EARLINET climatology

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OUTLINE

- **EARLINET infrastructure for climatological study**
- **Methodology**
- **Seasonal behaviour**
- **Free troposphere contribution**
- **Comparison with AERONET and MODIS data**
- **Climatological representativeness of EARLINET database**

EARLINET

- **EARLINET was established in 2000 with the main objective to make a qualitatively and quantitatively significant database for the horizontal and vertical distributions of atmospheric aerosols over Europe**

- **In almost 10 years of life of the network, stations were added and systems upgraded enhancing the observational capability in terms of both geographic coverage and investigated properties.**

EARLINET database

EARLINET vertical profiles are archived in a devoted database in a standardize NetCDF format.

EARLINET database is organised into 10 categories:

Climatological

Measurements performed 3 times per week on the base of a fixed time schedule

Saharan dust

Measurements performed in correspondence of alerts based on Saharan dust forecasts distributed to all EARLINET stations by the NTUA (National Technical University of Athens) group

Calipso

Measurements performed following a devoted measurement strategy realized and optimised by the CNR-IMAA group

Cirrus

Files characterized by the presence of cirrus clouds

EARLINET database

Diurnal cycle

Coordinated measurements performed in case of stable high pressure conditions in order to study the evolution of diurnal cycle

Etna

Observations performed during Etna's eruptive periods

Forest fires

Observations in correspondence of forest fire episodes

Photosmog

Observation of particular photosmog events

Rural-urban

Measurements performed at pretty close stations but with different characteristics (one rural and one urban) in cases of stable condition

Stratosphere

Measurements vertically extending up to the stratosphere for the stratospheric aerosol layer monitoring

METHODOLOGY

For this climatological analysis, only measurements from climatological category are considered.

Largely populated Saharan dust and Calipso categories could improve the statistics of this study, but they can also bias the study because, in case of Saharan dust intrusions, the aerosol content is higher than what typically observed, and because aerosol extinction measurements included in Calipso categories are typically performed in the middle of the night (around 2 am LT) when the aerosol content is very low.

On the other hand, Climatological category contains also some profiles belonging to other categories and on a sufficient large number of profiles these data will be representative of the natural variability and occurrences of special events at each station.

METHODOLOGY

For homogeneity with studies on aerosol impact on radiation budget and for the possibility of comparison and integration with widely used passive data, AOD has been selected for this first climatological analysis. This is just one of the optical properties measurable by lidar instruments, but up to now it is the primary investigated parameter for the aerosol impact on radiation budget.

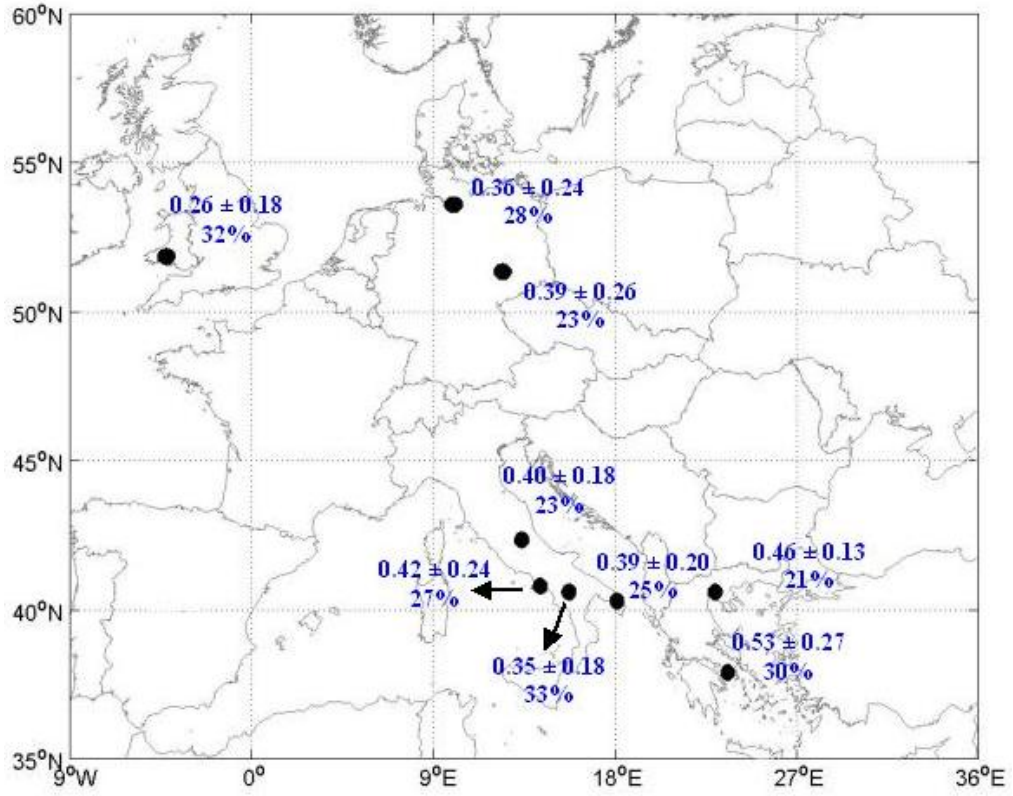
The contribution of the free troposphere to the total columnar aerosol optical depth is considered for taking into account the vertical distribution of the particles.

Only Raman stations are considered because able to measure directly the AOD.

Only QA EARLINET data are considered: May 2000-December 2007 period

Averaged AOD at 355/351

Standard deviation values are reported as errors and free troposphere contributions as percentage values.
Mean and standard values calculated in this way provide information about the typical aerosol load and its variability at each considered station.

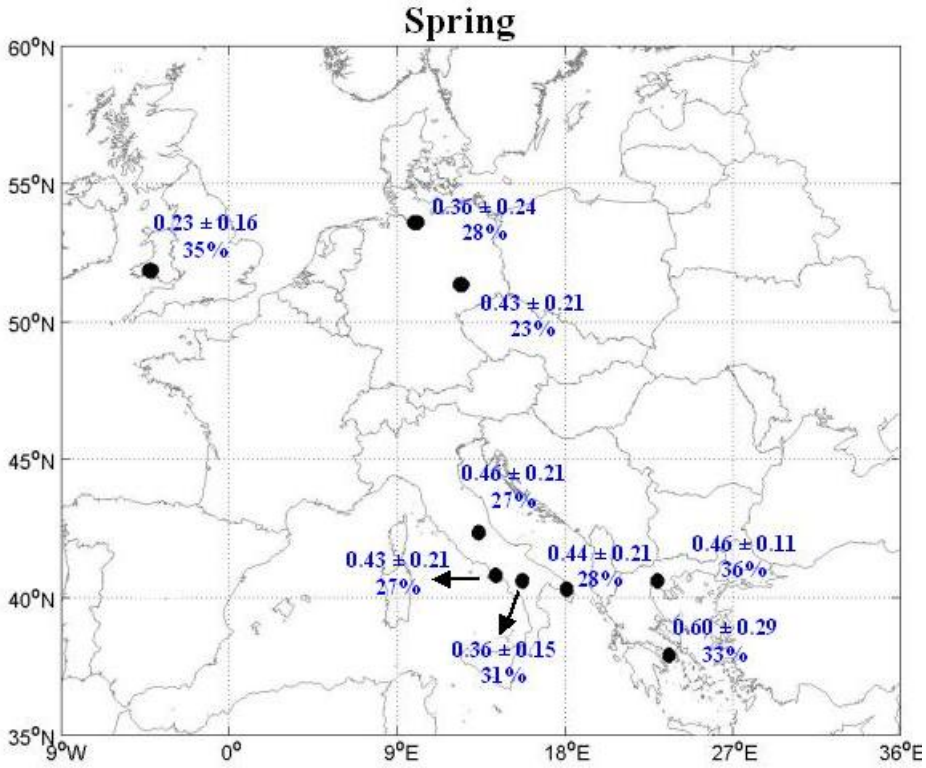


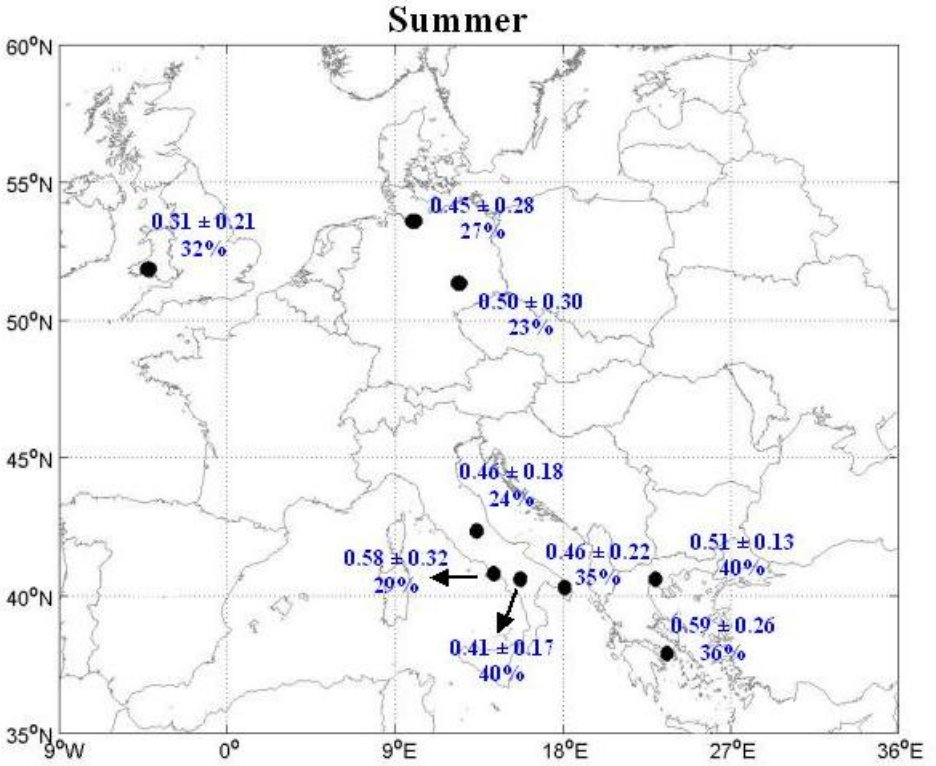
AOD typically higher at Southern Europe stations respect to Northern and Central Europe ones

larger AOD values are observed at Eastern Europe stations probably because of the pollution on East developing countries

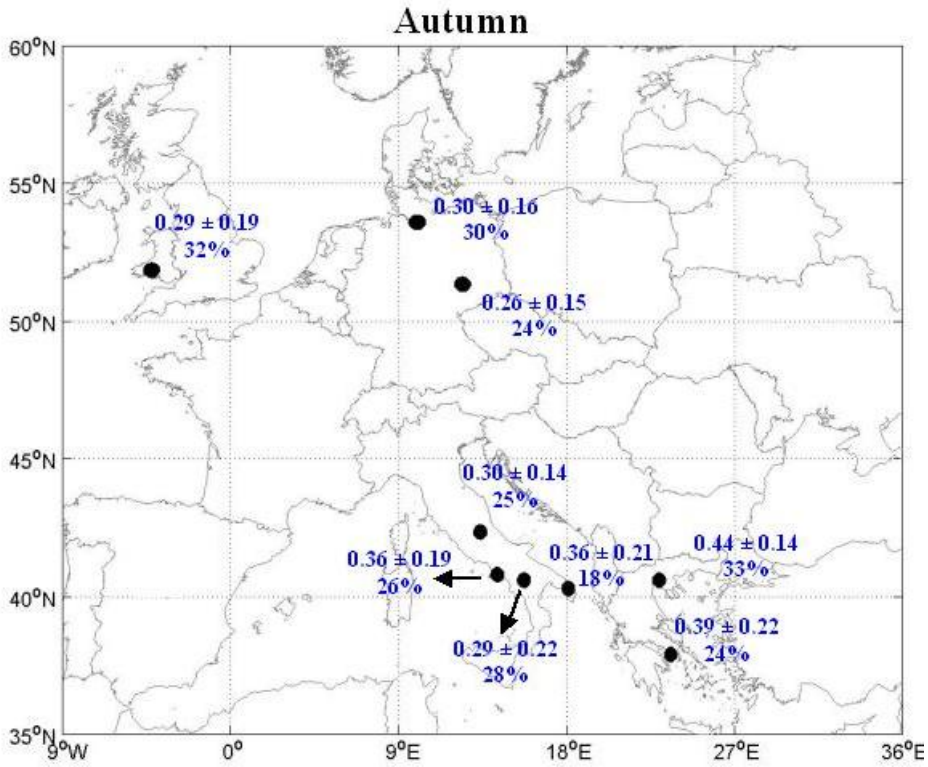
lowest values are observed at the maritime site of Aberystwith

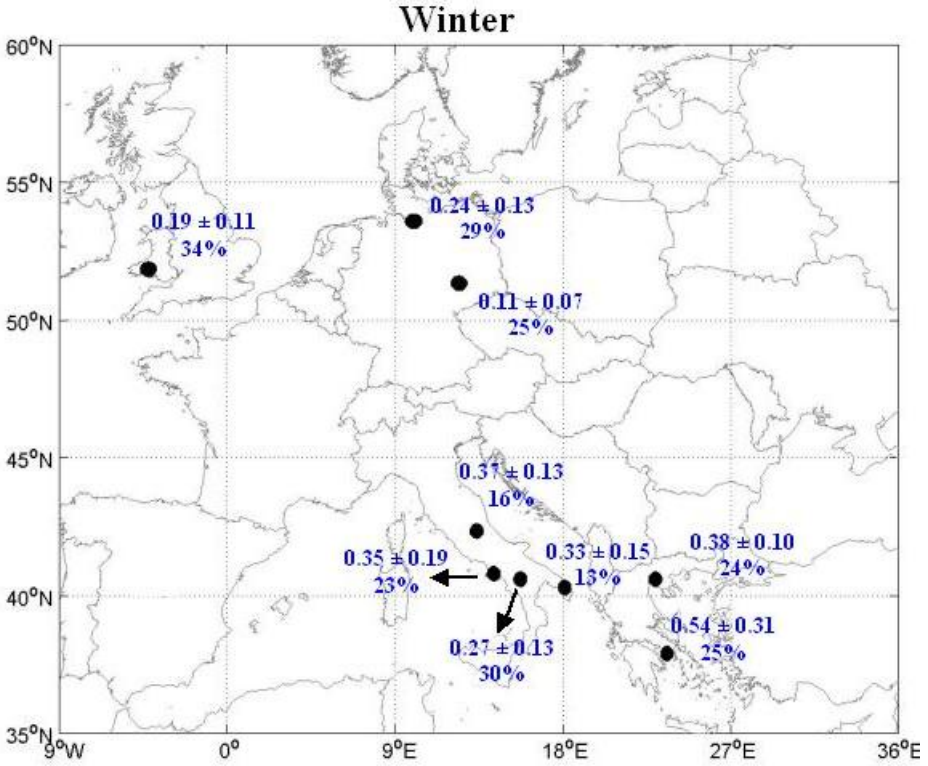
Seasonal Behaviour





Seasonal Behaviour





Seasonal Behaviour

High values are observed at Greek stations during the Summer where forest fires often occurs.

A strong seasonal dependence of AOD values is observed at Italian stations where the Saharan dust intrusions are very common during Spring and Summer seasons.

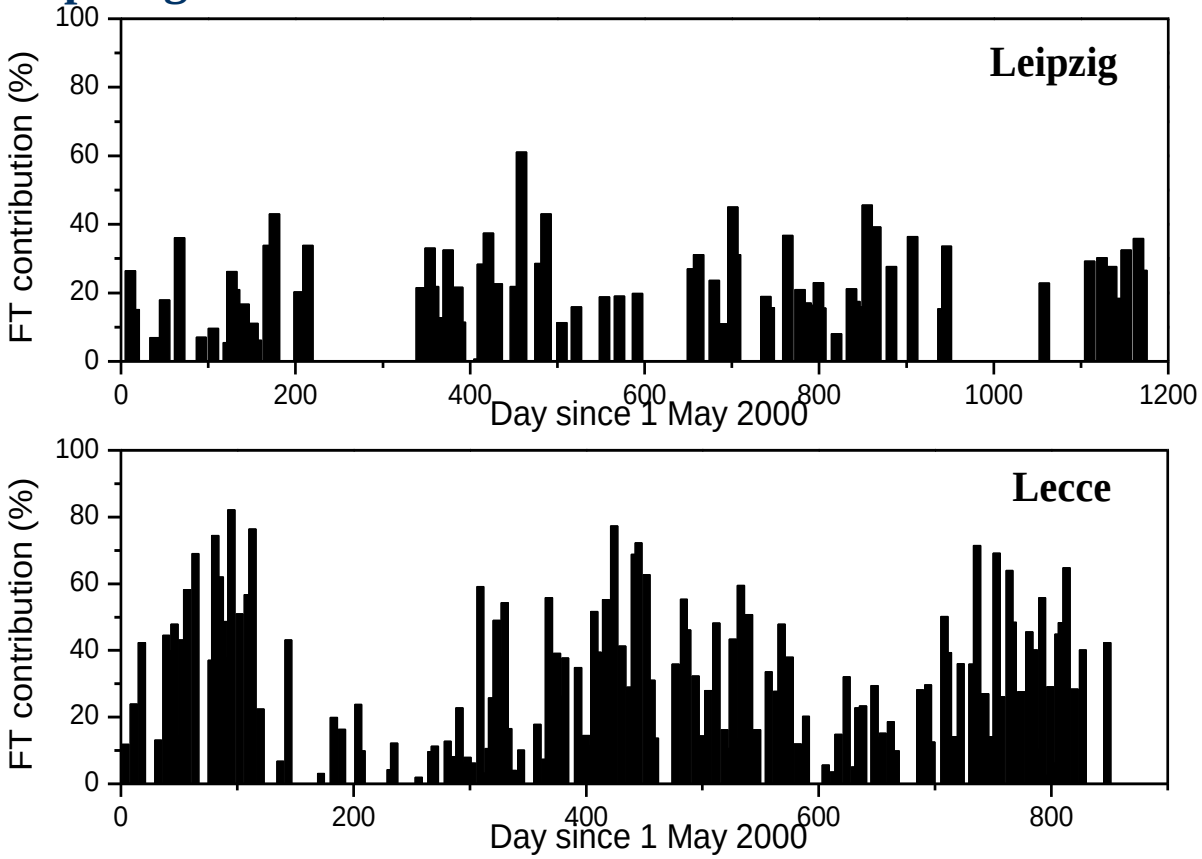
For all the stations, a smaller variability (measured by the AOD std) is observed during Autumn and particularly during Winter because of the low occurrences of forest fires and Saharan dust intrusions during these seasons and as a consequence of the favoured convective activities during the warmer seasons.

At Aberystwith the free troposphere contribution is almost constant during the year and is higher or at least equal to what observed at the other stations on the same period. This is probably due to the fact that the PBL contribution is lower at this unpolluted station.

Free troposphere contribution to the total aerosol optical depth is almost constant at Central Europe stations, as a consequence of the continental characteristics of this site.

Free Troposphere contribution

Free troposphere contribution (FT) to the total aerosol load is calculated in percentage to the total AOD starting from information provided by lidar about the PBL top height

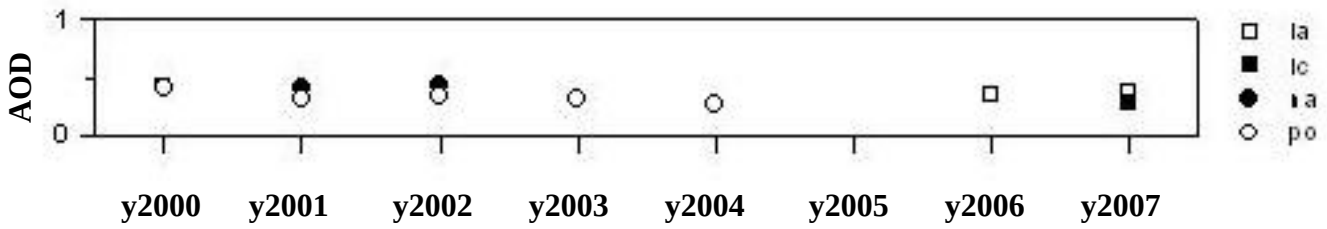


On average FT is about 30-35% for all considered stations.
Seasonal behavior due to Saharan dust episodes is evident in Southern Europe stations, where FT largely varies.

Multi-years behaviour

Annual averages calculated from the EARLINET Raman stations can be used to study possible trends in the aerosol load over the European continent. Annual averages are considered only if data are available for each season.

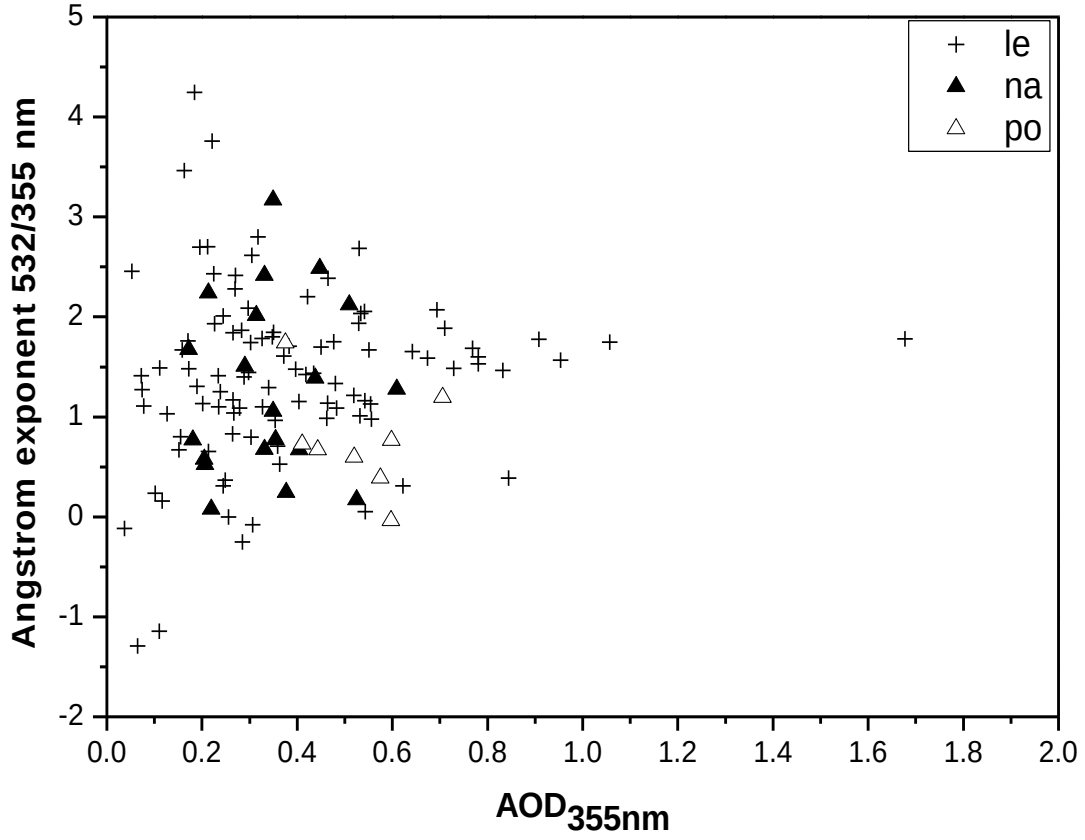
Example of annual behaviour over Italy.



A slightly decrease in AOD is observed from 2000 to 2003 with a new growth in 2004-2007 period.

Ångström Exponent @ 355/532 nm

Leipzig, Napoli and Potenza data are available for the period under investigation.



1.42 ± 0.88 @ Leipzig
1.29 ± 0.88 @ Napoli
0.75 ± 0.53 @ Potenza

Observed values spread between 0 and 3.
Large AOD values observed in Leipzig are related to cases of high aerosol load in PBL (>85% of the total) and Ångström exponent close to 2 (small particles).

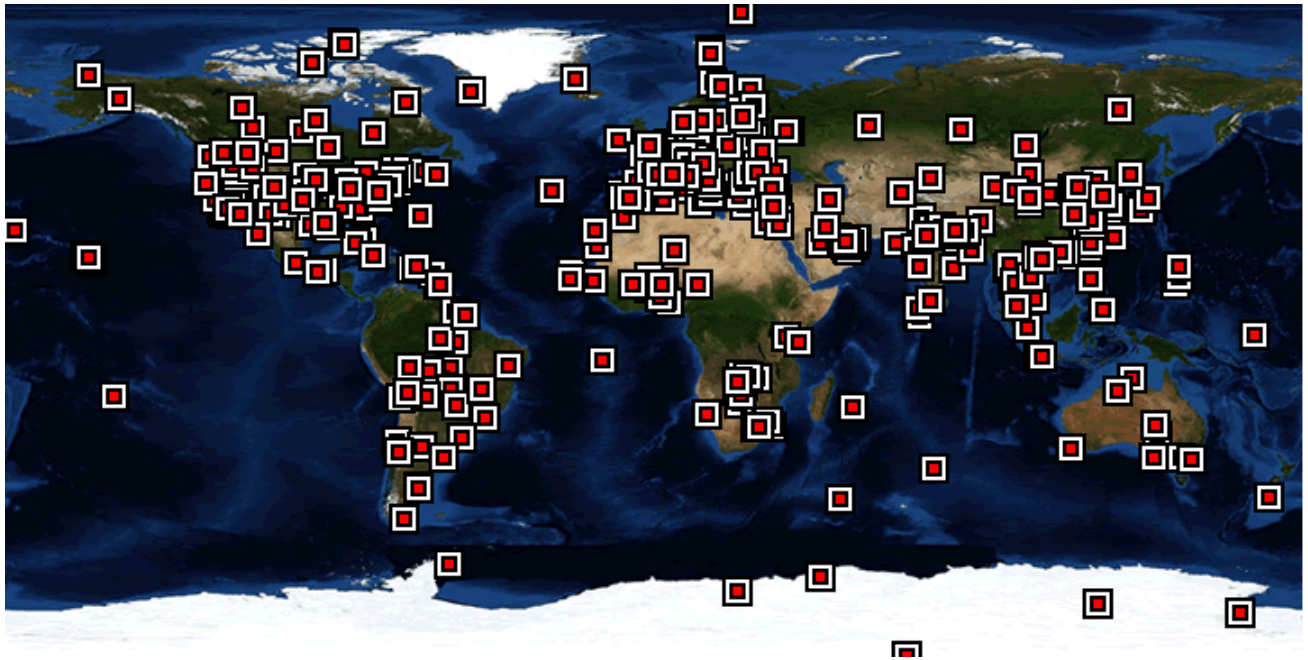
•**This climatological analysis of the aerosol optical depth at EARLINET stations allowed to investigate the Europe aerosol content on the base of the reference network for aerosol profiling.**

•**Raman lidar is recognized as the most powerful tool to investigate aerosol optical properties because it allows to obtain direct measurements of aerosol extinction (and therefore optical depth) without critical assumptions and to describe the aerosol vertical distribution.**

•**Current estimations of aerosol's effects on radiation budget are mainly based on columnar optical depth (AOD) measurements provided by AERONET Sun-photometer ground-based network and Modis satellite.**

•**Comparison and integration with data used in the past for assessment of aerosol impact on radiation budget are of primary interest.**

AERONET



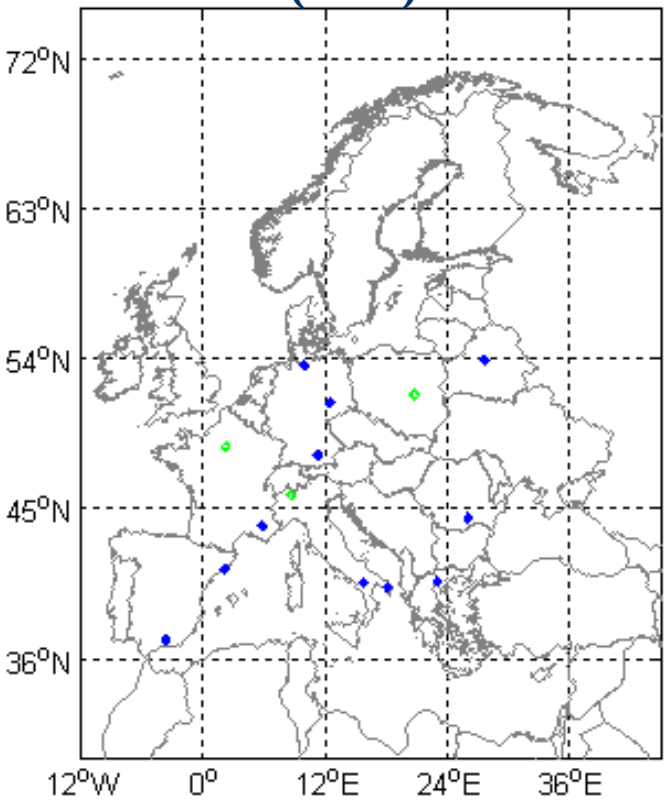
AERONET is the most extensive AOD network in the world with about 400 CIMEL automatic sun-photometers that provided aerosol measurements at about 800 sites (temporary and permanent) around the world since 1992.

Data are automatically analyzed and quality checked.

Spectral AOD, inversion products, and precipitable water are free and downloadable through AERONET website.

EARLINET-AERONET comparison

Co-located stations (2007)



blue = Raman EARLINET stations
green = elastic EARLINET stations

Comparison is performed in terms of the AOD

Only EARLINET Raman stations are considered.

Only QA AERONET and EARLINET data are considered
May 2000-December 2007 period

Only climatologic EARLINET measurements are considered in order to avoid bias due to special events occurrences.

In order to have a statistically significant comparison database, only stations with more than 100 extinction profiles retrieved during regular measurements have been selected.

EARLINET-AERONET comparison

Selected stations:

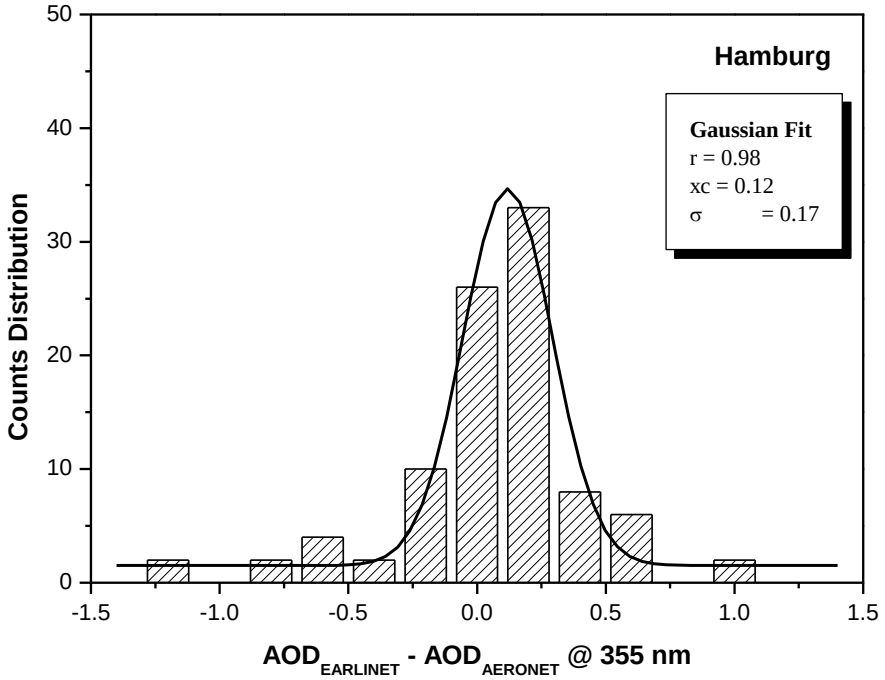
Hamburg and Leipzig in Germany, Potenza and Lecce in Italy and finally Thessaloniki in Greece.

For all these sites, vertical profiles of the aerosol extinction coefficient and AOD (on the whole column and in different atmospheric layers) are available at 355 (or 351) nm.

Leipzig EARLINET system is equipped with an additional receiving channel that allows the determination of AOD also at 532 nm.

AERONET AOD values are scaled to the lidar observation wavelength through the mean Ångström exponent measured by AERONET at the same station.

Difference of same-day measurements



Differences are on averages in agreement with zero, even if also large differences are observed.

Distributions are typically well fitted by Gaussian distribution centered around zero.

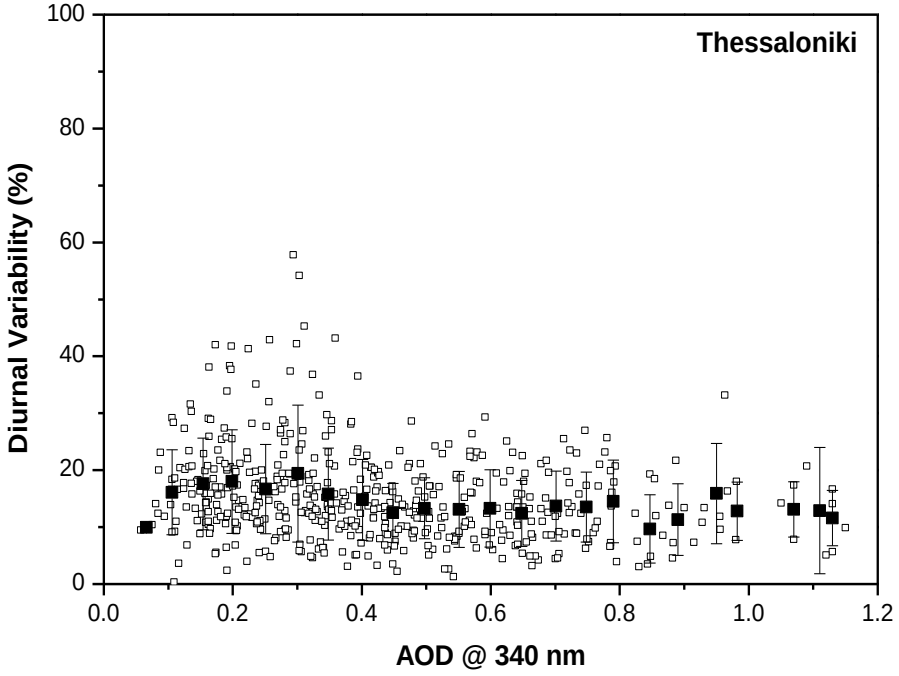
Some large difference values observed can be related to:
-no really simultaneous measurements
-presence of free troposphere layers

Station	$AOD_{EAR} - AOD_{AER}$	Cases number	Correlation coefficient	Center of fitting curve	Half width of fitting curve
Hamburg	0.05 ± 0.35	95	0.98	0.12	0.17
Leipzig	0.05 ± 0.20	44	0.93	0.04	0.16
Leipzig (532nm)	-0.001 ± 0.12	45	0.9	-0.005	0.13
Potenza	0.009 ± 0.22	41	0.94	0.023	0.14
Thessaloniki	0.15 ± 0.09	12	0.97	0.17	0.05

AOD variability

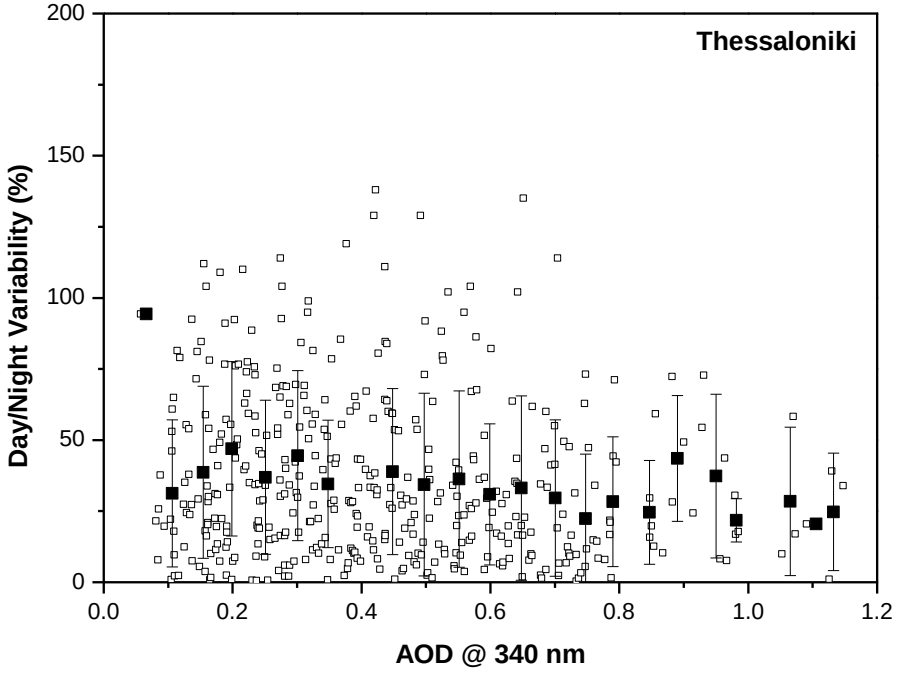
Diurnal variability: standard deviation of AOD measured by AERONET during the same day (respect to the diurnal average)

Day/night variability: difference between last value of 1 day and the first of the following (respect to the mean)



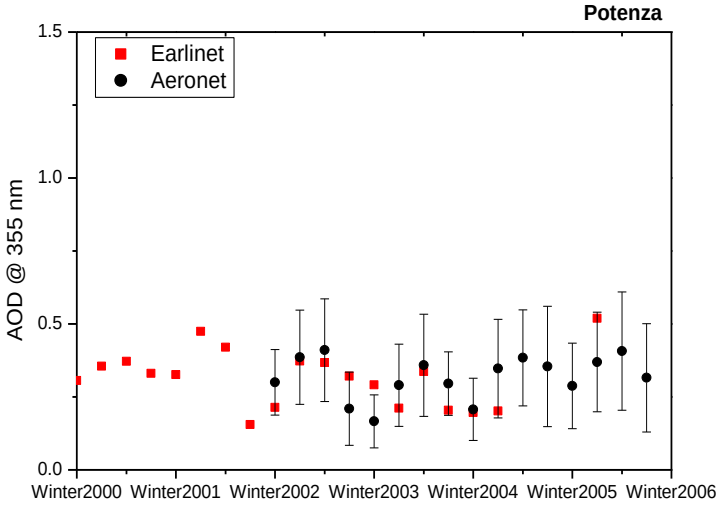
Typically 15-20% on average and constant with AOD. A large std is observed typically for AOD between 0.2 and 0.6.

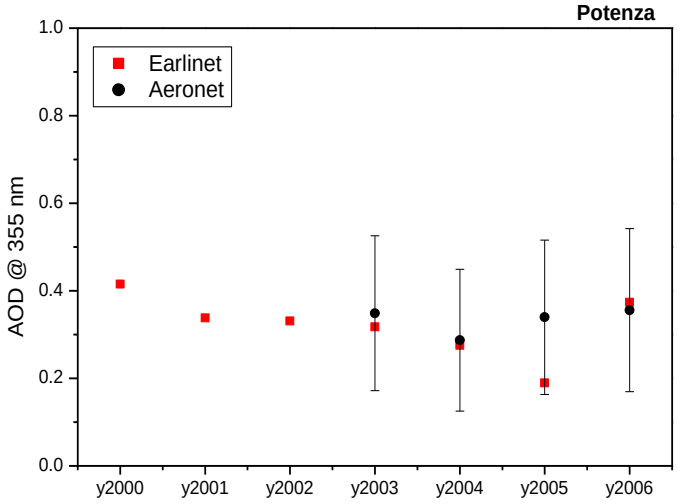
Typically 35-45% on average and constant with AOD. Values are more spread for AOD between 0.2 and 0.6.



EARLINET database is significant from a climatological point of view?

Station	AERONET	EARLINET
Hamburg	0.30 ± 0.23	0.36 ± 0.24
Leipzig	0.35 ± 0.22	0.39 ± 0.26
Lecce	0.33 ± 0.18	0.39 ± 0.20
Potenza	0.33 ± 0.18	0.35 ± 0.18
Thessaloniki	0.43 ± 0.23	0.46 ± 0.13
Leipzig 532nm	0.22 ± 0.15	0.22 ± 0.15

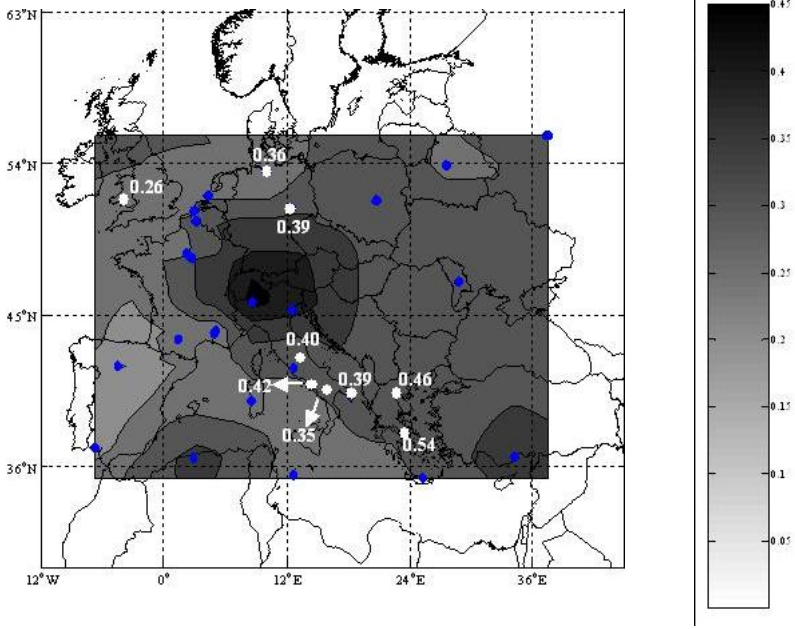




Good representativeness of EARLINET regular measurements (typically 50% of scheduled measurements are performed)

EARLINET geographical distribution is enough to avoid observational gaps?

Kriging approximation allows to provide a snapshot of the aerosol content over Europe and to understand if one database adds information to the other one or not.



- mean AOD values in the AERONET sites (blue points), averaged on at least 36 months measurements,

- contour map obtained using Kriging grid method

-mean EARLINET AOD values, obtained as average on all climatological quality assured data (white points).

EARLINET missing info:

-high aerosol content present over the Po Valley (elastic EARLINET station available at Ispra)

-towards Eastern Europe and Northern Africa (Sofia and Bucharest stations)

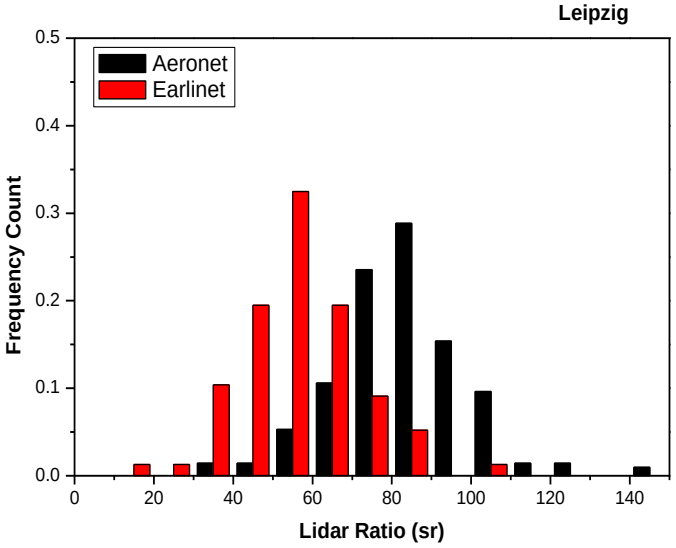
Ångström exponent and lidar ratio comparison

10 EARLINET stations have currently the capability to obtained simultaneously extinction profiles at 355 and 532 nm, even if regular data are not yet available.

For considered period, Ångström exponent is available only for Liepzig. mean values of 1.5± 0.8 (at 355-532 nm with lidar) and of 1.2 ± 0.3 (at 340-500

Station	AERONET 440 nm	EARLINET 355 nm
Hamburg	83 ± 16	61 ± 23
Leipzig	83 ± 19	56 ± 15
Lecce	74 ± 13	48 ± 24
Potenza	70 ± 14	39 ± 12
Thessaloniki	90 ± 14	45 ± 31
Leipzig 532nm	73 ± 17	57 ± 18

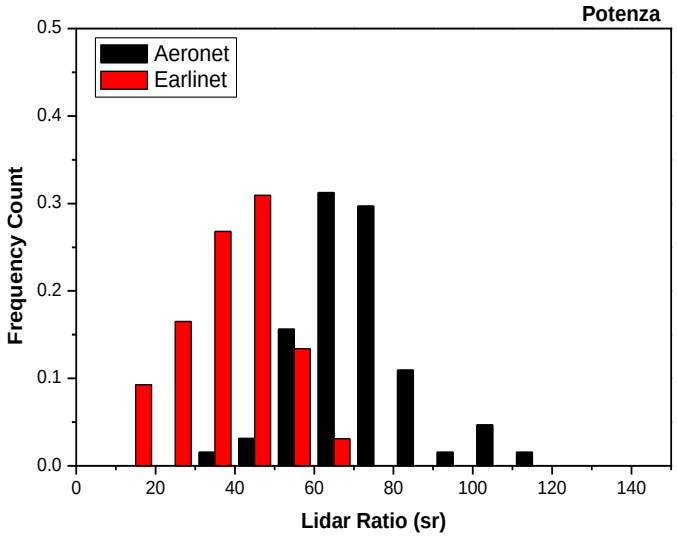
Lidar Ratio can be estimated by AERONET measurement of single scattering albedo and phase function.



$$S_i = \frac{4\pi}{\omega_0 P_i(180°)}$$

Ångström exponent and lidar ratio comparison

AERONET seems to overestimate lidar ratio effectively measured by lidars, in particular for the sites largely affected by Saharan dust events:Lecce, Potenza and Thessaloniki.



For Hamburg and Leipzig, a better agreement is observed both for the mean value and for the shape of the distribution itself.

Observed differences probably due to:

- Sun photometer does not measure the particle backscatter coefficient, but it is estimated from products of inversions

-columnar comparisons are affected by the large vertical variability observed

-comparison between daytime and nigh-time measurements: humidity and microphysical properties, and therefore lidar ratio, can strongly change.

EARLINET-MODIS comparison

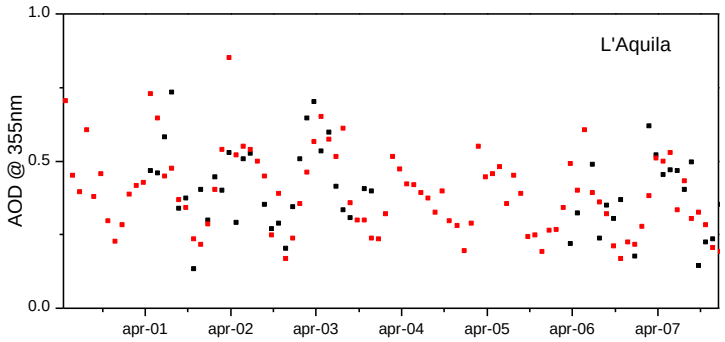
MODIS daily time series of aerosol optical depth at 550 nm of the collection 5 with a resolution of 1° × 1° data are considered.

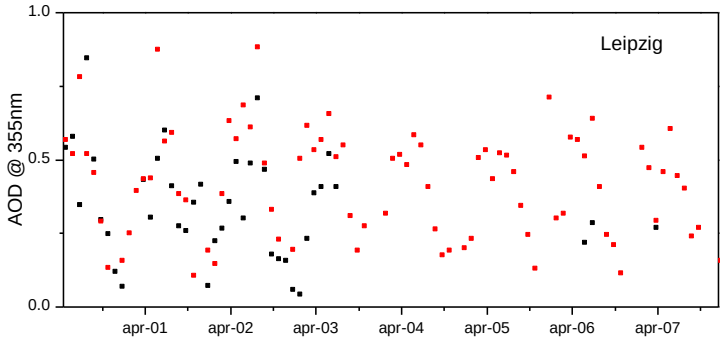
Measurements performed on the same day are compared.
Measurements collocation in time is not possible:MODIS are daytime data and EARLINET Raman data are only night time data.

For the climatological comparisons, only climatological EARLINET measurements are considered in order to avoid possible biases due to intense measurement periods related to special events observations.

MODIS data are scaled to the EARLINET measurement wavelength using the mean Ångström exponent measured at the closest AERONET station. In particular, EARLINET and AERONET instruments are co-located for Athens, Hamburg, Lecce, Leipzig, Potenza and Thessaloniki, while Mace-Head, Rome, and Potenza AERONET values are considered for Aberystwith, L'Aquila and Napoli, respectively.

Monthly Averages

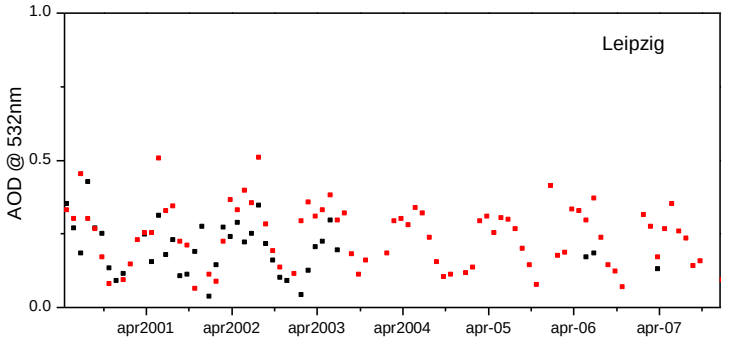




Modis: Red squares
EARLINET: Black squares

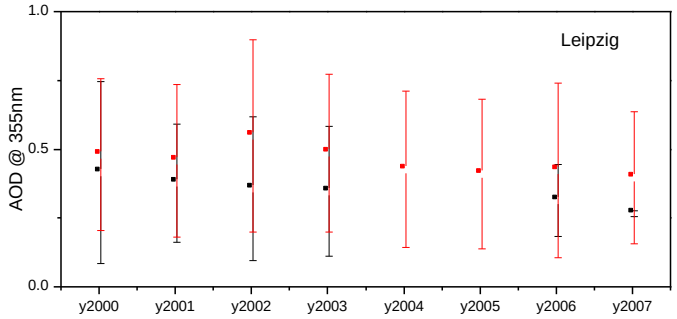
Seasonal behavior is typically seen by both lidar and spectrometer measurements with maximum during spring-summer and minimum during the coldest seasons.

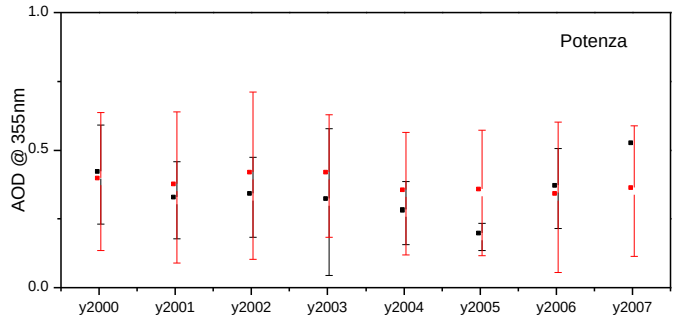
In general there is a good agreement between EARLINET and MODIS measurements.



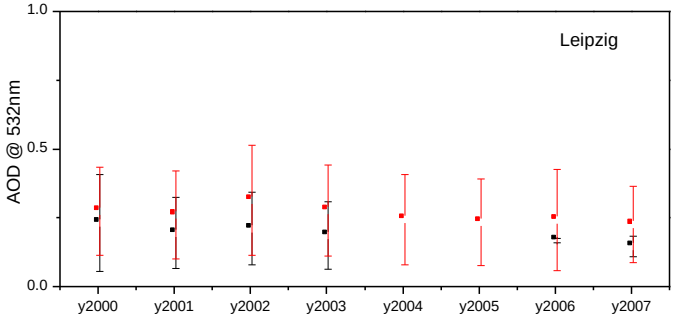
Annual averages

For almost all the stations, AOD in 2002 and 2003 is significantly higher than in the following years when the aerosol content decreases reaching a minimum around 2005/2006.





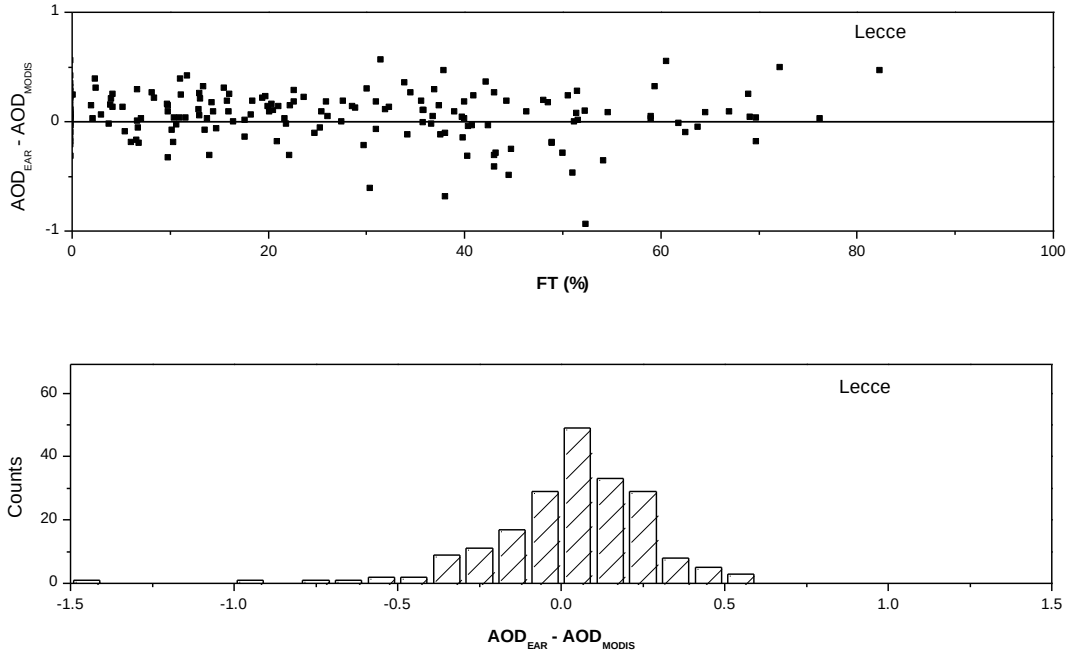
Even though within the errors, MODIS AOD is typically slightly higher than AOD measured by EARLINET stations. This could be related to :
-MODIS overestimation of AOD over land, but there could be other reasons for this difference
-small underestimation of AOD in EARLINET measurements could be due to the overlap function
-largest uncertainty in this comparison is the wavelength scaling through a mean Ångström exponent value.



This is confirmed by the better agreement obtained for Leipzig comparison at 532 nm rather than at 355 nm.

Difference of same-day measurements

Differences between EARLINET and MODIS AOD measured on the same day are calculated for each station. All available EARLINET data are considered independently from the observation category. If more EARLINET profiles are available for the same day, the mean AOD is considered for the comparison.

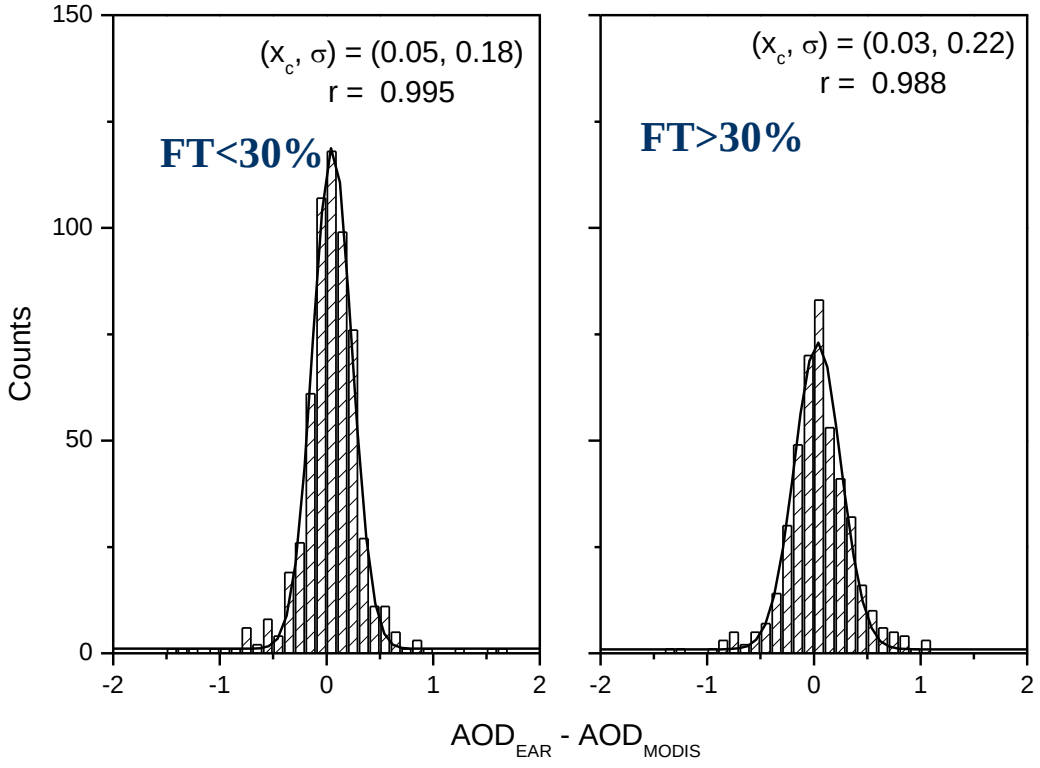


For all the stations, the mean differences are zero within the error.
The count distributions are typically well fitted by a Gaussian distribution (correlation coefficient higher than 0.9), centered at values lower than 0.05 with a half-width of 0.16.

Difference of same-day measurements

Considering all sites together, the differences distribution is well approximated by a Gaussian distribution centered around 0.04 with a standard deviation of 0.2. No bias is evident.

The probability distribution function of the EARLINET-MODIS differences for two classes defined by the FT contribution, lower and higher than 30% (typical mean FT observed over Europe).



Both distributions are well fitted by a Gaussian distribution with a mean value around 0.

Standard deviation of the fitting curve is slightly higher for cases with high FT aerosol load

in presence of high FT contribution, which typically indicates large scale processes, differences between satellites 1° × 1° measurements and punctual measurements of the AOD are typically more spread than for small FT contributions

Results

- Characterization of the typical AOD and FT over Europe

- Seasonal behaviour of AOD, its variability and FT contribution

- Comparison with co-located AERONET instrument demonstrates the representativeness of the climatological measurements scheduling established within EARLINET

- Comparison with MODIS 1°x1° data demonstrates the representativeness of AOD punctual measurements on this horizontal scale

Future plans

- Improvements resulting by the combined use of co-located AERONET and EARLINET measurements

- Comparison with others satellite passive instruments

- Investigation on horizontal representativeness (different horizontal scales)

- Investigation of representativeness taking into account vertical distribution of the aerosol

Acknowledgements

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