

Hurricane Fiona's impact at four caves of Puerto Rico

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Abstract

I used remote sensing practices to see what is the damage caused by Hurricane Fiona on forest areas with cave systems and how have they recovered. Caves have important and unique ecosystems with native species of insects, bats and crustaceans. Using Sentinel 2-MSI I was able to observe the damage on areas with caves like: Cueva Bonita at Toa Baja, Cueva Lucero at Juana Díaz, Cueva Culebrones at Arecibo and the Camuy's caverns. With Copernicus Open Access Hub I downloaded the images and analyzed the caves aforementioned: before the hurricane, after the hurricane and how they are recently, this done to compare the damage and the recovery, and to see in how much danger the biodiversity is. Locals tend to compare Hurricane Fiona to Hurricane Maria on how big the floods were even if Hurricane Maria was a category 5 hurricane and Fiona a category 1 hurricane. Taking this into account, I also downloaded images of the same locations but after Hurricane María. All the images went through NDVI measurements using ENVI. The NDVI and true color images showed almost no changes on vegetation after Hurricane Fiona but damage after Hurricane María was present. Some images even presented more vegetation after Hurricane Fiona.

Key words: Hurricane Damage, ENVI, NDVI and Remote Sensing

Introduction

Puerto Rico having a hurricane season 5 months long, is exposed to cyclones damages. During 2022, Hurricane Fiona a category 4 hurricane, impacted the island with rain floods of 30-60cm deep and winds of 111-116km/h according to the National Hurricane Center. The rains and strong winds have been documented to greatly damage the structure of forests (Chapman et al., 2008). Caves being inside forests are susceptible to danger and so are the species living in them. Puerto Rico's only native mammals are bats (Ganon et al., 2005), having 13 species, each one of them has important ecological roles such as plague control, pollination and dispersal of fruits. Being the main habitat at caves their population can lower drastically if threats like hurricanes disrupt the habitats. Members from organizations like Programa de Conservación de Murciélagos de Puerto Rico have said that they found multiple skulls of bats after Hurricane María, this is concerning since Puerto Rico has high cyclone activity. Although Hurricane Fiona was less impactful than Hurricane María, I analyzed the damage done by Hurricane Fiona with the objective of bringing awareness to know how to manage these scenarios. By comparing both Hurricanes' before, during and after images, there can be a better sense of the needs for recovery on forests and similar ecologically important areas. For this I analyzed four caves at Puerto Rico (Fig. 1) that are important ecologically and economically for tourism.

Methodology

Using the Copernicus Open Access Hub page, I downloaded 3 images per cave where it could be appreciated the areas where the caves are located. The three images were taken with the Sentinel 2 MSI instrument on the dates: July, September and October 2022. As an impact reference, images were also downloaded in October 2017 for comparison of Hurricane Maria

in the same areas. All images were analyzed using the ENVI program. First, using views I synchronized three true color images with "Link view". Then, I located the caves by coordinates: Cueva Culebrones in the Mata de Plátano reserve (Arecibo), Cueva Bonita (Toa Alta), Cueva Luceros (Juana Díaz) and Caverns of the Camuy River (Camuy). For better visibility of observed areas, I adjusted tools such as sharpen brightness and stretch. Having all the true color images already saved, I used the "Band Math" tool and applied the formula of $\frac{(\text{float}(b1) - \text{float}(b2))}{(\text{float}(b1) + \text{float}(b2))}$ to perform the NDVI and for better visualization and aesthetics I changed the color table to green white inverted. Lastly, annotations such as color bars, titles, timeline, scale bar, etc., were added. When all the results were done, the images were observed and compared.

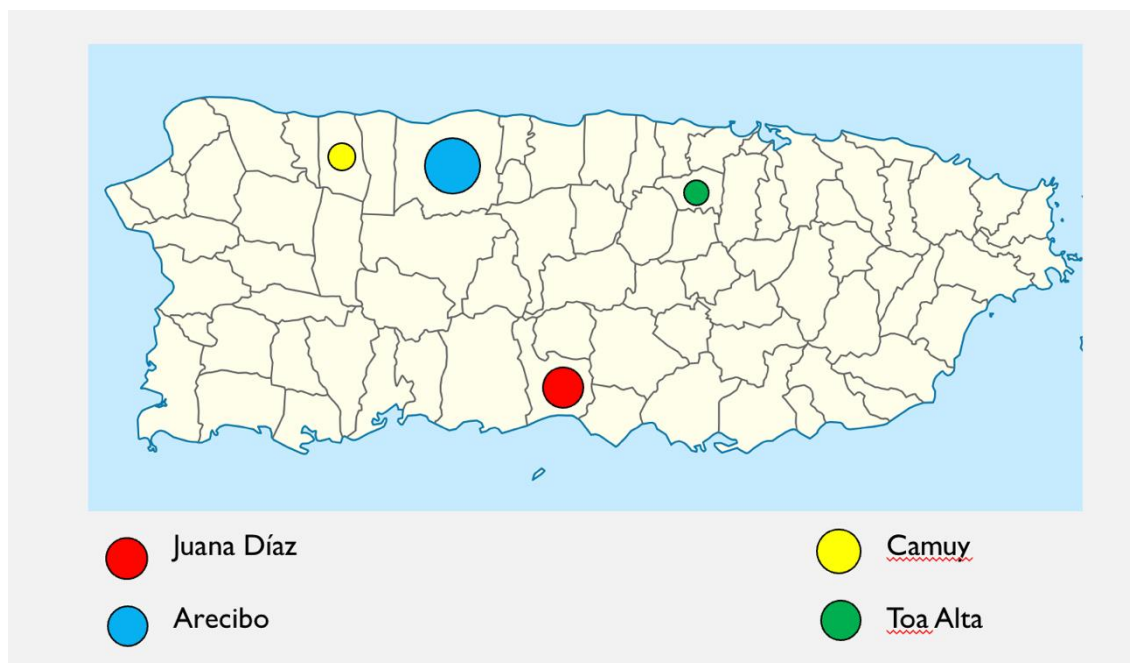


Figure 1. Caves observed for hurricane damage

Results and Discussion

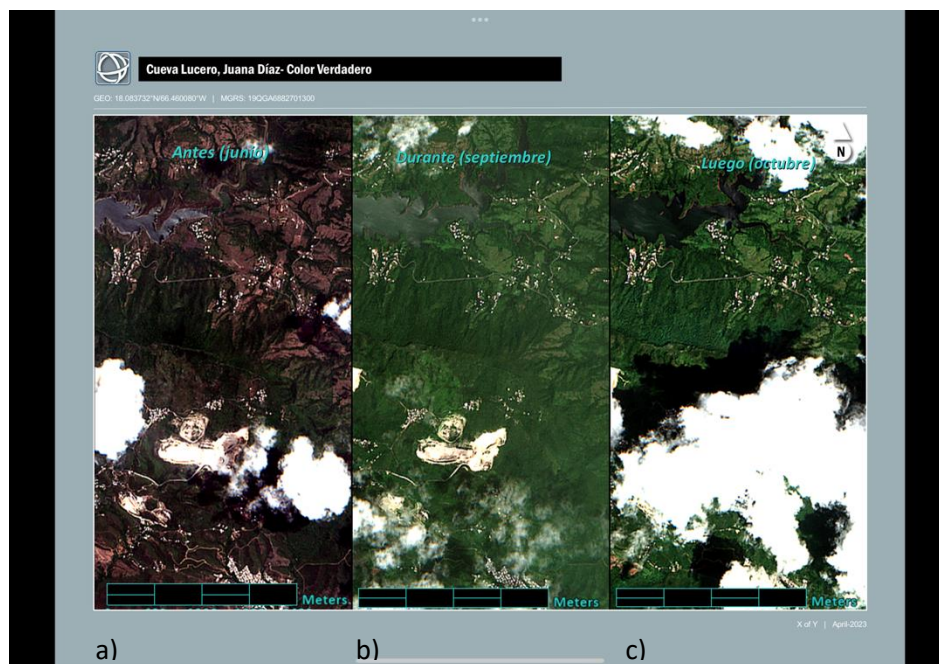


Figure 2. True Color ENVI image at Cueva Lucero before (a), during (b) and after (c)

Hurricane Fiona

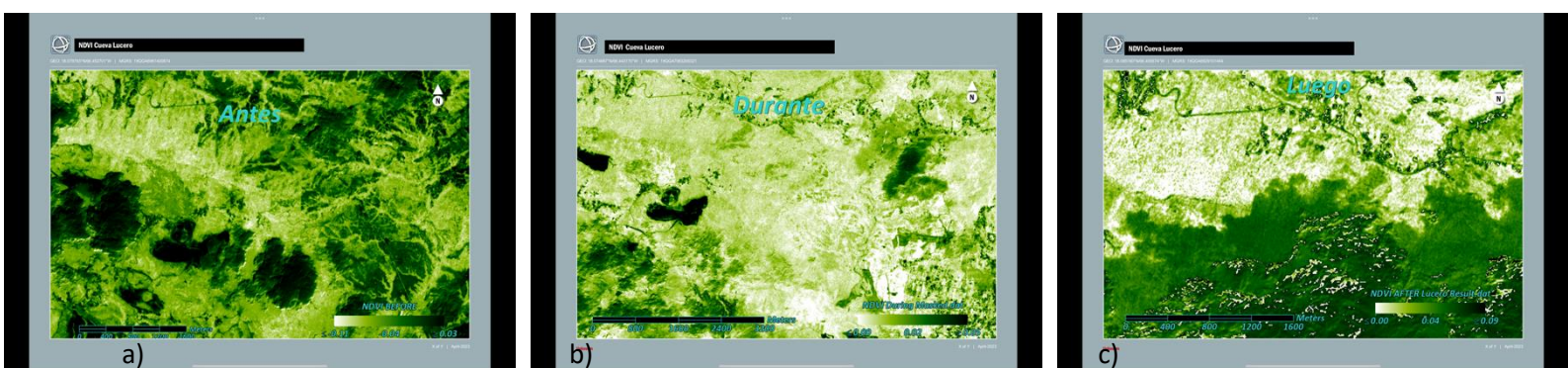


Figure 3. NDVI ENVI image at Cueva Lucero before (a), during (b) and after (c) Hurricane

Fiona

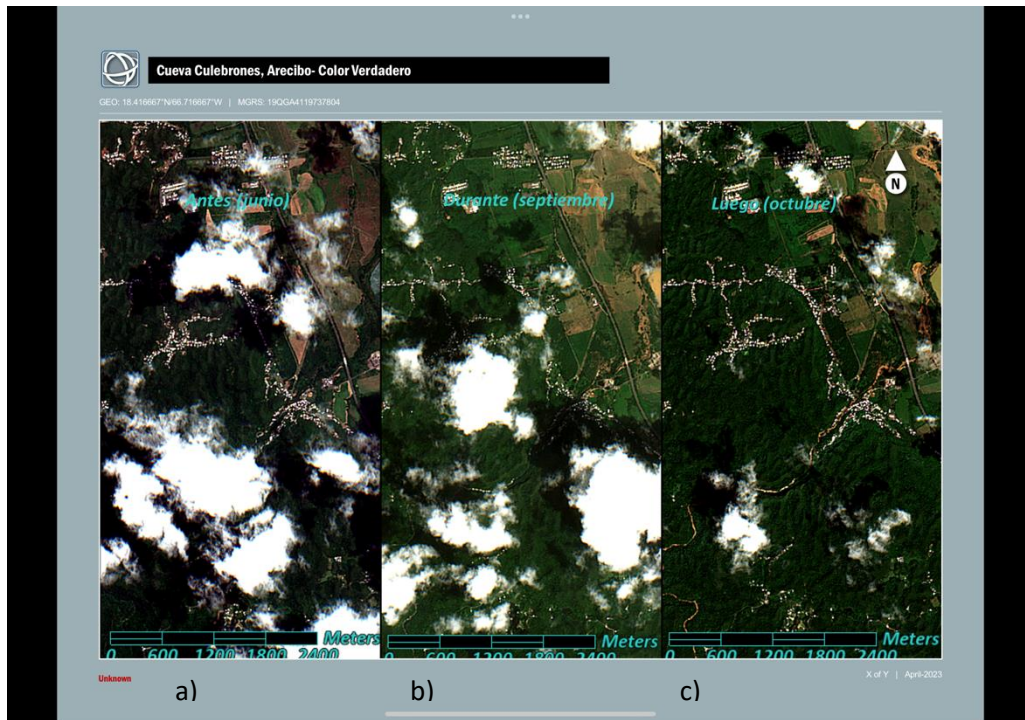


Figure 4. True Color ENVI image at Cueva Culebrones before (a), during (b) and after (c) Hurricane Fiona

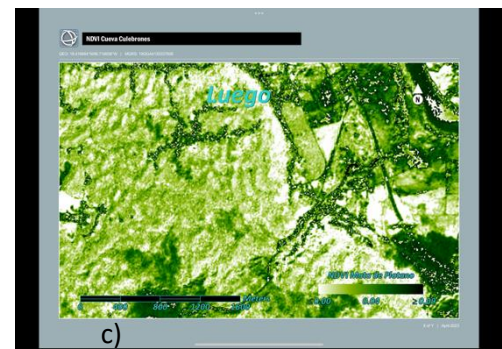
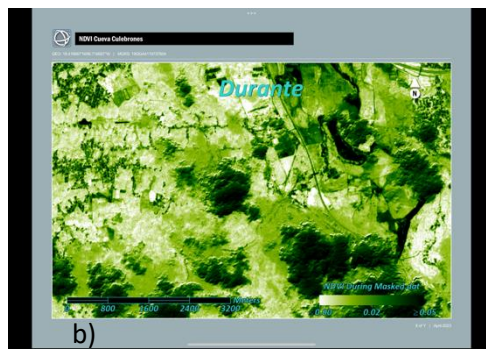
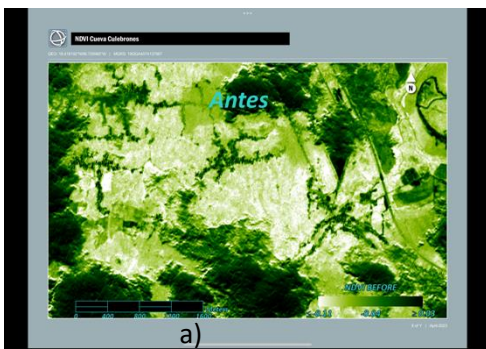


Figure 5. NDVI ENVI image at Cueva Culebrones before (a), during (b) and after (c) Hurricane Fiona

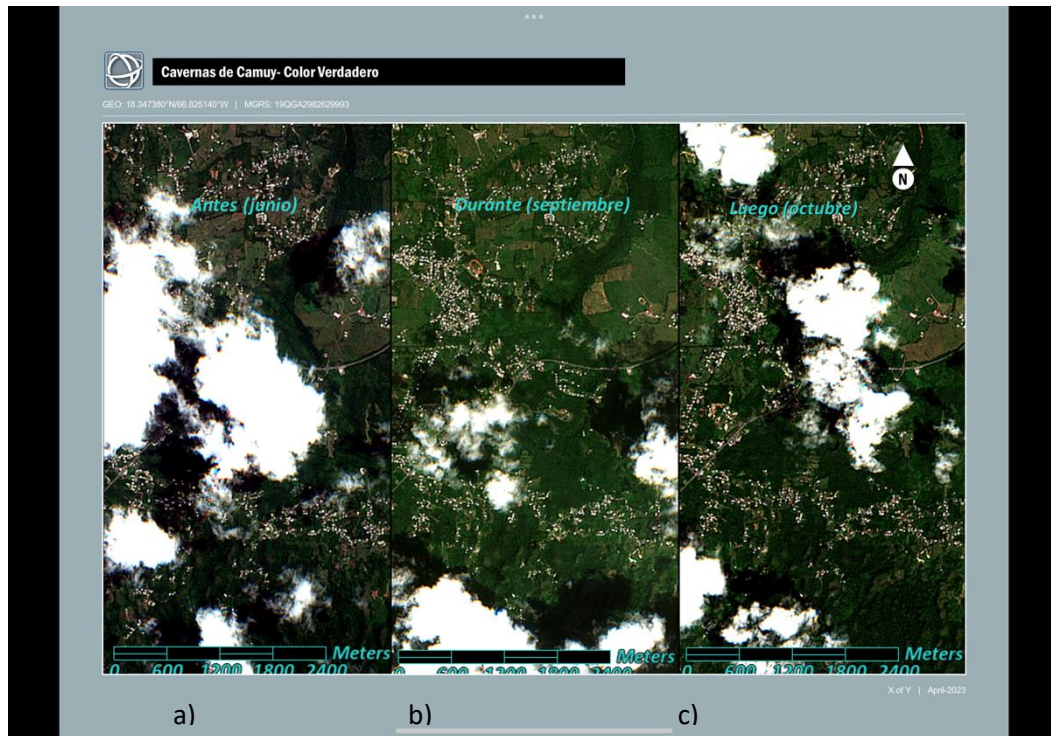


Figure 6.

True Color ENVI image at Camuy's Caverns before (a), during (b) and after (c) Hurricane Fiona

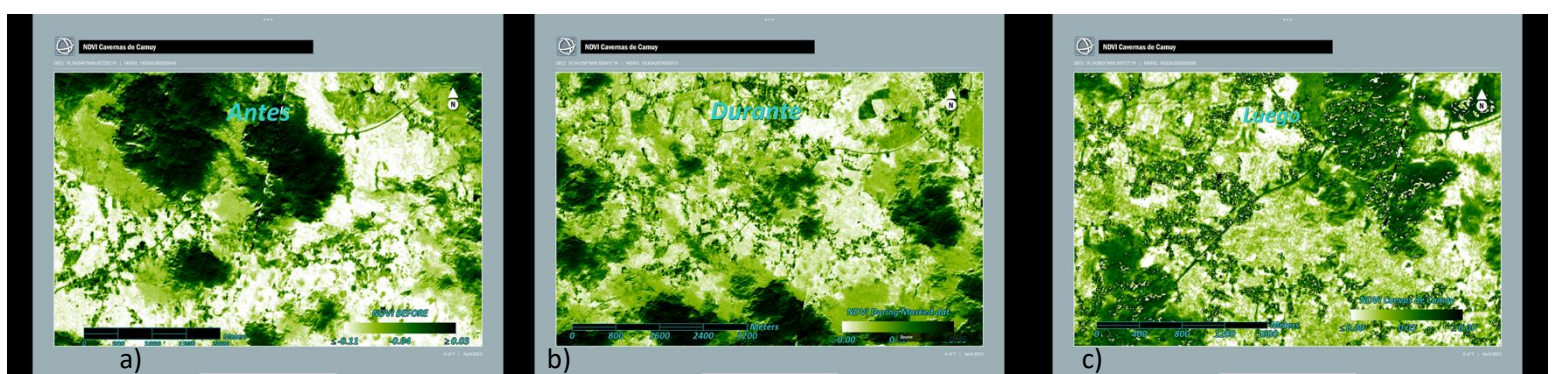


Figure 7. NDVI ENVI image at Camuy's Caverns before (a), during (b) and after (c)

Hurricane Fiona

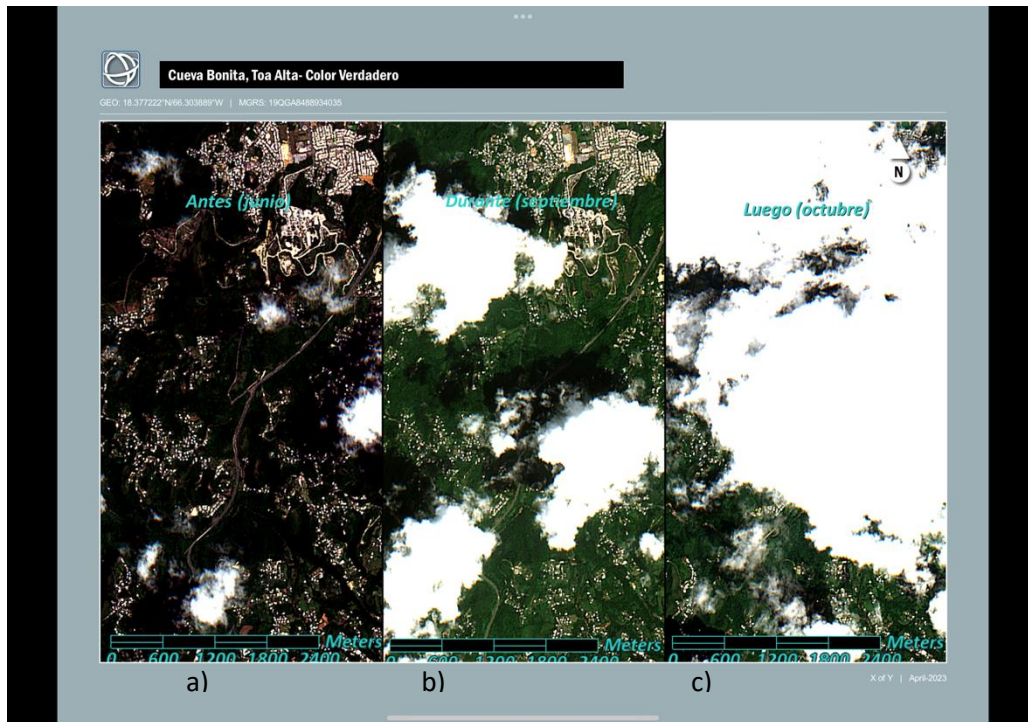


Figure 8. True Color ENVI image at Cueva Bonita before (a), during (b) and after (c)

Hurricane Fiona

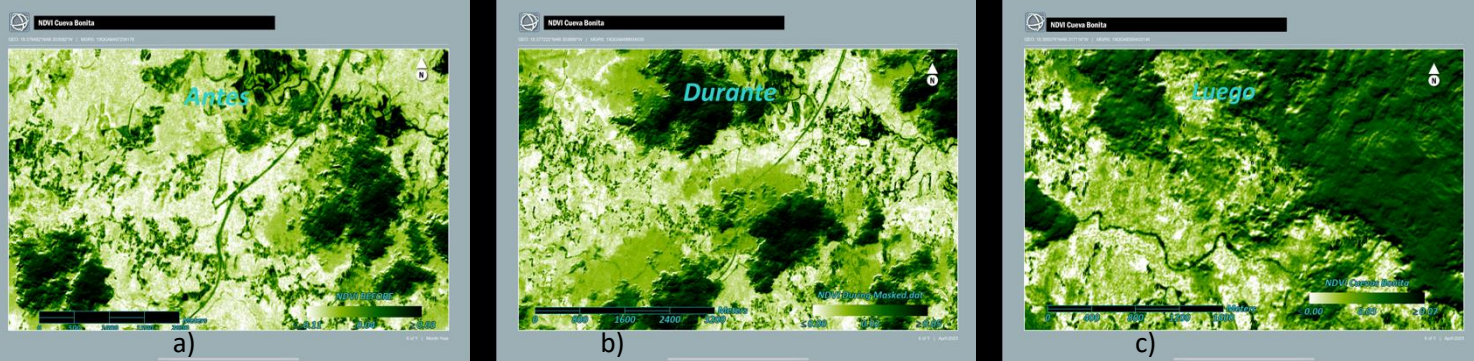


Figure 9. NDVI ENVI image at Cueva Bonita before (a), during (b) and after (c) Hurricane

Fiona

a)



b)



Figure 10. ENVI image at Cueva Bonita True Color (a) and NDVI (b) after Hurricane María

a)



b)



Figure 11. ENVI image at Camuy's Caverns True Color (a) and NDVI (b) after Hurricane María

a)



b)

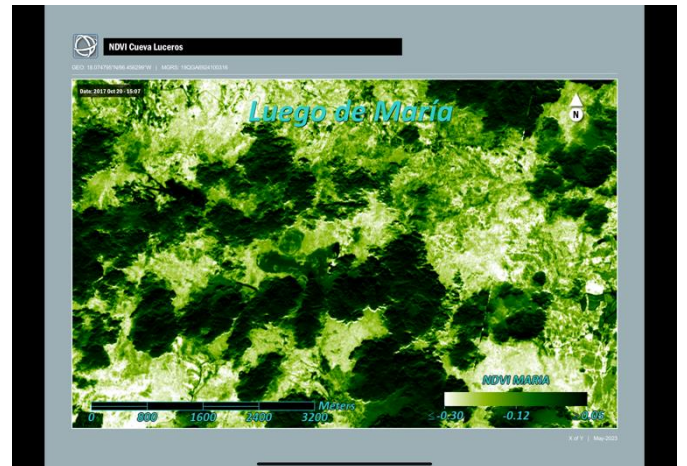


Figure 12. ENVI image at Cueva Lucero True Color (a) and NDVI (b) after Hurricane María

a)



b)



Figure 13. ENVI image at Cueva Culebrones True Color (a) and NDVI (b) after Hurricane María

After observing True Color and NDVI of all the images after Hurricane Fiona, there is no significant change on vegetation. In some cases there is a visible growth in vegetation like in Cueva Culebrones (Fig. 4 and fig. 5). At the same cave during Hurricane María (Fig. 13) the damage is easily visible even with the True Color image (Fig. 13.b). Even at Cueva Lucero (Fig 2 and fig. 3) there's almost no difference on vegetation changes after Hurricane Fiona, keeping in mind that the route of the hurricane was to the south of Puerto Rico and the deepest rain floods were nearby Juana Díaz according to the NHC, it's surprising how it's barely affected.

Conclusion

Hurricane Fiona even with the strong winds and rain, was not able to destroy the forests at the selected caves. There is little to no change vegetation wise even at the cave who was directly impacted with the hurricane's course. Hurricane María on the other hand, had damaged all of this caves on a makor scale. This is not a surprise since according to the NHC, Hurricane María had winds of 282km/h and around 121cm of rain doubling what Hurricane Fiona had measured. Although these results showed no major impact in this case, there should be a watch on hurricanes that are categorized 3 or more. Smaller ones like Fiona may not damage the forest to an extreme extent but stronger hurricanes can cause death to the biodiversity on this important places. Besides remote sensing, in situ observations should be done in case the sensors do not pick up smaller damages that can affect the biodiversity such as a tree blocking the entrance of a cave.

Acknowledgement

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ENVI- Geospatial Image Analysis Software