Case study of a Chinese dust plume reaching the French Alps

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[1] By combining reconstruction of airmass back-trajectories from dust deposition sites in Europe and measurements of the (Nd) isotopic composition of deposited dust particles, potential sources of different Saharan dust events can be identified. The study of "red dust" events collected in France allowed us to identify distinct North African source areas (e.g. Lybia *vs.* Mauritania). Surprisingly, the airmass trajectory of one dust event (March 6, 1990) was distinct from the others, and revealed a Chinese origin. The Nd isotopic composition of this dust was consistent with the range of isotopic compositions of Chinese loess. Moreover, an atmospheric global model simulation reveals that a dust plume left China before February 25, 1990, flew over North America around the February/March transition and reached the French Alps by March 6, 1990, revealing that intercontinental dust and pollutant transport may occur across the Pacific Ocean and the North Atlantic at the Westerlies latitudes. *INDEX TERMS:* 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0322 Atmospheric Composition and Structure: Constituent sources and sinks; 0345 Atmospheric Composition and Structure: Pollution—urban and regional (0305); 0341 Atmospheric Composition and Structure: Middle atmosphere—constituent transport and chemistry (3334); 0368 Atmospheric Composition and Structure: Troposphere—constituent transport and chemistry. **Citation:** Grousset, F., P. Ginoux, A. Bory, and P. Biscaye, Case study of a Chinese dust plume reaching the French Alps, *Geophys. Res. Lett.*, *30*(6), 1277, doi:10.1029/2002GL016833, 2003.

1. Introduction

[2] Dusts originating from the Sahara/Sahel region are frequently spread over the Mediterranean Sea [*Moulin et al.*, 1997], sometimes reaching France and even southern England [*Bücher and Dessens*, 1992]. These dusts can be easily sampled a few times a year in the French mountains – mostly in the Alps and the Pyrénées–where they suddenly cover snow surfaces with thin, red-to-brown blankets.

[3] The recognition of the source and transport pathways of these dusts can be addressed by different means. It is possible to analyze the mineralogical and/or geochemical composition of the dust, and to use this composition as a source fingerprint. It has been demonstrated that the study of the isotopic composition of the neodymium contained in the minerals, can be used as a powerful source-area fingerprint [*Goldstein et al.*, 1984]. By comparison to the composition of samples from the potential source areas (loess, sand dunes, etc), the location of a given dust source can be identified. Then, using archived meteorological data, it is possible, for a given fallout period, to reconstruct over a few days, the airmass backward trajectories responsible for the transport of these dusts, and then back to their source regions. This approach can be corroborated by satellite imagery (e.g. TOMS) for cloud-free areas [*Chiapello et al.*, 1999]. Finally, a global transport model driven by assimilated meteorology can be used to simulate dust deflation and long-range transport: it provides an independent constraint on the reconstruction of dust plume pathways. In this study, we have combined these three independent approaches for addressing the problem of the origin of the dusts collected in southern France.

2. Results and Discussion

[4] The Saharan dust is mostly made of crust-derived particles. Their mineralogical and geochemical composition is controlled by the lithology of the rocks from which they are derived and by the local climate and weathering regime. Naturally occurring stable and radiogenic isotopes are another potentially useful tracer to identify the source area. Dust particles derived from rocks of different lithologies and geological ages maintain an imprint of their crustal isotopic composition, e.g. $^{143}Nd/^{144}Nd$ [*Goldstein et al.*, 1984; *Grousset et al.*, 1998]. We thus have a suite of tracers which are characteristic of the source area. It has been demonstrated that combining airmass trajectory reconstructions and geochemical studies, permits pinpointing quite precisely the source regions of different dust fallouts [*Chester et al.*, 1984; *Bergametti et al.*, 1989; *De Angelis and Gaudichet*, 1991; *Chiapello et al.*, 1997; *Caquineau et al.*, 2002].

[5] Over the last 20 years, a few tens of red dust events suddenly covered snow surfaces in the Alps and Pyrénées mountains. They have been carefully sampled with plastic spatula and stored in clean bags [*Grousset et al.*, 1994]. For each of those, the Nd isotopic composition of their carbonate-free fraction has been analyzed [*Grousset et al.*, 1998]. The isotopic composition of Nd is usually defined by the $^{143}Nd/^{144}Nd$ ratio, which, for convenience, is normalized and reported as follows: $E_{Nd}(o) = ((^{143}Nd/^{144}Nd/0.512636) - 1).10^4$. Precision of the $E_{Nd}(o)$ measurements is $\leq \pm 0.2$. In northern Africa, $E_{Nd}(o)$ ranges from radiogenic values ($E_{Nd}(o) \approx 0$) in young volcanic areas to unradiogenic values ($E_{Nd}(o) \approx -20$) such as those observed in the Mauritania Archean provinces [*Grousset et al.*, 1998]. When comparing the data obtained on the particles sampled in Alpine and Pyrenean snows, to those of the isotopic composition of the different dust fields of North Africa, it appears that the dusts reveal generally a North African origin. Here we present

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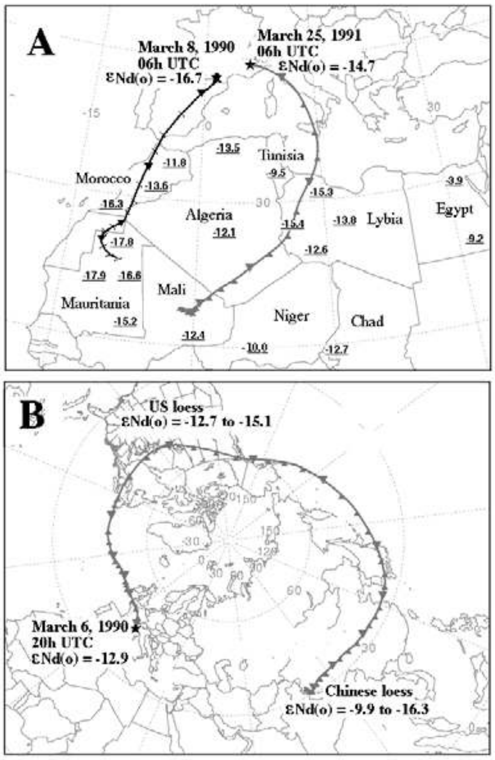

Figure 1. (a) Back trajectories reconstructed using the NOAA ARL Website (www.arl.noaa.gov/ready/), CDC1 meteorological data. 1) trajectory ending at 06:00 UTC, on March 8, 1990 (*dark pathway*); duration 96 hours, ending altitude: 3500 m above sea-level (ASL). Dust sampling site (Pyrénées, 2850 m ASL) symbolized by a black star. 2) trajectory ending at 06:00 UTC, on March 25, 1991 (*grey pathway*); duration 144 hours, ending altitude: 4000 m ASL. Dust sampling site (Mercantour, Alps, 1450 m ASL), symbolized by a grey star. Airmass positions are located every 6 hours (hachures) and every 24 hours (triangles). Underlined numbers represent E_{Nd}(o) values obtained on North African sand deposits [*Grousset et al.*, 1998]. (b) Backward trajectory ending at 06:00 UTC, on March 6, 1990; duration 315 hours, ending altitude: 3500 m ASL. Dust sampling site (Alps, 1450 m ASL) symbolized by a black star.

two examples of dusts collected in southern France and clearly derived from North African sources (Figure 1a). The following interpretations are based on both the dust isotopic composition and the reconstruction of airmass backward trajectories. We show two back-trajectories reaching the French Alps and Pyrénées from North Africa (Figure 1a) and another from East Asia (Figure 1B). The Nd isotopic signature of the March 8, 1990, dust event reveals an unradiogenic composition (E_{Nd}(o) = −16.7). Looking along its airmass pathway, it appears that such a negative value can only be found in the Mauritanian region. Now, if we consider the evolution of that airmass (Figure 1a), dust deflation must have occurred from northern Mauritania 2-to-4 days prior to its arrival in France. On the same figure, the Nd isotopic signature of the March 25, 1991 dust event to the northeast reveals a slightly more radiogenic composition (E_{Nd}(o) = −14.7). Considering the more easterly trajectory of its related airmass, this dust plume can only be linked to a Lybian source with similar negative values.

[6] The isotopic signature of the March 6, 1990 dust event in Figure 1b reveals an even more radiogenic Nd composition (E_{Nd}(o) = −12.9), than the two samples reported in Figure 1a. This kind of signature could be attributed to a North African origin (e.g. Lybia? Chad? Mali? Algeria?). The backward trajectory associated with this event, however, rules out a purely Saharan origin. It reveals a more classical northern hemisphere westerly regime, in which airmasses come from North America, and possibly from Asia. Indeed, it has long been suggested that dust plumes in the westerlies may have crossed the east coast ot North America [*Windom and Chamberlain*, 1978]. The Nd isotopic signature of this dust event (Figure 1b) falls also within the range of values that have been reported for US loess [*Taylor et al.*, 1983; *Biscaye et al.*, 1997]. In this case, it is clear that the sole Nd isotopic signature of the dust cannot fingerprint unambiguosly the source, but this information has to be corroborated with airmass trajectographies and model simulations.

[7] It is therefore more likely, as suggested by the reconstructed airmass trajectory (Figure 1b), that this dust plume was derived from Asia at a time of year when huge dust storms are emitted from China/Mongolia. It is well known that most of the North Pacific sediments contain a significant amount of Chinese dust [*Rea*, 1994]. The E_{Nd}(o) of the Chinese desert [*Bory et al.*, 2002] may explain the isotopic composition of the 6 March 1990 dust event. Indeed, the Takla-Makan in western China, one of the largest deserts in the world, is characterized by persistent dust activity with a maximum intensity in Spring [*Merrill et al.*, 1989; *Bory et al.*, 2002; *Prospero et al.*, 2002] and emits dust with an isotopic composition of −9.5 to −11.5 [*Bory et al.*, 2003]. This seasonal signal is consistent with the E_{Nd}(o) of the March 6, 1990 dust event (−12.9), especially when possibly admixed with the dust from a Saharan plume (see below).

[8] Although the Chinese dust plume in question passed over North America, we do not expect a significant contribution of dust from North American sources for several reasons. First, the major dust sources in North America are located in the southwestern USA [*Prospero et al.*, 2002], about 10 degrees of latitude south of the trajectory of the studied dust plume. Second, the averaged dust concentrations measured for 3 years at 36 sites over the US indicate a spatial maximum in southern California of 10 ug/m^3 and a minimum along the Rocky mountains with typical values of 3 ug/m^3 at the Canadian border [*Malm et al.*, 1994]. Such values of surface concentration are relatively low compare to the average concentration of 250 ug/m^3 observed in the Takla-Makan by *Zhange et al.* [1998], and the 10–15 ug/m^3 simulated concentrations at the Canadian border (Figure 2). Therefore, although we cannot dismiss completely the possibility of the addition of dust by local mixing over North America, it is reasonable to conclude that such contribution had no significant impact.

[9] The Global Ozone Chemistry Aerosol Radiation Transport (GOCART) model has been used to simulate dust distribution over the two last decades [*Ginoux et al.*, 2001, 2003]. Dust distribution is calculated by solving the continuity equation with four particle-size bins, from 0.1 to 6 μm.

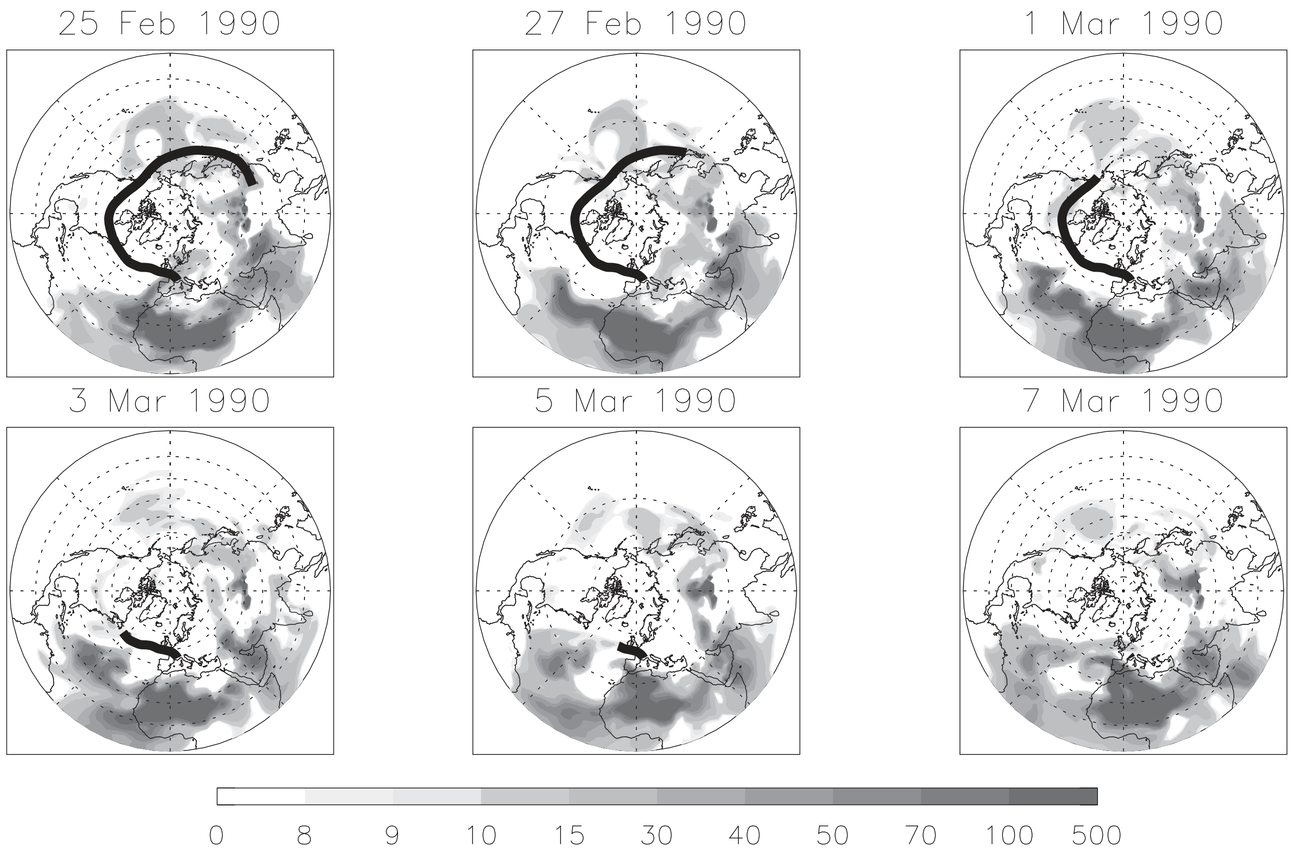

Figure 2. Stereo-polar projection of the daily dust concentrations (in units of μg m^{-3}) around 3 km altitude above sea-level, simulated with the GOCART model, from 25 February to March 7, 1990, every other day. The back-trajectories, calculated with NOAA NCEP re-analysis, are over-plotted with a thick line and are calculated with the starting point located in the Alps (44.34°N, 6.30°E) at time 6:00 UTC on March 6, 1990 and with the ending point at the shown day at 0:00 UTC.

Dust is uplifted by winds from preferential sources which are associated with topographic lows. The model has a horizontal resolution of 2° latitude and 2.5° longitude and 20 vertical sigma layers from the surface to 1 mb (~50 km above ground). All processes are driven by assimilated meteorological fields by the NASA Goddard Earth Observing System Data Assimilation System (GEOS DAS). Figure 2 shows the dust concentration around 3 km altitude above sea-level from February 25 to March 7, every other day. Around February 20, the model indicates that a dust plume was emitted from the Takla-Makan desert (>100 μg/m^3). The plume was then transported eastward over the Pacific to North America. By the end of February, it reached the west coast of Canada, and had spread to the east coast by March 1. Subsequently it moved across the North Atlantic to reach England on March 5. On that day, the trailing edge of the Asian plume ($\approx$10 μg/m^3) was connected with a Saharan dust plume such that the Asian plume preceded the Saharan plume over the Alps on the 7th. Over-plotted on the dust concentration in Figure 2 are the back-trajectories calculated from the shown day to March 6 using NOAA NCEP re-analysis. The airmass movement derived from the NOAA NCEP re-analysis is much faster than that of dust transported with GEOS DAS re-analysis used by GOCART. The difference starts to be obvious the days before March 1 and may be due to several factors: 1) poorly reliable back-trajectories for periods longer than 5 days, 2) the NCEP and GEOS DAS assimilation systems produce significantly different re-analyzed wind fields, or 3) the dust plume is transported at lower altitude, with slower winds, due to the gravitational settling. Despite this difference, they both show that the dust plume came from western China and crossed North America along or north of the US-Canada border.

[10] Three independent approaches thus lead to the conclusion that a Chinese dust plume reached the French Alps on March 6, 1990. Interestingly, two days later (March 8, 1990), a purely Saharan dust plume hit the Pyrénées (Figure 1a). The GOCART model simulation confirms such succession of dust plumes of different origins reaching France (Figure 2).

[11] It is known that these dust events are associated with pollution (heavy metal) fallout [*Grousset et al.*, 1994]. *Griffin et al.* [2001] have shown that the colonies of fungi and bacteria observed in the Caribbean are related to African dust. It has been suggested that trans-Pacific air pollution originating from Asia could affect North America [*Wilkening et al.*, 2000] even as far as Greenland [*Biscaye et al.*, 2000]. In the same way, trans-Atlantic air pollution originating from Asia could also affect Europe.

3. Conclusions

[12] In this paper, we have studied the origin of dust fallout over the French Alps. Three independent datasets (Nd

isotopic composition, GOCART transport model, and back-trajectories) have been used to locate dust origins in North Africa and East Asia, more precisely the Takla-Makan desert of China. Despite the fact that their isotopic signature could also point to a North African source and that both trajectories and models have large uncertainties, the evidence for a Chinese origin is strong. Thus, our analysis suggests that dust particles have traveled more than 20,000 km in about two weeks, and along their journey, crossed China, the North Pacific, North America and then the North Atlantic Ocean.

[13] It has been demonstrated that Chinese dust plumes reach western North America [*Wilkening et al.*, 2000] and that recent Chinese dust is deposited in northern Greenland [*Bory et al.*, 2002, 2003]. But, the fact that dust coming from Asia could reach Europe, has not previously been reported. Such intercontinental and transcontinental transport and the precise distinctions between source areas is important from the viewpoint of understanding the dust itself, but also from that of the heavy metal, fungal, bacterial and viral pollution that may be associated with it.

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