Comparative geomorphology of coral reefs from a joint analysis of ICESat-2 bathymetry and multi-spectral imagery using machine learning

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UC San Diego

NASA

esa

Introduction to coral reefs

- Covers 1% of the Earth’s surface.
- Supports the most species per unit area for marine ecosystems.
- Take between 100,000 to 30,000,000 years to fully form.
- Generates $375 billion each year through tourism.
- Numerous drugs developed from coral reef animals and plants.

Threats to coral reefs

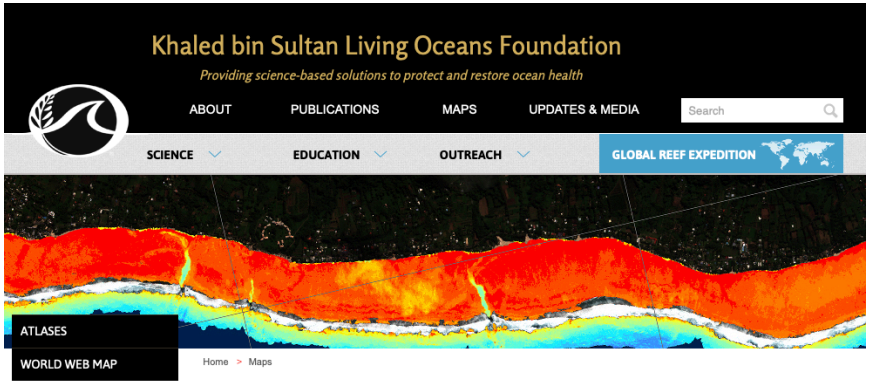
- Weather related damages – cyclones, hurricanes.
- Long periods of exceptionally low tides.
- Increased sea surface temperatures.
- Pollution – increases nutrient level that leads to higher algae growth.
- Overfishing.

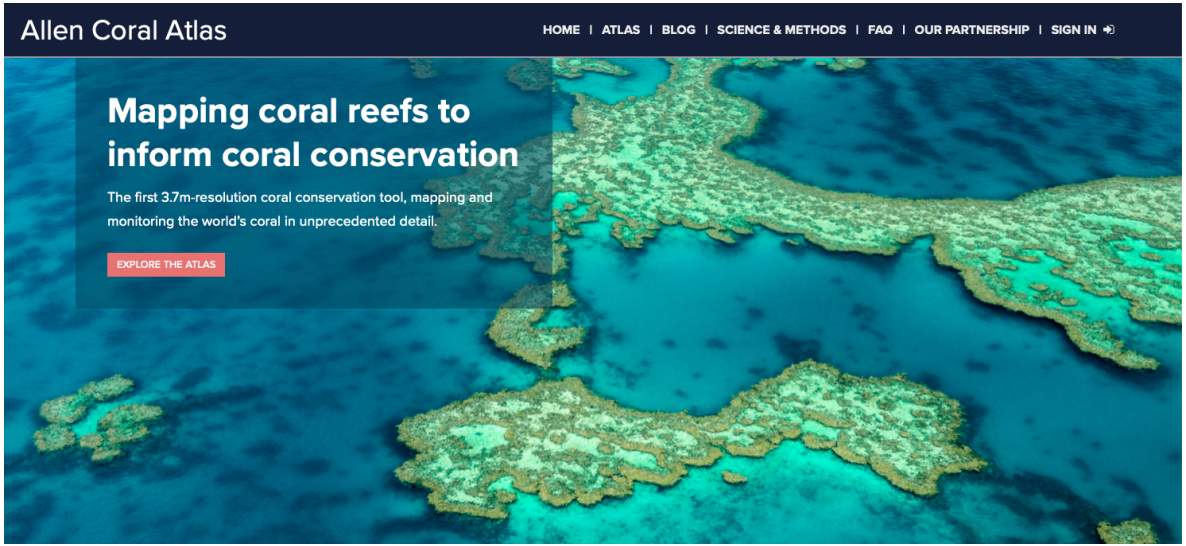
Healthy coral

Bleached coral

Coral reef mapping

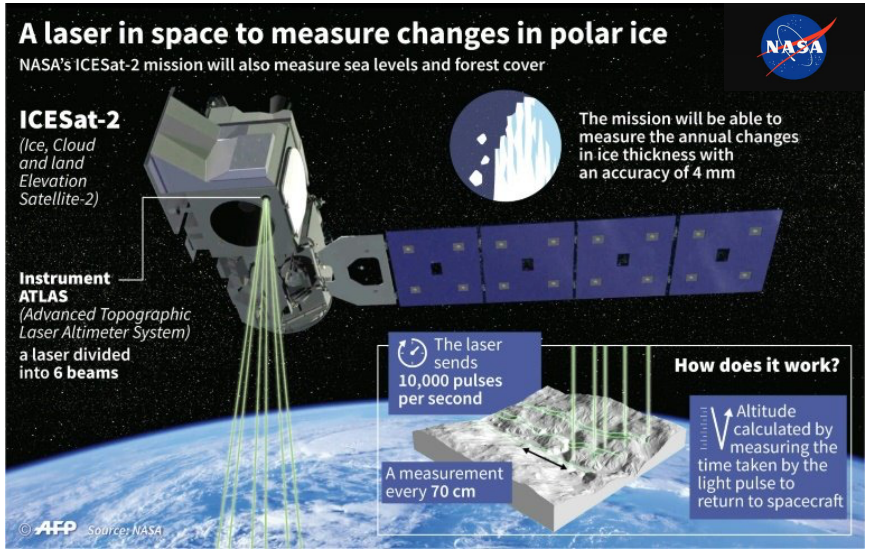
Currently there are two global coral reef mapping projects: the Allen Coral Atlas, and the Khaled bin Sultan Living Oceans Foundation.
They map depths using satellite imagery that is validated by sonar/lidar. This process is expensive and time-consuming.

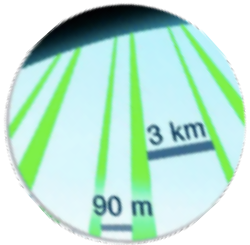




NASA's ICESat-2 Mission

- ICESat-2 is a satellite laser altimeter making repeated observations of ice/land/ocean elevations globally.
- ICESat-2's blue-green laser penetrates water and measures shallow water bathymetry to decimeter accuracy.
- **Our goal – use ICESat-2 data as "ground truth" for estimation of coral reef bathymetry.**





ICESat-2 projects six laser beams, separated by 90 m to 3 km.

Each beam can provide independent ground truth over a reef.

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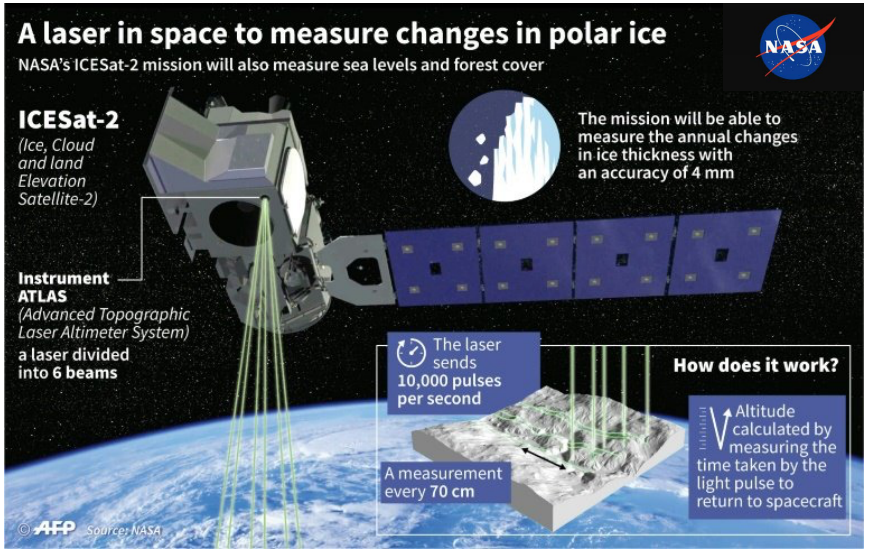
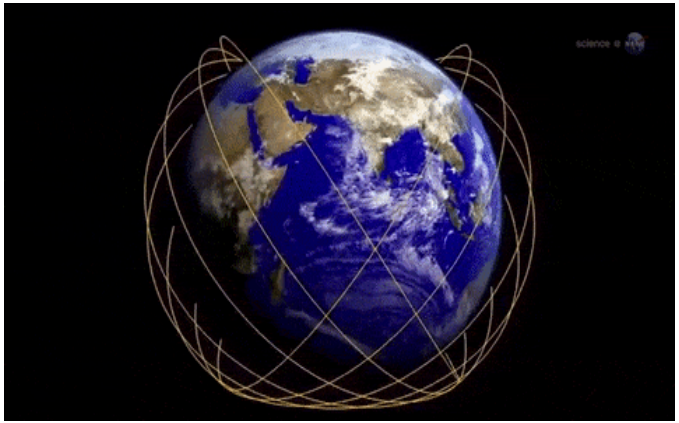
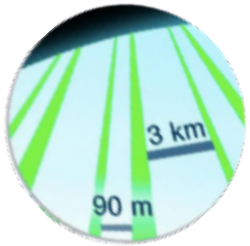




ICESat-2 orbits Earth 15 times daily…



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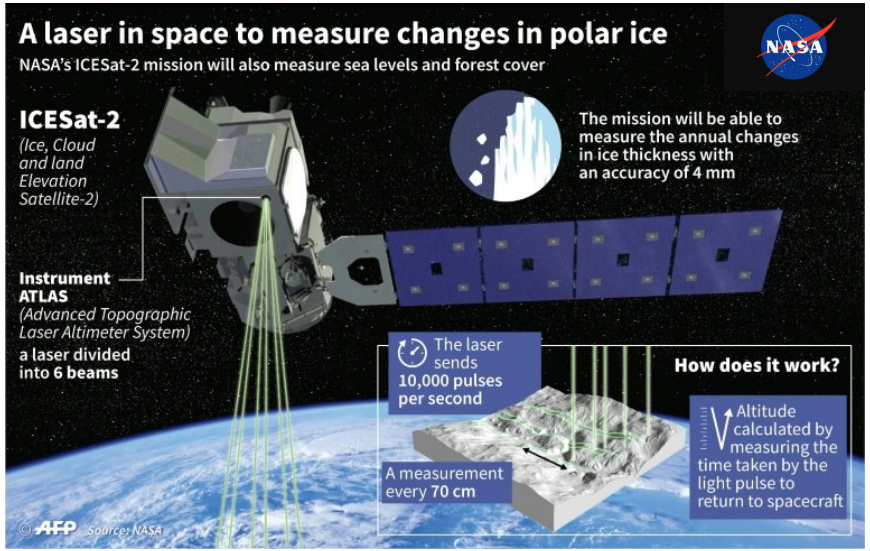
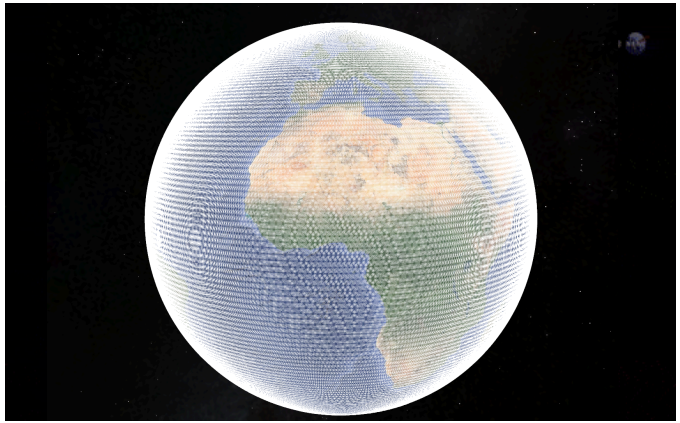
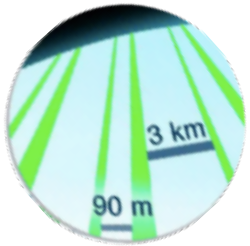




ICESat-2 orbits Earth 15 times daily… covering 1387 different ground tracks over 3 months before starting over.



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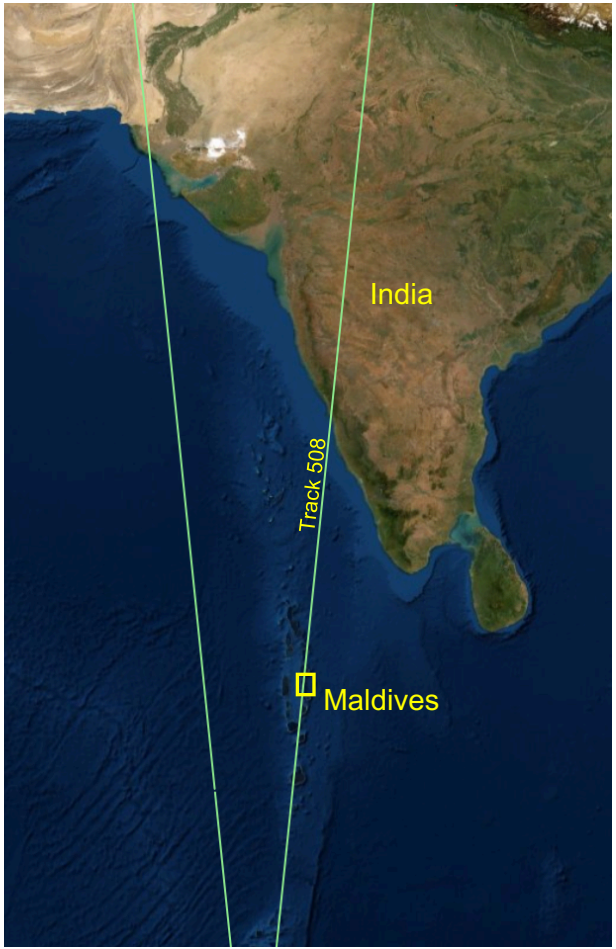
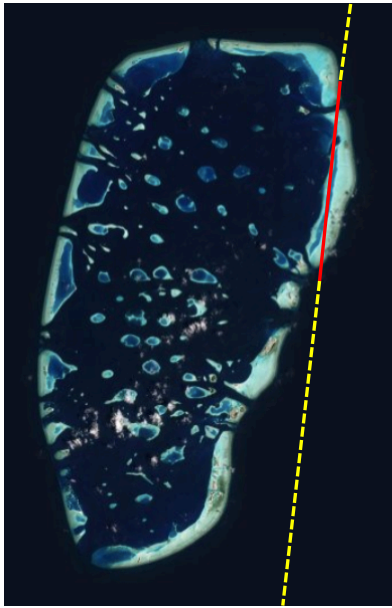
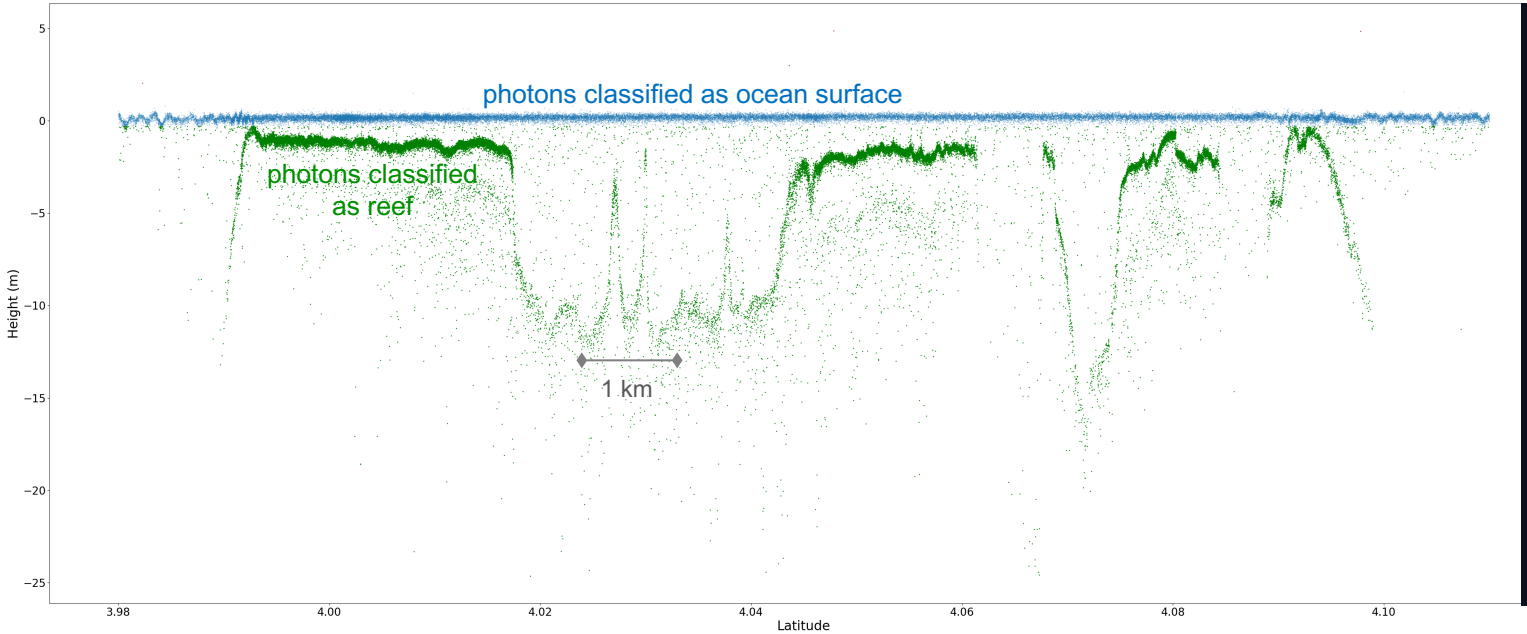
ICESat-2 bathymetry profile example (Dhiffushi, Maldives)

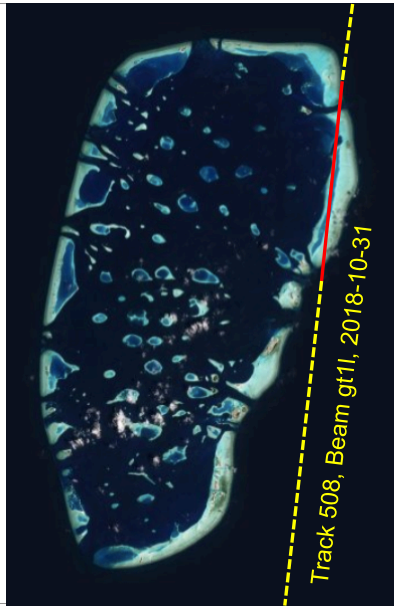




ICESat-2 bathymetry profile example (Dhiffushi, Maldives)

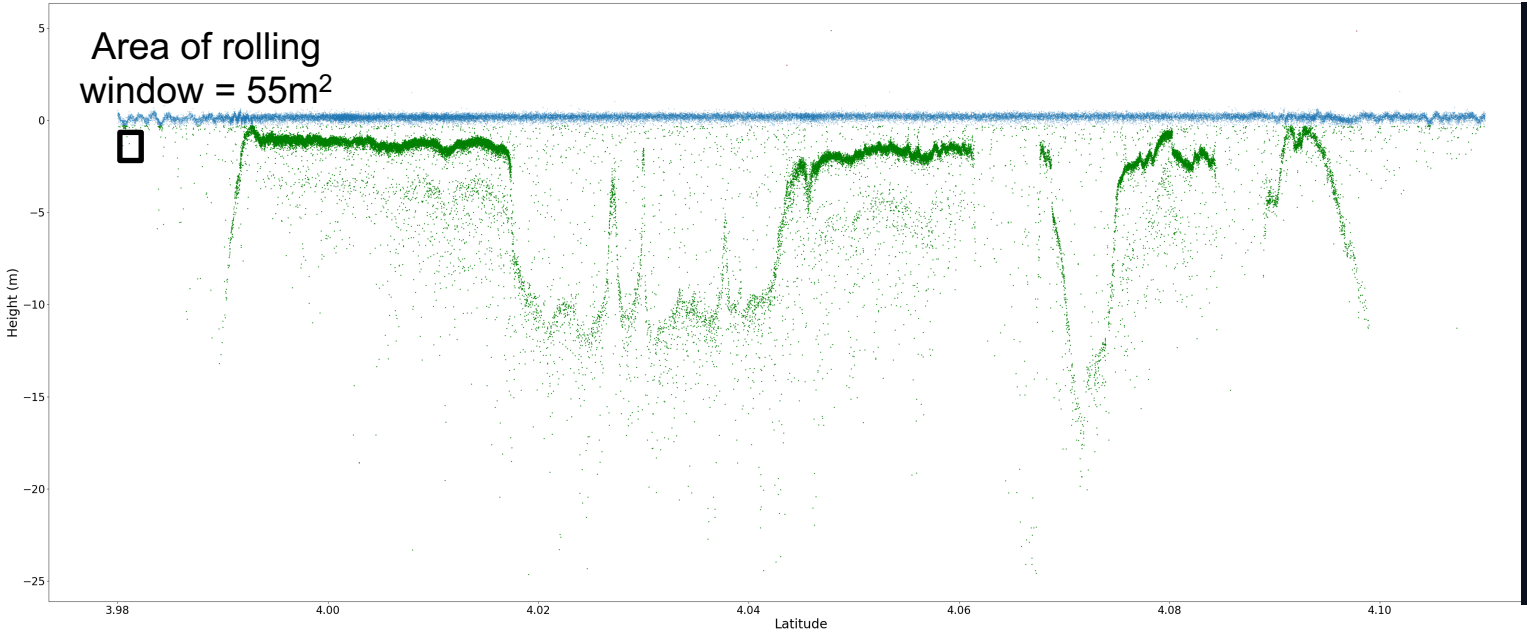
Classify individual ICESat-2 photons as reef or ocean

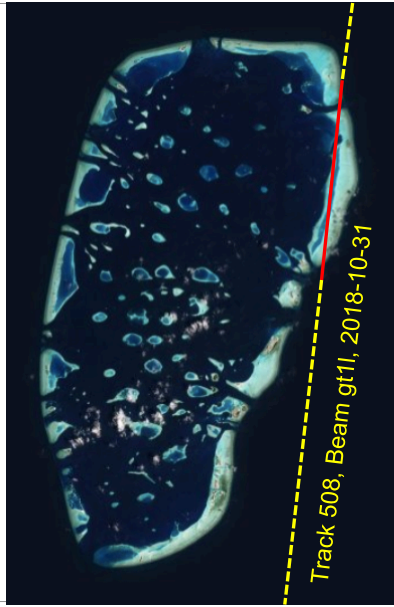




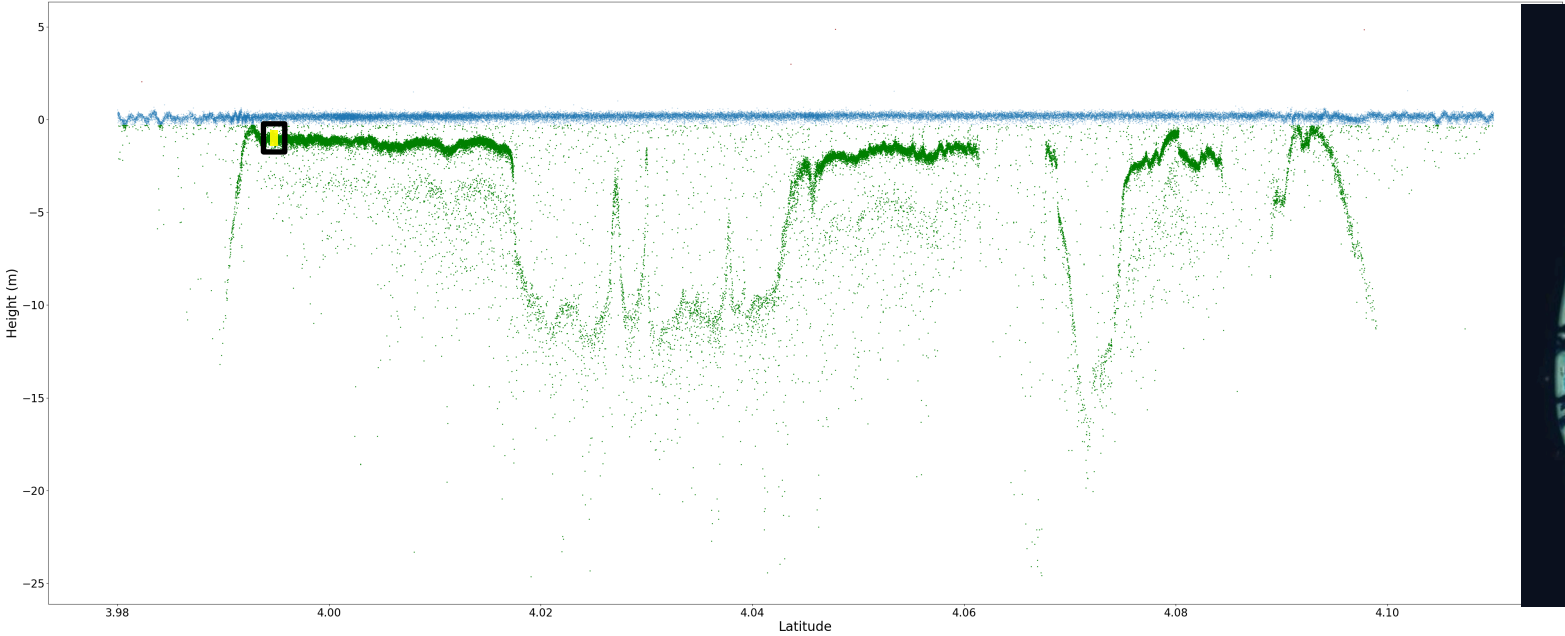
Methodology

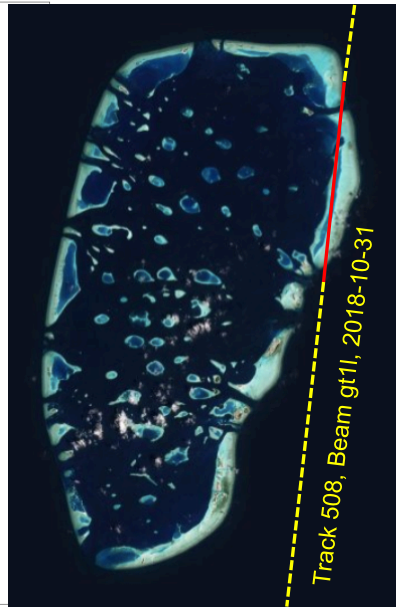
Iterate from left to right through reef using rolling window.





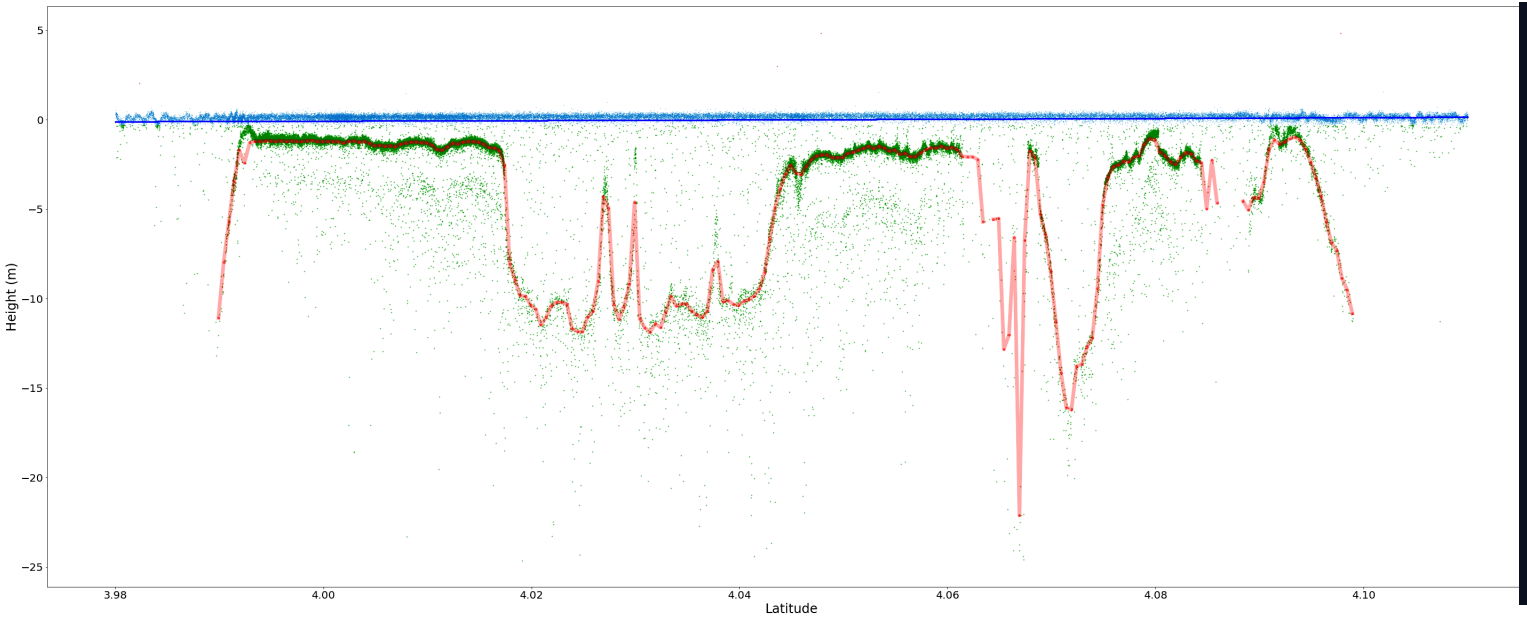
Use Interquartile range and median to generate
one representative point for each window.
Filtered results to include just back to back predictions

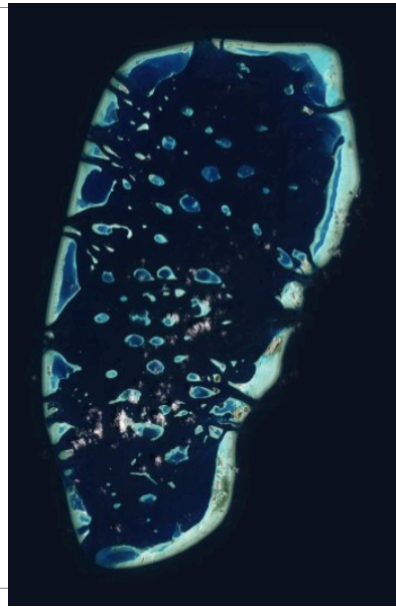




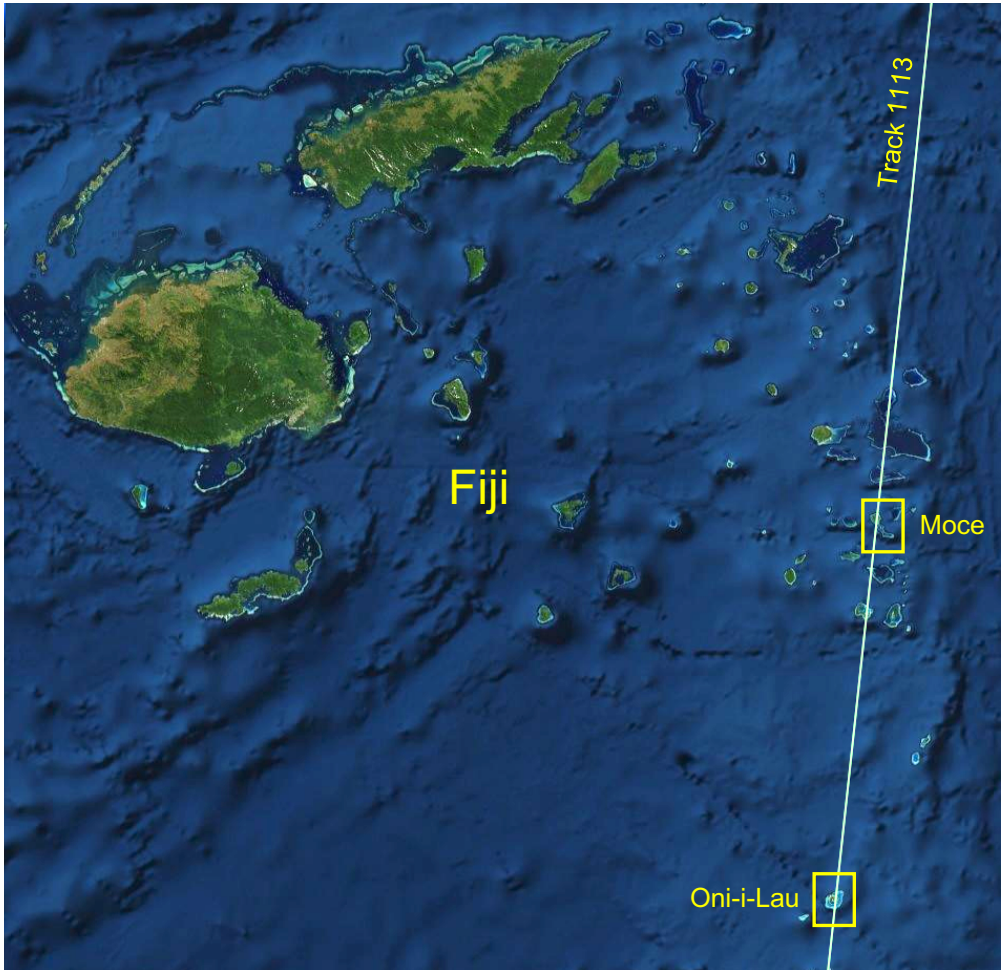
ICESat-2 bathymetry profile example (Dhiffushi, Maldives)

Profile generation: Bathymetry profile created by interpolation, correcting for refraction and referencing to mean sea level using independent tide estimates.

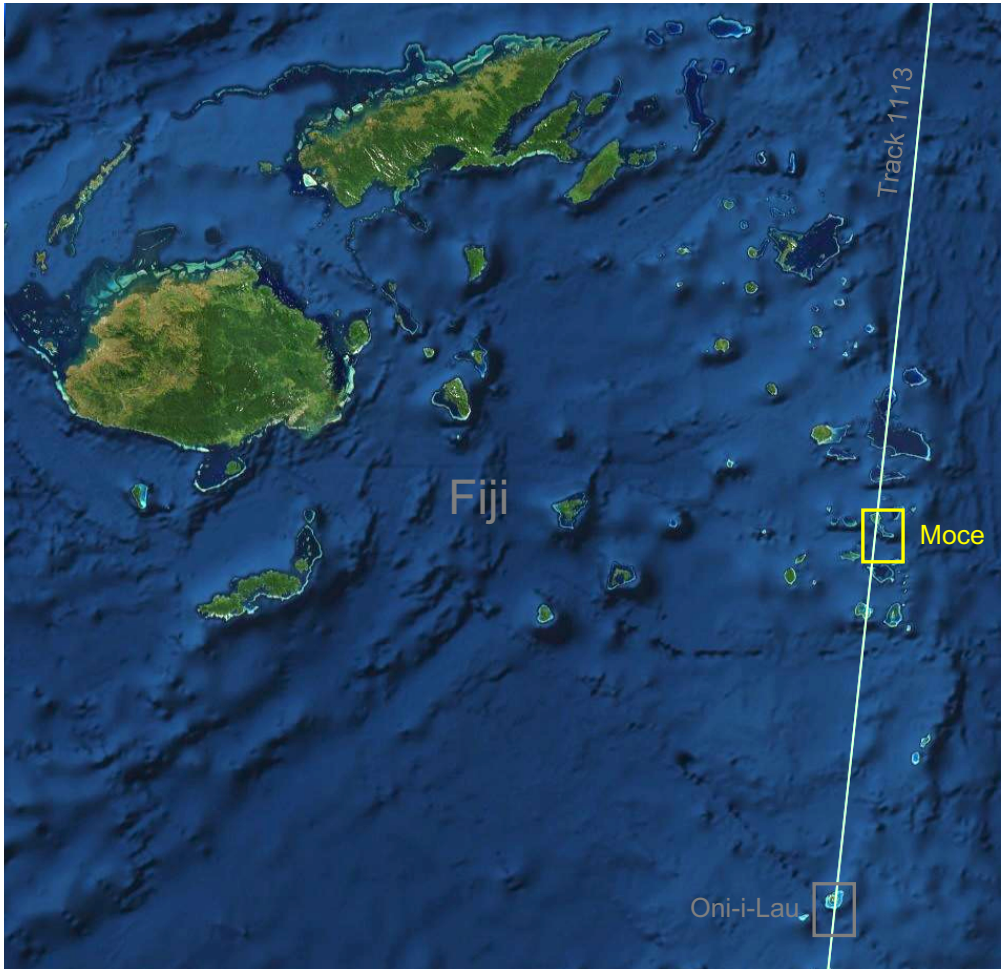




Output is a profile of bathymetry estimates at uniform interval, with reduced noise, but also with errors



Bathymetry estimation for two atolls in Fiji, both located on ICESat-2 track 1113

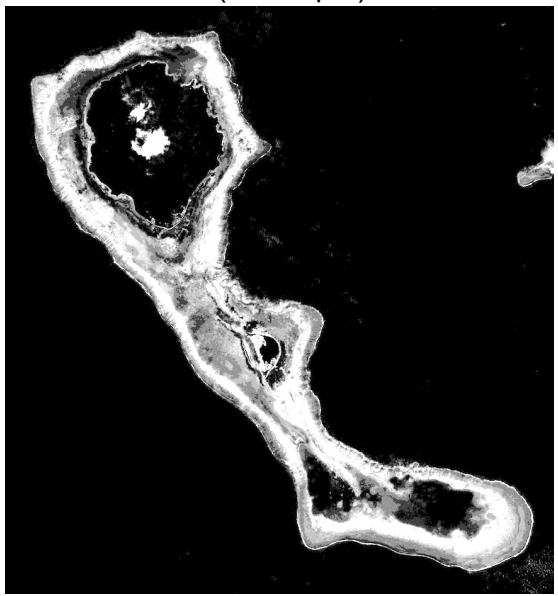


Moce

Sentinel-2 Multispectral Imagery (Moce, Fiji)

10-meter resolution
Global coverage
Freely/publicly available

Band 2 – Blue (0.490 μm)

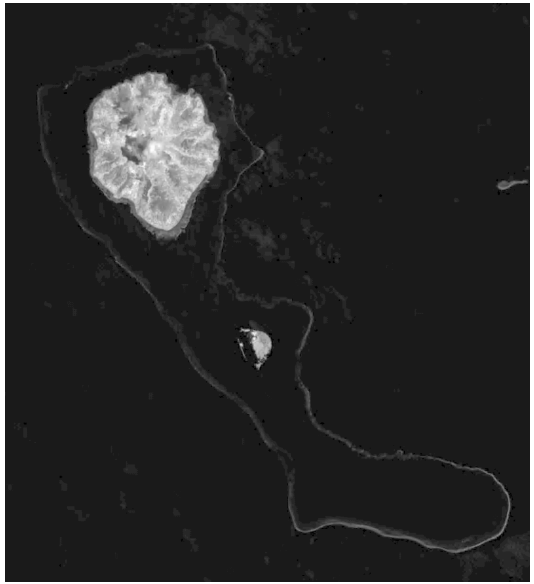


Penetrates water, low attenuation with depth.

Band 3 – Green (0.560 μm)

Penetrates water, moderate attenuation with depth.

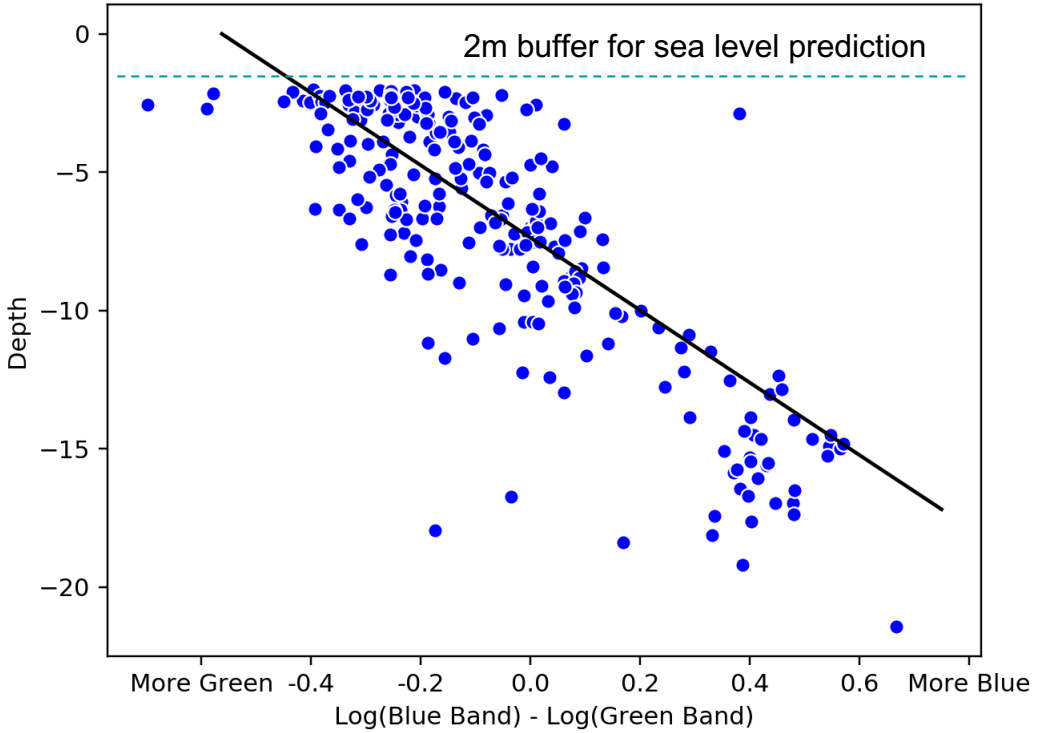
Band 8 – Near Infrared (0.842 μm)



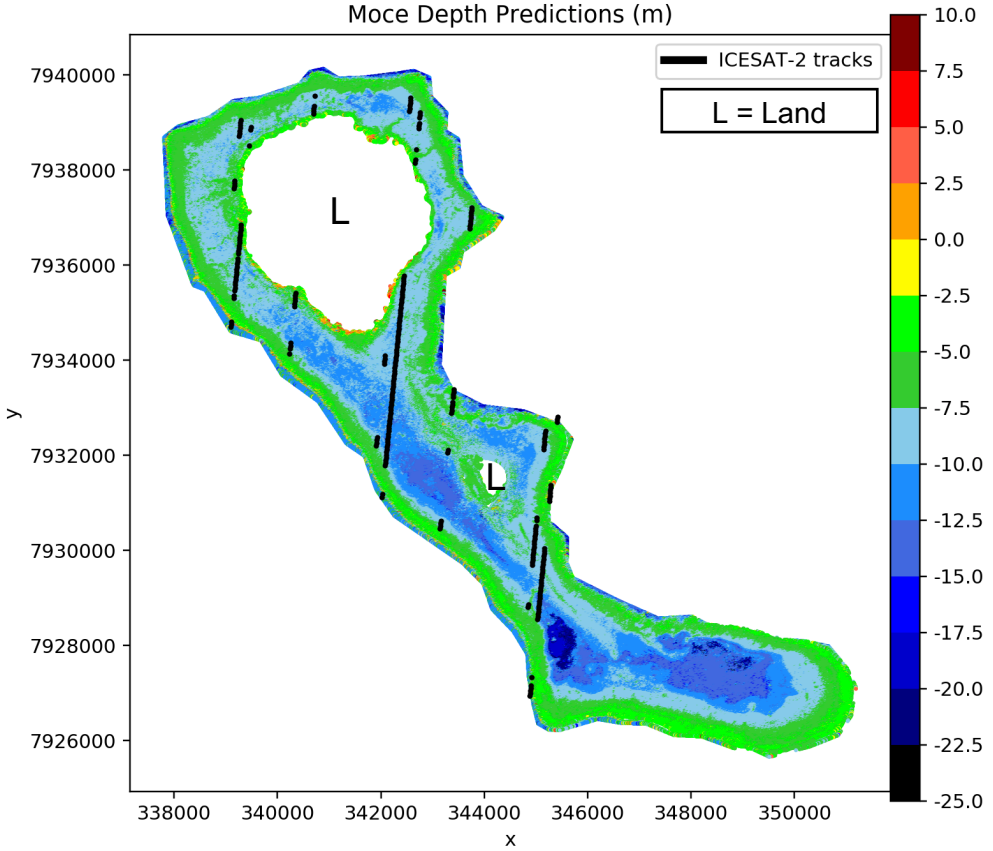
High reflectance from clouds/land, no water penetration.

Bathymetry from imagery

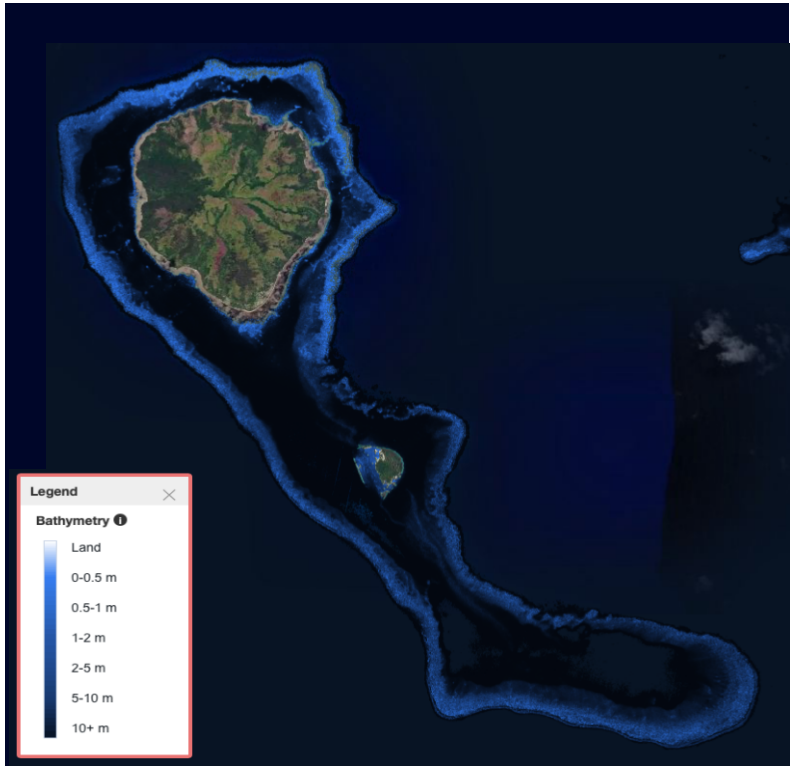
- Blue and green light that reflects from the seafloor is attenuated to different degrees by passage through seawater.
- Can use the linear relationship between [Log(blue light) – Log(green light)] to estimate depth from Sentinel-2 green and blue pixel values.
- Poor performance of imagery-only bathymetry estimates necessitates using independent bathymetry data to calibrate this relationship.
- Figure at right shows actual data over Moce using depths from an ICESat-2 profile and collocated Sentinel-2 pixels.

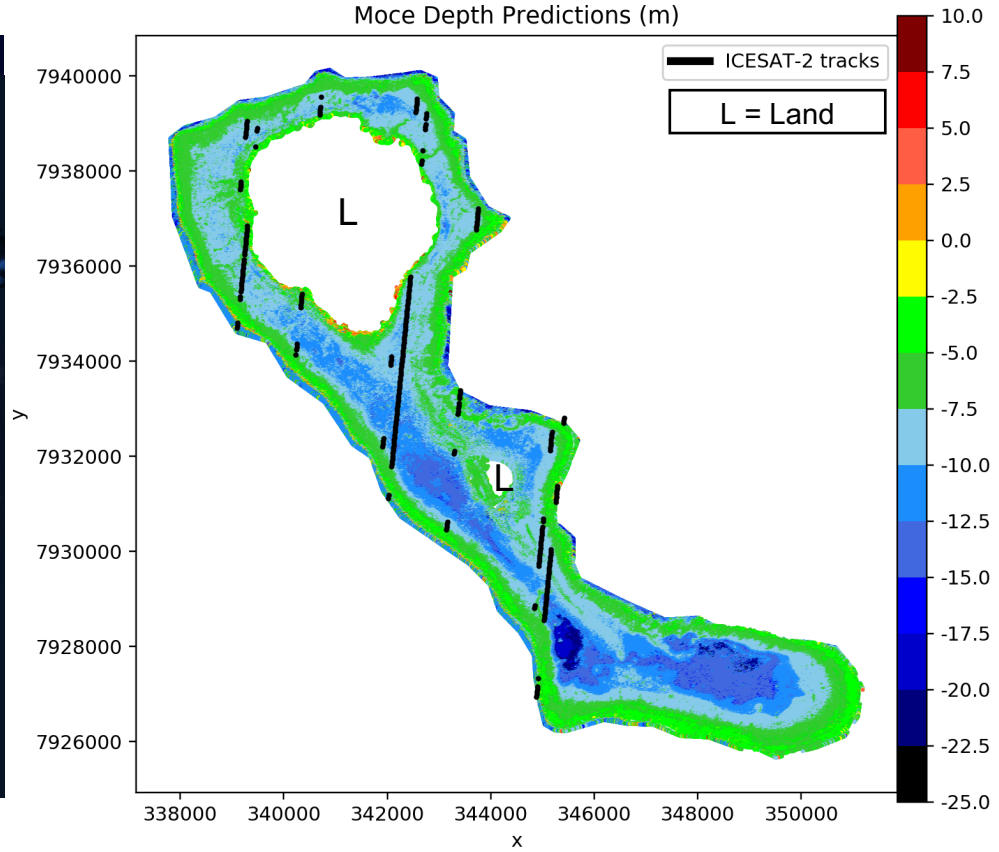


Moce, Fiji

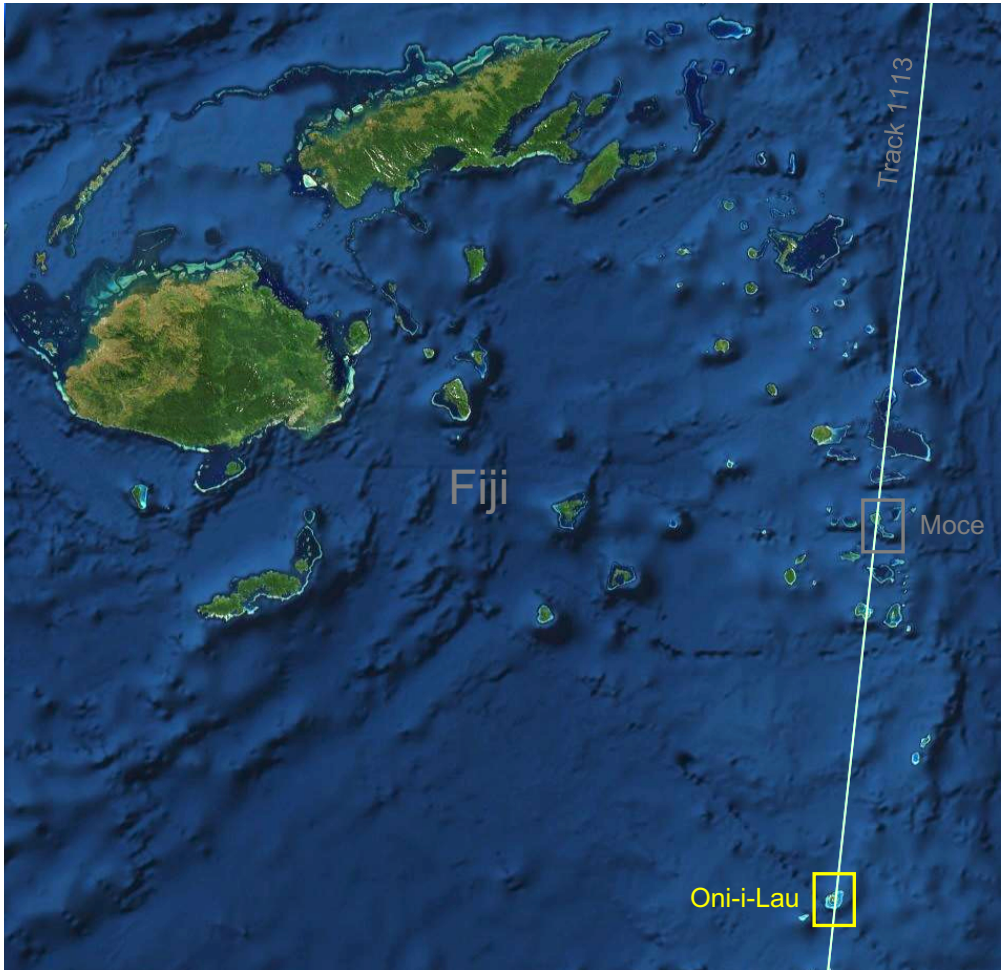

Moce Depth Predictions (m)
ICESAT-2 tracks
L = Land
L
L
7940000
7938000
7936000
7934000
7932000
7930000
7928000
7926000
y
338000
340000
342000
344000
346000
348000
350000
x
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
-7.5
-10.0
-12.5
-15.0
-17.5
-20.0
-22.5
-25.0

Moce, Fiji



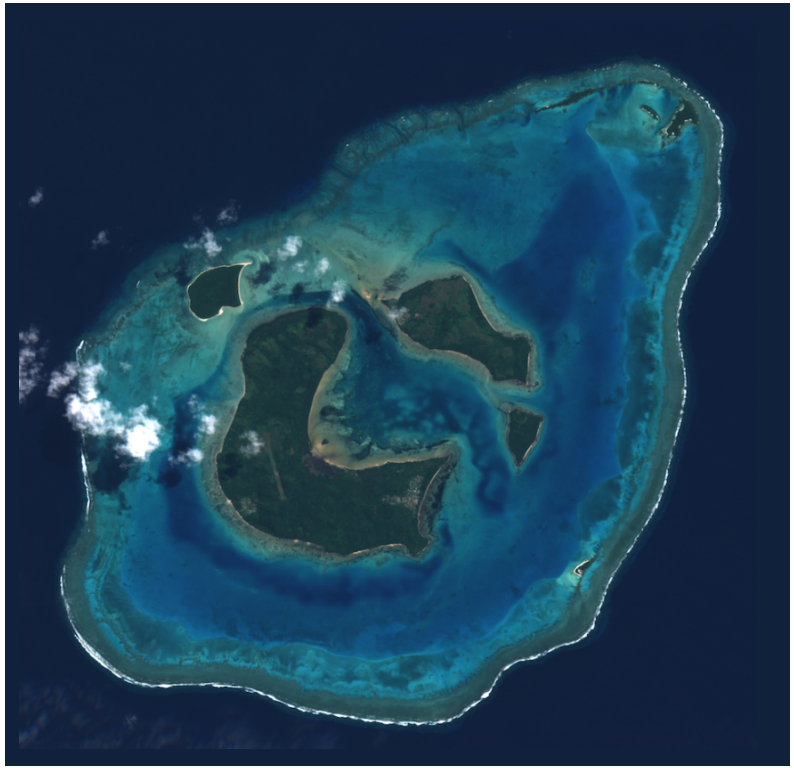


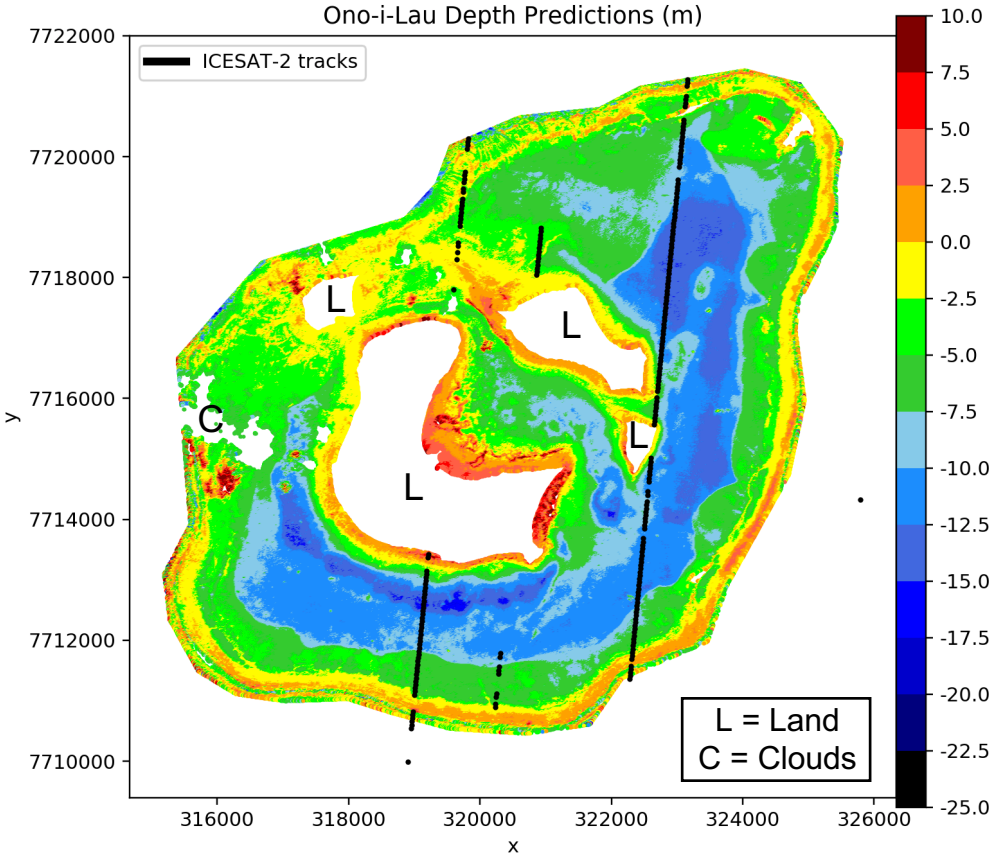
Bathymetry estimates from Allen Coral Atlas do not capture shallow/deep variations inside the atoll.



Oni-i-Lau

Ono-i-Lau, Fiji

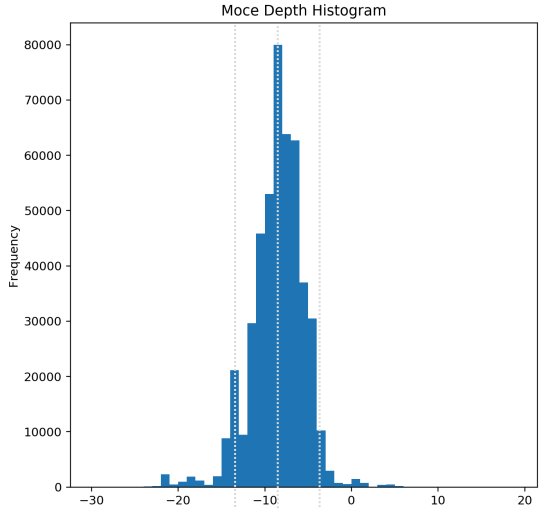


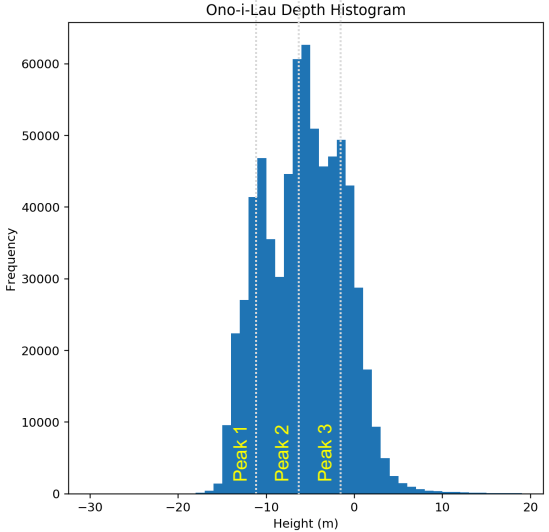


Comparison of imagery with bathymetry estimate (right) indicates that the bathymetry is biased high, so that shallow reef is assigned positive elevations. Averaging multiple estimates reduces errors such as these.

Bathymetry histograms of two Fiji reefs

- Oni-i-Lau exhibits three peaks in its bathymetry distribution (labelled in yellow as Peaks 1-3), all separated by ~5 m.
- Moce exhibits only two peaks, but these are also separated by ~5 m and may align with Oni-i-Lau peaks after estimates are averaged.





Conclusions

- We can estimate coral reef bathymetry anywhere on Earth using a combination of satellite imagery and satellite bathymetry.
- ICESat-2 photon data provide shallow bathymetry at 1-meter horizonal resolution, while satellite Imagery is at a 10m resolution suggesting that we can use higher-resolution imagery for bathymetric estimates
- Applications:
  - From reef depth distributions, we can identify which corals are at a higher risk of endangerment due to sea surface warming.
  - We can study the effect of natural disasters such as hurricanes by analyzing before and after bathymetry.