Assessing the long-term effect of hurricanes on the Caribbean mangrove structure with GEDI L3 data

C. H. Amaral[1,2], B. Poulter[2], T. Fatoyinbo[2], D. Lagomasino[3], P. Taillie[4], G. Lizcano[5], R. M. Roman-Cuesta[6]

[1]Universidade Federal de Viçosa, Department of Forest Engineering, Viçosa, MG 36570-900, Brazil
Email: chamaral@ufv.br

[2]NASA Goddard Space Flight Center, Biospheric Sciences Lab., Greenbelt, MD 20771, United States Email: {benjamin.poulter; lola.fatoyinbo}@nasa.gov

[3]East Carolina University, Department of Coastal Studies, Greenvile, NC 27858-4353, United States
Email: lagomasinod19@ecu.edu

[4]University of Florida, Department of Wildlife Ecology and Conservation, Gainesville, FL 32611, United States
Email: paultaillie@gmail.com

[5]Climate Scale, Rue Dieudonné Lefèvre, 17, 1020 Brussels, Belgium
Email: gil.lizcano@climatescale.com

[6]Wageningen University & Research, Laboratory of Geo-Information Science and Remote Sensing, 6708PB Wageningen - The Netherlands
Email: rosa.roman@wur.nl

1. Introduction

Mangrove forests are a key component of coastal ecosystems and play an essential role in protecting local communities from catastrophic storms, sheltering economic activities during hurricane exposure, and preventing permanent losses to economic activities (Hochard et al. 2019). Moreover, they are able to regulate the climate through carbon sequestration and storage and thus, their dynamics have a disproportionate impact on global carbon balance in comparison to other ecosystems (Friess et al. 2020). Therefore, increased frequencies and intensities of hurricanes are a major threat to the economic and ecologic stability of the Caribbean region (Collymore 2011; Camargo and Wing 2021). We herein aim to understand how the cumulative presence of hurricanes in the Caribbean and Gulf of Mexico regions (1979-2018) has affected the structure of the mangroves, particularly height, to navigate actions for regional coastal ecosystem conservation and restoration. To achieve this, we overlap the hotspots of hurricane wind affectation in that period, from the ERA5 reanalysis cumulative maximum winds at 31km resolution, and the Global Ecosystem Dynamics Investigation (GEDI) Level 3 (L3) gridded data at 1km resolution from 2019-2020 (Dubayah et al. 2021).

2. Data and Methods

2.1 Data

We used the 2019-2020 Global Ecosystem Dynamics Investigation (GEDI) Level 3 (L3) gridded mean canopy height, i.e., averages of the 30-m footprint RH100 metrics within each 1 sq. km cell (Dubayah et al. 2021). The Copernicus Climate Change Service (C3S) ERA5 reanalysis data (0.25° of spatial resolution and hourly temporal resolution) for maximum 3-second wind at 10 m height from 1979 to 2018 was used to estimate storm history (Hersbach et al. 2018). We also used 1996 and 2016 mangrove distribution data from the Global Mangrove Watch (GMW; Bunting et al. 2018) and data for the bio-regionalization of coastal and shelf areas (Spalding et al. 2007) for the entire Caribbean region, which comprises 25 countries from the southern United States down to Colombia and Venezuela (Figure 1).

Published in: Markus Hollaus, Norbert Pfeifer (Eds.): Proceedings of the SilviLaser Conference 2021, Vienna, Austria, 28–30 September 2021.
Technische Universität Wien, 2021. DOI: 10.34726/wim.1861
This paper was peer-reviewed. DOI of this paper: 10.34726/wim.1994

2.2 Methods

We first generated grids for the annual maximum sustained wind speed from 1979 to 2018 from the ERA5 hourly wind data that summarizes the maximum 3-second wind at 10 m height at every 31 km. The annual maximum wind speed values for each grid-cell were calculated from the available hourly data and converted to kilometers per hour. From this 40-composite-bands file, we calculated the 40-year cumulative sustained wind speed (km/h), the number of times each cell present maximum sustained wind speed higher than 119 km/h, which classifies it as a hurricane according to the Saffir-Simpson Hurricane Scale, and the time since the last hurricane.

We then created a mangrove mask based on the intersection between the 1996 and 2016 GMW layers (i.e., the current and historical extent combined) and generated random sampling points with 1-km spacing within this region. For each point we extracted the GEDI canopy height (m) (i), the 40-years cumulative sustained wind speed (km/h) (ii), the history of hurricane impact from 1979 to 2018 (iii), and the time since the last hurricane (iv). Points with no missing values summed 1,806. We then calculated the non-parametric Spearman rank coefficient (r) between (i) and (ii) and (i) and (iv) and tested whether heights of mangrove groups (i), which were impacted by zero, one or two hurricanes from 1979 to 2018 (iii), originate from the same distribution by means of the Kruskal-Wallis test. We analyzed the data for the entire Caribbean region but also by ecoregion.

3. Results and Discussion

We found that the median canopy height of the Gulf of Mexico and Caribbean mangroves is 5.36m, ranging from 1.42 to 21.53m tall (Figure 1).

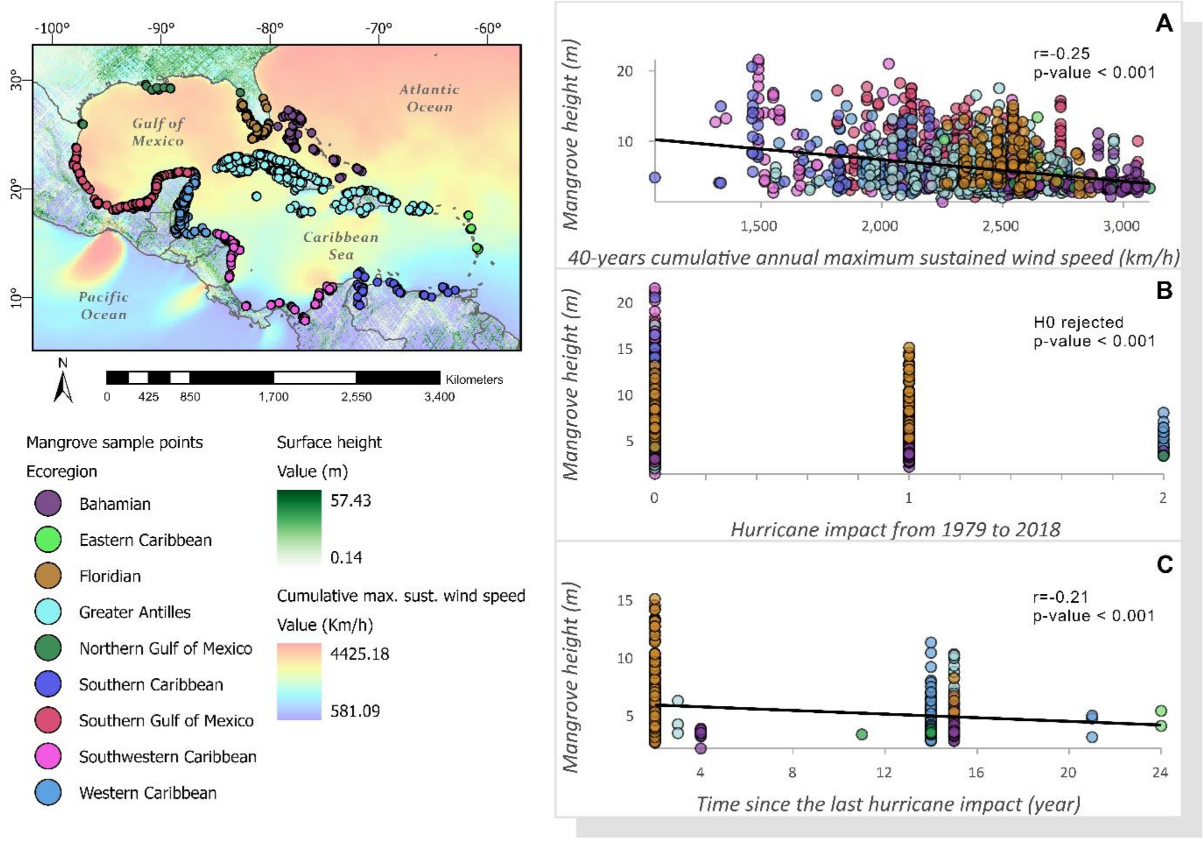

Figure 1: Location of sample points (n = 1,806) within the Gulf of Mexico and Caribbean regions where mangrove height was extracted using GEDI L3 data for 2019-2020, along a gradient of hurricane cumulative presence during the period 1979-2018.

Our results show a clear inverse relation between cumulative sustained wind speed from 1979 to 2018, and the height of Caribbean mangroves in 2019-2020 (Figure 1a). This relationship is corroborated by Simard et al. (2019) that correlated the global SRTM and ICESat-2/GLAS mangrove height estimates with the frequency of tropical cyclones. The tallest mangroves (of about 20 m) are in regions not affected by the strongest wind gusts and that stand out for their lowest cumulative wind speeds, i.e., in the Southern and Southwestern Caribbean regions (Figure 1a and 1b). Conversely, mangroves are less structurally diverse and shorter than 10 m in regions affected twice by the strongest wind gusts and that also present the highest cumulative wind speeds over the studied time range, i.e., in the Bahamian, Northern Gulf of Mexico, and in some places of the Western Caribbean region (Figure 1a and 1b). All regions presented a tendency of height decrease with rising cumulative wind speeds and the degree of correlation between these two variables is moderate for the Southern (r = -0.38) and Southwestern Caribbean (-0.33) regions and strong for the Northern Gulf of Mexico (-0.58).

ERA5 reanalysis appears to underestimate the maximum sustained wind speed, even though it is considered consistent to capture wind speed ranges (e.g., Jourdier 2020). Thus, the 119 km/h threshold captures higher category wind gusts with ERA5 data, like those observed in the 1995, 1998, 2004, 2005, 2008, 2015, 2016, and 2017 mega-hurricane seasons (Figure 1c). In general, we did not observe taller mangroves where the time since the last hurricane was longer, which suggests there was no regional pattern of structural resilience in mangroves hit by strong wind gusts. This expected pattern was seen in mangroves from the Greater Antilles (r = 0.42) and from the Northern Gulf of Mexico (0.41) moderately. The further exploration of GEDI L1 and L2 data will allow us to better understand the impact of hurricanes on the entire mangroves' vertical profiles.

4. Conclusions

GEDI L3 gridded data is a powerful dataset for understanding the long-term effect of extreme climate events on forest structure across large regions. Our results indicate that the cumulative impact of hurricanes seems to compromise the Caribbean mangrove structural diversity and that, in general, they appear not being structurally resilient upon hurricane impact.

Acknowledgements

This research was supported by BNP PARIBAS Foundation within the project "COastal biodiversity RESilience to increasing extreme events in Central AMerica (CORESCAM): implications for regional conservation and policy making".

References

Bunting P, Rosenqvist A, Lucas RM, Rebelo LM, Hilarides L, Thomas, N, ... and Finlayson CM, 2018, The global mangrove watch—a new 2010 global baseline of mangrove extent. *Remote Sensing*, 10(10): 1669.

Camargo SJ and Wing AA, 2021, Increased tropical cyclone risk to coasts. *Science*, 371(6528): 458-459.

Collymore J, 2011, Disaster management in the Caribbean: Perspectives on institutional capacity reform and development. *Environmental Hazards*, 10(1): 6-22.

Dubayah RO, Luthcke SB, Sabaka TJ, Nicholas JB, Preaux S and Hofton MA, 2021, *GEDI L3 Gridded Land Surface Metrics*, Version 1. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1865

Friess DA, Krauss, KW, Taillardat P, Adame MF, Yando ES, Cameron C, ... and Sillanpää M, 2020, Mangrove Blue Carbon in the Face of Deforestation, Climate Change, and Restoration. *Annual Plant Reviews online*, 3(3): 427-456.

Hersbach H, Bell B, Berrisford P, Biavati G, Horányi A, Muñoz Sabater J, Nicolas J, Peubey C, Radu R, Rozum I, Schepers D, Simmons A, Soci C, Dee D, Thépaut JN, 2018, *ERA5 hourly data on single levels from 1979 to present*. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). Available at: https://cds. climate. copernicus. eu/cdsapp

Hochard J P, Hamilton S and Barbier EB, 2019, Mangroves shelter coastal economic activity from cyclones. *Proceedings of the National Academy of Sciences*, 116(25): 12232-12237.

Jourdier B, 2020, Evaluation of ERA5, MERRA-2, COSMO-REA6, NEWA and AROME to simulate wind power production over France. *Advances in Science and Research*, 17: 63-77.

Simard M, Fatoyinbo L, Smetanka C, Rivera-Monroy VH, Castañeda-Moya E, Thomas N and Van der Stocken T, 2019, Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. *Nature Geoscience*, 12(1): 40-45.

Spalding MD, Fox HE, Allen GR, Davidson N, Ferdaña ZA, Finlayson MAX, ... and Robertson J, 2007, Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *BioScience*, 57(7): 573-583.