DUST/SAND STORMS OVER LIBYA: SPATIAL DISTRIBUTION, FREQUENCY AND SEASONALITY

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Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) Regional Center for Northern Africa-Middle East-Europe (NAMEE)

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Summary

The climate of most of the coastal region of Libya can be classified as semi-arid, while that of the rest of the country is arid. Rainfall is erratic with extremely variable yearly rainfall amounts: a series of dry years may follow a year with adequate rainfall. Furthermore, monthly and seasonal totals are not homogenous and most precipitation occurs during winter months.

Dust and sand storms, the focus of the present study, are one of the main extreme weather phenomena that affect Libya. In this paper, spatial and temporal distribution, frequency and seasonality are studied and analyzed. Normal frequency for the period 1961-1990 is computed and discussed on seasonal and annual basis. Finally, the annual frequency for the period 2000-2009 is computed and compared with the normal values in order to analyze temporal trends.

The analysis concludes that sand and dust storms occur in most stations almost the whole year. They are more frequent in spring, especially in April, with the highest annual frequencies observed at Tobruk airport (14.9 days), Hon (12.9), Sirt (11.2(and Ghadames (11.1). A net decrease of 30% is observed during the decade 2000-2009 when compared with the normal values for 1961-1990.

Key words: sand and dust storm, synoptic weather station, lee depressions, Libya

Contents

1. Introduction

Libya is situated in North Africa with approximately two thousand kilometers of coastline facing the central part of the Mediterranean basin. It is bounded on the south by Sudan, Niger and Chad and lies between Egypt to the east and Tunisia and Algeria to the west. Libya's area totals 1,759,540 km^2, with no interior rivers or lakes. Its terrain is relatively flat and mostly barren. Undulating plains, plateaus, and depressions imbed its flat land. Desertification and extremely limited fresh natural water are the main environmental concerns of Libya.

The whole Libya, a desert country, is located in north latitude and east longitude. Its geography (Fig. 1) encompasses the following features (Ogilbee and Tarhuni, 1962; El-Takhtiet, 1978):

- The Jefara plain (J in Fig 1), a quite plane land interspersed with sand dunes, extends along the Mediterranean coast from the Tunisian border to the city of Al Khoms
- The Al Jabal Al Akhdar highlands (Green Mountains), located in the vicinity of the coastal plain of northeast Libya.
- The Jabal Nafousa mountains, which form the southern boundary of the Jefara plain, rise about 600 meters above sea level (asl)
- The Akakos Mountains (K), which rise up to 1428 m asl, extend north to south in the eastern part of the Ghat Oasis.
- The Tibesti Massif (T), which rises to over 2,200 m asl, is the highest region of Libya. It is situated in the depopulated southern desert, near the Chadian border.
- The Great Sand Sea (S), a great mass of sand, which lies parallel to the Mediterranean coast and occupies most of the northeastern part of the Libyan Desert, from the Jalo Oasis to the Egyptian border. It extends south to the western part of Kufra district

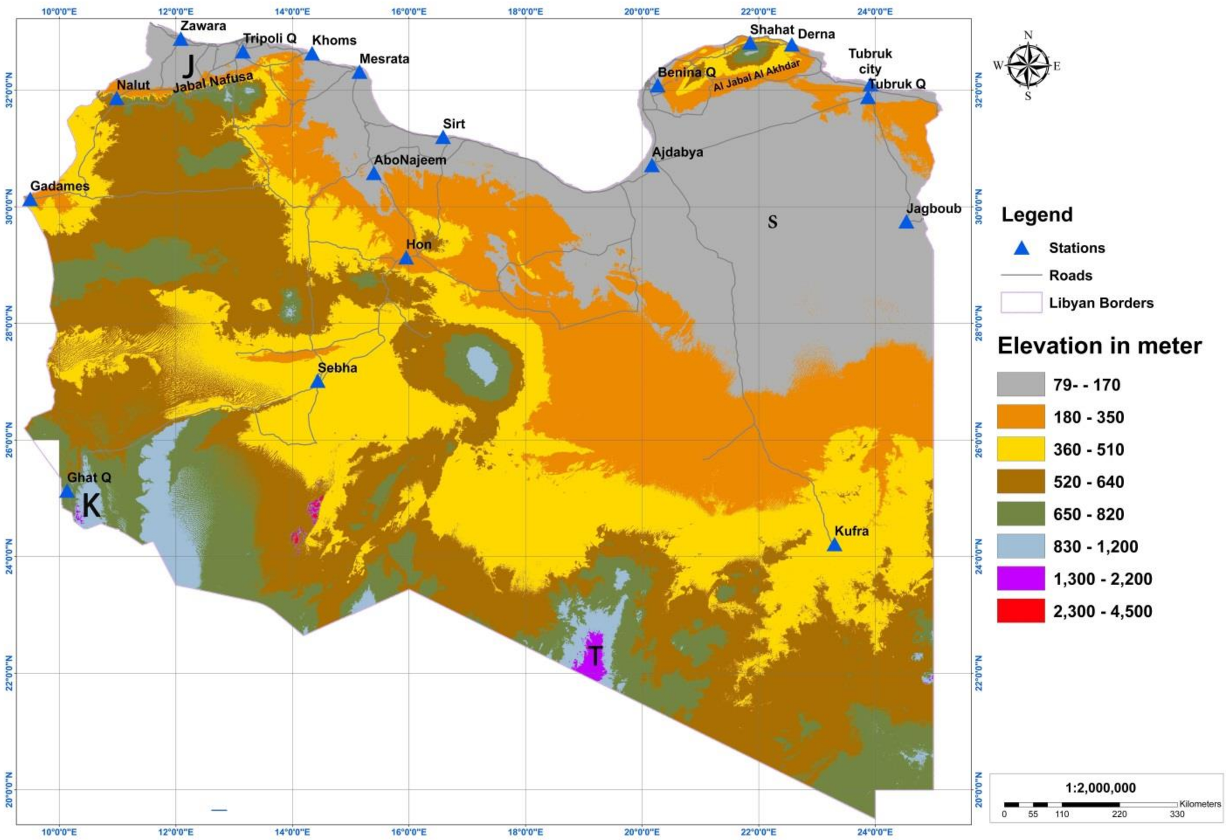

Figure 1: Topography of Libya and location of the synoptic weather stations used in the present study (blue triangles)

Most of the Libyan coastal region can be classified as semi-arid, while the rest of the country is completely arid. The climate is characterized by a high evaporation and wide diurnal temperature ranges, especially in the desert interior. Precipitation totals 400-600 mm in Al Jabal Al Akhdar and 300-400 mm in the rest of the relatively narrow northern coastal strip, including the Jabal Nafousa Mountains. On the other hand, the rest of the country suffers a severe lack of rainfall with totals barely reaching 30 mm, which represent an extreme aridity. Rainfall is erratic and yearly rainfall amounts are variable: many dry years may follow a year with acceptable precipitation. Furthermore, monthly and seasonal rainfall totals are not homogenous since most of the rain falls during the winter months.

The main extreme weather phenomena that affect Libya are: 1) sand and dust storms (SDS) that are the focus of the present study, 2) fog, 3) flash floods and associated convective weather phenomena, such as thunderstorms and 4) heat waves. SDS events are meteorological severe weather phenomena common in the Sahara desert as in other arid and semi-arid regions of the world. They are produced when a strong and turbulent wind lifts large quantities of dust or sand into the atmosphere. In the meteorological practice, such phenomena can only be reported as SDS when horizontal visibility[1] at eye level is reduced to less than 1000 m. If such condition is not satisfied (visibility is observed to be 1000 m or more), the phenomenon is reported as drifting/blowing dust/sand, rising sand or haze.

SDS affect almost the whole country, especially in spring. They can cause (directly or indirectly) economic and environmental losses as well as human deaths. SDS directly affect visibility. So, they severely affect take-off and landing operations in both civil and military aviation, can lead to the interruption of aeronautical activities, cause delays, cancellations and deadly accidents. SDS may also affect maritime and land transportation. Dry deposition of sand can bury roads and cause deadly accidents. On the other hand, SDS can disturb marine transportation and preclude ships from entering the Tripoli sea port. Other direct impacts of SDS are damages to the telecommunication and electric lines as well as to property, damage to pasturelands when strong and dry winds associated with SDS blow grass and topsoil away and disturbance of daily commercial and military operations near desert regions (Barnum et al., 2003).

From the radiation budget perspective, the air turbidity increases with SDS occurrence and hence affects the radiation balance. Airborne atmospheric particles directly impact radiative equilibrium between Earth’s surface and atmosphere by modifying planetary albedo and reducing the quantity of radiation reaching the Earth’s surface. Consequently, they affect the weather and climate (Mitsakou et al., 2008; Yu et al., 2001). Saharan dust modifies both solar radiation by reflecting back part of the short-wave radiation into space, and Earth’s infra-red radiation emitted to space (Goudie and Middleton, 2001). Aerosols also indirectly affect clouds climate forcing by serving as condensation nuclei and thereby modifying rainfall totals (Maley, 1982) and by increasing the clouds albedo. As quoted by Eddenjal (2004) both effects contribute to large uncertainties in assessing radiative forcing in climate modelling.

Based on the author’s experience, the large-scale land misuse (abuse) in some parts of Libya may lead to soil erosion (soil loss) and desertification (Fig. 2). IPCC (2001) pointed out that dry land, where human activity has disturbed soil conditions or has reduced vegetation cover, can become a dust source region. Indeed, vegetation cover, wind speed and soil moisture are the main factors of dust emission in the Saharan regions (Ridley et al., 2012).

Figure 2: Example of land use change: Land disturbance and deforestation

El-Tantawi (2005) suggested that arid and semi-arid climate conditions increase the potential for erosion in the event of high intensities of precipitation and windstorms. He added that the western part of Libya, including the Jefara Plain and the Jabal Nafousa mountains, experiences both wind and water erosions. According to Ben-Mahmoud et al. (2000), in the coastal areas, the terrain subject to water erosion represents about 30 % of all lands, whereas the proportion raises to 70% in the arid regions of southern Libya.

The goal of this work is to study the spatial and temporal patterns of SDS over Libya including their frequency and seasonality.

2. Meteorological conditions associated with dusty conditions

In spring, most of the Libyan weather stations are on or near the track of the Atlas lee cyclones that are generated by the evolution of an upper-level trough over North Africa (Thorncroft et. al., 1996) where the sea surface temperature is still low and the Mediterranean front is often very sharply defined. Although these depressions usually produce cloudy and rainy weather, their most significant effect is the onset of strong winds associated with considerable temperature changes, rising sand and visibility reduction. Thus, in spring, the outbreak of SDS in North Africa occurs when Atlas lee depressions initiated south of the Atlas Mountains pass over arid and semi-arid regions. Such Saharan lows, as they are sometimes called, represent significant synoptic structures, which can arise in winter and spring (i. e. Thorncroft et. al., 1996) and inject a large amount of dust and sand particles into the atmosphere. Fig. 3 shows the typical tracks of the Atlas lee cyclones. The shaded area in the northwest of Africa (southern boundary of Atlas ranges) is the generation area of Saharan depressions that affect Libya, producing SDS events and occasionally convective rain episodes. As shown in the figure, most of the cyclones move northeastwards through the Gulf of Gabes, whereas others follow the Libyan coastline. It should be noted that such depressions are occasionally accompanied by cold fronts that affect almost all the Libyan country.

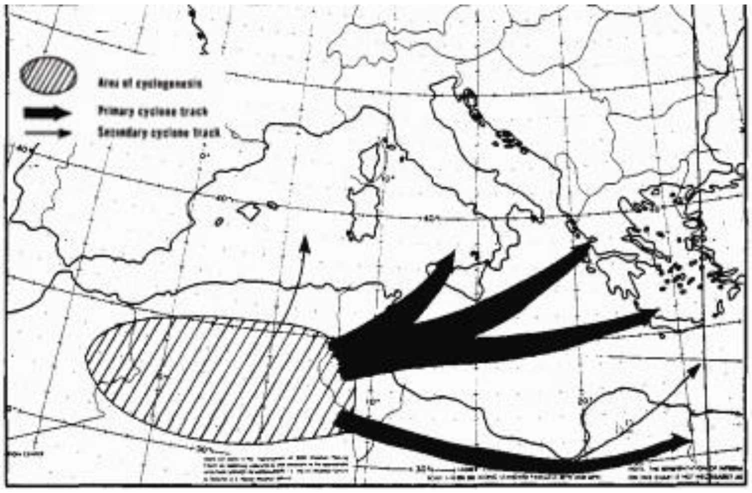

Figure 3: Typical trajectories of the Atlas lee depressions across northwestern and mid of North Africa. The insert shows the initiation area and tracks of Atlas lee cyclones (Reproduced from Brody and Nestor, 1980)

In summer, the country is mainly under the influence of small depressions or troughs, which are generally shallow. These thermal depressions usually develop over southern Tunisia (west of Gadames) and cause the temperature to reach 45ºC or more. Fine dust rises up and produces hazy condition over many areas of west Libya. Ghibli is the local name of the dominant winds east of both thermal lows and Atlas lee cyclones.

3. Data collection

Data used in this study have been collected from the Libyan National Meteorological Center (LNMC). They represent in-situ observations of visibility (indirect dust measurements). It should be noted that Libya presents considerable gaps in data coverage, especially in the interior, with most parts of the Libyan Desert lacking of weather stations (see Fig. 1). Daily data from 17 synoptic weather stations have been collected and used in the analysis (see Fig. 1 and Table 1). Seven other stations have been excluded from the study because of the unavailability of long and complete digital records. Data have to be used with caution as visibility is measured subjectively.

Station	WMO code	Latitude	Longitude	Altitude (m)	Period
Nalut	62002	31.87	10.98	621	1956-2009
Zawara	62007	32.88	12.08	3	1956-2009
Tripoli Apt.	62010	32.67	13.15	82	1956-2009
Mesrata	62016	32.32	15.05	32	1956-2009
Sirt	62019	31.20	16.58	14	1956-2009
Ajdabya	62055	30.72	20.17	7	1956-2009
Benina Apt.	62053	32.08	20.27	129	1956-2009
Shahat	62056	32.82	21.85	621	1956-2009
Derna	62059	32.78	22.58	26	1956-2009
Tubruk Apt.	62063	32.10.	23.93	51	1955-1983
Tubruk city	62062	32.02	23.93	50	1985-2009
Gadames	62103	30.13	9.50	347	1962-2009
Hon	62131	29.12	15.92	267	1956-2009
Sebha	62124	27.02	14.45	432	1962-2009
Jagboub	62176	29.90	24.53	-1	1956-2009
Kufra	62271	24.22	23.30	436	1956-2009
Ghat Apt.	62212	25.13	10.15	693	1979-2009

Table 1: Synoptic weather stations used in the study (source: Libyan National Meteorological Center).

4. Findings

The monthly and annual frequency of days with recorded SDS has been computed for the 17 selected stations and the period displayed in Table 1. Results are shown in Table 2 and the geographical distribution of annual SDS frequency is represented in Figure 4.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Nalut	0.1	0.4	0.6	0.7	0.5	0.1	0.0	0.0	0.1	0.1	0.1	0.3	3.1
Zawara	0.6	0.8	1.3	1.1	0.8	0.5	0.1	0.1	0.3	0.6	0.4	0.5	7.2
Tripoli Apt.	0.2	0.3	0.5	0.6	0.3	0.2	0.1	0.0	0.1	0.2	0.1	0.2	2.8
Mesrata	0.2	0.2	0.3	0.4	0.2	0.1	0.0	0.0	0.1	0.2	0.0	0.2	1.9
Sirt	1.2	1.1	1.7	2.1	1.1	0.6	0.1	0.1	0.5	0.7	0.8	1.2	11.2
Ajdabya	0.3	0.6	1.6	1.6	1.1	0.6	0.4	0.5	0.3	0.5	0.5	0.5	8.5
Benina Apt.	0.2	0.2	0.4	0.8	0.4	0.2	0.1	0.1	0.4	1.0	0.8	0.6	5.2
Shahat	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3
Derna	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Tubruk Apt.	1.9	2.1	2.1	2.4	1.3	0.7	0.3	0.0	0.5	0.8	0.7	1.4	14.9
Tubruk city	0.7	0.4	1.0	0.6	0.4	0.1	0.0	0.0	0.3	0.2	0.6	0.4	4.7
Gadames	0.4	0.6	1.8	2.4	2.2	1.5	0.4	0.3	0.5	0.4	0.1	0.5	11.1
Hon	1.0	1.3	2.4	2.8	1.8	1.2	0.4	0.2	0.4	0.4	0.3	0.7	12.9
Sebha	0.3	0.7	1.7	1.4	1.4	0.6	0.2	0.1	0.3	0.4	0.2	0.1	7.4
Jagboub	0.7	0.8	1.4	1.6	1.1	0.3	0.1	0.2	0.1	0.1	0.3	0.5	7.2
Kufra	0.1	0.4	0.8	1.1	0.6	0.0	0.0	0.0	0.0	0.1	0.0	0.0	3.1
Ghat Apt.	0.0	0.1	0.0	0.2	0.4	0.5	0.0	0.0	0.3	0.1	0.0	0.0	1.6

Table 2: Monthly and annual mean frequency of days with SDS for the period listed in Table 1

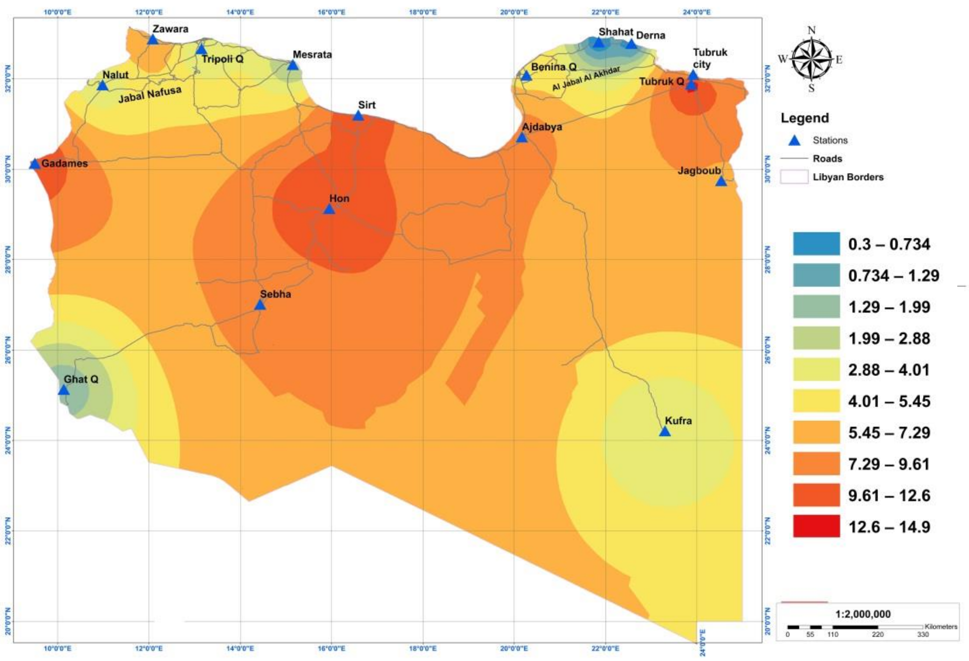

Figure 4: Geographical distribution of the annual SDS frequency for the period listed in Table 1

It can be noticed that although SDS can occur almost throughout the whole year, their frequency is higher between January and June. The peaks occur in April (8 stations), in March

(5 stations) and in October (1 station). The annual frequency of days with SDS ranges from 0.3 days at Shahat to 14.9 at Tobruk airport. Hon (12.9), Sirt (11.2) and Ghadames (11.1) also present high frequencies. It is worth to highlight the difference between Zawara (7.2) and Tripoli airport (2.8), both in the Jifara plain. It can be partly explained by the location of the latter within a cultivated area.

The low frequency observed at Shahat (0.3) and Derna (0.4) can be explained by the proximity to the Al Jabal Al Akhdar highlands, which surround the stations from South to Southwest and act as a barrier that blocks the passage of sand clouds. Moreover, the soil around the stations mainly consists of clay. Something similar occurs at Ghat, a station located in the southwestern part of Libya and surrounded by a sand desert. Although it is affected by the same low-pressure systems that other synoptic weather stations, it presents the third lowest SDS frequency (1.6). The cause is also related to orographic factors, since the station is situated in the lee of mountain ranges and hilly areas, which slow down the wind and act as a barrier to the movement of sand fronts.

The maximum annual frequency is recorded at Tobruk airport (14.9) in the northeast of the Libyan coast. SDS generally arrive here from the southwestern regions, that is, from the Great Sand Sea, the second largest permanent sandy spot on Earth. In contrast, Tobruk city presents a much smaller SDS frequency (4.7). This station is surrounded by the sea and urbanized areas, whereas the airport is in an open area several kilometers inland.

Normal monthly, seasonal and annual SDS frequency is computed for the reference period 1961-1990. Figure 5 shows the seasonal values for the different stations and Figures 6-10 represent their geographical distribution. In winter, the frequency ranges from 0.0 at Shahat to 4.0 at Sirt. Relatively high frequencies are observed at Zawara and Hon (2.7) and Gadames and Jagboub (2.1). In spring, the frequency varies from 0.0 at Shahat to 8.5 at Gadames, with high values at Hon (6.8) and Sirt (6.1). In summer, the frequency ranges from 0.0 at Shahat, Derna and Kufra to 3.2 at Gadames, with high values at Jagboub (1.9) and Hon (1.6). Finally, in autumn, values range from 0.0 at Shahat and Derna to 2.3 at Benina, with 2.1 at Sirt and 1.6 at Zawara.

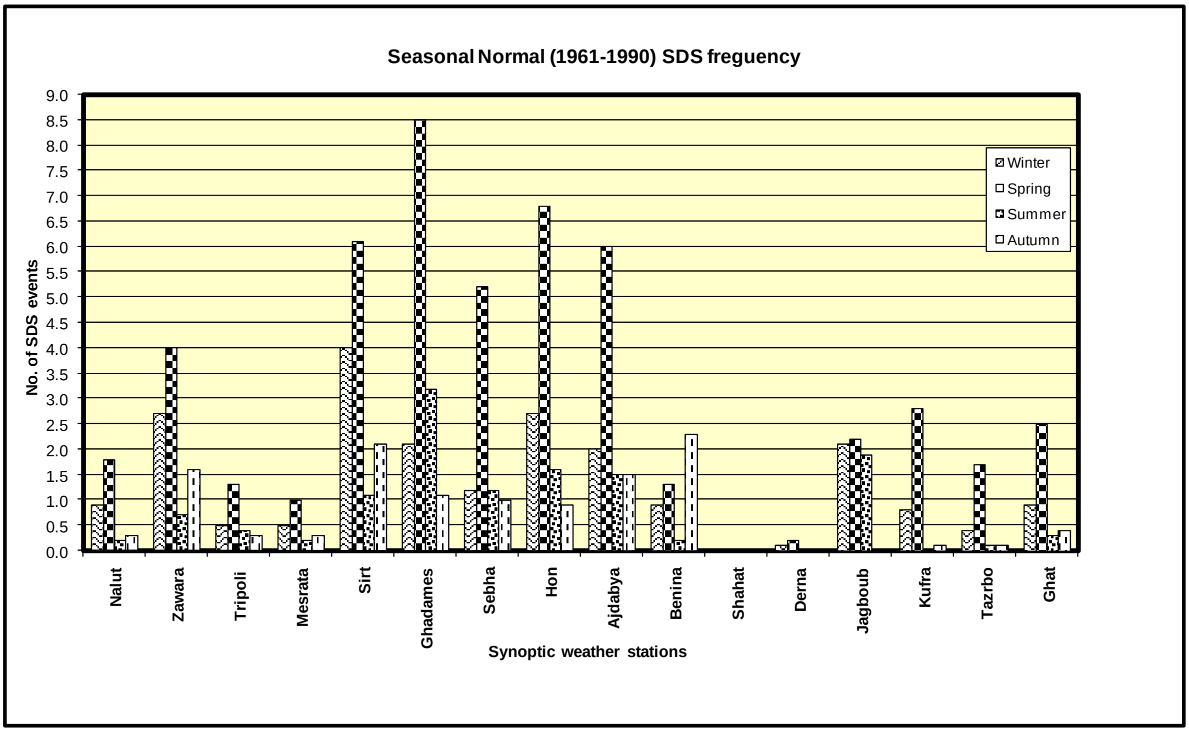

Figure 5: Seasonal normal SDS frequency (1961-1990). Bars represent winter, spring, summer, and autumn values from left to right

Spring, followd by winter, presents the maximum frequency of SDS across most of the country. An exception is Benina, where the highest frequency is observed in autumn, followed by spring. The other exception is Ghadames, where summer presents the second highest seasonal frequency due to the thermal lows originated in southern Tunisia, west of the oasis.

It can be highlighted again that the effect of Atlas lee depressions (and associated cold fronts) is very important. Apart of Shahat, where the absence of SDS in all seasons is explained by its particular location in the Al-Jabal Al Akhdar highlands, the lowest annual frequencies are found in the stations located in the southern part of the country, distant from most of the Atlas lee depressions' tracks (see Figure 3).

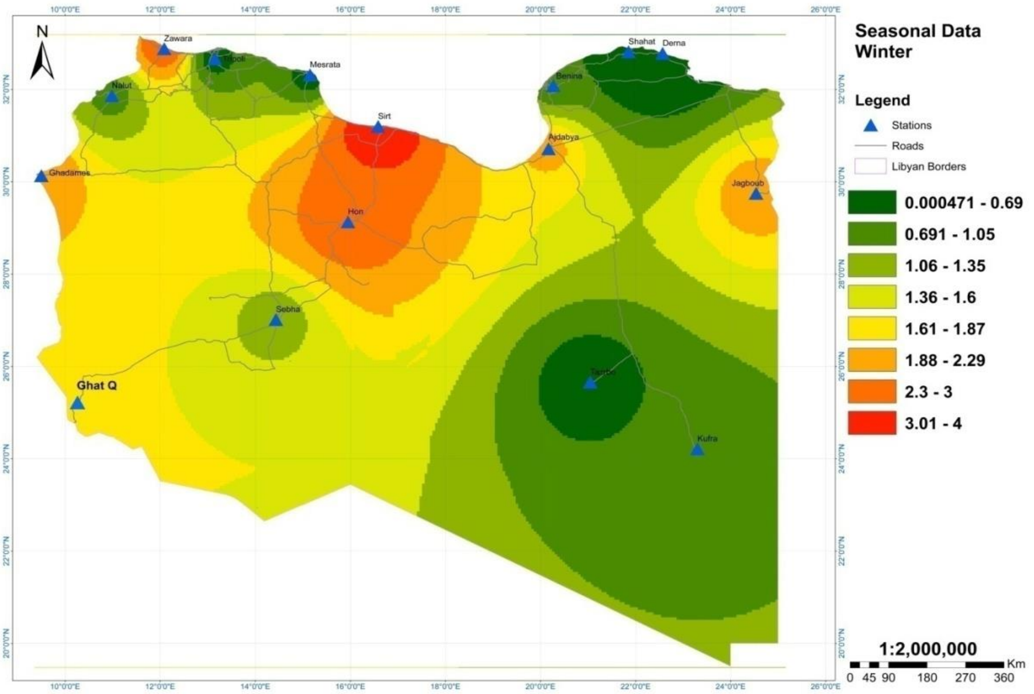

Figure 6: Normal SDS frequency in winter (1961-1990)

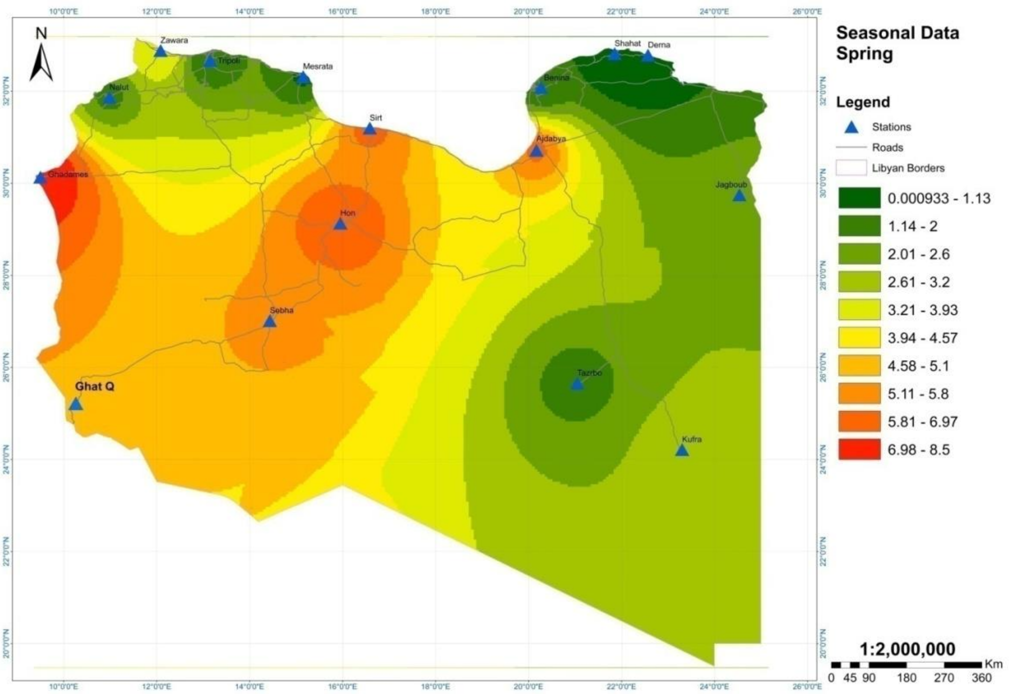

Figure 7: Normal SDS frequency in spring (1961-1990)

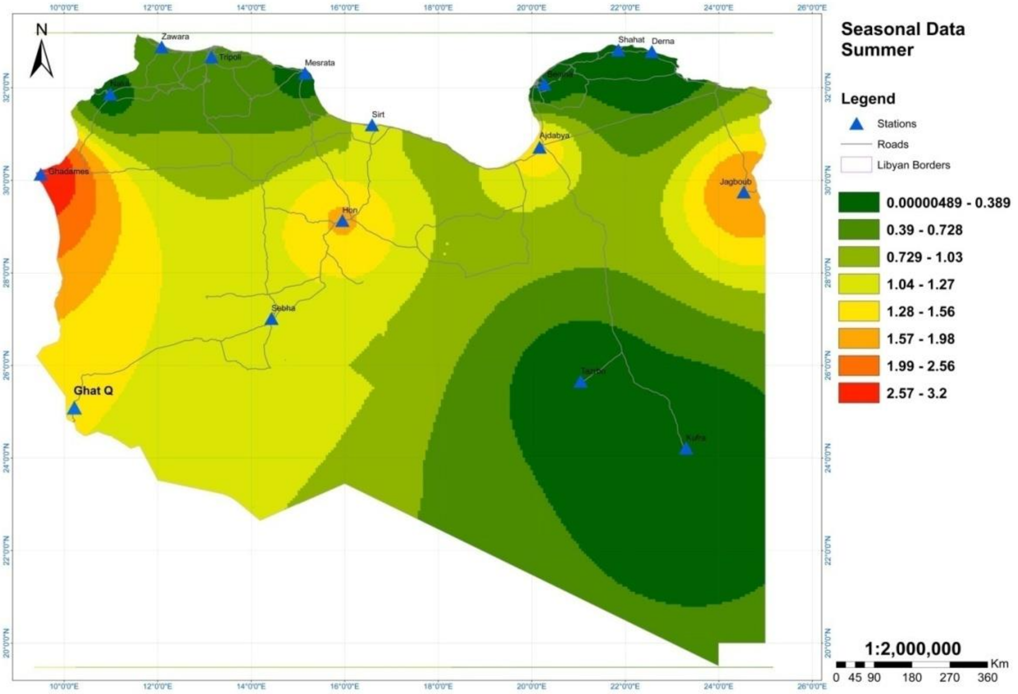

Figure 8: Normal SDS frequency in summer (1961-1990)

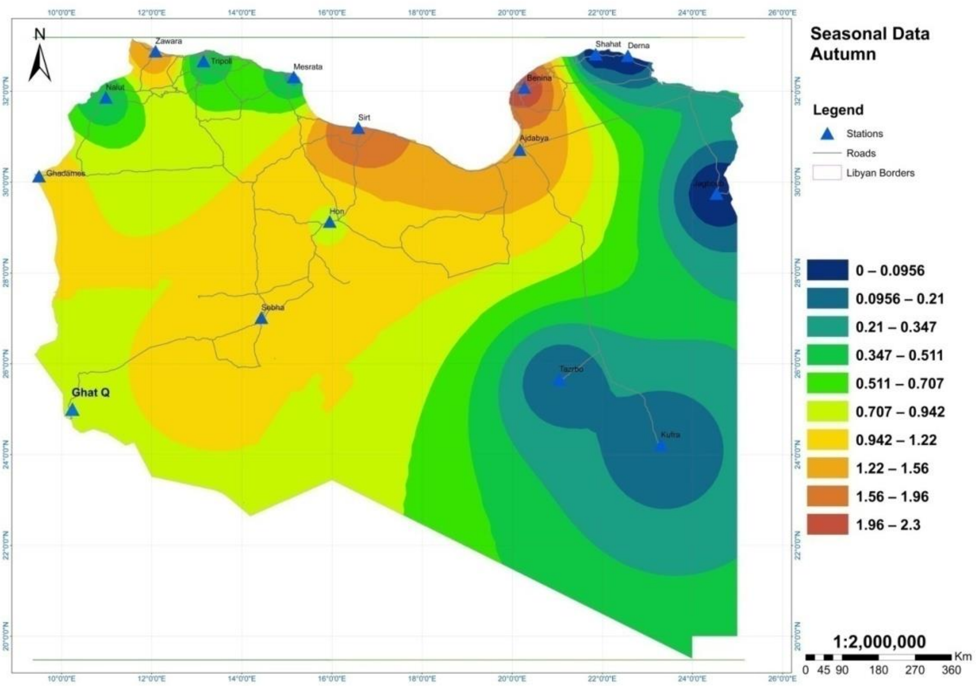

Figure 9: Normal SDS frequency in autumn (1961-1990)

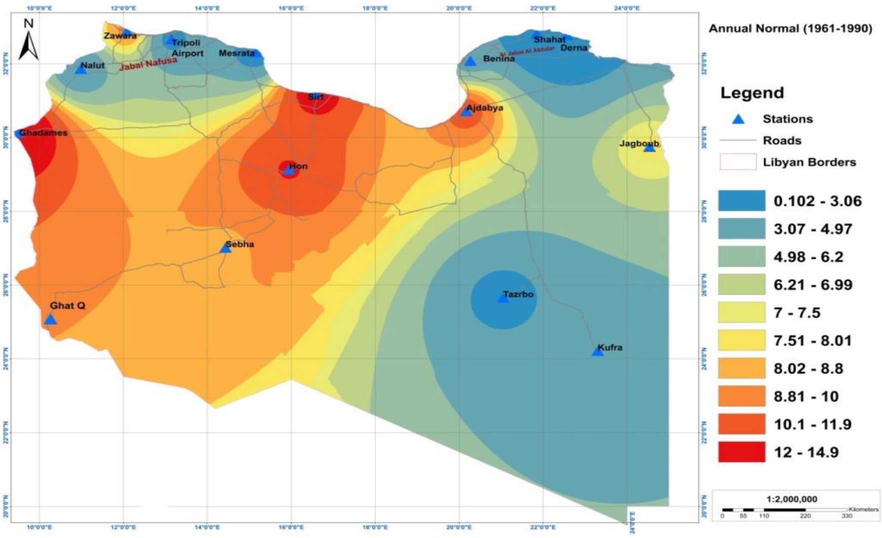

Figure 10: Normal annual SDS frequency (1961-1990)

SDS frequencies are also computed at 15 stations for the period 2000-2009 and compared with the normal values 1961-1990 in order to assess temporal trends. Stations have been selected based on data availability covering both periods. The annual SDS frequency for both periods is represented in Figure 11, Figure 12 shows the spatial distribution of SDS frequency for the period 2000-2009 and Figure 13 the spatial distribution of the difference between both periods. For the most recent decade, Hou presents the highest frequency. This station, like Ghadames that has the highest frequency for 1961-1990, is situated in the Sahara desert, close to the tracks of the Atlas lee cyclones.

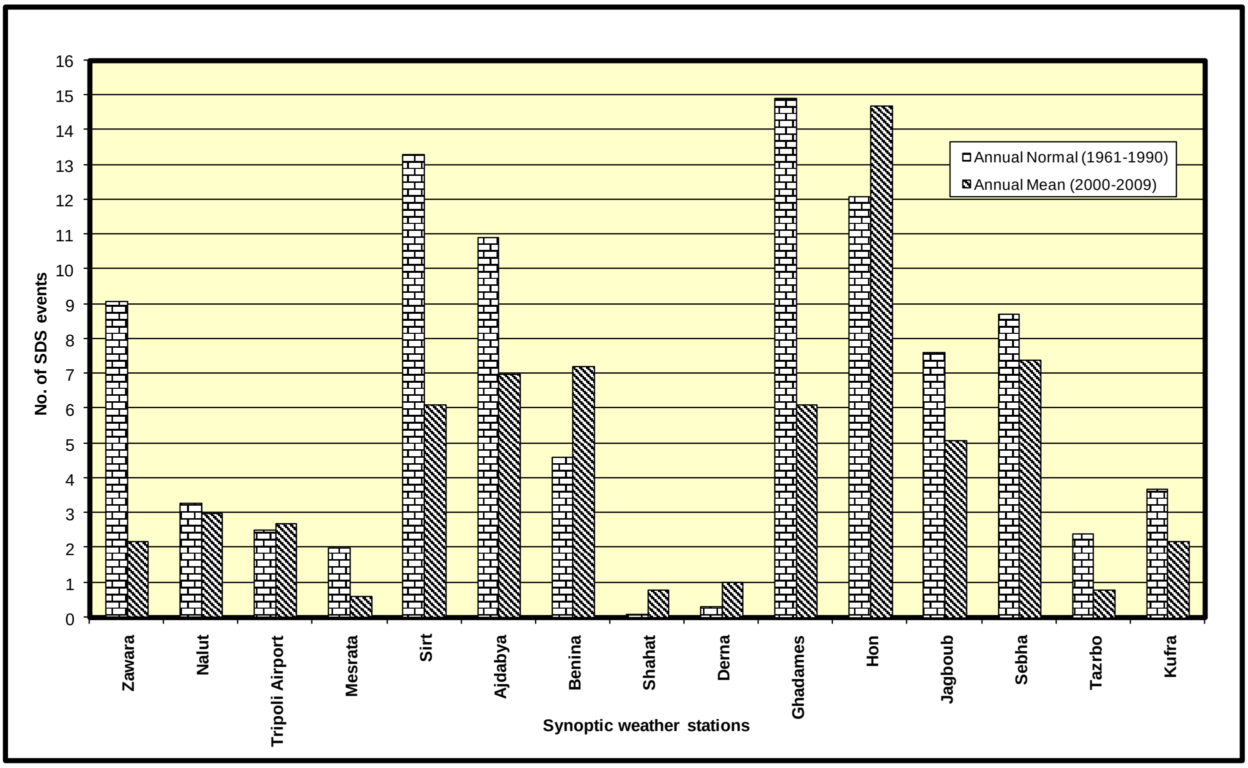

Figure 11: Annual SDS frequency for the period 1961-1990 (left bar) and 2000-2009 (right bar)

Ten of the fifteen stations analyzed present a decreasing trend, with the most notable drops in Ghadames (-8.8), Sirt (-7.2) and Zawara (-6.9). On the other hand, a significant increase has been found in Hon and Benina (+2.6). For the whole country, a net decrease of 30.1% is estimated for the decade 2000-2009 in comparison with the normal reference period.

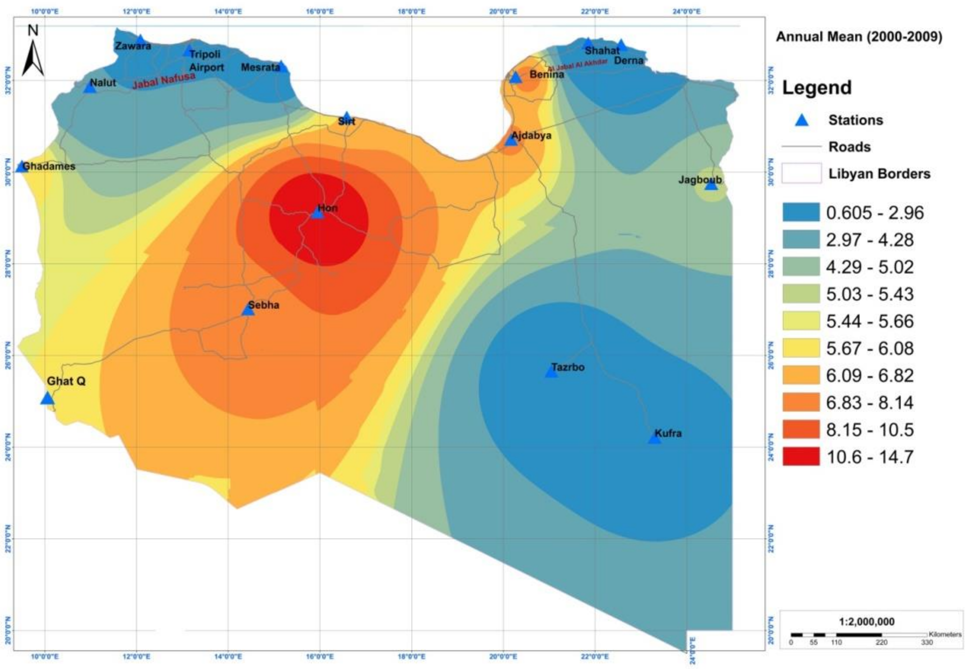

Figure 12: Annual SDS frequency for the period 2000-2009

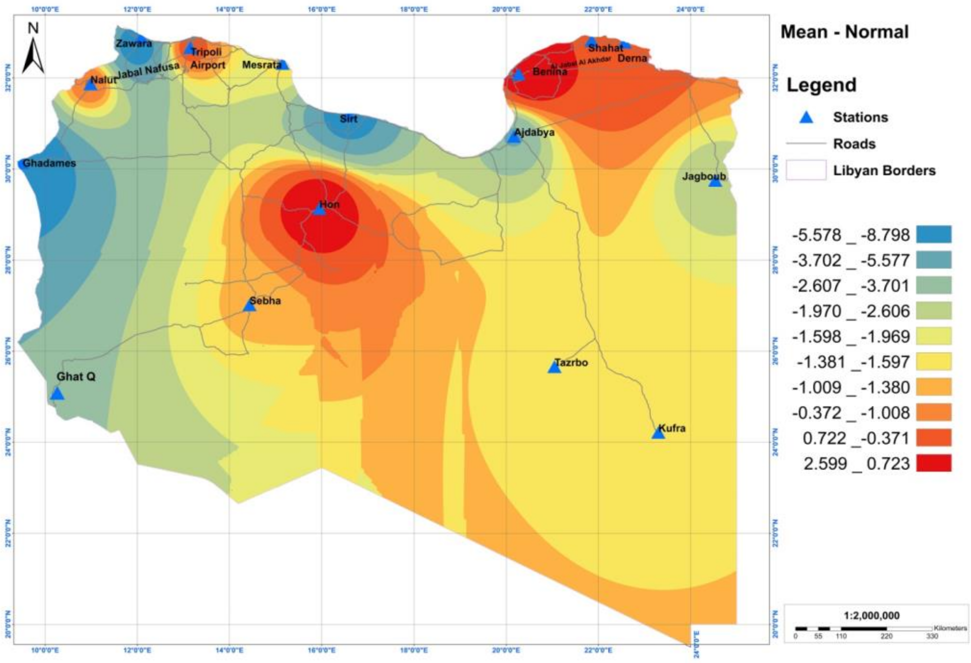

Figure 13: Difference between normal SDS frequency and SDS frequency for the period 2000-2009

The annual SDS frequency for the different periods at the analyzed stations is synthesized in Table 3.

Frequency	Annual frequency for the period listed in table 1	Normal annual frequency (1961-1990)	Annual frequency for the period 2000-2009
Very high frequency (> 9 days)	Tubruk airport, Hon, Sirt, and Ghadames	Gadames, Sirt, Hon, and Ajdabya	Hon
high frequency (6-9 days)	Ajdabya, Sebha, Zawara, and Jagboub	Sebha and Jagboub	Sebha, Benina airport, Ajdabya, Gadames and Sirt
Moderate frequency (3-6 days)	Benina airport, Tubruk city, Nalut, and Kufra	Benina airport, Kufra and Nalut	Jagboub
Low frequency (1-3 days)	Tripoli (airport), Mesrata, and Ghat (airport)	Tripoli airport, Tazrbo, and Mesrata	Nalut, Tripoli airport, Zawara and Kufra
Very low frequency (≤ 1 day)	Derna and Shahat	Derna and Shahat	Derna, Tazrbo, Shahat, and Mesrata

Table 3: synthesis of the annual SDS frequency for the different periods

5. Conclusions

In this paper we used visibility observations to analyse the spatial distribution, frequency and seasonality of SDS in Libya. Records show that SDS events affect all the synoptic weather stations, especially in spring (from February to May). The highest frequency in spring may be explained by the seasonal weather patterns affecting the North Africa Saharan regions, which are mainly controlled by the monsoonal behavior of the Atlas lee mountains lows. The peak is found in April and March. However, relatively high frequencies are observed as early as in December and persist until June in the western areas. High SDS frequencies found in western and northern Libya in summer, especially in June, are supposed to be associated to Saharan thermal lows. However, although the weather patterns play a key role in the geographic distribution of SDS, local effects have also a very important influence.

A net decrease of 30.1% in the SDS frequency is observed during the decade 2000-2009 when compared with the normal values for the reference period 1961-1990. This unexpected result does not reflect the desertification, which is largely witnessed in many parts of northern Libya, for example in the Jifara plain. The reason of this decrease is not clear and can be attributed to various factors, not ruling out a shortcoming in the observing practices. Unfortunately, there are not enough weather stations to shed more light on the role of desertification on the SDS frequency trend.

6. Recommendations

The current number of synoptic weather stations in Libya is insufficient and must be increased, especially in the Gulf of Sidra, where the desert extends northward to the coast, and in the southern regions of the country. Moreover, all meteorological data must be digitized in order to be available and usable for research purposes aimed at achieving socio-economic benefits and facilitating sustainable planning and definition of development strategies. The availability of weather information is crucial to support policy makers in the design of action plans to combat desertification, to mitigate the effects of climate change and to improve the management of natural resources.

A ground–based observational network for aerosols should be designed and implemented in order to achieve a good characterization of sand and dust particles by in-situ measurements. It should be done after a thorough analysis of the requirements (identification of optimal measuring sites and technical specifications for the stations and instruments) as well as building capacity of staff to operate and maintain the stations. Measurements near source areas are very important in order to conduct in-depth research that advances our understanding of SDS events.

Extensive work and research projects on SDS and related subjects must be set up and supported. Moreover, data exchange among countries is indispensable. Satellite and ground-based data as well as model simulations are fundamental to investigate the characteristics of Saharan dust release and transport from daily to multi-annual time scales.

Public awareness of SDS and their adverse socio-economic impacts is also crucial to improve the management of natural resources, especially water, vegetation and soil. Media should be heavily involved to raise such awareness.

Finally, projects to stabilize sand surfaces must be carried out. Libya already conducted successful projects to fix sand dunes in the 1960s and 1970s, when it was considered a world pioneer in activities aimed at combating desertification (El-Tantawi, 2005). Planting trees and shrubs is an effective way to combat the sand movement and desertification processes.

7. Acknowledgements

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