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Monitoring the Effects of Saharan Dust Storms on Perceptible Water Over the East Region of Puerto Rico

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Abstract

African aerosols reaching the Eastern Caribbean region during the summer months, has serious consequences to human and ecosystems health, ocean fertilization, climate, and global warming. This work evaluated the utilization of processing satellite images using ENVI software. NDDI was calculated in ENVI to obtain the concentration of dust over the region of interest. This product were compared against with ground-based instruments, and trajectory models. Trajectory models were used to assess daily influence of Saharan dust in Puerto Rico from the study period from May until September, 2013. Aerosol optical depth (AOD) measurements at various wavelengths, the Angstrom Coefficient were obtained from the AERONET station located at Roosevelt Roads in Fajardo, P.R. AOD values were compared against with satellite images in days of dust storm influence and the Hysplit trajectory model was helpful to confirm the African origin of dust events reaching Puerto Rico. The higher AOD values observed were ranging between 0.3 to 0.4, during June 28, 2013. Ground-based instruments, satellites and models showed similar trends in AOD but ground-based values are higher than satellite- based ones. Given the difficulties associated to this type of study, any comprehensive evaluation of African dust should consider the use of various tools.

Keywords: ENVI, NDDI, Dust, Aerosol, Puerto Rico, CCN

1. INTRODUCTION

Dust storm is one of global scale natural hazard and climatic phenomena that can affect global and regional weather and climatic systems as well as human and ecosystems health. Africa is a region with frequent dust storms because of its special geological and environmental characteristics. In addition to hazardous effects on local environment, dust storms from Africa may also affect the genesis and intensification of tropical cyclones over the Atlantic basin (Qu et al., 2005). The mechanism of dust transport and the complete effects of dust storm on weather systems and environment are still on continuous investigation because they are not completely clear. Recent experiments in southern Florida using aircraft and polarization lidar shows that mineral dust particles transported from Saharan Africa are effective ice and cloud condensation nuclei and they can potentially enhance precipitation in mixed-phase clouds by indirect aerosol effects (Kenneth et al., 2003). Cloud Condensation Nuclei (CNN) are aerosols that act as the initial sites for condensation. Particles in the air become surfaces on which water vapor can condense into cloud droplets or cloud ice particles (Sassen et al., 2003). Dust aerosols are thought to suppress precipitation however under some environmental conditions they behave as CCN aerosols as an indirect effect. The specific environmental conditions are still not completely known but some researchers found that dust aerosol indirect effect on warm clouds strongly depends on the cloud precipitation regime and cloud top height, indicating the importance of aerosol vertical transport and aerosol-cloud interaction (Sassen et al., 2003). In this paper we want to investigate if dust aerosols show behavior of cloud condensation nuclei on the east side of Puerto Rico during the months of May-September. We have proposed to use a Normalized Difference Dust Index (NDDI) to detect sand and dust storms. NDDI equation:

$$(NDDI = \frac{2.13\mu m - 0.469\mu m}{2.13\mu m + 0.469\mu m})$$

It uses Moderate Resolution Imaging Spectroradiometer (MODIS) band 3 (0.469 μm) as the reference band and band 7 as the dust sensitive band (Qu et al., 2005). These bands have a resolution of 500m.

2.METHODOLOGY

Daily satellite images from the Moderate Resolution Imaging Spectroradiometer (MODIS) on-board Terra (morning) was evaluated in the analysis. The study took place during the month of May thru September. The MODIS sensor views the entire surface of the Earth every one to two days. The sensor data products are used to describe features of land, oceans, and atmosphere that can be used for studies of large to global scale processes. MODIS collection-L-1, Atms and Land. (1 ×1 degree spatial resolution) data was evaluated. Images were open on ENVI.

2.1 Image Download

Five Level 1 Terra MODIS Images from 2013 were downloaded from:http://ladsweb.nascom.nasa.gov/browse_images/ collection 5, based on each of the months (May through September) where the trade winds flow from the west of Africa to the Atlantic carrying along with them dust particles.

The two MODIS instruments, the first launched on 18 December 1999 onboard the Terra Platform and the second on 4 May 2002 onboard the Aqua platform, are uniquely designed (wide spectral range, high spatial resolution, and near daily global coverage) to observe and monitor Earth changes. The MODIS sensor offers high radiometric sensitivity (12 bit) in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm. Each downloaded file provided Emissivity, Radiance and Reflectance bands but only the reflectance bands were used.

2.2 ENVI Processing

Each image was processed to obtain the NDDI product through ENVI classic software. The MODIS images were first georeferenced using the ENVI Classic Map tool with the corresponding projection of Puerto Rico, which is in meters in the UTM zone 19 N, North America 1927. The images were then process through the Band Math tool, which allows to insert and calculate the NDDI equation for each image. NDDI values ranges between -1 to 1, because of this, values that did not fit that range we proceed to mask the image using the masking tool from ENVI main menu. To have a better visual of the NDDI final products a color ramp was applied to each image.

2.3 Ground-based measurements: AERONET

Ground-based data was obtained from the Aerosol Robotic Network (AERONET) station at Roosevelt Road, Fajardo P.R. The AERONET is an international network of sunphotometers to measure aerosol properties. It is a ground-based remote sensing instrument part of the aerosol network established by NASA Goddard Space Flight Center. The AERONET provides an accessible public database of aerosol optical and physical properties for aerosol analysis. The instrument provides continuous observations of Aerosol Optical Depth (AOD) at different wavelengths, and many other parameters including Angstrom Coefficient (at various ratios) and, fine and coarse mode fractions.

The aerosol optical depth or optical thickness (AOT) or aerosol optical depth (AOD, τ or Tau) is the degree to which aerosols prevent the transmission of light. It is defined as the integrated extinction coefficient over a vertical column of unit cross section. Extinction coefficient is the fractional depletion of radiance per unit path length (also called attenuation especially in reference to radar frequencies). The Angstrom coefficient (AC) is a useful quantity to assess the particle size (the larger the exponent, the smaller the particle size) of atmospheric aerosols or clouds, and the wavelength dependence of the aerosol/cloud optical properties.

This work evaluated AERONET AOD level 1.5 daily average data at 870, 500 and 440nm, the Angstrom coefficient using 500/870nm. Higher quality AERONET level 2 data was not available. Database was downloaded and saved as an Excel spreadsheet for further analysis.

2.4 Trajectory Models

Trajectory models were used to confirm the African origin of dust reaching Puerto Rico. The HYSPLIT trajectory model predicts the forward or backward trajectory of a particle or air parcel. The HYSPLIT model was run to confirm the African origin of storms reaching Puerto Rico. The runs used the GDAS (global-2006 present) meteorological data set. Specific settings for our analysis were: backward trajectory direction, isobaric vertical motion, latitude: 18.32 N, longitude: -65.96 W (Fajardo, P.R.), total run time of 240 hrs (10 days), and heights of 2000, 2500, and 3500 meters.

2.5 Weather Radar and forecast discussions.

To visualize weather products, archive radar composites were obtained: (http://www.wunderground.com/radar/radblast.asp?ID=JUA) to see the formation of rain over Puerto Rico. The image presented were captured around 2: 00 pm local hour.

The weather forecast for each day was supported using http://mesonet.agron.iastate.edu/wx/afos/ which the "afdsju" were used for PIL product and about 60 entries.

3. RESULTS

Processed NDDI images were analyzed from the following dates:

- **May 11, 2013**

Mostly sunny skies prevailed across the local region early. Late in the afternoon, showers with isolated thunderstorms started to develop along the Cordillera Central of Puerto Rico. In synopsis discussion there was a weak surface low-pressure area north of the area will slowly move toward the northwest through the weekend.

In the product of NDDI, Figure 1., it seems that the dust clusters presented in the image is concentrated in specific regions like clouds and not as plumes. Mostly, low concentrations of dust are presented over land rather than ocean. Higher concentrations of dust are located in the nucleus of the dust cloud and is appear in color red, where maximum NDDI values is close to 1. Due to the poor concentration of dust over the area, small particles could be a good source for cloud condensation nuclei for the isolated showers originated over the Cordilleras in the afternoon (Figure 3.). The height of 3500 meters confirms the African origin from the South-Western Africa. This is indicative that there was a very low concentration of dust over the area (Figure 2.).

- **June 28, 2013**

Very little shower activity was observed during most of the day. During the afternoon isolated showers with thunderstorms developed across the northwest corner of Puerto Rico due to the low level moisture combined with diurnal heating and local effect. Weather products and satellite images indicated a drier air mass has moved across the local area. This dry air could be accompanied by some dust particles. No significant precipitation over the eastern region was reported (Figure 6). Synopsis scale, a broad surface high pressure across the Atlantic continues to promote a moderate to fresh trade wind flow.

NDDI product shows no high concentrations of dust over the eastern region. NDDI values are ranging between -1 to 0. This is indicative that there was a low concentration of dust located mostly over the east coast of the island. Little portions of dust, as shown in Figure 4., are not responsible in the isolated showers generated over the western side of the island. In overall, the NDDI product does not show similar trends with the day forecast discussion.

The African Origin was confirmed in Central Africa region based on 3500 meters of height (see Figure 5).

- **July 5, 2013**

Very dry conditions and plenty of sunshine prevailed this afternoon across Puerto Rico. An area of very fry air moved over the Caribbean region today. There was no rainfall generation during the afternoon due to the presence of dry air (Figure 6.). Synopsis: Surface high pressure across the western Atlantic will generate moderate to fresh trade wind flow through all week.

The NDDI product shows moderate to high concentrations of dust over the South region on Puerto Rico (where the NDDI value takes between 1.5 to 1 approximately, Figure 7.). However, small amounts of dust dispersed in the north side of the island. No dust concentrations over the ocean were displayed in the image.

The African origin at 3500 meters of height was confirmed in the Northern part of Africa (Figure 8.).

- **August 8, 2013**

An upper level ridge will meander over the forecast area. Clusters of showers embedded in the trade winds will be affecting the islands from time to time. Easterly flow at low levels has transported patches of moisture across the coastal waters (Figure 12.). This produced showers and isolated thunderstorms across parts of the island once again during the rest of afternoon.

The NDDI product shows no presence of dust intrusions over the island nor even in the ocean (Figure 10). However, HYSPLIT does not show any particle coming from the Saharan Desert (Figure 11.). This suggests that there was no dust storm in the vicinity.

- **September 16, 2013**

Under the influence of an upper level trough, it will bring deep moisture. Conditions will remain favorable for daily afternoon showers and thunderstorms over North-Western of Puerto Rico. Steering flow will remain between 5-10 knots from Southeast, which should favor slow storm motion, and risk of localized heavy rainfall. The presence of moist and local effects produced heavy rain Northwestern part and isolated showers in the eastern of Puerto Rico (Figure 15.).

The NDDI product shows low portions of dust over the northern of Puerto Rico, where the NDDI is ranging between -1 to a little more than cero (Figure 13). There is a little cluster of dust over water in the southeast of Vieques. According to HYSPLIT, no African dust origin was reported (Figure 14).

Based on Table 1., it shows the AOD values at three different wavelengths. It can be seen that June 28th was the day with high AOD value. According to HYSPLIT it confirmed that the African Origin and the weather conditions were drier. However, radar shows some isolated shower over the east portion of the island. This could be that small dust particles behaved as cloud condensation nuclei. The next influenced dust day was July with AOD values around 0.2 to 0.3 which shows moderated presence of dust and no presence of rain over the east portion of the island. AOD values are a strong support for identifying dust over the region of interest.

4. CONCLUSION

If our final conclusion was based in our qualitative data, which are the NDDI products compared with Radar Composite data, we can conclude that the NDDI is a relative good index for detection of dust storm movement and that dust aerosol may actually behave as CCN, creating drizzles 1 to 4 hours after initial appearance on the same area, east of Puerto Rico. But if we based our conclusion on our quantitative researched data based on public database of AOD, AC, HYSPLIT, RADAR, we must conclude that the NDDI is not a good index for the detection of dust particles in the east of Puerto Rico and that dust aerosols do not behave as CCN. AOD values from AERONET compared with NDDI data does not show similar trends, that is why NDDI may not detect accurately dust aerosols. Quantitative data tends to be more reliable than qualitative data and ground based tools like AERONET, collect data physically, which is more reliable. For this paper we decided to rely on the quantitative data results, so we conclude that NDDI for this particular case did not detected accurately dust movement and that dust aerosols did not behave as CCN

5. RECOMMENDATIONS

There is a strong possibility that other corrections out of our knowledge had to be made to the NDDI products to obtain a more accurate dust movement detection on the east of Puerto Rico. For this we recommend more research about the NDDI equation and its uses, the NDDI may need improvement in the equation. Although we opted to go with the quantitative results these are all ground based data, while dust aerosol detection occurs at the top of the atmosphere, there is a possibility that there will always be little no none relation when comparing these two different data sets. We recommend comparing NDDI data with other dust detecting products that have the same spatial resolution as the NDDI products and the same method of detection, at the top of the atmosphere.

6. REFERENCES

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APPENDIX

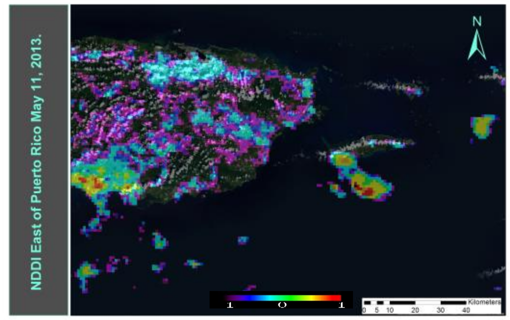


Figure 1. Terra MODIS image shows NDDI values in the east of Puerto Rico.

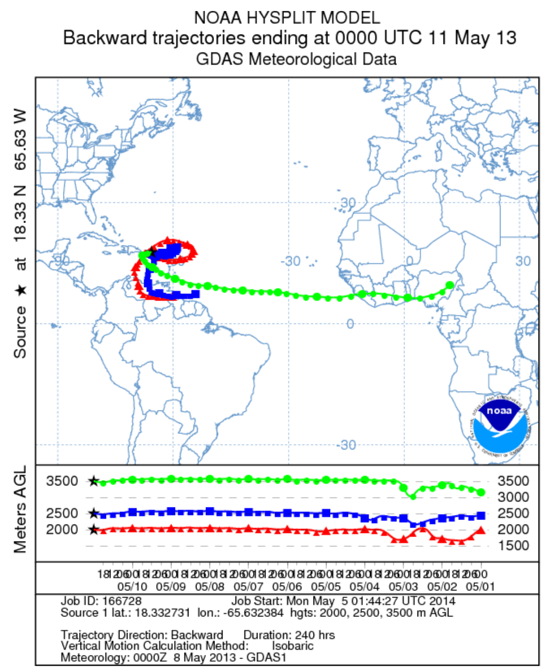


Figure 2. HYSPLIT of May 11, 2013.

Figure 3. Radar composite of May 11, 2013 at 2:00, local hour.

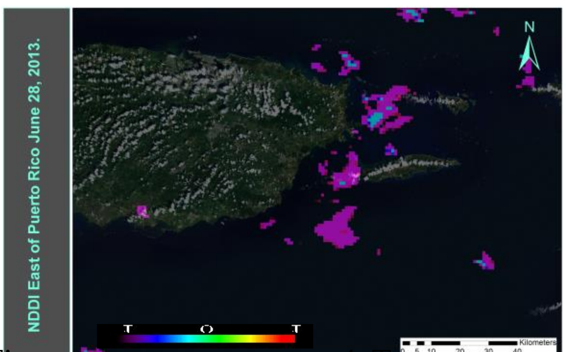
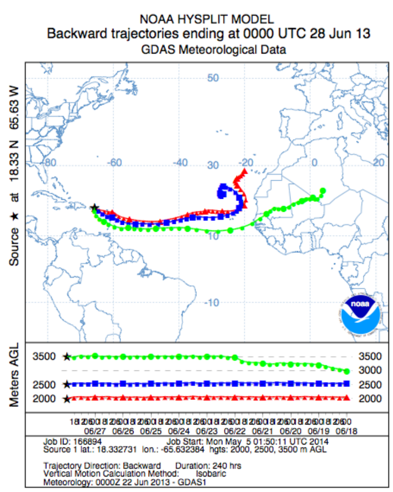


Figure 4. Terra MODIS image shows NDDI values in



the east of Puerto Rico.

Figure 5. HYSPLIT of June 28, 2013.

Figure 6. Radar composite of June 28, 2013 at 2:00, local hour.

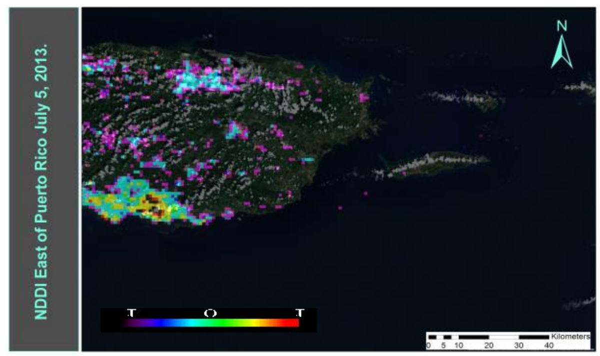


Figure 7. Terra MODIS image shows NDDI values in the east of Puerto Rico.

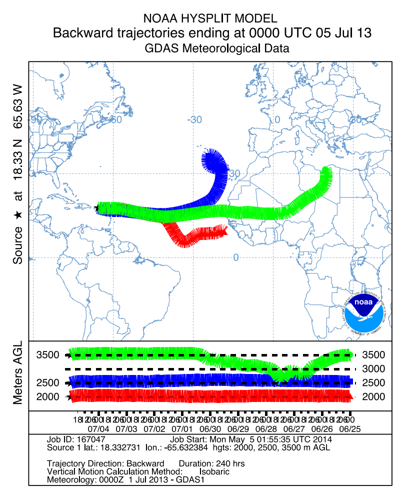


Figure 8. HYSPLIT of July 5, 2013.

Figure 9. Radar composite of July 5, 2013 at 2:00, local hour.

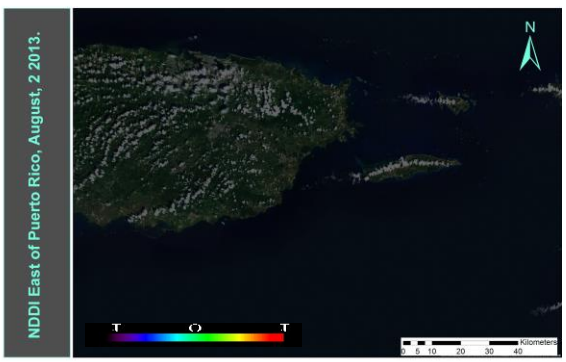


Figure 10. Terra MODIS image shows NDDI values in the east of Puerto Rico.

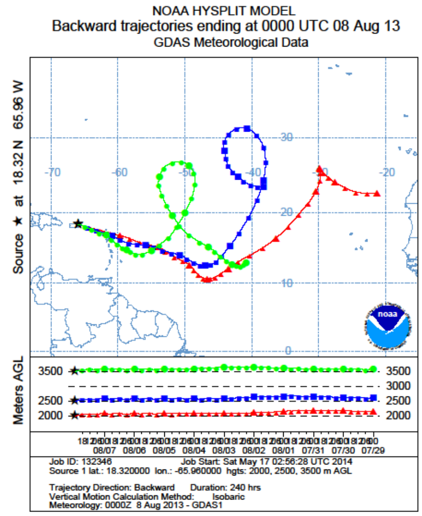


Figure 11. HYSPLIT of August 8, 2013.

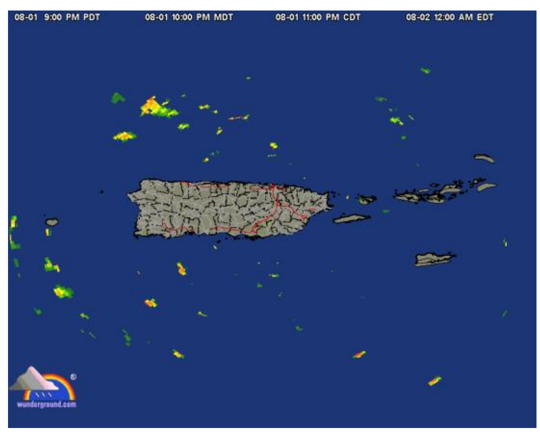


Figure 12. Radar composite of August 8, 2013 at 2:00, local hour.

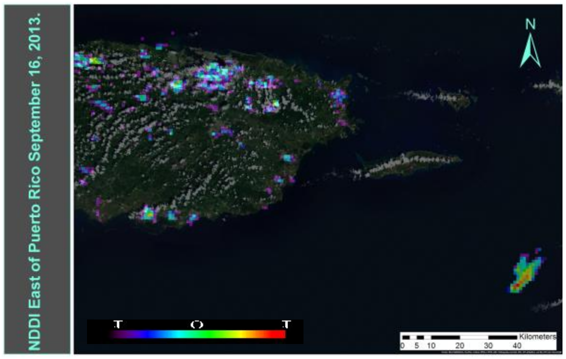


Figure 13. Terra MODIS image shows NDDI values in the east of Puerto Rico.

Figure 15. Radar composite of September 16, 2013 at 2:00, local hour.

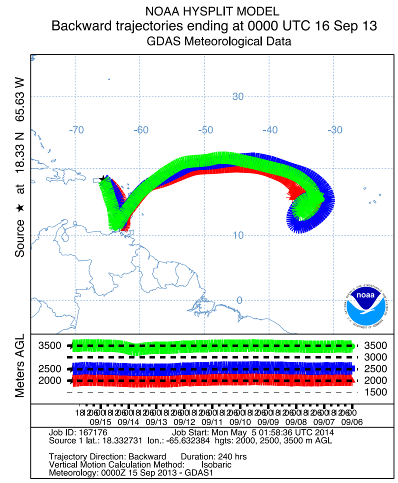


Figure 14. HYSPLIT of September 16, 2013.

Days	AOD 870nm	AOD 500nm	AOD 440nm	AC 500/870	HYSPLIT	RADAR
11-May	0.063975	0.141276	0.158226	1.437889	YES (3500)	NO
28-Jun	0.272828	0.312502	0.314248	0.245303	YES (3500)	YES*
5-Jul	0.277271	0.316993	0.321878	0.241419	YES (3500)	NO
2-Aug	0.40452	0.458602	0.460257	0.304138	NO	NO
16-Sep	0.050807	0.092745	0.098441	0.995929	NO	NO

Table 1. Shows AOD values at 870nm, 500nm, and 440nm and the AC at 500/870nm captured from AERONET Roosevelt Roads station, Fajardo, P.R., HYSPLIT African dust confirmation and Radar rainfall confirmation.