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AWESOME, THE DUST OF THE SAHARA IN THE SKY OF THE AMERICA CONTINENT

Godzilla, the biggest dust storm in half a century

IMPRESSIONNANT, DE LA POUSSIERE DU SAHARA DANS LE CIEL DU CONTINENT D'AMERIQUE

Godzilla, la plus grande tempête de poussière depuis un demi-siècle

REMINI B.

Department of Water and Environmental Sciences, Faculty of Technology, Blida 1 University, Blida 9000, Algeria.

reminib@yahoo.fr

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ABSTRACT

Nicknamed Godzilla, a large dust storm from the Sahara Desert flew over the Atlantic Ocean during June 5-26, 2020, reaching the Caribbean and the Americas. By consulting the satellite images for the month of June 2020, the uprising of the dust storm took place on June 5, 2020 in the desert of Tanezrouft (Algeria). It is at the level of the throat area located on both sides of the mega-obstacle: Tassili N'Ajjer -Hoggar, which the harmattan from Libya accelerates following a decrease in pressure. Accordingly, the violence of the wind causes heavy erosion and uplift of fine particles in the air. This is the first departure from the Algerian Sahara of the largest amount of dust in more than half a century.

Keywords: Hoggar-Tassili N'Ajjer, Dust storm Godzilla, Sahara, America, Atlantic Ocean,

RESUME

Surnommée Godzilla, une immense tempête de poussière en provenance du désert de Sahara a survolé l'océan Atlantique durant la période du 5 au 26 juin 2020 pour atteindre les Caraïbes et les Amériques. En consultant les images satellites du mois de juin 2020, le soulèvement de la tempête de poussière a eu lieu le 5 juin 2020 dans le désert de Tanezrouft (Algérie). C'est au niveau des aires de Col situées de part et d'autre du méga-obstacle : Tassili-Hoggar, que l'harmattan en provenance de la Libye s'accélère suite à une diminution de pression. En conséquence, la violence du vent engendre une forte érosion et un soulèvement des fines particules dans le ciel. C'est le premier départ du Sahara Algérien de la plus grande quantité de poussière de plus d'un demi-siècle.

Mots clés : Hoggar-Tassili N'Ajjer, Tempête de poussière Godzilla, Sahara, Amérique, Océan Atlantique,

INTRODUCTION

Sand and fine particles from the Sahara, the most beautiful desert in the world fly over the Atlantic Ocean every year to reach the continent of America. It is confirmed, since 2007, NASA thanks to the Calipso satellite has followed and quantified the transfer of Saharan dust going from the Sahara to the Amazonian forest by crossing the Atlantic Ocean over a distance of more than 5000 km (Tambert, 2016 ; Chavetnoir, 2015). About 182 million tons of dust, including 27.7 million tons of fine particles, land on the entire Amazon rainforest (Aline, 2016; Gray, 2015). About 43 million tons of sediment will reach the Caribbean Sea (Gray, 2015). Depending on its weight, the rest of the dust falls into the Atlantic Ocean along its path. If today all the light was made on emissions of Saharan dust to North America, however, places of departure and lift this dust have not been elucidated. It was only recently that an approach was made by Remini (2017) who identified the three export zones for dust. The first concerns the Bodélé area (Chad). It is the most dust-exporting place on the other side of the Amazon. The study showed about 53% of sandstorms occurred in this region during the period: 2009-2017 (Remini, 2017). This result confirms those obtained by the work of Chauveau and Leconte (2015), Tremblay (2008) and Souto (2014) who recommend that half of the dust that flies over the Atlantic Ocean comes from the Bodélé depression. The second starting point for dust is located in Algeria in the corridor formed by the Tademaït plate and the Tassili N'Ajjer-Hoggar massif. About 30% of dust storms occurred in this area during the period: 2009-2017 (Remini, 2017). Finally, the third starting point for particles is located in Niger to the north and south of the Aïr massif. About 17% of the total number of storms appearing in the Sahara originated in this area during the period: 2009-2017 (Remini, 2017).

If today overflying the Atlantic by dust from the Sahara is confirmed by the data collected by the NASA satellite on the period 2007-2013 (Timbert, 2016). In a first approach, the locations of particles starts in the Sahara have been defined (Remini, 2017), however, little mastery causes and dust lifting mechanisms in the atmosphere. It is in this sense that this article attempts to explain to the great cloud of dust from the Sahara flew over the Atlantic ocean during the period from 5 to 26 June 2020.

STUDY REGION AND WORK METHODOLOGY

In our study we are interested in two regions; one emitting dust and the other receiving dust. These are, respectively, the Sahara Desert and the continent of America; two continents located on either side of the Atlantic Ocean (fig. 1). The Sahara annually exports tons of fine sand and dust and particularly during the period: March-June to the continent of America that is on the other side of the Atlantic Ocean.

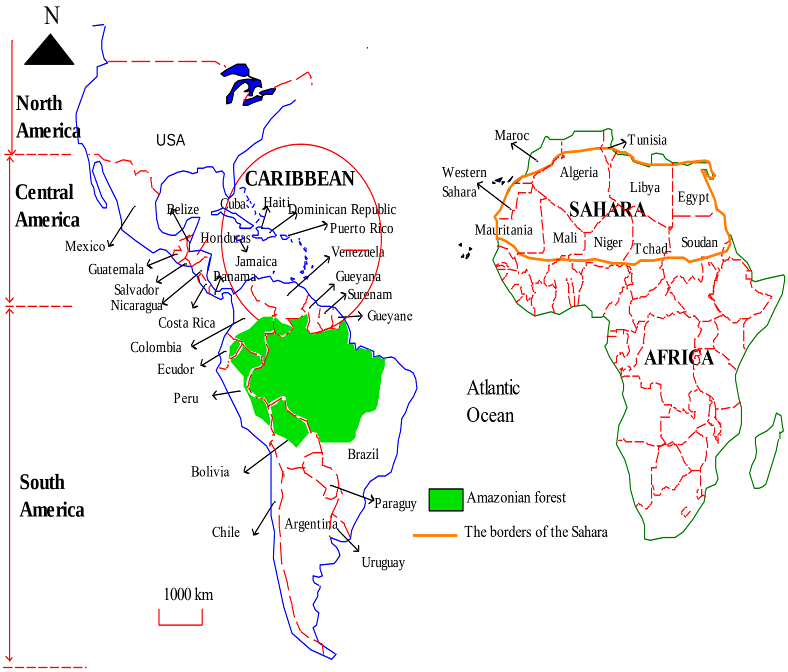
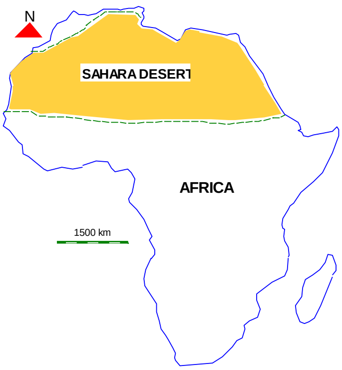
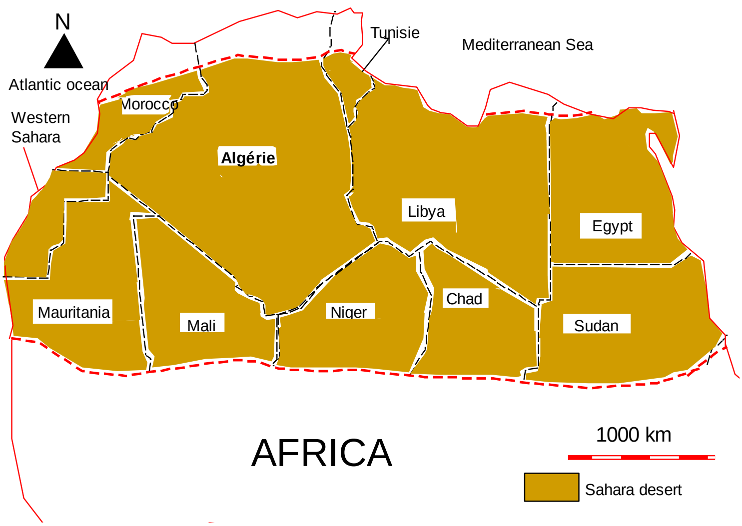


Figure 1: The Caribbean countries as well as the continents of North, Central and South America are the regions that receive dust from the Sahara Desert (Remini, 2020)

The most beautiful and the largest hot desert in the world, the Sahara with an area of over 8.5 million km^2 is located north of the African continent. It extends over 9 countries: Algeria, Mali, Mauritania, Niger, Tunisia, Morocco, Sudan, Chad, Libya, Egypt and Western Sahara (fig. 2 (a and b)). All this area of the Sahara is occupied by Ergs, plate, Regs, Hamadas, Rivers, rocky massifs, Sebkhas, Chott, Gueltas and oases. The sand or dune space formed by the Ergs represents only 20% of the entire surface of the Sahara.



a) Diagram of the African continent (Remini, 2020)



b) The limits of the Sahara desert

Figure 2: Geographical location of the hot Sahara desert (Remini, 2018)

RESULTS AND DISCUSSION

The subject is both very interesting and complex. For this paper we have provided an approach to the place of departure (particle takeoff aerodrome) and the mechanism of dust lifting to reach the atmosphere.

The Sahara: The originality of a desert

Dust storms occur in arid areas when winds rise into the atmosphere large quantities of fine dust and sand that can travel thousands of kilometers. These sandstorms can reach outsized which are accompanied by a fine particles in high concentration in the air. Every year, this weather phenomenon manifests itself in the hot deserts of the planet.

Considered to be the largest desert on the planet, the Sahara is driven by very active wind dynamics. Besides the Sahara desert exporting more fine sand and dust to the oceans and continents than other deserts of the world (CNRS, 2016) (Fig. 3). More than half of the dust deposited in the oceans comes from the Sahara desert. In second place we find the Arabian Desert, followed by Central Asia and finally the Chinese desert. However the deserts of America and South Africa are the least active. In addition to its beauty, the Sahara is a vast area of arid 8.5 million km^2.

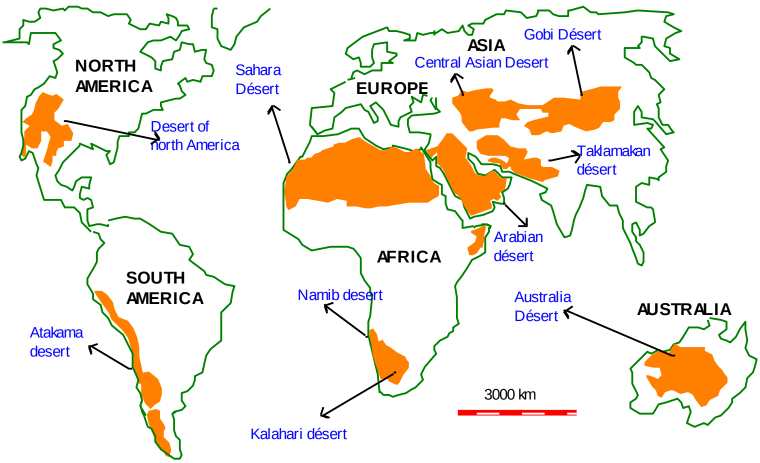


Figure 3: The deserts of the world (Diagram Remini, 2020)

However, Ergs and sand dunes occupy only 20% of the total area, or 1.7 million km^2, what paradox?

Indeed dust emissions from the Sahara Desert is the largest compared to other deserts of the world lies not in its immensity but rather the existence of large rock masses occupying an area of 820 km^2 or 10% of the area total of the Sahara and half of the area occupied by the dunes (fig. 4).

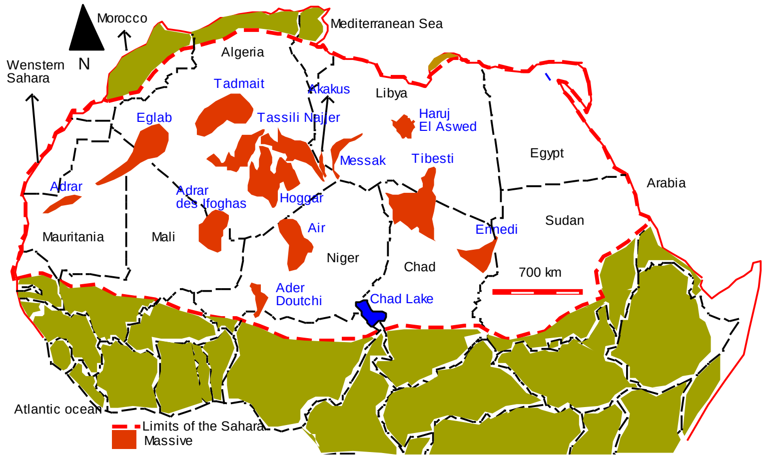


Figure 4: Mega-obstacle layout in the Sahara Desert (Remini, 2020)

In addition to the existence of wind and sand, perfect arrangement of mega barriers creates exceptional wind dynamics allowing the formation and shaping of Ergs and lifting dust obeying the laws of fluid mechanics.

In the Sahara, the wind is the main carrier of sand. The obstacles, whatever their size, their shape and nature (trees, slopes, reliefs, massif) introduce a macro roughness which causes an increase in pressure drop and reduced wind velocity, thus promoting the sandy deposit and the formation of dunes. The mega obstacles, geometric and topographic depressions configurations (lakes, saline lakes and salt pans) form and shape the Ergs. The distribution of mass in the Sahara creates corridors, and Venturi, in obedience to Bernoulli's theorem. Moreover, the largest Venturi of the planet is in the Sahara desert is exactly in the desert of Chad (Remini, 2018)

The areas of shelter and throat: privileged places of dust rising

When an isolated obstacle placed in a fluid stream, opposes a resistance to flow and causes a division of the lines of current in two branches. Once the obstacle crossed meet downstream in a gluing area where the flow returns to its initial state. It appears between the obstacle and the gluing area a sector where there is a disorder of the flow known as the wake (also called shelter area, not deposit, recirculation). This results from fluid streams wake of detachment, it has an effect on the various areas that form in the vicinity of the obstacle; It develops when the frictional resistance becomes negligible shape of the resistance (pressure).

Five sectors were differentiated by the fluid dynamic behavior (Figure 5):

• At point A called the stopping point; the upstream area of the obstacle, the pressure is maximum and the speed is low or zero. In the case of wind circulation, this area is the site of a sandy deposit.

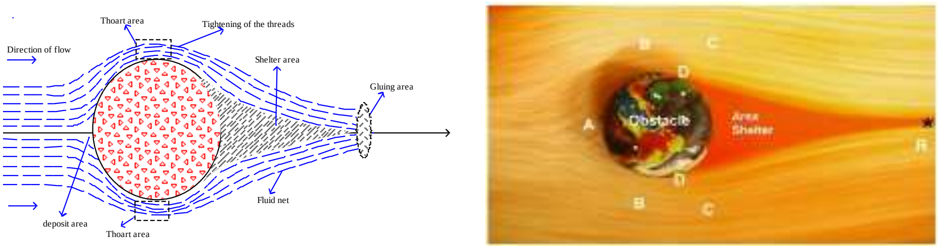
• From A to B, according to Bernoulli's theorem applied to the fluid thread of ABC, the pressure decreases, the speed increases and the fluid threads tighten; this is the area of the throat. It is an area of erosion and transport, where wind corrosion on the ground can be active.

• Beyond point B, the pressure increases again and the result is a sudden decrease of speed, the fluid threads deviate from the obstacle; this is the detachment area.

• Point D called the point of separation beyond which, the speed along the wall is in the opposite direction of the flow. Points of detachment formed on the surface of the wall of a line of detachment.

From point D, the boundary layer detaches from the wall, forming a vortex wake (E). This area does not have a deposit at the outer boundary of the wake area.

• At the downstream of the area of the wake, is the point of reattachment of the primer which is potentially the maximum deposit area. In the case of wind circulation, we speak of the shelter area which does not include a deposit. At the downstream of the area of the wake, is the area of gluing which is the primer of the sand deposit area. The gluing area is rich in sandy deposit, sandstorms after being deflected by the obstacles will return to their original direction.



a) The five areas obtained b)l'aire d'abri (Photo. Remini, 2018)

Figure 5: Dynamic behavior of wind circulation in the presence of an obstacle

Based on this teaching demonstration, two privileged areas may be dust rising places synoptic scale (Fig. 6). This is of two throat areas and the shelter area. In the throat area, the pressure falls and winds are accelerating. On the other hand in the enclosure area, the disorder, there is eddies and turbulence. By analogy, we deduced that the topographic obstacles in the Sahara have the same effect. Two Ergs corresponding to throat to bypass the massif wind. In this case, the wind currents are tightening, the wind speed increases and the pressure decreases. Erosion is intense; the formation of longitudinal strands predominates. The sediment budget is negative. Downwind of the obstacle, to form a shelter or recirculation area, the area is devoid of sand. In windy weather, due to the disorder, dust rises in the sky. At the downstream thereof, gluing area, where the wind after being deflected vertically and horizontally, find the initial direction of wind currents. Erg formed is positive sedimentary budget. The "Sif" shaped dunes are the majority.

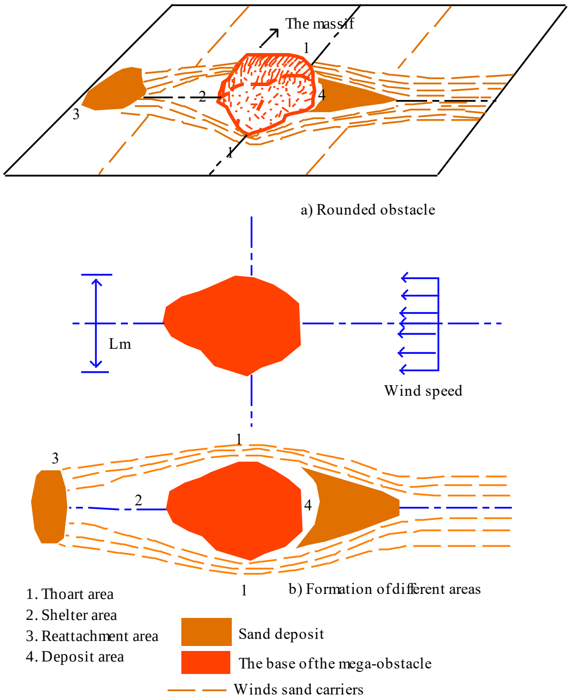


Figure 6: Diagram showing the areas obtained under the effect of a mega-obstacle on wind circulation (Remini et al, 2011; Remini, 2001)

Mechanisms and location of dust rising in the Sahara

Today, the overview of several tons of dust from the Sahara to the continents of America is known by the scientific community. In contrast places and mechanisms of dust in the atmosphere of the uprising remain an unsolved problem. For us, this phenomenon perfectly resembles the takeoff of an airplane that requires a fairly high speed before flying. Indeed, the wind is blowing very hard with extremely high speed capable of lifting as far as possible dust in the atmosphere. Once these fine particles are suspended off the ground, they will be supported by air currents to carry out the Sahara to the Caribbean and the Americas continents. So one parameter characterizes the rising dust, it is the wind speed.

To be an uprising or a starting ground solid particle must have winds. The dust lifting mechanism in the Sahara is based on the Venturi principle. So tightening air flukes cause a decrease in pressure and therefore become stronger winds. The Sahara has all the conditions to locate the privileged places of increased wind speed and dust rise. These types of areas are located just downstream of the throat and Venturi areas generated by the effect of rock massifs on wind circulation. Passing through the throat areas, the winds accelerate and lift fine sand and dust into the atmosphere. Far from the ground, fine particles will be picked up by atmospheric currents to fly over as far as possible. Three most active dust export areas of the Sahara emerge (fig. 7):

- Area downstream of the mega Venturi (Bodélé area - Chad)
- Areas downstream of throat areas generated by the Hoggar-Tassili N'Ajjer massifs (Tanezrouft desert - Algeria)
- Areas downstream of the thoarts formed by the Aïr massif (Niger).

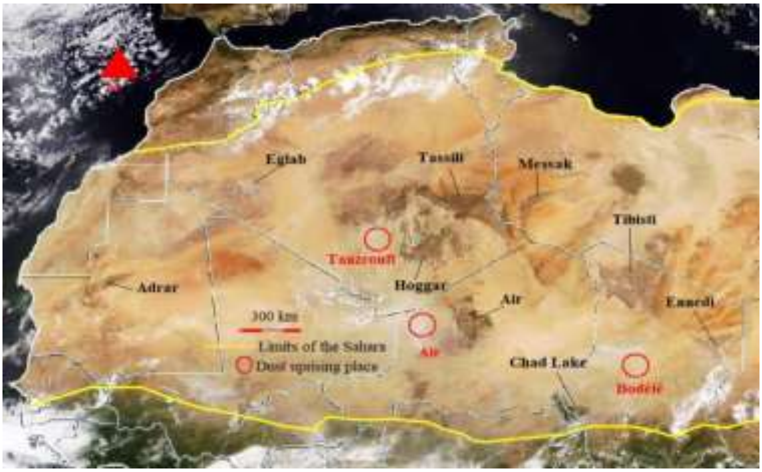


Figure 7: Location of places of dust uplift in the Sahara desert (Scheme Remini, 2020)

These areas are characterized by 3 successive areas (fig. 8):

- Zone 1: Very violent winds.
- Zone 2: Dust rise.
- Zone 3: Formation of dust clouds.

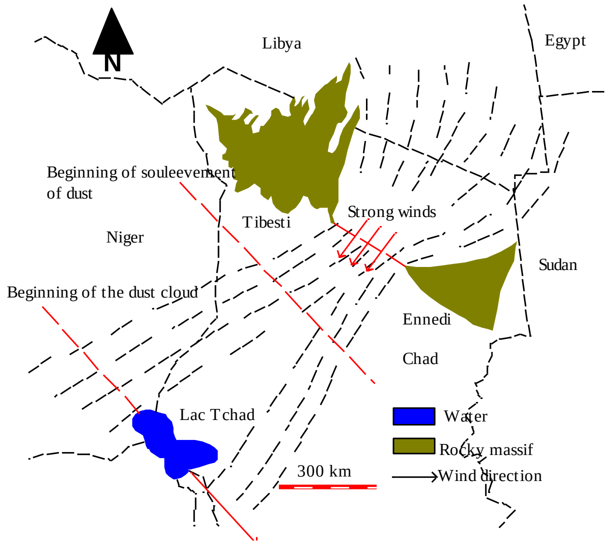


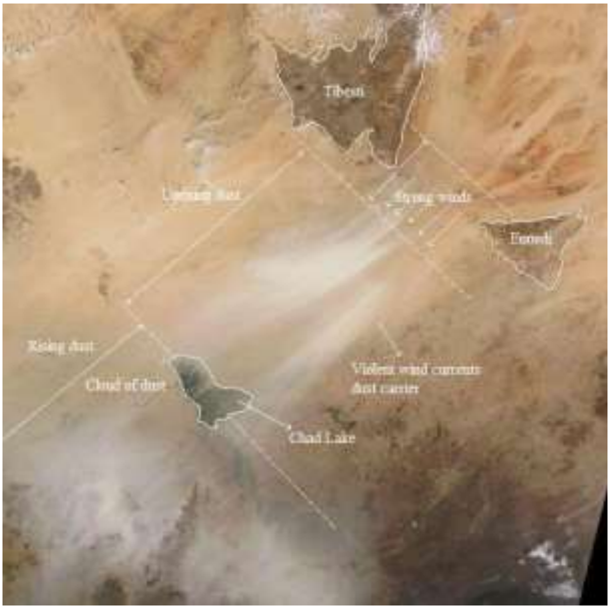
Figure 8: Three stages for flying over a dust storm from the Bodélé region (Scheme Remini, 2020)

The first source of export of dust towards the Atlantic is the area of Bodélé. Dust storms are formed under the effect of mega Venturi of Bourkou (Chad). Indeed, wind currents sand transporters leave the Venturi with extremely high speeds can lift dust highly concentrated finely divided at first, dust storms, once formed, can move to the Mauritanian rating. Lake of Chad, located 700 km downstream of the Bodélé depression, acts as a topographic relief. Indeed, wind currents carriers of sand and dust from the Bodélé region is divided into two branches around the Lake of Chad. This new situation causes an acceleration of wind currents and thus allows the grains of sand and dust particles to maintain as long as possible in the atmosphere to reach the coast of the Atlantic Ocean. An average distance of 2000 km from the area of Bodélé. From there, the sand particles (depending on particle size), are transported by sea currents to the other side of the Atlantic. An approach to the formation of dust clouds mechanism to the place of Bodélé comprises three steps (Figure 9 (a, b and c).)

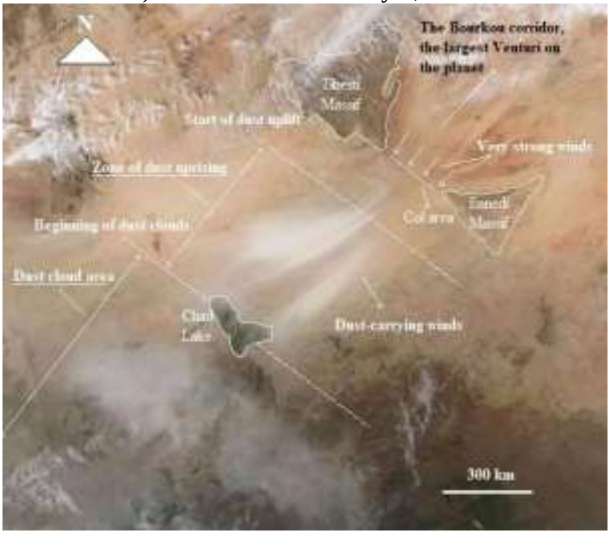
-In a first step, the wind currents (harmattan) from Libyan rush into Bourkou row (formed by the two mega obstacles: Tibesti and Ennedi) which takes the form of Venturi. The air streams are tightened, the pressure decreases and therefore the winds became more violent.

-In the second stage, high winds passing over Bodélé depression raise the dust of the ground for a distance of over 600 km before reaching Chad Lake. The latter plays the role of a topographic relief share the current wind dust carrier into two streams to get around Chad Lake. The wind speed increases even more.

-In the third stage and just after Lake of Chad, dusty plume takes the altitude and away from the ground to reach the atmosphere. The cloud of dust, once formed takes the speed of the air current for flying the Atlantic ocean.



a) Dust storm of January 4, 2016



January 17, 2017

January 18, 2017

Figure 9: Mechanisms of dust uplift in the Bodélé area (Remini, 2020. Diagram taken from NASA Earth worldview satellite images)

More than 53% of sandstorms which manifests itself in the Sahara desert are original to the Bodélé region (Chad). Even large-scale storms that release very dense sandstorms come from the Bodélé area. This situation is the result of very strong winds blowing from the Mega Venturi of Borkou. Moreover, the work of Abouchami et al. (2013) considers that the Bodélé depression (Chad) is the largest source of Saharan dust reaching the Amazon Basin in the transatlantic transport.

The second source of dust export comes from the effect of all massifs: Hoggar-Tassili N'Ajjer –Messak grouped into a single mega-obstacle placed in the line of the wind currents transporting sand from Libya. The subdivision of the wind flow into two branches; one goes through the north of the massif. The other goes through the south of the massif to meet downstream of the latter to form the reattachment area. The throat areas deduced from the wind circulation around this set of massifs which are also areas of tunnels formed by the mountain of Hoggar and the plate of Tademait in the north. In this area, wind erosion is active and therefore dust uplift is very frequent. In the south, the nets of the wind currents rush and tighten in the corridor formed by the Hoggar and Air massifs. At the exit, the winds accelerated under the effect of the throat, bypass the mega-obstacle of Hoggar and describe an arc of a circle under the effect of the Adrar des Ifoghas massif to then reach the topographic relief of Eglab. The storm is supported by the winds which bypass and follow the shape of the Eglab massif. The wind flow that blows from the NE-SW direction along the tunnel generated by the Tademait plate and all Hoggar-Tassili N'Ajjer abuts against the head of the Eglab massif (lying on a length of 700 km on the NE-SW line in line harmattan) and divides into two branches. One crosses the Echech Erg and the other passes through the Iguidi Erg, whose nets of air is narrowing and speed increasing in order to reach the Adrar Plate. In this case, the wind-carrying sand current is divided into two branches which accelerate under the effect of throat areas to reach the Atlantic Ocean. At this stage dust storms are picked up and carried by sea currents to the Caribbean and the Americas. In short, the massive rocky Hoggar-Tassili N'Ajjer- Messak, Eglab and Adrar form a single unit. The four massif part in the increase in wind speed, the raising of dust and birth dust clouds (fig.10)

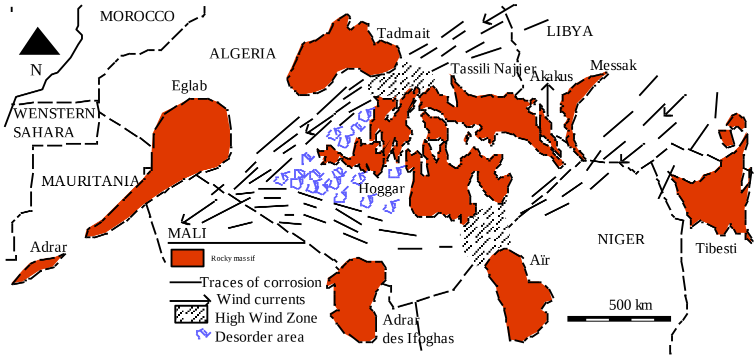


Figure 10: The Hoggar-Tassili N'Ajjer-Messak, Eglab and Adrar massifs form a single unit which is responsible for the dust uplift (Remini, 2020)

For the dust-raising mechanism in the Tanezrouft desert, the strong winds passing through thoart areas (the south and north of the Hoggar-Tassili N'Ajjer-Messak massif) from Libya increase in speed. Immediately afterwards, the detachment of the air streams on the walls of the mega-obstacle promotes the lifting of dust in the sky. Arriving in the Shelter area where there is disorder and turbulence, the dust rises as high as possible, forming a plume of dust. Arrived at the Eglab thoart areas, the dusty plume maintains its speed up to the aerodynamic relief of Adrar, the dust plume will be taken over by the sea currents. More than 30% of the total numbers of sandstorms that appear in the Sahara are produced in the Tanezrouft desert. For example, the birth of the dust storm in the Tanezrouft desert from January 2 to 3, 2015 began on January 2, 2015 with an intense dust uplift about 200 m downstream of the northern thoart. On January 3, 2015, the dust storm decreased in intensity as the wind speed decreased and as a result there was little dust uplift (Fig. 11 (a, b and c)).

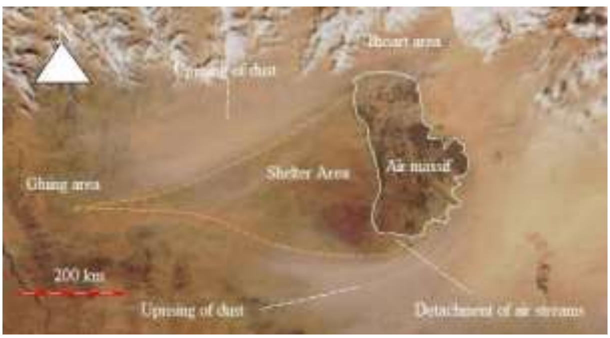
a) January 1, 2015 - No dust rise

b) 2 janvier 2015 : Apparition d'un violent vent de poussière

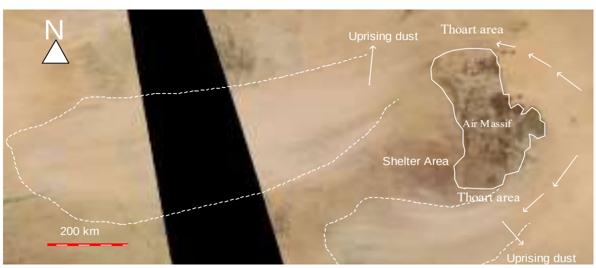
c) January 3, 2015: Decrease in plume intensity

Figure 11: Dust uplift in the Tanezrouft desert (Algeria) during the dust storm of January 2 to 3, 2015 (Remini, 2020, NASA Earth worldview)

The third source of dust exports to the Atlantic is in the Niger desert, which is located downstream from the thoart areas of the topographic relief of the Aïr. Under the effect of the high speed of the two branches of Aeolian currents that bypass the massif, dust uplifts occur north and south of the massif after the thoart areas. Dust storms occur in the West thoart area of the Tibesti topographic relief. Then, these dust storms are carried away by the wind currents which are divided into two branches by the Massif of Aïr which is on the east-west direction. One goes from the north and the other from the south of the Air relief. Another trajectory coming from Mourzouk Erg is diverted to the north of the Aïr. On the other hand, Mainguet et al (1983) has shown that the wind flow from the Erg of Mourzouk to the north and bends the wind current which has crossed the Erg of Fachi Bilma. In the pass areas bypassing the topographic relief of the Aïr relief by Harmattan, the air streams tighten and the wind speed increases. Highly energized dust clouds easily reach the Atlantic Ocean. It turns out that more than 17% of the total number of storms raging in the Sahara originate from Niger and more exactly in the thoart areas of the Aïr massif. The dust storms of December 23, 24, 2016 as well as the storm of January 17, 2017 are two educational examples which clearly illustrate the division of the wind current carrying fine particles into two branches by the Aïr massif. Usually the wind power comes from Libya through the corridor formed by the Messak and Tibesti massifs. So for this third place, the Tibesti, Messak and Aïr massifs constitute a single unit to ensure the increase of the wind speed, the raising of dust and the formation of the dust cloud (fig. 12 (a and b)). These satellite images are a good illustration of the dynamic behavior of the fluid (air) in the presence of a mega-obstacle (Aïr) on a synoptic scale. The same results were obtained in the laboratory concerning the flow of a fluid (water) in the presence of an obstacle. This is a wake area and thoart areas that look a lot like that of nature (fig. 13).



a) Dust rise from the dust storm from December 23 to 24, 2016



b) Dust flow from the dust storm of January 17, 2010

Figure 12: Third place of relief and formation of the dust cloud after the areas of thoart of Air massif (Niger) (Remini, 2020, NASA Earth worldview)

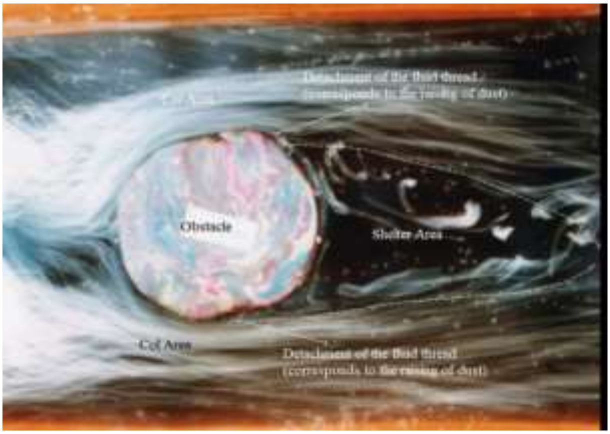
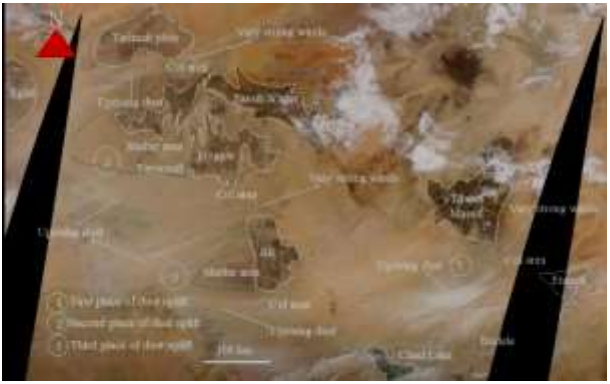


Figure 13: Dynamic behavior of a fluid (water) in the presence of an obstacle (Photo. Remini, 2014)

It all depends on the magnitude of the wind blowing in this vast Sahara desert, the amount of dust exported to the Atlantic varies depending on the onset of sandstorms in the three regions and the duration (number of days) of the storm. One can see dust storms formed in one, two or all three places at the same time. For example, during the sandstorms of December 12, 2013 and November 30, 2015, an impressive cloud of dust rose over the three regions (Chad, Algeria and Niger), heading towards the Atlantic ocean by crossing the border of West Africa, 6000 km long (fig. 14 (a and b)). The skies of twenty countries have been invaded by dusty particles. These are: Algeria, southern Moroccans, Libya, Niger, Mali, Mauritania, Senegal, Chad, Mali, Egypt, Gambia, Guinea Bissau, Sierra Lione, Cote D'ivoire, Liberia, Ghana, Togo, Benin, Bourkina Fasso, Nigeria and Western Sahara.

a)Dust storm of November 30, 2015



b) Dust storm of December 12, 2013

Figure 14: Operation of the three places of dust raising in the Sahara (Remini, 2020, NASA Earth worldview)

Taking into account the storms that occurred during the period: 2000-2020, we have illustrated on a map the path of dust storms from the sources of the dust rise to the western border of Africa (fig. 15)

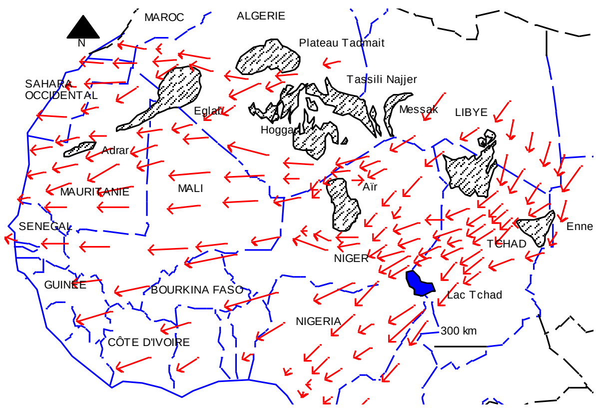


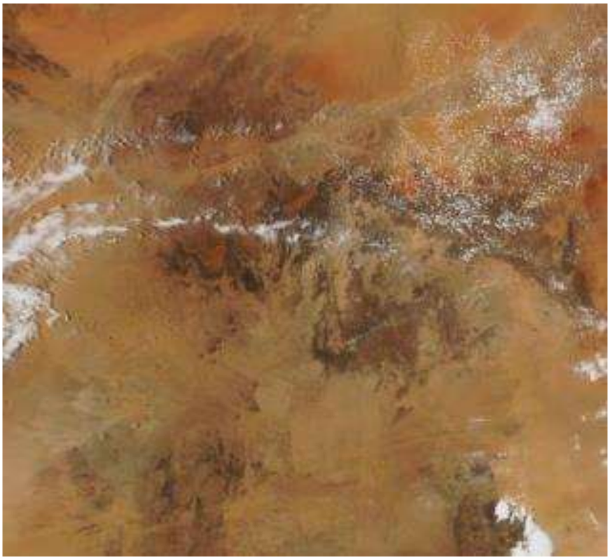
Figure 15: Diagram of the path of dust towards the Atlantic Ocean (Remini, 2020, NASA Earth worldview)

Godzilla, a dust storm like no other

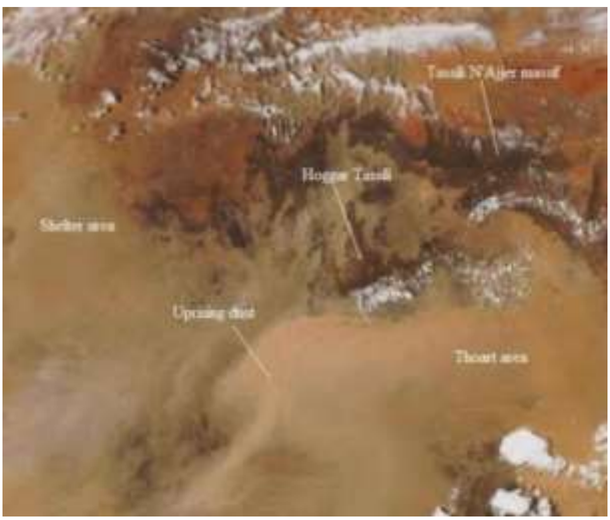
Impressive, fine sand and dust of the Sahara Desert in the skies of the American continents and the Caribbean. Such a phenomenon appears every year, but the dust storm of June 2020 has taken on another much larger dimension. Unheard of for over 50 years, a very dense cloud of dust took 4 days to reach the Gulf of Mexico over a distance of 10,000 km. The dust cloud with a very high concentration of fine particles sprinkles the lands of the Caribbean countries and the Americas. Without forgetting the route of the Atlantic Ocean which is watered by the dust storm. A not insignificant percentage of sand is deposited in the ocean in decreasing order of their mass and therefore they cannot reach the other side of the Atlantic ocean. Only the finest particles that have the chance to land on the lands of the Caribbean and the Americas. Only precipitation can disturb and precipitate the end of the transatlantic sand journey. A large amount of fine particles will eventually settle in the middle of the Atlantic Ocean. As half of the world's population was dealing with COVID19, a huge cloud of dust, the largest in more than half a century, is flying over the Atlantic Ocean to reach the Americas. According to some researchers, this is the largest mass of dust exported from the Sahara to the northern United States in more than half a century. Other authors consider this dust storm to be the most violent on the planet in decades (Sermondadaz, 2020). Spotted by a NOAA satellite, a voluminous cloud of dust from the Sahara reached the Gulf of Mexico and southeastern Texas. A huge mass of fine particles (not assessed), which can cause harmful problems such as air pollution, thus threatening the health of the population. On the other hand, a significant quantity of phosphorus which made the transatlantic journey with the Saharan dust is essential for the development of the Amazonian forest. However, this airlift of dust transfer from a dry environment (Sahara) to a humid environment (Amazon Basin) is quite normal. Each year, and more particularly during the spring period, several tons of fine sand arrive in the American continent. It is estimated at 182 million tons (Aline, 2016; Gray, 2015). But the most astonishing, it is for the first time in more than half a century, that such a voluminous cloud of dust flew over the Atlantic Ocean without interruption, i.e. more than 4000 km during the period from 4 to 22 June 2020. Nicknamed Godzilla, the dust storm of June 2020 raises questions about where and how an impressive amount of dust is lifted from the ground into the atmosphere.

Evolution over time of the dust storm Godzilla

Today after consulting satellite images taken by the NASA satellite, we found that the Godzilla dust plume originated in the area of Tanezrouft. Exactly in the Shelter area formed by the Hoggar-Tassili mega-obstacle. This stony area is characterized by the absence of sandy deposits and the strong presence of strong winds. In a first approach, we believe that the dusting of the Godzilla storm took place in the shelter area after the trade winds were subdivided by the Hoggar-Tassili N'Ajjer mega obstacle into two wind currents. The dust storm Godzilla began June 5, 2020 after a lifting of the dust by forming a highly concentrated finely divided plume at the shelter area located in the desert Tanezrouft (Fig. 16 (a and b)). From Libya, harmattan was divided into two branches by the mega obstacle Hoggar-Tassili N'Ajjer. At the area of thoart south of Hoggar, the speed of wind currents increased to raise dust on the ground to the sky. Once in the shelter area, mess area, the dust plume took altitude.



a) Mega-obstacle Hoggar-Tassili without the presence of a dust storm on June 4, 2020



b) Appearance of a very concentrated dust plume in Tanezrouft area on June 5, 2020

Figure 16: Beginning of the formation of dust storm Godzilla (@ NASA Earth worldview)

However, on June 6, the accelerated wind current at the thoart area north of Hoggar-Tassili N'Ajjer raised a denser and much larger dust plume which took a NE-SW direction. The dust plume from the south of the mega obstacle Hoggar-Tassili N'Ajjer continues its advance in the SE-NW direction to reach the rocky massif of Eglab (Fig.17).

Figure 17: The dust plume leaves the continent of Africa on June 6, 2020 (@ NASA Earth worldview)

The two plumes met at the level of the Adrar plate, an aerodynamic massif, and at the pass areas where high winds prevail. Thanks to this significant kinetic energy, the sandy cloud takes altitude and which the African continent begins to fly over the Atlantic Ocean on June 7, 2020. Impressive, A dust cloud with an area of 750,000 km^2 too loaded detaches from the desert and begins to gain altitude to join the sea currents. This most important step in the process of the evolution of a dust storm that characterizes the uplift of particles. Due to its weight, a large percentage of the sediment detaches from the cloud and falls into the ocean. Only light particles will continue their way to the other shore. Already two days after the onset of the storm, the sand locomotive was 4000 km from the place of departure (Tanezrouft desert) and 1500 m from the Mauritanian coast (fig. 18).

On June 8, 2020, the cloud moves towards the other side, but the dusty cloud increasingly loses concentration of fine particles. The cloud increasingly releases coarse particles. Over the course of one day, about 800 km were flown over by the dusty plume, which increasingly grew larger, occupying an area of about 1.2 million km^2 (fig. 19). More and more, there will be months of dust dusting the ocean, there are fine particles that can still continue the journey.

Figure 18: On June 7 the dust storm begins to move away from the African continent (@ NASA Earth worldview)

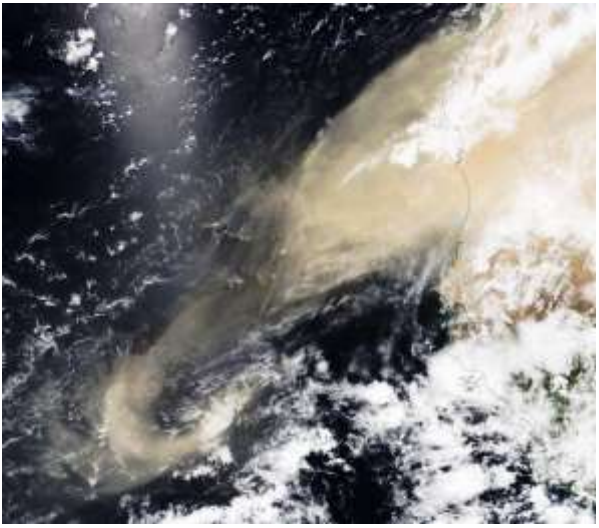


Figure 19: On June 8, 2020, the dust cloud is advancing more and more towards the other side of the Atlantic (@ NASA Earth worldview)

Around June 15, the dust plume occupied an area of more than 4 million km^2. On June 17, the dust plume moved towards the northern ocean covering an area of 5.5 million km^2 (Fig. 20).

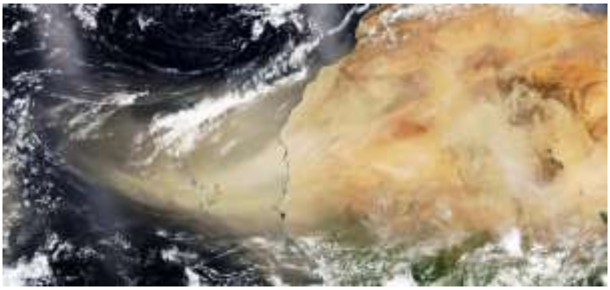
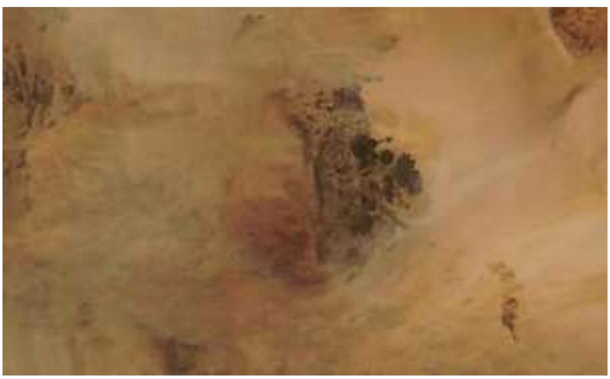


Figure 20: On June 17, the dust cloud moves towards the North Atlantic Ocean. (@ NASA Earth worldview)

At the same time, a second but less virulent storm occurred in the Niger desert, in the shelter area produced by the Aïr mega-obstacle. The winds from Libya are subdivided by the Aïr massif into two parallel branches. The winds in the thoart areas obtained under the effect of the Air relief accelerate to lift the fine particles in the shelter area (Fig. 21).



a) June 16, 2020: Before the arrival of the dust winds

b) June 17, 2020: The South thoart area is clearly visible

Figure 21: A second dust storm has broken out in the Niger desert. (@ NASA Earth worldview)

On June 20, the dust cloud hit the coasts of Venezuela, Suriname, Guyana and the Amazon. Impressive, A gigantic cloud with an area of 8 million km^2. A natural air bridge between the African continent and the American continent over a length of 4500 km (fig. 22).

Figure 22: On June 20, 2020, continuous contact between the two continents thanks to the dust plume. (@ NASA Earth worldview)

On June 21, 2020, the cloud moved a little north to reach the Caribbean; its area exceeded 9 million km^2. On June 22, 2020, the plume covers the Caribbean countries and reaches the coasts of countries in Central America and the Gulf of Mexico. On June 24, 2020, Storm Godzilla swept through Mexico and the southern United States (Fig.23).

Figure 23: On June 24, 2020, as the first dust storm hits the countries of Central America, a second dust storm that started on June 17, 2020 is approaching the Amazon Basin (@ NASA Earth worldview)

On June 26, a second small dust storm hit the Amazon rainforest (Fig. 24). This is the dust cloud that was triggered on June 17 in the Shelter area produced by wind currents under the effect of the Aïr massif.

Figure 24: On June 26, 2020, the second storm that started on June 17, 2020 from the Niger desert sprinkles the Amazon rainforest (@ NASA Earth worldview)

DISCUSSION

Yes, the dust of the Sahara travels every year to the Caribbean and the Americas. It sprinkles the ocean, the beaches of the Caribbean countries and the lands of the countries of northern South America, the lands of the countries of Central America and the southern United States. Not to mention that Saharan dust fertilizes the lands of the Amazon and allows the largest forest on the planet to grow. Knowing that the torrential rains which fall on the Amazon basin cause an intense departure of phosphorus towards the Atlantic Ocean via the Amazon River. Each year, the Amazon River discharges considerable amounts of sediment into the Atlantic Ocean as a result of watershed erosion, including 22,000 tons of phosphorus (Gray, 2015). (Fig. 25 (a and b)).

a) Rejection of August 12, 2020

b) Rejection of July 12, 2020

Figure 25: An average interannual inflow of the Amazon River at the mouth of the Atlantic Ocean equal to 209,000 m^3/s. A significant solid flow including 20,000 tones/year of phosphorus discharged by the Amazon River into the Atlantic (@ NASA Earth worldview)

This same quantity is compensated by the dust rich in fertilizers from the Sahara. In fact, every year, an amount of dust estimated at 27.7 million tones sprinkles the Amazon basin out of the 182 million tons of dust leaving the Sahara (Aline, 2016; Gray, 2015)(fig. 26). A mass of phosphorus estimated at 22,000 t/year lands in the Amazon basin (Gray, 2015). An essential quantity for the development of the Amazon rainforest.

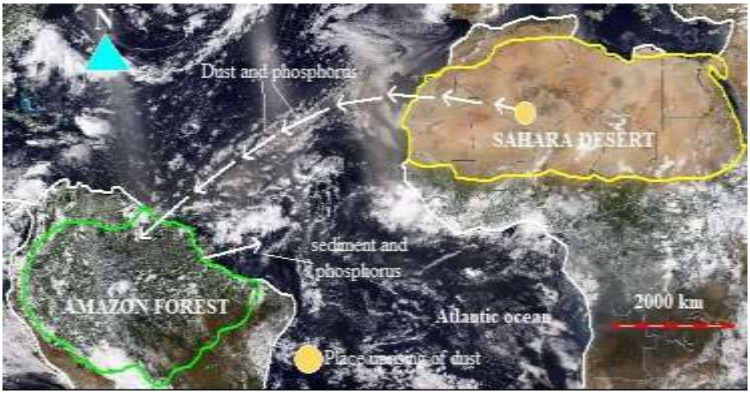


Figure 26: Approximate overview of dust and phosphoric particles between the Sahara and the Amazon basin (Remini, 2020 @ NASA Earth worldview)

It is not the sand of the dunes that fly over the Atlantic Ocean, nor is it the large Ergs that export their sands to the other side of the ocean. It is thanks to the wind and the presence of mega-obstacles that a very active wind dynamic has arisen in the Sahara. Moreover, it is the particular pattern which was established by the brilliant arrangement of the mega-obstacles which gives the Sahara desert its originality. Such architecture has allowed the sand to remain in very specific areas in order to form and shape the Ergs. On the other hand, dunes located in areas of deflation generate a massive departure of sand to supply other Ergs.

The effect of the arrangement of the topographic reliefs on the Aeolian circulation creates a wind dynamics which causes the mobility of the sand especially in periods of spring and autumn. This is how the movement of sand adopts saltation as a mode of transport. It is dust, not sand, that flies over the Atlantic Ocean thanks to air currents. So it is the fringe of fine particles that is affected by the transatlantic journey. In addition, it is not in just any corner of the Sahara that we observe a rise of dust, but it is in very specific places. Three places of dust rise have been defined by the arrangement of mega-obstacles in the Sahara: Bodélé (Chad), Tanezrouft (Algeria) and Aïr (Niger) (fig. 7). The starting point of the big dust storms generally took place in the region of Bodélé (Chad). But the uniqueness of Godzilla, the greatest storm of the past 50 years, is not only in its greatness, but in its place of "birth" Tanezrouft (Algeria). Indeed, a very condensed cloud rose thanks to very strong winds in a very specific place near the Tanezrouft desert. This place can only be the thoart areas located on either side of the largest rocky massif in the Sahara, which is the Tassili N'Ajjer-Hoggar-Messak. It is at the thoart that the air streams tighten, causing a decrease in pressure and consequently an increase in wind speed. This causes dust to rise in the sky at the edge of the Shelter area. Unstable in time and space, the shelter area has no limits, but it is characterized by disorder, turbulence and the appearance of vortices. Covering an area of 300,000 km^2, the shelter area formed by the largest massif in the Sahara has all the qualities to send dust as high as possible. Approaching the Eglab mega-obstacle, the dust plume in a first phase is carried by the winds emanating from the area of the northern thoart of Hoggar-Tassili N'Ajjer. In a second phase, the dust plume while gaining volume is carried away by the very strong winds generated by the thoart area of the south of the Eglab relief. The aerodynamically shaped Adrar relief located on the same line of the Eglab massif (East-West) further accelerates the wind and allows the dust plume to gain more height before reaching the air currents. By analyzing the dust storms generated in the Tanezrouft desert during the period 2000-2020, we note that the Tassili N'Ajjer - Hoggar, Eglab and Adrar massifs form a single unit (fig. 10). We have established the approximate area of dust uplift as well as the passage of dust storm Godzilla prior to the over flight of the Atlantic Ocean (Fig. 27).

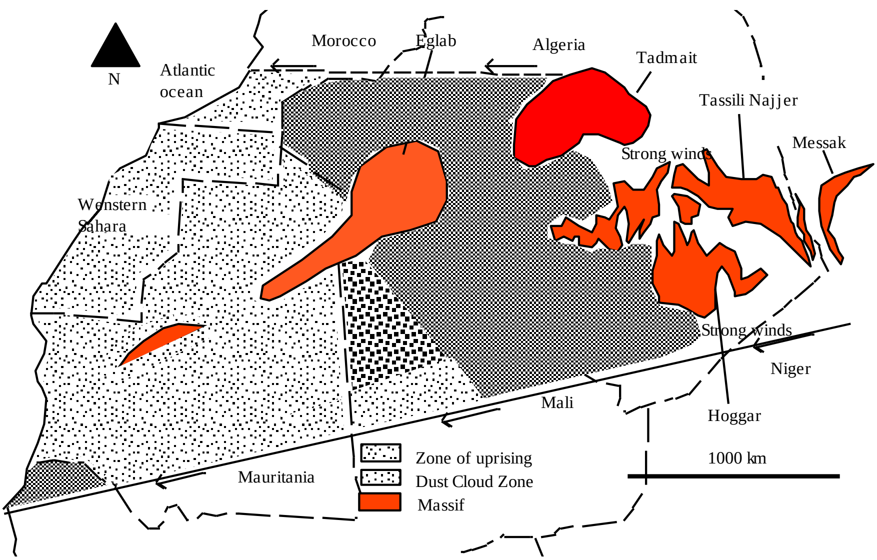


Figure 27: Diagram of the probable passage of dust storms from the whole of the Hoggar-Tassili N'Ajjer massif to the Atlantic Ocean (Remini, 2017)

Then it flew over the Atlantic Ocean for 4 days to reach the Gulf of Mexico for a distance of 10,000 km. The dust cloud with a very high concentration of fine particles sprinkles the lands of the Caribbean countries and the Americas. Without forgetting the route of the Atlantic Ocean which is watered by the dust storm (fig. 28).

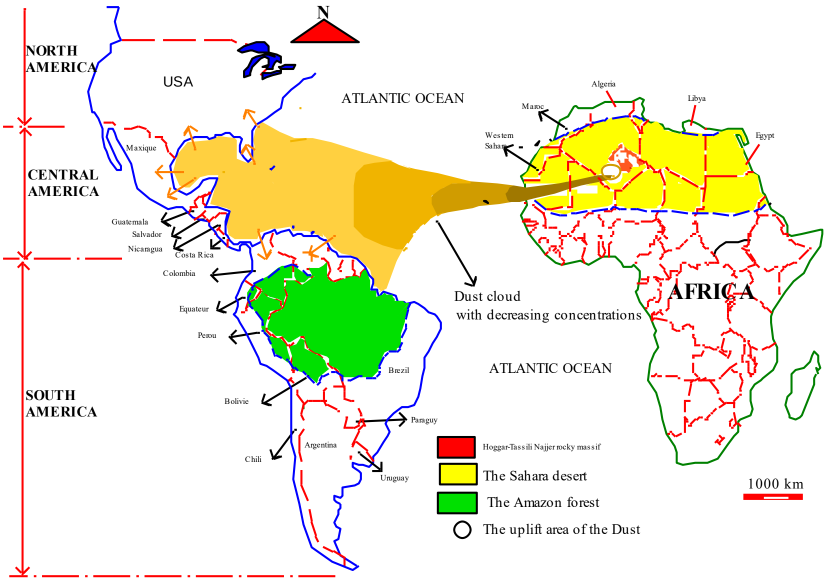


Figure 28: Rough diagram of the journey of Godzilla dust from Tamanrasset to the Americas (Remini, 2020)

Never seen before, a storm as important as that of Godzilla for half a century (Mayer, 2020). Its head has arrived in the Americas and its tail is in the Sahara, ie a plume length equal to 5000 km; an uninterrupted airlift of dust. We also noticed that the dust storms that originate from the Tanezrouft Desert are low in volume and not very concentrated. On the other hand, the storms raised in the Bodélé area (Chad) are generally the most virulent from a "lifespan" point of view and the concentration of fine particles in the air. So is there a scientific explanation for Godzilla; the biggest storm ever seen for over 50 years and which started in Tanezrouft area and not in Bodélé area as usual.

CONCLUSIONS

During the period June 4-26, 2020, a dust storm from the Sahara Desert hit countries in the Caribbean, northern South America, Central America and the southern United States. Godzilla; an impressive dust storm unheard of in over 50 years took 22 days to fly over 10,000 km. The transatlantic journey of the dust cloud between the two continents is a very common meteorological phenomenon, however, the dust cloud “Godzilla” is gigantic and of high concentration of fine particles; its tail is in the Sahara, while its head is flush with the coasts of the continent of America. Three places of dust rising have been identified in the Sahara. Bodélé (Chad) is the most dust-exporting region to the American continent. More than 53% of dust storms started from this small dusty area of Bodélé. However Godzilla, the biggest dust storm for half a century had its departure from the desert of Tanezrouft (Tamanrasset, Algeria) and not from Bodélé depression.

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