Study of the impact of mineral dust on the solar irradiance using ground-based remote sensors

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Mineral dust

Atmospheric mineral dust affects the Earth's radiation budget.
Aerosols force climate in two ways;

-direct radiative forcing: the scattering of incoming shortwave radiation solar radiation and the absorption/emission of the outgoing longwave terrestrial radiation.

-indirect radiative forcing, mainly by effects of aerosols on cloud properties. (A minor indirect effect involves the heterogeneous chemistry of greenhouse gases: these gases may react at the surface of an aerosol and therefore change radiative properties)

Aerosol radiative forcing depends upon its mineral composition (different minerals absorb and reflect different proportions of solar radiation), size and shape. For example, cylindrically shaped dust particles absorb more solar energy than spherical objects of equal mass.

Aerosol and Solar Energy Tools

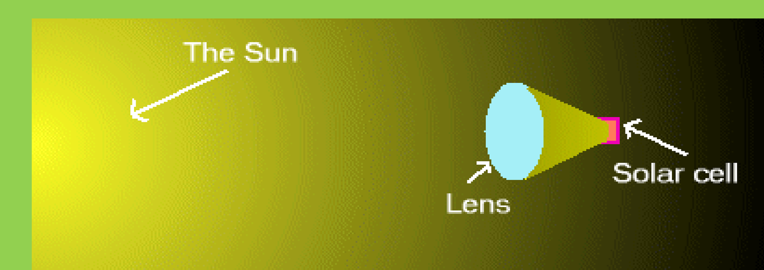
A quantitative characterization of the impact of climate variability at the regional scale is needed to increase the efficiency and sustainability of the energy system.
Aerosol and clouds effect on the radiation budget needs to be assessed for any solar application.

Both direct and diffuse components of the solar radiation needs to characterized

In particular, diffuse radiation is approximately 25% of the incident radiation when the sun is high in the sky, depending on the amount of dust and haze in the atmosphere.

About two-thirds of the sky radiation ultimately reaches the earth as diffuse sky radiation.

…and new technologies like solar concentrators can better exploit also the scattered sunlight.



OSCAR project

OSCAR is a project funded under the FESR 2007-2013 program
Specific objectives of the project are:

► Design and of a low-cost prototype-station able to provide integrated measurements for the quantification of the impact of climate variability on surface radiation;

► Development of a simplified methodology for the estimation of the impact of climate variability on surface radiation using a low number of measured variables as those measured by the OSCAR prototype;

► Study of correlation between the surface radiation, precipitation, aerosol and cloud properties using historical advanced data available at CIAO (CNR-IMAA Atmospheric Observatory- 40.60N, 15.72E, 760 m a.s.l.) running Potenza, Italy.

Partners: CNR-IMAA, FMI

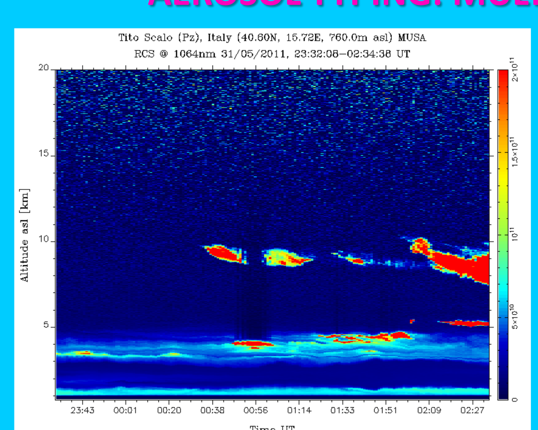
End of the project: December 2015

Dataset and approach

The following data collected from 2009 to 2013 at CIAO (CNR-IMAA Atmospheric Observatory - www.ciao.imaa.cnr.it) have been considered:

1. EARLINET multi-wavelength Raman lidars measuring in clear sky about five times per week (aerosol optical properties);
2. CIMEL sun photometer measurements and retrievals (aerosol radiances, aerosol optical depth, Angstrom coefficient, and radiative forcing estimation) provided by AERONET (aeronet.gsfc.nasa,gov).

AEROSOL TYPING: MULTI-λ RAMAN LIDAR + BACKTRAJECTORIES



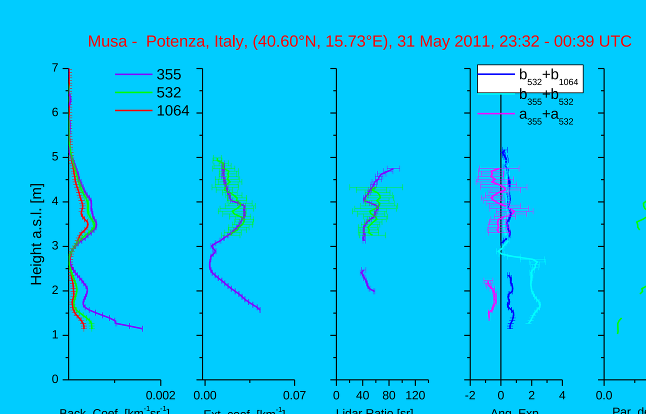


Figure 1: Left panel, time series of the range corrected signal at 1064 nm measured on the 31 May 2013 with MUSA lidar at CNR-IMAA Atmospheric Observatory (15.72E, 40.60N , 760 m a.s.l., Potenza, Italy); right panel, "3+2" analysis (including linear particle depolarization ratio) performed in the time range within 23:32 and 00:39 UTC on the same day.

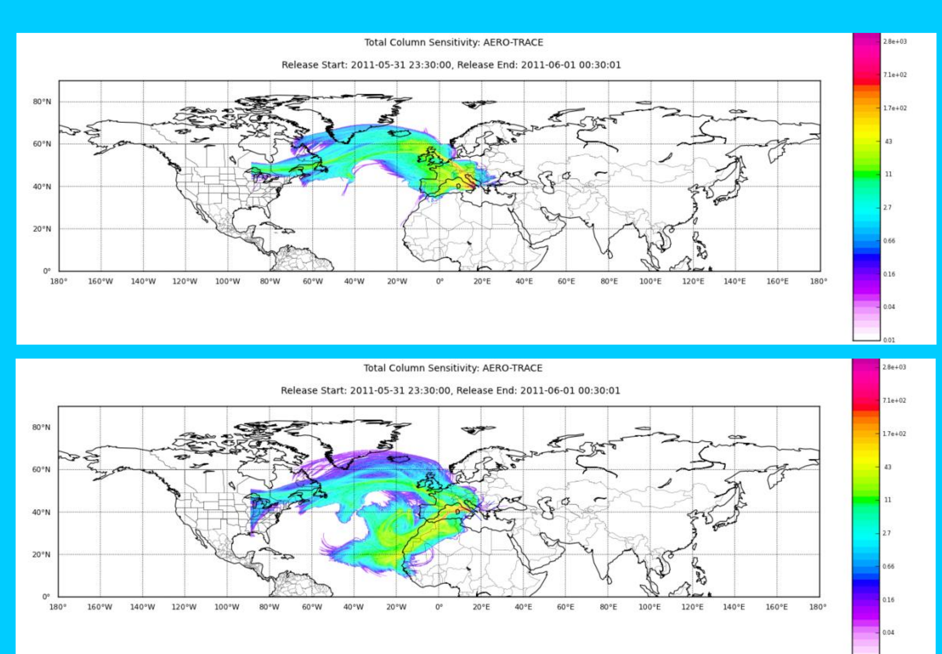


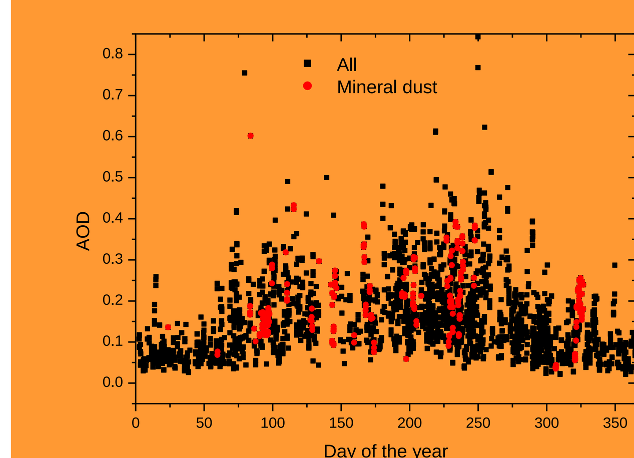
Figure 2: 7-day backtrajectory analysis calculated using FlexPART model for both the aerosol layer reported in the "3+2" analysis of the Figure 1.

Results

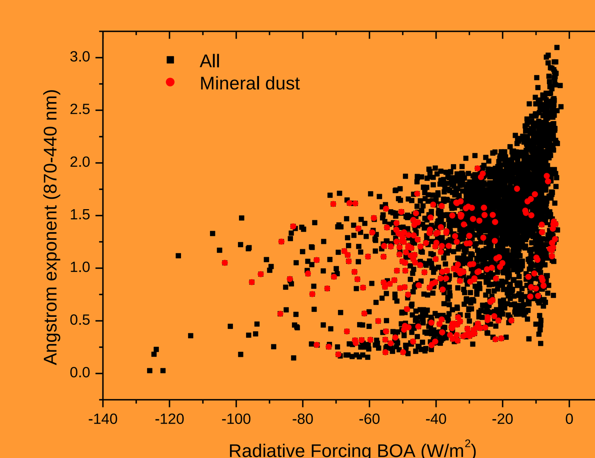
Aerosol optical properties and radiative forcing

The radiative forcing (RF) at the bottom of the atmosphere (BOA) as calculated by AERONET has been studied as a function of:
- quality assured (lv2.0) the aerosol optical depth and the 870-440 nm Angstrom coefficient retrieved using the sun photometer measurements;
- day of the year.

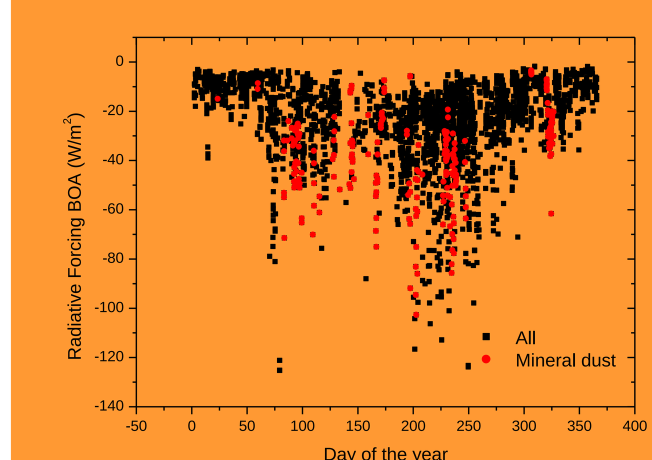
The data analysis shows the comparison between the radiative forcing for all the aerosol types (black dots) and for dust particle only (red dots).



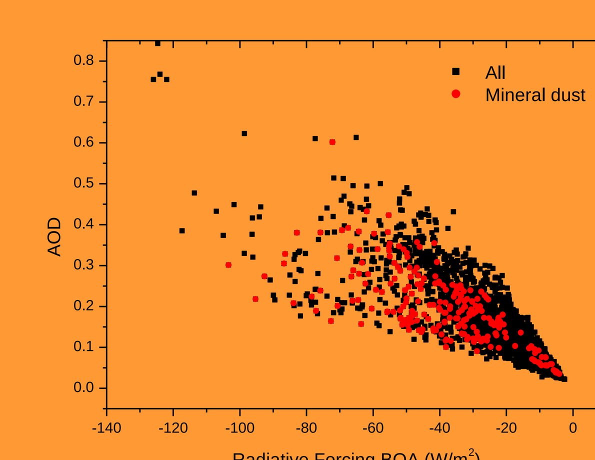
Most of the dust cases are observed from April to September but a few cases are also observed in Winter



Angstrom coefficient (inversely proportional to the particle size) show no precise correlation with the radiative forcing at BOA (Madonna et al., 2014). As expected, the size of dust particles is typically larger than the average of all the other aerosol types together.

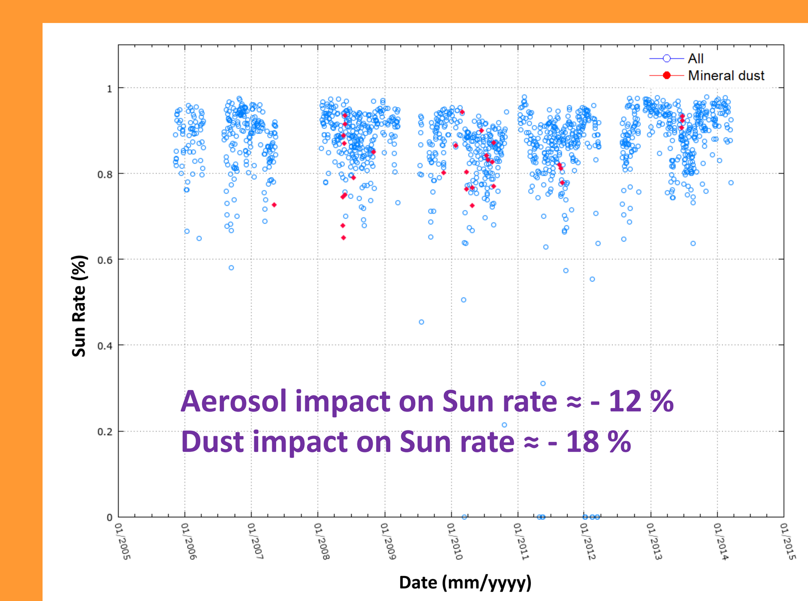


Dust RF at BOA is typically larger than -20 W/m^2 while for other aerosol types RF can be also lower. Correlation with column water vapor content and been investigated but without any signficant result.



The presence of a quasi-bilinear correlation between the RFs at BOA and the AOD is observed for all the aerosol types.
RFs at BOA within -100 W/m^2 and -80 W/m^2 are corresponding to an increase in the AOD between 0.2 and 0.4.
The slope of the dust data cluster provides more negative RFs at lower AODs with respect to the other aerosol types.

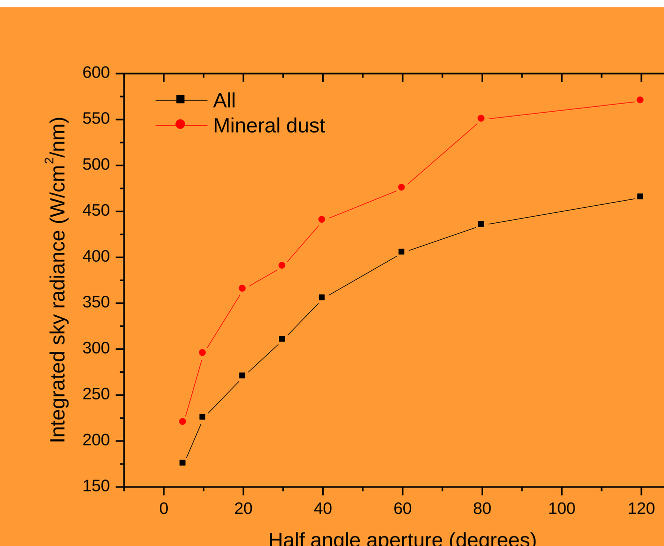
Direct and diffuse radiation



The direct and the diffuse components of the solar radiation have been studied.

Considering the Sun rate, more than 12 % of the solar direct radiance is lost in scattered radiation at the ground due to the presence of aerosol in the atmosphere;

In the case of mineral dust the Sun rate decrease of more than 18 %



Using AERONET scanning measurements, it is also possible to observe that:

- half of the scattered radiation is detected in ±10°, 2/3 of the scattered radiation is in ±40°, and

- a large increase in the radiation scattered by dust between 6° and 10°.

CONCLUSIONS

1. Mineral dust RF at BOA is typically larger than -20 W/m^2 , while for other aerosol types RF may have lower values.
2. Mineral dust show more negative values of the RFs at lower AODs with respect to the other aerosol types.
3. RFs shows a quasi-bilinear correlation with the at BOA and the AOD is observed for all the aerosol types.

The design of next generation of solar tools might consider the outcome of these kinds statistics to increase their efficiency

OUTLOOK

a. Comparison with radiation measurements performed with a surface radiation station (BRSN-like);
b. Correlate the statistics with the altitude of the aerosol layers in the free troposphere;
c. Enlarge the statistics by typing aerosol particles using only data from transport models, including the products provided by MACC-II (https://www.gmes-atmosphere.eu/services/sr/).

References

Madonna, F., F. Amato, L. Mona, M. Rosoldi, G. Pappalardo: *OSCAR : A portable prototype system for the study of climate variability*, in Proceedings of DUST2014, 1st International Conference on Atmospheric Dust, 1-6 June 2014, Castellaneta, Italy.

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