AOD measurement and data processing I

Henri Diémoz [1]

[1]Environmental Protection Agency of the Aosta Valley (ARPA Valle d'Aosta)

h.diemoz@arpa.vda.it
EUBREWNET Training School 2016

Aerosol (air + solution): a colloidal system of solid or liquid particles in a gas

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Milk is a colloid

Introduction

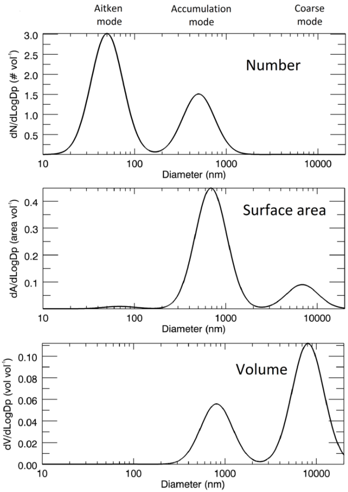
What is aerosol?

Aerosol (air + solution): a colloidal system of solid or liquid particles in a gas = everything is not a gas in the atmosphere

Introduction

What is aerosol?



Extraordinary range of sizes

Introduction

Why is it important?

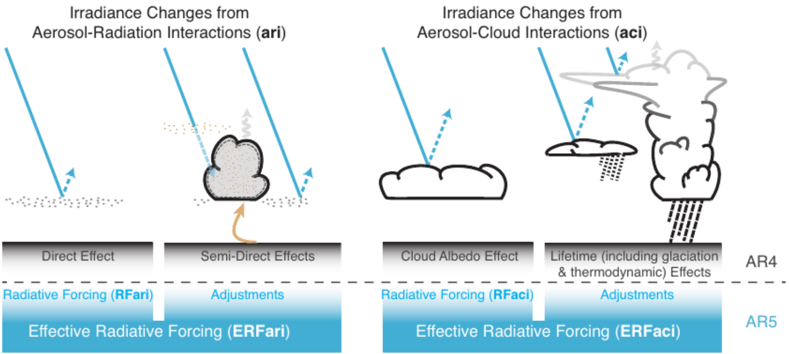
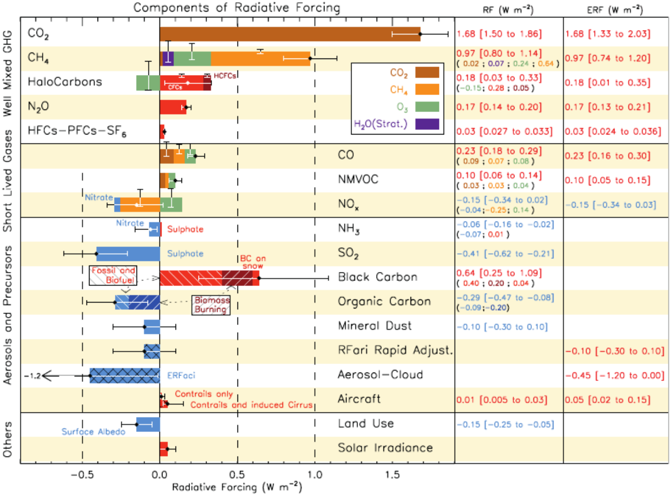


Figure 7.3 | Schematic of the new terminology used in this Assessment Report (AR5) for aerosol–radiation and aerosol–cloud interactions and how they relate to the terminology used in AR4. The blue arrows depict solar radiation, the grey arrows terrestrial radiation and the brown arrow symbolizes the importance of couplings between the surface and the cloud layer for rapid adjustments. See text for further details.

Variety of effects on climate (IPCC, 2014)

Introduction

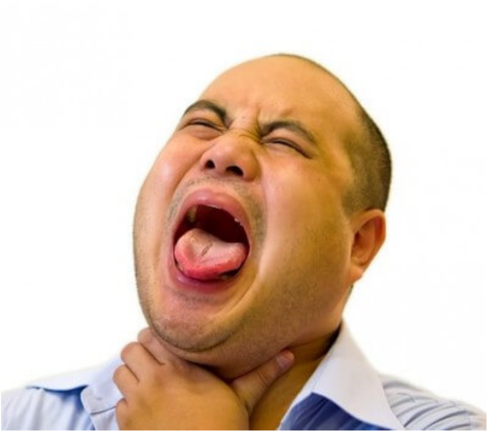
Why is it important?



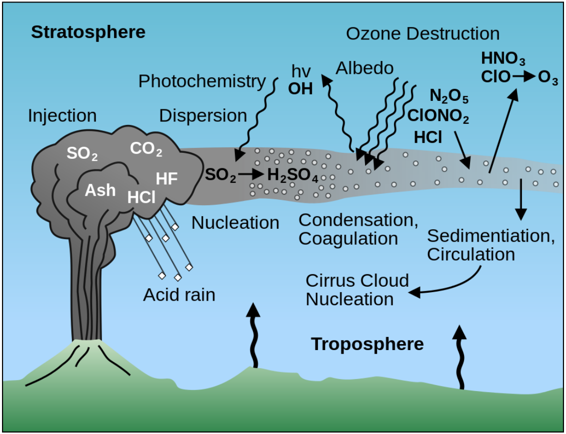
IPCC (2014)

Introduction

Why is it important?



Air quality and human health (WHO 2006)



Interactions with ozone – heterogeneous chemistry (Solomon, 2016)

Introduction

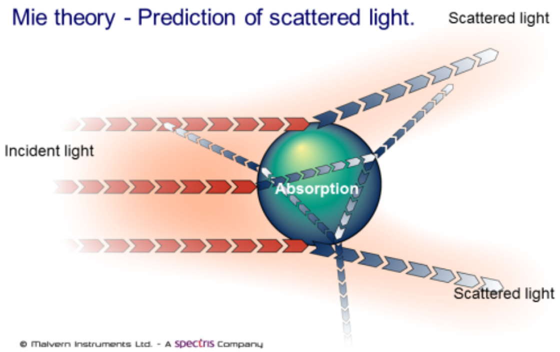
Why is it important?

Air traffic

Introduction

Why is it important?

Impact on landscape visual quality

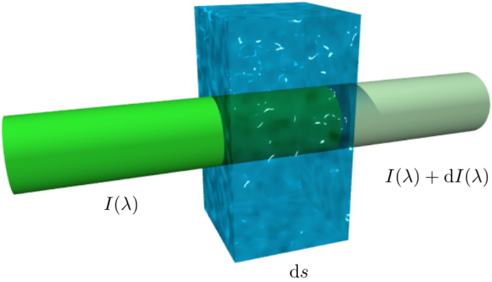


Mie theory ($\lambda \simeq D$)

Bouguer-Lambert-Beer law (1729)

$$dI = -K_{ext}\rho I ds \qquad (1)$$

$$[K_{ext}] = \frac{m^2}{kg} \qquad (2)$$



Extinction = Absorption + Scattering

If only aerosol extinction is taken into account,

$$I(\lambda) = I_0(\lambda)\, e^{-\mu_a \tau_a(\lambda)} \tag{3}$$

- $I(\lambda)$ direct irradiance at ground
- $I_0(\lambda)$ exoatmospheric irradiance (ET constant)
- μ_a air mass factor
- $\tau_a(\lambda)$ **aerosol optical depth (AOD)**

Strictly holds only for monochromatic light $\rightarrow$ problems if FWHM or spectral gradients are too large (e.g., UV)

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Aerosol optical depth (AOD)

- ✓ very simple concept
- ✓ very simply measurable
- ✓ can be used to compare aerosol burdens at different sites
- ✗ does not tell what are the absorbed and scattered fractions
- ✗ does not tell much about aerosol type and properties

Angstrom exponent: $\tau(\lambda) \equiv \beta\, \lambda^{-\alpha}$

- ✓ representative of particles size
- ✓ allows to identify some kinds of particles (e.g., mineral dust = low α, ash = high α)
- ✓ can be determined from reliable measurements of AOD at different wavelengths

Single scattering albedo (SSA): $\frac{SCATTERING}{EXTINCTION} = \frac{SCATTERING}{SCATTERING + ABSORPTION}$

- ✓ fundamental for climate studies: do aerosols absorb solar radiation (warm up atmosphere) or scatter radiation (cool down atmosphere)?
- ✓ can help to determine the aerosol composition (e.g., black carbon)
- ✗ information about scattered light is needed (i.e., direct sun is not enough)
- ✗ complex retrieval (inverse problem)

Main networks

- AERONET (AErosol RObotic NETwork, NASA): worldwide coverage, all inversions
- SKYNET: mainly Asia + Europe (EUROSKYRAD), all inversions
- GAW-PFR: background sites, only AOD (and Angstrom exponent)
- the Brewer network! More than 200 instruments worldwide potentially able to measure AOD in the UV (and visible) range

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Aerosols measurements with the Brewer: a short bibliography

AOD from residuals of direct sun ozone measurements (UV)

- Carvalho & Henriques (2000): AOD from DS
- Gröbner et al. (2001): comparison with a Li-Cor spectrophotometer
- Marenco et al. (2002): AOD from DS, fixed filter, interfilter calibration, comparison to MFRSR
- Cheymol & De Backer (2003): analysis over a long period (1984–2002), trends, Pinatubo eruption, sensitivity tests
- Cheymol et al. (2006): analyses on several Brewers, effect of spectral filter transmittance
- De Bock et al. (2014): better cloudscreening, relations between UV global irradiance and AOD

Aerosols measurements with the Brewer: a short bibliography

AOD with other methods (UV)

- Kerr (2002): AOD from group scans (9x5 wavelengths)
- Cede et al. (2003): calibration of diffuse radiance, FOV, jump-scans with a MkIII (3x6 wavelengths)
- Kazadzis et al. (2005): absolute calibration of DS spectral irradiance, comparison of AOD and Angstrom to a Bentham spectroradiometer and a MFRSR, analysis of 7 years
- Kazadzis et al. (2007): analysis of 9 years of spectral measurements of AOD, comparison of single- and double-monochromator Brewers and Cimel
- De Bock et al. (2010): AOD from sun scans at 340 nm, comparison to Cimel, analysis 2006–2010

Aerosols measurements with the Brewer: a short bibliography

AOD from direct sun routine (VIS, MkIV Brewers)

- Gröbner & Meleti (2004): analysis 1991-2002, UV and visible measurements (MkIV), validation with a Cimel (AERONET), Angstrom exponent from UV-VIS
- Diémoz et al. (2016): comparison to Cimel at 440 nm, instrumental effects, biases in Langley at polluted sites

Aerosols measurements with the Brewer: a short bibliography

Single scattering albedo

- Balis et al. (2003, 2004): SSA from global irradiance and models
- Bais et al. (2005): assessment of SSA accuracy of various methods (best: direct/diffuse irradiance ratio), analysis of 5 years of SSA from global irradiance and AOD
- Ialongo et al. (2010): SSA using Brewers and comparison to models
- Amiridis (2011): SSA from global irradiance, AOD and RTM

Aerosols measurements with the Brewer: a short bibliography

Uncertainty and biases

- Silva & Kirchhoff (2004): comparison between single- and double-monochromator Brewers to assess effect of straylight on AOD
- Arola & Koskela (2004): extensive investigation of biases when measuring AOD with Brewers (e.g., FOV, diurnal variability, NO2, straylight...). Negative Angstrom exponents due to uncertainties
- Cede et al. (2006): effect of internal polarisation
- Diémoz & Carreño (2015): different polarisation effects on MkII, MkIII and MkIV (cf. poster at QOS)
- Carlund et al. (2016): comparison to UV-PFR, complete assessment of uncertainty (cf. talk in joint session)

AOD is estimated from the residuals of ozone measurements

$$ln(I_{CORRECTED}(\lambda)) = ln(I_0(\lambda)) - \mu_a \tau_a(\lambda) - ABS/SCA\ OTHER\ SPECIES$$

N.B. Brewer countrates are expressed in $10^4 \cdot \log_{10}$ units, therefore it is necessary to convert natural logarithms to $\log_{10}$

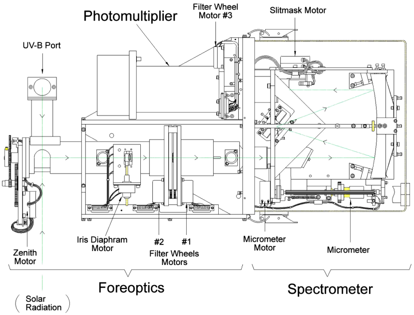
$ln(I_{CORRECTED}(\lambda))$: AOD estimation is based on *absolute* measurements!

- temperature correction (absolute): $ln(I) + TC(T)$ (not always available with requested accuracy)
- "neutral" density filters: $ln(I) + lnAF_p(\lambda)$
  - from standard lamp measurements
  - from continuity of measurements during observation
- correction for the effects of internal polarisation: $ln(I) + PC(\theta)$

AOD measurements with the Brewer

Effects of internal polarisation

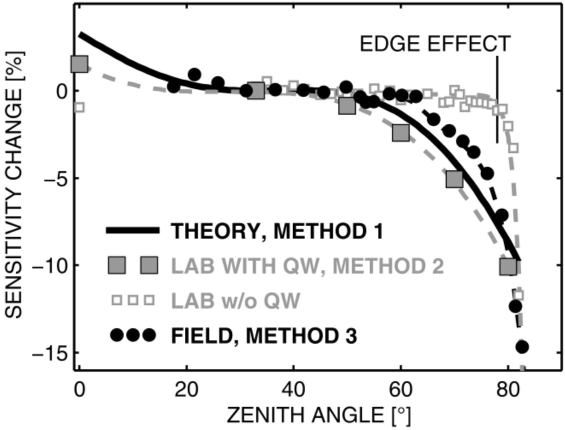
1. Fresnel effects through the flat quartz window
2. the diffraction grating approximately acts as a linear polarizer



Coupling between these two effects produce a remarkable (>10%) decrease of *absolute* sensitivity at high SZAs

AOD measurements with the Brewer

Effects of internal polarisation



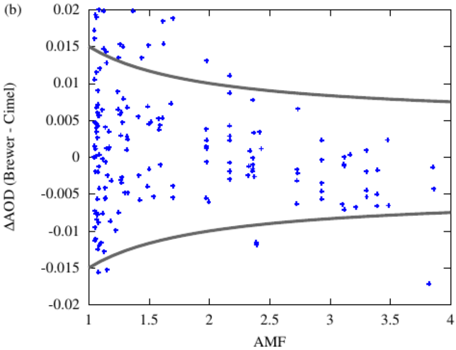
Cede et al., 2006

$ln(I_0(\lambda))$: depends on the instrument and can change with time!

- depends on day of year: $ln(I_0(\lambda)) - 2ln(d_{E-S}))$
- can be obtained by transfer from other measurements
- or from Langley plots at a pristine site

$\tau_{Brewer} \equiv \tau_{Reference}$

- therefore, $ln(I_{CORRECTED}(\lambda)) + \mu_a \tau_a(\lambda) + ...) = ln(I_0(\lambda))$



Limits for traceability (95% of points) are $\pm(0.005 + 0.010/\mu_a)$ (WMO 2004)

$$ln(I_{CORRECTED}(\lambda)) = ln(I_0(\lambda)) - \mu_a \tau_a(\lambda) - ABS/SCA\ OTHER\ SPECIES$$

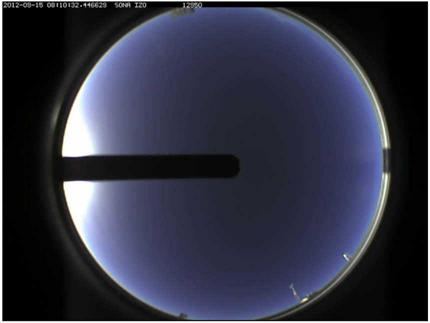
Equation of a straight line

- $y = ln(I)$
- $x = \mu_a$
- $ln(I_0)$ is the intercept
- τ_a is the slope
- *ABS/SCA OTHER SPECIES* (e.g. Rayleigh scattering) can be added to either y or $\mu\tau$

... provided that τ_a is constant (e.g. high-altitude sites, stable atmosphere).

AOD measurements with the Brewer

What is a Langley plot?



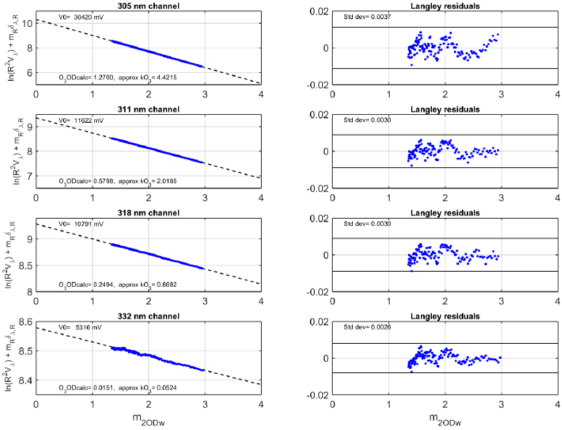


Figure from Carlund et al., 2016.
Several weeks/months are required for good statistics

$$ABS/SCA\ OTHER\ SPECIES =$$
$$\mu_R\,\tau_R(\lambda) + \mu_{O3}\,\sigma_{O3}(\lambda)\,X_{O3} + \mu_{SO2}\,\sigma_{SO2}(\lambda)\,X_{SO2}$$

- Rayleigh (e.g., Bodhaine et al., 1999)
  - depends on pressure: $\tau_R(\lambda) = \frac{p}{1013.25\ hPa}\delta_R(\lambda)$
  - what pressure? Mean or measured?
- ozone
  - X_{O3} from Brewer is slightly offset
  - $\sigma_{O3}(\lambda)$ must be convoluted with the Brewer bandpass at each slit
  - $\sigma_{O3}(\lambda)$: which spectroscopic dataset? What temperature?
- SO_2?

If every effect has been taken into account, we end up with $\mu_a \tau_a(\lambda)$

- several algorithms to calculate μ_a, e.g. Kasten and Young (1989) for air mass and Michalsky (1988) for solar zenith angle

Other issues

Radiometric stability

Instruments change with time...

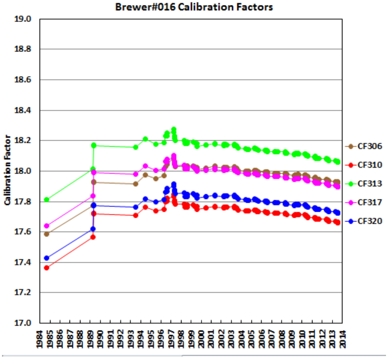
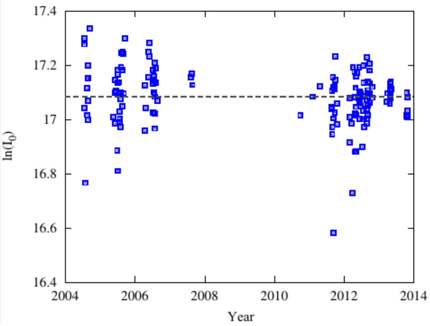
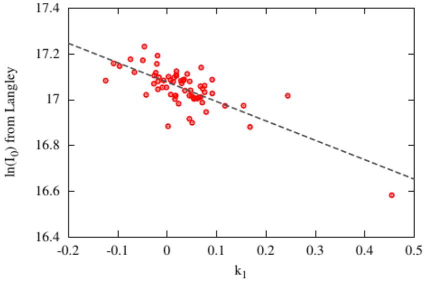


Figure from De Bock (2015)

- travelling standards?
- Langley plots on site?





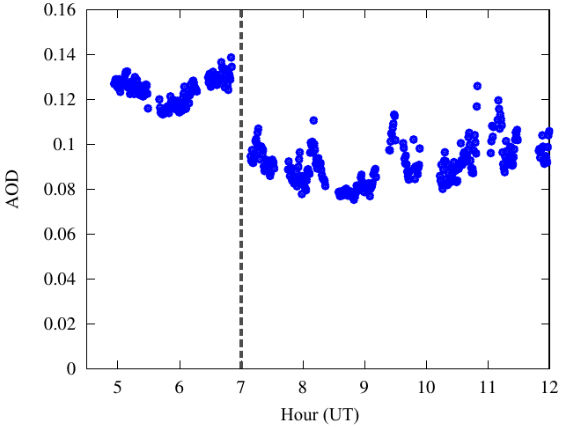
Most of the ETC scatter in Athens comes from the AOD daily curvature (Diémoz et al. 2016)

Clouds can significantly impact AOD measurements. Automated and objective algorithms have been developed, based on:

- temporal variability of samples in a DS cycle
- variability of consecutive measurements
- variability in a day
- second derivative of measurements (curvature)

Not easy to develop universal criteria for different time schedules (EUBREWNET)

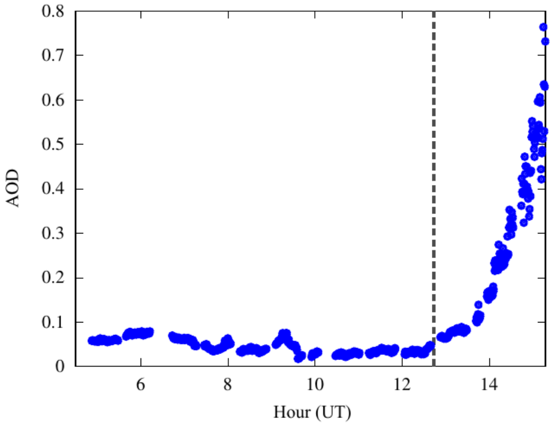
Other issues
Cleaning



Absolute measurements → the quartz window must be cleaned often!

Other issues

Pointing accuracy



... and check the sighting and PC synchronisation!