AEROSOL DISTRIBUTION OVER THE WESTERN MEDITERRANEAN BASIN DURING A TRAMONTANE/MISTRAL EVENT

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Abstract: This paper investigates experimentally and numerically the time evolution of the spatial distribution of aerosols over the Western Mediterranean basin during March, 24 1998 Mistral/Tramontane event documented during the FETCH experiment. Mistral and Tramontane are very frequent northerly wind storms (5-15 days per month) accelerated along the Rhône and Aude valleys (France) that can transport natural and anthropogenic aerosols offshore which can in turn have an impact on the radiation budget over the Mediterranean Sea and on precipitation.

Keywords: *Valley winds, Mistral and Tramontane, aerosols*

1. INTRODUCTION

The Mediterranean basin is featured by an almost-closed ocean basin surrounded by mountain ranges in which numerous rivers rise, a contrasted climate and vegetation from south to north, numerous and rapidly growing built-up areas along the coast with several major cities. Industrial activity, traffic, forest fires, agricultural and domestic burning are the main source of pollution in Europe whereas the close vicinity of the Saharan desert provides a source for considerable amounts of dust (Fig. 1). Aerosols contribute to decrease air quality

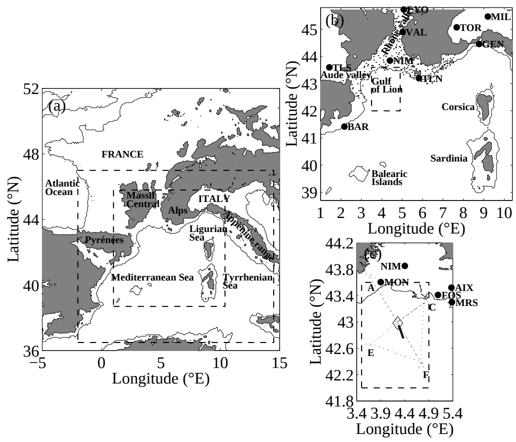

Figure 1: Map of France (a), of the western Mediterranean basin (b) and of the Gulf of Lion (c) with the topography shaded in grey when higher than 500 m above sea level. The rectangles in dashed line display the large, medium and small domains of the MM5 and CHIMERE simulations. The acronyms AIX, BAR, FOS, GEN, MIL, MON, MRS, NIM, LYO, TLN, TLS, TOR and VAL stand for the city names Aix en Provence, Barcelona, Fos/Berre, Genoa, Milano, Montpellier, Marseille, Nîmes, Lyon, Toulon, Toulouse, Torino and Valence, respectively.

on a large scale and reduce precipitation in the region (Lelieveld et al. 2002). They also affect the Mediterranean biogeochemistry by deposition of dissolved inorganic phosphorus, silicon and iron which constitute an important pathway for nutrients to the photic zone of the Mediterranean Sea.

The western Mediterranean climate is frequently affected by the Mistral and its companion wind, the Tramontane which are frequent severe northerly/northwesterly winds that develop along the Rhône and Aude valleys (Fig. 1) and advect the pollutants away from their sources of emission over the Mediterranean Sea. The FETCH experiment which took place in March-April 1998 in the Gulf of Lion (Hauser et al. 2003), offers an ideal framework to investigate the aerosol transport over the Mediterranean Sea during Mistral. The March 24, 1998 Mistral case is investigated with numerical simulations from the MM5 mesoscale model (Dudhia 1993) and the chemistry transport model CHIMERE (Vautard et al. 2001).

This article aims at analyzing: (1) the relation between the dynamic processes driving the small-scale structure of the Mistral flow and the aerosol distribution; (2) the amount of aerosol mass transported by the Mistral and Tramontane in addition to the background aerosol mass; and (3) the aerosol sources and composition, especially the sea-salts which can have a significant contribution under strong wind conditions.

2. THE MARCH 24, 1998 MISTRAL/TRAMONTANE EVENT

The March 24, 1998 Mistral event was featured by the existence of an upper level trough associated with a cold front progressing toward the Alps and a shallow vortex (1014 hPa) over the Tyrrhenian Sea between Sardinia and continental Italy, at 0600 UTC. As the day progressed, the low over the Tyrrhenian deepened (from 1014 to 1008 hPa between 0600 and 1500 UTC) while remaining relatively still. After 1500 UTC, the low continued to deepen (from 1008 to 1002 hPa) while moving to the southeast. The diurnal evolution of the Mistral and the Tramontane is evidenced on the 950 hPa-simulated wind field (Fig. 2). In the early stage

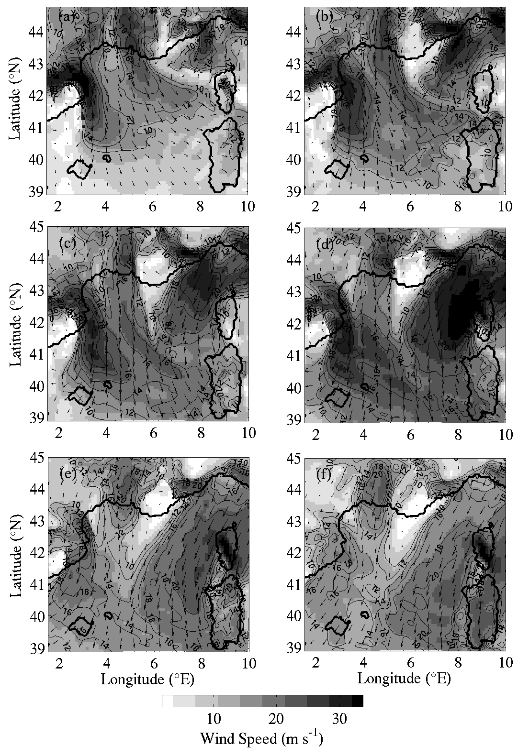

Figure 2: Horizontal wind fields simulated with MM5 (at 950 hPa) and extracted from domain 2 on March 24, 1998 at 0600 (a), 0900 (b), 1200 (c), 1500 (d), 1800 (e) and 2100 UTC (f), respectively. The isocontours represent the isotachs. Contour interval is 2 m s^{-1} from 10 to 20 m s^{-1}. The black solid line represent the coastline.

(low at 1014 hPa, 0600 UTC), the Tramontane flow prevailed over the Gulf of Lion due to the high position of the depression. The Mistral extended all the way to Southern Corsica. To the north, a weak easterly outflow was observed over the Gulf of Genoa. As the low deepened (1010 hPa), the prevailing wind regime shifted to a well-established Mistral peaking around 1200 UTC. The Mistral was observed to reach Southern Sardinia where it wrapped around the depression. At this time, the outflow from the Ligurian Sea (i.e., Gulf of Genoa) had become stronger. In the afternoon, the Mistral was progressively disrupted by the strengthening outflow coming from the Ligurian Sea in response to the deepening low over the Tyrrhenian Sea (1008 hPa, 1500 UTC) and the channelling induced by the presence of the Apennine range (Italy) and the Alps. In the evening, the Mistral was again well established over the Gulf of Lion as the depression continued to deepen (1002 hPa, 2100 UTC), but moved to the southeast reducing the influence of outflow from the Ligurian Sea on the flow over the Gulf of Lion. During this period, the Tramontane flow appeared to be much steadier than the Mistral and less disrupted by the return flow associated with the depression. This complex evolution of the flow affects directly the aerosol distribution over the western Mediterranean.

3. AEROSOL DISTRIBUTION AT THE SCALE OF THE WESTERN MEDITERRANEAN BASIN

During the morning period, the Genoa cyclone is located immediately to the east of Corsica. Over the southwestern region of the Mediterranean basin, large aerosol loading can be attributed to ship emissions (Fig. 3a, b). South of Sardinia, the air circulating around the Genoa surface low brings ship emissions to southern Italy.

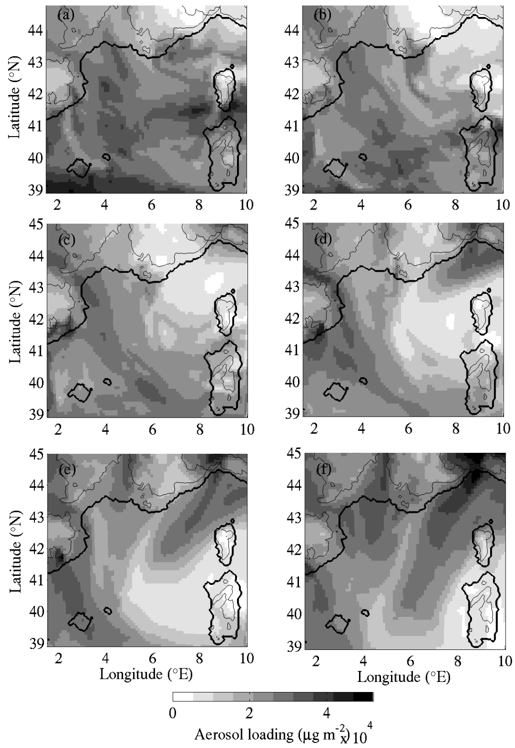

Figure 3: Aerosol loading over the western Mediterranean basin. Panels a, b, c and d display the particulate concentrations fields modelled with CHIMERE on domain 2 at 0600, 0900, 1200, 1500, 1800 and 2100 UTC, respectively. Solid lines represent the coastlines and elevations beyond 500 m.

North of this band, most of the aerosol loading over the Mediterranean Sea is of local origin (inter-continental ship tracks and coastal urban and industrialized area such as Barcelona, Marseille/Fos-Berre, Toulon), with one exception along the Aude valley where the Tramontane transports offshore continental aerosols. The plume over Toulon stagnates in the western Alps wake trailing downstream across the Alps. Finally, the close location of the Genoa cyclone from Corsica and the absence of strong winds during the morning period lead to the fact that the region north and northwest of Corsica is only influenced by marine clean air.

During the afternoon period, the Genoa cyclone intensifies and moves southeastward, about 300 km east of Sardinia over the Tyrrhenian Sea. The Tramontane has nearly vanished so that the polluted air of the morning stagnates in the Aude valley. Conversely, the Mistral has intensified and most of the aerosols exported offshore originates from central France and Marseille/Fos-Berre. The Ligurian outflow brings in the aerosols emitted from the major industrialized Italian cities (Milano and Torino) over the western part of the Mediterranean basin. This is consistent with aerosol optical depth values of 0.1 (the simulated AOD is about 0.09) and 0.3 at 870 and 440 nm, respectively, measured at Ispra (Italy) with the photometer of the AERONET network. A narrow band of clean air separates the two major plumes extending more than 300 km over the sea. This cleaner air corresponds to the western Alps wake and, associated with large horizontal shear of wind, acts as a dynamical barrier, preventing any lateral exchanges between the Mistral and the Ligurian outflow. The southeastward displacement and intensification of the Genoa cyclone increases the meridian extension of the Mistral that sweeps away the band of aerosols emitted from the ships that skirt the North African coast in the morning (Fig. 3c, d). All day long, sea-salts are put into suspension in the region of strong winds but their contribution to the overall aerosol loading ranges between 1 and 10 % only.

Figure 4 displays the amount of aerosol mass transported by the Mistral, Tramontane and the Ligurian outflow in addition to the background aerosol mass (computed from the CHIMERE simulations by taking the minimum value of the aerosol loading between March 23 and March 25 at every point of the simulation grid). It shows that the aerosols transported by the Mistral, Tramontane and Ligurian outflow are from marine origin and from the main industrial sources (Marseille/Fos-Berre; Po valley) and represent 3 to 4 times the background aerosol amount.

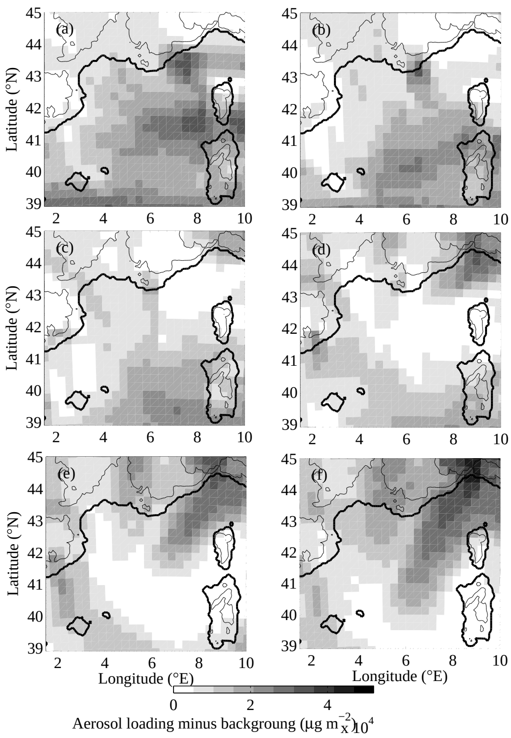

Figure 4: Same as Fig. 3 for the difference between the total aerosol loading and the background aerosol loading.

4. CONCLUSION

This paper shows that Mistral and Tramontane contribute to export far offshore a large amount of aerosols emitted over continental Europe (in particular ammonium nitrate and sulfates) and along the shore from the industrialized and urban areas of Fos-Berre/Marseille, as well as from the Po valley. The amount of aerosol loading solely due to the Mistral, Tramontane and the Ligurian outflow is as large as 3-4 times the background aerosol amount and the contribution of sea-salt particles to the total aerosol loading and optical depth ranges from 1 to 10 %. Due to the time evolution of the Genoa cyclone position, the aerosol concentration pattern is very unsteady, as the Tramontane prevails in the morning hours of March 24, leaving place to the Mistral and an unusually strong Ligurian outflow in the afternoon. The Genoa surface low contributes to advect the aerosols along a cyclonic trajectory which skirts the North African coast and reach Italy.

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REFERENCES

Dudhia, J.A., 1993: Nonhydrostatic version of the Penn State-NCAR mesoscale model: validation tests and simulation of an Atlantic cyclone and cold front. *Mon. Wea. Rev.*, **121**, 1493–1513.

Hauser, D., and co-authors, 2003: The FETCH experiment: an overview. *J. Geophys. Res.*, **108**, doi:10.1029/2001JC001202.

Vautard, R., Beekmann, M., Roux, J., Gombert, D., 2001: Validation of a hybrid forecasting system for the ozone concentrations over the Paris area. *Atmos. Env.*, **35**, 2449Ű-2461.