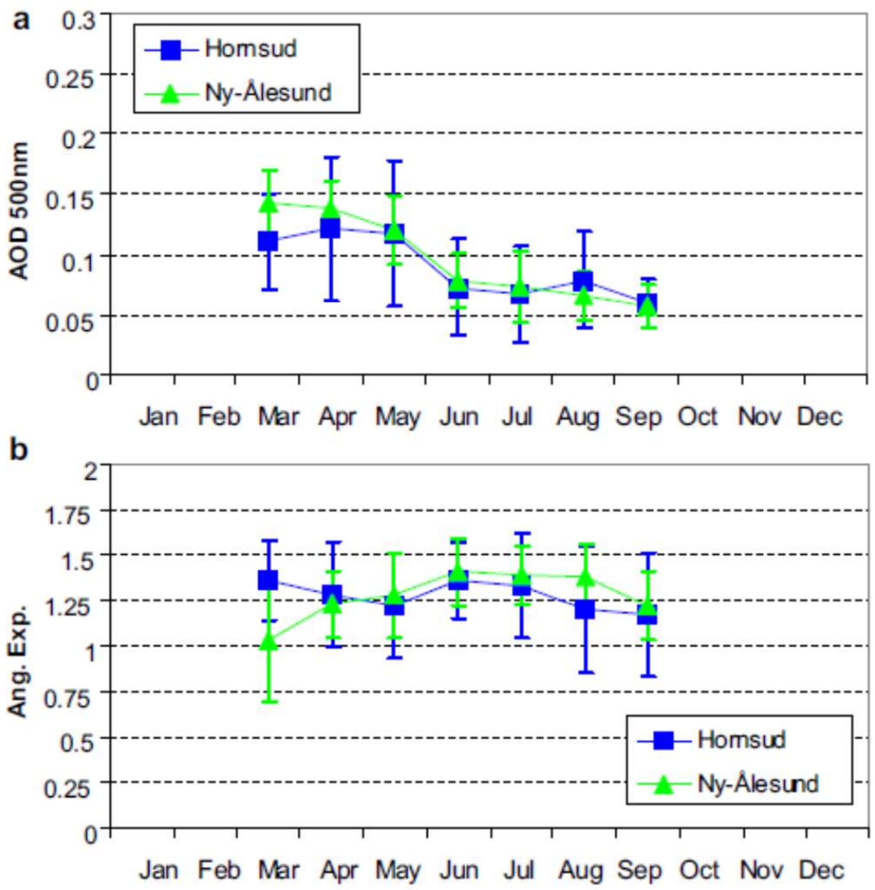
Photometer and lidar measurements in Spitsbergen

christoph.ritter@awi.de

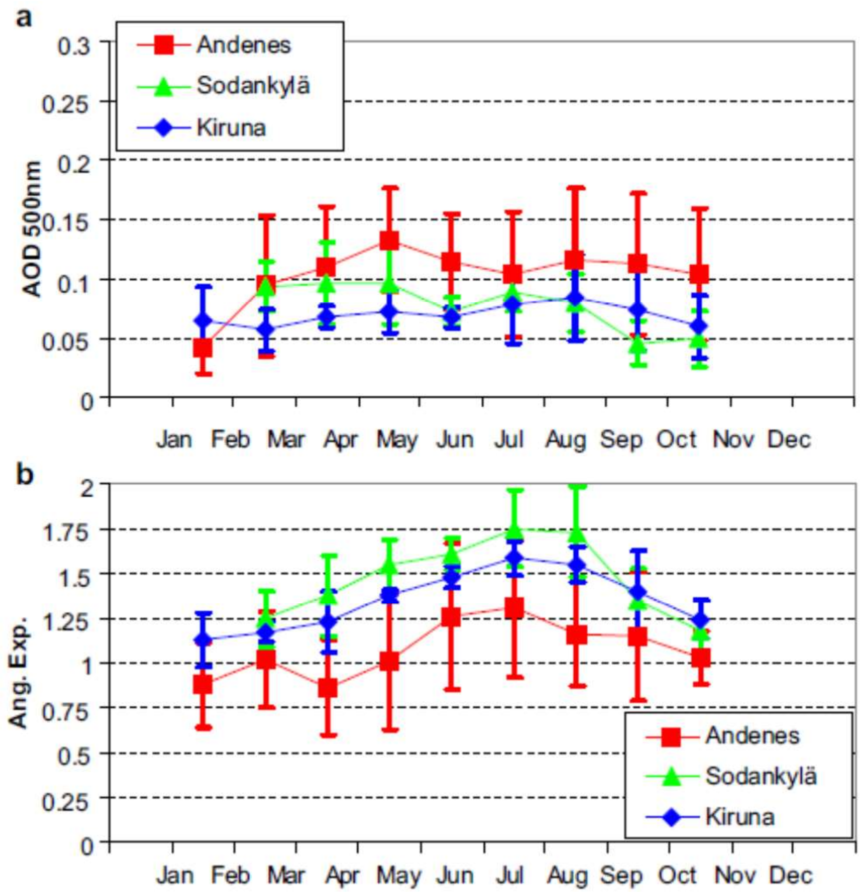
And:
Sandra Graßl, sandra.grassl@awi.de

Typical AOD values from Toledano 2012 Atmos. Environm.

Spitsbergen



Scandinavia

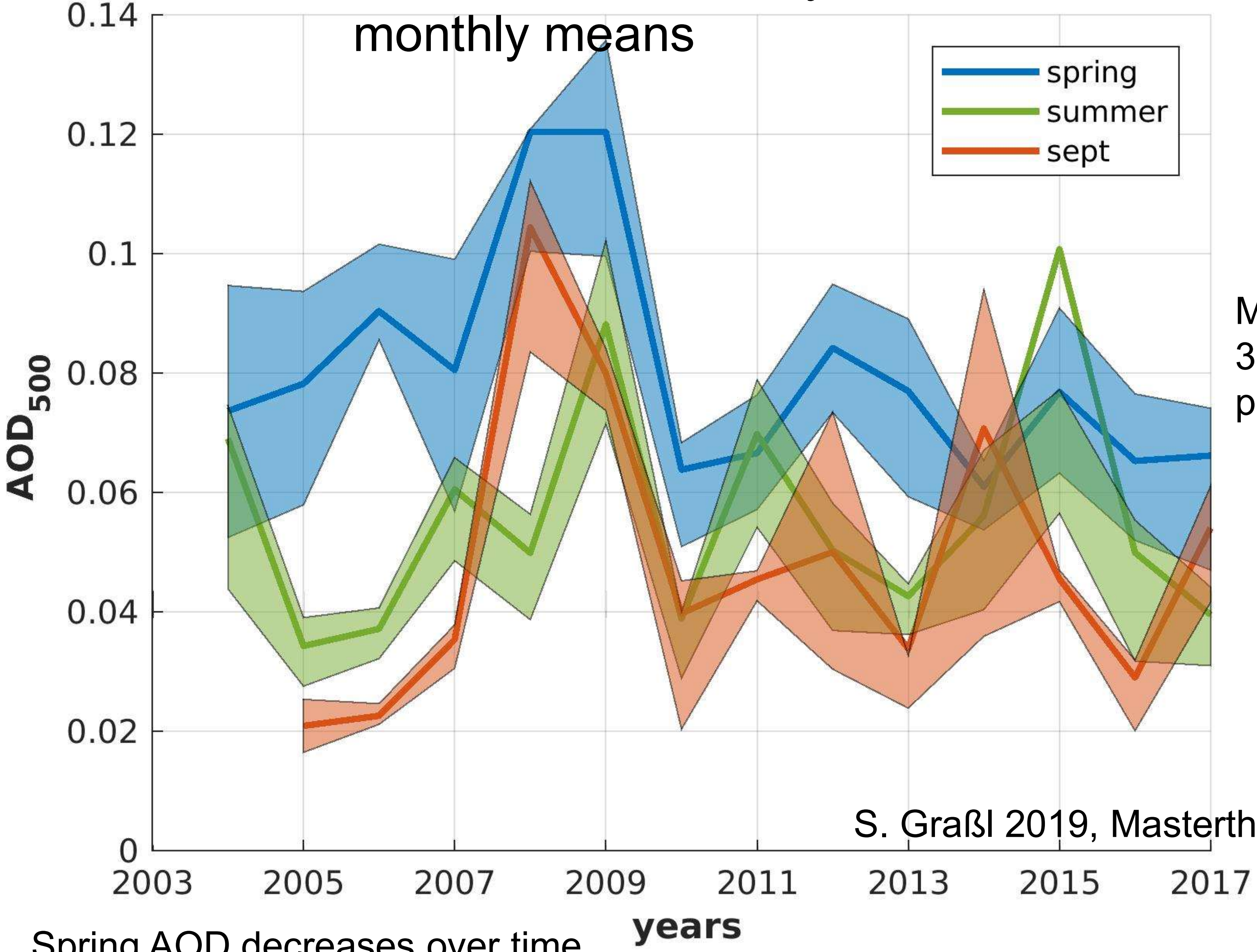


Spring: Arctic-AOD > N-European-AOD
No Haze in Scandianvia
No „easy" direct pollution transport from Europe

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

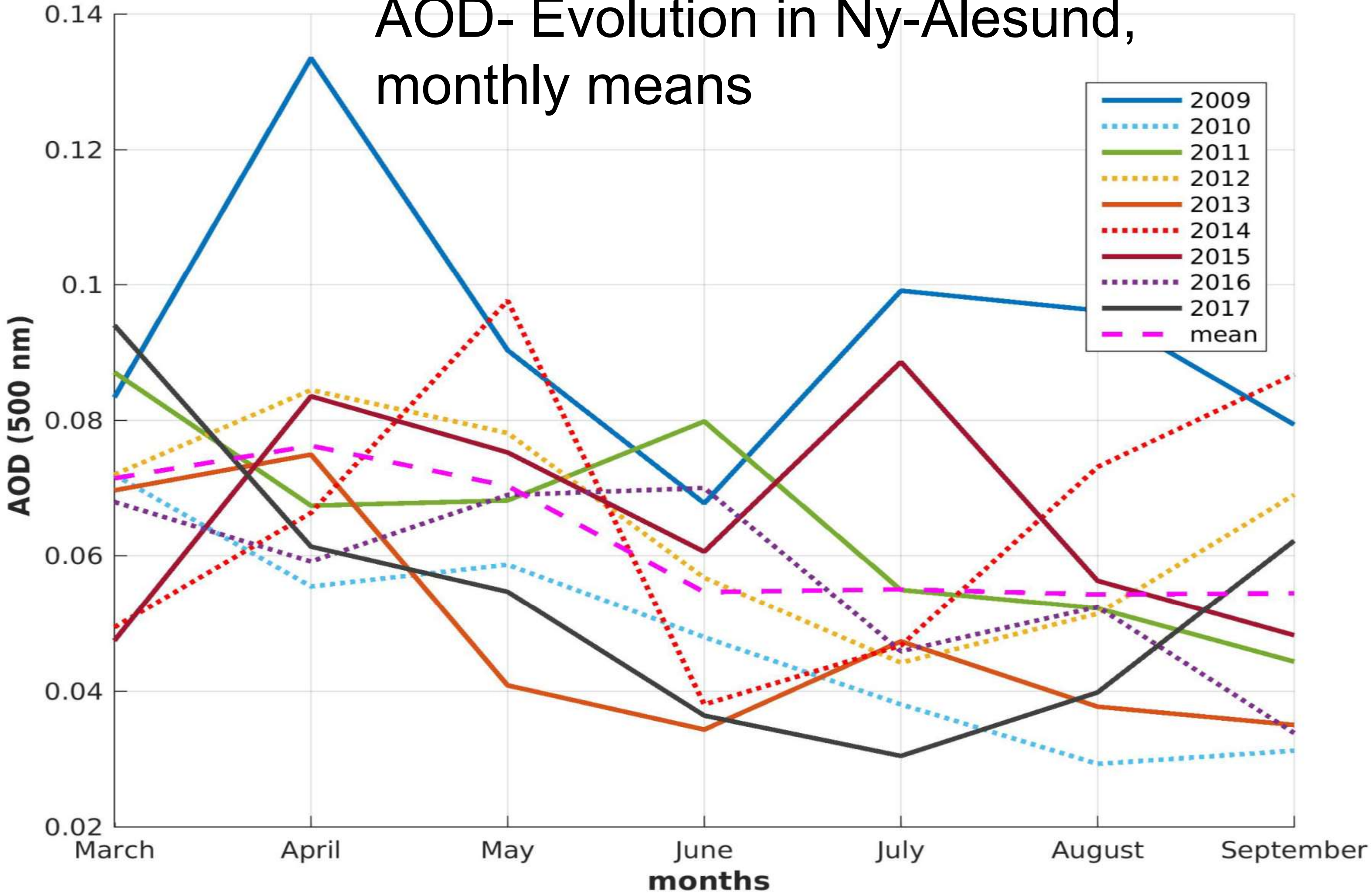


Median, 30% and 70% percentile

S. Graßl 2019, Masterthesis

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

AOD- Evolution in Ny-Ålesund, monthly means

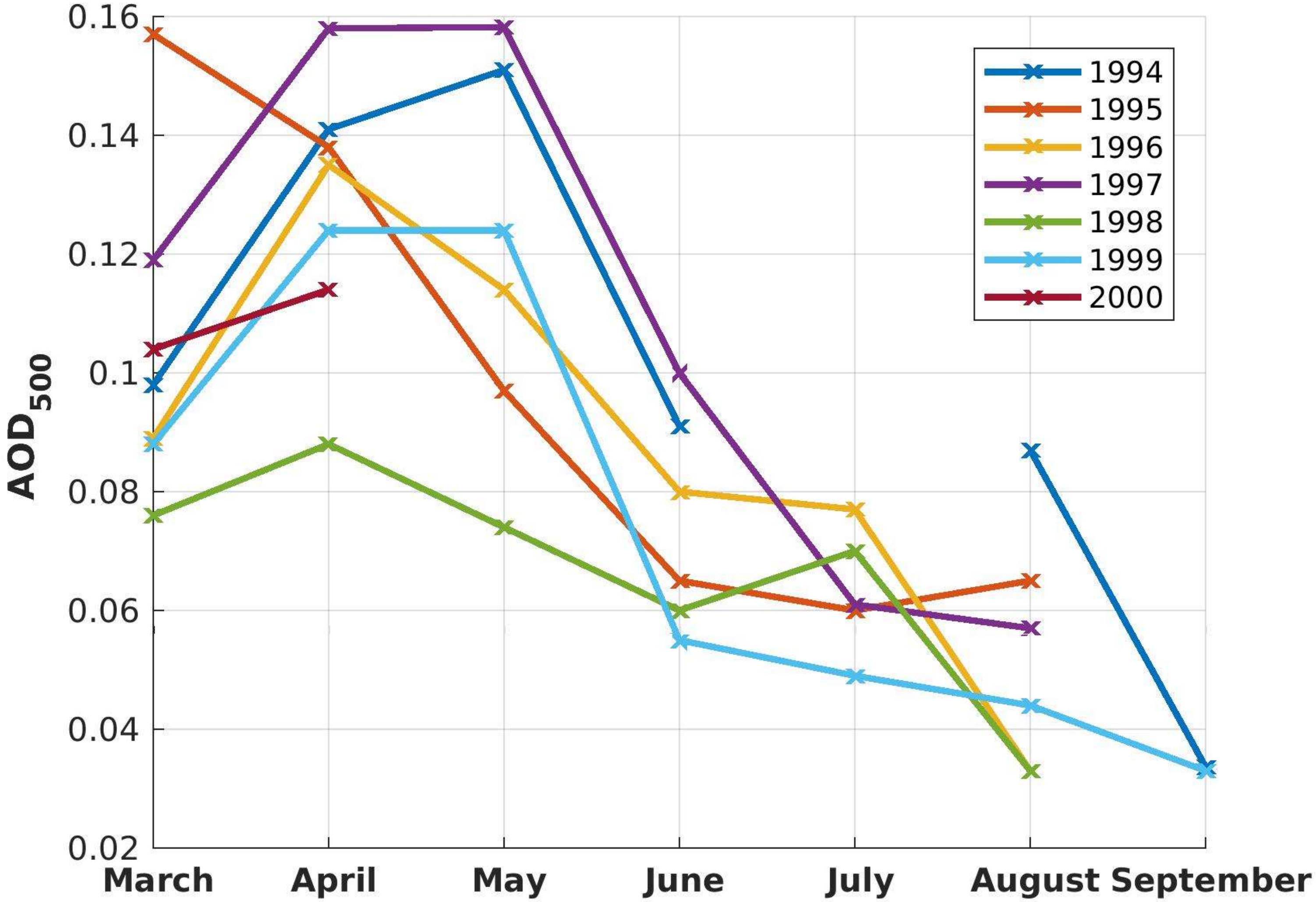


S. Graßl 2019, Masterthesis

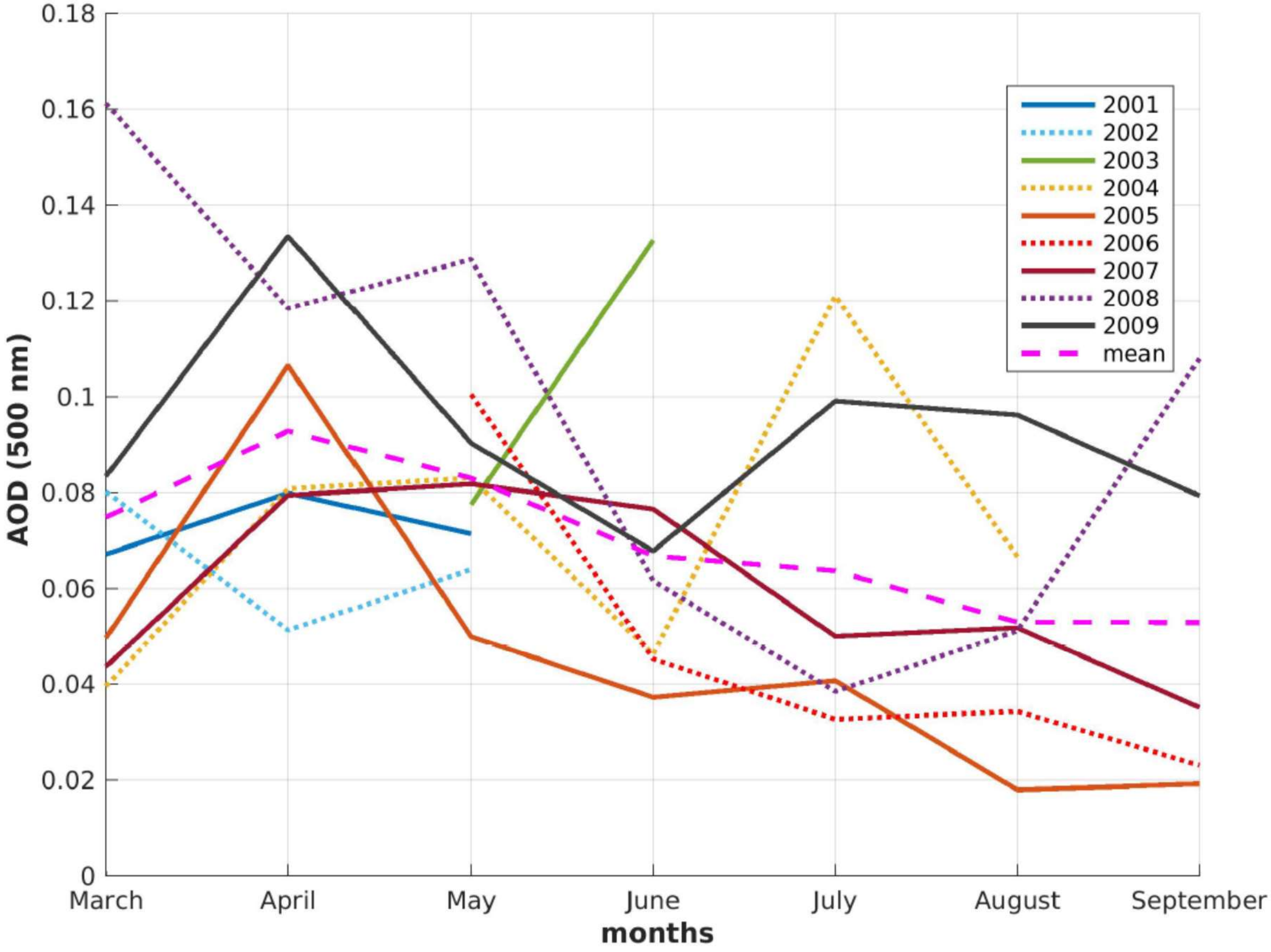
Spring AOD decreases over time
→ annual run of AOD becomes flatter
2009 was last polluted year
Generally high variability

Jul- Sep 2009: Mt Sarychev

Old date from Herber 2002:
More Haze and longer Haze periods, (still in May!)

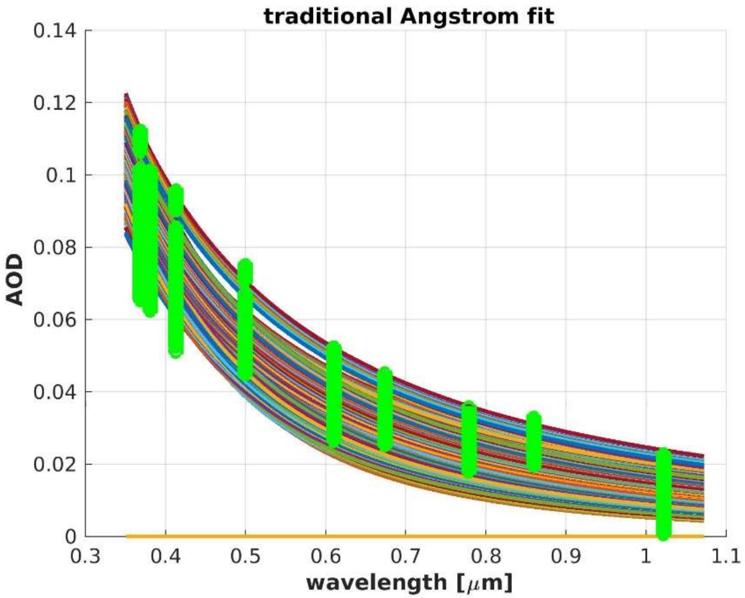


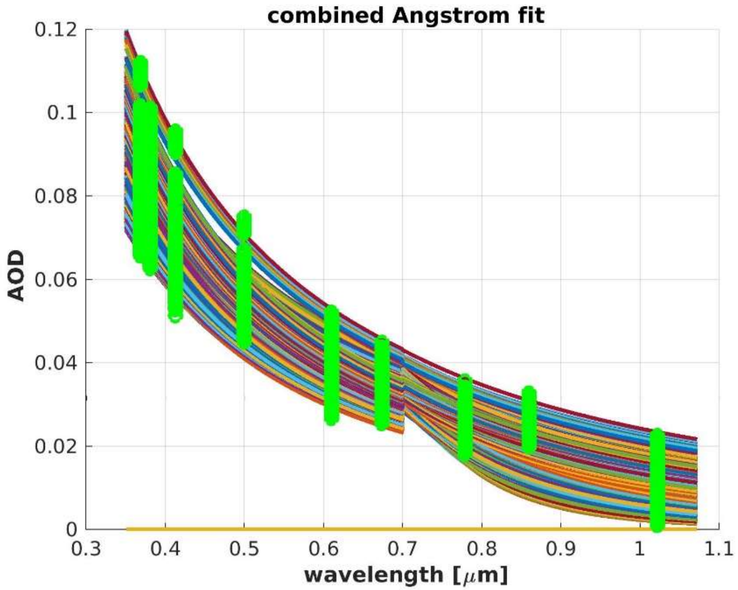
And the years in between, AOD is shrinking but with high variability



New approach of photometer evaluation:

1) Information content: (many data from 2013)





Traditional Angstroem exponent:

$$\tau = C\,\lambda^{a}$$

Same data set but separate fits for λ > or < 700nm

Angstroem exponent for data Ny-Alesund wavelength dependent

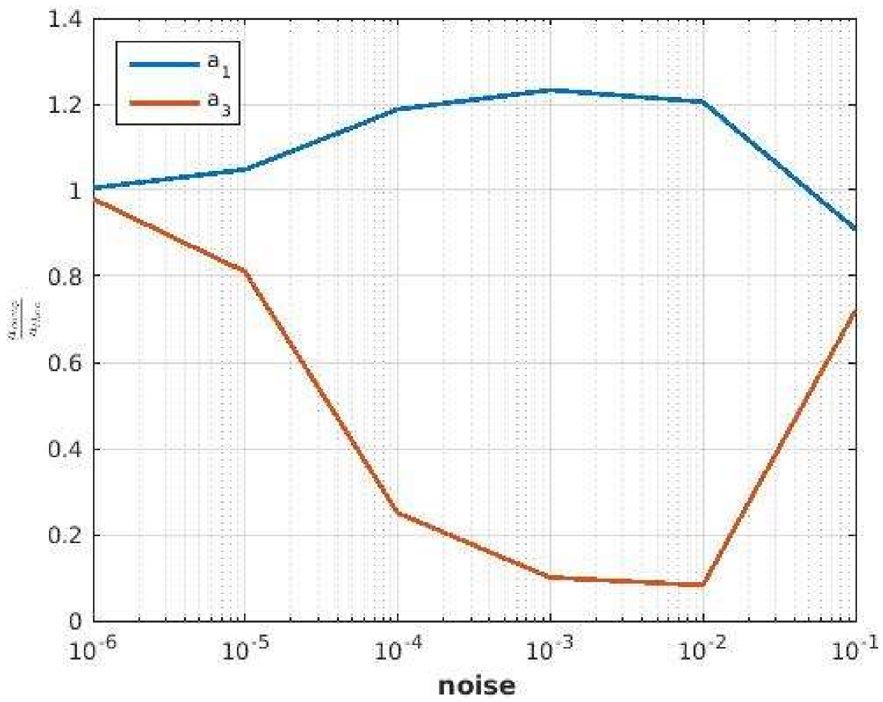
In an ideal world one could imagine:

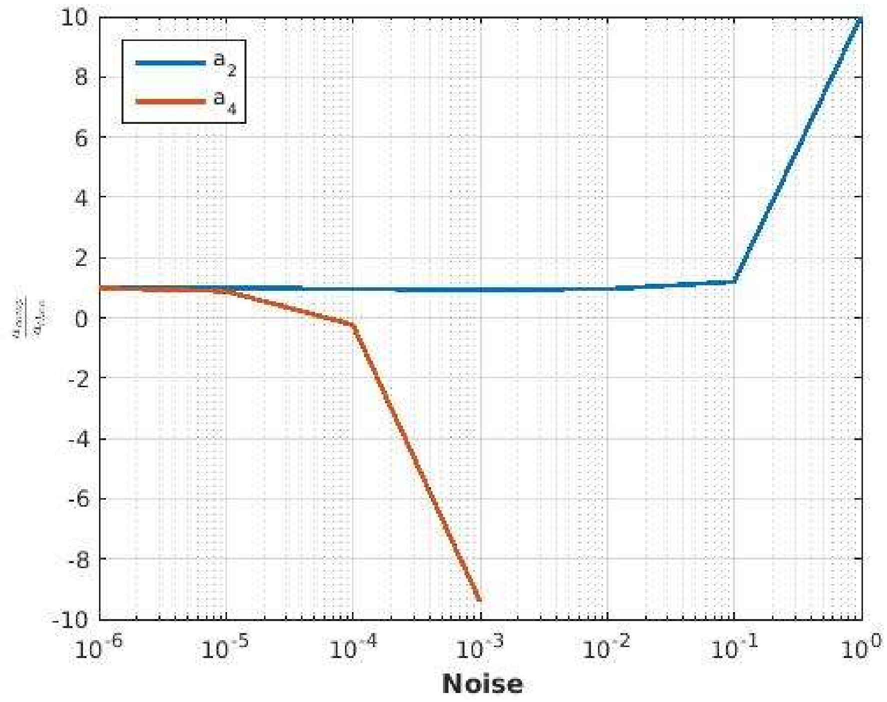
$$\tau = a_1 \lambda^{a_2} + a_3 \lambda^{a_4}$$

coarse - fine- mode

Method: invent a_1, a_2, a_3, a_4 $\Rightarrow$ τ_{theo} add noise

Use Levenberg-Marquardt to retrieve a1, a2, a3, a4 back





Hence: this approach will only work if $\Delta\tau/\tau = O(10^{-5})$

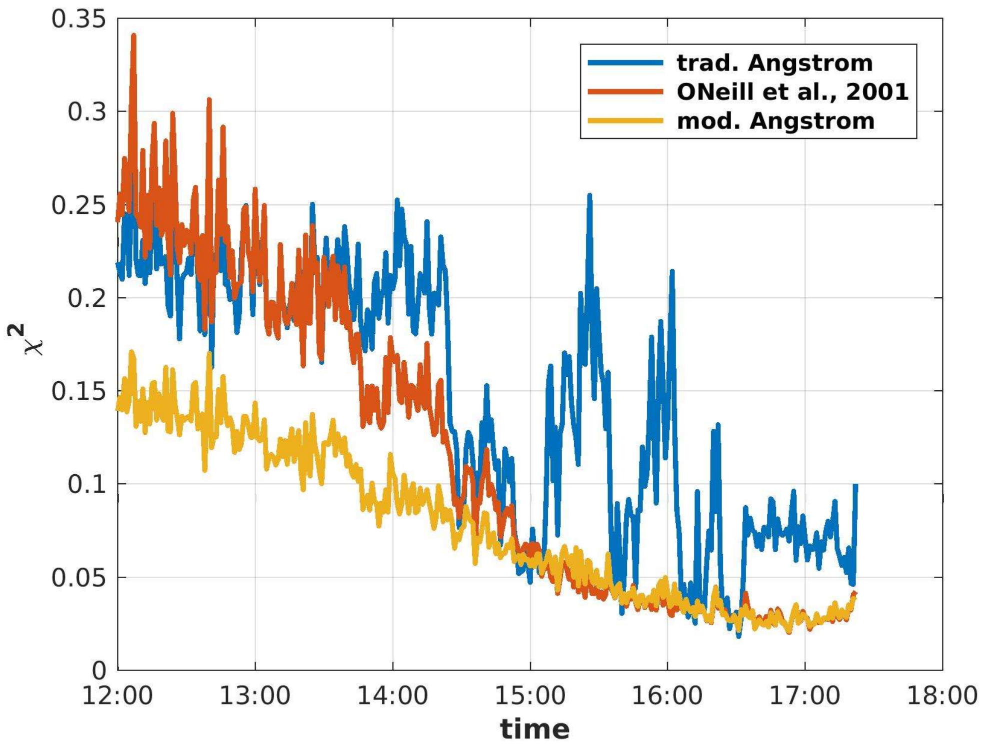
Hence we are looking for an easy approach which contains more information than the traditional Angstroem and chose:

$$\tau = C\,\lambda^{-\alpha + \beta \cdot \lambda}$$

α: „modified Angstroem" β: „spectral slope"

α: AE (λ) = 0 β: d/dλ (AE)

Again we use the LM to retrieve C, α, β from the measured τ(λ)
Fitting possible up to $O(10^{-1})$



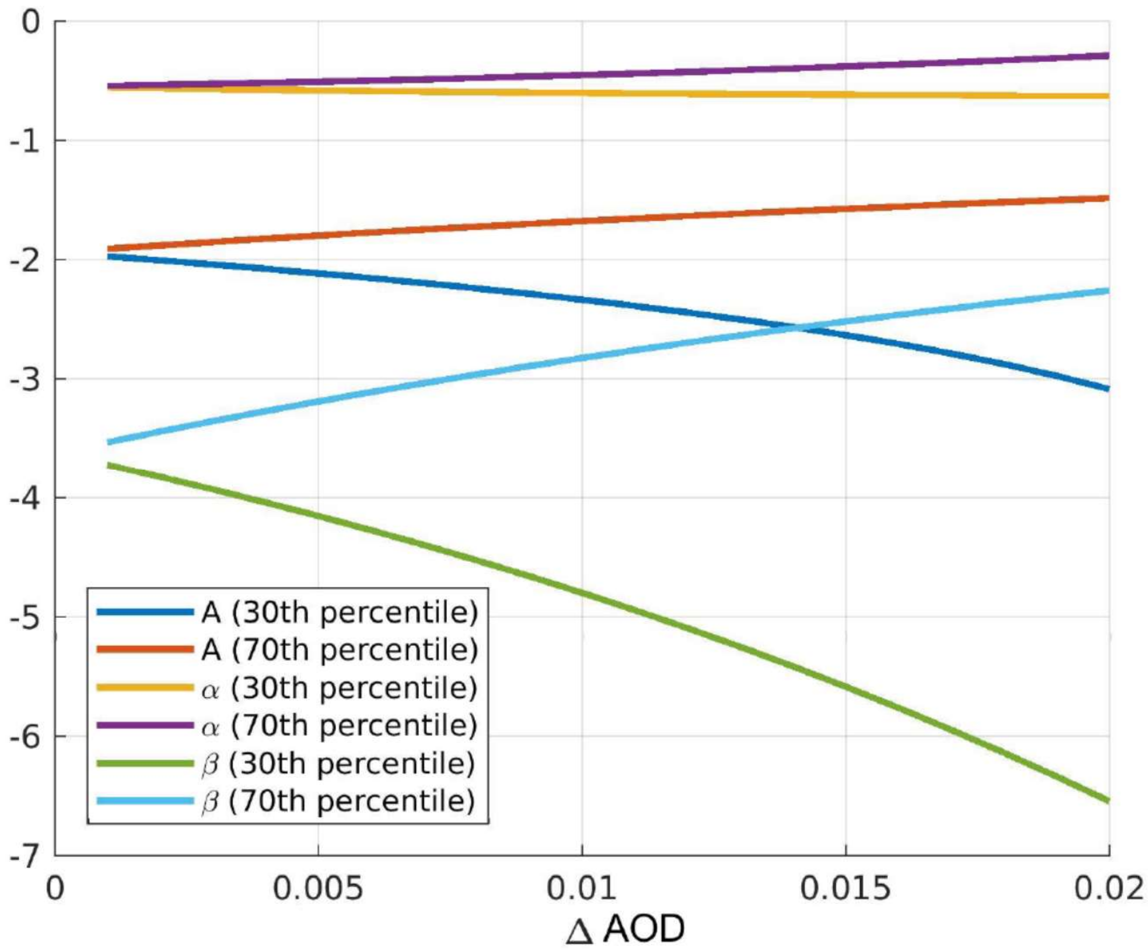
$$\tau = C\,\lambda^{-AE}$$

$$\log\tau = C + \log\lambda + (\log\lambda)^2$$

$$\tau = C\,\lambda^{-\alpha + \beta \cdot \lambda}$$

Information content of photometer data:

Approach:
1) Chose arbitrary τ(λ)
2) Add 100 noise realisations with given ΔAOD
3) Retrieve for each noise realisation A, α, β

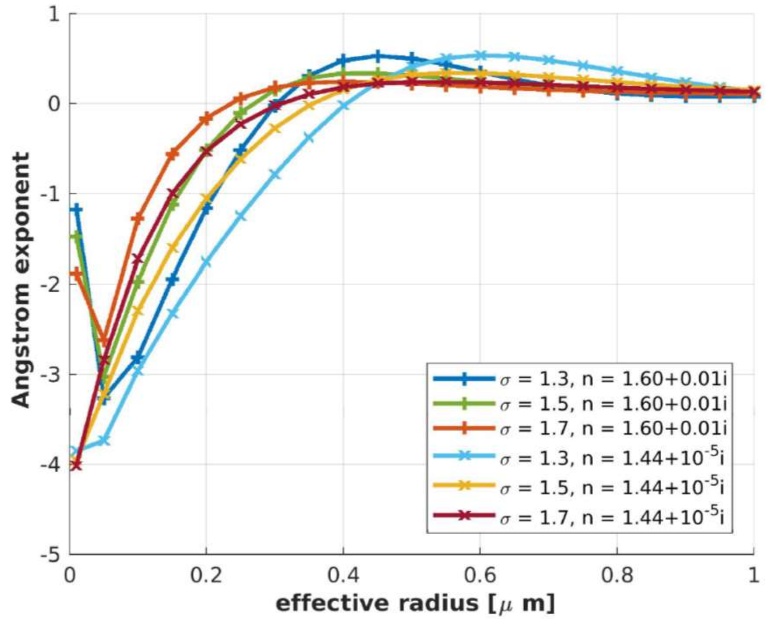


FWHM spread:
(for ΔAOD = 0.01)

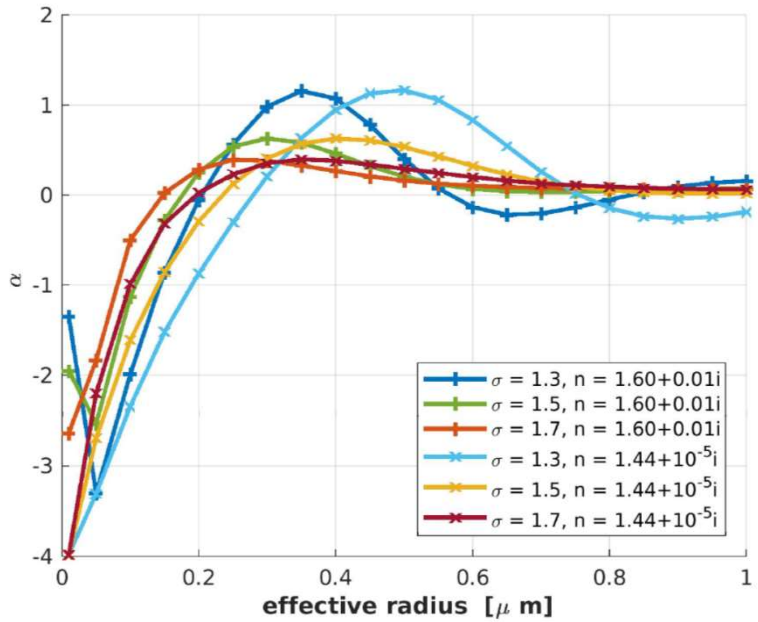
A= 0.14
α=0.66
β=1.96

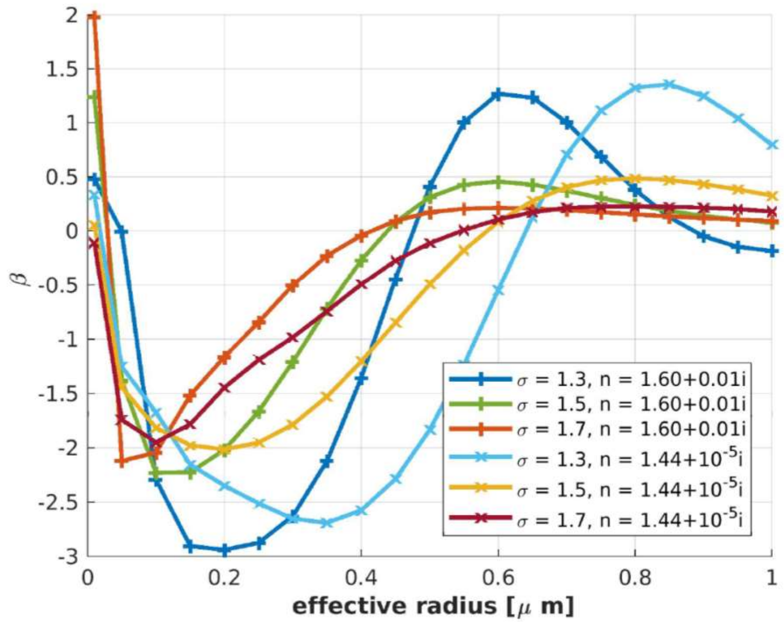
Information content behind photometer data:

Invent log-normal distributions (σ, n, r_eff)
Mie: ⟶ retrieve A, α, β



Above 0.4μm grey approximation approaches



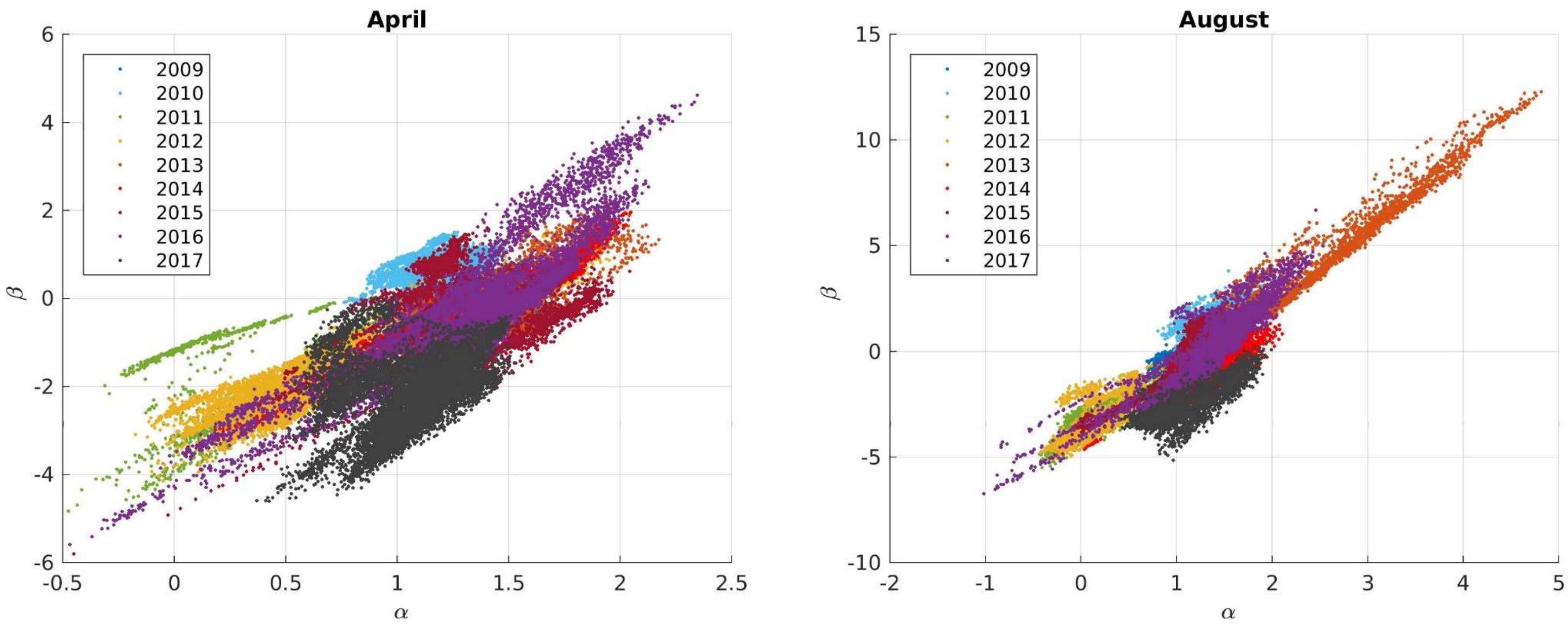


What do α and β tell us?

Both are intensive quantities, so they can be plotted against each other independent of aerosol concentration

Recall: $\tau = C\, \lambda^{-a+b\cdot\lambda}$ = C λ^{-Exp}

Hence: β< 0: AE stronger negative for IR (Expon. for IR closer to -4)
β = 0: traditional Angstroem law good
β > 0, requiers small α
Often Exponent smaller for IR than for UV



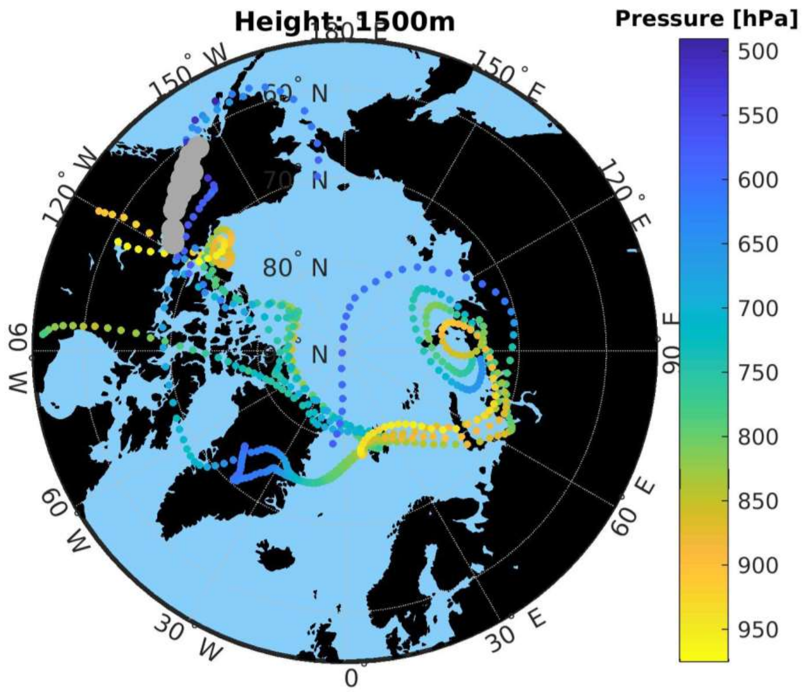
Non-uniqueness of size estimation from A, α, β

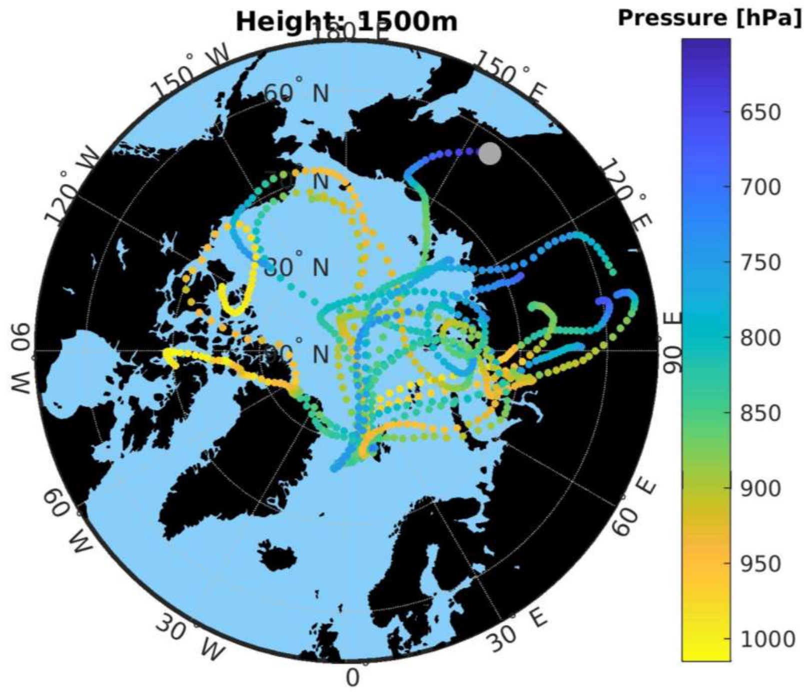
refractive index $n_1 = 1.60 + 0.01i$			
σ	A	α	β
1.3	$r_{eff,1} = 0.01\mu m$ $r_{eff,2} = 0.18\mu m$	$r_{eff} = 0.13\mu m$	$r_{eff,1} = 0.11\mu m$ $r_{eff,2} = 0.34\mu m$
1.5	$r_{eff} = 0.14\mu m$	$r_{eff} = 0.09\mu m$	$r_{eff,1} = 0.09\mu m$ $r_{eff,2} = 0.20\mu m$
1.7	$r_{eff} = 0.10\mu m$	$r_{eff} = 0.07\mu m$	$r_{eff,1} = 0.11\mu m$ $r_{eff,2} = 0.34\mu m$
refractive index $n_2 = 1.44 + 10^{-5}i$			
σ	A	α	β
1.3	$r_{eff} = 0.16\mu m$	$r_{eff} = 0.10\mu m$	$r_{eff,1} = 0.09\mu m$ $r_{eff,2} = 0.16\mu m$
1.5	$r_{eff} = 0.21\mu m$	$r_{eff} = 0.14\mu m$	$r_{eff,1} = 0.06\mu m$ $r_{eff,2} = 0.35\mu m$
1.7	$r_{eff} = 0.28\mu m$	$r_{eff} = 0.19\mu m$	$r_{eff,1} = 0.05\mu m$ $r_{eff,2} = 0.16\mu m$

Assuming A= -1, α=-1, β=-1.5 (typical for Ny-Ålesund) different solutions are possible

Open questions: Pollution pathways

Graßl, 2019: Flextra with ERA-interim

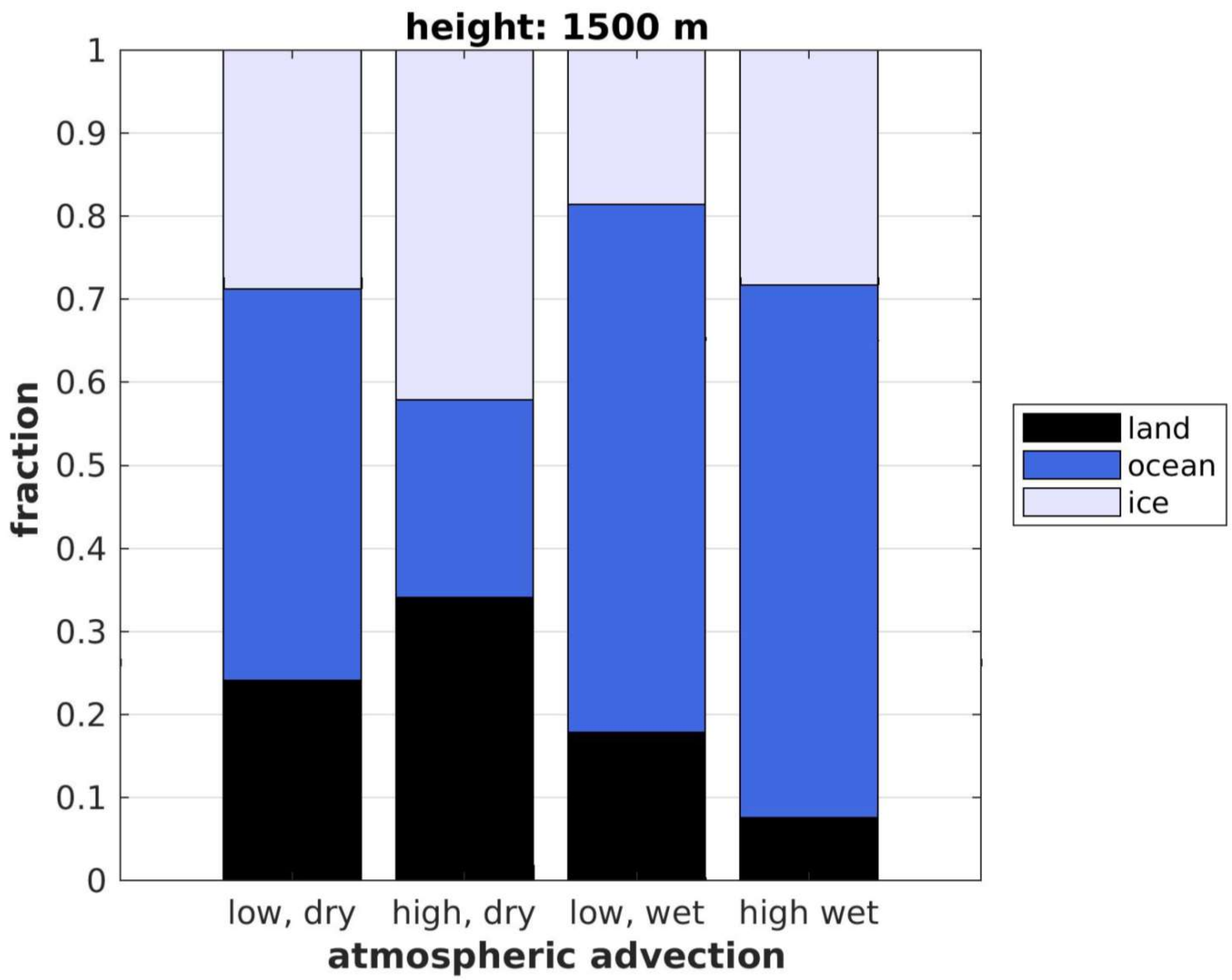




Low AOD (April 2013) high AOD

5 days trajectories too short
Reanalysis products show large differences
Slightly higher AOD from Siberia

Sea ice as reduced sinks?



FLEXTRA 5 days (with photometer) Aprils 2013-2016

High aerosol load due to sources <u>and</u> sinks

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

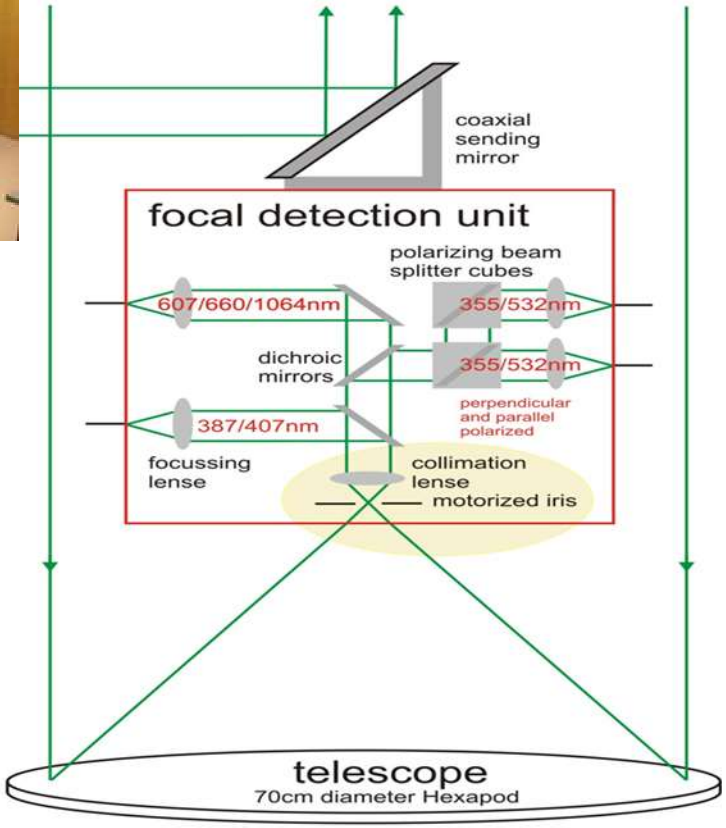
Best conditions for aerosol transport:
Air over source regions in BL with enough wind speed
Ascend of the air (higher wind speed, 5 days, less precipítation)
Advection over sea ice

MOSAiC: coordinated observations with surrounding stations needed

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



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]

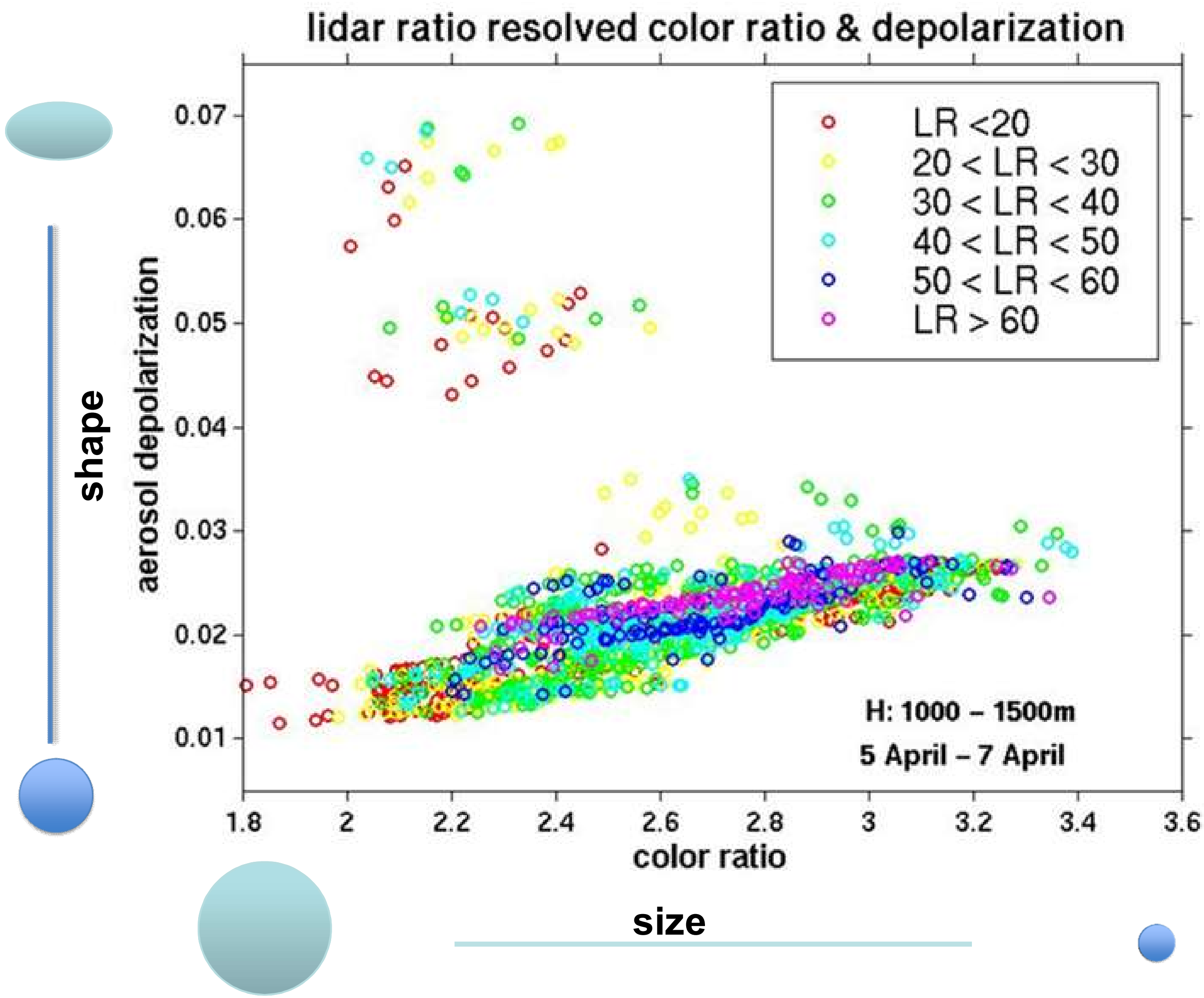
colour ratio CR = $\frac{\beta_{\lambda 1}}{\beta_{\lambda 2}}$ (size) [$\beta \sim \lambda^{Å}$ $-4 < Å < 0$]

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!

Mixing state of aerosol:



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

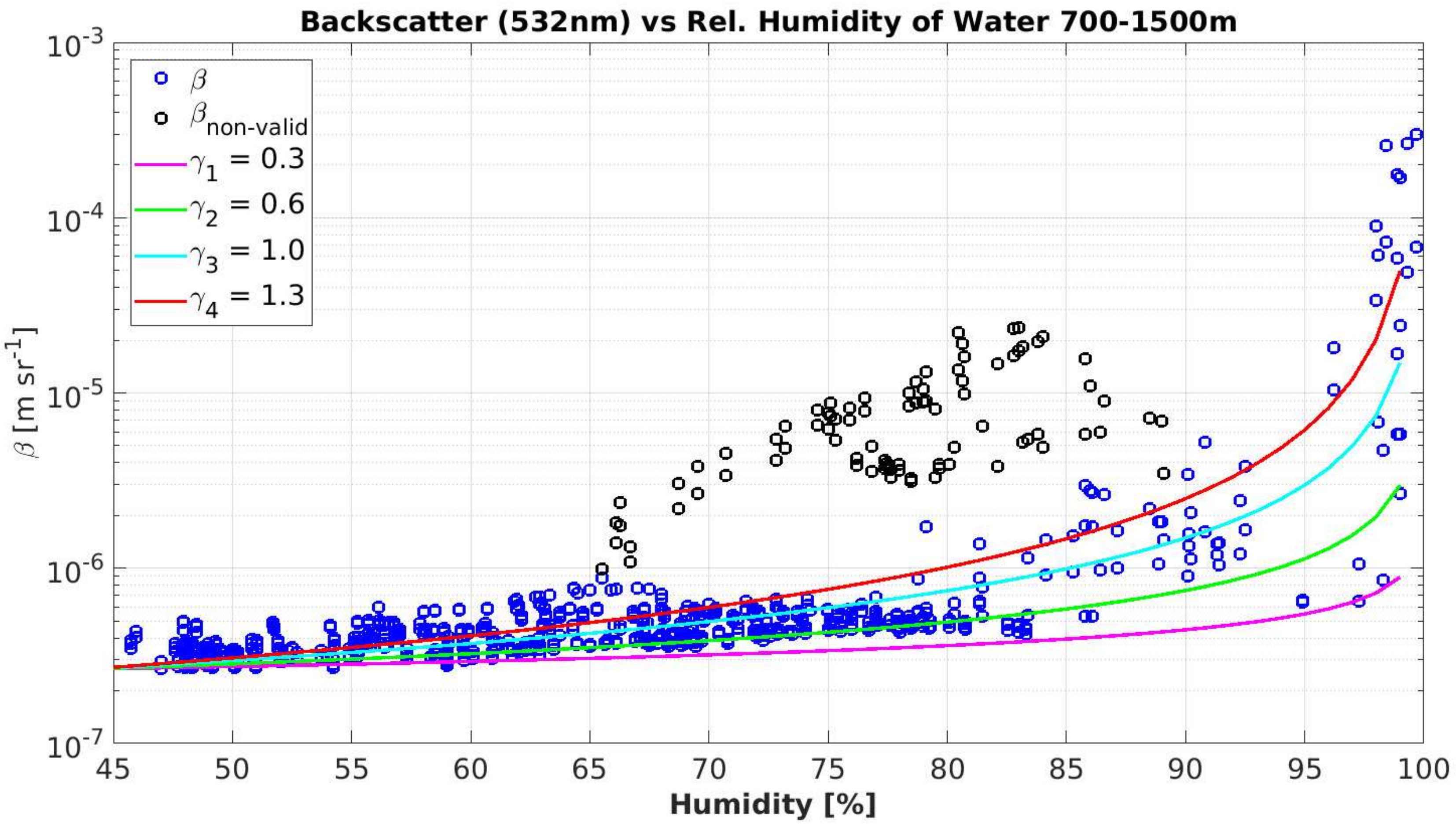
Chemistry unrelated to size and shape

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

Color ratio, depol. ratio both intensive quantities

Lidar and contemporary radiosonde: hygroscopic growth?

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



A theory is short, concise and complete and is believed by nobody except of its inventor.

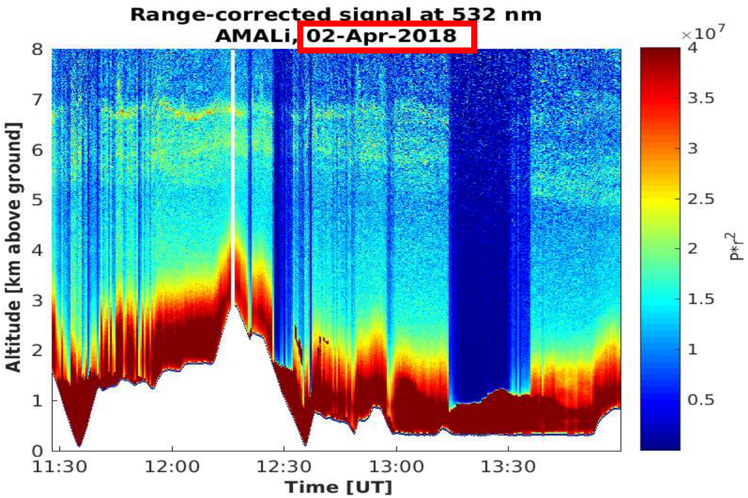
Observational data are noisy, strange and incomplete and are believed by everybody except of the one who measured them.

Picture:
Loriot 1923 - 2011

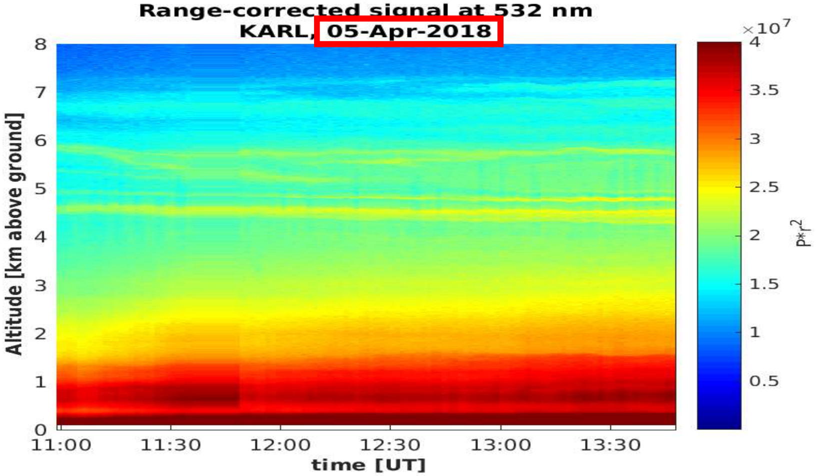
Thank you for your attention!

AC3 and PAMARCMiP 2018:

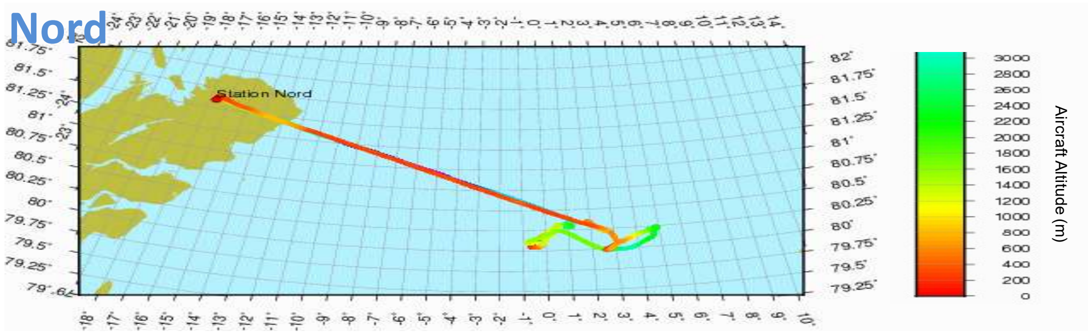
Persistent layer of aerosol in 5-7km



Ny-Ålesund, Spitsbergen



Polar5 flight-track towards Station Nord



Compare remote sensing to in-situ

Calculate radiative forcing

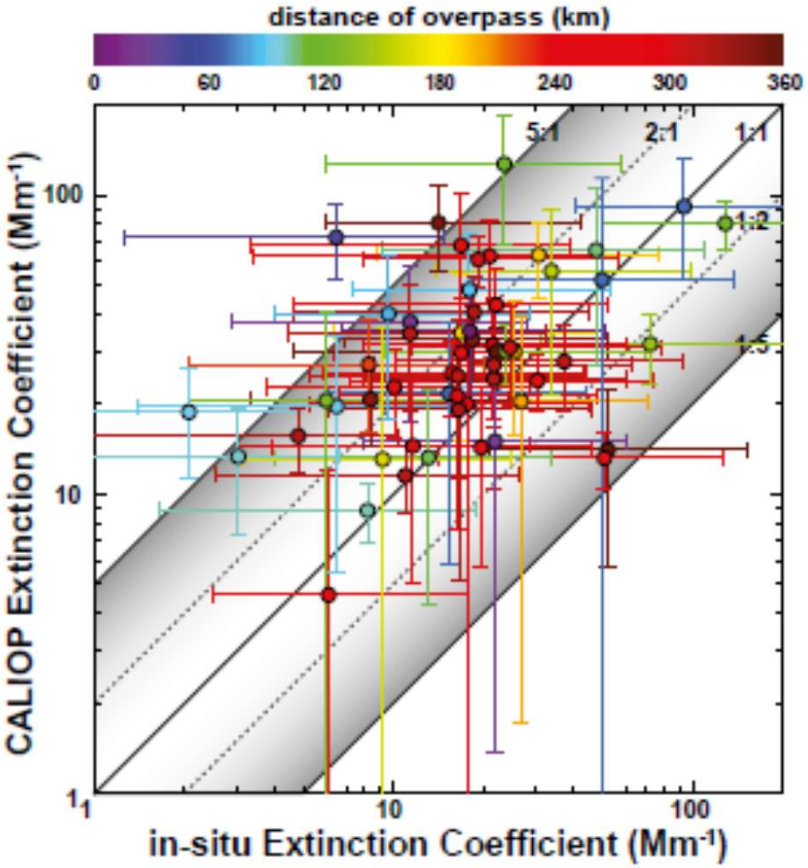
Open questions:
2. Does remote sensing overestimates extinction?

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!