Aerosol optical properties: from ground-based measurements to LIDAR measurements

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Topic

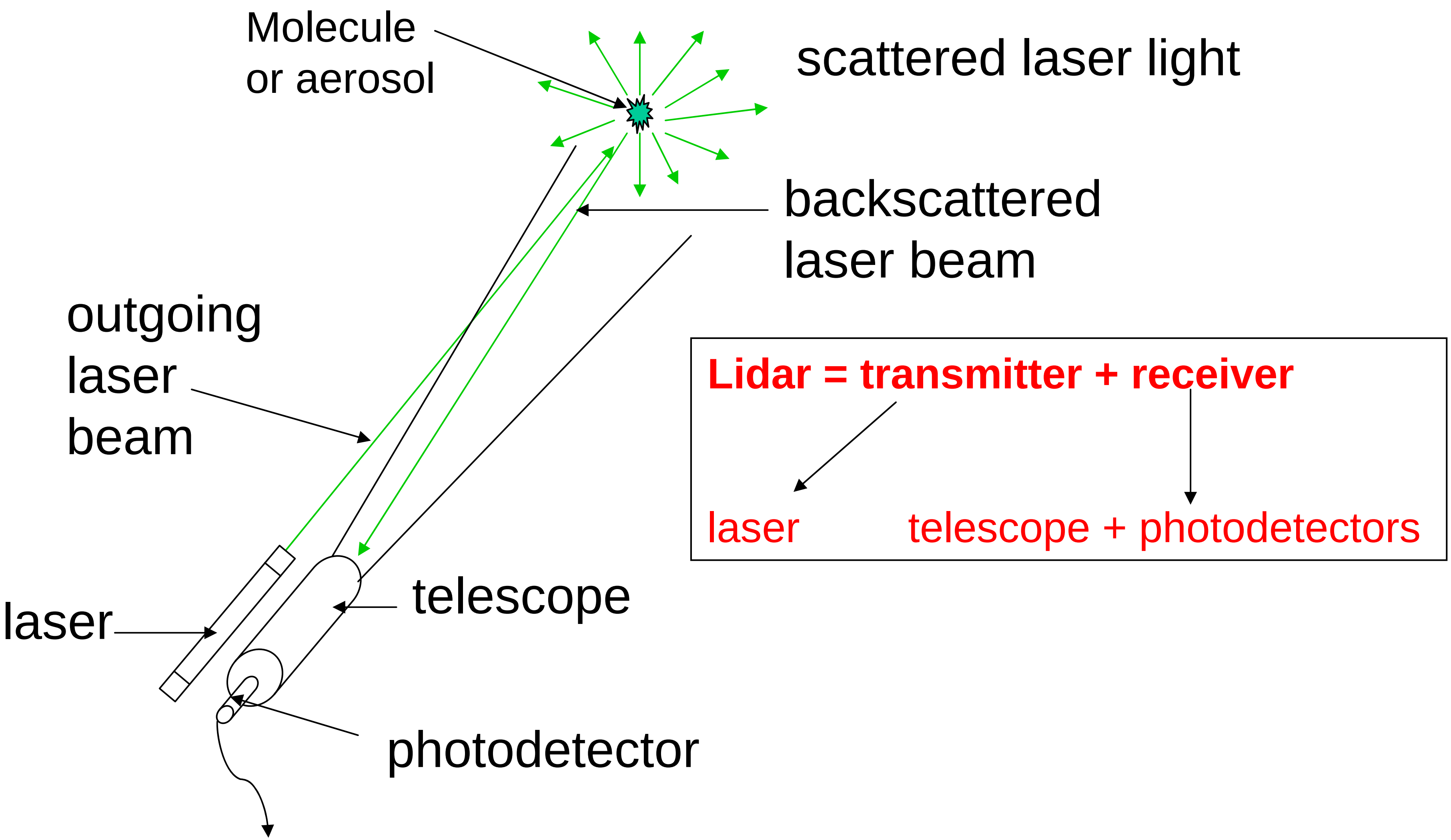
1) Aerosol optical properties as retrieved from LIDAR measurements, using two different methods

- Vertical measurements (Raman method)
- Scanning measurements (multi-angles method)

2) Aerosol hygroscopicity at Ispra EMEP-GAW station

- Aerosol hygroscopic growth
- Aerosol enhancement factors

LIDAR = Light Detection And Ranging



Scanning multi-wavelength lidar
USDA and JHU lidars

Multi-wavelength Raman lidar
Meteorological Institute, University of Munich

Aerosol optical properties – LIDAR - overview

EARLINET

27 stations

- 6 backscatter lidar stations
- 13 Raman lidar stations
- 8 multi-wavelength Raman lidar stations

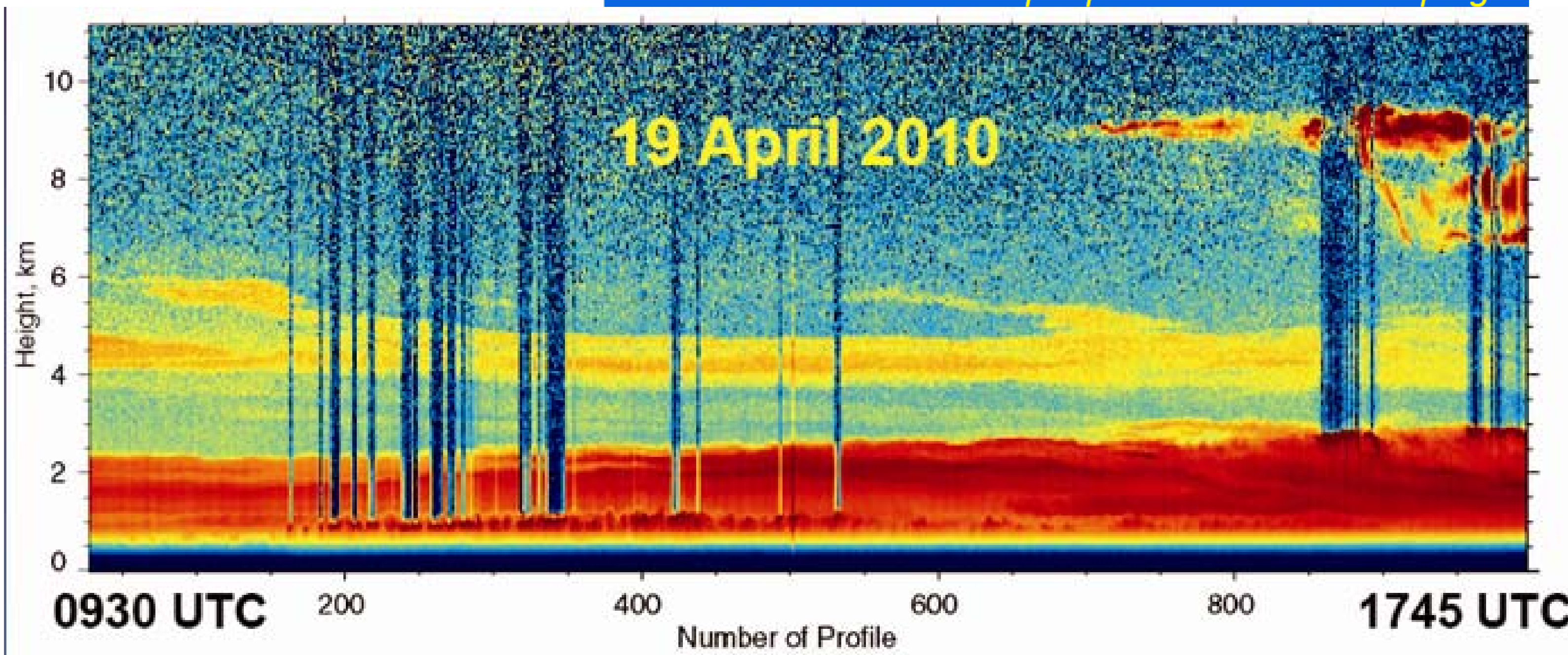
European Aerosol Research LIdar NETwork

EARLINET paper to be submitted:
“EARLINET observations of the Eyjafjallajökull volcanic cloud over Europe”

Lidar profiling of ash and sulfate particle mass over central Europe after the eruption of the Eyjafjallajökull volcano

Albert Ansmann and Matthias Tesche et al.

Leibniz Institute for Tropospheric Research Leipzig



"Vertical versus scanning lidar measurements in horizontal homogeneous atmosphere", M. Adam, submitted to Applied Optics

Goal: compare the aerosol backscatter and extinction coefficients as retrieved from vertical elastic and Raman channels with those derived from multi-angle measurements acquired by elastic channels.

Vertical measurements	Multi-angle measurements
- Elastic (355nm and 532nm) and Raman (387nm and 607nm)	-Elastic (355nm and 532nm) -15 elevation angles

Methods compared:

Backscatter coefficient β_p: far-end, aerosol backscatter ratio and multi-angles

Extinction coefficient κ_p: Raman and multi-angles

LIDAR equations

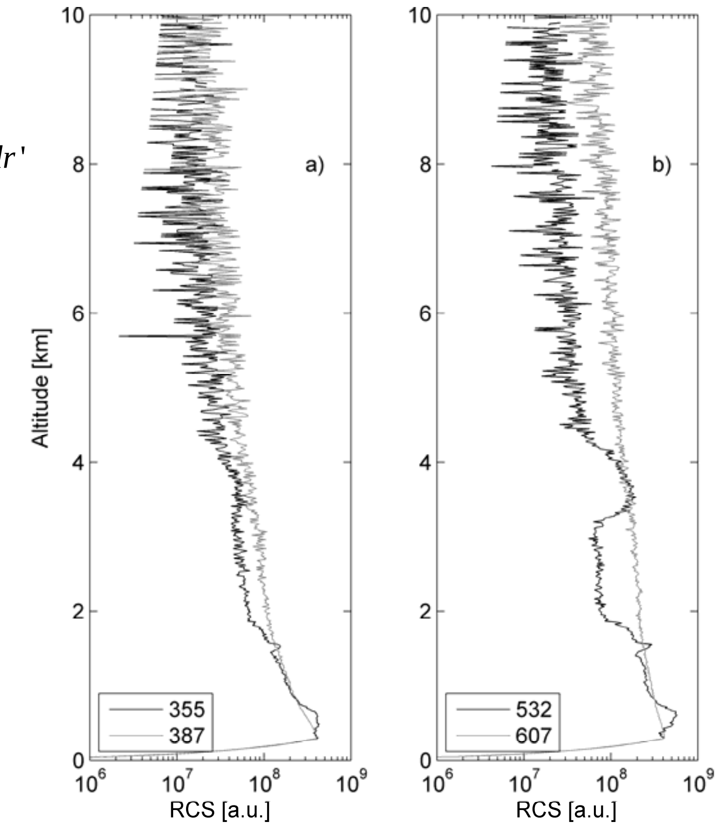
Elastic backscatter

$$P(\lambda_L, r) = \frac{C_L}{r^2}\left[\beta_m(\lambda_L, r) + \beta_p(\lambda_L, r)\right] e^{-2\int_0^r \left[\kappa_m(\lambda_L, r') + \kappa_p(\lambda_L, r')\right] dr'}$$

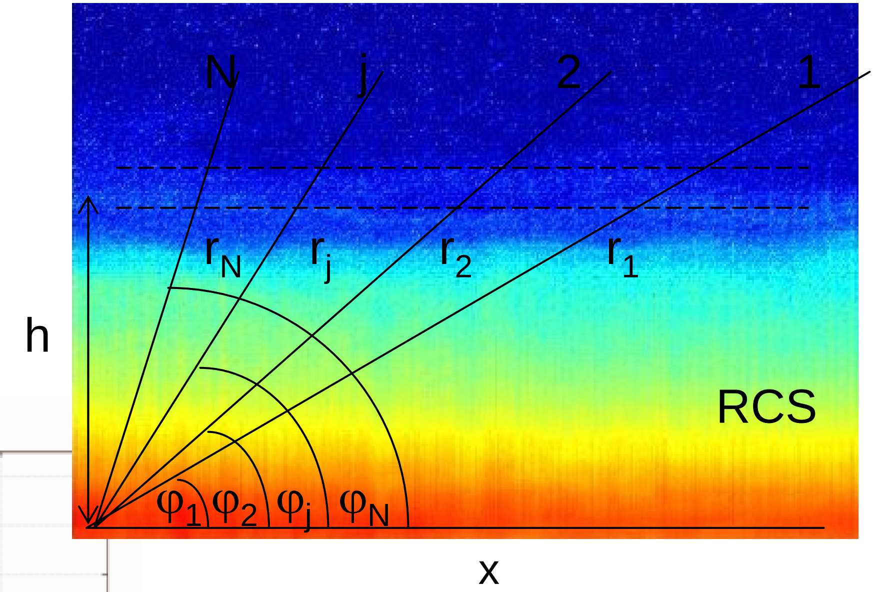
RCS=P(λ,r)r²

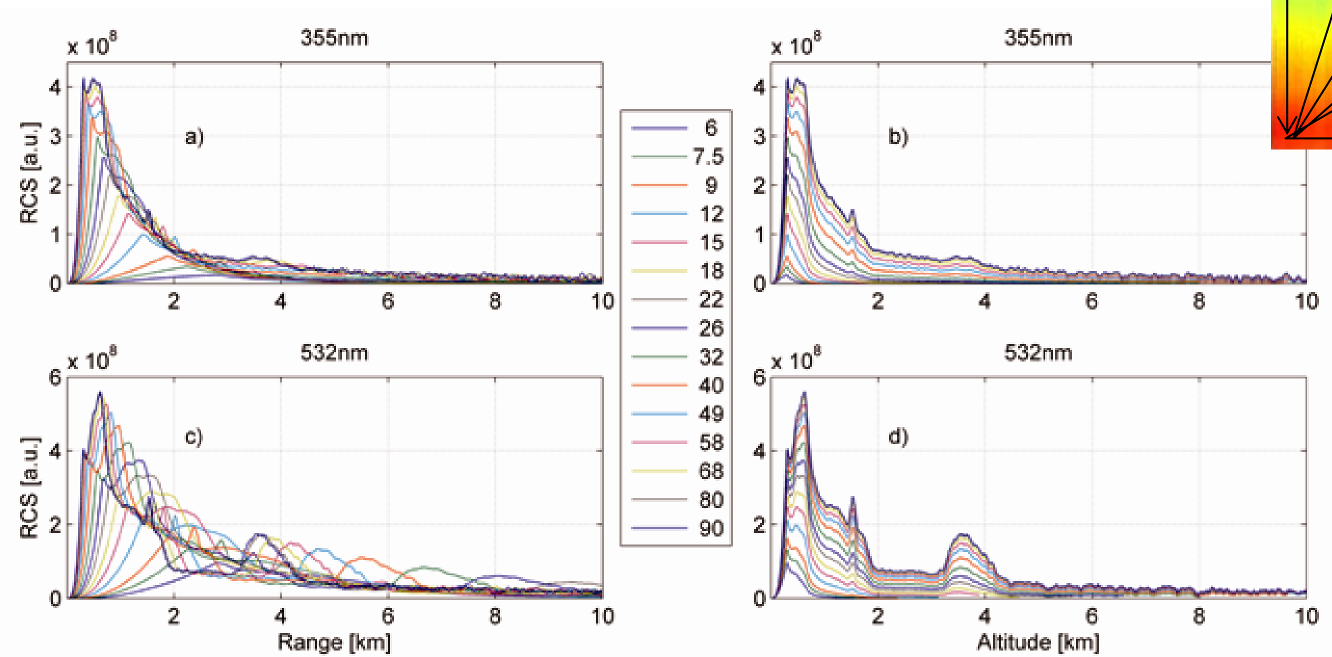
Raman backscatter

$$P(\lambda_R, r) = \frac{C_R}{r^2}\left[\beta_m(\lambda_R, r)\right] e^{-\int_0^r \left[\kappa_m(\lambda_L, r') + \kappa_p(\lambda_L, r') + \kappa_m(\lambda_R, r') + \kappa_p(\lambda_R, r')\right] dr'}$$



Multi-angle measurements





RCS at 15 elevation angles, as a function of range (a-c) and height (b-d) for 355 nm (a-b) and 532 nm (c-d).

Recall lidar equation: $P(r)r^2 = C\beta_t(r)e^{-2\tau(0,r)}$

Multi-angles method

$$y_i(h) = \ln\left[P_i(h)\left(h/\sin\phi_i\right)^2\right] = \ln\left[C\beta_{t,i}(h)\right] - 2\tau_{t,i}(0,h)x_i$$

$x_i=1/\sin(\phi_i)$

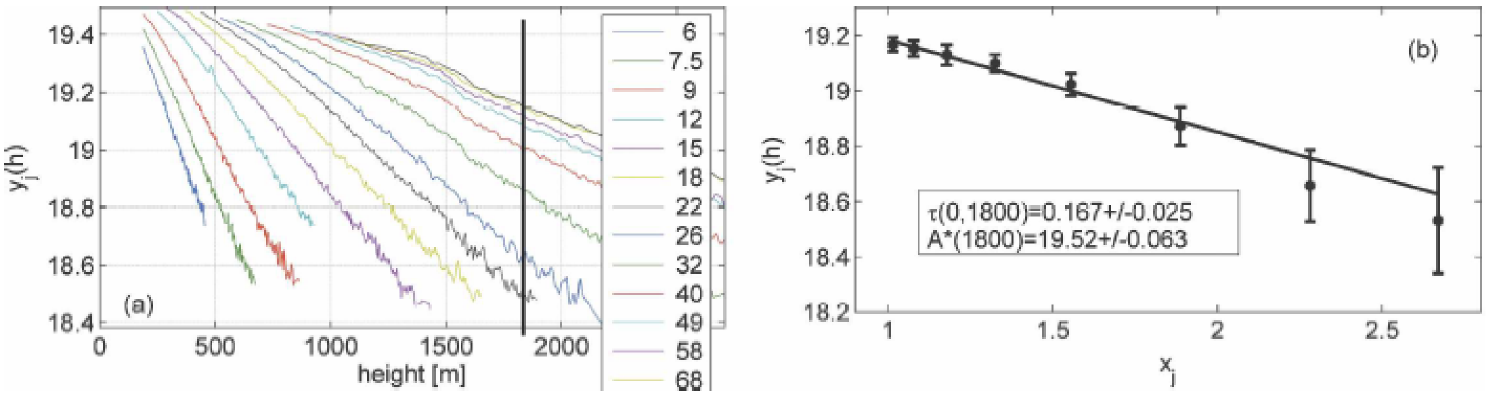
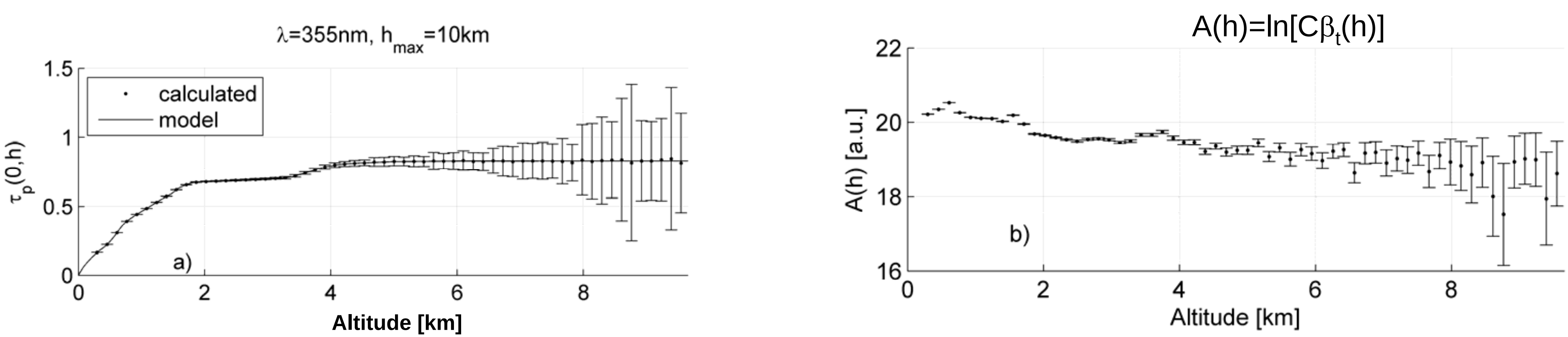


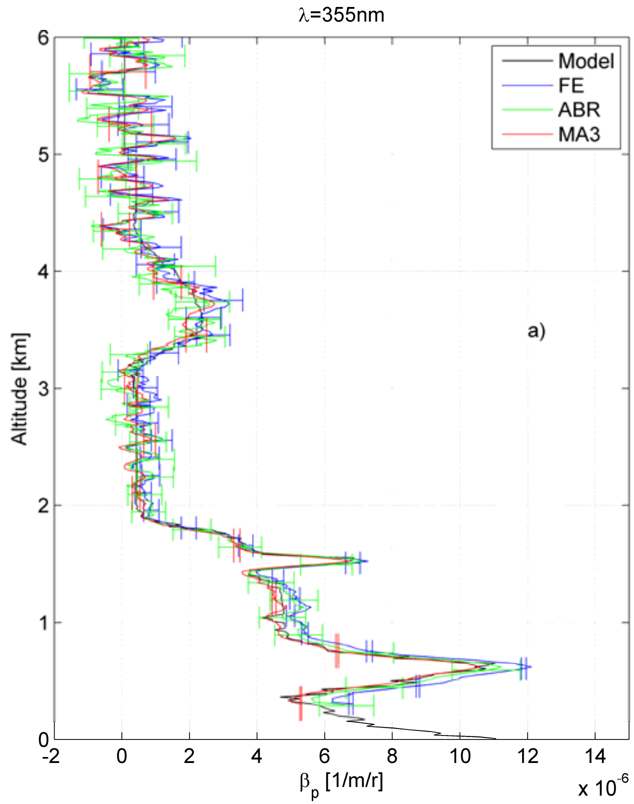
FIG. 4. Example of linear regression to determine $\tau(0, h)$ and $A^*(h)$ for a particular height. (a) In this example, the regression is determined for h = 1800 m. (b) Values of $y_j(h$ = 1800 m) are plotted with respect to x_j.

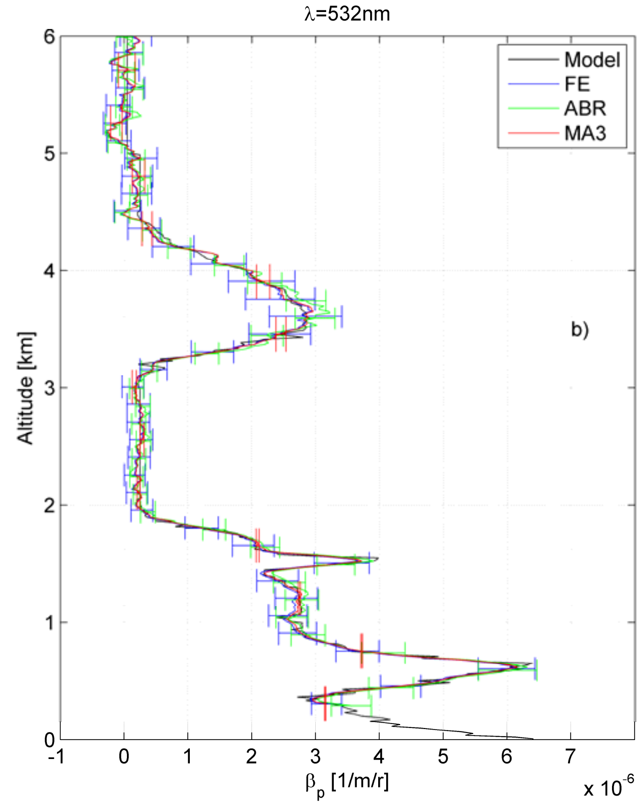
$\Rightarrow$



Aerosol optical properties – LIDAR

Aerosol backscatter coefficient





Mean relative error MRE (%) (regression)

$MRE_{min}=MRE-\varepsilon_{MRE}$

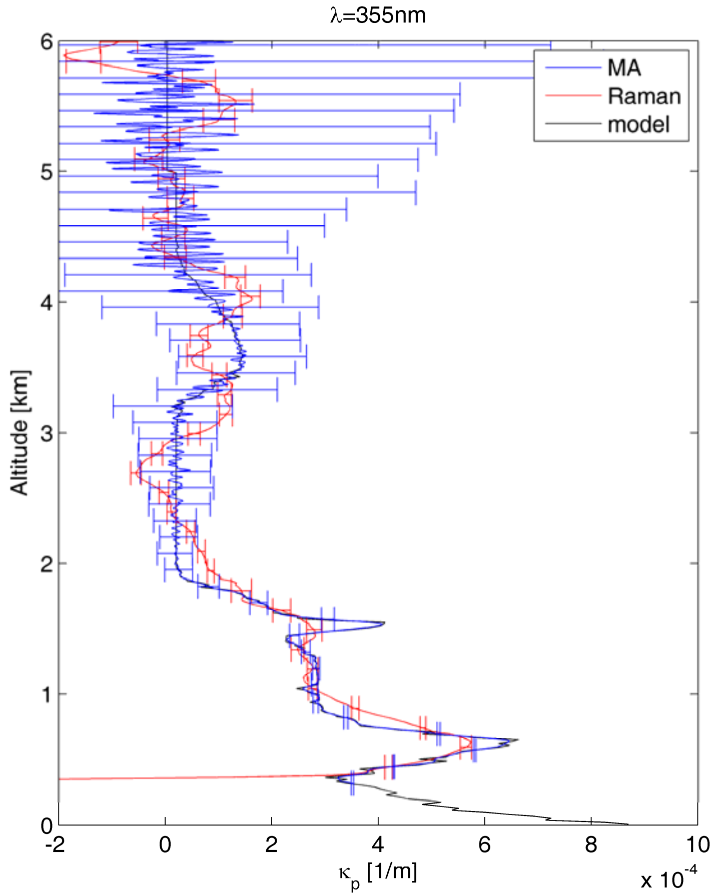
$MRE_{max}=MRE+\varepsilon_{MRE}$

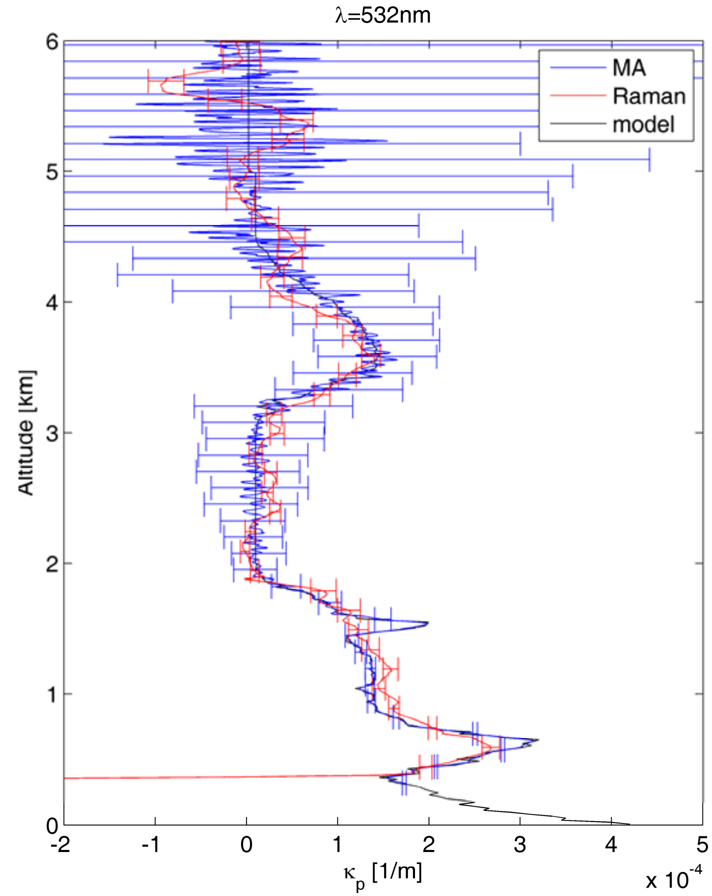
Method		Altitude [km] 0.3–2	3–4.4
FE	MRE_{min}	5.7	0.69
	MRE_{max}	6.5	13.6
ABR	MRE_{min}	1.2	-3.6
	MRE_{max}	6.8	14.5
MA	MRE_{min}	**-5.9**	**-2.4**
	MRE_{max}	**-5.6**	**5.6**

Method		Altitude [km] 0.3–2	3–4.4
FE	MRE_{min}	-4.8	-3.4
	MRE_{max}	-0.99	4.8
ABR	MRE_{min}	**-2.5**	2.3
	MRE_{max}	**0.71**	6.9
MA	MRE_{min}	-4.7	**0.46**
	MRE_{max}	-1.1	**1.91**

Aerosol optical properties – LIDAR

Aerosol extinction coefficient





Mean relative error MRE (%) (regression)

$MRE_{min}=MRE-\varepsilon_{MRE}$

$MRE_{max}=MRE+\varepsilon_{MRE}$

Method		Altitude [km] 0.3–2	3–4.4
MA	MRE_{min}	**-3.4**	**-28.1**
	MRE_{max}	**-2.9**	**25.3**
Raman	MRE_{min}	-14.4	-115.1
	MRE_{max}	-13.3	-108.4

Method		Altitude [km] 0.3–2	3–4.4
MA	MRE_{min}	**-3.2**	**-17.9**
	MRE_{max}	**-2.2**	**17**
Raman	MRE_{min}	-10.1	-29.6
	MRE_{max}	-8.3	-25.3

Conclusion:

- In horizontal homogeneous atmosphere, multi-angles methods provide more reliable results

MRE is computed through the regression between retrieval and model

Next:

- Methods comparisons in horizontal non-homogeneous atmosphere
- Methods comparisons with real data

Aerosol hygroscopicity - overview

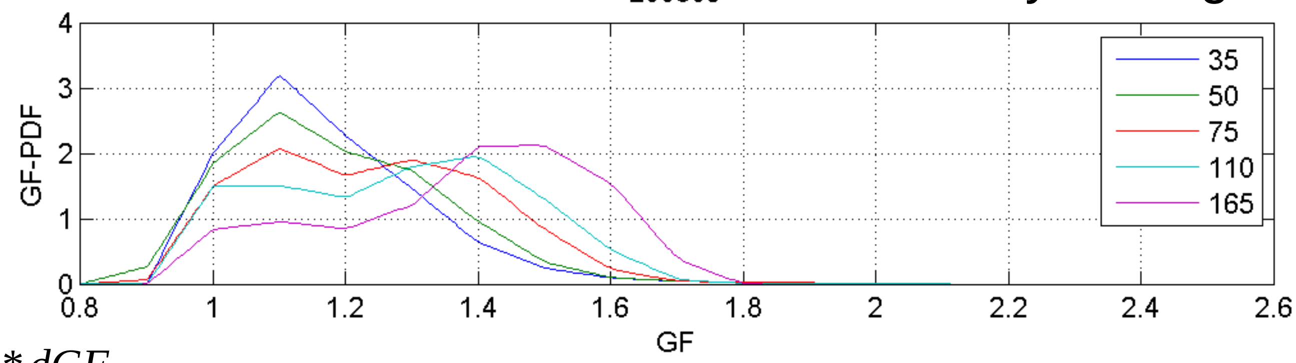
- **Usually, the aerosol optical, microphysical and chemical properties are determined in dry conditions (<30% RH)**
- **These properties need to be corrected to ambient conditions**
  - to characterize the atmosphere as it is
  - to compare with other measurements taken in ambient conditions (e.g. lidar extinction with in-situ scattering + absorption)
  - to be used as input in further studies (e.g. radiative transfer → aerosol extinction, absorption and asymmetry factor required)

Aerosol hygroscopicity - overview

- **Variables used to characterize aerosol hygroscopicity:**
  - Growth factor GF(RH)=d_{wet}/d_{dry} → GF(RH) determines the change in particle size distribution
  - Enhancement factor f(RH)= θ(RH)/θ(RH=0) where θ can be scattering (σ), absorption (α), extinction (κ), backscatter (β) coefficient or asymmetry parameter (*g*) → f(RH) determines the change in aerosol optical properties (scattering, absorption, extinction, backscatter coefficients and asymmetry parameter)
- **Typical measurements (methods)**
  - GF(RH) is determined by HTDMA measurements at 90% RH
  - f(RH) is determined by simultaneously measurements using two instruments, one in dry and one in wet conditions (e.g. nephelometer)
- **If measurements of f(RH) are not available, then Mie theory is used**

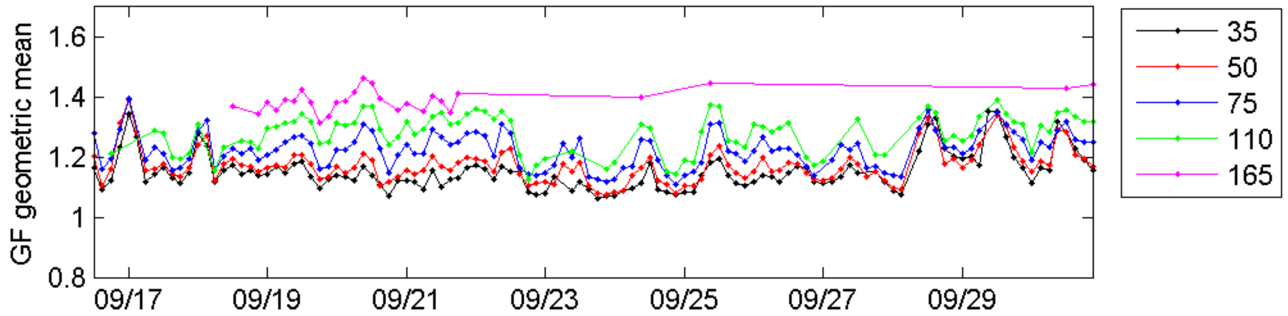
Averages over 3h

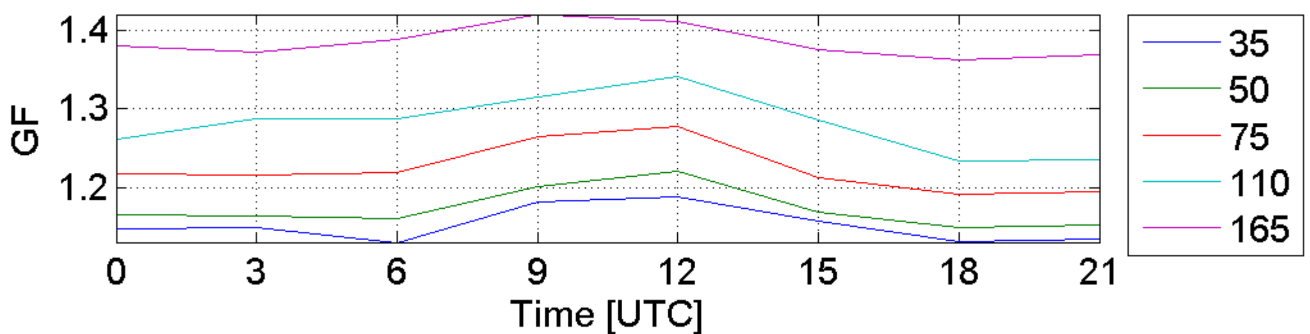
monthly average



$$\langle GF \rangle = \int_0^\infty GFPDF(Ddry, GF) * GF * dGF$$

$\langle GF \rangle_{35}=1.15$
$\langle GF \rangle_{50}=1.17$
$\langle GF \rangle_{75}=1.22$
$\langle GF \rangle_{110}=1.28$
$\langle GF \rangle_{165}=1.39$



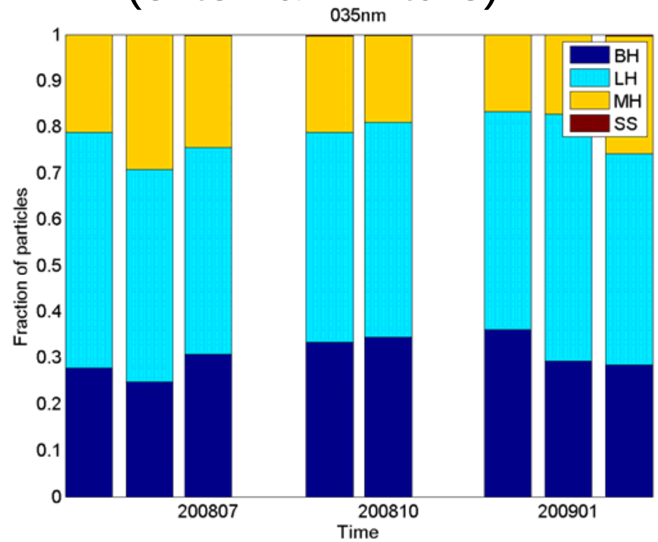


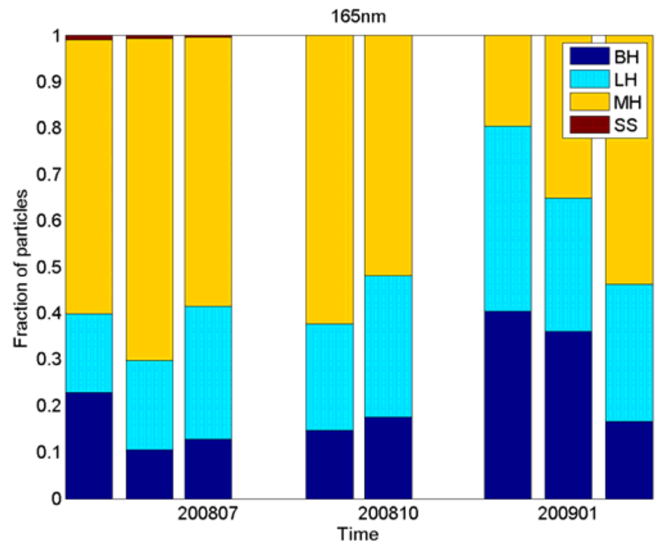
diurnal cycle
(monthly average)

Statistics over 8 month (May 2008 – Feb 2009)

BH=barely hygroscopic (GF < 1.09)
LH=less hygroscopic (GF ∈[1.09 1.28])
MH=more hygroscopic (GF ∈[1.28 1.78])
SS=sea salt (GF > 1.78)

Aerosol mixture
(external mixture)





Methodology used at Ispra EMEP station to determine enhancement factor

Input:

- measurements of aerosol GF at 90% RH (165nm particles)
- measurements of NSD (DMPS+APS) taken at RH<30% ("instruments conditions")
- measurements of aerosol scattering (nephelometer), absorption (aethalometer) at "instruments conditions"

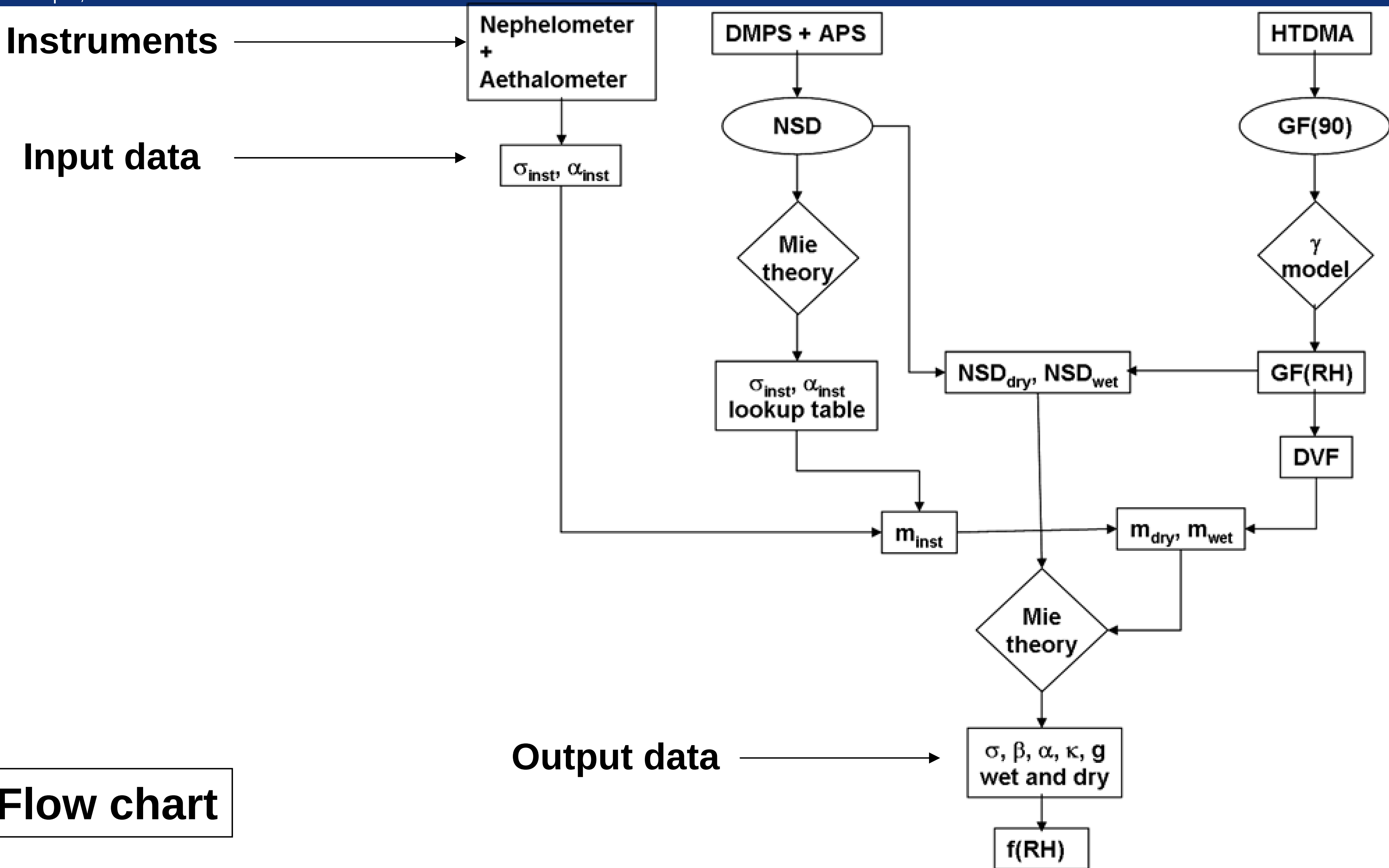
Output (use Mie theory):

- dry (RH=0%) and ambient (wet) aerosol scattering, absorption, extinction, asymmetry parameter ⇒ enhancement factor f(RH)

Assumptions/criteria during computations

- Mie theory assumptions
- Particles number does not change with RH
- Instrument refractive index (m) is determined by matching measured and computed σ and α. Note: only data within $\pm$ 5% difference in RH between DMPS and nephelometer are used.
- $GF(RH)=(1-RH/100)^{-\gamma} \leftarrow \gamma$ from b.c. at RH=90%
- $m=(1-v)m_w + v*m_d$ where v is volume fraction of the hydrophobic fraction: $v=1/GF(RH)^3$

Aerosol hygroscopicity
Enhancement factor f(RH)



Flow chart

Error estimation → sensitivity study

$$\varepsilon_y = 100\frac{1}{2}\left(\left|\frac{y_m}{y}-1\right|+\left|\frac{y_p}{y}-1\right|\right)(\%)$$

y corresponds to the input parameters x (ε_x=0, i.e. no error in input parameters), while y_m and y_p correspond to the input parameters x-ε_x and x+ε_x respectively

Errors in input data:

$\varepsilon_{NSD}= \pm$ 10%NSD, $\varepsilon_{d\_inst}= \pm$ 3%d_{inst}, $\varepsilon_{\sigma}= \pm$ 1.5%σ, $\varepsilon_{\beta}= \pm$ 1.5%β, $\varepsilon_{\alpha}=\pm$4%α, $\varepsilon_{<GF>}=\pm$5%<GF>

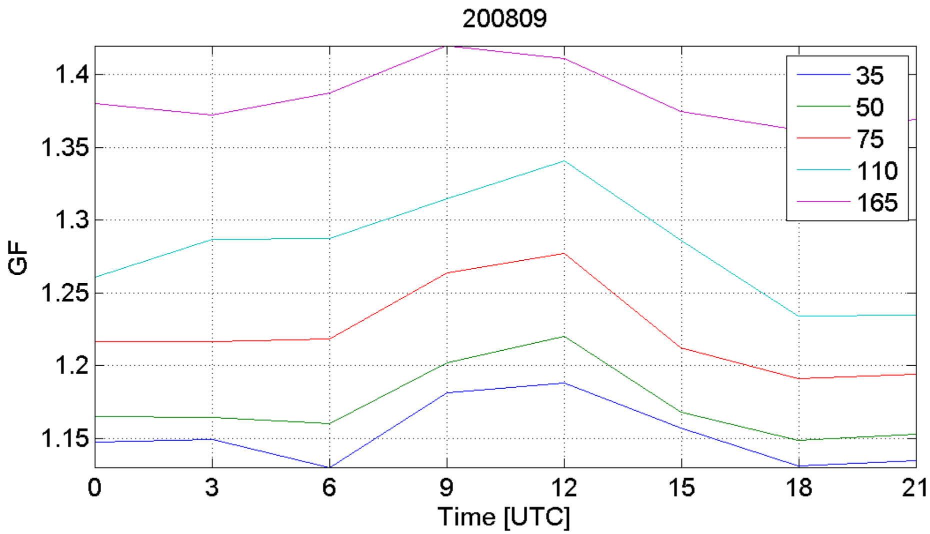
Growth factor $GF(RH)=d_{wet}/d_{dry}$

- Use measurements of aerosol GF at 90% RH (165nm particles)

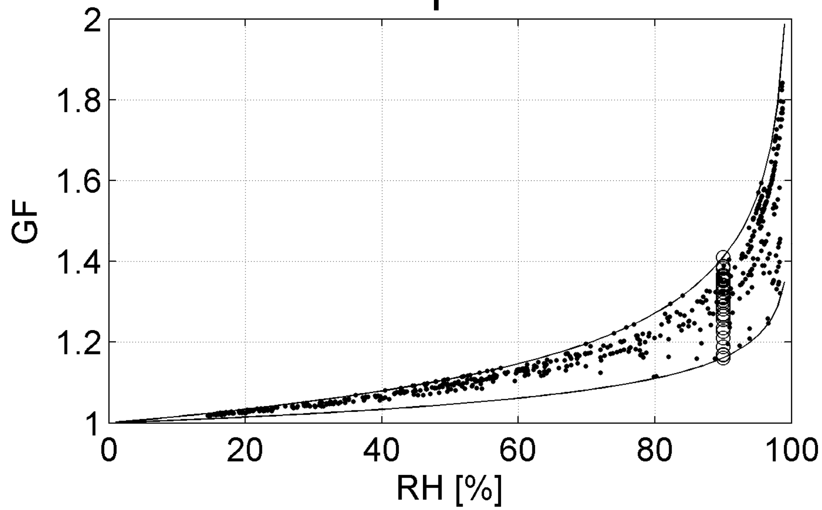
$GF(RH)=(1-RH/100)^{-\gamma}$

γ from b.c. at RH=90%

GF(90) monthly diurnal averages



Humidogram GF(RH) for 165nm particles

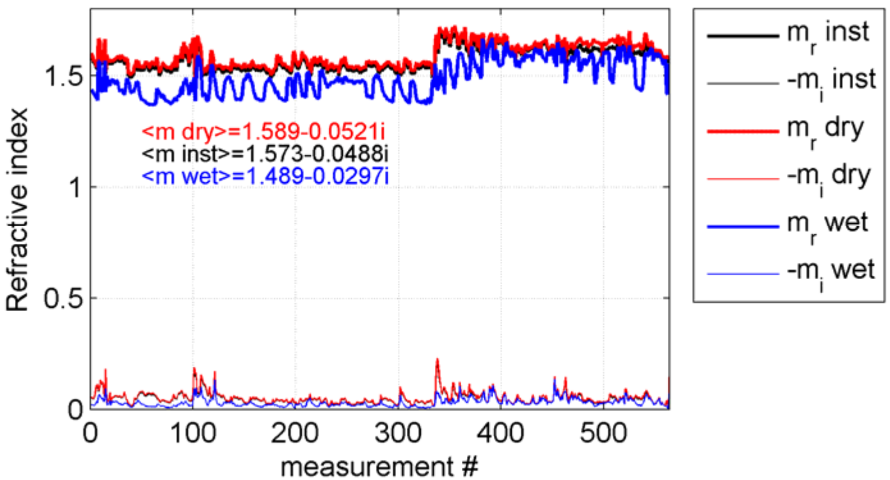


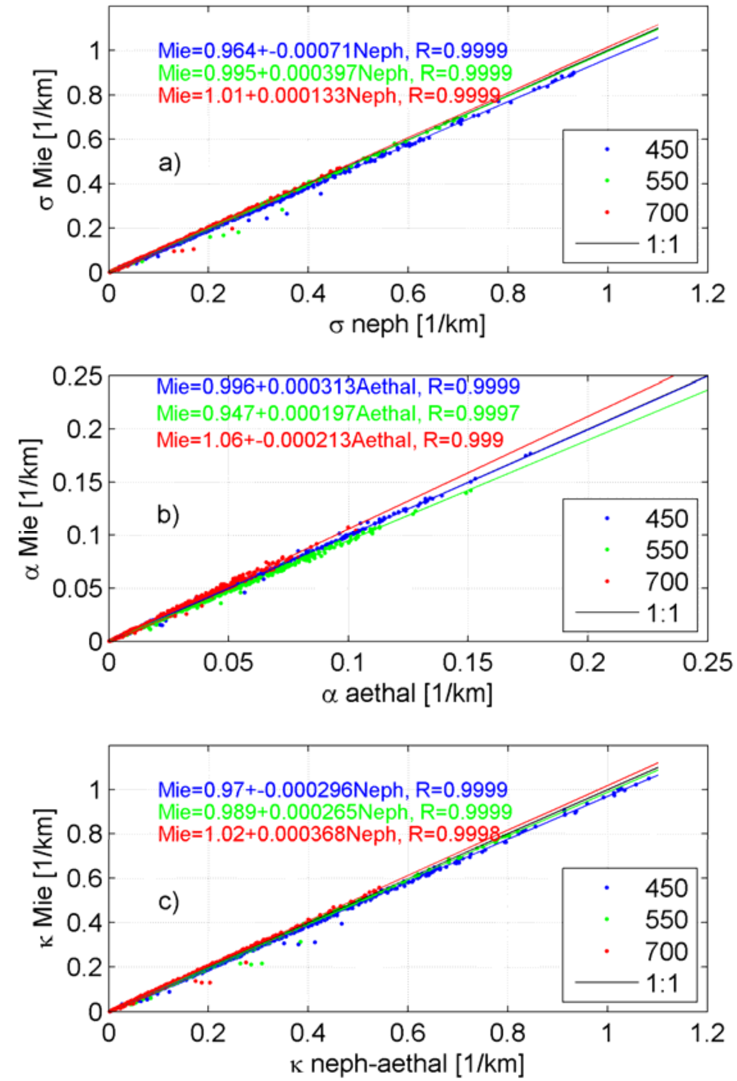
Enhancement factor f(RH)

Data availability: 1062 hourly data over 84 days (during 2008-2009)

eliminate outliers ⇒ final data set: 564 hourly data

Fitting measured and computed scattering, absorption and extinction coefficients → m_{inst}





m_{inst} + DVF → m_{dry} and m_{wet} → σ, κ, α, β, g dry and wet → f(RH)

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Aerosol hygroscopicity
Enhancement factor f(RH) - Results

Ispra, 1 December 2011

f(RH) for λ=550 nm

aerosol scattering coefficient

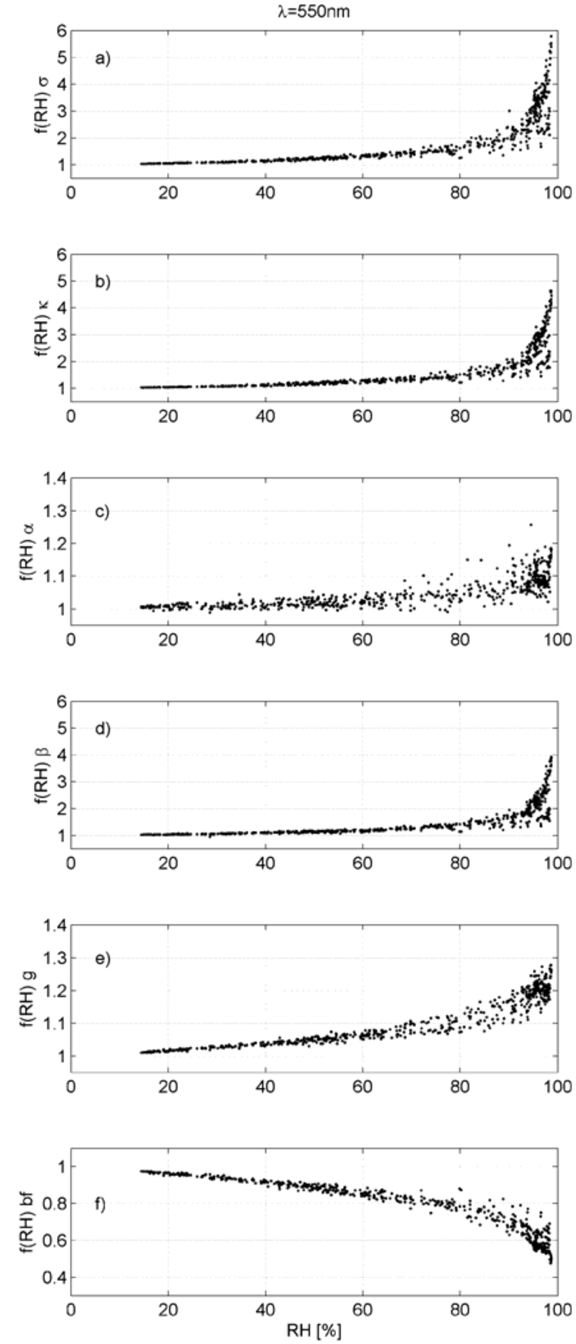
aerosol extinction coefficient

aerosol absorption coefficient

aerosol backscatter coefficient

aerosol asymmetry parameter

aerosol backscatter fraction



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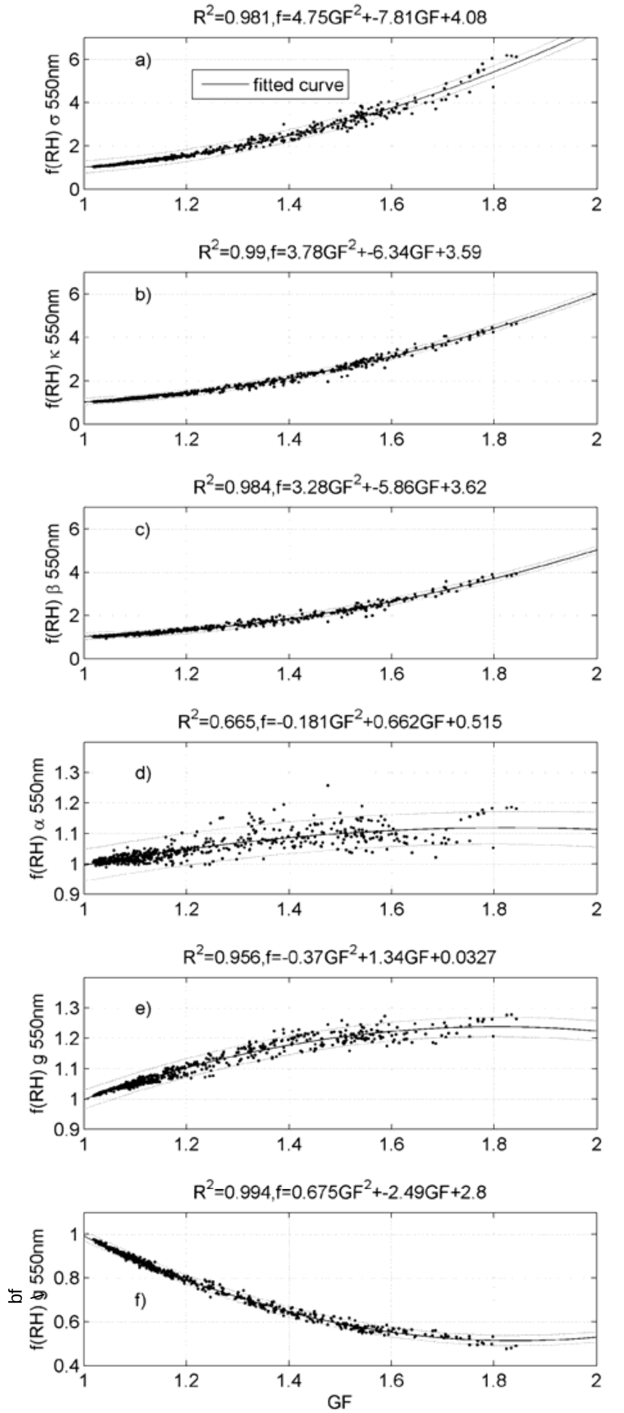
Aerosol hygroscopicity
Enhancement factor f(RH) - Results

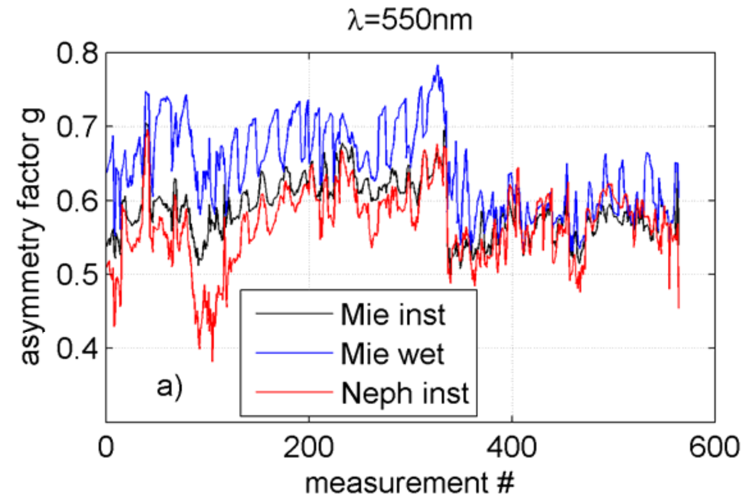
Ispra, 1 December 2011

Strong correlation between enhancement factor and growth factor for scattering, extinction, backscatter coefficients, asymmetry parameter and backscatter fraction



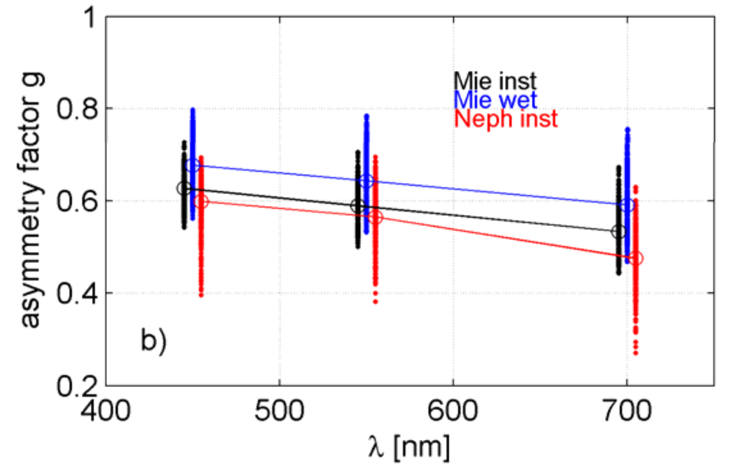
Aerosol hygroscopicity
Enhancement factor f(RH) - Results

Asymmetry parameter *g*



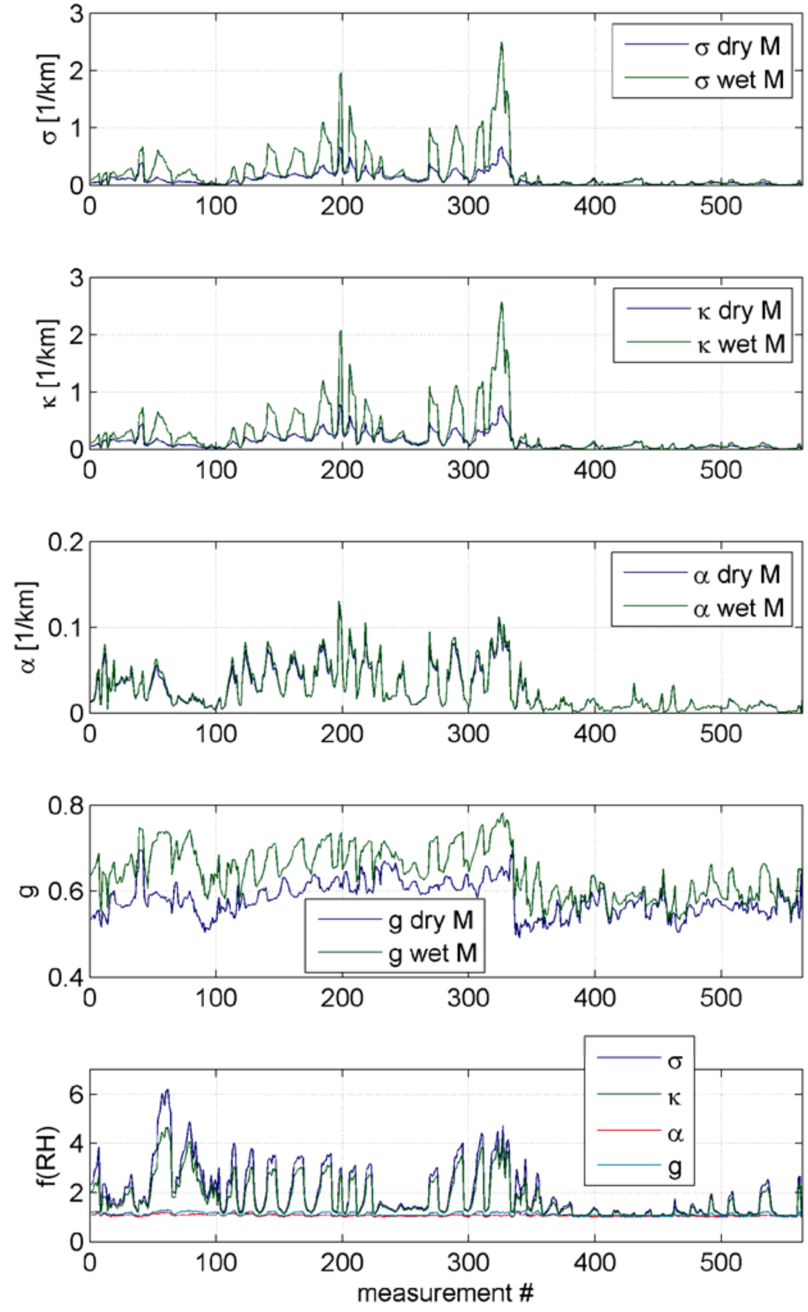
Relative difference wet/dry [%] (Mie):

450	550	700 nm
8.03	9.21	10.78



Aerosol hygroscopicity Enhancement factor f(RH) Results

Correction to ambient conditions for aerosol scattering, extinction and absorption coefficients, asymmetry factor (e. g. λ=550nm)

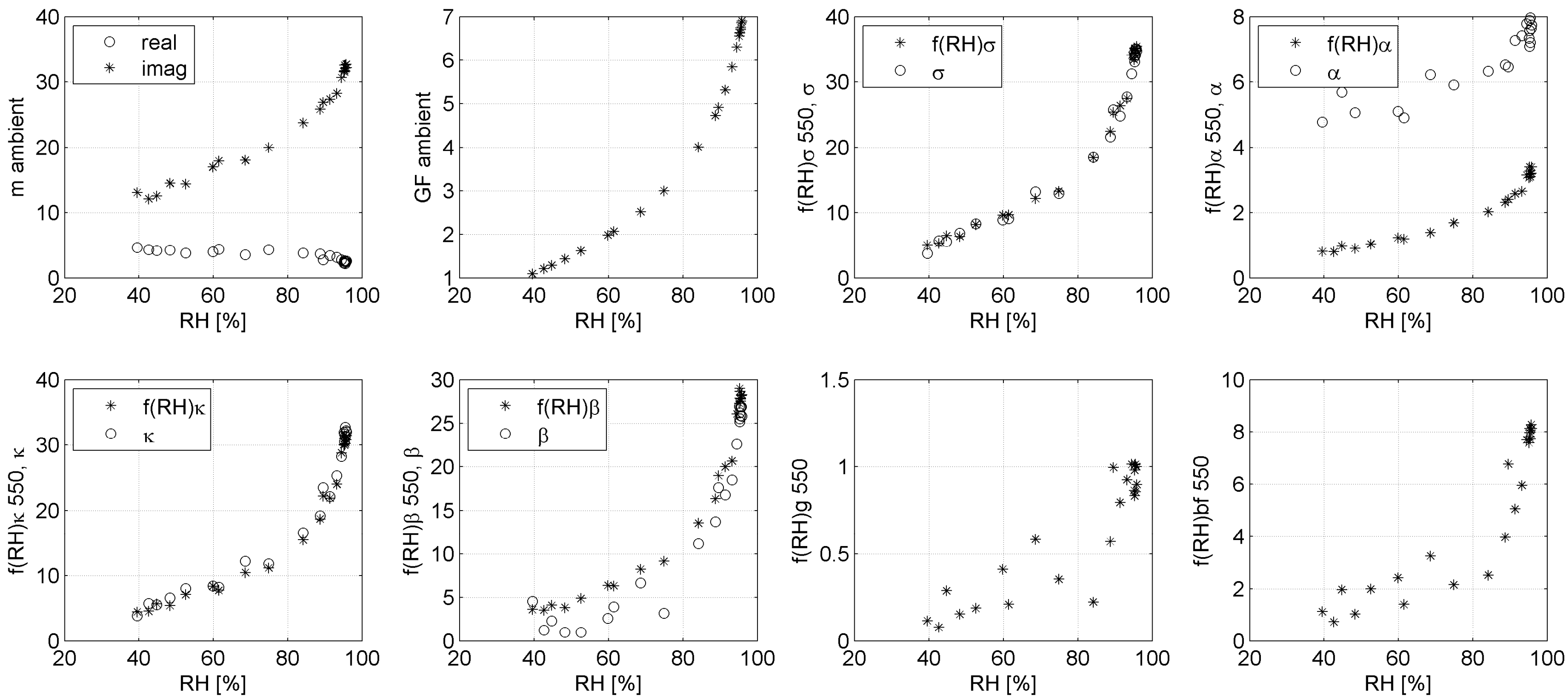


Aerosol hygroscopicity
Enhancement factor f(RH) - Results

Mean errors [%] for the main variables. The optical parameters represent 550nm.

Errors e.g. 10.02.2009

	m_r	m_i	g_{Mie}	b_{Mie}	GF	σ_{Mie}	α_{Mie}	κ_{Mie}	β_{Mie}
Dry	4.8	11.2	3.2	8.0	-	1.3	4.4	1.5	2.8
Inst.	4.6	11.9	3.2	8.3	1	2.0	4.6	2.2	2.3
Wet	3.0	RH	3.2	10.9	RH	RH	RH	RH	RH



At 90% RH:

- **GF = 1.32 ± 0.06**
- **<f(RH)> at 550nm**
  - 1.72 ± 0.79 for κ
  - 1.94 ± 1.04 for σ
  - 1.55 ± 0.62 for β
  - 1.05 ± 0.05 for α
  - 1.11 ± 0.08 for g

- **Asymmetry factor g**
  - Relative difference [%] wet/dry conditions

λ [nm]:	450	550	700
	8.03	9.21	10.78

- **A strong correlation is found between f(RH) and GF(RH) for σ, κ, β, g**
  - ⇒ given GF climatology and f(RH) – GF(RH) correlation, correct the optical variables for ambient conditions
  - The corrections for ambient conditions can not be ignored

Aerosol hygroscopicity - Conclusions

Next steps:

- Correct the measurements taken at low RH ("instruments conditions") to ambient conditions
- Calculate radiative forcing for both dry and wet conditions and see the implications
- Acquire a new nephelometer for direct measurements on scattering enhancement factor

J.P. Putaud - discussions

S. Martins dos Santos - measurements HTDMA, nephelometer, DMPS and APS

A. Dell'Acqua - measurements aethalometer

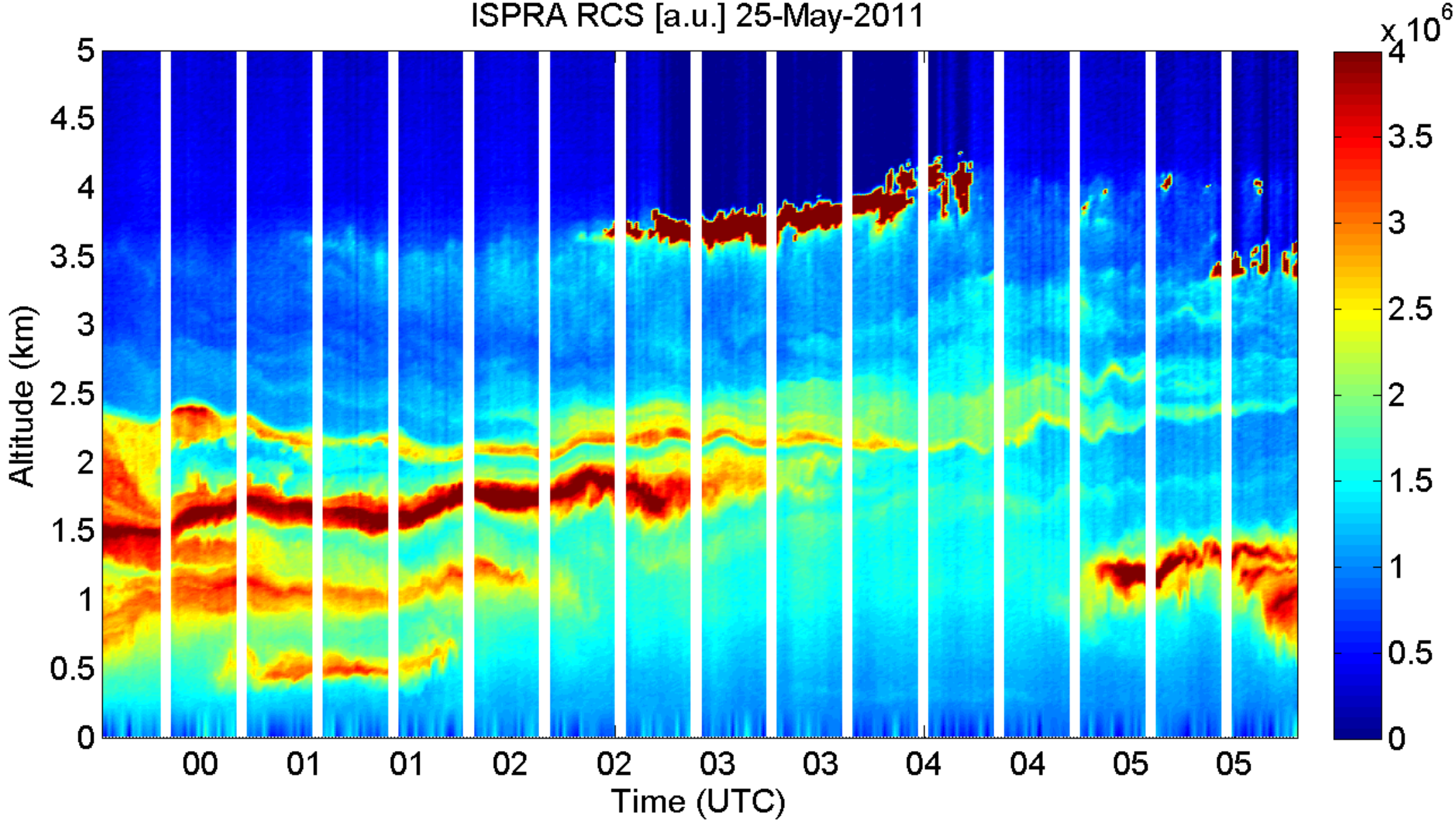
C. Gruening - preliminary data processing

Paper to be re-submitted

In addition, common paper on hygroscopicity over Europe, has to be submitted

Thank you for your attention!

After questions you are invited for a glass of wine!



p.s. Don’t forget to buy the lidar! You promised!