LONG-RANGE TRANSPORT OF SAHARAN DUST OVER EUROPE OBSERVED BY LIDAR AND SUN PHOTOMETERS (EARLINET , AERONET) AND SATELLITE OBSERVATIONS.

L. Sauvage[1], J.Pelon[1], F. Fierli[2], P.Chazette[3], P. Goloub[4], C. Munoz[5], M. K Srivastava[6], M. Wiegner[7]

(1) Service d'Aéronomie, Paris, France
(2) ISAC, CNR, Rome, Italy
(3) Laboratoire des Sciences du Climat et de l'Environnement, Saclay
(4) Laboratoire d'Optique Atmosphérique, Lille, France
(5) Universitat Politecnica de Catalunya, Barcelona, Spain
(6) Observatoire de Neuchatel, Neuchatel, Switzerland
(7) Meteorologisches Institut der Ludwig-Maximilians-Universität, Munich, Germany

Email : laurent.sauvage@aero.jussieu.fr

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ABSTRACT

A strong dust outbreak over western Europe has been documented by means of lidar and photometer networks and satellite observations (TOMS, METEOSAT, MODIS). We observe distinct layers versus height above different lidar stations with high optical thickness. Depending on their height, these layers present very different properties. A main layer owed a high lidar depolarisation ratio up to 20% and very low angstrom coefficient near 0. Other layers up to 6km showed more mixed aerosol characteristics. We linked this layers and characteristics with the source regions south of Atlas mountain and in the Hoggar area, found from backtrajectories analysis,

INTRODUCTION

Dust particles play a major role in the atmosphere [Dulac et al., 1996]. It has indeed been shown from modelling studies that the radiative properties of mineral dust aerosol, depending on their size distribution, could induce regional changes in radiative flux at the top of the atmosphere as larger as $+15 Wm^{-2}$ at solar and $+ 5 Wm^{-2}$ at thermal wavelengths in the annual mean [Tegen et al., 1996]. However little is known about their vertical distribution and transport at the synoptic scale [Sokolik et al., 2002]. A few studieson Saharan dust transport has already been conducted using lidars [Karayampudi et al, 1999]. Recently the EARLINET lidar network has been deployed in Europe to establish a tri-dimensional aerosol climatology [Böesenberg et al, 2003] . It allowed especially to observe saharan dust transport events towards Europe [Papayannis et al, 2002].

Small and large size particles are both important in atmospheric processes. Small particles which have a strong radiative impact are expected to be transported over large distance. Large particles that have a more important surface which may favour chemical modifications in the atmospheric gas composition and may behave as ice nuclei. However, due to their size, they are expected to sediment quite quickly.

In this paper we describe the spatial distribution of dust during a major Saharan dust transport event which began on the 10th of October 2001, leading to particle transport towards northern Europe. We have analysed the evolution of the vertical structure of the dust layers and the changes in the microphysical properties during this transport. We show that the presence of large particles is observed far away from the source in the whole advected dust layer. It is shown that the dynamics of a frontal system allows to counteract the sedimentation process.

OBSERVATIONS

A strong frontal system was present over the western part of the Iberian peninsula on the 10th of October 2001. Moreover a high was centred above Tunisia. This pattern induced a high middle tropospheric jetstream oriented to the north. It initiated the transport of dust layers lifted above occidental Saharan regions towards western Europe.

We used for the analysis data from the EARLINET lidar. We also analysed measurements from the French airborne lidar LEANDRE that flew over Mediterranean sea and France, and photometer data (AERONET network) as reported in Figure 1. These data were combined with spaceborne measurements from TOMS, METEOSAT and MODIS to identify the source regions.

From the TOMS images, we can observe the presence of a dust cloud coming from the Sahara, crossing the Mediterranean sea towards Barcelona and south west of France and reaching north of France on the 12th (Figure 1). The dust was mainly located over western France.

RESULTS

The aerosol optical thickness above Bordeaux reached 1.4 on the 11th, a very high value that is coherent with MODIS data. More on the edge of the dust cloud, an AOT of 0.4 was recorded in Avignon during the following day when the dust cloud moved eastward. From the size distribution and angstrom coefficient values derived from photometer measurements, we conclude that the dust layer was mostly constituted of large particles. The distribution peak is centred at about 4µm above Bordeaux, Toulouse and Avignon on the 11th in the South of France The properties of the core of this dust cloud remained almost constant at Lille on the 13th and Leipzig on the 14th (Figure 2).

Lidar observations over South of France, Palaiseau and Neuchatel show a high depolarisation ratio up to 20% on a main layer at 3km (Figure 3). It indicates the presence of non spherical aerosols. Moreover, multiwavelength lidar measurements in Paris and Munich allowed us to determine for an angstrom coefficient. On the 12th and 13th of October we found very low angström coefficients between 0 and 0.3 in the main dust layer at 3km on the 12th of October over Palaiseau in the morning and on the 13th October over Munich. We also found this low angstrom coeff. on a layer near 4km above Munich. This indicates the presence of large non spherical particles in these layers. Other layers were detected but showed lower depolarisation and higher angstrom coefficient.

ORIGIN OF DUST LAYERS

Bakctrajectories and potential vorticity horizontal fields have been computed to get an indication of the origin of dust and better describe dynamical processes leading to the long transport northward. These last parameters have been derived from FLEXTRA model calculations using the ECMWF analyses (Stohl et al., 1999). From 3D backtrajectories we have tracked the different layers detected over lidar sites spread over Europe and link observations made over selected sites.
Air masses arriving over Palaiseau on the 12th at 10.30 UT originate from several locations of Sahara (Figure 4). Upper layer observed by lidar above 3km is coming from the west coast (an already lifted dust layers at 2km). The main aerosol layer (between 2 and 3km) finds its origin in the occidental saharan region south of Altas mountain (5W / 20-25N). This layer corresponds to quickly elevated layers from the ground. That may explain the difference of the properties between the different layers derived from lidar data, the main layer at 3km showing evidence of large non spherical particles.

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Other detected layers were coming from Hoggar region (0-10E/20-30N). We can expect from satellite observations and backtrajectories that this region was already contaminated by polluted air masses coming from east of Europe.

From potential vorticity field analysis we observe that instabilities were present in a layer between 900 and 650hPa on the edge of the jetstream. Moreover a strong upward motion was detected near the Atlas region. This PV tube oriented to the north make in evidence the layer in which large aerosols were imbedded and conduct up north.

CONCLUSION

A very strong event of saharan dust outbreak occurred from the 11th till the 16th of october 2001. The dust cloud has been advected towards western Europe. This event allowed us to characterize the dust particles, these particles having had no interaction with water clouds. Using lidar and photometer networks we followed the temporal and spatial evolution of aerosols above Europe.
Several layers have been detected from the ground up to 5,5km. A main layer was present around 3km, containing large and non spherical mineral particles
Other layers were composed probably of a mix of anthropogenic and saharan dust aerosols. This led to a different signature in the lidar signal than the one of the main dust layer (low depolarization and high value of angstrom coefficient).
We have linked the observed layers at different heights and above different lidar stations and found the source regions. We used for this purpose backtrajectories. We discriminated several source areas, two regions being located in the occidental saharan regions, a third one more in the west (Hoggar region). Other layers were detected above Europe and are coming from saharan regions but at higher altitude. The main layer detected at 3km over several lidar stations has been first lifted above the Sahara up to 6,5km by convective effects, synoptic dynamic forcing effect and also by orographic effect above Atlas mountain. The aerosols has then been maintained in the middle troposphere during several days and transported further than 5000km from their source region.
This kind of strong dust outbreak has been recorded several times since 2000. Impacts on European climate are not negligible. Then systematic observations should be carried on by homogeneous lidar networks and spatial observations.

REFERENCES

[1] Bösenberg J., et al., EARLINET: A European Aerosol Research Lidar Network, *MPI Report* Vol. 348, Max-Planck-Institut für Meteorologie, Hamburg, Germany, 2003.
[2] Dulac F., Moulin C., Lambert C.E., Guillard F., Poitou J., Guelle W., Quetel C.R., Schneider X., Ezat U., Quantitative remote sensing of African dust transport to the Mediterranean, *The impact of Desert*

Dust Across the Mediterranean, pp. 25-49, edited by S. Guerzoni and R. Chester, Kluwer Acad., Boston, Mass., 1996.
[3] Karyampudi M.V., Stephen P. Palm S. P., Reagen J.A., Hui Fang, William B. Grant W.B. , Hoff R.M., Moulin C., Pierce H. F., Torres O., Browell E.V., Melfi H.S., Validation of the Saharan Dust Plume Conceptual Model Using Lidar, Meteosat, and ECMWF Data, Bull Am. Soc., 80, No. 6, 1045 – 1075, 1999.
[4] Papayannis A., et al., Two years of continuous observations of Saharan dust events over the European continent using a coordinated lidar network in the frame of the EARLINET project, *Laser Remote Sensing in Atmospheric and Earth Sciences,* Proceedings of the 21st International, Laser Radar Conference, Quebec City, Canada, 349-352, 2002.

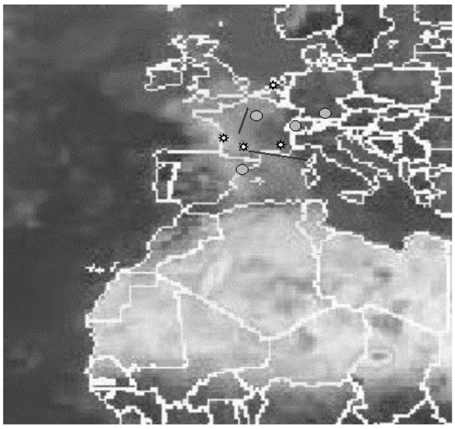

Figure 1 : TOMS aerosol index image. This shows the transport of dust from Saharan regions up to north of France. Photometer and lidar stations and airborne lidar track are respectively shown with stars, gray circles and black lines.

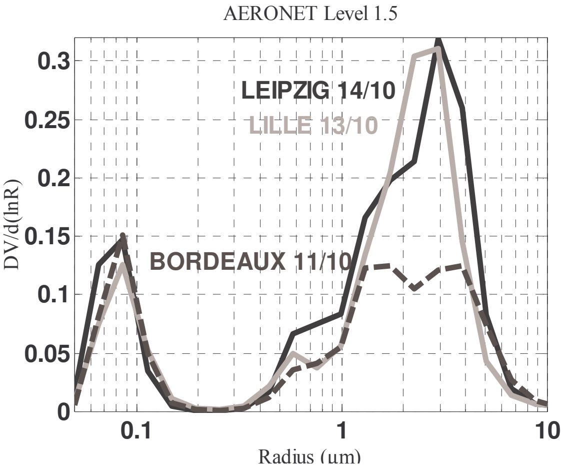

Figure 2 : Particle size distribution derived from photometer measurements at Bordeaux, France the 11th of october 2001, at Lille (North of France) on the 13th and Leipzig (East Germany) on the 14th. The coarse mode is well present on this picture between 1 and 7µm. It shows that the large dust aerosols were

[5] Sokolik I.N., Winker D.M., Bergametti G., Gillette D.A., Carmichael G., Kaufman Y.J., Gomes L., Schuetz L., Penner J.E., Introduction to special section : Outstanding problems in quantifying the radiative impacts of mineral dust, *J. Geo. Res.*, 106, D16, 18,015 – 18,027.
[6] Stohl, A., Haimberger L., Scheele M.P., Wernli H., An intercomparison of results from three trajectory models. *Meteorol. Applications* 8, 127-135, 1999.
[7] Tegen I, A.A. Lacis and I. Fung, The influence of mineral aerosols from disturbed soils on the global radiation budget, *Nature*, 380, 419 -422, 1996.

FIGURES

maintained in the middle troposphere during several days.

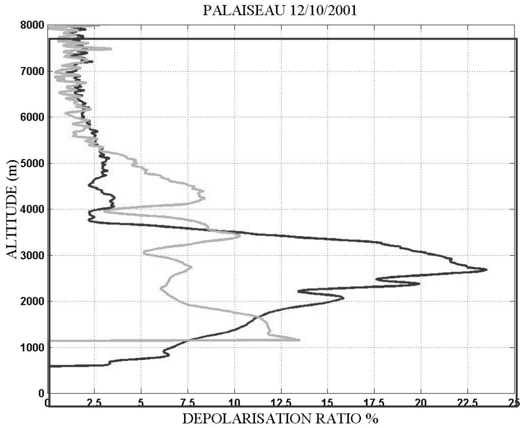

Figure 3 : Depolarization ratio vertical profile determined from lidar measurements at 532nm probed at Palaiseau on the 12th of october 2001 at 1030UT (gray line) and 1516UT (black line).

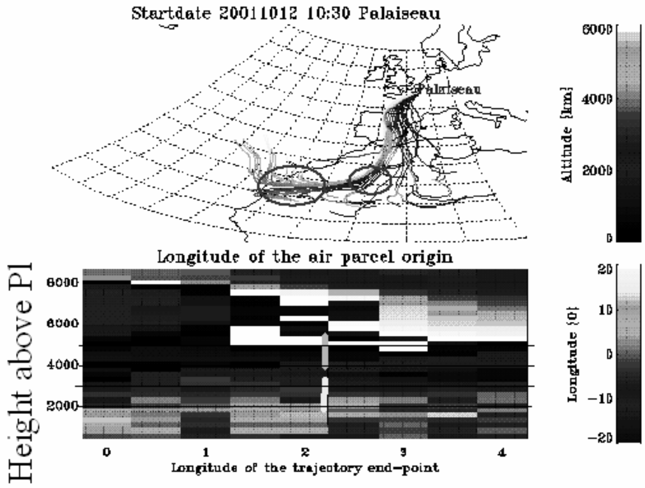

Figure 4 : Backtrajectories arriving at Palaiseau at different heights (using a step of 250m) on the 12th of October at 1030UT.