Dust storms and haboobs

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Weather Insight - dust storms and haboobs

What is needed to generate a dust storm?

Dust storms are most common in the world's arid regions and deserts, but can form anywhere where strong winds combine with sediment that can be easily uplifted into the air. Dust is normally generated by a process called 'saltation': winds above a threshold wind-speed (typically around 6 to 11 m/s) entrain larger particles (0.1 to 1 mm) which bounce across the surface. These particles are themselves too heavy to be lifted high into the air, but energy released when they impact the soil can overcome binding forces, allowing smaller particles (typically 0.1 to 50 microns) to be emitted and entrained into the atmosphere. Dust aerosol is typically an external mixture of quartz, clays (such as kaolinite, illite), calcite, gypsum and iron oxides. Particles are typically non-spherical and platelet shaped. Ideal conditions for dust uplift are strong winds, little or no vegetation and a dry, sediment-based surface. Emission rates are usually considered to be a cubic function of friction velocity, with no emission below a threshold corresponding to a 10-m wind-speed of around 6 to 11 m/s. Emission is therefore a highly non-linear response that depends only on the relatively rare high wind-speed events, making it a challenge to model. Major dust sources include dried up lake beds (e.g. the Bodélé Depression in the southern Sahara), and areas affected by rare flash floods which bring new supplies of sediment to be uplifted, as soon as it becomes dry again.

What is a haboob?

A variety of mechanisms can generate winds strong enough to uplift dust, but haboobs are one of the most important and spectacular. Haboobs originate from convective storms, with the name deriving from the Arabic word meaning 'strong wind.' Over arid regions, much, if not all of the precipitation can evaporate before reaching the ground, which cools the air, causing it to descend. -. On reaching the surface, the air is forced to spread out as a density current. Winds in such 'cold-pool outflows' can exceed 20 m/s, resulting in dust uplift and very high dust loads. The result is a moving 'wall of dust', or haboob dust storm (Figure 1). Such haboobs are amongst the most intense dust storms on Earth.

Haboobs can form from any cloud that generates precipitation, and can span scales from around a kilometre to hundreds of kilometres, with the larger ones clearly visible from space (Figure 2). Haboobs are found in many regions of the world, though the northern Sahel and margins of the Sahara are hotspots of haboob activity, since systems such as the West African monsoon bring the moisture needed for rain formation into arid areas. Haboobs are also often found where mountains can trigger afternoon thunderstorms, e.g. the Atlas mountains on the northwest edge of the Sahara.

What other phenomena can generate the high winds needed for a dust storm?

Mid-latitude frontal systems can affect sub-tropical deserts such as the Sahara, especially in spring, creating large and intense dust storms. More widely, the effects of synoptic-scale pressure gradients on winds and dust uplift can be greatly enhanced by formation of nocturnal low-level jets (NLLJs, Figure 3). Due to the formation of strong stable nocturnal boundary layers (BLs), air above the nocturnal BL can be decoupled from the surface drag and therefore accelerates in a NLLJ. After sunrise, intense surface heating and the resultant growth of the day-time convective BL mixes momentum from the jet down to the surface giving strong gusty winds, which can generate intense dust storms.

In summertime NLLJs around the Saharan Heat Low provide a significant fraction of Sahel/Saharan emission, with haboobs providing the other main contribution (Marsham et al., 2013). NLLJs channelled by orography also dominate emission from the Bodélé Depression (Washington et al., 2005), but this source is more active in winter. Finally, surface heating in the day time can generate dust plumes and 'dust devils'. Rapid ascent of heated air and associated convergence in the boundary layer can give locally strong winds and sometimes strong rotation (Sinclair, 1969). The overall contribution to such small features to the earth's dust budget is probably small, perhaps around three percent (Jemmett-Smith et al., 2015), but with large uncertainties.

What impacts do dust storms have?

Dust storms can dramatically reduce visibility and call an abrupt stop to many human activities, as conditions can quickly become very hazardous for transport, including aviation. In the Middle East and North Africa, $13 billion GDP is lost annually due to dust storms (UNEP, 2016). Dust degrades air quality by raising particulate matter concentrations, negatively impacting human health and is also linked to meningitis outbreaks (Querol et al., 2019). Dust and its transport over large distances affects the weather locally and globally, by interacting with both the solar and thermal infrared radiation that controls Earth's energy budget (Ryder et al., 2019). Dust is an important source of ice nucleating particles and aged dust can in addition act as cloud condensation nuclei (Cziczo et al., 2013). Dust deposited to land an ocean surfaces, sometimes thousands of kilometres from its source, provides vital nutrients to the biosphere, coupling the dust cycle with the carbon cycle.

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Figure 1: Photograph of the leading edge of a haboob in Hombori, Mali (photo courtesy of Françoise Guichard, CNRS Photothèque).

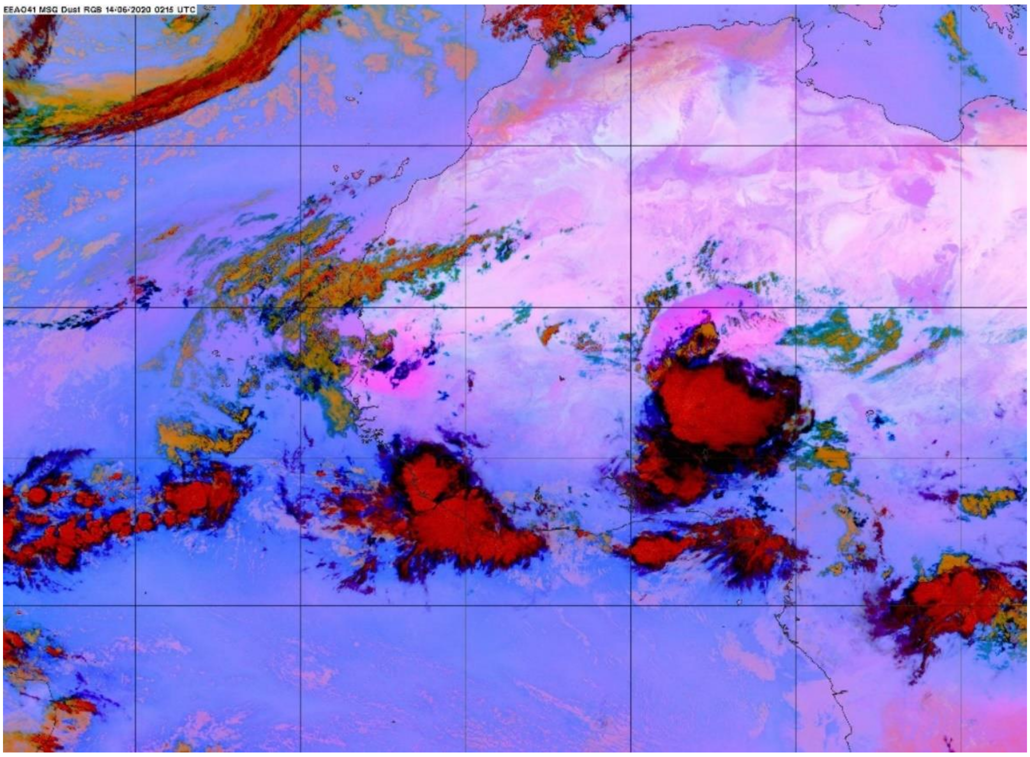

Figure 2: A dusty haboob viewed from space. Meteosat Second Generation Spinning Enhanced Visible and InfraRed Imager (SEVIRI, Lensky and Rosenfeld (2008)) red-green-blue false colour imagery from 02:15 UTC 14th June 2020. The haboob can be seen over western Niger, eastern Mali and southern Algeria in bright pink, stretching around 1,300km along its leading edge. The parent deep convective clouds (red/orange/black) can be seen over Nigeria and southern Niger. This haboob was one of several which went on to contribute to the historic 'Godzilla' Saharan dust plume of June 2020 (Yu et al., 2021).

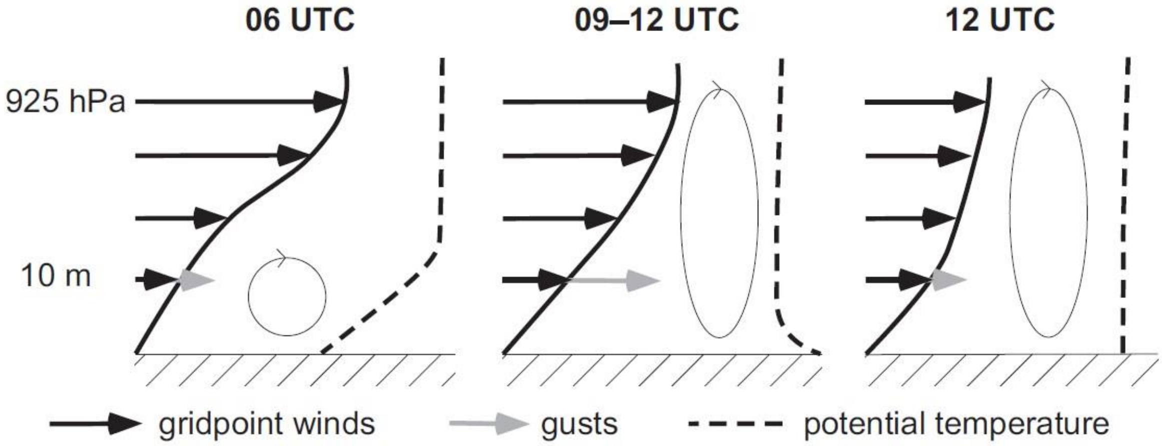

Figure 3: Schematic depiction of typical changes in low-level wind, gusts, potential temperature and turbulence during the morning hours as the NLLJ is mixed downwards generating strong surface winds. (Reproduced from Knippertz (2008)).