Seasonality in European Red Dust/“Blood” Rain Events

by Joshua R. White, Randall S. Cerveny, and Robert C. Balling Jr.

Sahara-derived dust rains, termed “red rains” or, more ominously, “blood rains,” are relatively rare meteorological phenomena associated with Saharan dust transport occurring across Europe. These red-rain events have been recorded throughout European history, with tales of ancient or medieval “blood rains” being described by Livy, Cicero, and Geoffrey of Monmouth, among others. As Livy noted for 181 B.C., a shower of blood fell near the Roman Senate: “In the precinct of Vulcan and Concord there was a shower of blood . . . Being disturbed by these prodigies and deaths, the Fathers decreed, both that the consuls should sacrifice full-grown victims to whatever gods it seemed proper.” Less drastically, modern investigations of colored rains referenced in the scientific literature, such as in the 2009 Atmospheric Environment article by Coz et al., utilized back-trajectories of air masses, chemical analysis, and remote-sensing techniques to evaluate the source and chemical composition of specific Saharan-origin colored rains across Europe.

Because of the phenomenon’s relative infrequency and a prevalent case-study scientific approach to such events, one aspect of red-rain events that has not received significant attention is the seasonality. A couple of past studies (Dessens 1990; Burt 1991) created preliminary frequency analyses of colored-rain events for their specific regions [France (64 events) and Great Britain (25 events)]. Specifically, Lannemezan, France, demonstrated seasonality such that most frequent dust-fall events occurred in the summer (Dessens 1990). Burt (1991) found that Great Britain red-rain observations increased from 1968 to 1990, which might be attributed to observational bias due to increasing awareness of the phenomenon.

We have assembled a new, more comprehensive red-dust-rain event archive consisting of a listing of 549 colored-rain cases across all of Europe, including specific month/day/year occurrence. A total of 510 of these events occurred after 1900. These colored-rain cases were collected from three primary sources: (a) documented published papers; (b) images of known dust-transport events using satellite data by NASA’s Earth Observatory and other imagery; and (c) limited media accounts of such phenomena. Because we are particularly concerned with seasonality, we selected events linked to terminology such as “blood,” “red,” “dust,” “mud,” or “colored” rain for which existed specific dates and times of year (or, in some cases, simply the month and year of the occurrence). All data, together with the relevant references to each event, can be accessed at http://azclimate.asu.edu/bloodrain.php.

Analysis of our spatially and temporally extensive dataset of 549 events suggests that colored-rain events can occur throughout the year across Europe (Fig. 1), but do demonstrate seasonality. Spain tends to receive the most red-dust-rain events due to its close proximity to the source dust from the Sahara. The maximum occurrence of colored-rain events for the Iberian Peninsula region is spring (MAM), but they can occur throughout the year, with winter (DJF) being the least active season for such phenomena. However, for most of Western Europe, red rains occur most frequently in the spring and most infrequently during the summer.

An example of the meteorological conditions for summer red rains in Western Europe (particularly Spain, France, and Great Britain) can be seen (Fig. 2) using the NCEP/NCAR Reanalysis dataset for analysis of an event that occurred on 22 June 1988. For this June 1988 red-dust rainfall, the migratory 700-hPa height field (Fig. 2b) over southern Spain and northern Morocco on the day of this
event showed a low-level flow from the Atlantic that advected midlevel (700-hPa) moisture (Fig. 2a) into the region, providing the necessary moisture for the colored-rain event. The cutoff flow at the 500-hPa height (Fig. 2c) allowed the dust and moisture to fall over the northeastern region of Spain near Barcelona while the main downstream flow prevented it from reaching any farther into Europe. A key means of evaluating the pathway for such dust transport is through the calculation of the TOMS aerosol index (AI). The TOMS AI is a measure of how much the wavelength dependence of backscattered UV radiation from an atmosphere containing aerosols (Mie scattering, Rayleigh scattering, and absorption) differs from that of a pure molecular atmosphere (pure Rayleigh scattering). Quantitatively, the aerosol index AI is defined to be:

$$\text{AI} = 100\log_{10} \left[ \frac{I_{\text{Meas}}}{I_{\text{Calc}}} \right]$$

Where $I_{\text{Meas}}$ is the measured 360-nm EP-TOMS radiance, and $I_{\text{Calc}}$ is the calculated 360-nm EP-TOMS radiance for a Rayleigh atmosphere. Under most conditions, the AI is positive for absorbing aerosols such as Saharan dust, and negative for nonabsorbing aerosols (pure scattering).

For the 22 June 1988 event, the TOMS AI displays high aerosol concentrations extending throughout the affected region (Fig. 2d). Sensors collected fallen red-rain samples in the northeastern region of Spain near Barcelona in a holm oak forest (Montsery). This region often receives such events, and the forest itself depends on the influx of calcium supplied by these events. Although occurring during the summer, this pattern is actually typical for most red-rain events occurring in western Europe, particularly Spain. Such an upper-level pattern allows for dust pickup and transport from the Morocco/Algeria region, which is a source region for the dust.

To demonstrate the specific path of that transport, we employed the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to compute back-trajectories using gridded data from the NCEP/NCAR Reanalysis dataset. This Lagrangian model uses dispersion for a specified particle or puff so that it can be viewed as a simple trajectory requiring only a three-dimensional velocity field. This allows the source regions for each of our colored-rain events to be identified, and to provide the most likely track that the particulates traveled to reach their final destination. To run the analyses, we used the HYSPLIT system via the Real-Time Environmental Applications and Display System (READY), which is a web-based system linked to a world network of data run through the Air Resources Laboratory at NOAA. Figure 3a displays the results of the 22 June 1988 Spanish blood-rain back-trajectory analysis. This analysis reveals that the parcel’s vertical ascent is one of the most significant aspects of the dust transport. For all three cases, the terminal 3500-m level represents the parcel’s location within the precipitating cloud.
layer at the specific event location. Backtracking from that terminal height, each trajectory shows that these parcels not only originated over the identified source region, but also developed very close to the surface. In this Spanish rain event, as well as in the Swedish example discussed below, the initial heights in Africa were below 500 m. This strongly reemphasizes that substantive surface dust can be uplifted and advected into Europe to be deposited as colored rain.

In contrast to the rather consistent seasonal distribution of red-rain events in the Iberian Peninsula region, Central Europe tends toward a bimodal seasonal distribution, with the majority of its events occurring in spring and autumn. For example, the NCEP/NCAR Reanalysis 700-hPa circulation associated with the red-snow event over Sweden on 10 March 1991 indicates that the event began with a trough at the 700-hPa height level centered west of France (Fig. 4b). Midlevel (700-hPa) moisture can also be seen moving around the trough from the Adriatic Sea (Fig. 4a). This low-level moisture mixed with the aerosols, resulting in red- and yellow-colored snowfall. At 500 hPa, a large cutoff low was positioned over the Atlantic Ocean west of France (Fig. 4c). Because of the magnitude and positioning of the upper-level trough, dust was advected from the central Sahara to Sweden, as evidenced by the high values of the TOMS AI extending from the Mediterranean across central Europe (Fig. 4d). The yellow snow fell in northern Sweden, in the city of Arjeplog, and in Finland, which was confirmed by several collection samples set up throughout the Alps. This type of dust-storm event allows dust entrainment from the Morocco/Algeria region, as identified by Coz and colleagues and by Franzén and colleagues (Coz et al. 2009; Franzén et al. 1994), and the HYSPLIT back-trajectory simulation (Fig. 3b). This event demonstrated a southerly flow, thereby allowing the dust to be carried through central Europe into northern Scandinavia and deposited as a yellow snow.
Seasonally, Eastern Europe, particularly Turkey, Greece, and Russia, experiences the majority of its colored events in spring. For example, the NCEP/NCAR Reanalysis 500-hPa circulation associated with the red-rain event across Turkey on 18 April 2005 shows that the day of the red-rain event a 500-hPa cutoff low was established over northern Italy (Fig. 5c). Additionally, the cutoff low was also evident at a low level (700 hPa) over northern Italy, advecting both moisture from the Mediterranean and dust entrainment from the Algeria/Libya region, which is a source region identified by Coz et al. (2009) and confirmed by the HYSPLIT back-trajectory simulation (Fig. 3c). By the day of the event, the TOMS AI indicates high concentrations of particulates over Turkey (Fig. 5d). The red rain that fell in the city of Mersin was identified by several samples collected from sensors around that city, which sits on the edge of the Mediterranean Sea.

Consequently, the climatological synoptic conditions responsible for the geographic variability in the seasonality of European red-rain events is seen to be linked to the interaction between migratory Rossby waves (often in the form of stagnant or quasistationary cutoff lows that persist long enough to force particulates northward across the Mediterranean or western Atlantic) and aerosol uplift from three distinct North African source regions. While attributes of any individual event might be created due to sudden synoptic shifts in storm track and intensity of the overlying storm system, our analyses of the past century’s red-rain events suggest a climatic consistency to the seasonality and synoptic conditions of these phenomena.

Climatological tabulation of such events (which have not created injury or marked property damage) may provide a new gauge of climate change because of their past relative rarity. If, as new events are noted and analyzed, changes in the seasonality, magnitude, or overall frequency are discovered, such changes may provide valuable information on shifts in circulation and dust mobility, at least over the Eastern Hemisphere. Consequently, we stress that this is a first attempt to establish a continental-scale database for red-rain events, and that citations for additional events are wel-

Fig. 3. NOAA HYSPLIT back-trajectory model results for three “blood rain” events, all with starting heights of 3,500 m AGL: (a) Montseny, Spain (23 Jun 1988), 48-h duration simulation; (b) Arjeplog, Sweden (10 Mar 1991), 120-h duration simulation; (c) Mersin, Turkey (18 Apr 2005), 48-h duration simulation.
comed. The data, together with the relevant references to each event, can be accessed at http://azclimate.asu.edu/bloodrain.php. Because of the rarity and visually unconventional (or, to some, frightening) appearance, the colored-rain phenomenon across Europe is likely to continue to be the source of interesting scholarly work as well as of marked interest by the general public.

ACKNOWLEDGMENTS. We thank the many scientists involved in red-rain case studies for their data and, in particular, Dr. Turkan Özsoy of Mersin University, Turkey, for colored-rain data for Turkey. We greatly appreciate a reviewer’s suggestion to conduct the HYSPLIT back-trajectory simulations, as well as additional suggestions by the editor.

FOR FURTHER READING


fig. 5. Synoptic situation associated with red precipitation event over Eastern Europe on 1200 UTC 18 Apr 2005. (a) NCEP/NCAR Reanalysis 700-hPa relative humidity (percent); (b) NCEP/NCAR Reanalysis 700-hPa height contours (dam); (c) NCEP/NCAR Reanalysis 500-hPa height contours (dam); (d) TOMS Aerosol Index values (unitless).