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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. Existing natural and man-made aerosols, sources, altitude, area, 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 and taken partially from simulation models, they may have 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 large amount of dust was transported all the way to the eastern Caribbean during that time. Its impact on the storm during its formative days is studied, showing what extent aerosol loading occurred in the hurricane system as well as what type of aerosol loading it was.

Data and Study Area
The study area in question encompasses most of the central Atlantic, an area where most Atlantic tropical cyclones form during the month of October. The central southern Caribbean is included due to Hurricane Sandy officially becoming a tropical storm in the central southern 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. This path was also the path of Invest 99L, a tropical disturbance that eventually form into Hurricane Sandy. An additional zone positioned 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 9th, 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 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).

Methodology
MODIS, TERRA and AQUA Satellites were used to obtain cloud top temperature, cloud top pressure, aerosol component, Aerosol optical depth 500 nm, Ocean CCN, Fine Mode Fraction, Coarse Mode Fraction, Mass Concentration, and Average Ice Nuclei Radius data for the zones. MISR was used to obtain precipitation data. CALIPSO was used to obtain vertical profiles for aerosol loadings in trophy areas before and after the genesis of the tropical cyclone.

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 thickest examined region having an AoD of 0.16, a significant increase over the Caribbean average of 0.1. The transport of aerosols was relatively rapid, with the AoD spikes occurring two to four days after the African dust event and persisting for at most two days afterwards. Zone 1, which was closest to the event, experienced a CCN density 4 times greater than the day before, well above the average of the area during the timeframe. Precipitation was greatly reduced until the aerosol levels were returned to normal after three days. Zones 4 and 5, in contrast, had appreciable amounts of precipitation, going as high as 31.1 mm/day during the event along with increases of AOD in the zones. These 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 ratio of 0.599 on October 13th, where zone 6, one of the more important zones, shows 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. Observations (continued)

backscatter, at 4-11 N latitude (Figure 4a), -8-11 N and 51-66 W. Figure 4b), 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 area, from 0-1 km (Figure 4a) to 3-5 km (Figure 4b) shows a decrease in height to 2 km as it moves westward towards deposition of coarser particles as well as contributing to 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 were carried to areas that they cannot be seen 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 nucleation of evaporation 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 dense 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 aerosols may have affected its formation and entire lifetime as evidenced by the relatively significantly aerosol-loading present in and around Sandy. Vertical profiles show aerosol-laden clouds 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, key factors that allow unstable pressure systems to form into a tropical cyclone. Combined with previous research, this supports that aerosols may be hindering precipitation and hurricane formation (by heavy overloading) but may also be able to encourage rainfall, updrafts, and deep clouds that can produce ice nuclei cores with relatively small amounts of additional aerosols.

Future Research
The next step is to evaluate the possible effects of the fine mode dust aerosol loading on a computer simulated Hurricane Sandy to see if the dust presence played any role in hurricane invigoration or depolarization.

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