MONITORING OF EASTERLY SAHARAN DUST STORMS

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ABSTRACT

The Sahara serves as one of the largest reservoirs of mineral dust in the world. This study focuses on easterly Saharan Saharan Dust Storms into Atlantic Ocean. It was possible to trace the movement of a dust storm from Mauritania across the Atlantic Ocean to Venezuela. During the period of the study, six dust storms of different intensity were recorded. Satellite monitoring with SeaWiFS and Meteosat was done on a daily basis from the first of January to the 15th of May 2001. While dust sources are active all year, they become especially strong during the summer (J.M. Prospero, 1996), consequently this study focuses primarily on the months of least activity. While the effects of mineral dust on cloud seeding has been addressed in the Middle East (Rosenfeld, 1997), this study has found evidence of cloud seeding over the North Atlantic Ocean. Ground station data yields to the fact that many dust storms are small events, which are difficult to detect on satellite imagery.

INTRODUCTION

Even though remote sensing is still one of the youngest sciences, it has revolutionized the way we study the world. Amongst one of its most common applications, is the study of storms. Remote sensing has allowed us to study storms that stretch over several thousands of kilometers.

This project focuses on the study of westward Saharan dust storms between the first of January and the 15th of May 2001. The genesis, the movement and to some extent also the deposition of Saharan sand storms, will be discussed. The limitations and benefits of satellite data versus ground station data will also be addressed.

METHODS

The SeaWiFS satellite is a sun synchronous satellite that is able to provide new imagery every 24 hours. It has a swath width of 2,801 km and spatial resolution of 4.5 km. Because of its low temporal resolution it was also necessary to use the geostationary satellite Meteosat. Meteosat has a temporal resolution of 30 minutes and a spatial resolution of 5*9 km. While SeaWiFS operates only in the visible bands, Meteosat has the advantage of also providing infrared and water vapor imagery and therefore is more useful for monitoring weather patterns. This data is provided by the Naval Research Laboratory at http://kelvin.nrlmry.navy.mil:9999/aerosol/. In addition to this, the website also contains plots depicting aerosol and weather modeling derived from the above satellite data. The most useful plots depict the difference between dust aerosols and smoke aerosols. This is important because it is impossible to differentiate visually between dust and smoke, especially in the southern portion of the study area that is greatly affected by large numbers of wildfires. All measurements of the optical depth are done at a wavelength of 0.55 microns for both smoke and dust. Furthermore, the plots are based on the assumption that both dust and smoke have different radii, refracted indices and specific extinction. For dust, we assume particles of 1 micron radius and a refractive index of 1.55 + .001i. The specific extinction is $0.5m^2$ g^1. For smoke, we assume particles of 0.01 micron radius and a refractive index of 1.55 + 0.1i. The specific extinction is $7.1m^2$ g^{-1}. Given the limitations of this method (radii sizes of smoke and dust are averages) it is possible to differentiate the bulk of smoke from the bulk of dust. The above plots also include wind direction and speed as well as atmospheric pressure patterns. The data derived from these plots was then compared to ground station data also provided by Naval Research Laboratory. This data set, includes horizontal mean visibility, wind direction and speed, as well as a classification system for sandstorms.

The first weeks of this study were mostly aimed at understanding the leading forces that trigger sand storms. The data used for this research came from NOAA - CIRES Climate Diagnostics Center at http://www.cdc.noaa.gov/. The data contains daily global atmospheric pressure patterns at 1000mb, 800mb, 700mb, 500mb and 250mb and existing anomalies. The gained knowledge was then applied for all six dust outbreaks.

When monitoring the movement of the sand storms I became increasingly interested in the causes for their deposition. While this question was too large to be answered in this study and still remains largely unanswered (J.M. Prospero,1996), I have found clear evidence of cloud seeding using ground station data from NOAA-CLIMVIS at http://www.ncdc.noaa.gov/.The latter evidence was discovered by plotting precipitation against aerosol content or mean visibility.

Finally, a map was created using friction velocity plots from the Naval Research Laboratory to map out the areas of highest dust emission. Dust emission occurs whenever the friction velocity exceeds a threshold value and the surface moisture is less than a critical value. In the Saharan region the surface moisture is almost always less than a critical value and values for the threshold of Saharan sand dunes are known.

RESULTS AND DISCUSSION

During the period of January first through May 15th 2001, six distinct dust storms were observed. All six storms were caused by an unusually strong Azores High that produced summer-like surface wind conditions (strong easterlies) over northwest Africa. The analyses of the 1000mb, 800mb, 700mb and 500mb heights revealed that anomalies were found up to 500mb but not in the 250mb. Furthermore the dust storms of greater intensity were also controlled by more dominant pressure pattern anomalies. This is especially true for the Feb. 10-14th dust storm in which case easterly winds stabilized over several days and caused an anticyclone to occur over northern Marocco and southern Spain. It is yet unclear what exactly causes this high-pressure system to develop but one of many factors point towards the rising levels of greenhouse gases (ECO, 1994).

Another important aspect for the generation of dust storms in the northern portion of the Sahara comes from the effect of the Atlas mountain range which can cause strong surface winds to run down its mountain slope and pick up sand as it heads south. This wind is generally known as the Aejej.

The maximum concentration of dust was measured in the center of the dust storm and is given in a range of values.

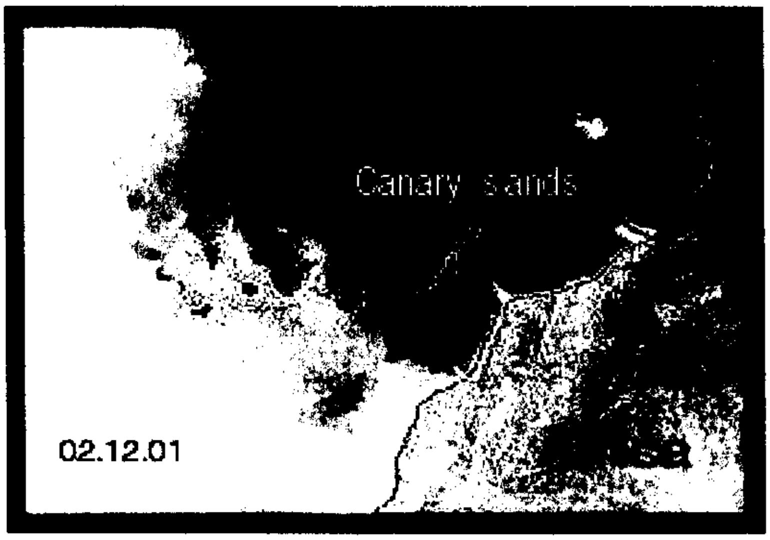
Fig. 1

25.01-31.01	640-1280 ug/m^3
10.02-14.02	5120-10240 ug/m^3
10.03-14.03	1280-2560 ug/m^3
22.03-23.03	320-640 ug/m^3
5.04-10.04	640-1280 ug/m^3
11.05-13.05	1280-2560 ug/m^3

The importance of these concentrations becomes evident when comparing them to the normal conditions, which yield to concentrations of 10-160 ug/m^3. This tells us that the concentrations during a dust storm are up to three orders of magnitudes higher. One can therefore assume that the transport of dust into the North Atlantic Ocean is primarily controlled by dust storms events rather than a continuous flux.

All dust storms were within the 700mb boundary and thus confirm the assumption that winter storms are primarily driven by lower level winds (K.Pye, 1987). This was also determined by SeaWiFS satellite images that showed a distinct wind shadow behind mount Mount Teide, Tenerife (3718m) during the February storm (Fig.2).

Fig.2

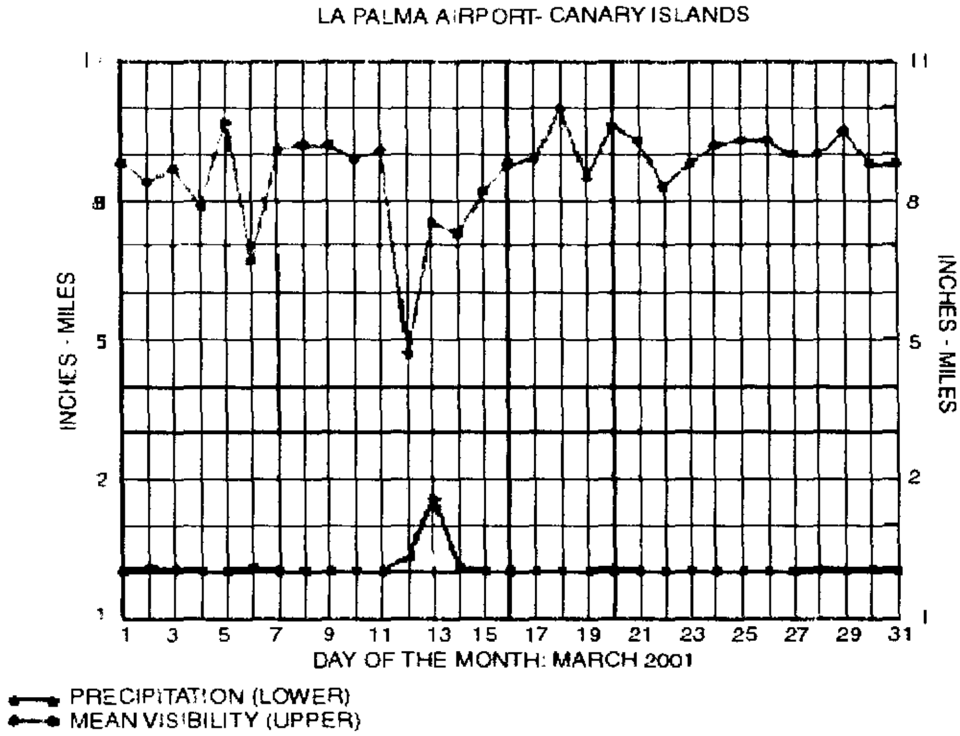


It was possible to trace the February dust storm from Mauritania across the Atlantic Ocean to Venezuela. While the dominant movement of this dust storm headed out to the Canary Islands but then turned towards the north and headed for Spain, a smaller plume that was presumably at higher elevation, continued in its westward direction and reached Venezuela eight days after leaving Mauritania. This result coincides with the studies done by Prospero (1996) who has estimated dust storms to cross the Atlantic Ocean in 7 days. It was interesting to see that after having reached ~1000km off the coast of Mauritania the intensity of the dust signal did not drop off any further but remained relatively stable during the crossing of the Atlantic Ocean. It appears that most of the dust must have been deposited during these first 1000km.

While most of the deposition of aerosols into the Atlantic Ocean is dry deposition (Prospero, 1996), there is clear evidence of cloud seeding as a direct response to several dust storm events. Cloud seeding increases the number of nuclei in cloud formations and hastens the transformation of water vapor in the cloud into droplets.

This may happen even when clouds are not visually evident but the moisture content of the air is high enough. There was no evidence for cloud seeding on the western coast of the Sahara but evidence was only found on the islands of Cape Verde, the Canary Islands and the Azores where humidity levels are relatively higher. Evidence for this was found for the February 10-14th, the March 10-14th and the May 11-13th storms. The chances of a simple coincidence are relatively rare given the fact that all three island nations record an average precipitation of close to zero for the given months. Furthermore, a close look at the March 10-14th data (Fig.3) reveals that the mean visibility increases before the maximum precipitation starts to occur and thus signifies the direct reaction to the increased number of precipitation nuclei.

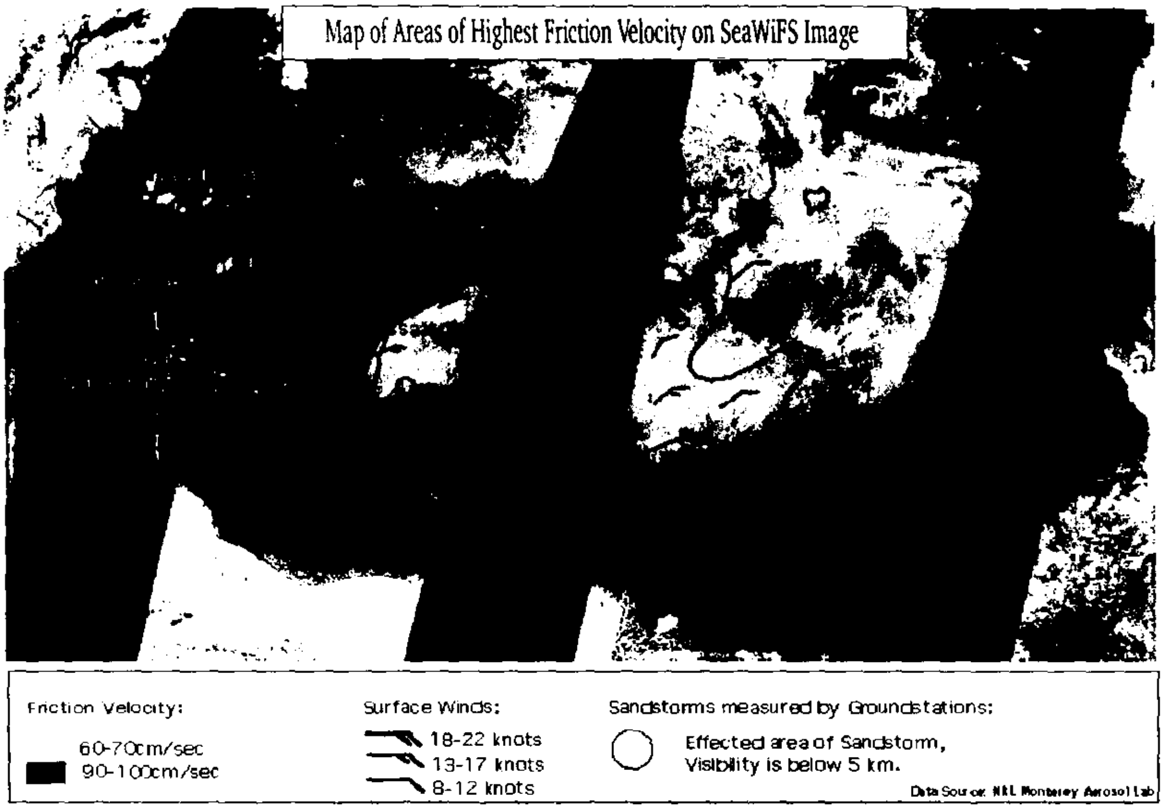
Fig. 3



This data may suggest that dust storms play an important role for precipitation and one may speculate that an increase in number of dust storms may cause more precipitation to occur.

When comparing the ground station data to the satellite data for the period of the study, it is interesting to see that the data sets differ quite significantly. It was noticed that a multitude of signals for dust being raised by wind was recorded by ground stations during a time when aerosol models, based on the satellite observations, displayed little signs of dust emission. In most cases this may be due to the fact that these dust storms are on the order of 5-10 km2 and thus are simply too small to be recorded on models that display all of northern Africa. Another interesting aspect can be seen in two of the six storms where ground stations that are not in an area of highest friction velocity recorded severe sand storms. The reason for this comes from the fact that the front of a sandstorm is often characterized by reduced wind speeds, lower friction velocities but a high atmospheric pressure gradient. In conclusion, one may say that the satellite imagery is an excellent tool for monitoring the big movements and changes that occur over the period of several days while groundtruthing remains an essential portion when quantifying these observations. It must also be said that the contrast between the Sahara desert and dust plumes is rather minute and good visibility can only be gained once a dust plume is over the ocean. The use of infrared band through Meteosat enables dust be more visible (by giving a cooler signature) over land but has its limitations given the fact that it only detects rather severe dust storms and has difficulties distinguishing between different aerosols (C.I. Measures, 2000). However, improvements in sensors and algorithms can be expected to minimize most of these problems.

Finally, I have created a map for the areas of highest dust emission for the last six dust storms. I have used SeaWiFS and NRL Monterey Aerosol Lab Data to create this map. It is important to map out from which area most sand is picked up in order to better forecast and predict the impacts of a dust storm. For example, if the area of highest dust emission is high in iron content, one might expect a very different environmental impact to one that is low in iron content. The map displays that the area (20-25N and 10-0W) of the Tiris Zemmour in northern Mauritania/Mali has the highest frequency of dust emission. At last it must be noted that this map may not be a good indicator of the overall dust emission because of the limited amount of data given by the short period of study. Measurements of dust emission are usually done on the order of several years (J.M. Prospero,1995).


Map of Areas of Highest Friction Velocity on SeaWiFS Image

Data Source: NRL Monterey Aerosol Lab

CONCLUSION

This project has several conclusions.

1. All six sand storms were driven by an anomalous high-pressure pattern over the Azores and southern Spain.
2. While the bulk movement of all dust storms moved west and then turned north towards Spain, some dust crossed the Atlantic Ocean in eight days. This confirms measurements of seasonal dust flux for Barbados (Prospero, 1996), which are low during the winter months and high during the summer months. The opposite is true for southern Spain.
3. The storms observed all seem to have been driven by winds below ~3000m. This may explain why much of the dust does not travel as far as during the summer months where winds may range up to ~ 6000m.
4. Satellite imagery revealed that most sand was lost during the first ~1000km after leaving the coast of Africa.
5. There was evidence for cloud seeding from ground station data from Cap Verde, Canary Islands and Azores.
5. NRL aerosol modeling is not always in agreement with ground station observations. Smaller (5-10km) dust storms are not recorded.
6. The area of highest friction velocity for the six storms has been determined to lie in the area of 20-25N and 10-0W.

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