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Aerosols, Hurricanes, and their Interactions : A Case Study of Hurricane Sandy

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Abstract

The effects of heavy aerosol loading on extreme atmospheric events such as hurricanes have only relatively recently been investigated. Having both natural and man-made sources, aerosol loadings can alter the humidity, heat, and cloud formation in an area, and by extension its precipitation and wind. While the precise effects of aerosols on such extreme events is not entirely understood, they may have had an effect on Hurricane Sandy, an unexpected tropical storm that caused massive amounts of damage. The presence of a significant aerosol source from west Africa was detected from October 8th, 2012 to October 11th, 2012. A fair amount of dust was transported all the way to the eastern Caribbean during that time. Its presence in the storm during its formative days is studied, showing to what extent extra aerosol loading occurred in the hurricane system as well as the type and origin of these aerosols.

Data and Study Area

The study area encompasses most of the central Atlantic Ocean and the Caribbean. The central southern Caribbean is included due to Hurricane Sandy officially becoming a tropical storm in the area, and the West African Coast is included due to its role as the source of significant dust aerosols.

Six zones were established along the path of the dust transport from Africa to the Caribbean (Figure 1). Part of this path was also the path of Invest 99L, a tropical disturbance that would eventually form into Hurricane Sandy. An additional zone centered on the eye of Hurricane Sandy on its day of elevation to hurricane status was also made and examined.

The case study of Hurricane Sandy begins on October 8th, 2012, which is also the second day of a large dust storm event that occurred in the Mauritania region of Africa. This massive dust event lasted for three days total with a large amount of the dust blowing westward over the central Atlantic ocean. The study ends on October 23rd, 2012, one day after the official formation of Hurricane Sandy (with the exception of some CALIPSO data taken beyond this time).

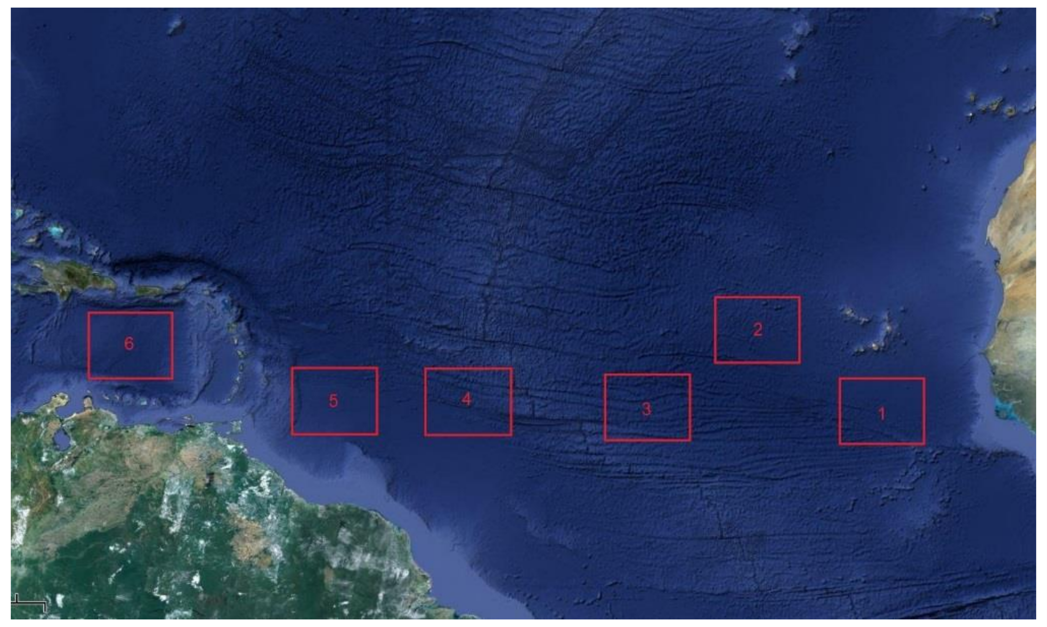


Figure 1. The six zones of study between the West African dust source and the genesis zone of hurricane sandy (genesis zone not in picture).

Methodology

MODIS TERRA and AQUA Satellites were used to obtain cloud top temperature, cloud top pressure, angstrom component, Aerosol optical Depth 550 μm, Ocean CCN, Fine Mode Fraction, Coarse Mode Fraction, Mass Concentration, and Average Ice Nuclei Radius data for the zones. Additional AoD readings were obtained from the Guadaloup and Calhau stations through AERONET. MISR was used to obtain Precipitation data.

CALIPSO was used to obtain vertical profiles for aerosol distributions in periphery areas before and after the genesis of the tropical cyclone. HYSPLIT with NCEP Reanalysis Data and the NRL/Monterey Aerosol models were used to confirm dust aerosol pathing.

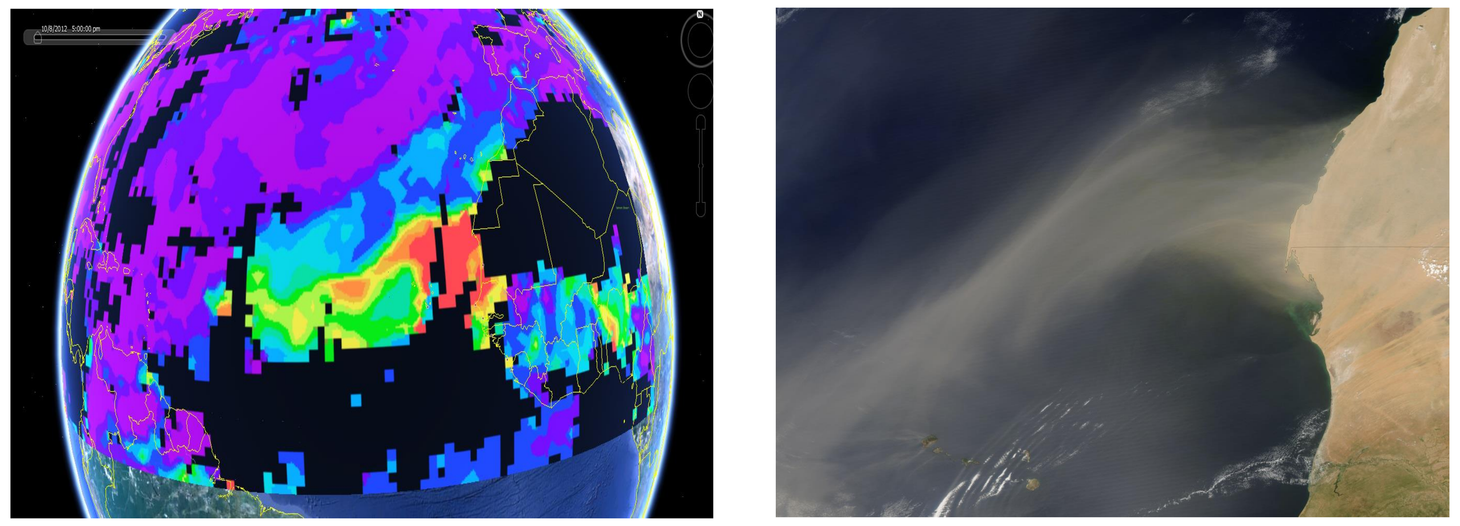
Observations

Before Hurricane Sandy's development a large dust event occurred in the Mauritania region of Africa with a spiked AOD up to 0.8 (Figures 2 & 3). The Dust event then pushed out over the Atlantic, far enough that it affected the Caribbean with the farthest examined region having an AOD of 0.16, a significant increase over the Caribbean average of 0.1. The initial transport of aerosols was relatively fast, affected zone 6 by October 12th while HYSPLIT showed other aerosols from the same event remaining mostly motionless for a few days in the central Atlantic. Precipitation was greatly reduced in overloaded Zones, such as Zone 1 and Zone 2. In contrast, zones 4 and 5 had appreciable amounts of precipitation, going as high as 51.1 mm/day during the event alongside increases of AOD in the zones. These AoD increases were significant, with most averaging 0.2 to 0.3, well above the normal AoD average of 0.1 for the areas. Zone 4 saw a massive AOD rating of 0.599 on October 13th. Zone 6 experienced a steady increase in precipitation after October 15th .

The formation of Hurricane Sandy required an unstable easterly wave. While two such easterly waves were present in the area at this time frame, only one would go on to become Hurricane Sandy: Invest 99L. Invest 99L was first tracked in the Central Atlantic Ocean on July 31st, 2012, at the southeastern edge of Zone 4. Figure 4c shows a large amount of fine aerosols persisting in the atmosphere far beyond the lifespan of the coarse aerosols from Figure 5.

Angstrom exponent values did not exceed 0.55 across all zones until October 15 with one single day exception of 0.8 in zone 1, reflecting a dominance of coarse and fine dust with a low possible mixing scenario of fine pollutants, namely sulfates since there is no possible significant source of black carbon over the Mauritania region. After October 15, higher Angstrom exponent values between 1 and 1.4 have been observed, mainly across zones 4, 5 and 6, suggesting higher mixing and more sulfate abundance. Hence, the fine aerosols remain close to the Hurricane and the related precipitation, both before and during its formation.

It is clear that the dust event that originated over the Mauritania/Sahel region is easily detected and capable of being analyzed, such as with MODIS. Our research has benefitted from Earth-viewing satellite sensors and an integrative approach to dust storm by looking at the vertical structure and aerosols types. We can present another piece of satellite evidence for the dust event in question being present and likely altering local conditions for Hurricane Sandy. During this dust outbreak preceding Sandy development, a compilation of CALIPSO measurements over time are used to detect and monitor the event to understand how up lofted and transported aerosols. Figure 4a shows evidence of dust blowing off the west coast of Africa reaching high altitudes when the dust storm activity was highest over the Mauritania region. All the CALIPSO vertical profiles (0-30 km) presented here depict a night time overpass (in UTC), and latitude-longitude (location) in the X-axis.



Figures 2 and 3. A spectral image of the Mauritania Dust event off the coast of West Africa (Fig. 2) and the same event seen with normal photography from space (Fig 3.)

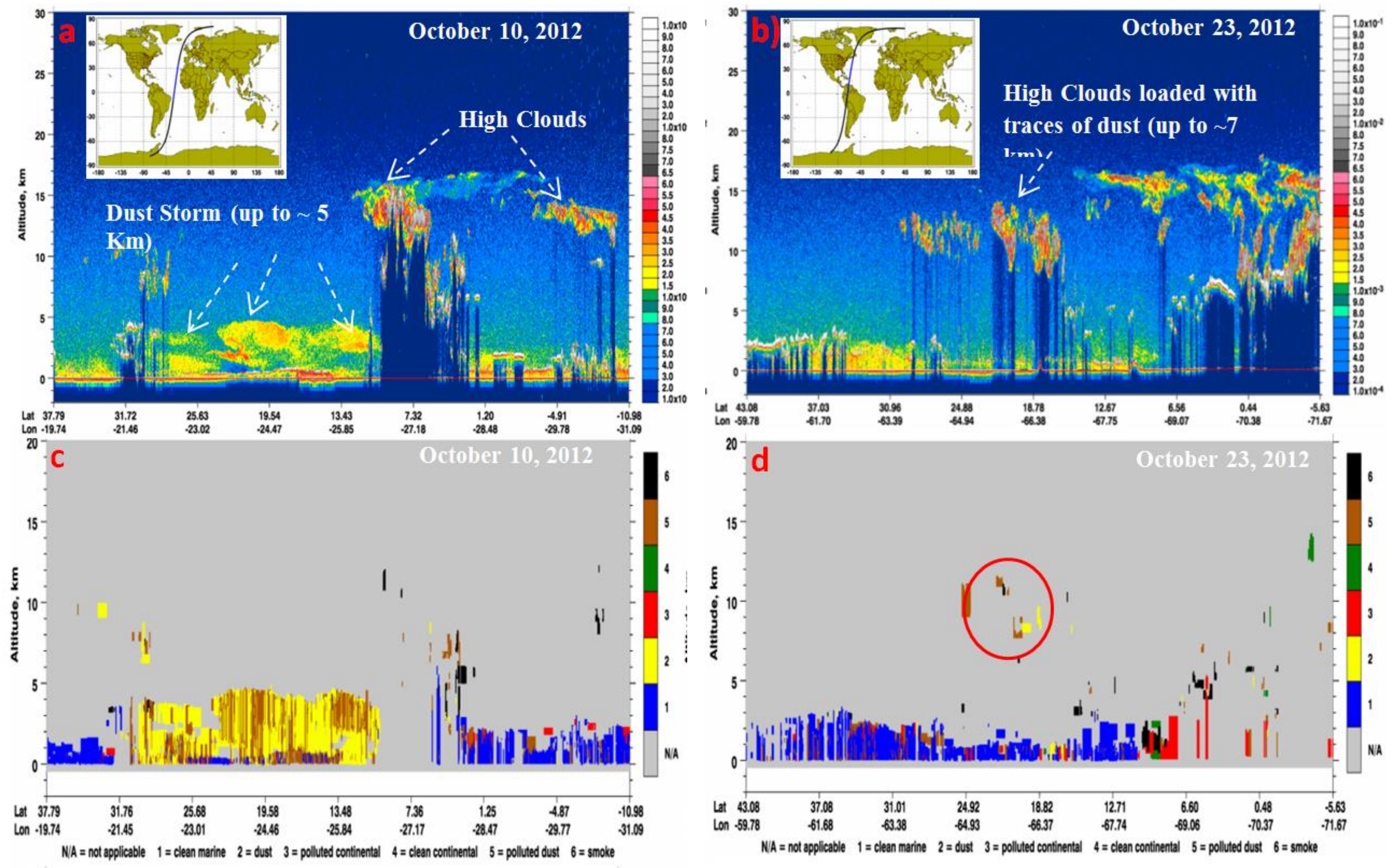


Figure 4. CALIPSO Profiles of October 10th (Passing near the West Africa coast) and October 23rd (Passing through Hurricane Sandy's Periphery). Yellow marks represent dust, and brown represents polluted dust. Notable dust presence on the 23rd has been circled in red.

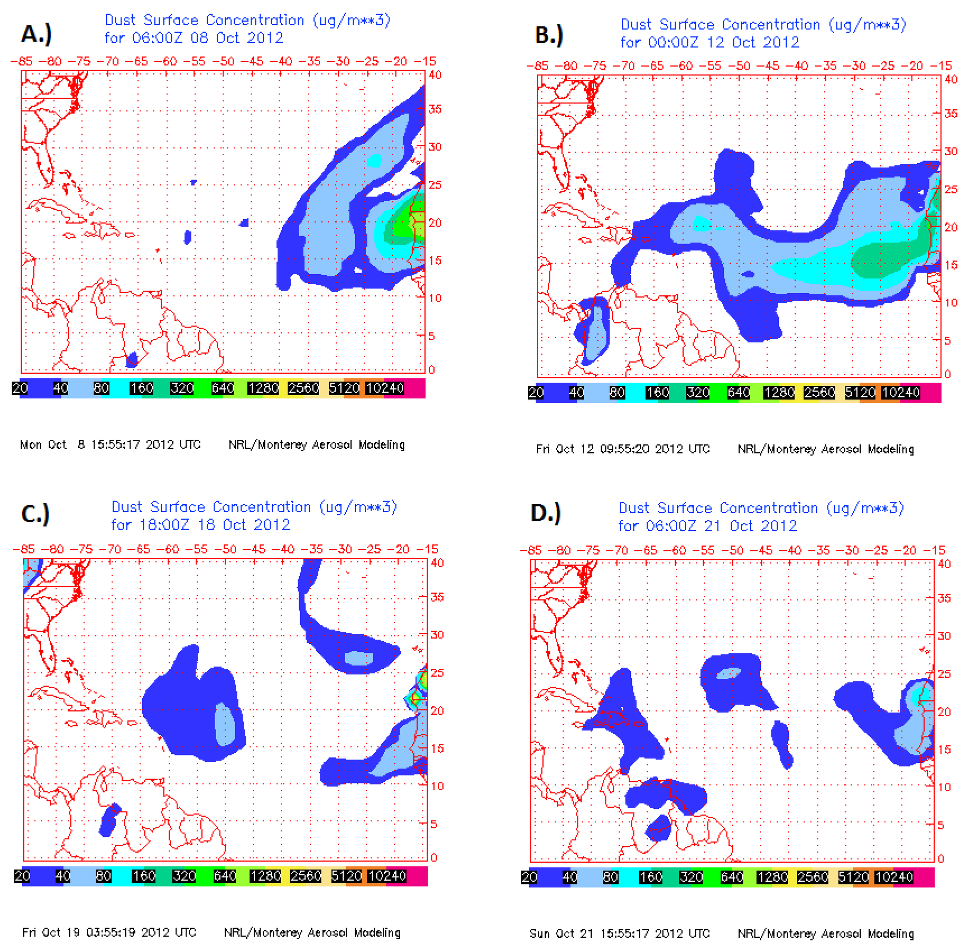


Figure 5. Aerosol position and intensity snapshots showing its progression over the course of two weeks. A.) Aerosols on October 8th, 2012. B.) Aerosols on October 12th, 2012. C.) Aerosols on October 19th, 2012. D.) Aerosols on October 21st, 2012.

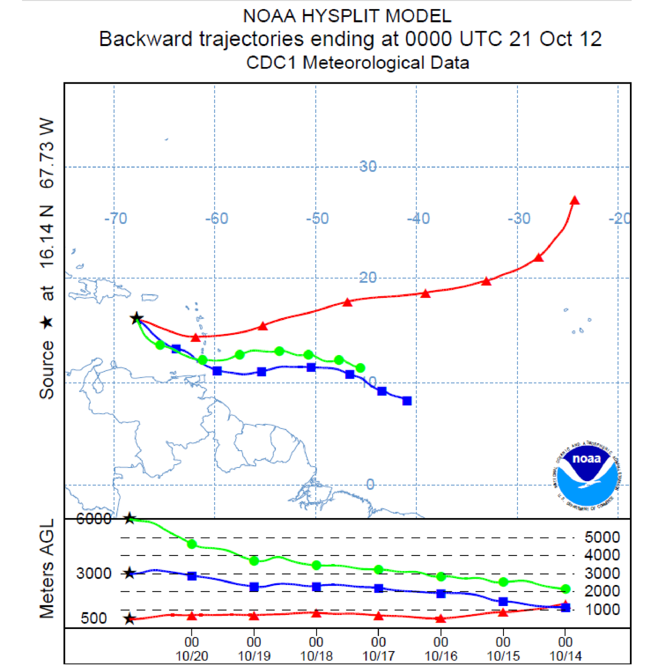


Figure 5. HYSPLIT 7-day Back trajectory of aerosols present near Puerto Rico on October 21st, 2012. The blue and green trajectories line up with the aerosol loading from figure 5 and are ascending as they approach they Caribbean and closer to Tropical Depression Sandy.

Observations (continued)

Clouds, with very high backscatter, at ~4-11° N latitude (Figure 4a) and ~8-17° N latitude (Figure 4b), block the backscatter from the atmosphere (appear as deep blue) below themselves. These vertical profiles marked the presence of various dense layers of dust over the 6 zones highlighted in Figure 3 across the Atlantic (at 0-5 km height) that shows the state of vertical mixing of the dust in the atmosphere. Further, that dense layer of dust between 0-5 km show a gradual decrease in the height to 2 km as it moves westwards owed to deposition of larger particles as well as contributing in the seeding process of the tropical disturbance.

Figure 4b shows a CALIPSO pass along the periphery of Hurricane Sandy on October 23rd, after it was officially declared a hurricane. Small but significant amounts of dust and other aerosols can be found even with the cloud cover, and the resulting clouds in which they are contained are both slightly lower and much more vertically oriented than normal, clean high-top clouds. However, these vertical dirty clouds are still around the 10 km range, high enough for precipitation cores to form as Ice Nuclei for evaporative processes and rain processes.

Conclusions

Observations of Hurricane Sandy cannot be completely conclusive due to a number of reasons. A big, glaring issue is the ability to gather data concerning tropical cyclones, especially remotely. Many satellite tools are incapable of penetrating deep cloud cover, and it shows in this research. It's also important to remember that this is observational data of a single incident alone. However, it gives strong indications that Saharan dust aerosols were present and may have affected its formation and entire lifetime as evidenced by the not-insignificant dust aerosol presence in and around Sandy. Vertical profiles show clouds with dust aerosols spanning multiple kilometers up into the troposphere to heights that can form IN, which mineral dust is very good at forming. These high, deep clouds lend to stronger updrafts and formation of storm clouds for precipitation when combined with naturally present sea salt aerosols, key factors that allow unstable pressure systems to form into a tropical cyclone. Combined with previous research, this suggests that aerosols may be able to encourage rainfall, updrafts, and deep clouds that can produce ice nuclei cores with relatively small amounts of additional aerosols.

The next step is to evaluate the extent of the effects of the fine mode dust aerosol loading on a computer simulated Hurricane Sandy to see if the dust presence played a significant role in hurricane invigoration or depowering.

Acknowledgements

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