Project 14 (WP1): Impact of dust on Infrared radiation

Project lead: Paola Formenti and Yves Balkanski
Post-doctoral researcher : Claudia Di Biagio
Project Start/End : 5 October 2014 - 5 October 2016

Position offer:
The laboratory of excellence L-IPSL of the Institut Pierre-Simon Laplace offers a 2-year post-doctoral position to work on optical properties and radiative impact of mineral dust aerosols.

Context: Mineral dust is one of the most abundant aerosol species in the atmosphere and strongly contributes to the total aerosols content and direct radiative effect. At the present time, large uncertainties still exist in the estimation of the dust radiative effect and its climatic impacts. The reduction of these uncertainties is crucial in order to better understand the climate of the present, and in particular the role played by anthropogenic aerosols. Mineral dust can be considered, in fact, as part of the natural aerosol background, so the quantification of its radiative effect is a prerequisite for a more accurate assessment of the impact of the aerosols of anthropic origin on climate. The quantification of the radiative impact of dust aerosols represents also a necessary step to make projections on the climate of the future. Dust emissions are strongly sensitive to climate changes and the concentration of mineral dust is expected to largely change in the next decades as a consequence of changes in surface wind speed, precipitation, vegetation cover, or bare soil fraction. The changes in the radiative effect of dust aerosols associated with the modification in its atmospheric concentration will possibly contribute to the instauration of different climate conditions in the next decades. Due to all these considerations, the reduction in the uncertainties associated to the estimation of the mineral dust radiative effect emerges as a key scientific priority.

Due to its characteristic mineralogical composition and particle size distribution, mineral dust can affect both the solar and the infrared radiation fields by scattering and absorption. At present the main difficulty in estimating the dust direct effect is due to the incapability of quantifying the infrared contribution to its total radiative perturbation. One of the main causes for this is the poor knowledge of the dust optical properties and their variability.

Whereas in the last few years extensive work has been done to characterise the absorption properties of mineral dust in the shortwave, current available data on dust infrared optical properties mainly concern measurements of the refractive index of single minerals composing dust. However, due to the differences in the chemical/crystallographic state between the reference minerals and the minerals in the natural aerosol, and also to the difficulty of finding an appropriate mixing rule, the calculation of the dust refractive index based on information on its single constituents has been proven highly uncertain. On the other side, only very few studies, from a limited number of geographical locations worldwide, has been performed on natural aerosol samples. Hence, to date, the natural variability of the dust infrared refractive index and optical properties remains not represented.

Description of work: Within this context, the main aim of the postdoc is to work at improving the knowledge on the infrared optical properties of dust aerosols and associated radiative effects.

The work is performed based on two main tasks:

(i) the experimental development of parameterizations of the dust infrared optical properties as a function of mineralogical composition and size. This task is based on the mathematical inversion of infrared extinction spectra which are measured in situ IRFT spectrometry in the CESAM simulation chamber at LISA (CESAM, Experimental Atmospheric Multiphasic Simulation Chamber). The particle generation and injection protocols, which control the representativeness of the size distribution and the composition of the generated aerosol with respect to natural conditions, have been optimised with particular attention to the coarse-mode fraction which is the most efficient in interacting with longwave radiation. The particle lifetime of coarse particles is sufficiently long (several hours) in order to investigate the optical properties of the aerosol altered by the different ageing processes. Dust generation is performed by mechanical shaking of the soil grains liberate the grain finer fraction in a similar way that it is done by the sandblasting process during natural aerosol emission. The LISA has an extensive storage bank of natural parent soils from major source regions worldwide. These measurements will provide with the optical properties of mineral dust from different source regions, therefore of different mineralogy, in the fine and coarse size fractions.

(ii) the integration of those parameterizations in the scheme of LMDzOR-INCA coupled to RRTM radiative module .We will link the work of the first task to the global dust distribution by computing the radiative properties of mineral dust based on an original soil database that has been created at IPSL (Journet et al., 2014). This soil mineralogy database allows estimating the mineralogical composition of the airborne aerosols. The optical properties are calculated knowing, for each mineral fraction, the infrared complex refractive index taken from literature values. For a given source region, the result of these calculations will be constrained to the optical properties estimated experimentally in task 1. This will allow taking into account the regional variability of the mineralogical composition, which at present is not represented in climate models.

By combining (i) and (ii), it will be possible to perform simulations to analyse the climate sensitivity to the dust radiative effect including a realistic representation of the infrared radiative effect. Based upon our knowledge of size distribution and of the mineralogical composition we will also assess the uncertainties of both the SW and the LW radiative effect of aerosols which will allow constraining the whole impact of dust on climate.

Supervision team: Paola Formenti and Yves Balkanski

Duration and salary: 24 months with a net monthly salary around 2000 euros, commensurate with experience. This includes social services and health insurance.

Contact for applications: Applications should include a vita, a statement of interests and the names of at least two references including e-mail addresses and telephone numbers. Applications should be submitted by e-mail to J-L Dufresne (Jean-Louis.Dufresne@lmd.jussieu.fr).

Results:

During the first year of the postdoc the point (i) of the project was realized. Laboratory experiments were performed in the CESAM chamber by considering 19 aerosol sources worldwide. These sources were selected based on two criteria: 1) sources had to represent all major arid and semi-arid regions and 2) their mineralogy should envelope the largest possible variability of the soil mineralogical composition at the global scale. A summary of the mineralogical composition of the nineteen selected soils is shown in Fig. 1 in comparison with the full range of variability obtained considering the data from dust source areas worldwide. As illustrated by Fig. 1, the samples chosen for this study cover the entire global variability of the soil compositions derived by Journet et al. (2014).

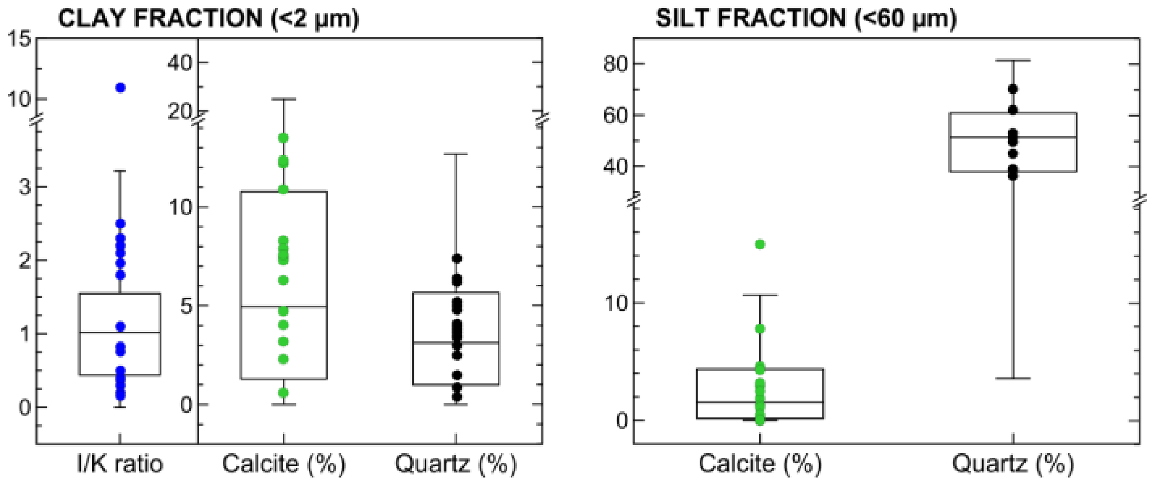

Figure 1. Box and whisker plots showing the variability of the soil composition in the clay and silt fractions at the global scale. Data are from the soil mineralogical database by Journet et al. (2014). Dots indicate specific mineralogical characteristics (illite-to-kaolinite mass ratio, I/K, calcite and quartz contents, extracted from Journet et al.) of the soils used in CESAM experiments.

The 19 different generated aerosol samples in the CESAM chamber were characterized by a realistic size distribution, including both the sub-micron and the super-micron fraction, and compare well with field data from different source regions (Di Biagio et al., 2016). Chemical analyses were performed to estimate the mineralogical composition of the aerosol dust samples. Main detected minerals include clays (illite, kaolinite, chlorite, smectite), quartz, calcite, dolomite, feldspars, and iron oxides. The different aerosol samples present a very different mineralogy, which well represents the heterogeneity of the dust composition at the global scale.

The dust extinction spectrum in the 2-16 µm spectral range was measured in CESAM. An inversion algorithm was then applied to retrieve the dust spectral complex refractive index based on the simultaneous measurements of the extinction spectra and particle size distribution. The retrieval algorithm combines Mie calculations, Lorentz formulation for electromagnetic scattering/absorption, and the Kramers-Kronig relationship linking the real and the imaginary parts of the refractive index (Di Biagio et al., 2014; 2016). The uncertainty on the obtained n and k is estimated at ~20%.

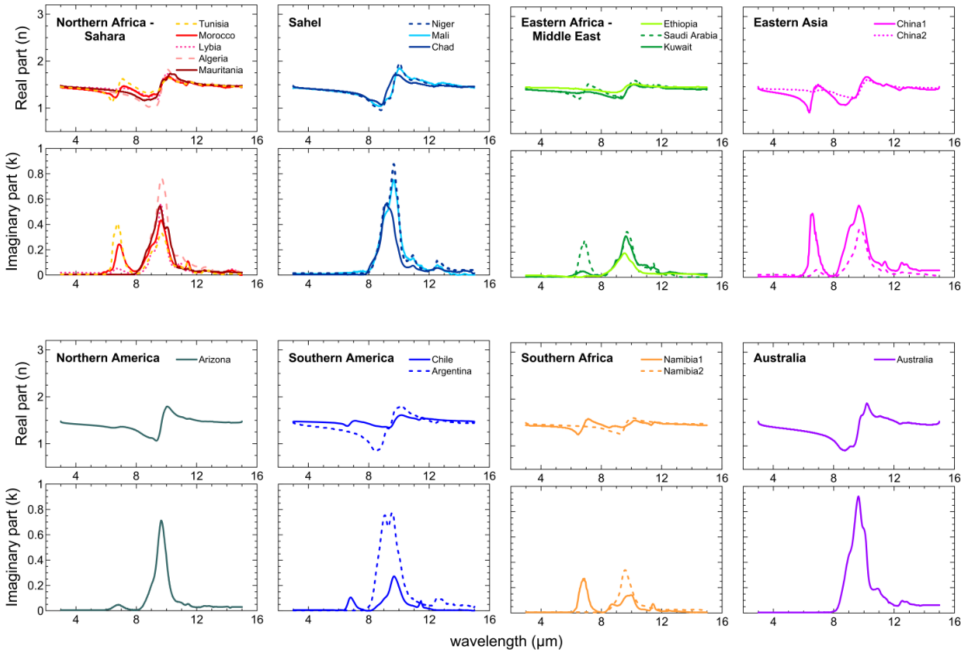

Figure 2. Dust spectral complex refractive index measured in the infrared spectral range for the 19 different aerosol samples considered in this study.

Figure 2 shows the range of complex refractive indices estimated in the LW for the 19 aerosol samples analysed. The dust LW refractive index largely varies both in magnitude and spectral shape for the different samples. Large differences are found between samples originated in different desert areas, as well as for dust in the same desert area, such for example Northern Africa or South America, which suggest refractive index variability both at the regional and at the global scale.

Absorption bands are linked to the presence of different minerals within aerosols, which in turn vary the origin of the samples. Absorption in the LW is controlled by clays, quartz, and calcite. A linear relationship was found between the magnitude of the imaginary part of the refractive index with calcite and quartz content at specific bands in the LW, as illustrated in Fig. 3. We suggest that these linear relationships may lead to predictive rules to estimate the refractive index of dust in specific bands based on an assumed or predicted mineralogical composition, or conversely, to estimate the dust composition from measurements of the extinction at specific wavebands. This can have key implications for the representation of dust in climate models and for remote sensing applications.

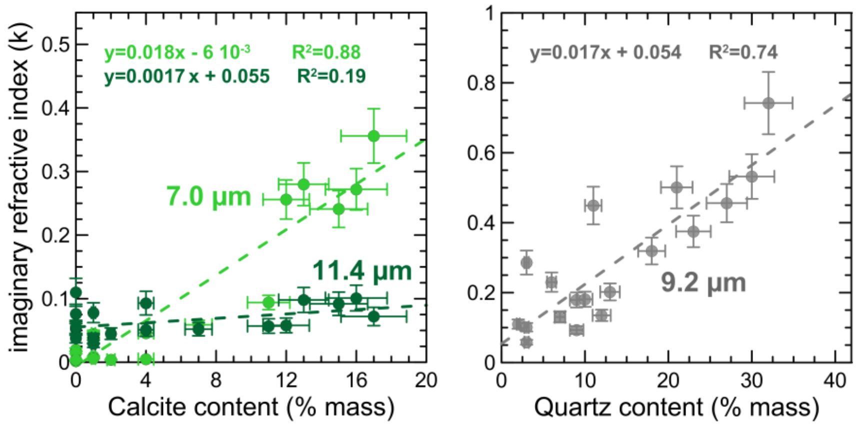

Figure 3. Imaginary part of the complex refractive index (k) versus the mineral content (in % mass) for the bands of calcite (7.0 and 11.4 µm) and quartz (9.2 µm). The linear fits are also reported for each plot.

Figure 4 shows the full range of variability of the real and imaginary parts of the dust LW refractive index. As shown in Fig. 4, at the global scale, the full range of variability of the dust refractive index is quite large. Our results in Fig. 4 are also compared with estimates of the dust refractive index from available literature studies. These literature values are nowadays used as the main references for dust longwave optical properties in climate models. In particular, Volz (1973) is the most used reference to calculate the dust radiative effect in the longwave spectral range.

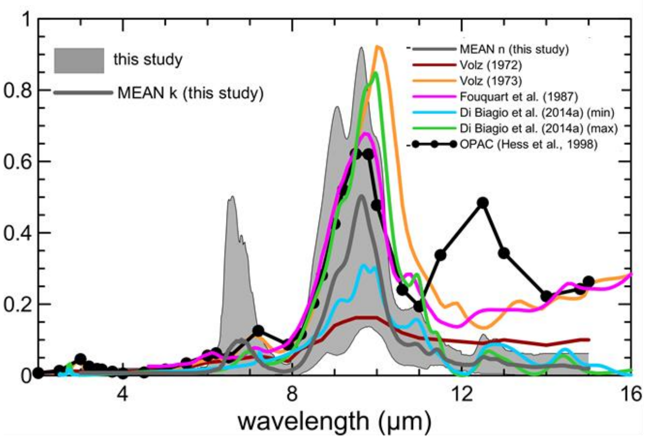

Figure 4. Full range of variability of the imaginary part of the dust refractive index in the UV-VIS and in the LW as obtained in this study, in comparison with values from the literature (Volz (1972) for rainout dust collected in Germany; Volz (1973) for dust collected at Barbados; Fouquart (1987) for Niger sand; Di Biagio et al. (2014b) from Algeria and Niger; Dubovik et al. (2002) from AERONET data; Patterson et al. (1977) for Saharan dust; Hess et al., (1998) for the the OPAC database).

Global simulations with the LMDz-OR-INCA model coupled with the RRTM radiative transfer module were performed to provide a new estimate of the dust LW direct radiative effect based on the new refractive index values. The results of the simulations at the surface, Top-of-Atmosphere (TOA) and in the atmospheric column are shown in Figure 5, also in comparison with the results obtained by using the Volz (1973) refractive index. The mean of the refractive indices from chamber experiments was used in the simulations. As illustrated in Fig. 5, with the new refractive index the dust effect in the LW is up to an order of magnitude less than what obtained with Volz (1973).

When the max and the min of the LW refractive index values from Fig. 4 are used in the simulations, the LW dust effect is between +0.018 – +0.111 Wm^{-2} at TOA, which in absolute values is 4-25 times lower that the effect in the SW estimated at -0.48 Wm^{-2} (Balkanski et al., 2007). These values obtained by using the new refractive indices values from chamber experiments thus bracket the variability of the LW dust effect at TOA, and evidences the fact that the use of literature values of the dust refractive index may induce a bias in the estimate of the global dust radiative effect.

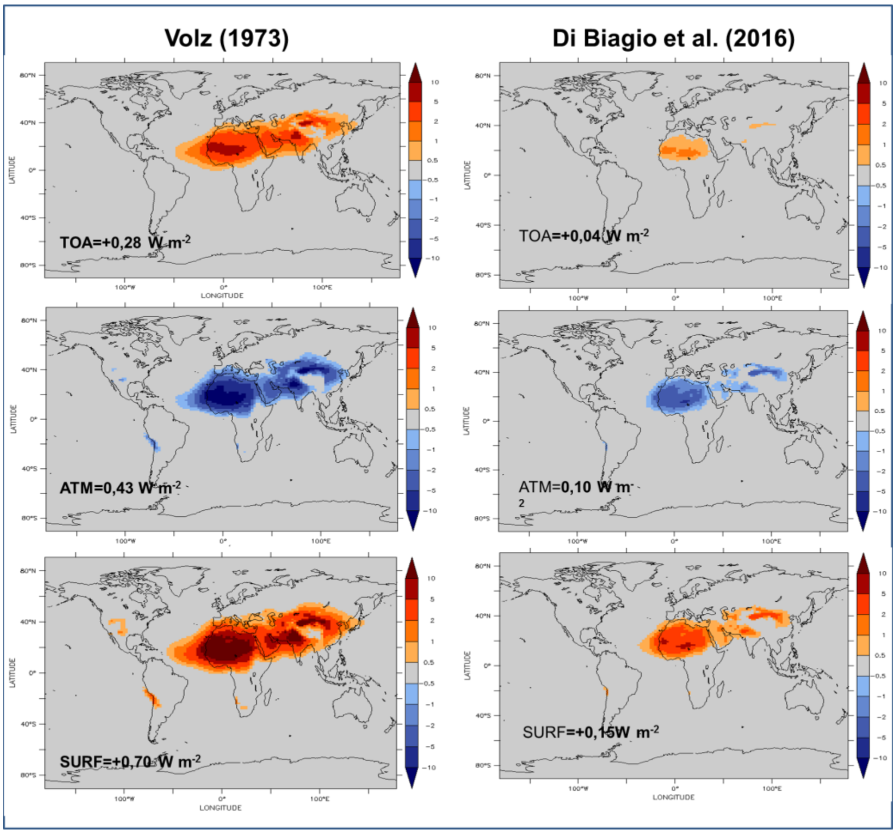

Figure 5. Global LW direct effect all-sky estimated with LMDz model coupled with the RRTM radiative module for dust by using the refactive index from Volz 1973 (left panel) and the mean from Di Biagio et al. (2016) (right panel). The global and annual mean of the dust direct effect all sky at the different levels is also reported in the plot.

Perspectives

Concurrently with the LW measurements, also the absorption and extinction spectra of dust in the SW range were measured during CESAM experiments. The inversion of these data in link with the particle size will allow estimating the dust refractive index and its global variability also in the SW (Di Biagio et al., in preparation). In particular, the link of the imaginary part of the refractive index to iron oxide content will be investigated, to provide explicit relationship linking these two parameters. This could be very helpful to improve the representation of the dust SW refractive index in climate models. The successive step will consist at performing model simulations also using the results in the SW, so to provide a new estimate of the variability of the dust radiative effect also in this spectral range. This will make us able to constraint the variability of the total dust direct effect on climate.

References

Balkanski, Y., Schulz, M., Claquin, T., and Guibert, S.: Reevaluation of mineral aerosol radiative forcings suggests a better agreement with satellite and AERONET data, Atmos. Chem. Phys., 7, 81–95, doi:10.5194/acp-7-81-2007, 2007.

Di Biagio, C., P. Formenti, S. A. Styler, E. Pangui, and J.-F. Doussin, Laboratory chamber measurements of the longwave extinction spectra and complex refractive indices of African and Asian mineral dusts, Geophys. Res. Lett., 41, 6289-6297, doi:10.1002/2014GL060213, 2014.

Di Biagio, C., P. Formenti, Y. Balkanski, L. Caponi, M. Cazaunau, E. Pangui, E. Journet, S. Nowak, S. Caquineau, M. O. Andreae, K. Kandler, T. Saeed, S. Piketh, D. Seibert, E. Williams, and J.-F. Doussin, Global scale variability of the mineral dust longwave refractive index: a new dataset of in situ measurements for climate modelling and remote sensing, *Atmos. Chem. Phys. Discuss.*, doi:10.5194/acp-2016-616, 2016.

Di Biagio, C., et al., Global scale variability of the mineral dust shortwave refractive index and single scattering albedo and relationship to iron content, *Atmos. Chem. Phys. Discuss.*

Journet, E., Balkanski, Y., and Harrison, S. P.: A new data set of soil mineralogy for dust-cycle modeling, Atmos. Chem. Phys., 14, 3801-3816, doi:10.5194/acp-14-3801-2014, 2014.

Volz, F. E.: Longwave optical constants of ammonium sulfate, Sahara dust; volcanic pumice and flyash, Appl. Optics., 12, 564-568, 1973.