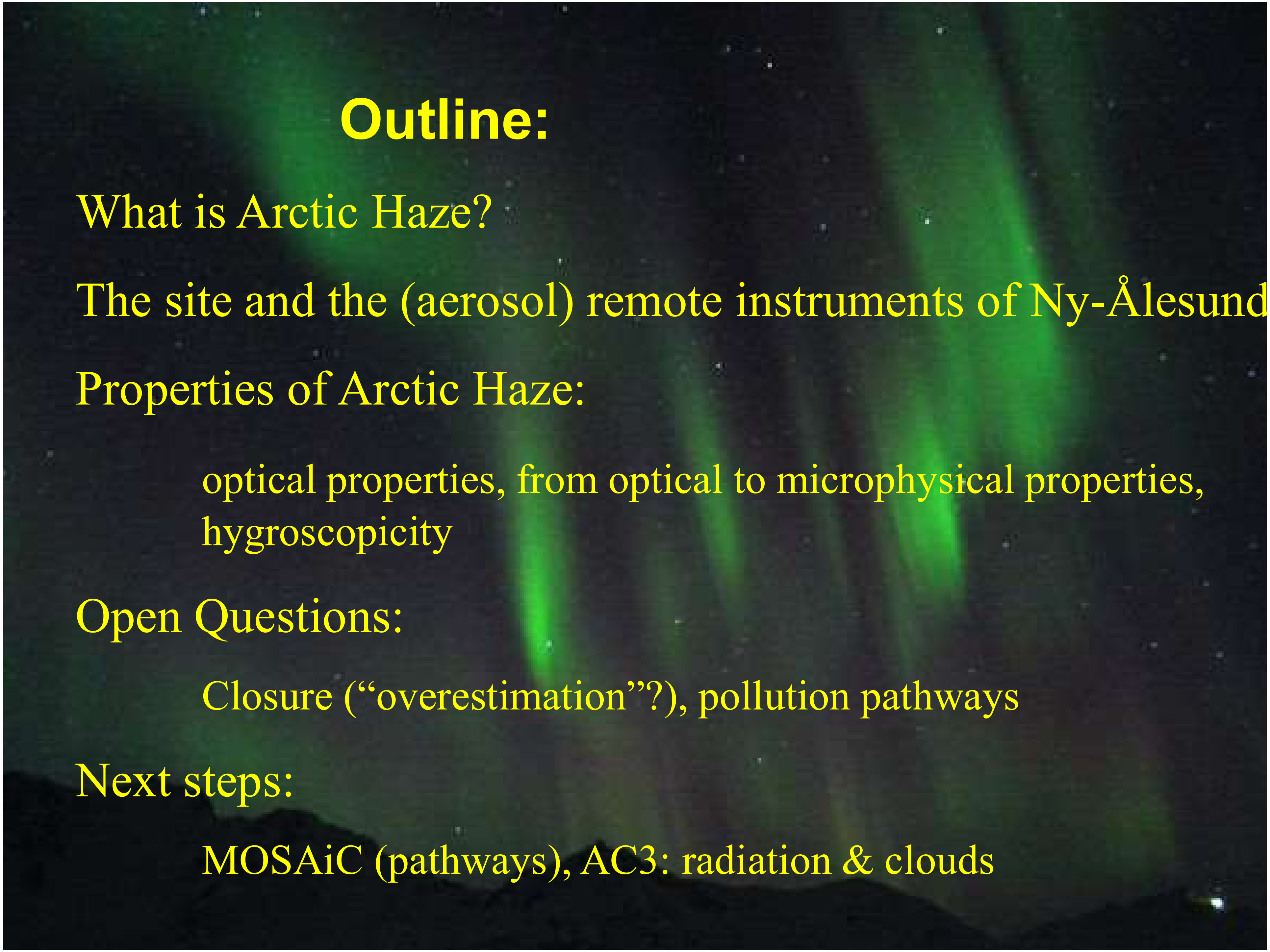


Outline:

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

Arctic Haze: spring-time „air-pollution“ in the Arctic

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)

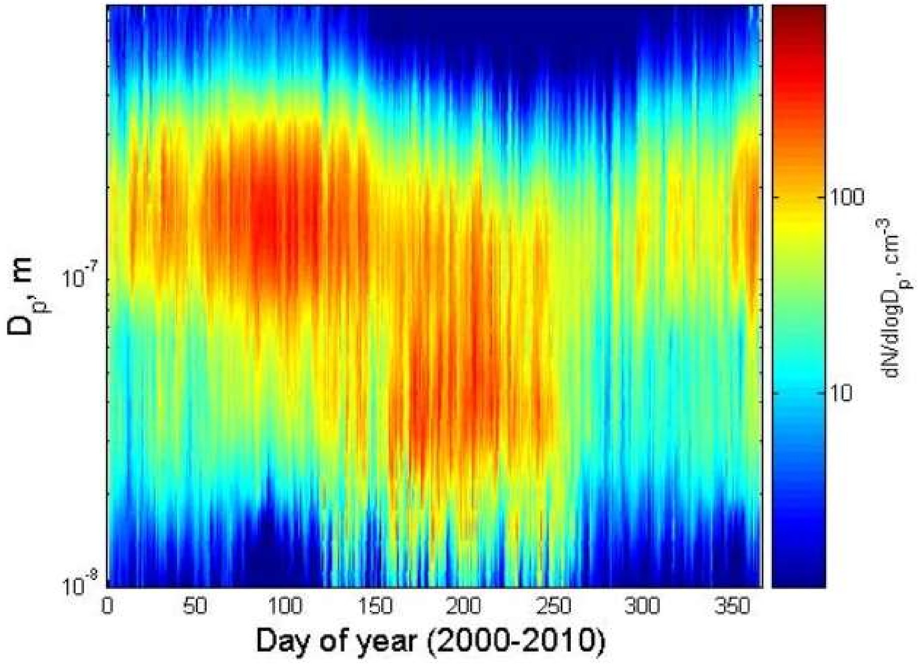
mixing state: turns into internal mixture during aging (Hara 2003)

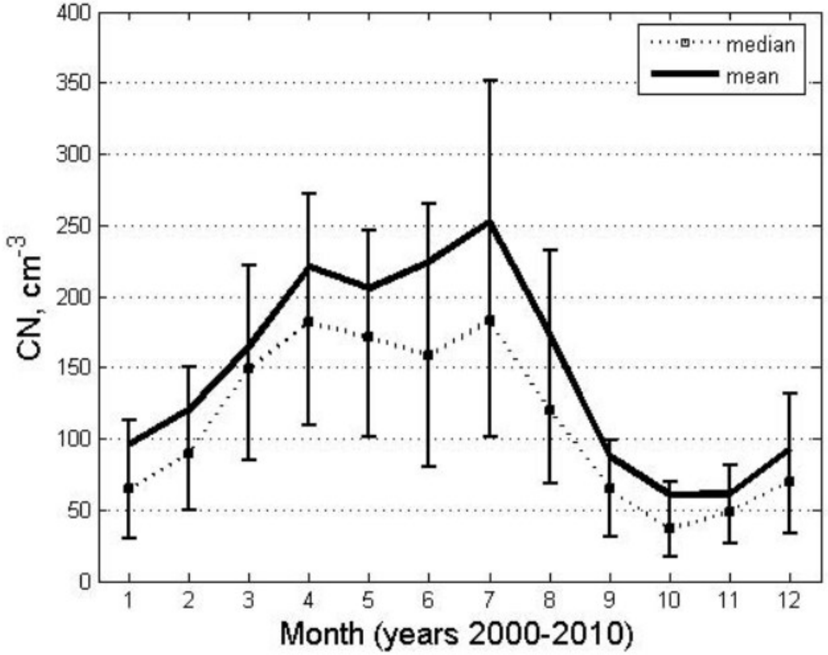
Size: around 0.2µm diameter (Tunved 2013)

Max AOD due to size not due to concentration!

Photo:
Extreme event, agricultural flaming May 2006
(Stohl 2006)

Tunved 2013, ACP: Arctic aerosol life cycle

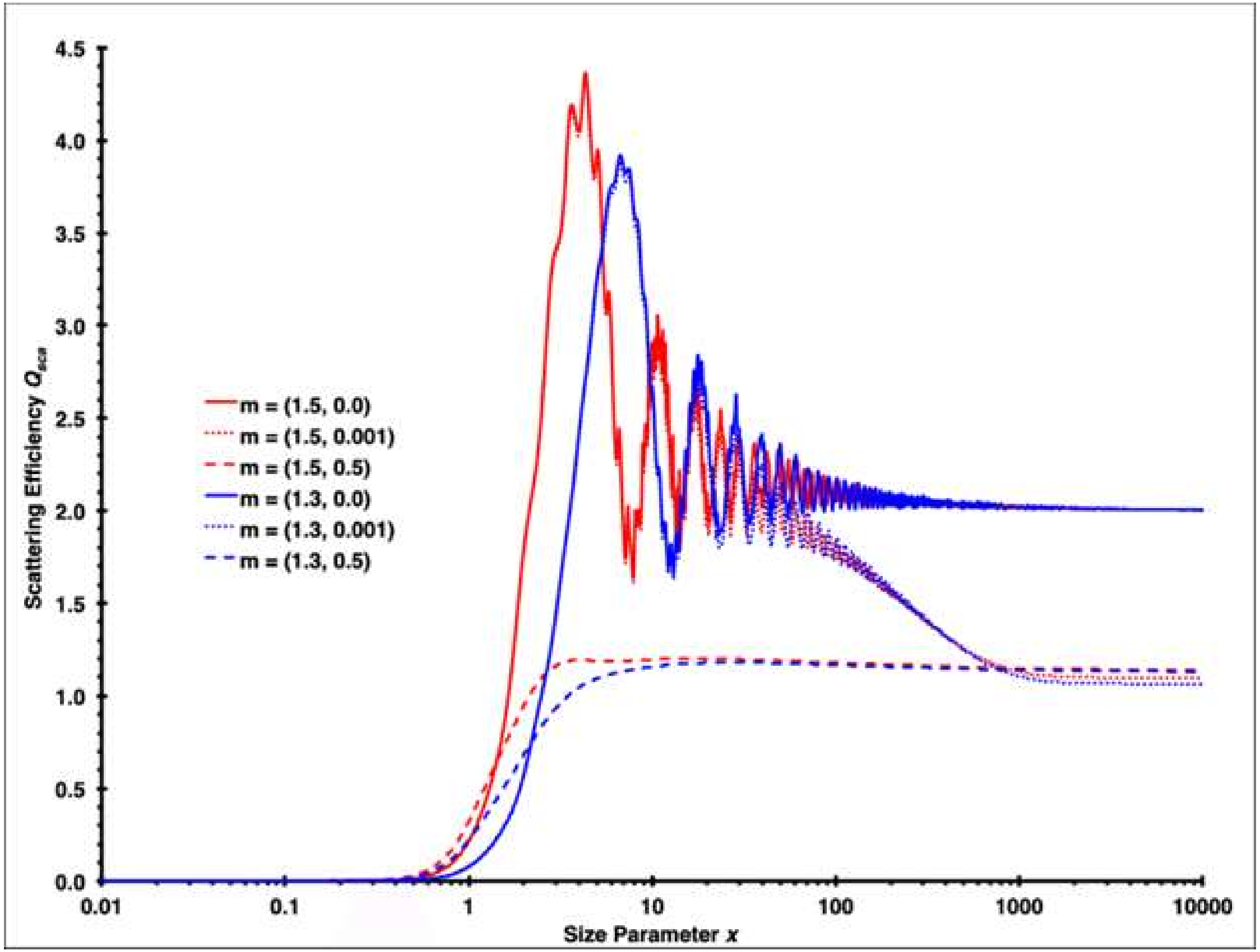




Arctic Haze in spring: because particles are larger, have larger scattering efficiency

Max. aerosol number concentration in summer due to marine aerosol

Scattering efficiency, Mie theory:



Size parameter:

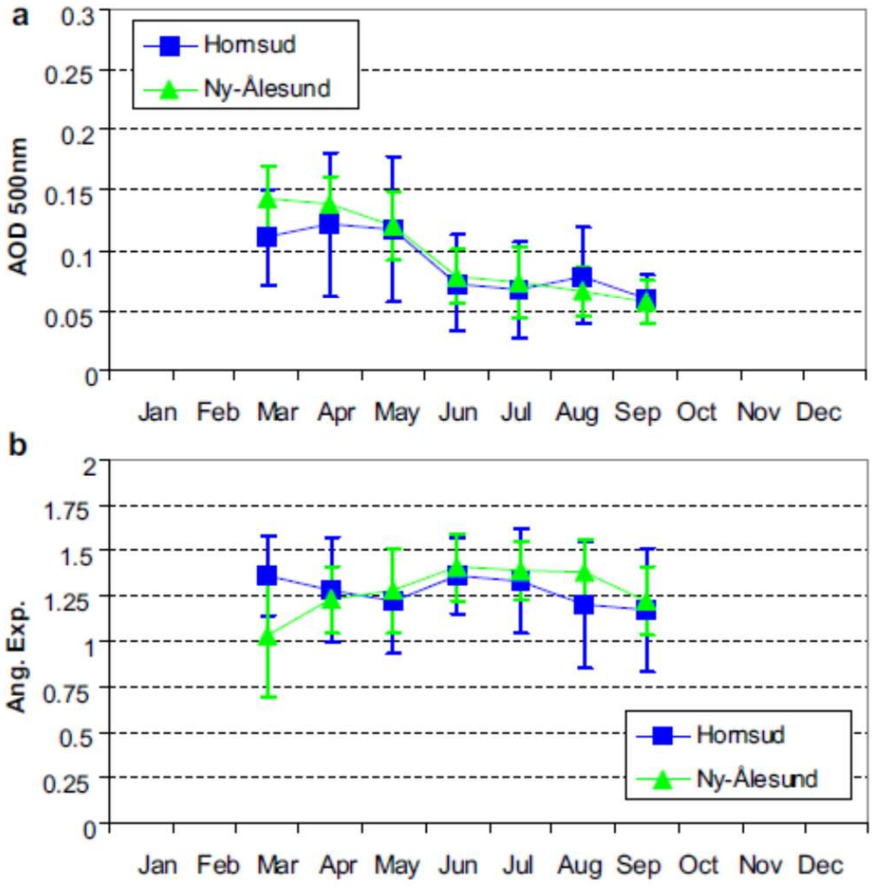
$$x = \frac{2\,\pi\,r}{\lambda}$$

x=1 for
λ =355nm
means:
r =56nm

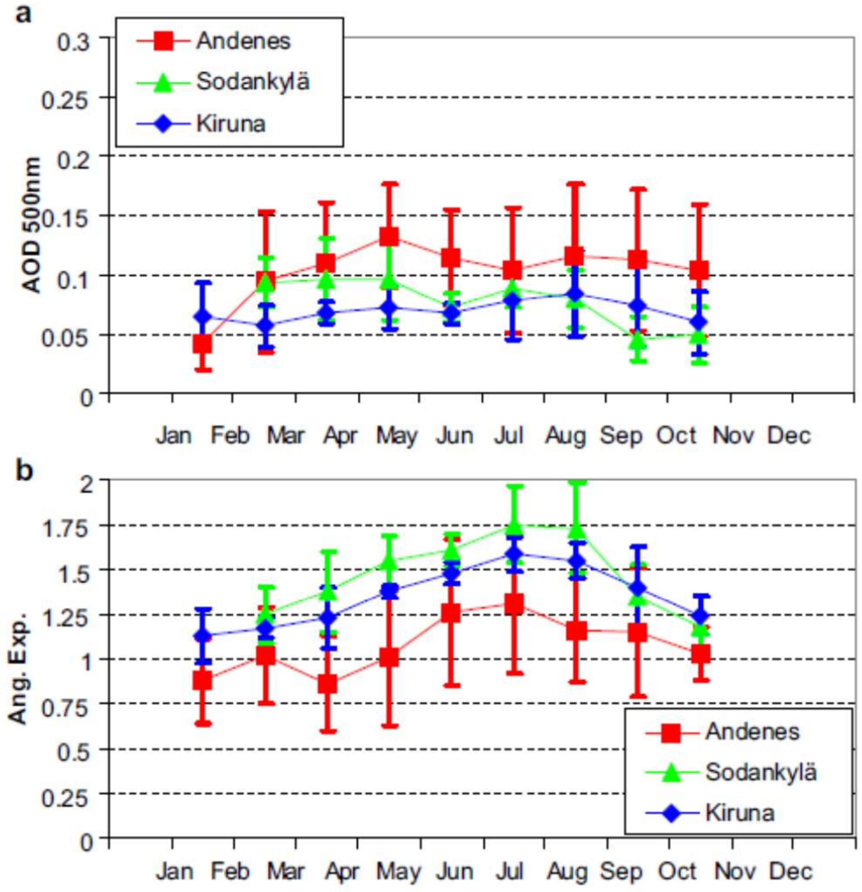
Arctic aerosol is generally small and at the edge of visibility!

Typical AOD values from Toledano 2012 Atmos. Environm.

Spitsbergen



Scandinavia

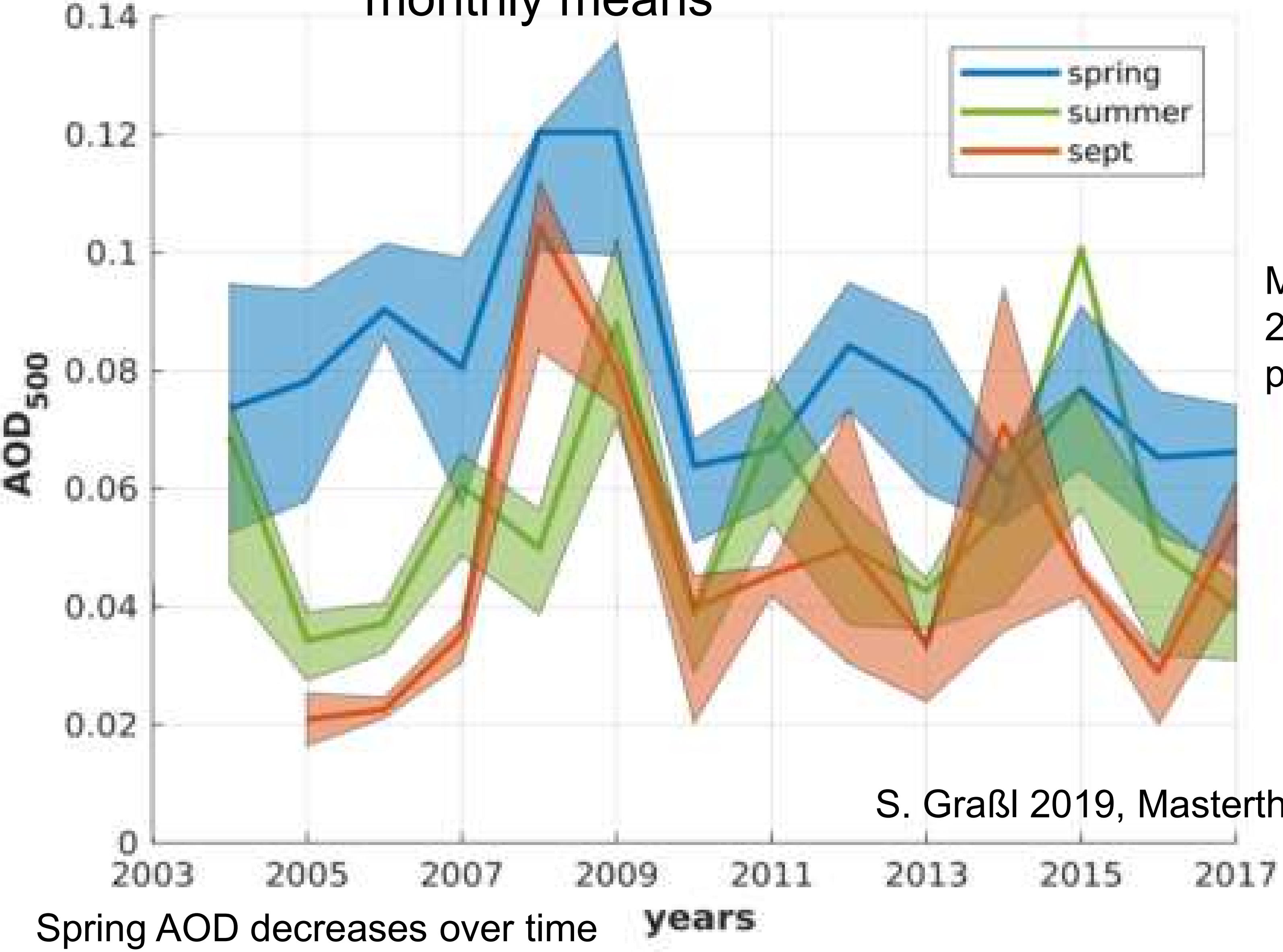


Spring: Arctic-AOD > N-European-AOD
No Haze in Scandianvia
No „easy" direct pollution transport from Europe

Contrary: Eckhardt 2003 (Flextra, CO Tracer) „NAO + faciliates transport into Arctic"

Aerosol may have different pollution pathways than trace gases!

AOD- Evolution in Ny-Ålesund, monthly means



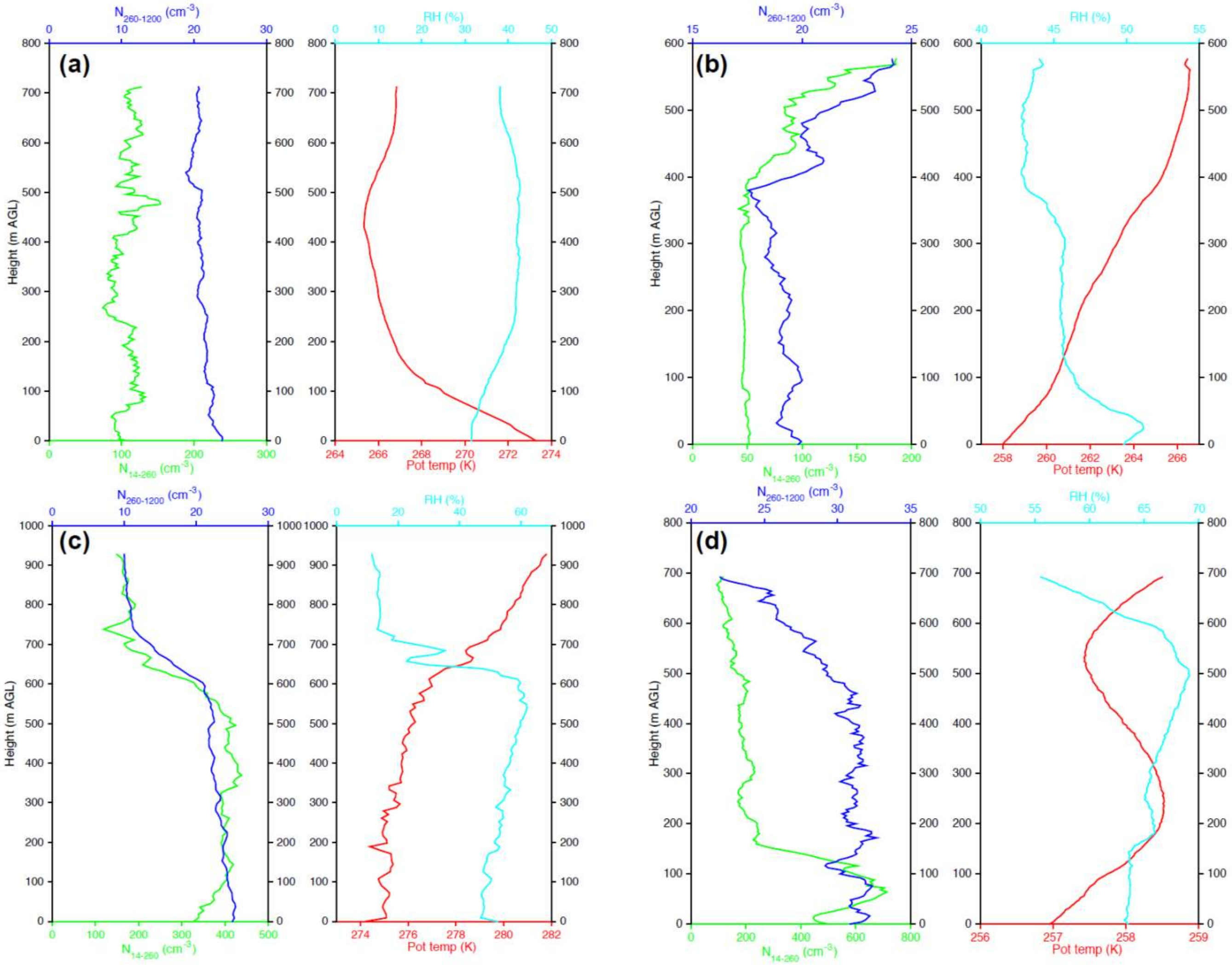
Median,
25% and 75%
percentile

S. Graßl 2019, Masterthesis

Spring AOD decreases over time
→ annual run of AOD becomes flatter
2009 was last polluted year Generally high variability

Ferrero et al, ACP 2016: vertical profiles of aerosol Tethered balloons with particle counters

a) const. aerosol load – (but convection seldom)
b) More areorol higher up – advection!
c) More aerosol close to ground (sources?)
d) Difference Aitken vs. Accumulation, strange temp. profile



Aitken particles, accumulation mode particles, poten. temp, rel, hum.

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

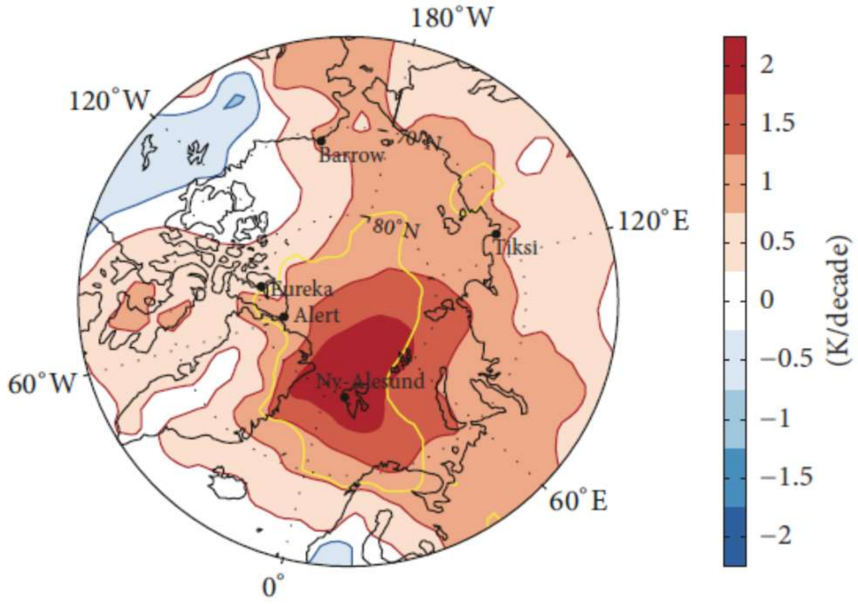
European Arctic warm: Gulf stream, Westspitsbergen current
Spitsbergen treaty 1920

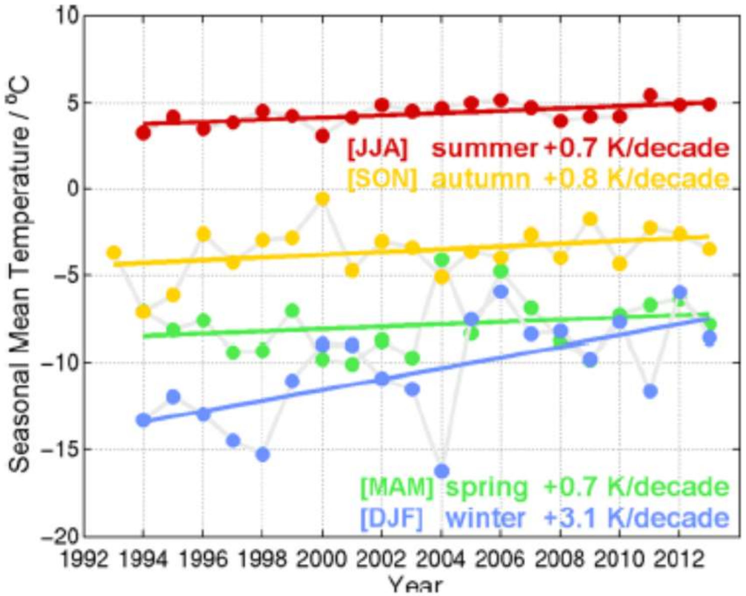
Ny-Ålesund, 78.9ºN, 11.9ºO – one of the northernmost settlements:

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


Balloon launch facility
Observatory
78°55'25"N, 011°55'21"E
N

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):

Since 1992.
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

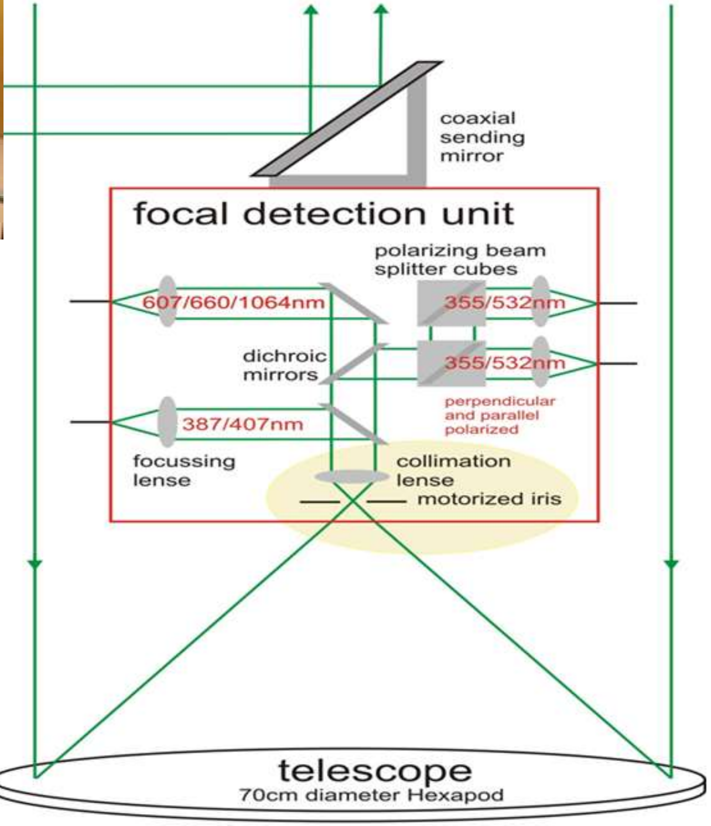
Jan 2019: winter-campaign

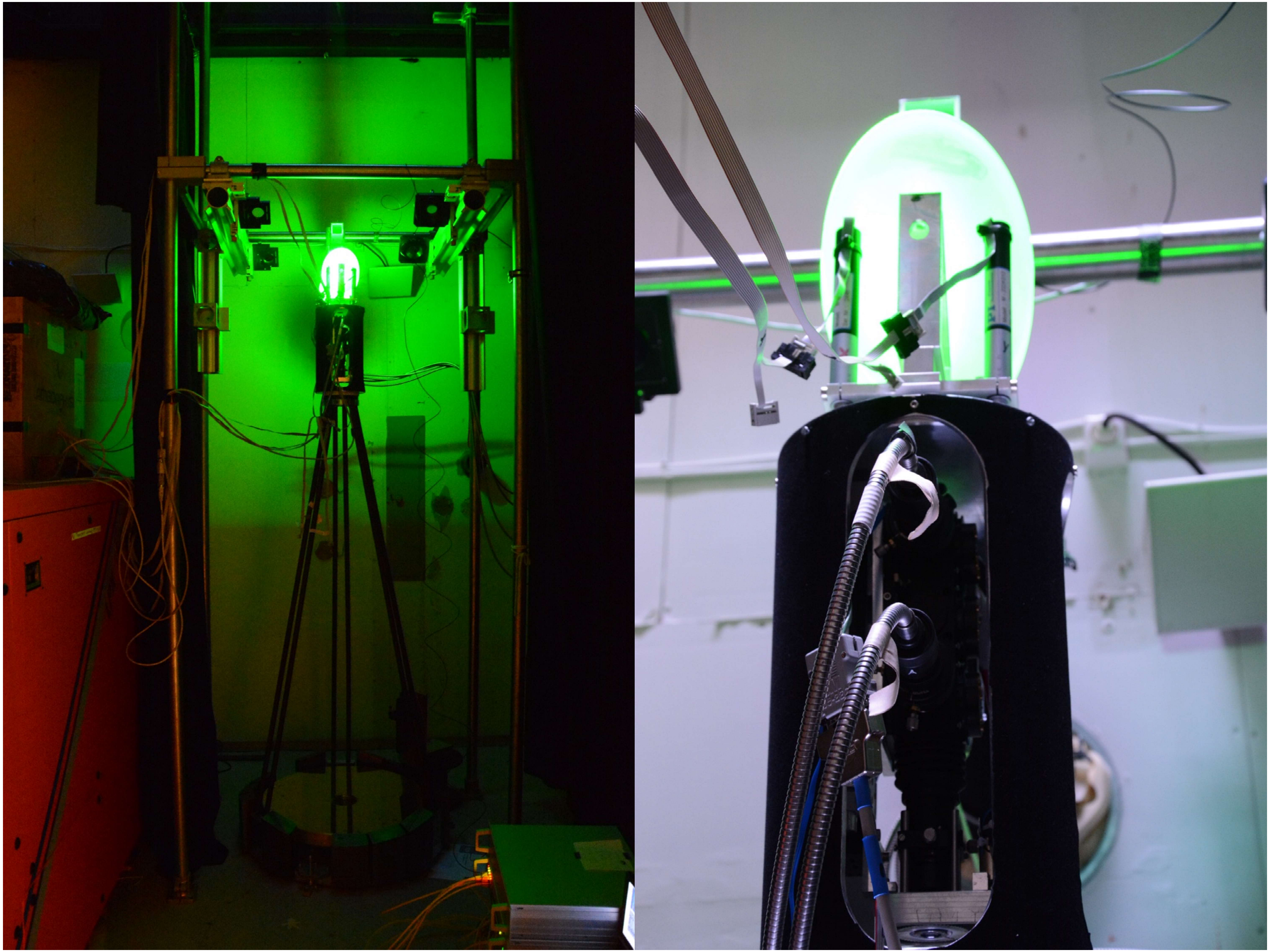
Tonight!!!!
Tue, 21. Jan
17:30

KARL: Koldewey Aerosol Raman Lidar

Backscatter (β) @ 355nm, 532nm, 1064nm
Extinktion (α) @ 355nm, 532nm
Depolarisation (δ) @ 355nm, 532nm
Water vapor (mr) @ 407nm, 660nm

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

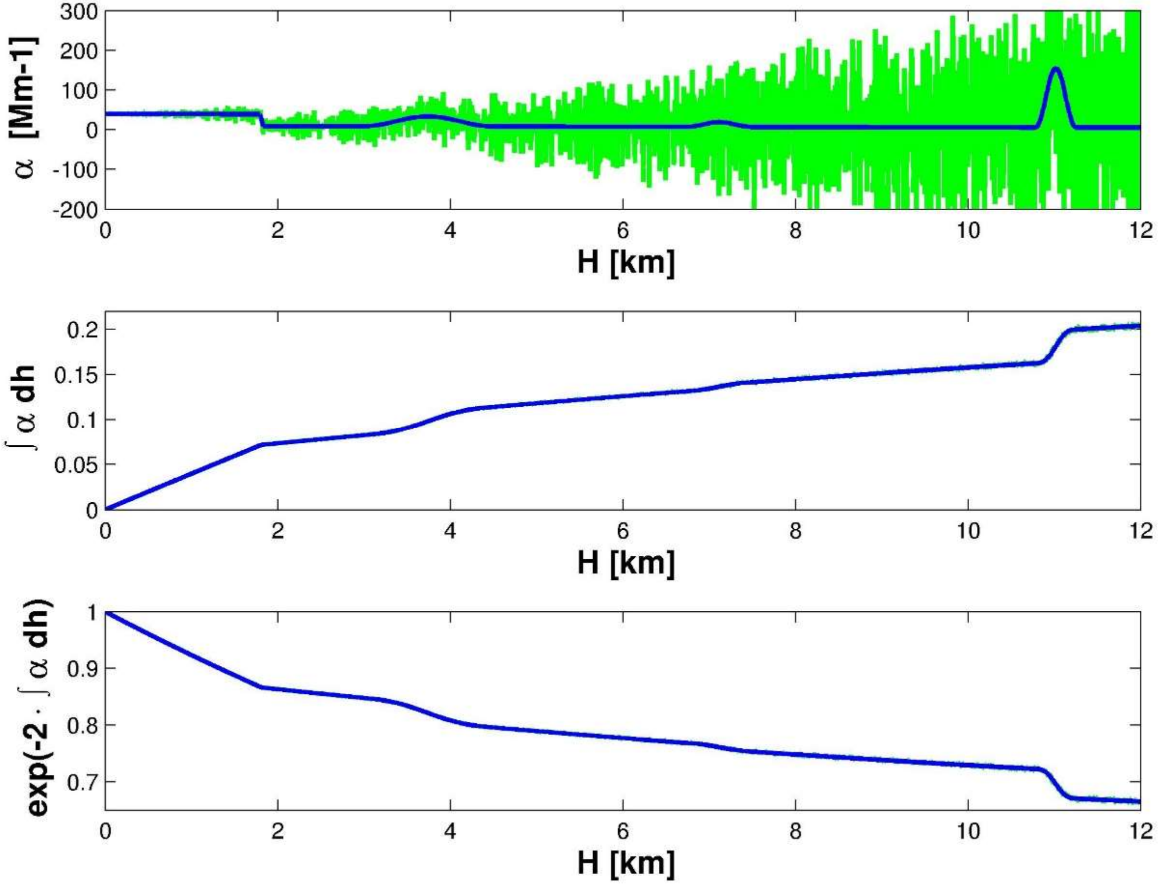




Challenges with extinction in lidars:

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:

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

Do not smooth or fit your lidar profile !!

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

$$P_r\,(z_t) = C_r\,\rho(z_r)\,{}^{1}/_{{z_r}^2}\ \underbrace{\exp\left(-\int_0^{z_b} \alpha\ \ldots dz\right)}_{P_r(z_b)\ {z_b}^2 / C_r\rho(z_b)} \cdot \exp\left(-\int_{z_b}^{z_t} \alpha\ \ldots dz\right)$$

Layer AOD

If the derivative ${}^{\partial}/_{\partial z}$ 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)

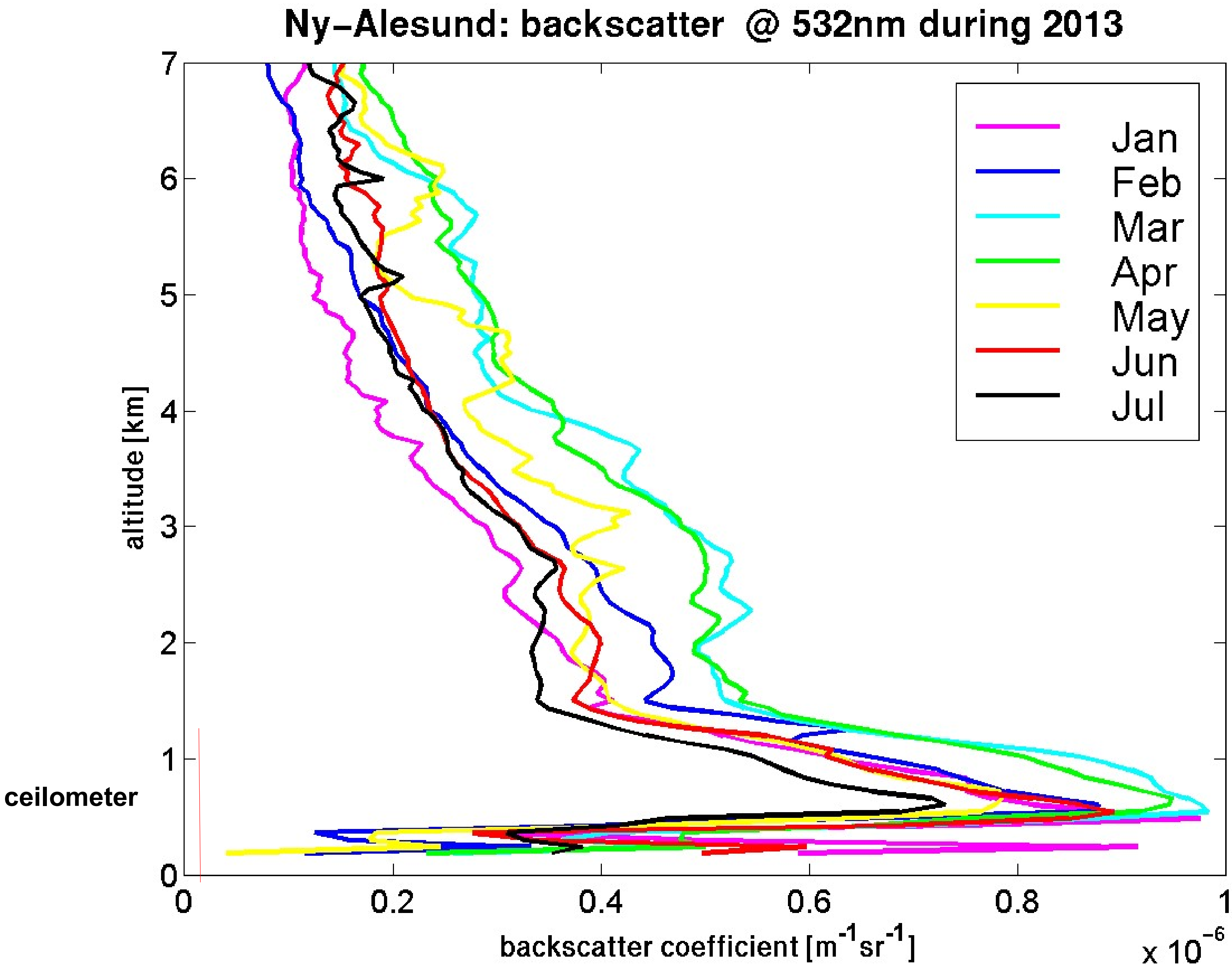
depolarisation $\delta = \frac{\beta_\perp}{\beta_=}$ (shape) [dipole moment]

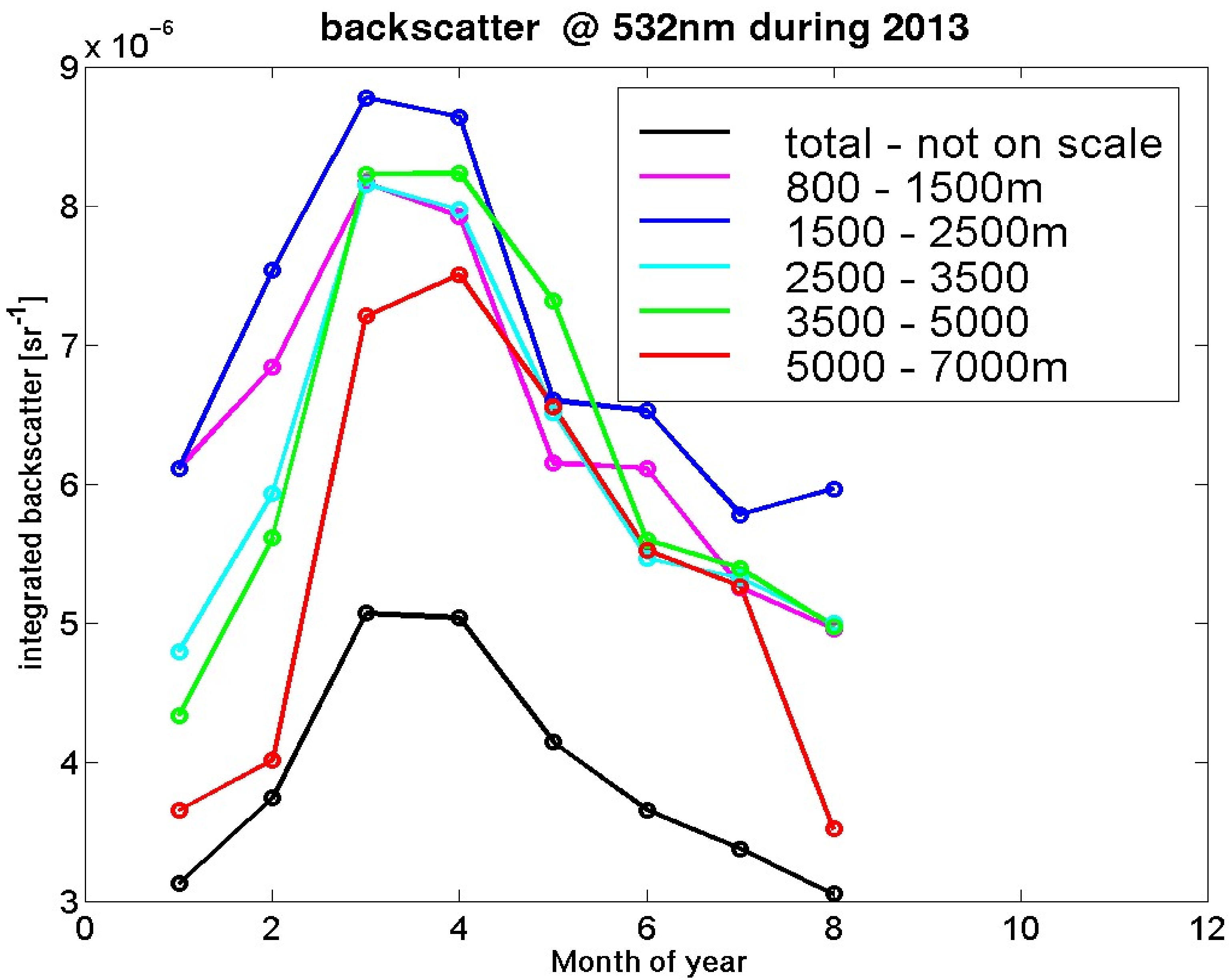
colour ratio CR = $\frac{\beta_{\lambda 1}}{\beta_{\lambda 2}}$ (size) [$\beta \sim \lambda^{Å}$ $-4 < Å < 0$]

lidar ratio LR(λ) = $\frac{\alpha^{aer}}{\beta^{aer}}$ (index of refraction, size, shape)

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

→ it's about getting the intensive quantities!

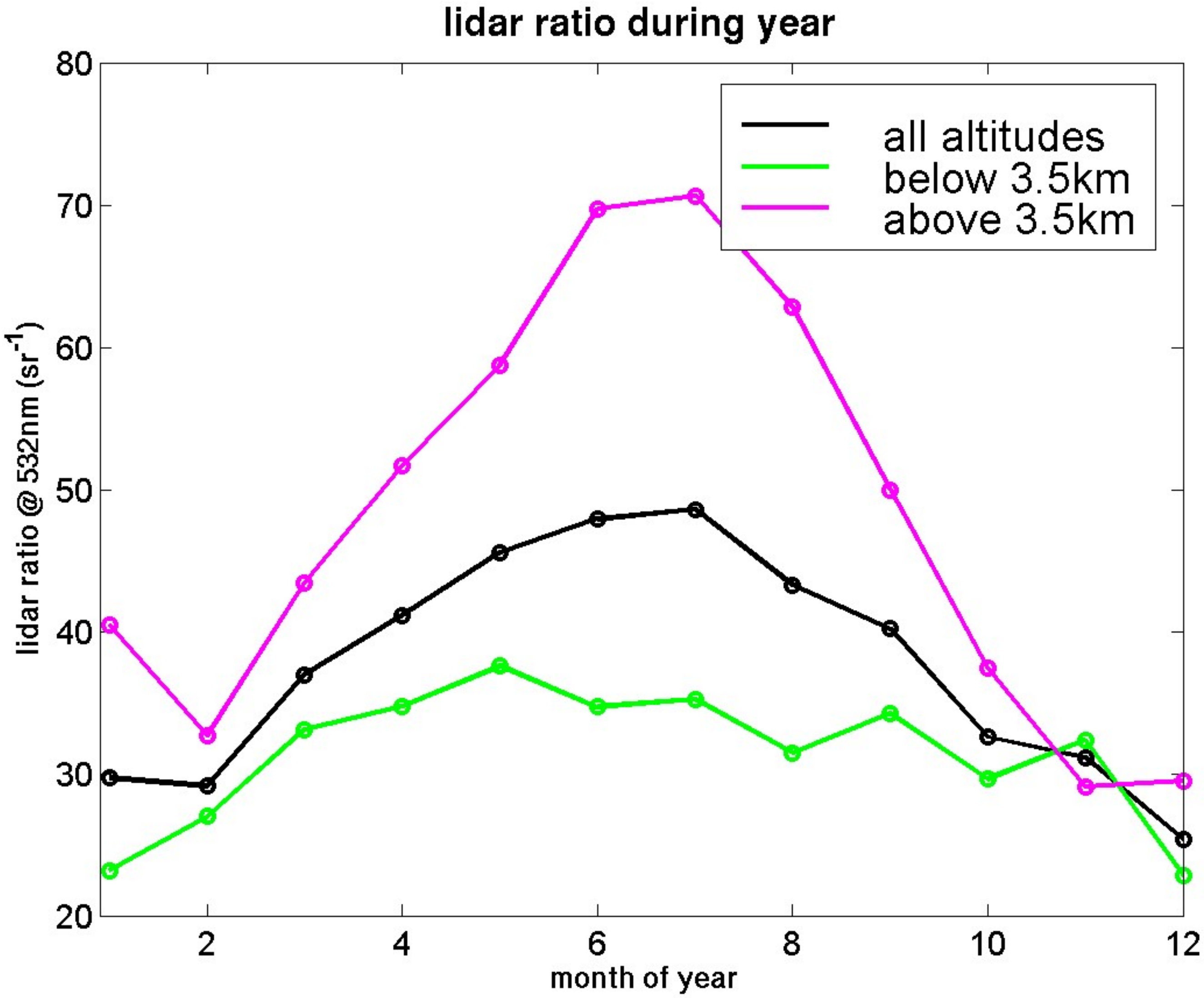

Ny-Alesund: backscatter @ 532nm during 2013
altitude [km]
7
6
5
4
3
2
1
0
ceilometer
0
0.2
0.4
0.6
0.8
1
backscatter coefficient [$m^{-1}sr^{-1}$]
x 10^{-6}
Jan
Feb
Mar
Apr
May
Jun
Jul



optically detectable aerosol disappears from ground up during season

AOD from photometer shows max. in April

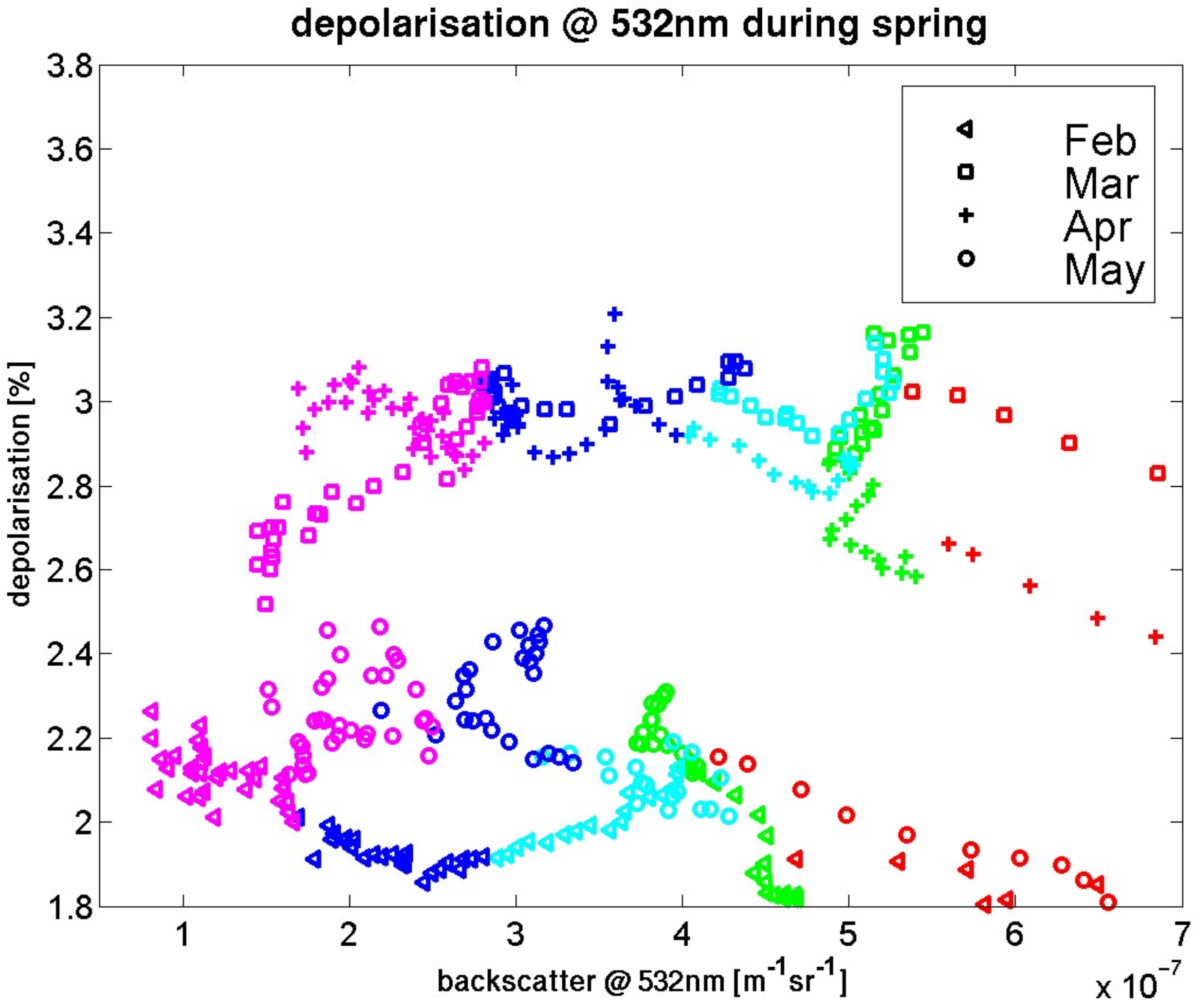
Annual cycle in Lidar ratio? Data from 2013



$$LR = \frac{\alpha^{aer}}{\beta^{aer}}$$

Generally:
LR355 < LR532

Intensive quantity: aerosol depolarisation (shape)



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

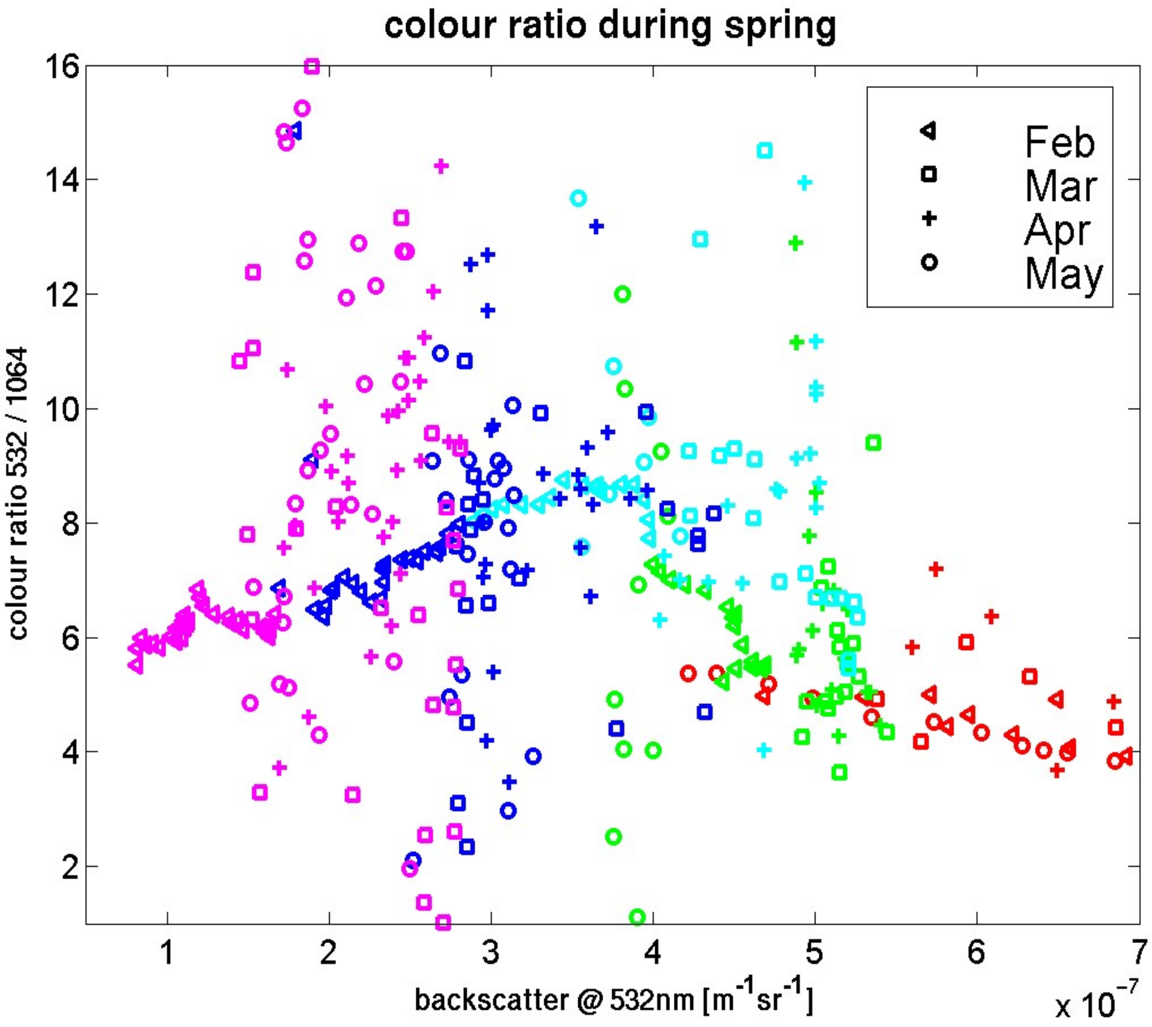
Particles more spherical outside haze season!
(Mie better)

Extensive quantity

Intensive quantity: color ratio (size)

small

large



800m – 1500m

1500m – 2500m

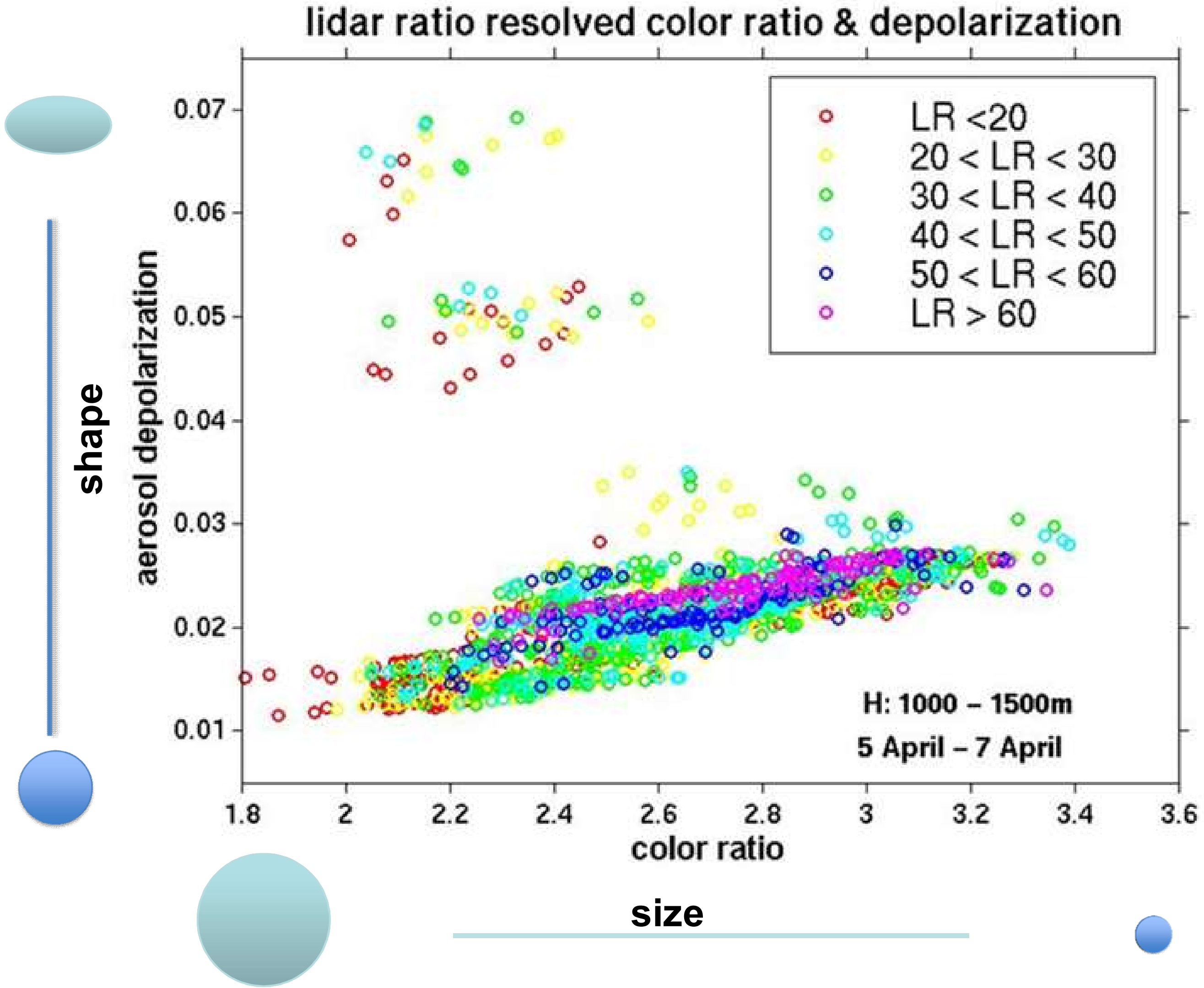
2500m – 3500m

3500m – 5000m

5000m – 7000m

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

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_{eff}, σ, N_0) and refractive index m from lidar data

Assume spherical particles, Mie theory, efficiencies $Q_{ext/\beta}$ are known

→ set of Fredholm integral equations for extinction & backscatter

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

$$\beta(\lambda) = \int_{R_{\min}}^{R_{\max}} Q_{\pi}(\lambda, r, m)\, \pi r^2\, n(r) dr$$

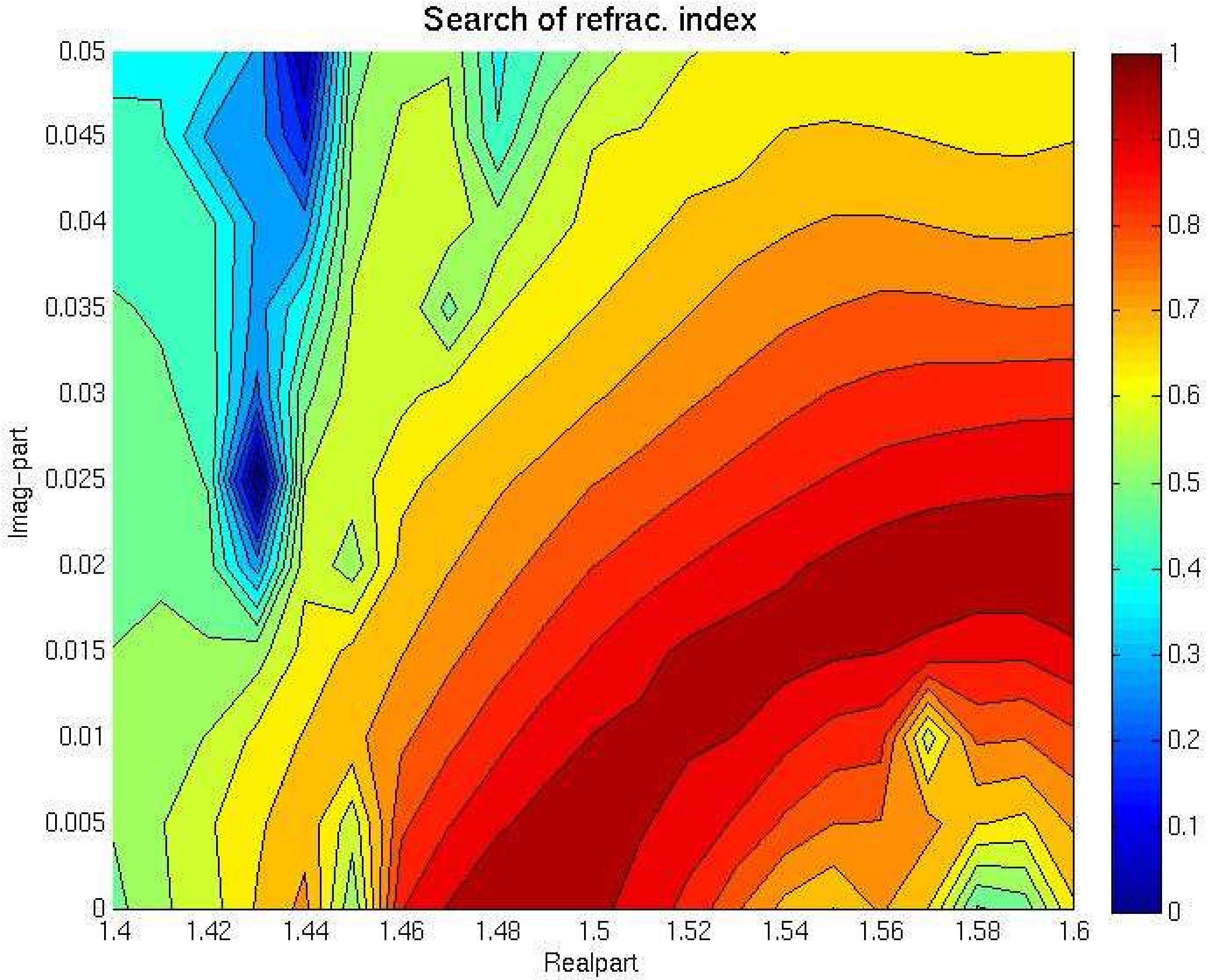
Retrieval of n(r) from Q, α, β is an ill-posed Problem

At least 2 α, 3β needed

But:

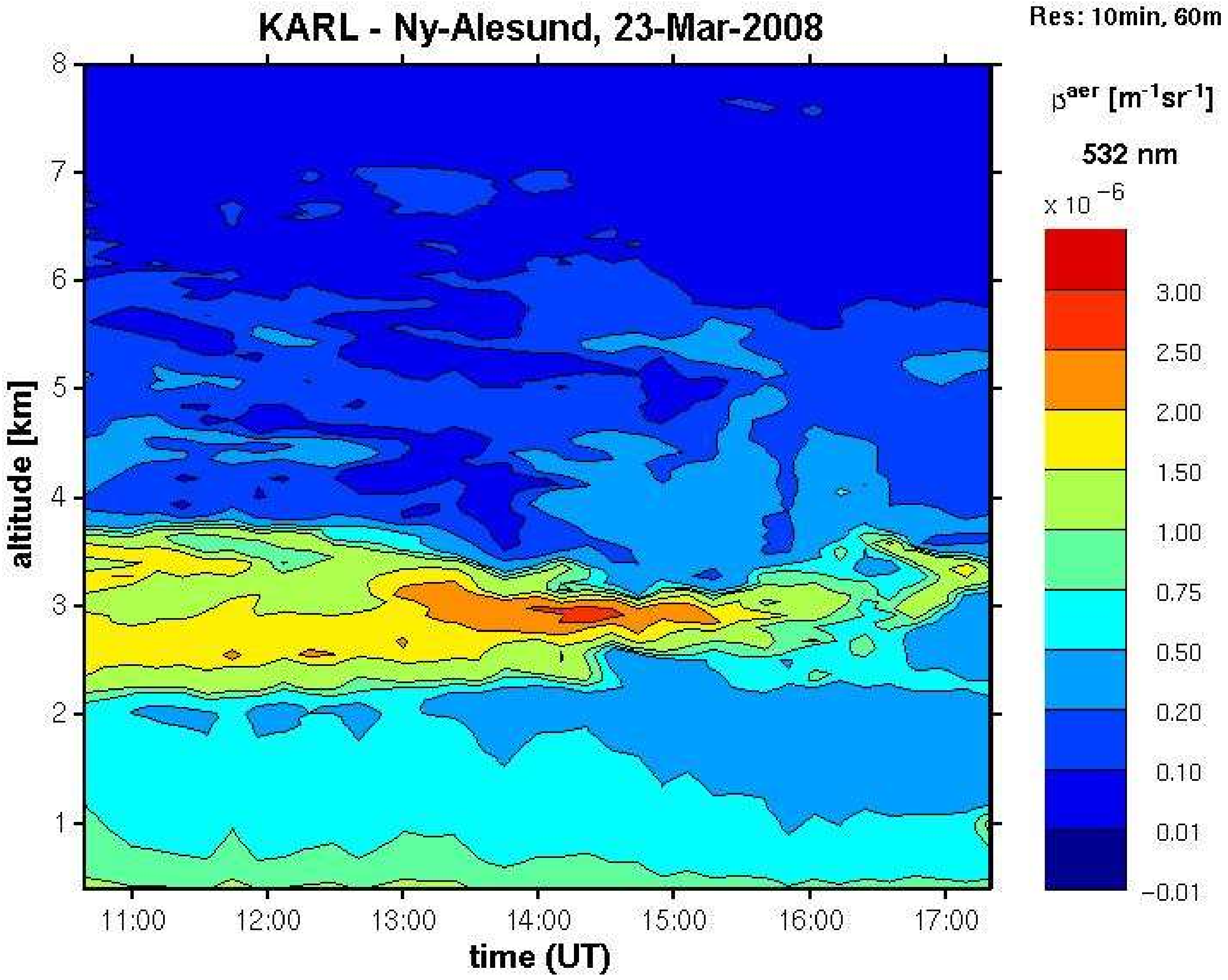
Lidar is only able to retrieve aerosol in accumulation mode: 0.1μ < r < 1.2μ

Difficulty: determine index of refraction:



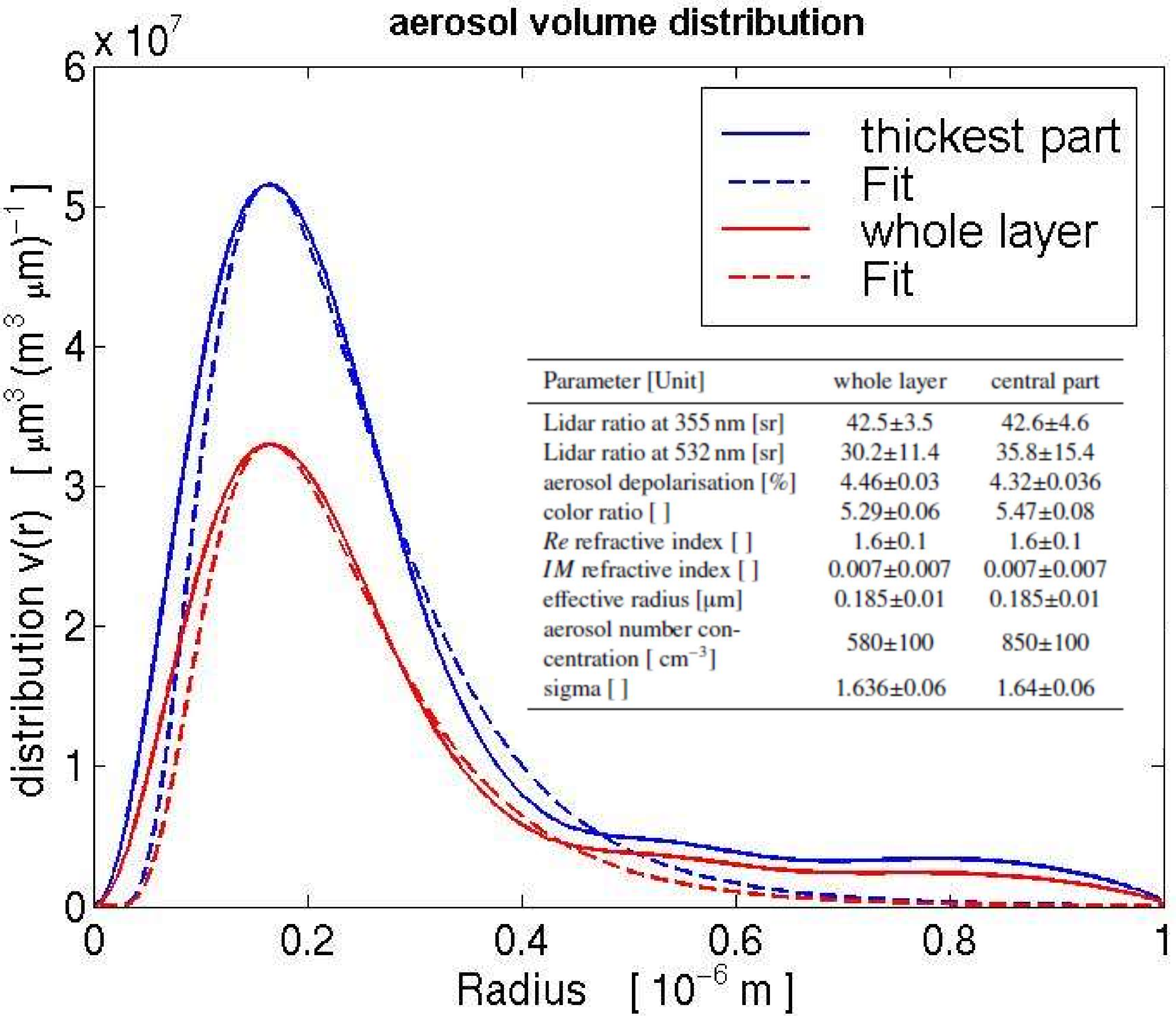
Lidar offers: backscatter and extinction. The refractive index depends on: scattering and absorption. Hence: from lidar alone an index of refraction is difficult to obtain. “Stripes” like this in the probability distribution do occur frequently.

Example case of Arctic haze:



backscatter

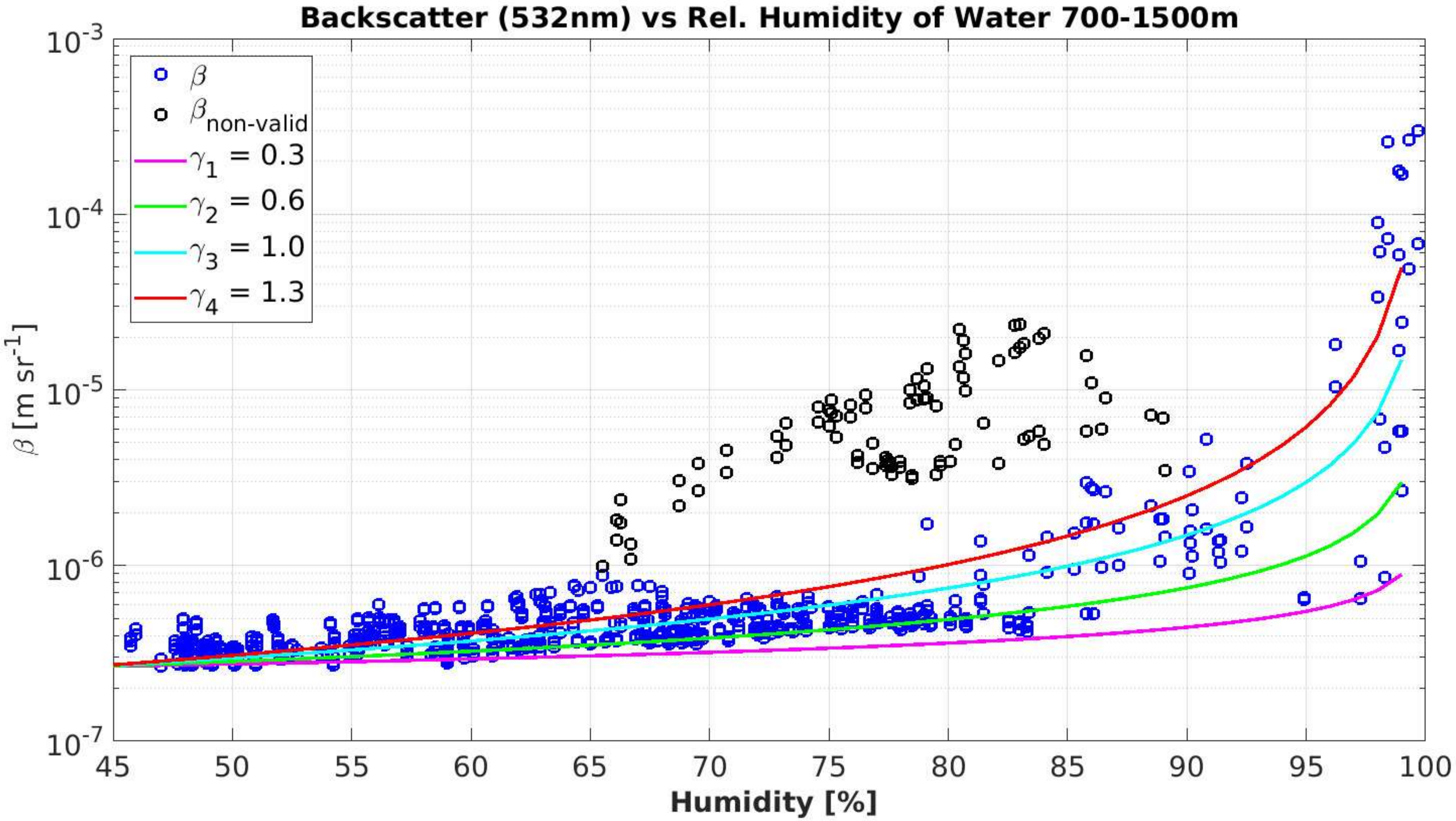
Why variation in the backscatter? Just fluctuation in number concentration or also in size and refractive index?



Parameter [Unit]	whole layer	central part
Lidar ratio at 355 nm [sr]	42.5±3.5	42.6±4.6
Lidar ratio at 532 nm [sr]	30.2±11.4	35.8±15.4
aerosol depolarisation [%]	4.46±0.03	4.32±0.036
color ratio [ ]	5.29±0.06	5.47±0.08
Re refractive index [ ]	1.6±0.1	1.6±0.1
IM refractive index [ ]	0.007±0.007	0.007±0.007
effective radius [µm]	0.185±0.01	0.185±0.01
aerosol number concentration [cm^{-3}]	580±100	850±100
sigma [ ]	1.636±0.06	1.64±0.06

Lidar and contemporary radiosonde: hygroscopic growth?

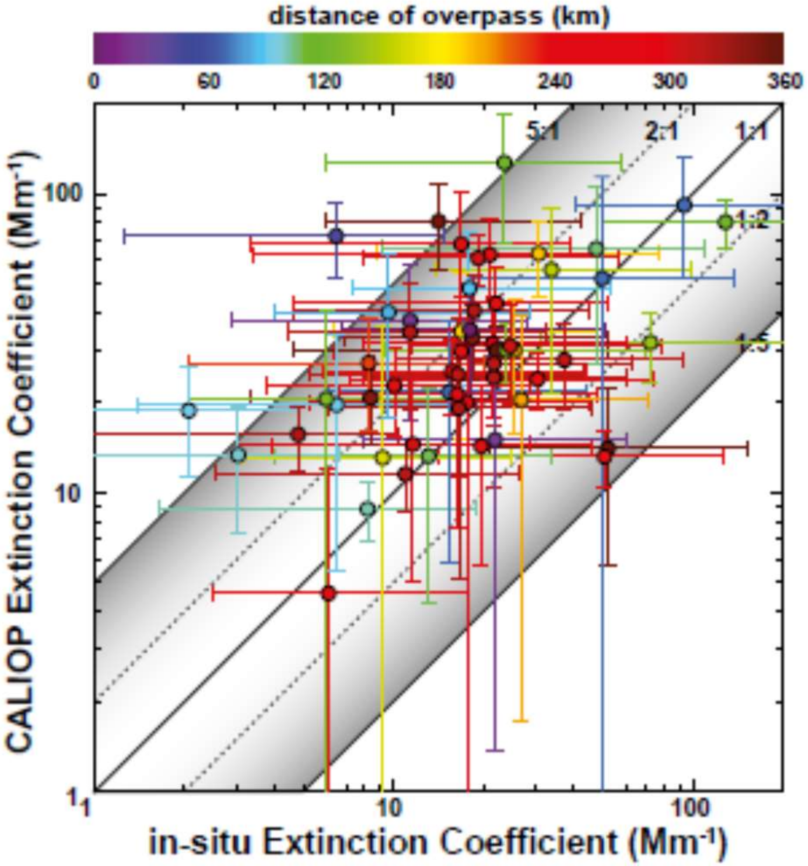
In-situ define scattering enhancement factor f(rh) = $(1-rh)^{-\gamma}$
Question: apply this to β (instead of σ)?
Assumption: all lidar data in a given time / height should belong to „same event“



Open questions:
1. Does remote sensing overestimates extinction?

Tesche et al. 2014 ACP:

Calipso_extinction > in-situ
(Zeppelin station)



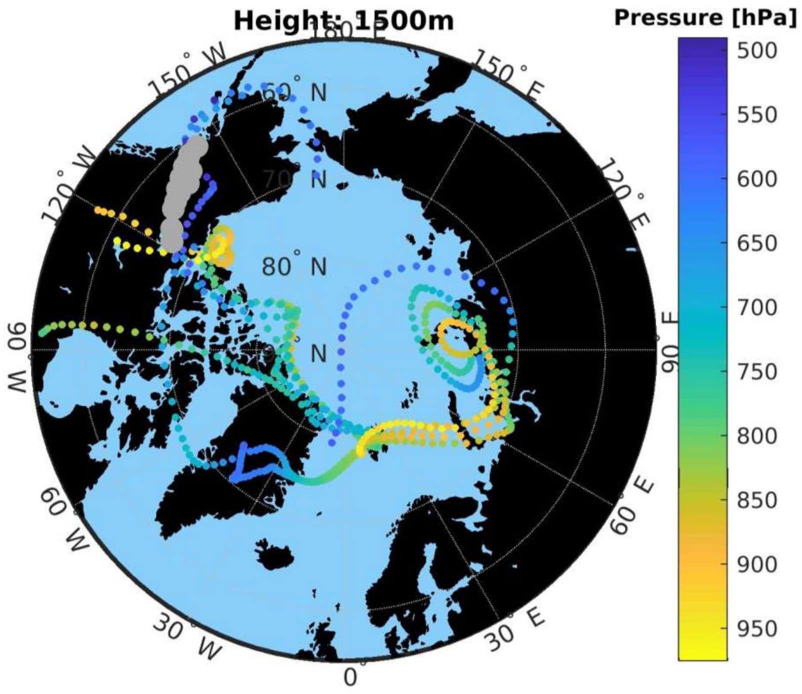
(what was NOT published in)
Lisok, 2016 Atm. Environm:

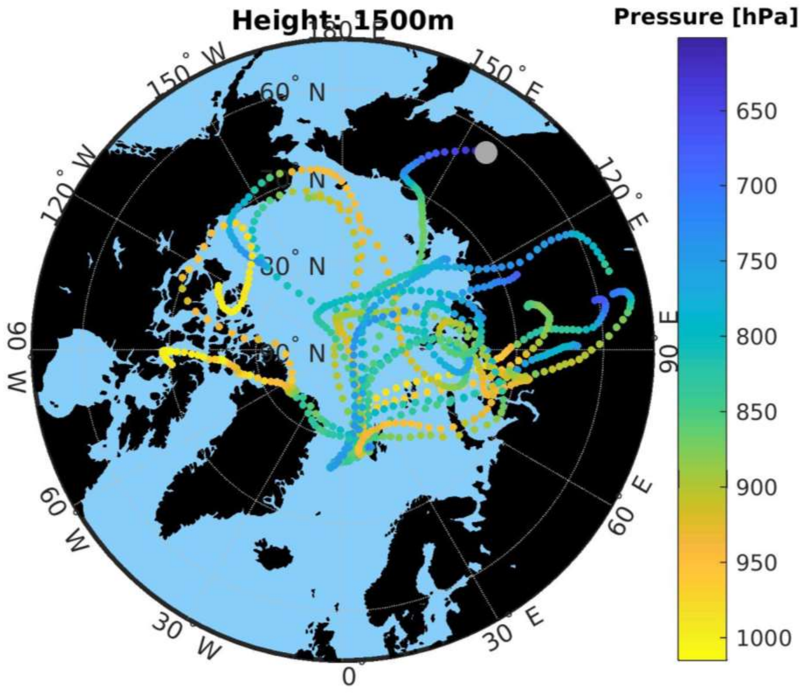
KARL_extinction > in-situ
(Gruvebadet station)
And extinction at ground, 1km,
2km altitude not correlated
Deviations also at rh =50%

Needs to be clarified during MOSAiC:
Less orography!

Open questions:
2. Pollution pathways

Graßl, 2019: Flextra with ERA-interim

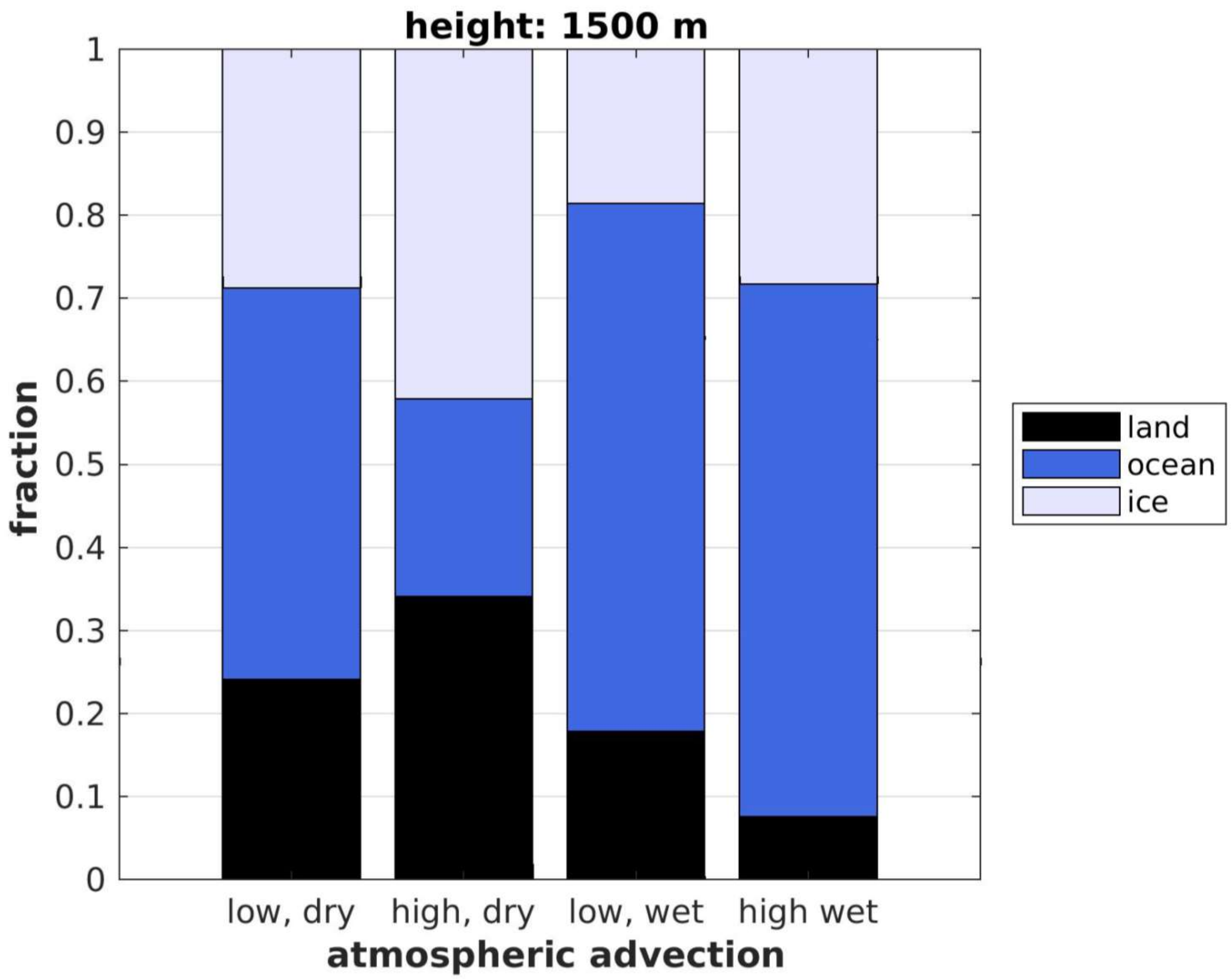




Low AOD (April 2013) high AOD

5 days trajectories too short
Reanalysis products show large differences
<u>Slightly</u> higher AOD from Siberia

Sea ice as reduced sinks?



FLEXTRA 5 days (with photometer) Aprils 2013-2016

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 precipítation)
Advection over sea ice

MOSAiC: coordinated observations with surrounding stations needed

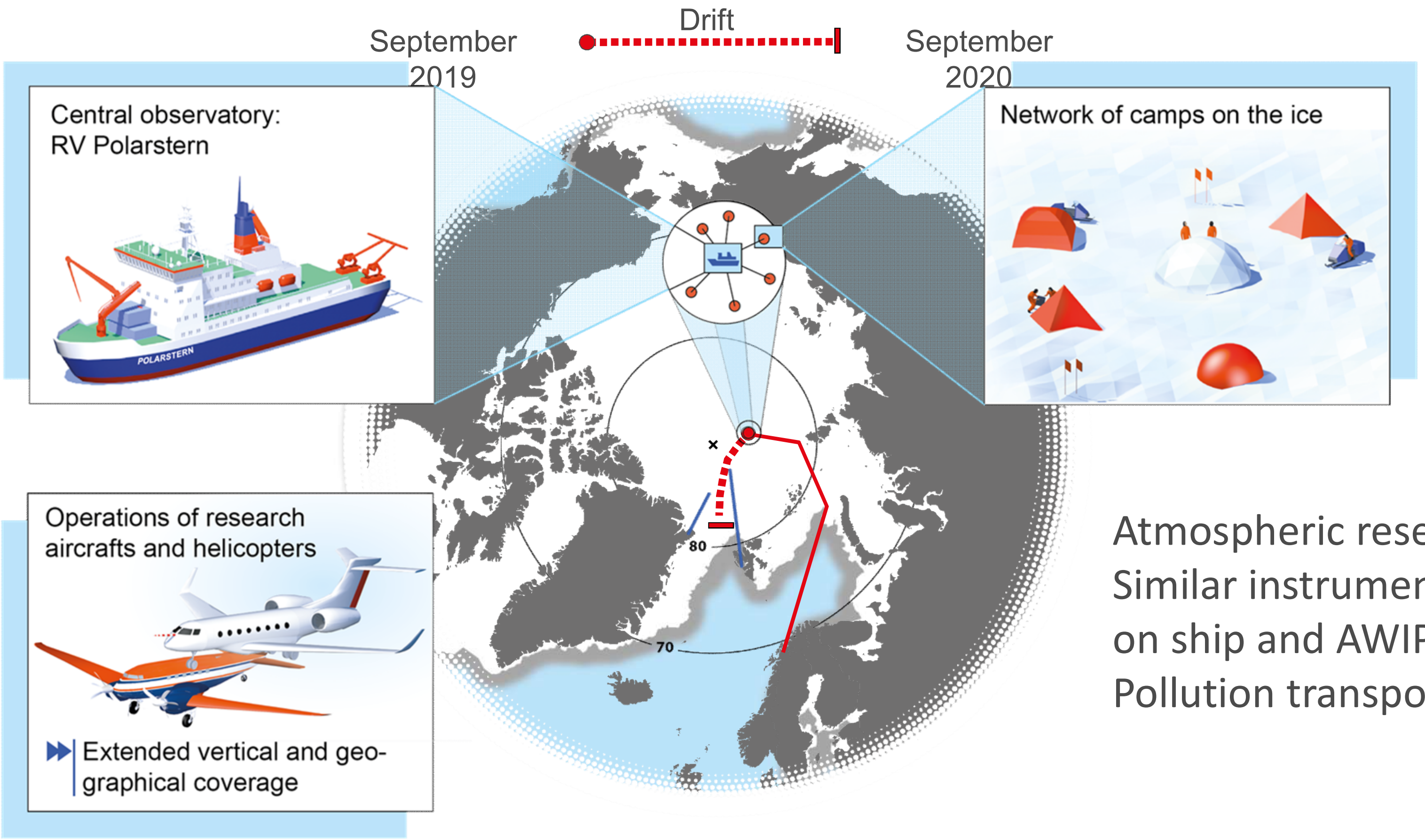
MOSAiC:

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

The MOSAiC Expedition



September 2019

Drift

September 2020

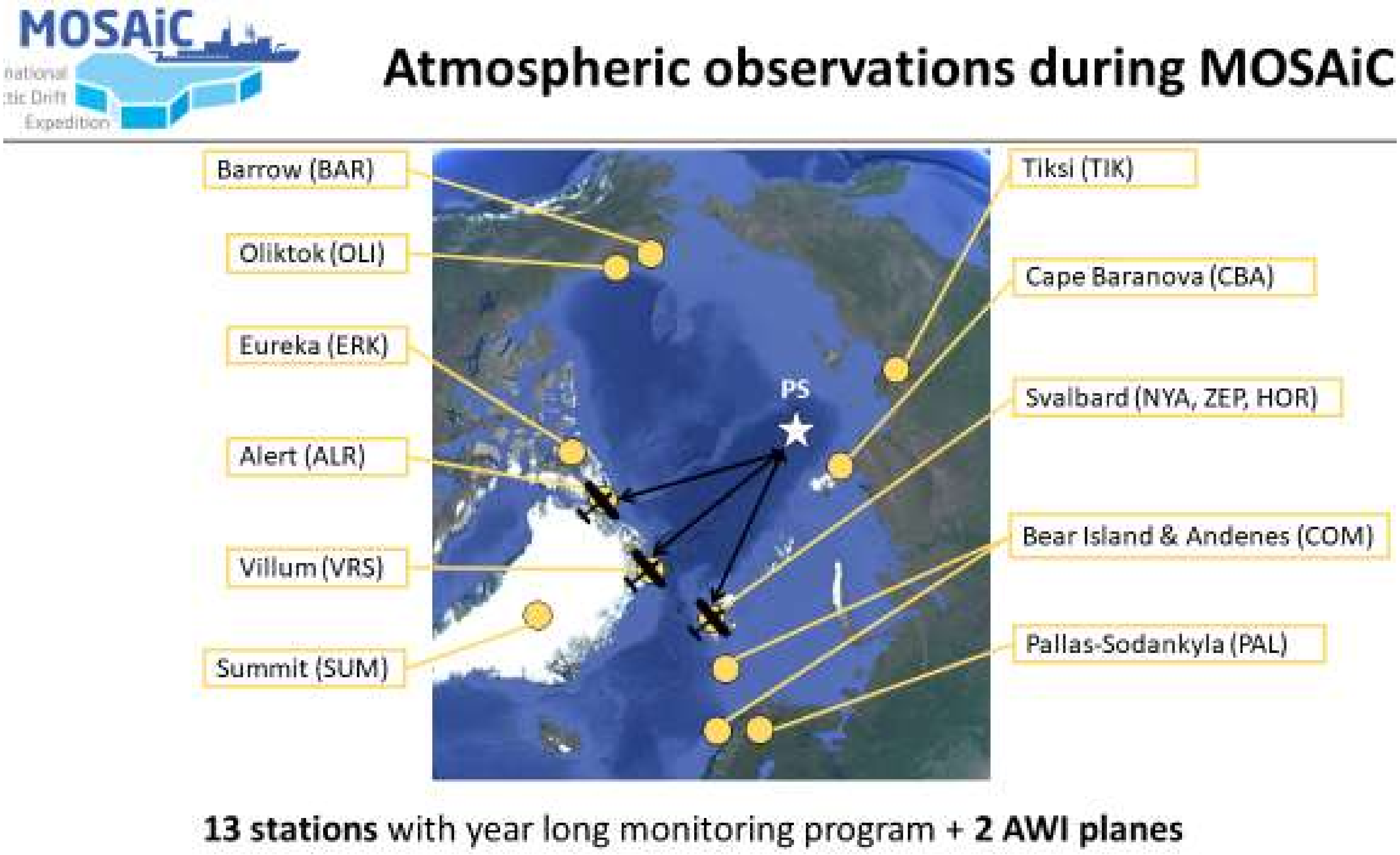
Central observatory:
RV Polarstern

Network of camps on the ice

Operations of research aircrafts and helicopters

Extended vertical and geographical coverage

Atmospheric research:
Similar instrumentation on ship and AWIPEV:
Pollution transport



Atmospheric observations during MOSAiC

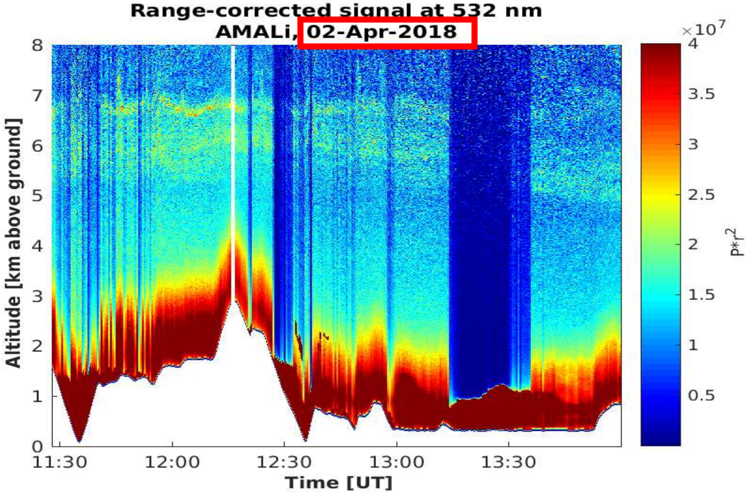
13 stations with year long monitoring program + **2 AWI planes**

Transparency from Marco Zanatta

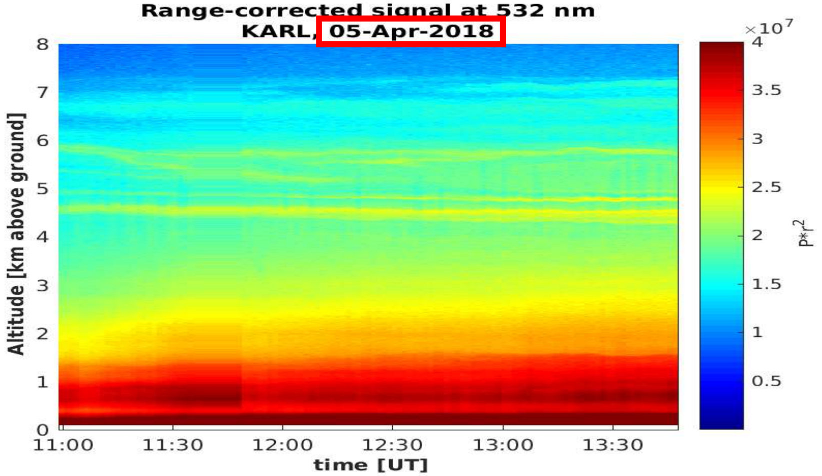
Several ground stations for meteorology and aerosol in-situ

AC3 and PAMARCMiP 2018:

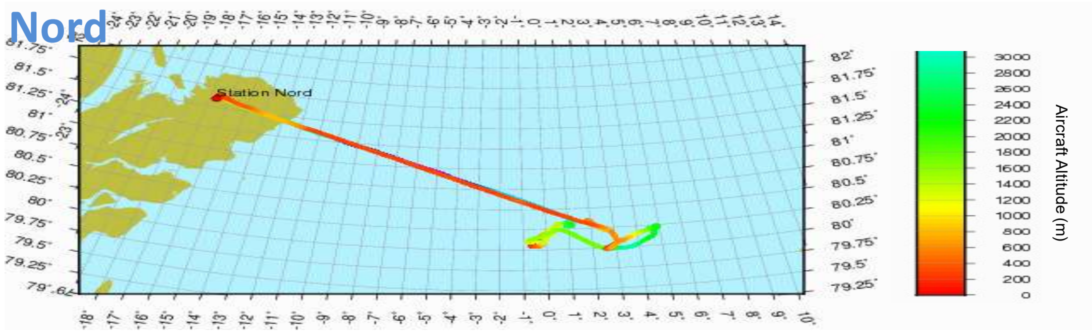
Persistent layer of aerosol in 5-7km



Ny-Ålesund, Spitsbergen



Polar5 flight-track towards Station Nord

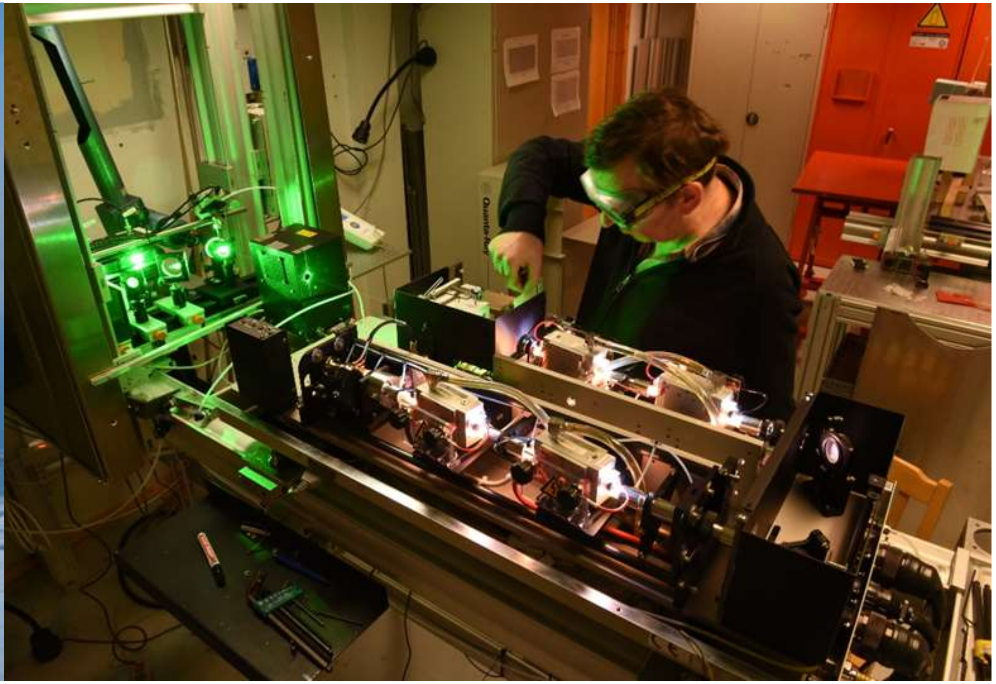


Compare remote sensing to in-situ

Calculate radiative forcing

Summary:

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.

Picture:
Loriot 1923 - 2011

Thank you for your attention!

Available aerosol measurements during MOSAiC

	POLARSTERN	AWI-A	ALR	COM	PAL	VRS	ZEP	NYA	OLI	BAR	CBA	TIK	HOR	ERK	SUM
AEROSOL BASIC															
Total number concetration	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟥	🟩
Total mass concetration					🟩							🟨	🟩	🟥	🟥
Number size distribution	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟨	🟩	🟥	🟩
Scattering	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟨		🟥	🟥
Absorption	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨		🟥	🟩
Exinction (direct measurement)			🟩					🟩	🟩			🟨		🟥	🟥
Cloud condensation nuclei	🟩	🟩		🟩		🟩	🟩		🟩			🟨		🟥	🟥
ChemistryOnline	🟩	🟩				🟧	🟩					🟨		🟥	🟥
ChemistryOffLine	🟩	🟩	🟩		🟩	🟩	🟩	🟩		🟩	🟩	🟨		🟥	🟥
EC/OC					🟩	🟩	🟩	🟩			🟩	🟨		🟥	🟥
OTHER															
refractory black carbon	🟩	🟩	🟩		🟩	🟩	🟩					🟨		🟥	🟥
Hygroscopicity (HTDMA)	🟩			🟩		🟩	🟧		🟩			🟨		🟥	🟥
In siu cloud activation (CVI or interstitial)	🟩	🟩			🟩		🟩					🟨		🟥	🟥
INP (online-offline)	🟩	🟩				🟩	🟩					🟨		🟥	🟩
Wet scattering	🟩											🟨		🟥	🟥
Cloud residual size distribution		🟩					🟩								
Cloud resiudal BC		🟩					🟩								
Cloud residual composition		🟩					🟩								
Cloud liquid water content		🟩					🟩								
Droplet size distribution		🟩					🟩								
CCN on cloud residuals		🟩					🟩								
Aerosol ion spectrometer (NAIS)							🟧								
SIngle particle BC both in aerosol and cloud residuals		🟩					🟩								
Bioaerosol single particle (MBS) botn in aerosols and cloud residuals							🟩								

Legend	
🟩	Observed
⬜	Not observed
🟧	To be confirmed
🟥	No ifo

Platforms	
AWI-A	AWI-Aircfrafts (Apr and Sept)
ALR	Alert
COM	COMBLE (Andenes+Bear Island)
PAL	Pallas
VRS	Villum
ZEP	Zeppelin
NYA	Ny-Alesund
OLI	Oliktok
BAR	Barrow
CBA	Cape Baranova
TIK	Tiksi
HOR	Hornesund
ERK	Eureka
SUM	Summit

Aerosol measurements:

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

Can be
In situ ↔ remote sensing

DMPS, Filter, (OPC)
“what aerosol is there”

“what is the optical impact of the aerosol”

Passive, without own radiation

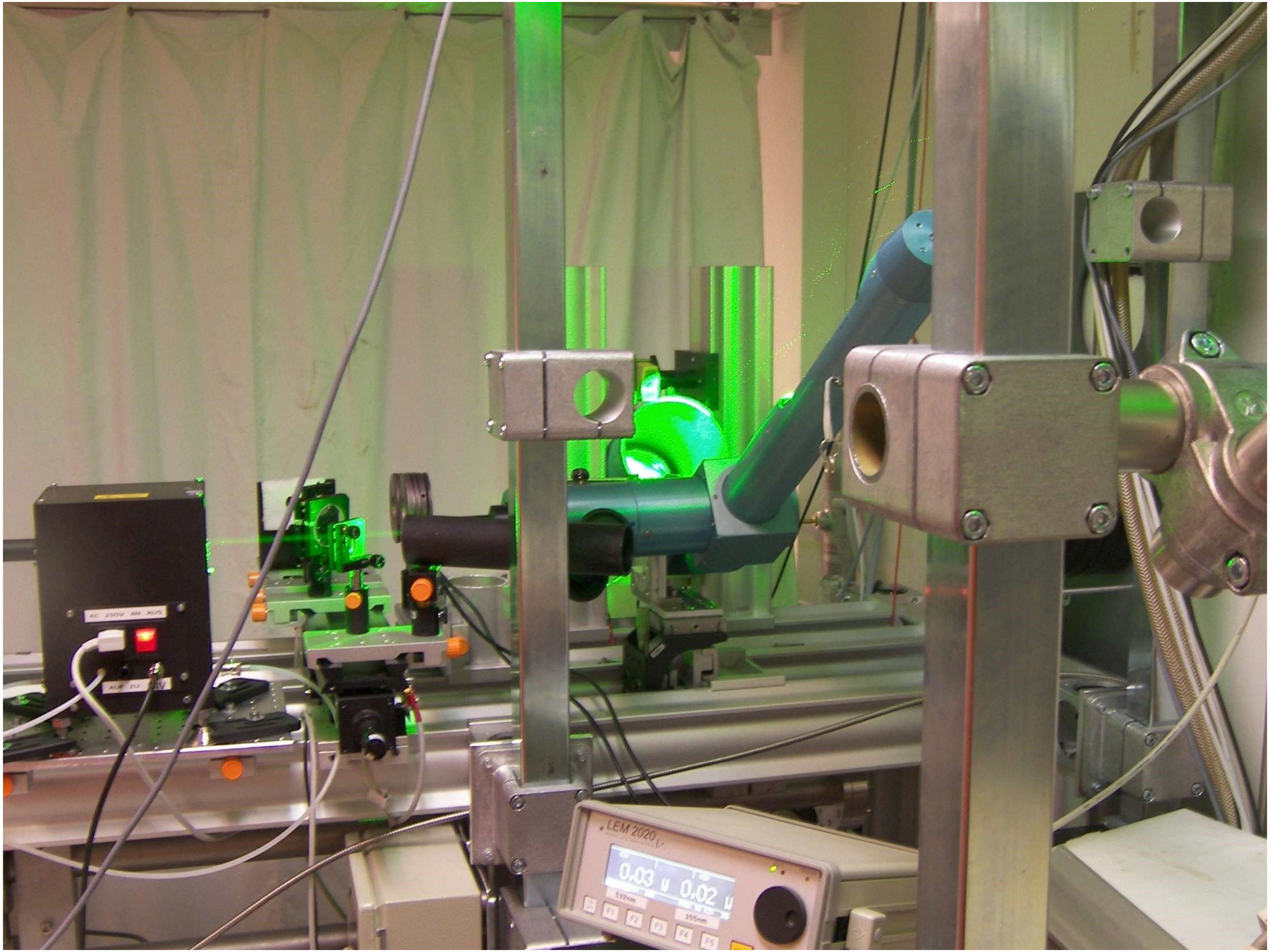
Active, emits own radiation: easier ranging

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

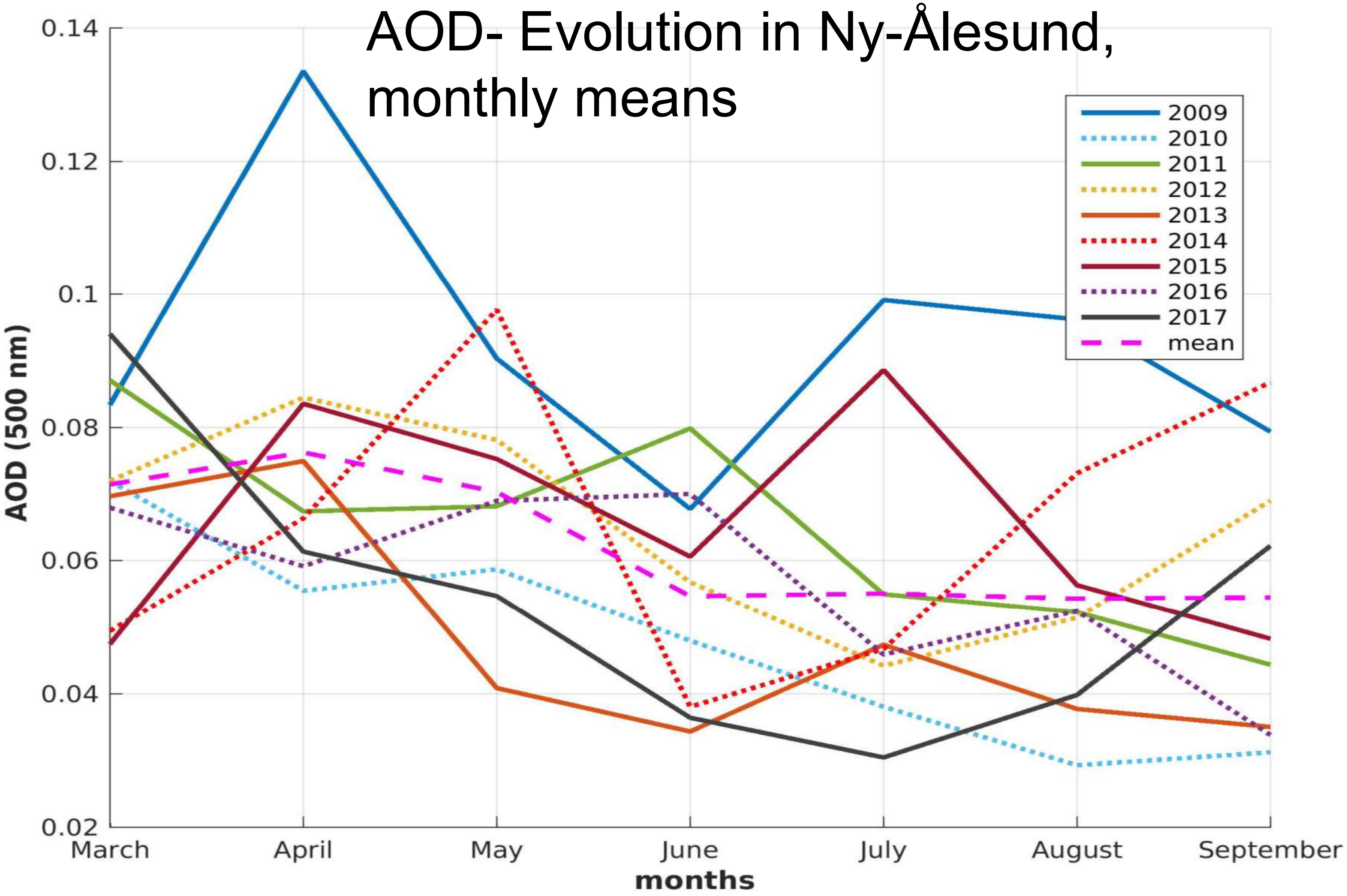
“closure experiments”

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


AC 230V AN AUS
AUF ZU
LEM 2020
0.03 W
0.02 W
532nm
355nm
F1
F2
F3
F4
F5

AOD- Evolution in Ny-Ålesund, monthly means



S. Graßl 2019, Masterthesis

Spring AOD decreases over time
→ annual run of AOD becomes flatter
2009 was last polluted year
Generally high variability

Principles and equation:

elastic:

$$P_e\ (z) = C_e\ \beta(z)\ {}^1/_{z^2}\ \text{exp}(-2\int_0^z \alpha_{\lambda_e}(\hat{z})\, d\hat{z})\ \cdot [O(z)]$$

P : return power [MHz]

β: backscatter [$m^{-1}sr^{-1}$]

α: extinction [m^{-1}]

O: overlap function

C: lidar constant (laser power, optics: transmission, PMT efficiency …)

$$\beta^{tot} = \beta^{Ray} + \beta^{aer}$$

$$\alpha^{tot} = \alpha^{Ray} + \alpha^{aer}$$

Raman –scattering, inelastic $\lambda_{elastic} \rightarrow \lambda_{Raman}$

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

ρ : air density, Raman scattering at nitrogen molecules

Extinction principally challenging!

It all depends on SNR

In total: 2 equations for α, β

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

$$P^{607nm}(z) = \hat{C} \cdot {}^{1}\!/_{z^2}\, \rho(z) \cdot \exp(-\int_0^z \alpha^{532} + \alpha^{607} d\hat{z})$$

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

$\Rightarrow$ equation for α^{532} but noisy

$$P^{607nm}(z) = \hat{C} \cdot {}^{1}\!/_{z^2}\, \rho(z) \cdot \exp(-\int_0^z f \cdot \alpha^{532}(\hat{z}) d\hat{z})$$

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

$$\beta^{\text{tot}} = \beta^{Ray} + \beta^{aer}$$

You need (always): 1) air density profile

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

$$P_r\,(\mathrm{z}) = C_r\,\rho(z)\,{}^1/_{z^2}\ \exp(-\int_0^z f\cdot\alpha_{\lambda_e}(\hat{z})\,d\hat{z})\cdot\ [O(z)]$$

$$P_e(\mathrm{z}) = C_e\,\beta(z)\,{}^1/_{z^2}\ \exp(-2\int_0^z(\alpha^{Ray}+LR\ \cdot\ \beta^{Aer})\cdot[O(z)]$$

Extinction in a lidar:

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

Do not smooth or fit your lidar profile !!

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

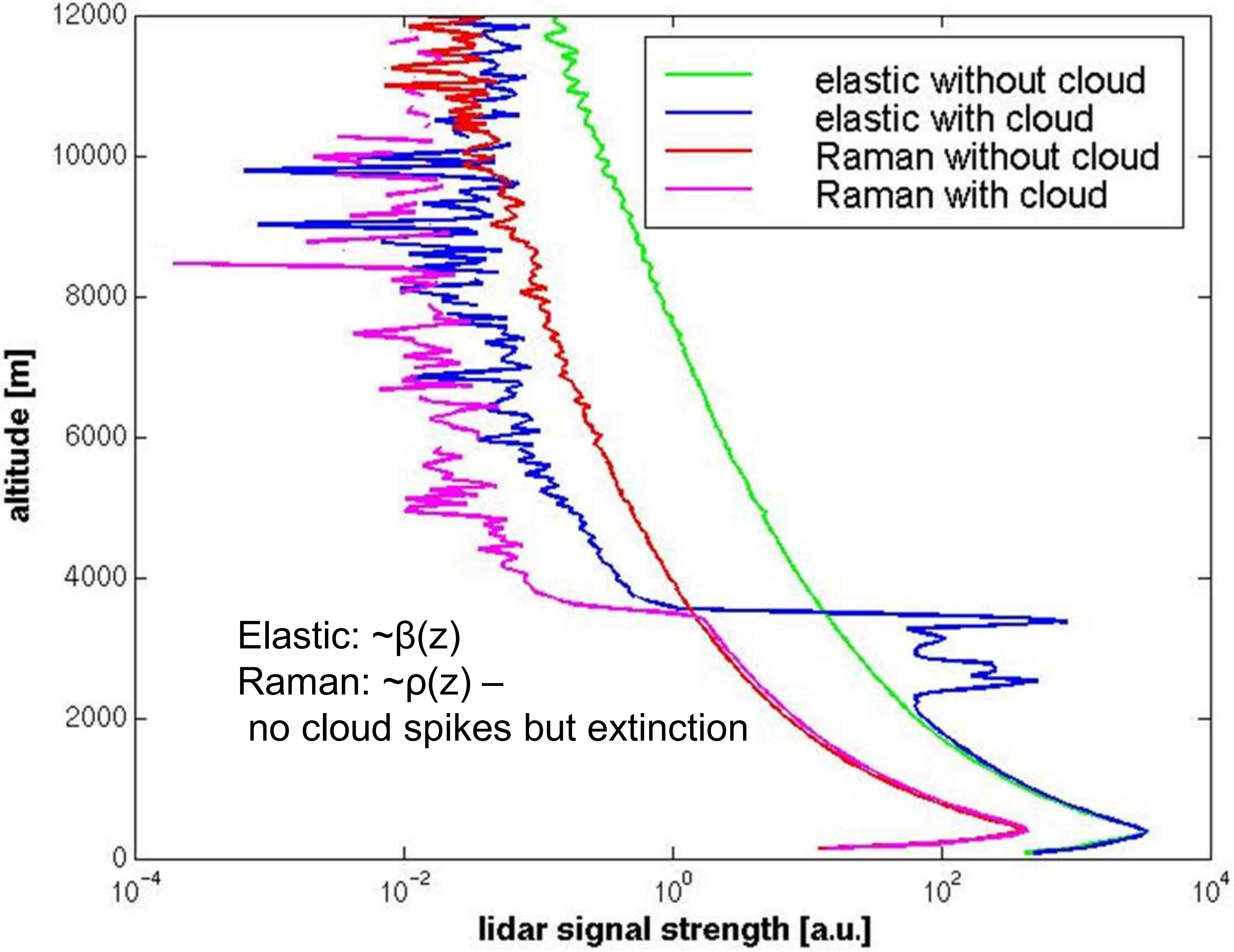
$$P_r\,(z_t) = C_r\,\rho(z_r)\,{}^{1}/_{{z_r}^2}\ \underbrace{\exp\left(-\int_0^{z_b}\alpha\ \ldots dz\right)}_{P_r(z_b)\ {z_b}^2 / C_r\rho(z_b)}\cdot\exp\left(-\int_{z_b}^{z_t}\alpha\ \ldots dz\right)$$

→ Layer AOD

If the derivative ${}^{\partial}/_{\partial z}$ harms, avoid it

Or make a statistic from unsmoothed lidar data
(first calculation, then averaging)

How do lidar signals look like?



Elastic: ~β(z)
Raman: ~ρ(z) –
no cloud spikes but extinction

Shortcomings of lidar data:

Phase function missing: only info around Φ =180 °

overlapp: boundary layer difficult

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

m_{real} ~ scattering m_{imag} ~ absorption
but we only have β, α

Weak absorption → ω insecure

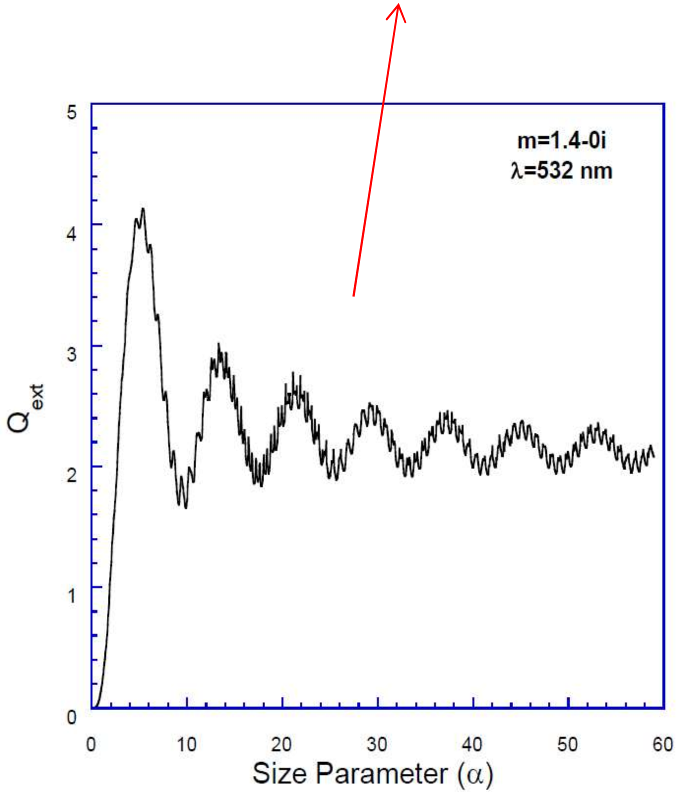
Only trustful info for accumulation mode:
Aitken: interacction too small
giant mode: Mie efficiency becomes flat

$$\alpha = \frac{2\,\pi\, r}{\lambda} \quad \leftrightarrow \quad r = \frac{\alpha\,\lambda}{2\,\pi}$$

$$\alpha \in [1 \;\dots 12],\;\; \lambda = 0{,}5\mu \rightarrow r \in [\tfrac{1}{4\pi} \dots \tfrac{3}{\pi}]\;\mu$$

conclusion: aerosol, cloud particles

For broad size
distribution
function becomes
smoother



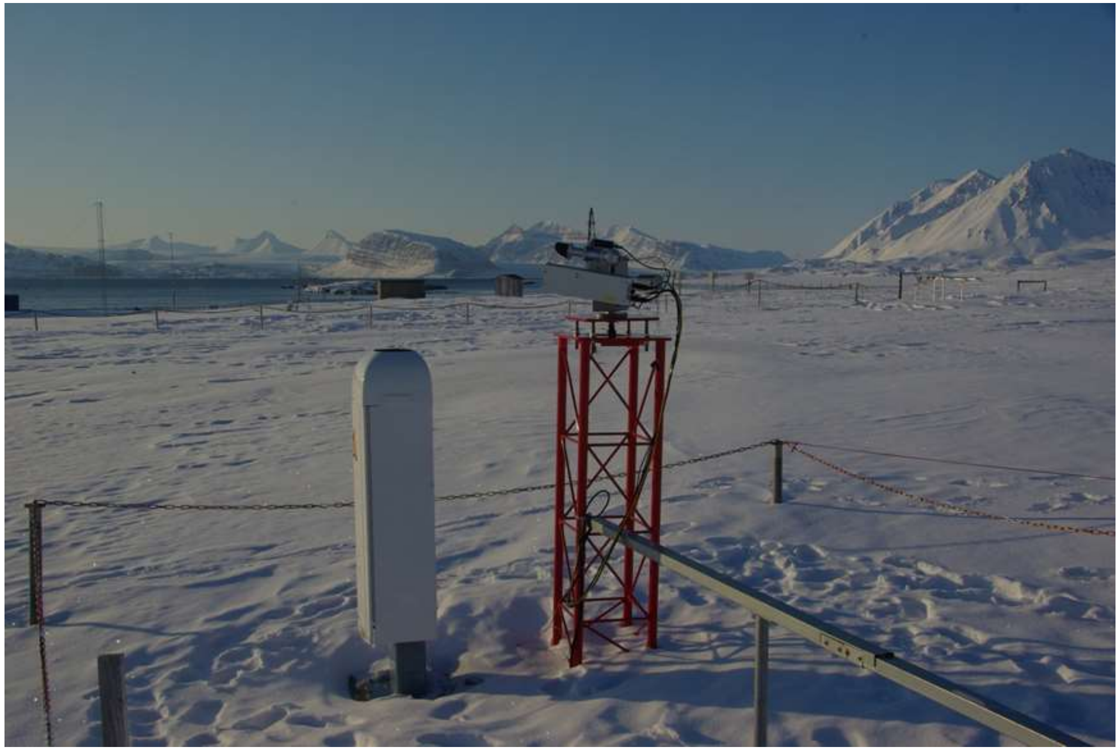
Results Haze season 2013:

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”:

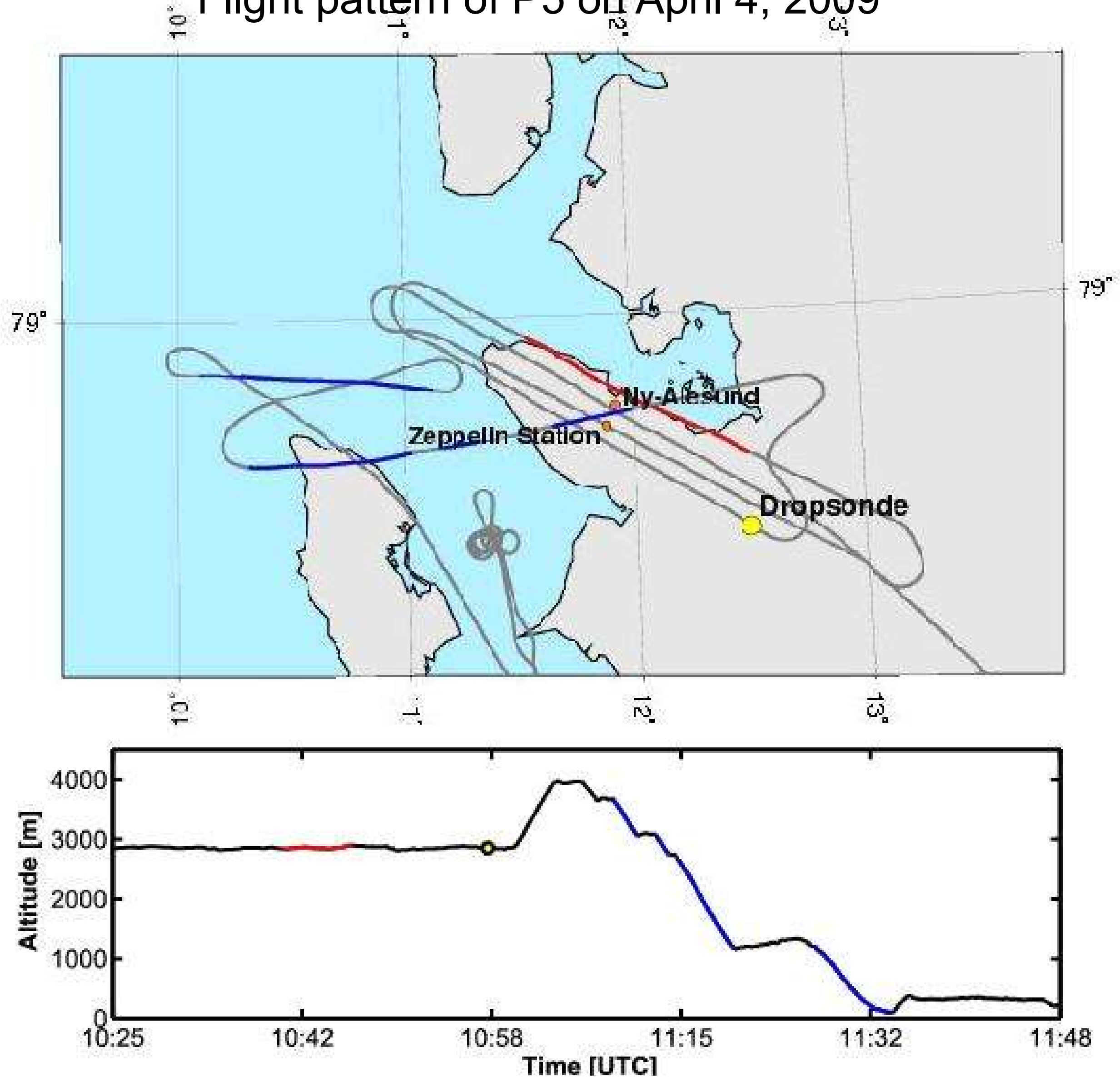
1) Closure on microphysics (locally)
2) Closure on radiative impact (column)

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

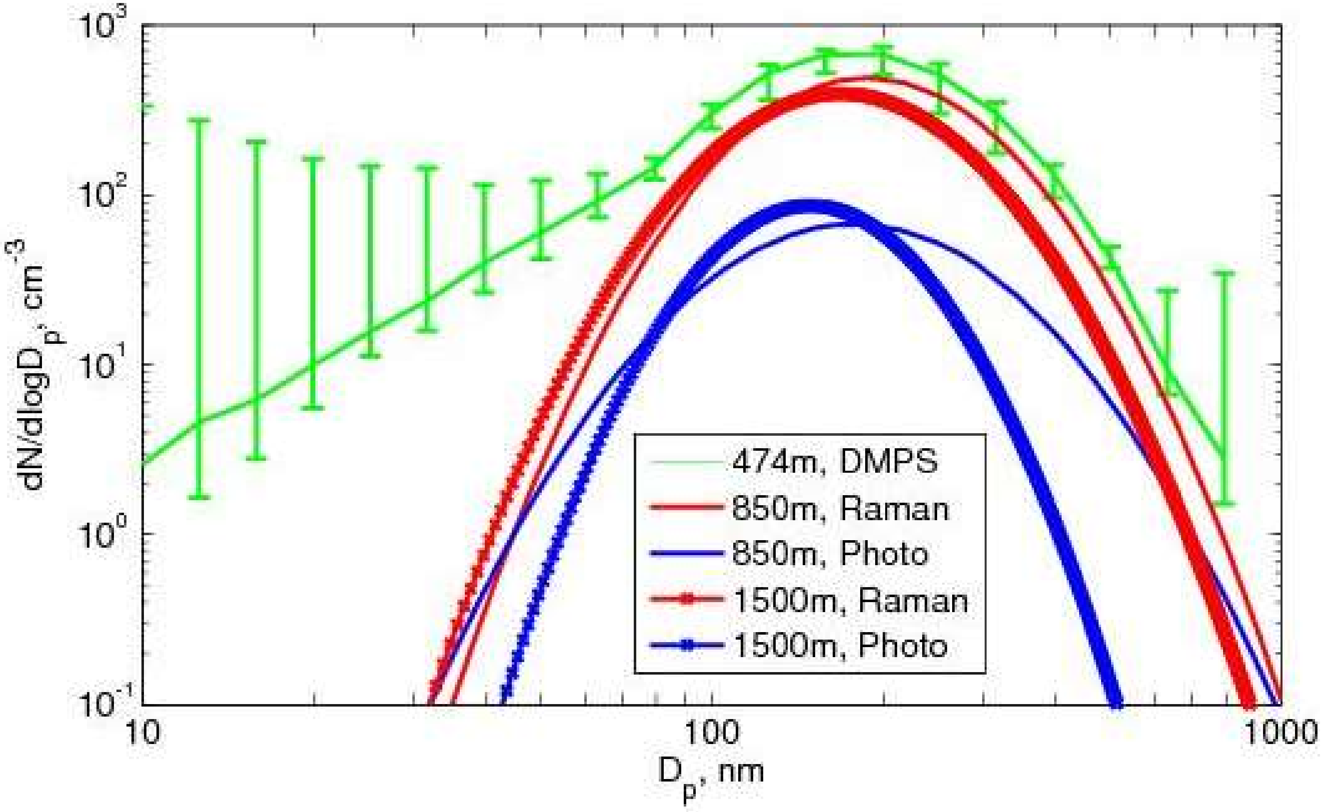


Red: AMALI lidar, downward looking

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

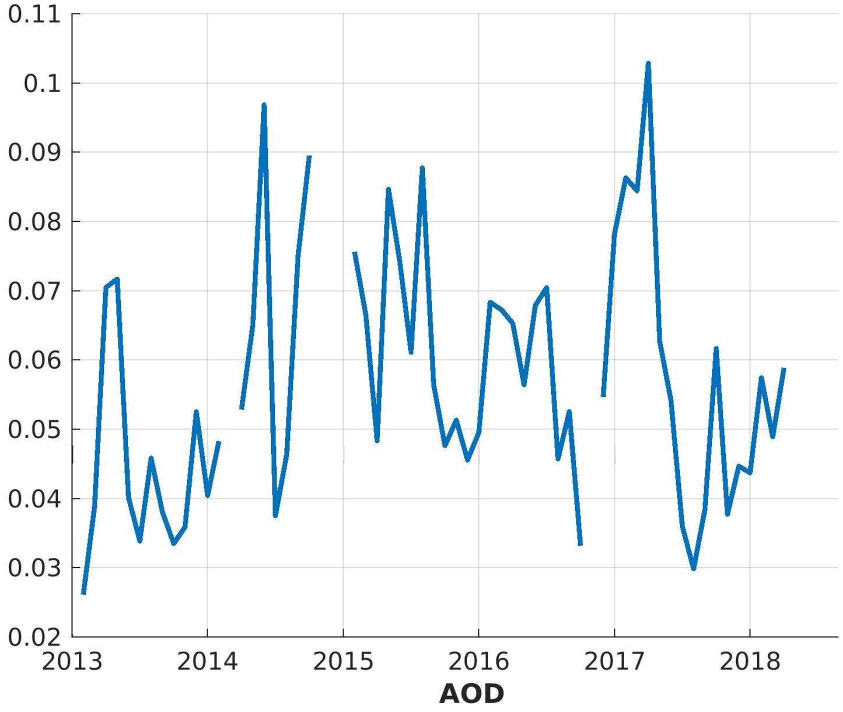
Should be compared to ground-based in-situ data:
Is the aerosol in the column / free troposphere the same as on ground?

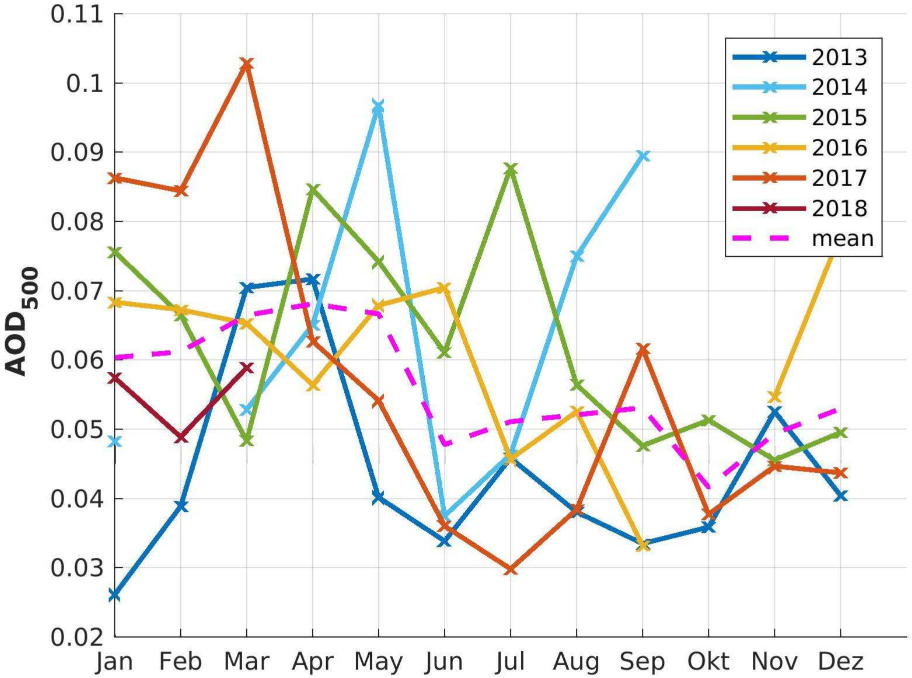
Has typical resolution of minutes / 10m

Arctic Haze: spring-time „air pollution“

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

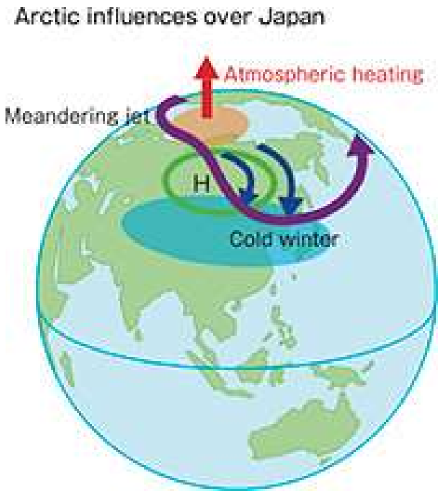
Max. in spring but large year to year variability
Sandra is analysing it:





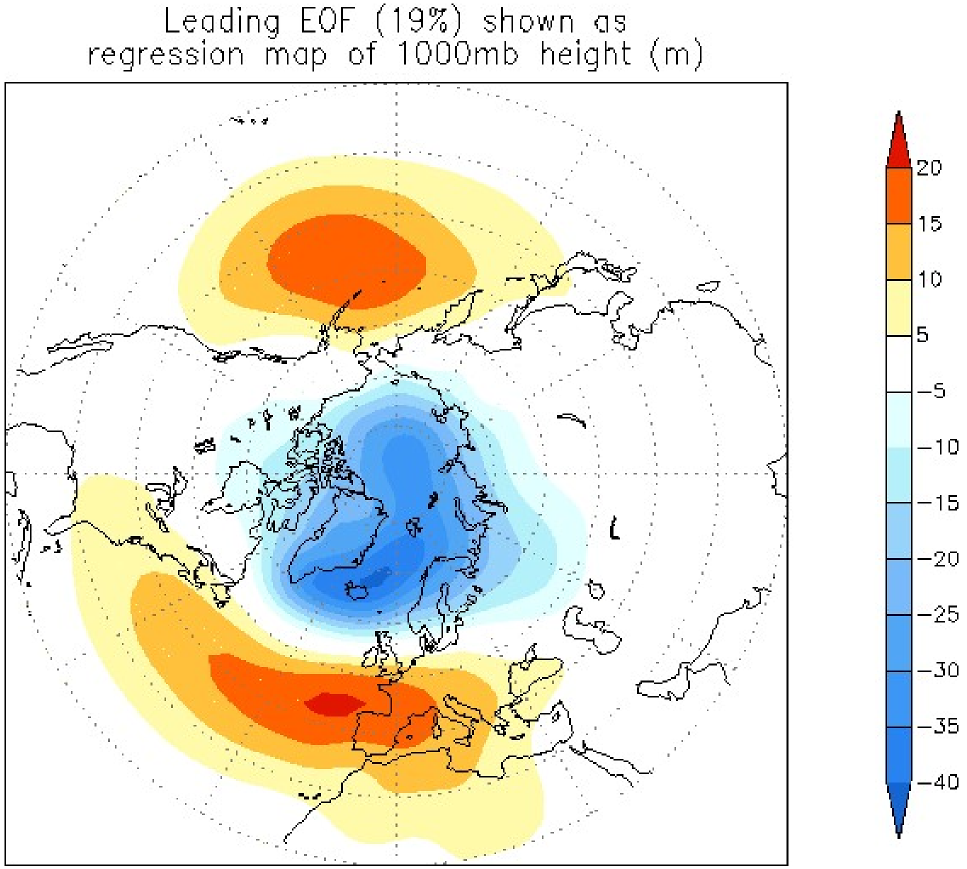
Motivation:

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



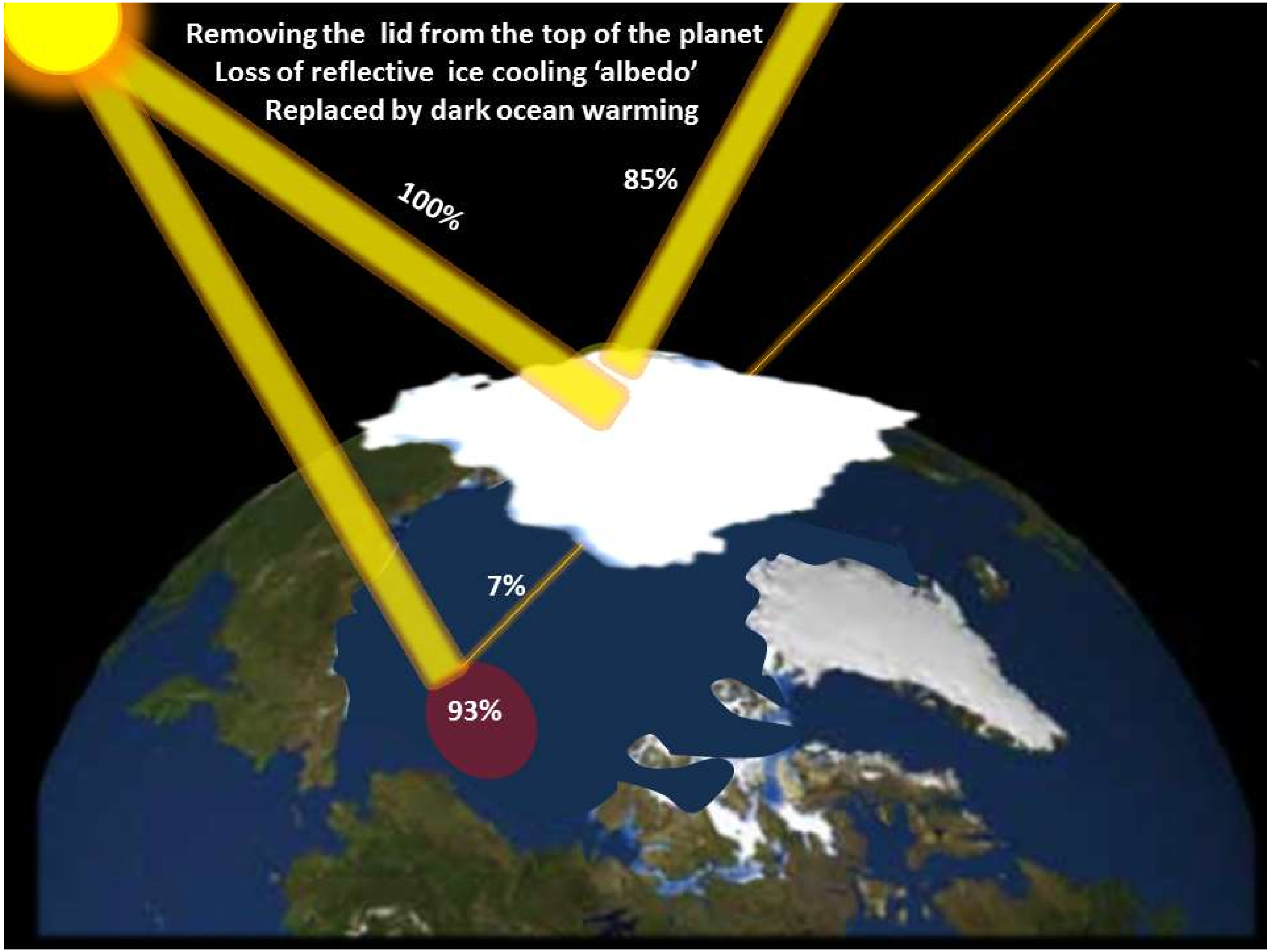
Sichtweise aus Japan

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 …

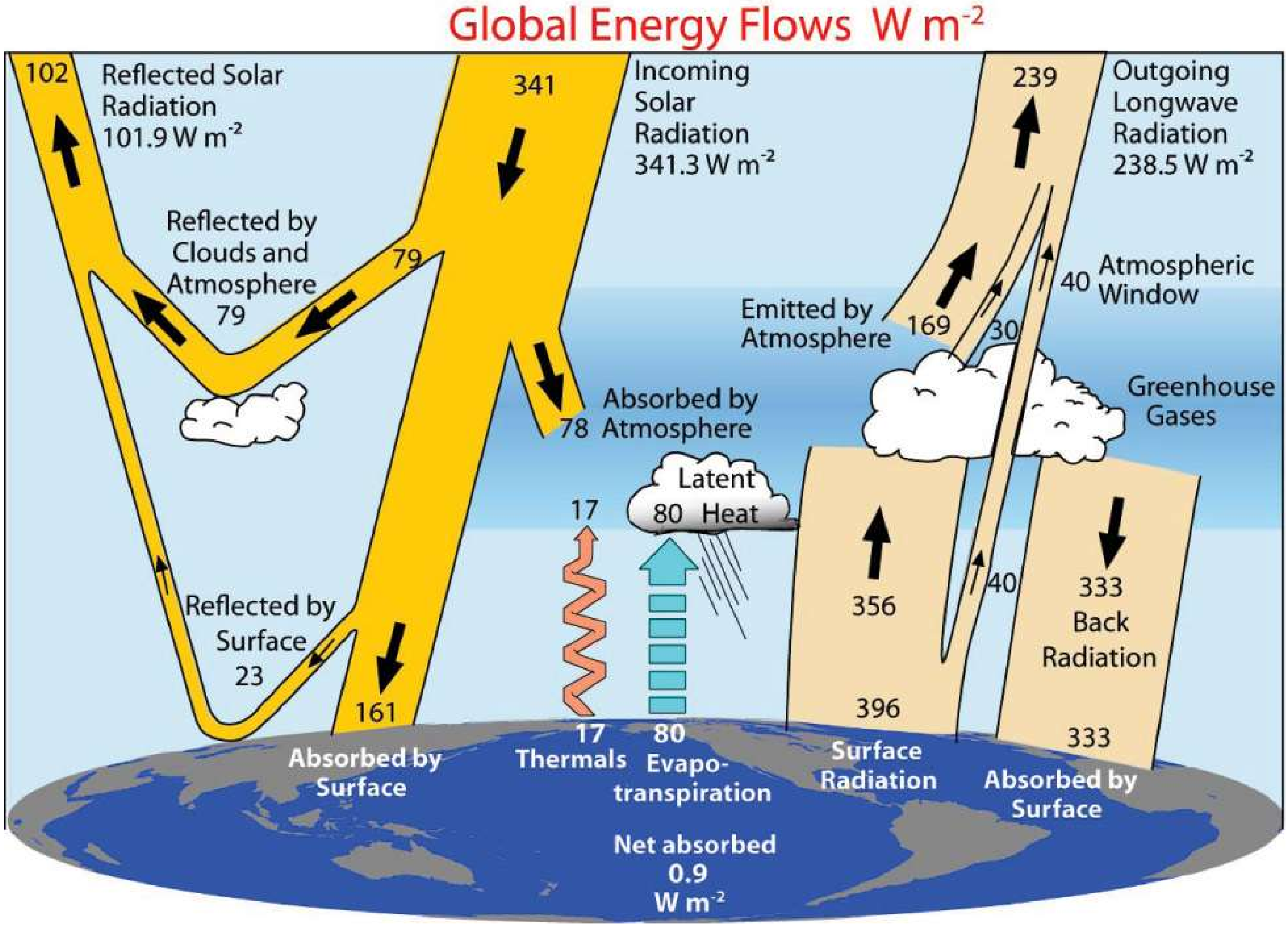


Eis-Albedo Rückkopplung

2014: Pithan, Mauritsen (MPI-Hamburg)

Arktische Verstärkung nur durch Temperatureffekte

(generell) Strahlungsbilanz:



Sehr verschiedene Prozesse, Subtraktion, Addition von ähnlichen Größen

Wolken wichtig!

Es gibt Eis- und Wasserwolken

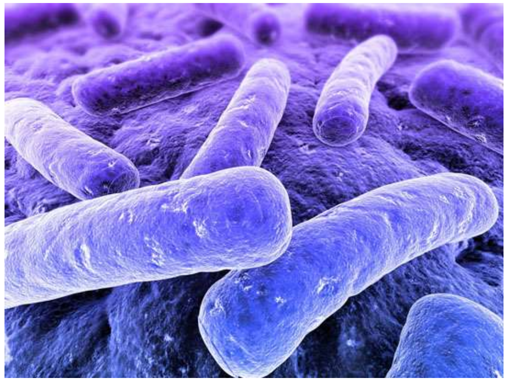
Absorbierte Energie > 0 →Erwärmung

Aerosole:
Alle festen oder flüssigen Teilchen in Atmosphäre als Trägergas:

Wüstenstaub
(Sahara, Gobi)

anthropogen

Biologisch:
Bakterien, Viren,
Pollen



weiterhin:
Seesalz, Vulknstaub,

„sekundärem Aerosol“, aus
reaktiven Gasen gebildet

Waldbrände

Durchmesser: 10nm -10µm
(Sedimentationsge-schwindigkeit
$\sim r^2$)

Ganz unterschiedliche Form,
Größe und Chemie

Ohne Aerosole kein Niederschlag!

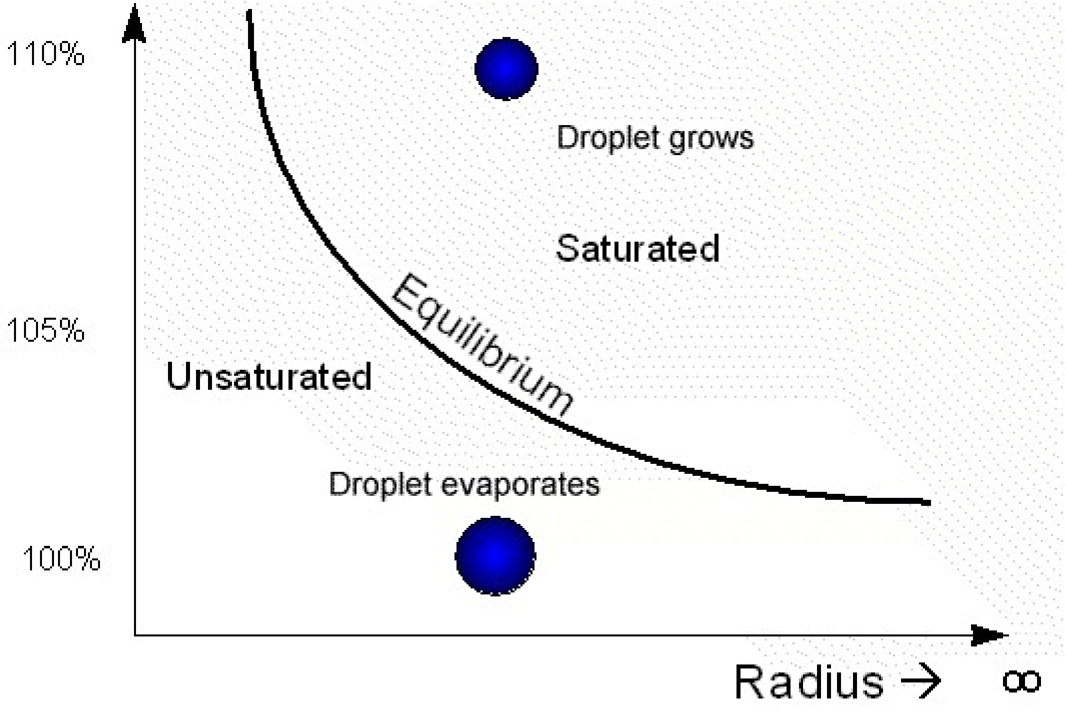
Betrachten kleine Wassertröpfchen:

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

„Oberflächenspannug aufrecht zu erhalten, kostet Energie, Natur will das vermeiden “

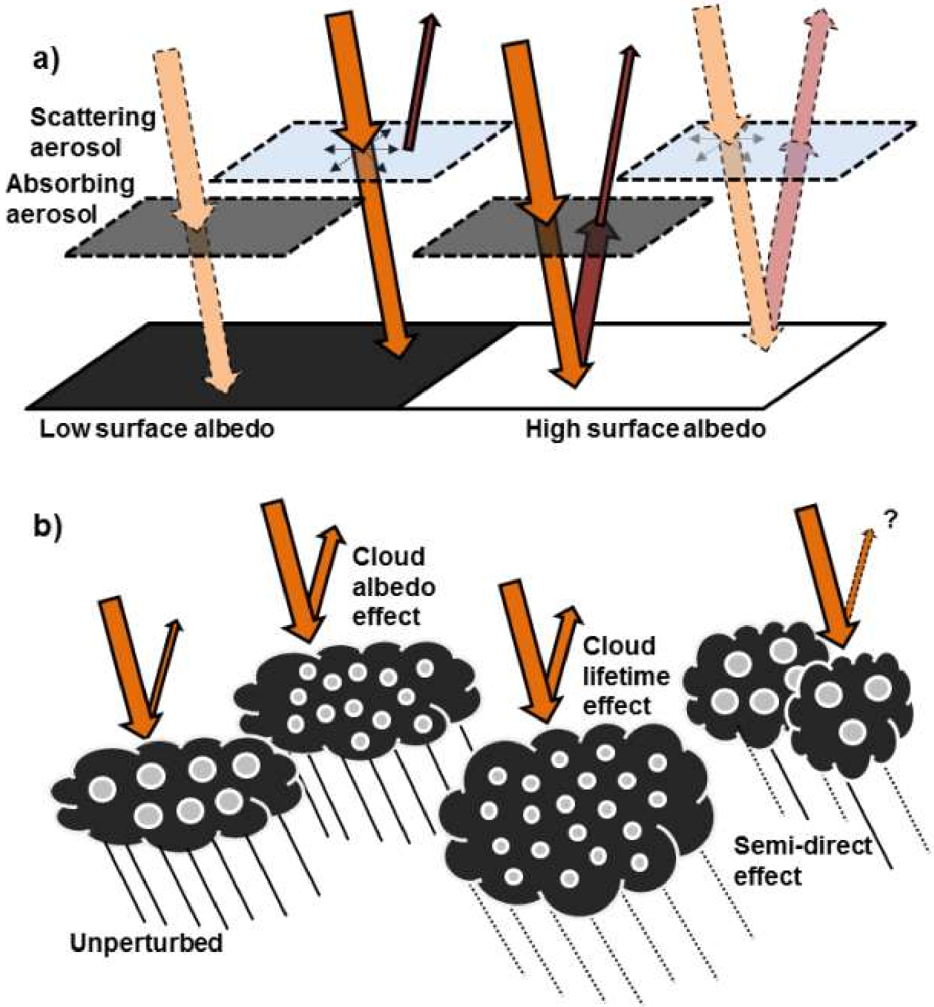
In reiner Luft bräuchte man eine Übersättigung von 450% bis sich aus Wasserdampf stabile Tröpfchen bilden

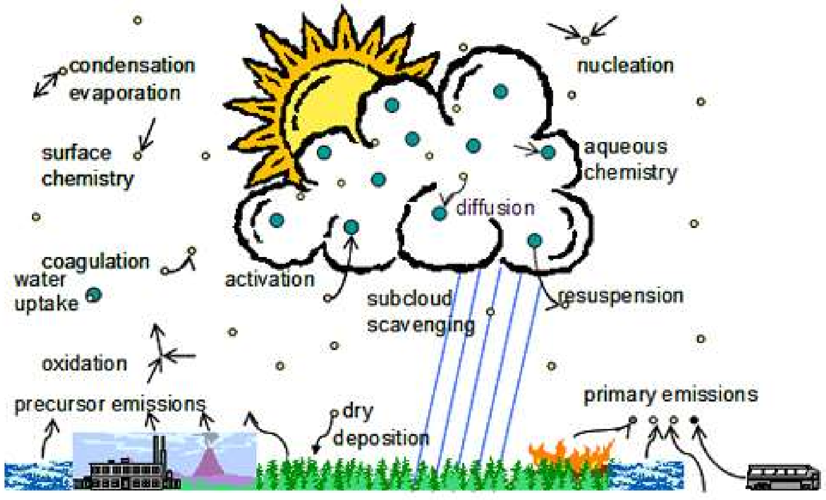
Aerosole stellen Oberfläche zur Verfügung, an der sich Wassermoleküle anlagern können



Aerosole beeinflussen Strahlungsbilanz:

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

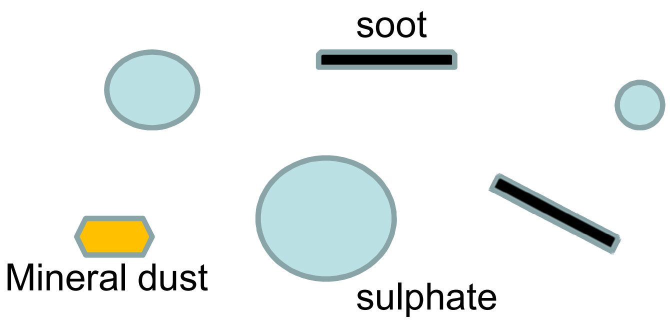




Aerosole ändern ständig
Durchmesser und chem.
Zusammensetzung
Verschwinden aus Atmosphäre
durch Niederschlag,
Sedimentation

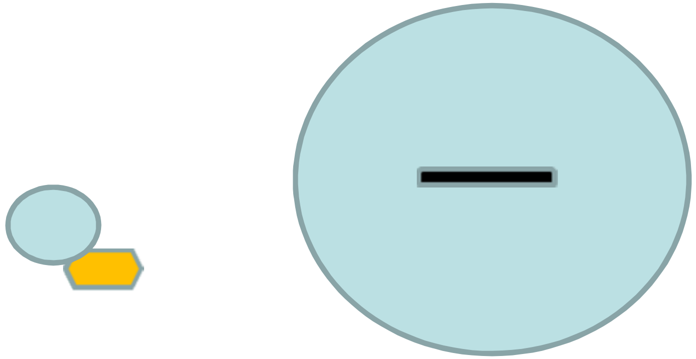
Consider an aerosol cloud:

a) External mixing



Chemically external mixture: most particles have one chemical comosition

b) Internal mixing:



Internal mixing: most particles have heterogene composition

Aging:
Due to Brownian motion coagulation, more internal mixture
But also new particle formation due to $SO_{2,}$ O_3 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

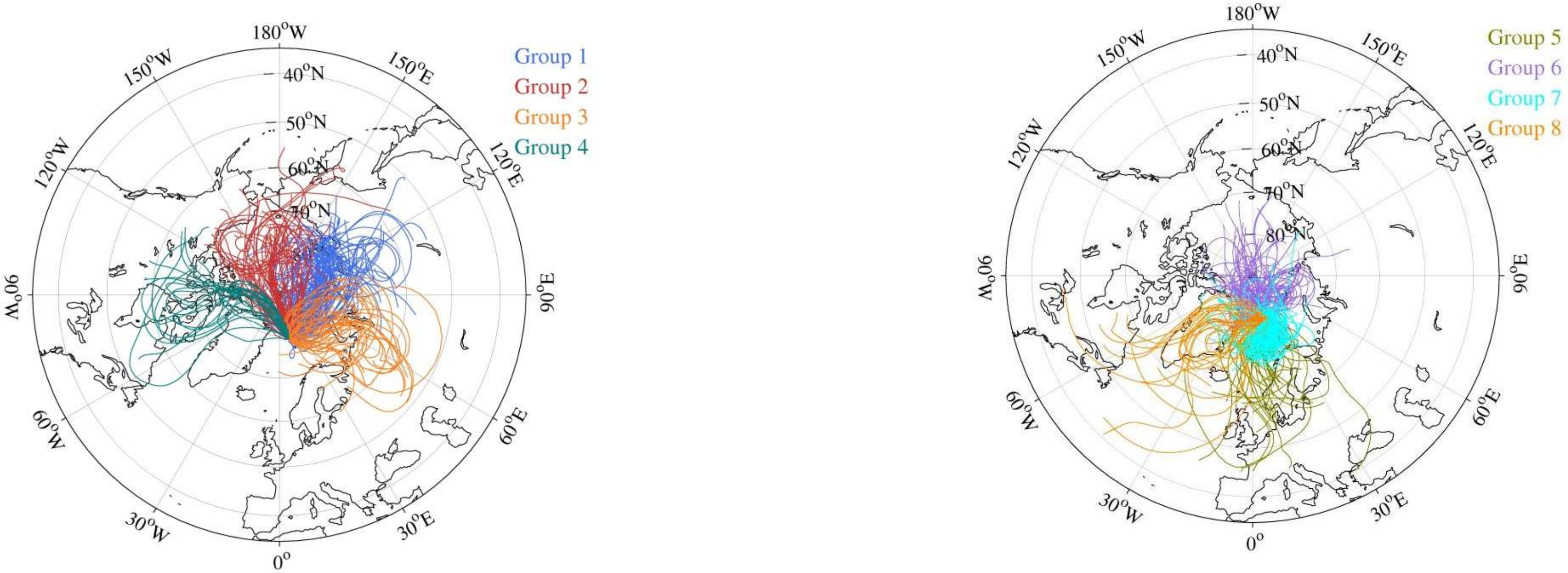
Deficiencies in description:

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

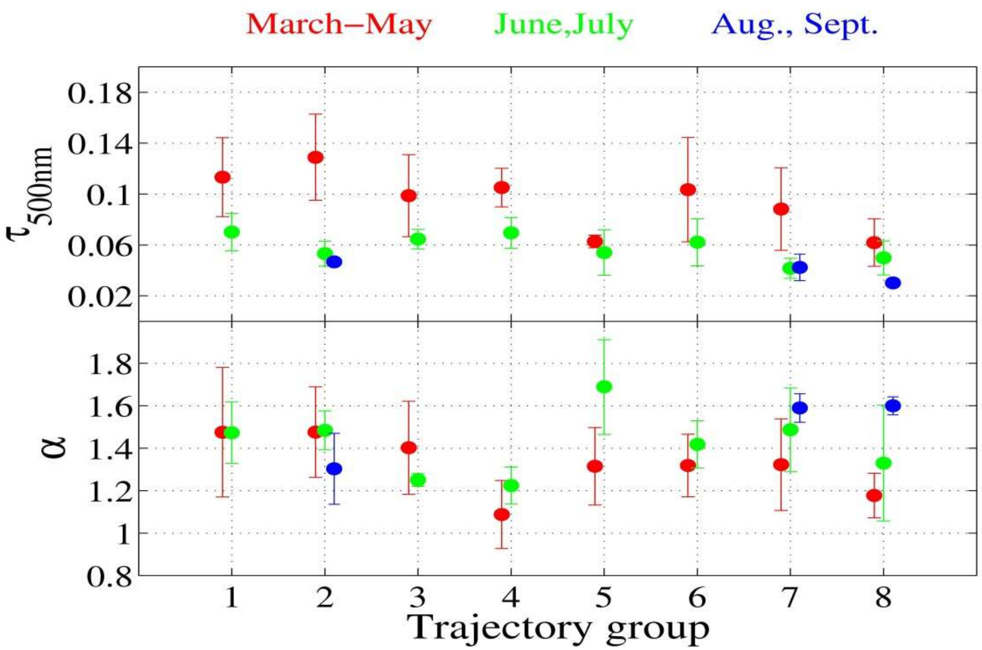
Introduction III where does the aerosol come from?



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	Cluster 5 Europe
2 Beaufortsea	6 central Arctic
3 Western Russia	7 local
4 North-East Canada	8 Greenland

Aerosol origin

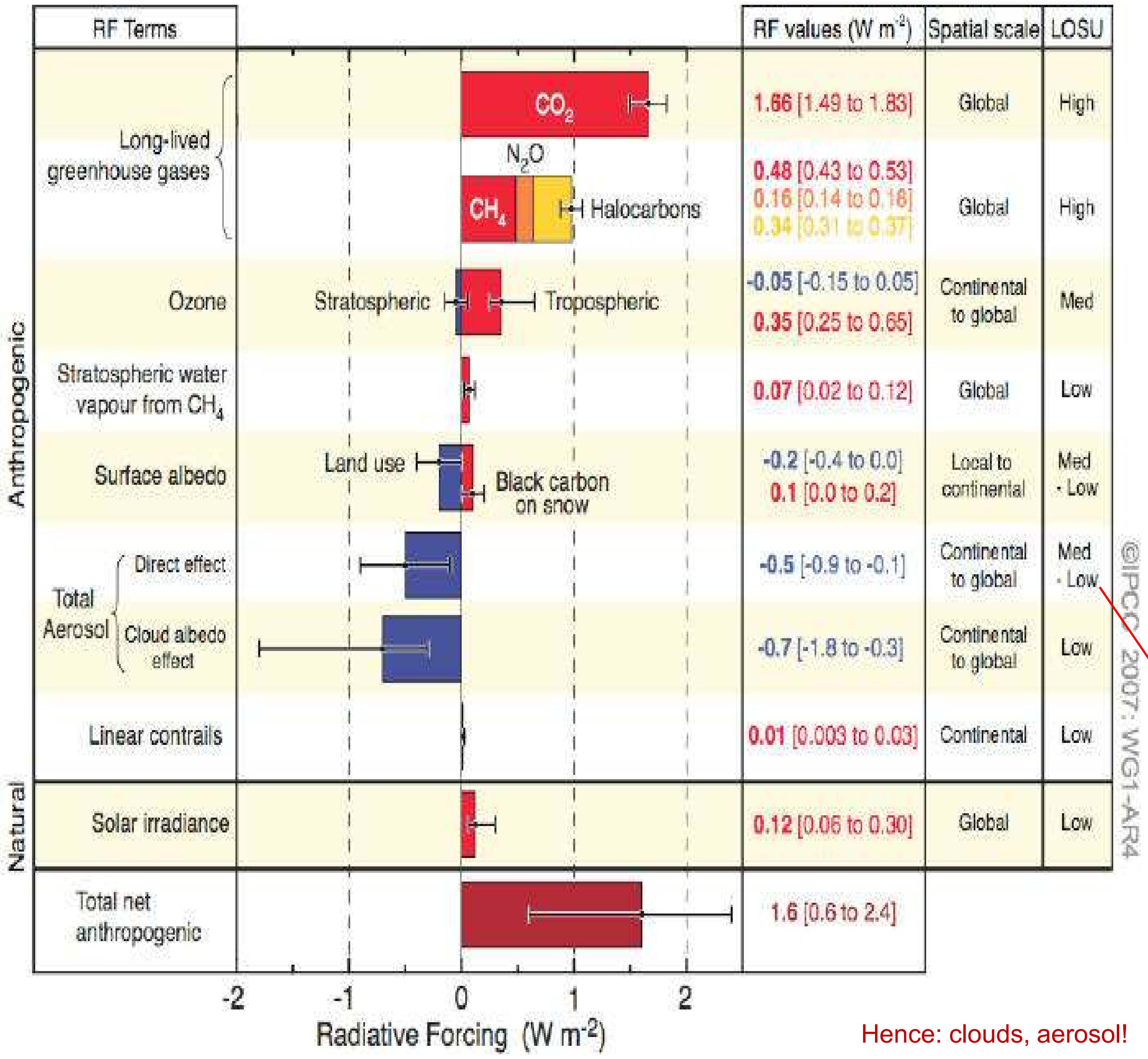


Cluster 1 Eastern Arctic/ Siberia
2 Beaufortsea
3 Western Russia
4 North-East Canada
5 Europe
6 central Arctic
7 local
8 Greenland

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 assoziated with cloud formation (no photometer observation and/or wet scavening)

Where does aerosol come from?
Measurements in central and Russian Arctic required!
Follow pollution plumes with aircraft/satellites over several days

Radiative Forcing Components



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

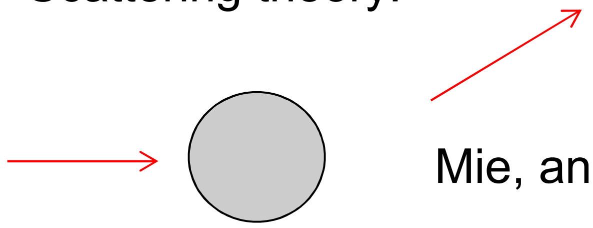
Remote sensing:

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

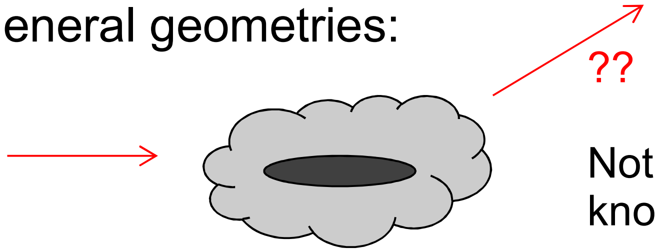
Scattering theory:



Mie, analytical

size, refractive index (RI)

General geometries:

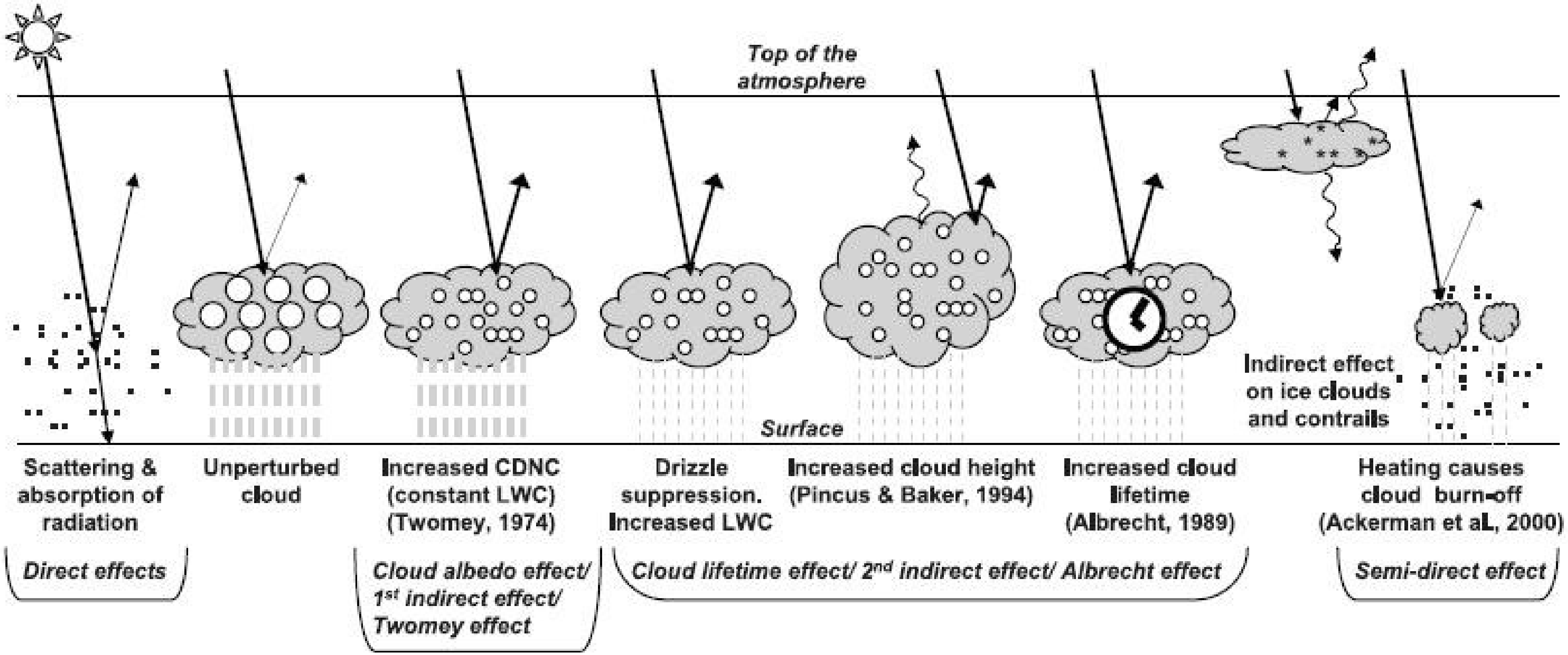


Not even known

size, shape, RI_eff

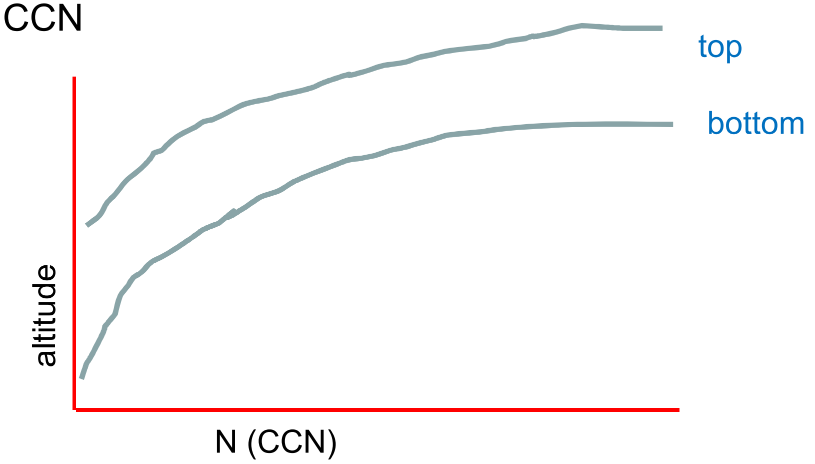
In situ & remote sensing must not agree

Overview over aerosol effects



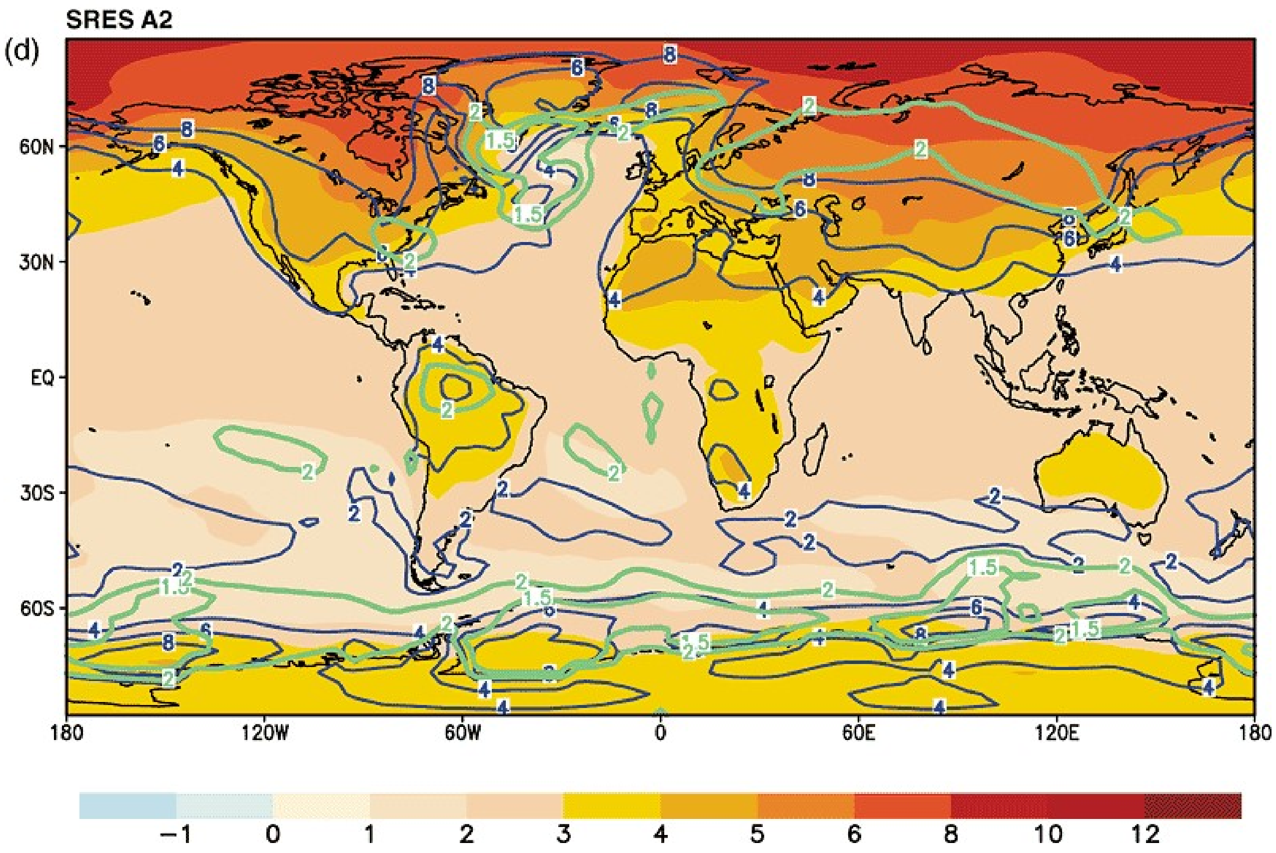
Twomey effect: smaller cloud particles have less absorption, more scattering (polluted clouds are whiter)
higher albedo, larger life-time

Pincus & Baker: cloud thickness and cloud top altititude 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”

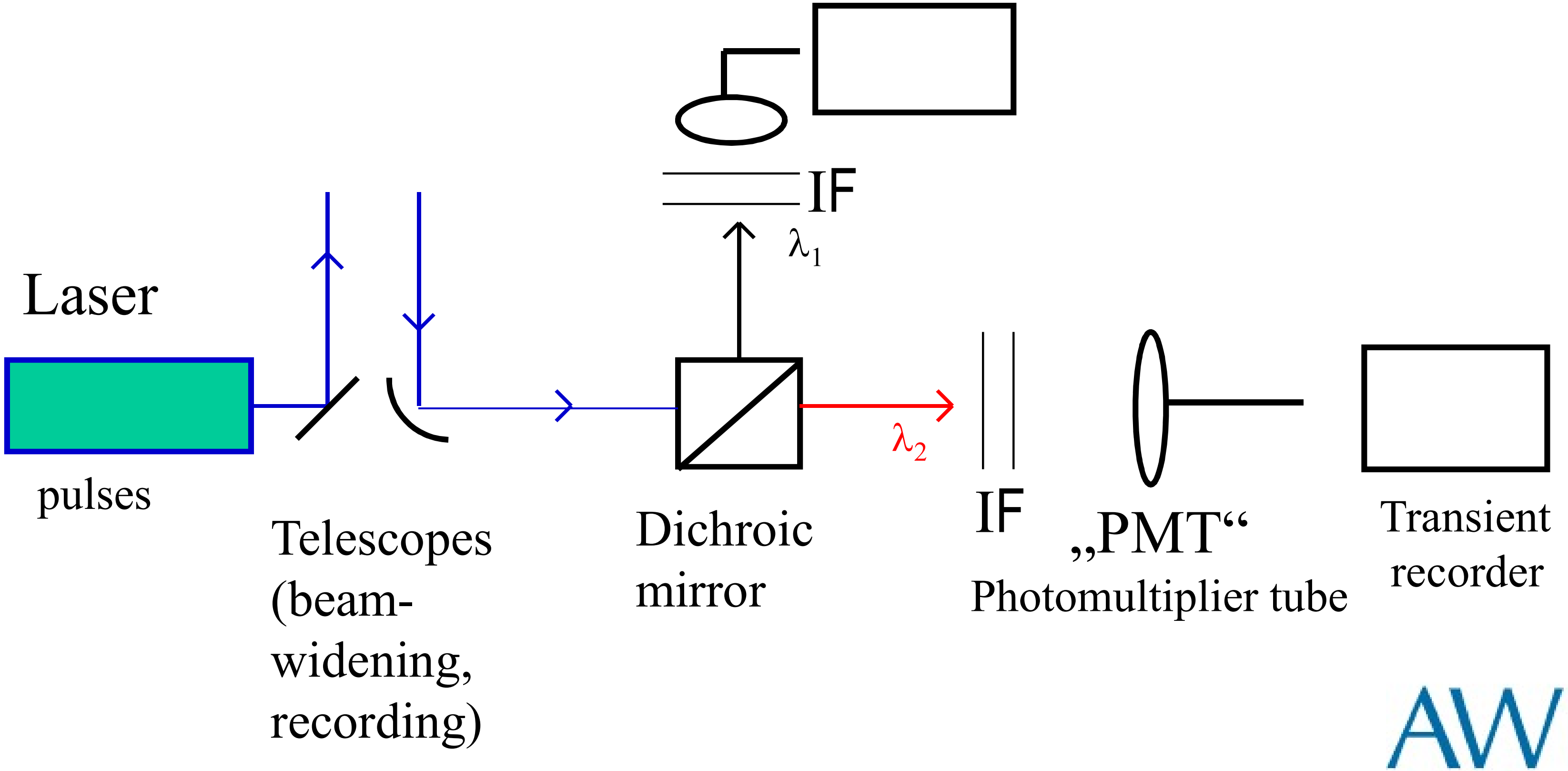


Polar amplification:
(from IPCC)
ΔT (2071 – 2100) – (1961 – 1990)
Reason: feedbacks (e.g. ice – albedo)

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



IF

λ_1

Laser

pulses

Telescopes (beam-widening, recording)

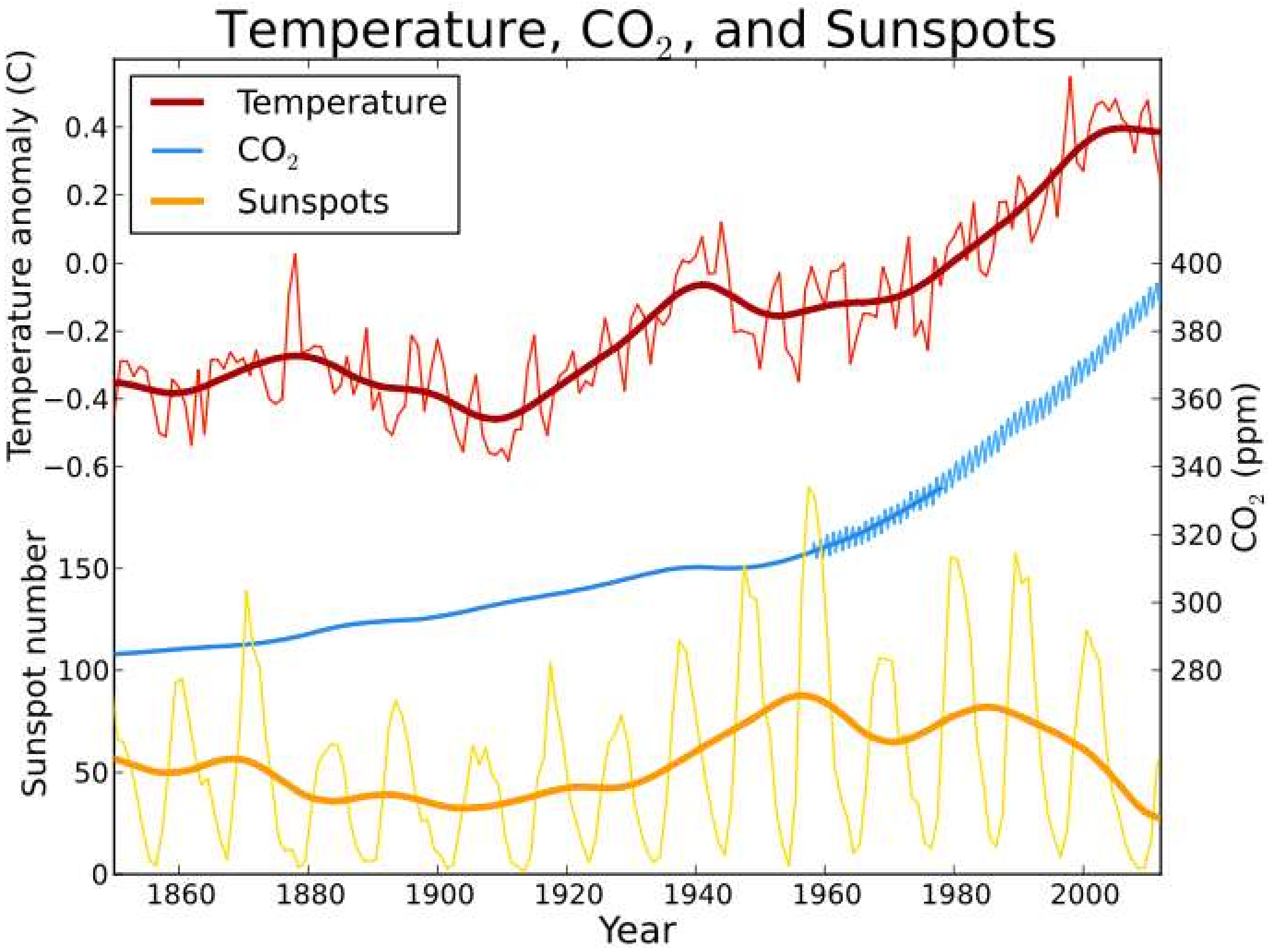
Dichroic mirror

λ_2

IF

„PMT“
Photomultiplier tube

Transient recorder


Temperature, CO_2, and Sunspots
Temperature
CO_2
Sunspots
Temperature anomaly (C)
0.4
0.2
0.0
−0.2
−0.4
−0.6
Sunspot number
150
100
50
0
400
380
360
340
320
300
280
CO_2 (ppm)
1860
1880
1900
1920
1940
1960
1980
2000
Year