Center for Global Discovery and Conservation Science
Arizona State University

Introduction

This quarterly water turbidity product was developed by the ASU scientific team of the Allen Coral Atlas. Water turbidity levels are commonly represented by Formazin Nephelometric Units (FNU). The downloadable turbidity maps are multiplied by 10 to be stored in a 16-bit integer format. Therefore, downloadable turbidity maps are in (FNU*10) units. For instance, a value "55" in the turbidity maps is "5.5 FNU". The maximum detectable turbidity value is 100 FNU. There are several steps in data processing that are outlined below.

Data Properties

The quarterly basemaps are created at a resolution of 10 m using the Google Earth Engine Sentinel-2 surface reflectance dataset. Sentinel-2 satellite images with minimal cloud coverage and sun glint over three months are selected. The input dataset is aggregated into a single mosaic output to calculate the highest turbidity value in three months.

Methods

We applied a Shallow Water Turbidity (SWaT) estimation algorithm in clean reef water regions to account for the effects of bottom reflectance and to derive accurate turbidity measurements (Li et al, 2022). In optically-deep waters (e.g., high turbidity river plume regions), we applied an optically-deep turbidity algorithm (Dogliotti et al, 2015). In SWaT, water turbidity (*T*) was calibrated using field-measured turbidity worldwide by using two wavelength-dependent calibration coefficients (i.e., $A_T^\lambda = \frac{\alpha}{f\pi R}$ and $C^\lambda = \frac{\beta f \pi R}{\beta+1}$) as:

$$T = \frac{A_T^\lambda \rho_w}{1-\rho_w/(C^\lambda)} \quad (1)$$

ρ_w is water-leaving reflectance. Both A_T^λ and C^λ are wavelength-dependent calibration coefficients that are calculated in different wavelengths as a globally applicable model.

In shallow coastal waters, the water-leaving reflectance (ρ_w) is calculated from the contribution of both water column (r_{rs}^{water}) and bottom reflectance (r_{bottom}):

$$\rho_w = \pi R(r_{rs}^{water} + r_{bottom}) \quad (2)$$

$$r_{bottom} = \frac{\rho_b}{\pi} e^{-KH} \quad (3)$$

where *H* is water depth, K is water-column attenuation, and ρ_b is bottom reflectance. So, water-column remote sensing reflectance (r_{rs}^{water}) was calculated in the SWaT as:

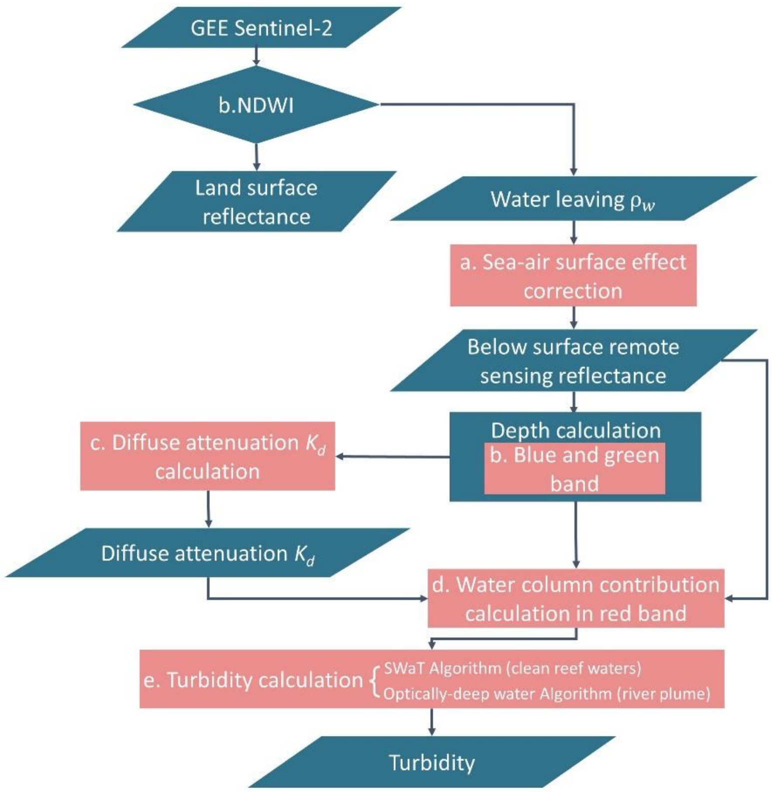
$$r_{rs}^{water} = \frac{\rho_w - R\rho_b e^{-KH}}{\pi R} \quad (4)$$

Turbidity in shallow coastal waters ($Turbidity$) was calculated as:

$$Turbidity = \frac{A_T^\lambda(\rho_w - R\rho_b e^{-KH})}{1-(\rho_w - R\rho_b e^{-KH})/(C^\lambda)} \quad (5)$$

We introduced the bottom reflectance contribution ($R\rho_b e^{-KH}$) to abbreviate bottom effects in the turbidity calculation (Li et al., 2022). We applied the value of (A_T^λ = 268.52) and (C^λ = 0.1725) based on the central wavelength of Sentinel-2's red band, which is calibrated in the previous studies as a global applicable model.

The following image shows the turbidity product's calculation steps:



Data Download

Turbidity products are downloadable. Downloaded quarterly turbidity maps show the highest turbidity value over a three-month period, which help to identify and detect the seasonal turbid waters hotspots over coral reefs and associated water environments. Downloaded turbidity products will appear different from what is represented graphically on the Atlas because of the visual transformations discussed below in "Visualization".

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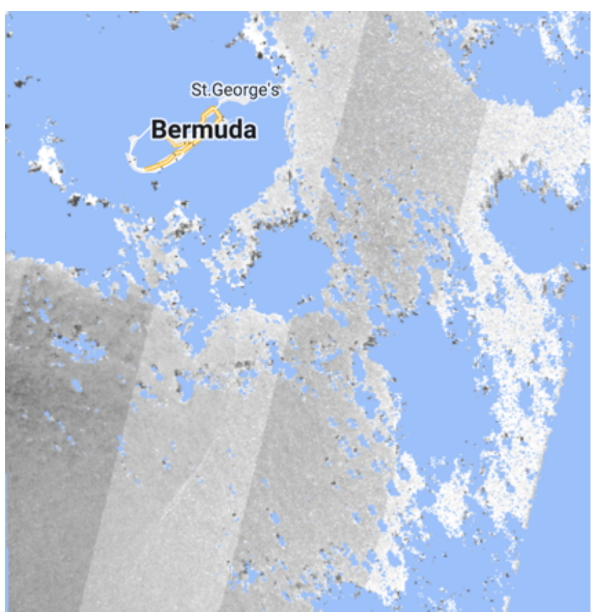
Visualization

We produced the turbidity maps visible in the Atlas by reducing the computed turbidity values to four possible bins representing low/no turbidity (values <= 50 (5.0 FNU)), moderate turbidity (<= 63 (6.3 FNU)), high turbidity (<= 80 (8.0 FNU)), and severe turbidity (> 80 (8.0 FNU)). These bins equate to the quartiles of the distribution of over 780 trillion turbidity pixel values computed across tropical coral reef habitat areas globally from October 2019 through July 2022. We smoothed the binned turbidity representation with a normalized gaussian filter ($\sigma = 10$) to produce a cleaner visual product.

Areas flagged as having no turbidity data are due to a lack of clean cloud-free Sentinel2 imagery to be used as input. Dense cloud, cloud shadows, strong sun glint, or no satellite observation all lead to unavailable input data. This is particularly pronounced in certain areas of the world, such as Western Micronesia and some remote atolls in the Pacific.

Turbidity Data Limitation

Our turbidity data is derived from the Sentinel-2 (S2) satellite images. The red band of the S2 image has a limitation in detecting weak signals over clean oceanic water regions. Therefore, there are illustration effects caused by S2 satellite input data, such as apparent lines or bands, as seen in the image below.



Algorithm Improvements

As of October 11th, 2022, all past quarterly turbidity data products have been replaced with data formulated by this method. While the two methods are similar, the new method is improved in the following ways:

1. Version 2.0 includes many non-reef waters including river plume regions, and our output in these non-reef areas gives good estimations in these river plume areas
2. Version 2.0 combines two different algorithms (SWaT and Optical deep water algorithms) for different regions

References

Li, J., Carlson, R. R., Knapp, D. E., & Asner, G. P. (2022). Shallow coastal water turbidity monitoring using Planet Dove satellites. *Remote Sensing in Ecology and Conservation*.

Dogliotti, A. I., Ruddick, K. G., Nechad, B., Doxaran, D., & Knaeps, E. (2015). A single algorithm to retrieve turbidity from remotely-sensed data in all coastal and estuarine waters. *Remote sensing of environment*, *156*, 157-168.