Aerosol hygroscopicity at Ispra EMEP-GAW station

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Content

- Aerosol hygroscopicity - overview
- Methods and methodology to determine aerosol hygroscopicity
- Results for Ispra EMEP-GAW station
- Conclusions

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 $\rightarrow$ aerosol extinction, absorption and asymmetry factor required)

- **Variables used to characterize aerosol hygroscopicity:**
  - Growth factor GF(RH)=d_{wet}/d_{dry} $\rightarrow$ 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* $\rightarrow$ f(RH) determines the change in aerosol 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 (methodology)**

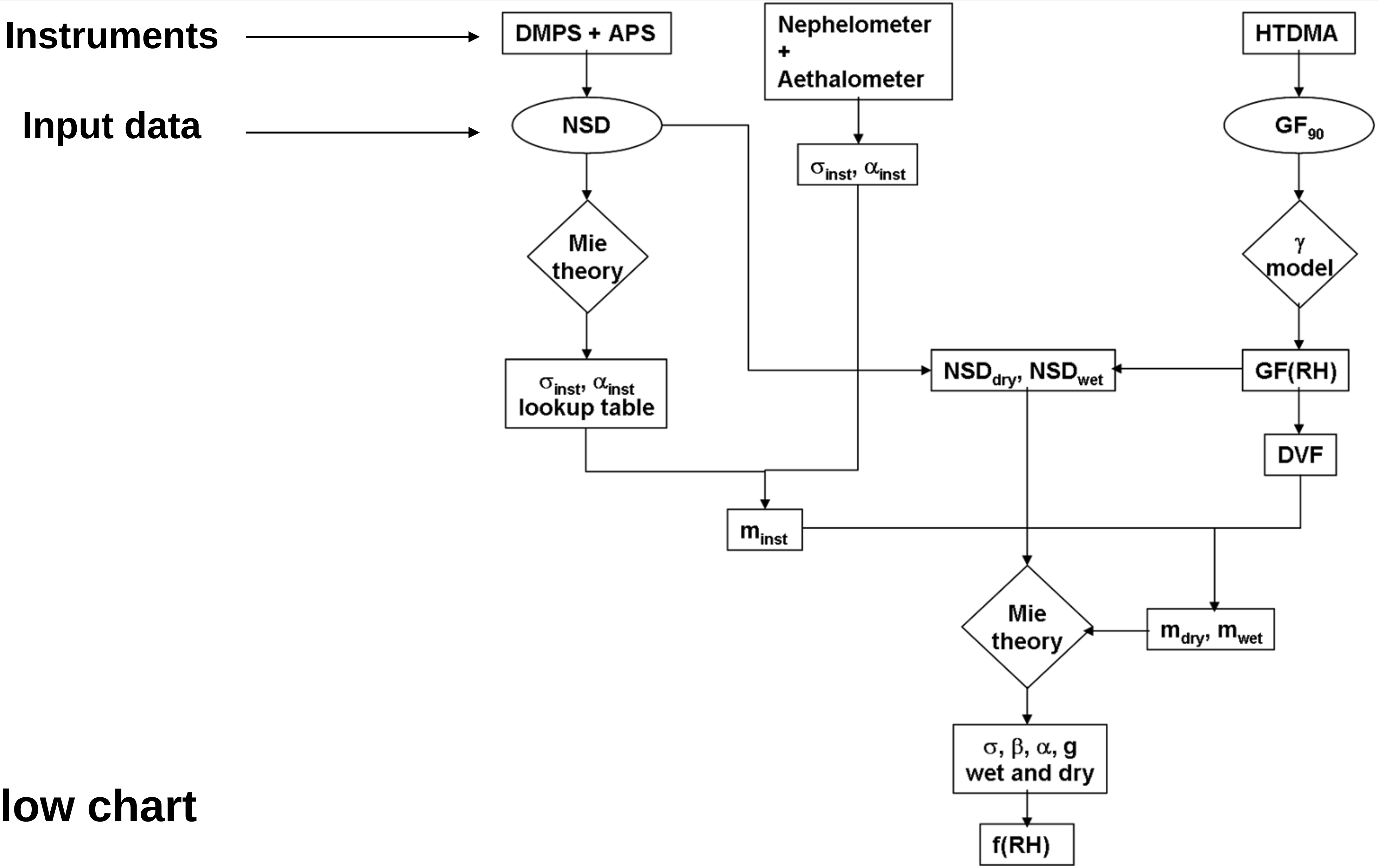
Methodology used at Ispra EMEP station to determine enhancement factor

- Use measurements of aerosol GF (HTDMA) at 90% RH
- Use measurements of NSD (DMPS+APS) taken at RH<30% ("instruments conditions")
- Use measurements of aerosol scattering (nephelometer), absorption (aethalometer) at "instruments conditions"
- Use Mie theory to compute dry (RH=0%) and ambient (wet) aerosol scattering, absorption, extinction, asymmetry parameter and 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 ± 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: $v=1/GF(RH)^3$

Methodology to retrieve aerosol hygroscopicity 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:

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

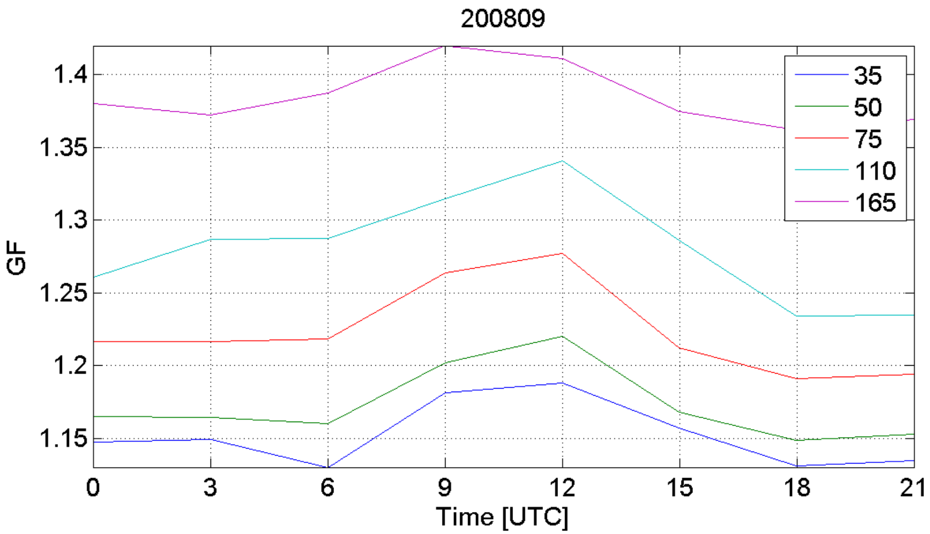
Growth factor $GF(RH)=d_{wet}/d_{dry}$

- Use measurements of aerosol GF (HTDMA) at 90% RH

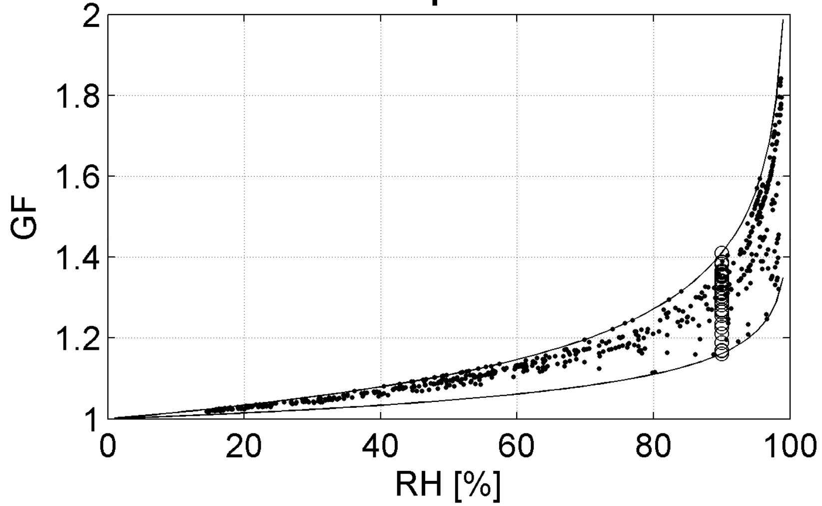
$GF(RH)=(1-RH/100)^{-\gamma}$

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 *m* outliers (difference measurements – computations < 30%) ⇒ 655 available hourly data

σ, α, κ: regression computed vs measured

- Eliminate outliers
- ⇒ 642 data for σ
- ⇒ 638 data for α
- ⇒ 641 data for κ

⇒ final data set: 564 data

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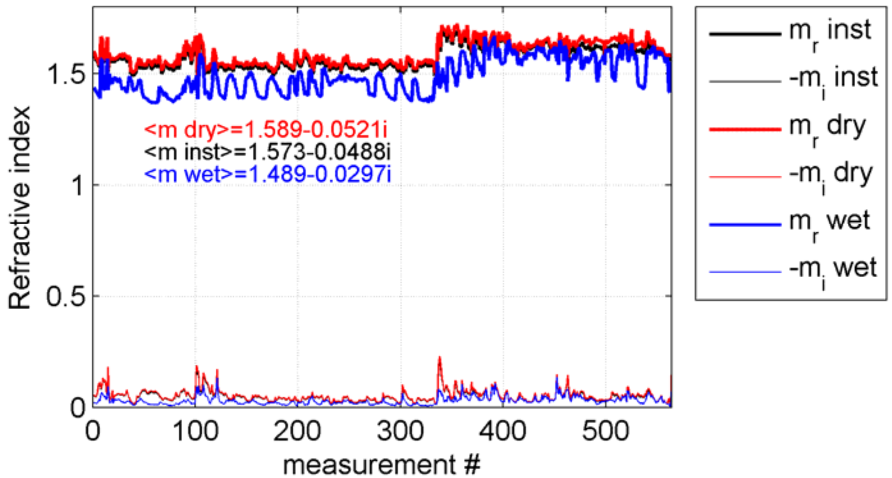
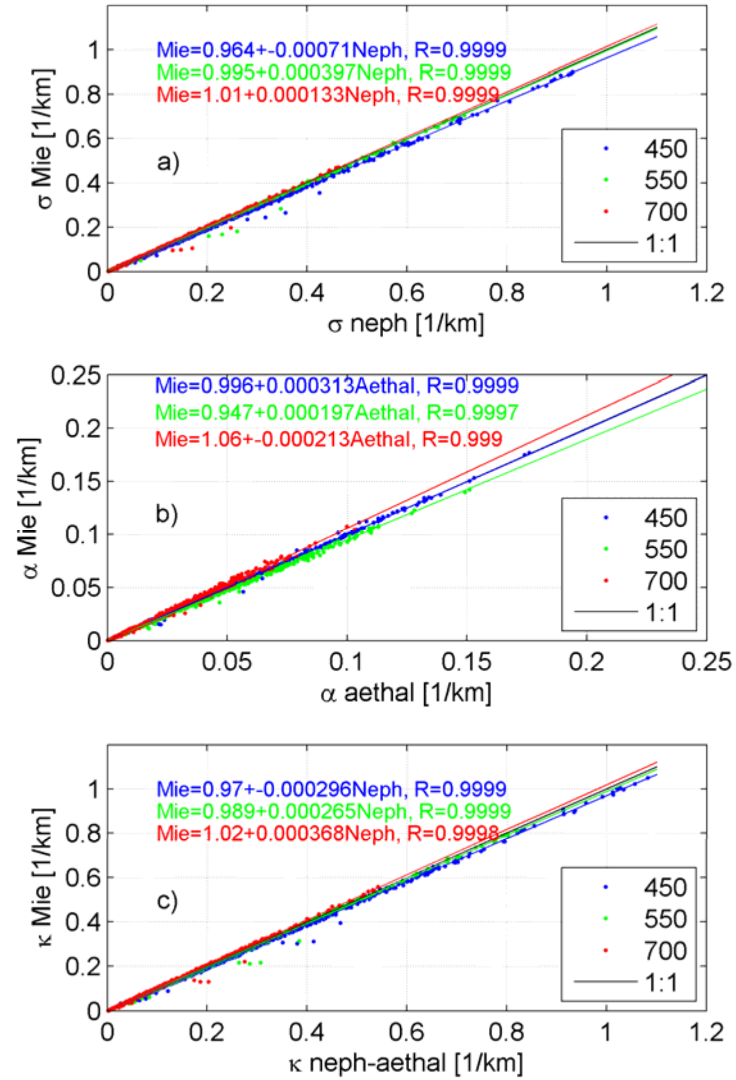
Results for Ispra EMEP station f(RH)

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





m_{inst} and DVF } → m_{dry} and m_{wet} → σ, κ, α, β, g dry and wet

↓

f(RH)

Results for Ispra EMEP station f(RH)

f(RH) for λ=550 nm

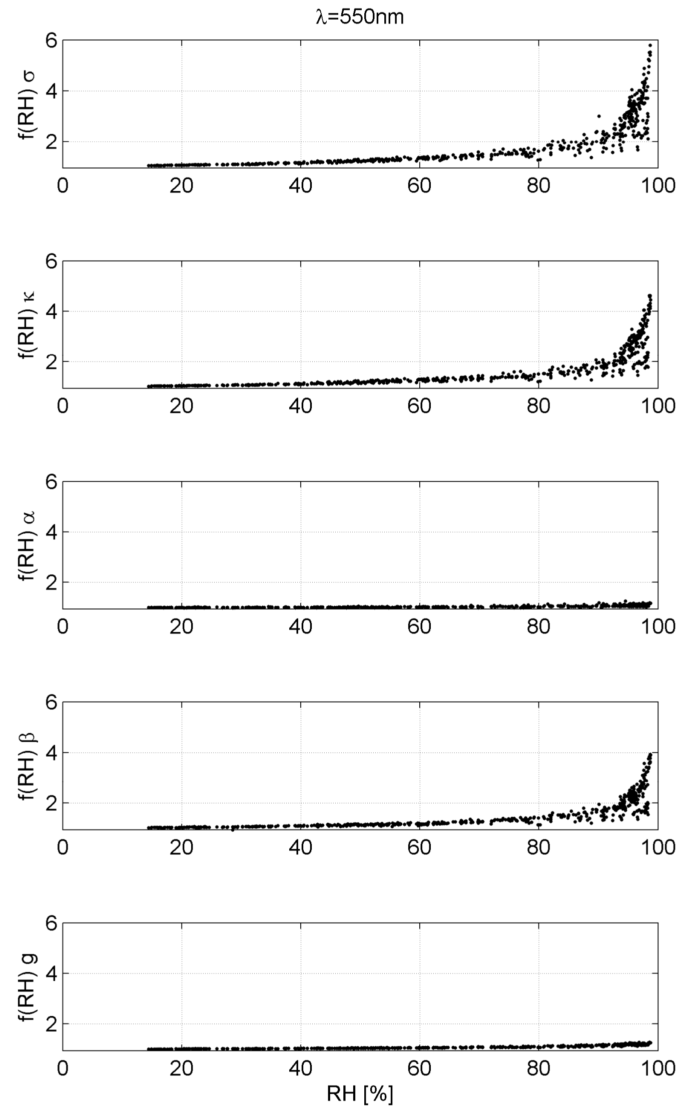
aerosol scattering coefficient

aerosol extinction coefficient

aerosol absorption coefficient

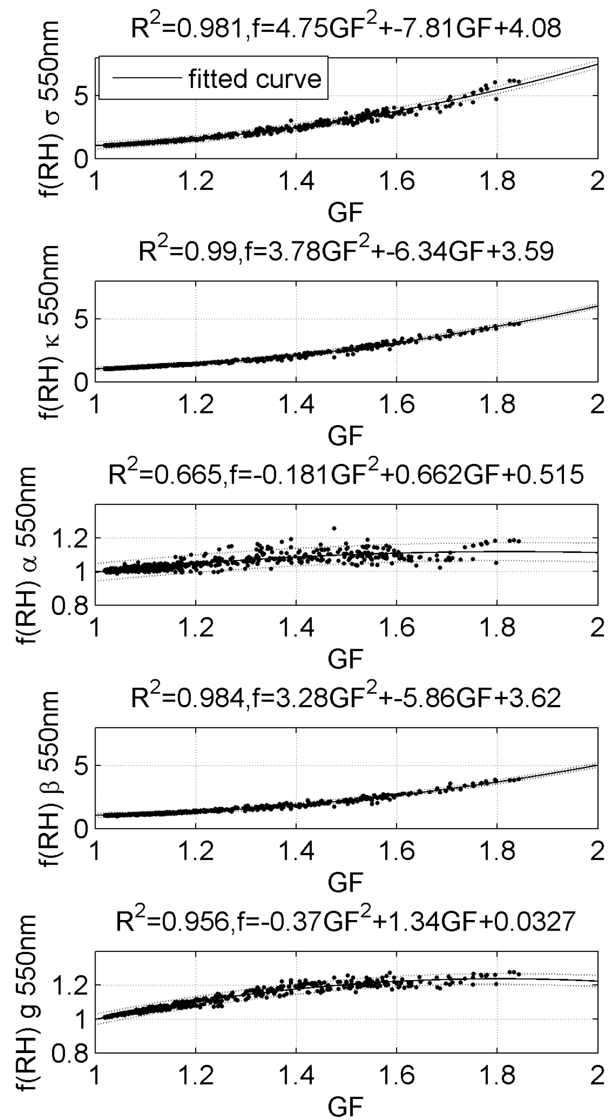
aerosol backscatter coefficient

aerosol asymmetry parameter



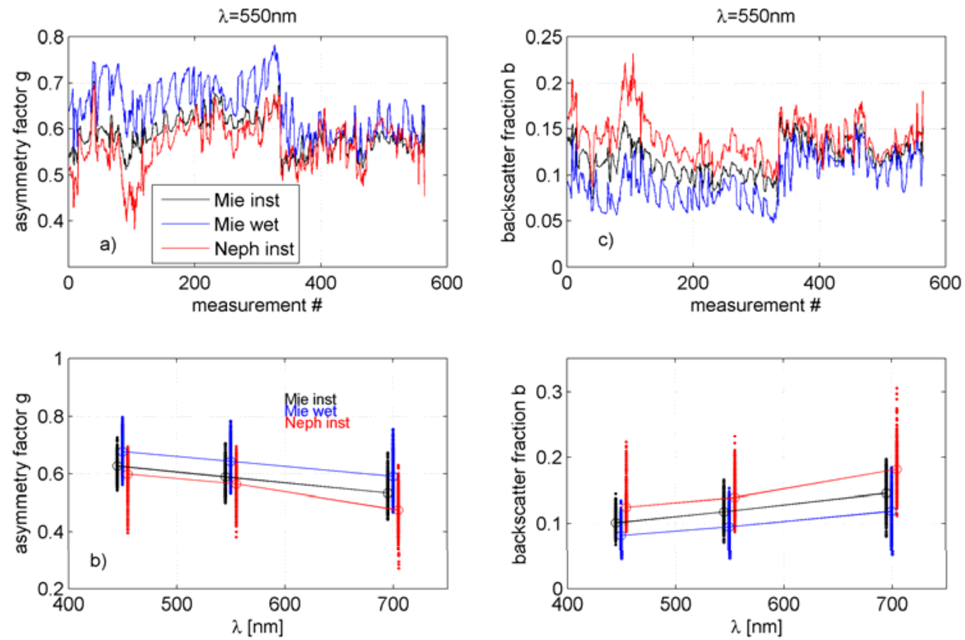
Results for Ispra EMEP station f(RH)

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



Results for Ispra EMEP station f(RH)

Asymmetry parameter *g* and backscatter fraction *b* (hemispherical backscatter/scattering)



Note: nephelometer: empirical formula (Arnott)

$g=-7.143889*b^3+7.464439*b^2-3.96256*b+0.9893$

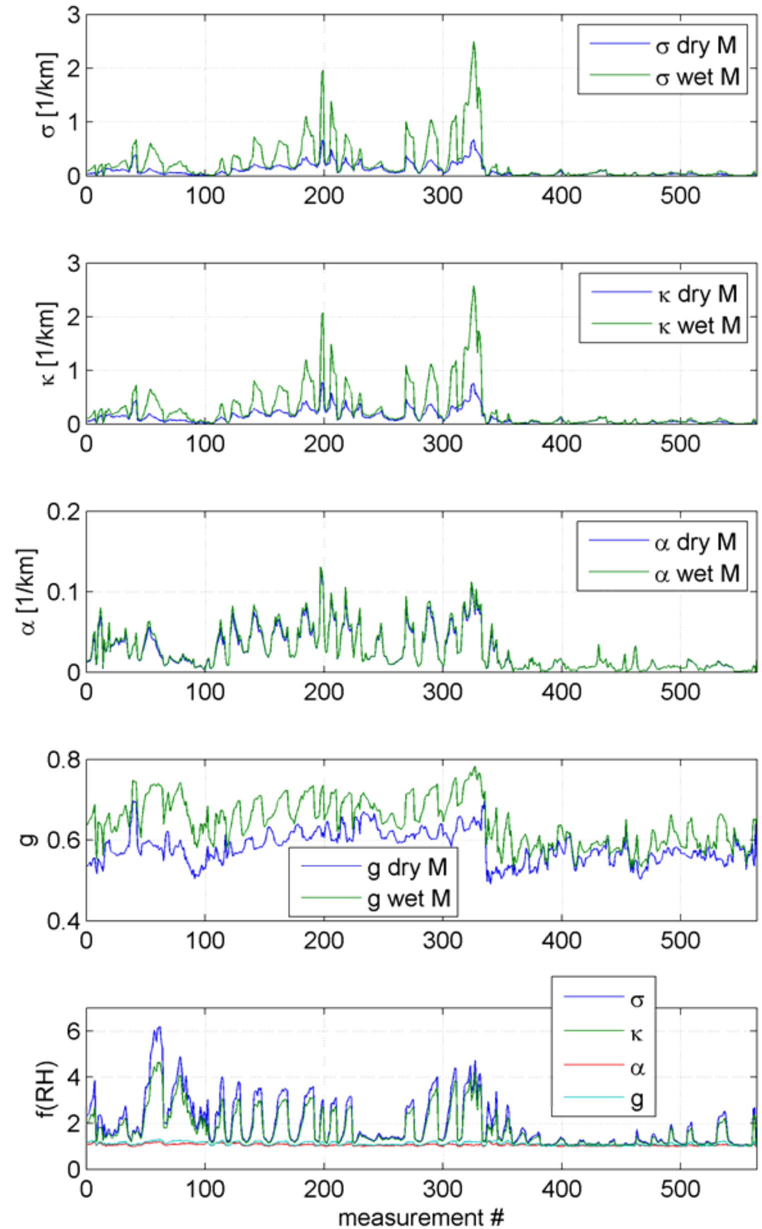
b = backscatter fraction

<u>Mean values asymmetry parameter</u>

	450	550	700 nm
Neph inst	0.60	0.57	0.48
Mie inst	0.63	0.59	0.534
Mie dry	0.62	0.58	0.53
Mie wet	0.68	0.64	0.527
<u>Rel diff Neph/Mie (%)</u>			
Inst:	-4.45	-4.03	-11.2
<u>Rel. diff wet/dry</u>			
Mie:	8.03	9.21	10.78

Results for Ispra EMEP station f(RH)

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

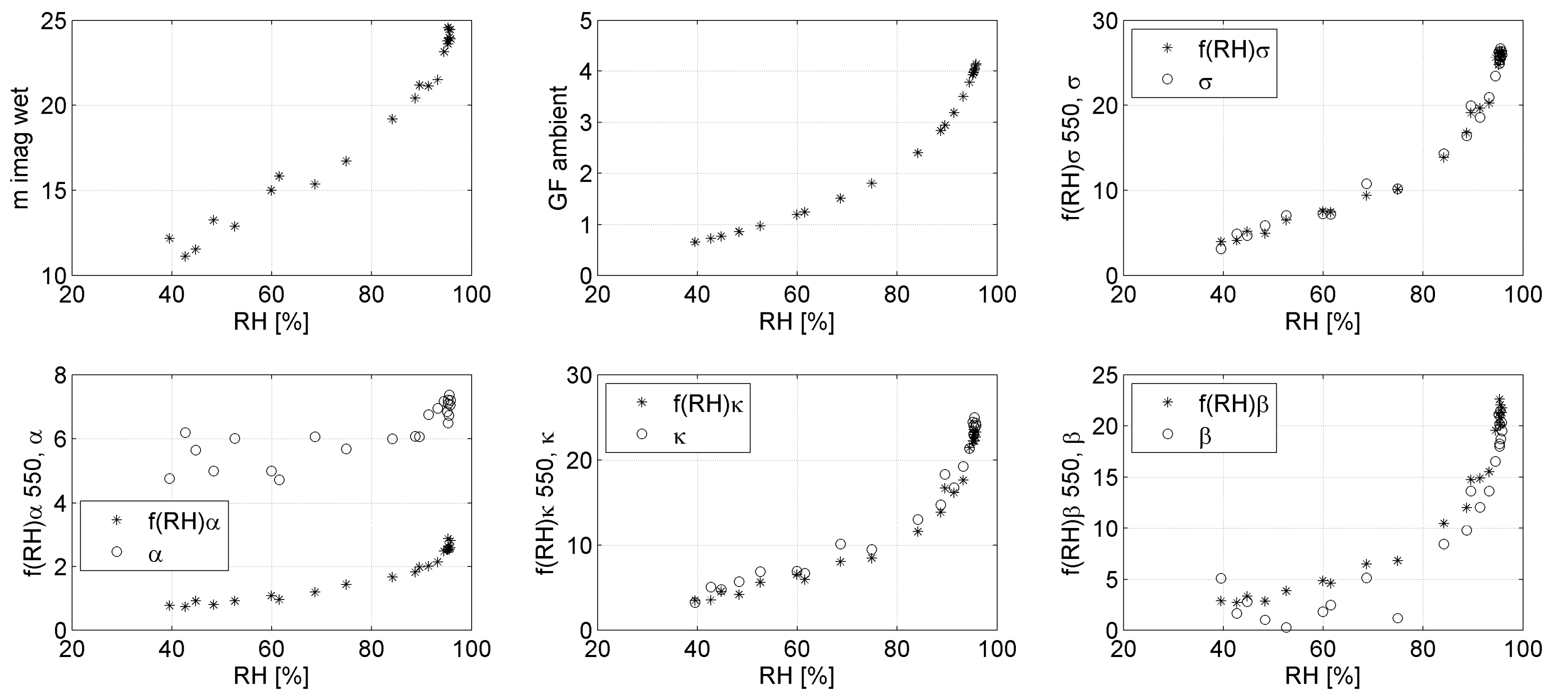


Results for Ispra EMEP station f(RH)

Errors e.g. 10.02.2009

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

	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	0.24	2.0	4.6	2.2	2.3
Wet	3.0	RH dep	3.2	10.9	RH dep	RH dep	RH dep	RH dep	RH dep



Conclusions

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/inst. conditions λ: 450 550 700nm

    Mie: 8.03 9.21 10.78

  - Relative difference [%] Neph./ Mie: Inst: -4.45 -4.03 -11.2

Conclusions

f(RH)

- Can be broadly described by the same power low as for GF(RH) → diurnal/seasonal behavior has to be checked
- A strong correlation is found between f(RH) and GF(RH) for σ, κ, β, g
- There is a weak correlation with absorption (absorption shows a weak change with RH)

Conclusions

- Given GF climatology and f(RH) – GF correlation, correct the optical variables for ambient conditions
- The corrections for ambient conditions can not be ignored

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

Collaborators

J.P. Putaud - discussions

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

A. dell'Aqua - measurements nephelometer and aethalometer

C. Gruening - preliminary data processing

Paper to be submitted to ACP

Thank you for your attention!

Zieger et al., 2010 ACPD (Cabauw)

$$\sigma_{ep}(\text{RH}) = c(f(\text{RH})\sigma_{sp} + \sigma_{ap}).$$

$c_p = p(h)T_0/p_0T(h)$ accounts for pressure and temperature differences inside (p_0, T_0) and outside $(p(h), T(h))$ the nephelometer.

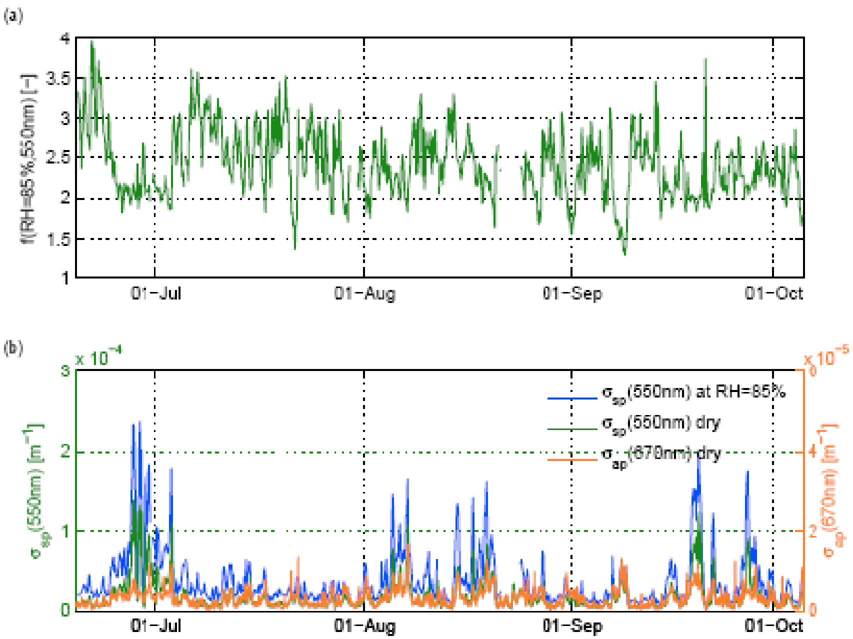


Fig. 1. Panel (a): Time series of the scattering enhancement factor f(RH=85%,550nm) measured at Cabauw, The Netherlands, during summer and fall 2009. Panel (b): Scattering coefficient at λ=550nm at RH=85% (blue line) and at dry conditions (green line) measured by the humidified nephelometer (WetNeph) and reference nephelometer (DryNeph). The absorption coefficient at λ=670nm (orange line) was measured by the multi-angle absorption photometer (MAAP) at dry conditions.

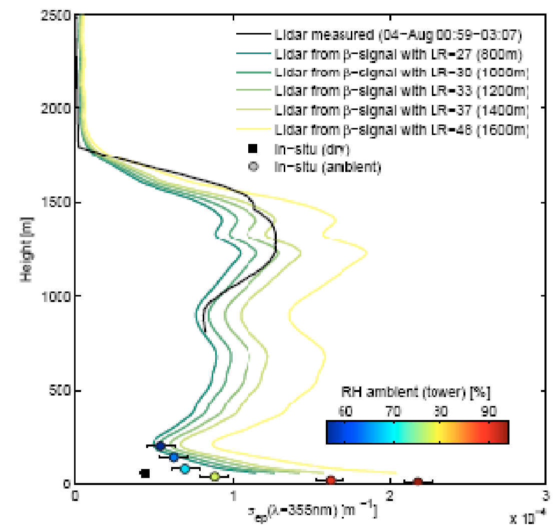


Fig. 11. Lidar and in-situ measurements of the aerosol extinction coefficient σ_{ep} at λ=355nm (4th of August 2009, 00:59 – 03:07). Black line: Direct lidar measurement of σ_{ep}; Colored lines: σ_{ep} calculated from the backscatter signal using measured lidar ratios (LR) obtained from mean values of different height levels (±100 m); black square: σ_{ep} measured in-situ at dry conditions; colored circles: σ_{ep} brought to ambient conditions (color code denotes the ambient RH measured at the tower, error bars are retrieved via Gaussian error propagation).