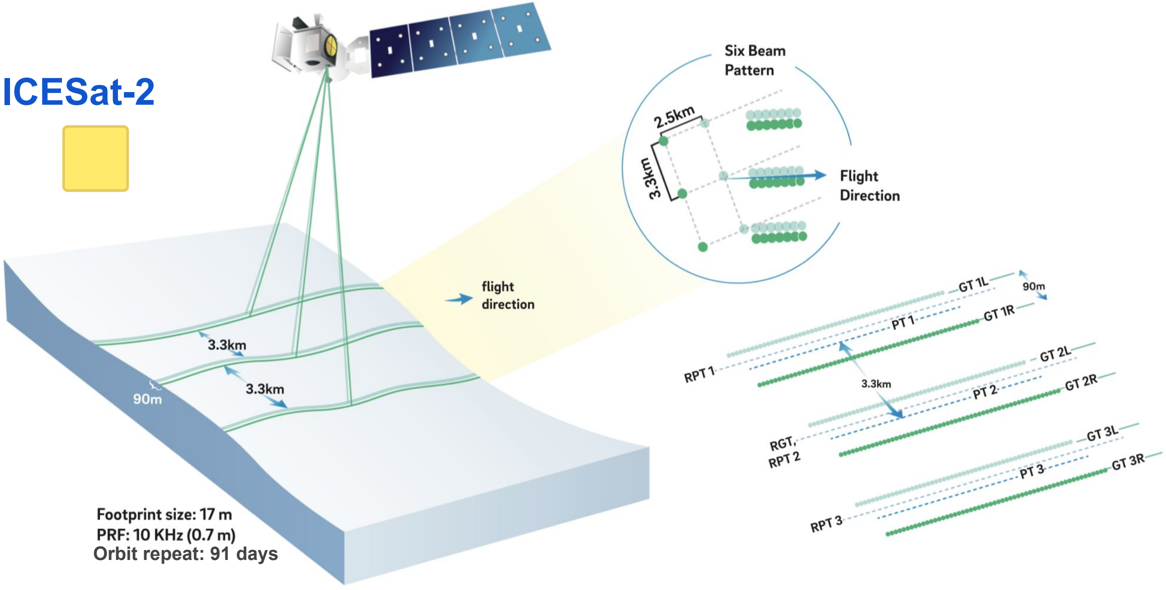
Assessment of ICESat-2 for the Recovery of Ocean Topography

ICESat-2



Launch date: September 15, 2018

(figure credit: Smith et al., 2019)

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Abstract

The Ice, Cloud, and land Elevation Satellite 2 (ICESat-2) laser altimetry mission, launched in September 2018, uses 6 parallel lidar tracks with very fine along-track resolution (15 m) to measure the topography of ice, land, and ocean surfaces. Here we assess the ability of ICESat-2 ocean data to recover oceanographic signals ranging from surface gravity waves (wavelengths from 30 m to 1000 m) to the marine geoid (wavelengths > 16 km). We focus on a region in the tropical Pacific and study photon height data in both the wavenumber and space domain. Results show that ICESat-2 can recover the marine geoid at wavelengths > 16 km which is similar to the best radar altimeter data. At some times, the amplitude, wavelength, and propagation direction of surface gravity waves areis well resolved by using a combination of the strong and weak beams, which are separated by 90 m. We find higher than expected power in the 3 km to 20 km wavelength band where geoid and ocean signals should be small. This artificial power is caused by the projection of large amplitude, 2-D surface waves from ~300 m wavelengths into longer wavelengths (5-10 km) because of the 1-D sampling along the narrow ICESat-2 profile. Thus ICESat-2 will not provide major improvements to the geoid in most of the ocean, although it may be valuable in regions where wave heights are generally low.

Outline

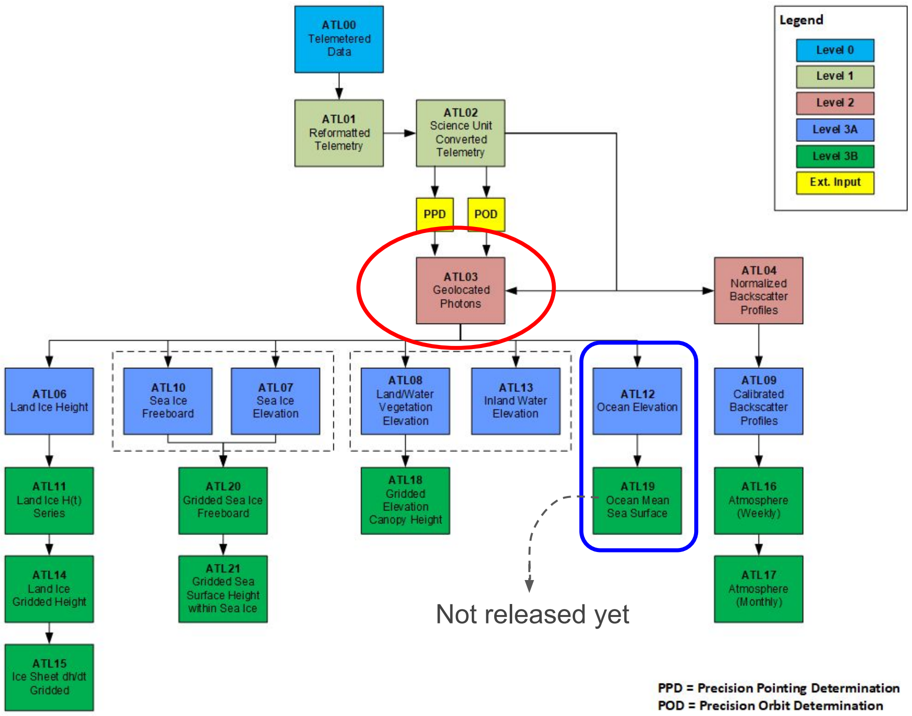
- ❑ Introduction
- ❑ Wavenumber domain analysis
- ❑ Space domain analysis

- Ocean topography
  - Surface waves (<1 km):
    - How do surface waves contaminate ICESat-2 observations?
  - Intermediate band (1-20 km):
    - What is the origin of the height signals in the 3 km to 20 km wavelength range?
  - MSS (>20 km):
    - Can the ICESat-2 ocean data be used to improve the MSS?

SSH (ocean topography) = MSS + oceanic variabilities (SLA) + error

MSS = geoid + ocean dynamic topography

ICESat-2 products



ATL03:

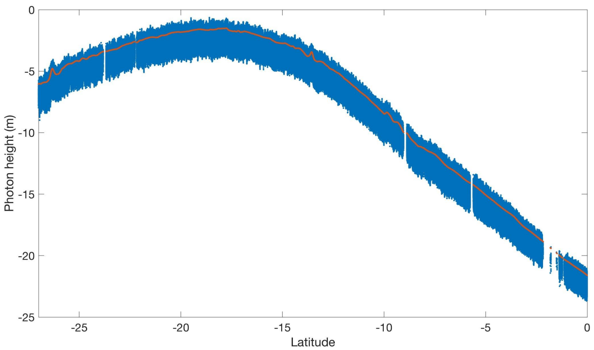
- sampling rate: 10 kHz (0.7m)
- Footprint size: 17m
- Noise, Buffer, Low, Medium, High
- x-y location uncertainty: 10 m

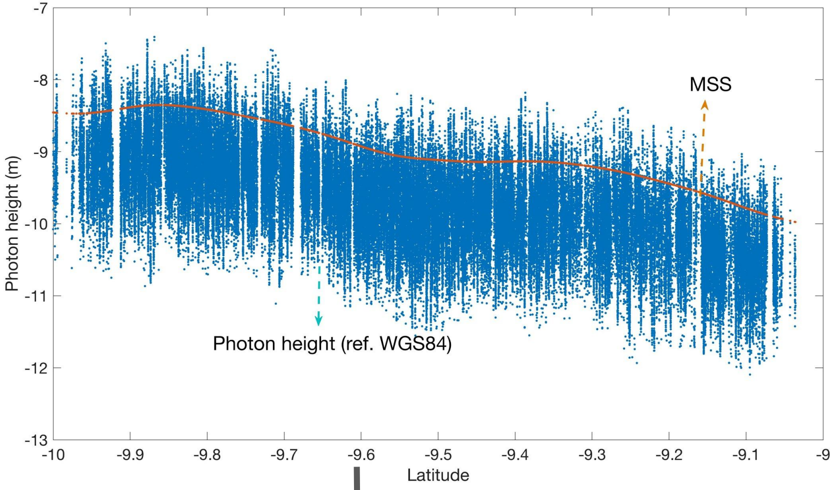
ATL12:

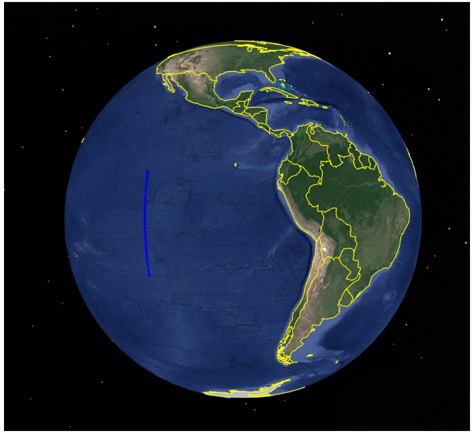
- Resolution: varies, 70m to 7km (> 4km in tropical Pacific)
- Aims to achieve standard errors in mean sea surface height of 1 cm or better

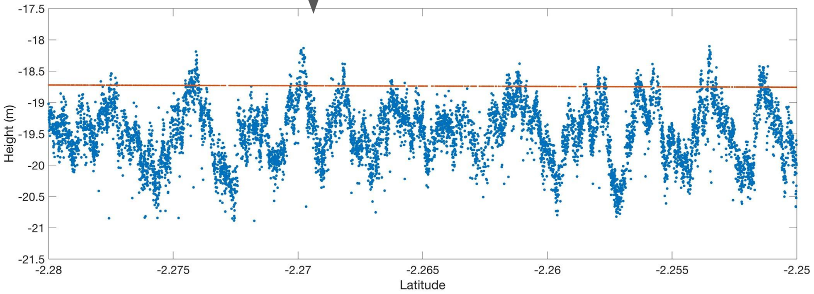
https://nsidc.org/data/icesat-2

Example: ICESat-2 geolocated photon SSH



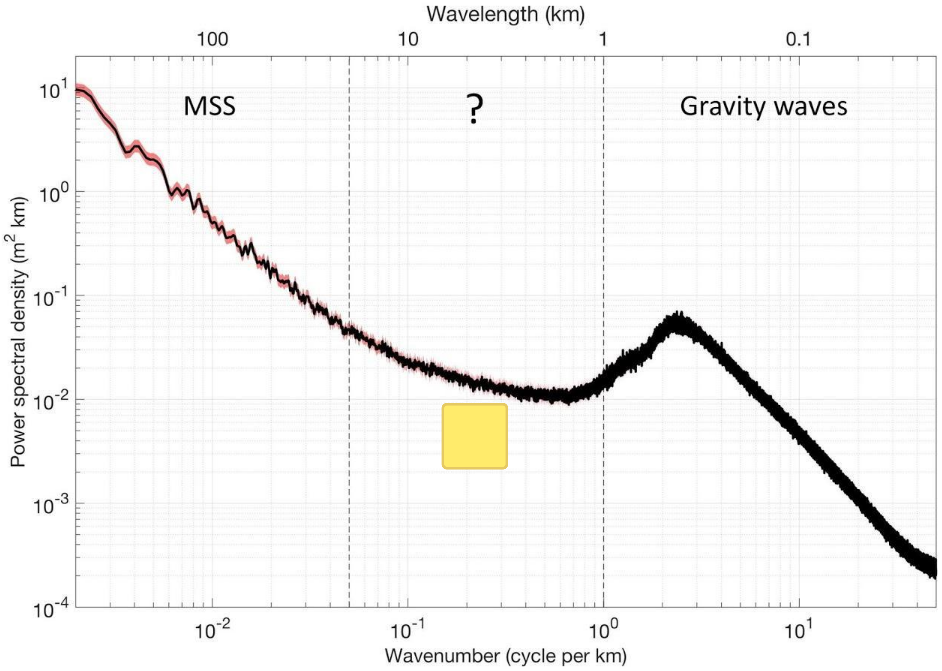






(beam 1l, track: 0394; cycle: 02; sensing time: 2019/01/23)

SSH (ref.WGS84) PSD in tropical Pacific (-120/-100/-11/-1)



Data processing:

- Geophysical corrections;
- Low-pass filtered at 30m;
- Lomb-Scargle periodogram (341 averaging)

MSS: > 20 km
intermediate band ~~(3-20 km)~~: 1 km - 20 km
gravity waves: < 1 km

Figure1. Averaged SSH power spectral density in the Pacific box. The spectrum can be divided into three bands representing the longer wavelength mean sea surface (MSS, 20-500 km), the shorter wavelength surface gravity waves (< 3 km), and the more poorly understood intermediate wavelength (3-20 km) band. The 99% confidence interval is shaded in red.

Wavenumber domain

Spectral coherence

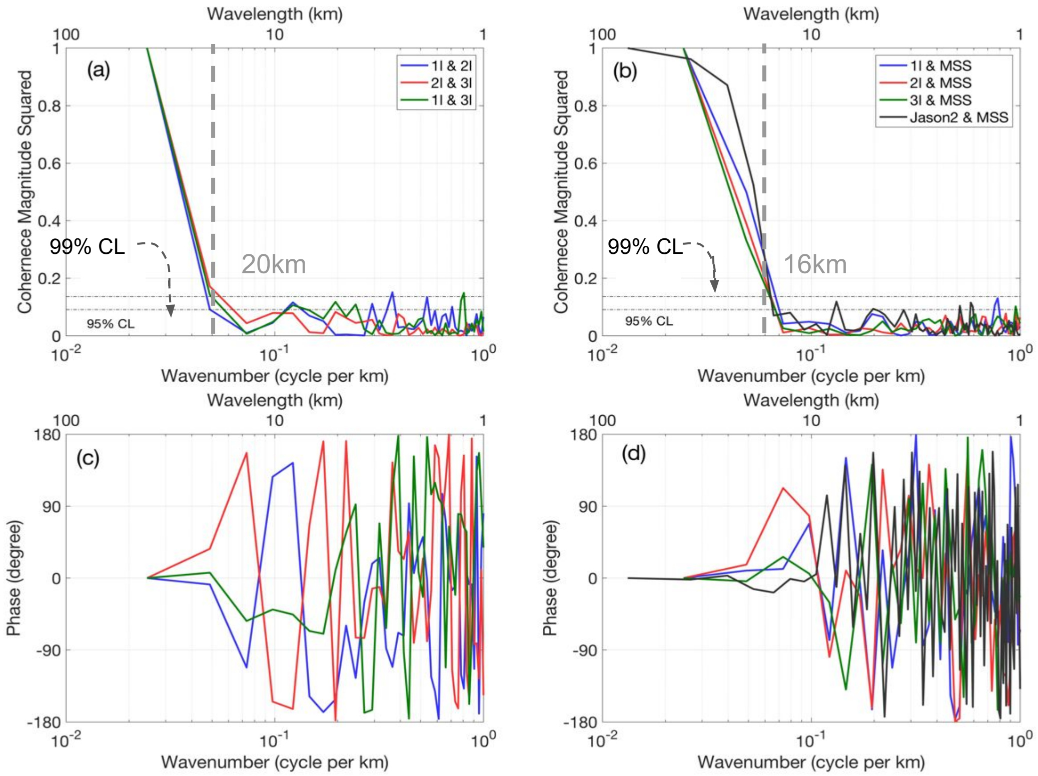
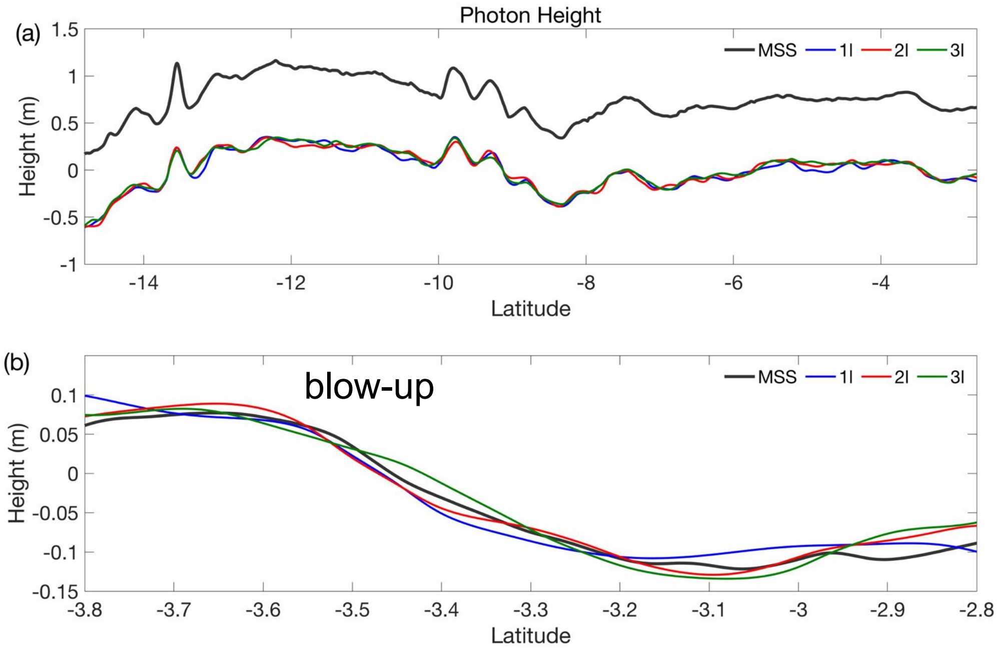


Figure 2. (a) Coherence and (c) phase between beams 1l-2l, 2l-3l, 1l-3l of a selected ICESat-2 track (ground track: 0394, cycle: 02). Coherence falls to below 95% CL at ~20 km. (b) Coherence and (d) phase between MSS and each strong beam. Black line is the coherence between 20Hz Jason-2 and MSS. Coherence falls to below 95% CL at ~16 km for both the ICESat-2 and the Jason-2 cases.

(ICESat-2: track: 0394; cycle: 02; sensing time: 2019/01/23)

Space domain: MSS

ICESat-2 SSH (low-pass filtered at 20km)



Data processing:

- MSS at beam 2l's position;
- Beam 1l and 3l have been corrected for MSS cross-track difference;
- linear trend removed.

Figure 3. (a) SSH of ICESat-2 3 strong beams (ground track: 0394, cycle: 02) along with MSS at beam 2l's position. Data are low-pass filtered at 20 km, and the linear trend of beam 2l has been removed from all four height series. The MSS is offset for plotting. (b) a shorter segment with no MSS offset. Tracks run almost (North-South) N-S so 1° in latitude corresponds to ~110 km along track.

Where does the cross-track difference (~0.3m) come from?

(ICESat-2: track: 0394; cycle: 02; sensing time: 2019/01/23)

Space domain: surface waves

ICESat-2 SLA (MSS removed)

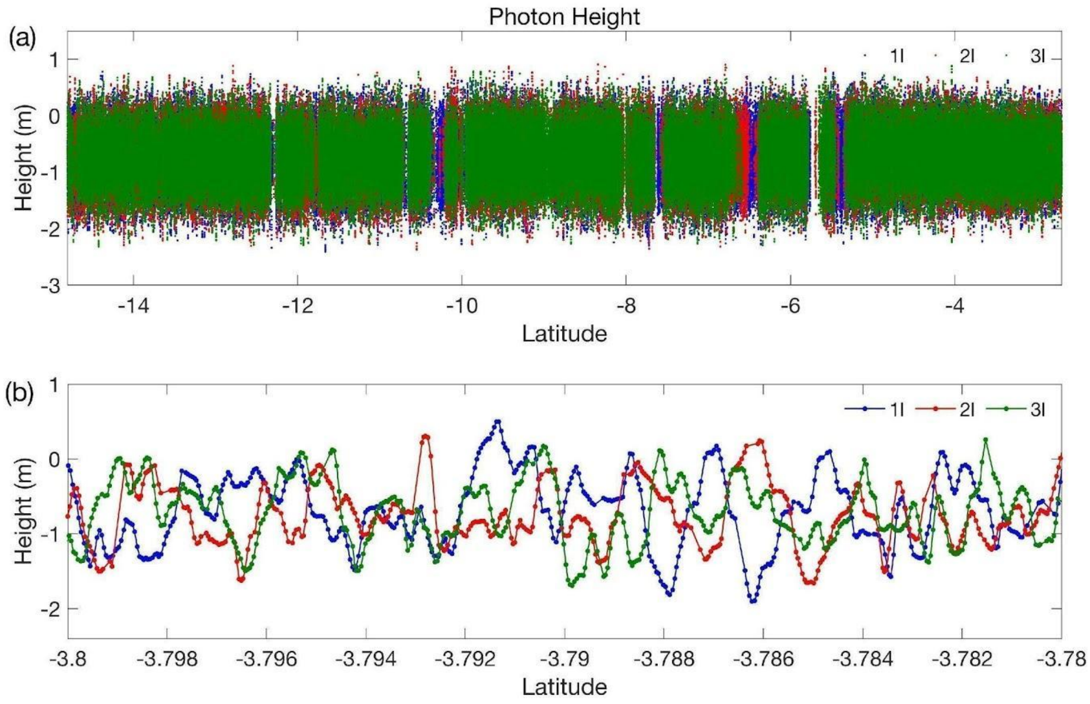
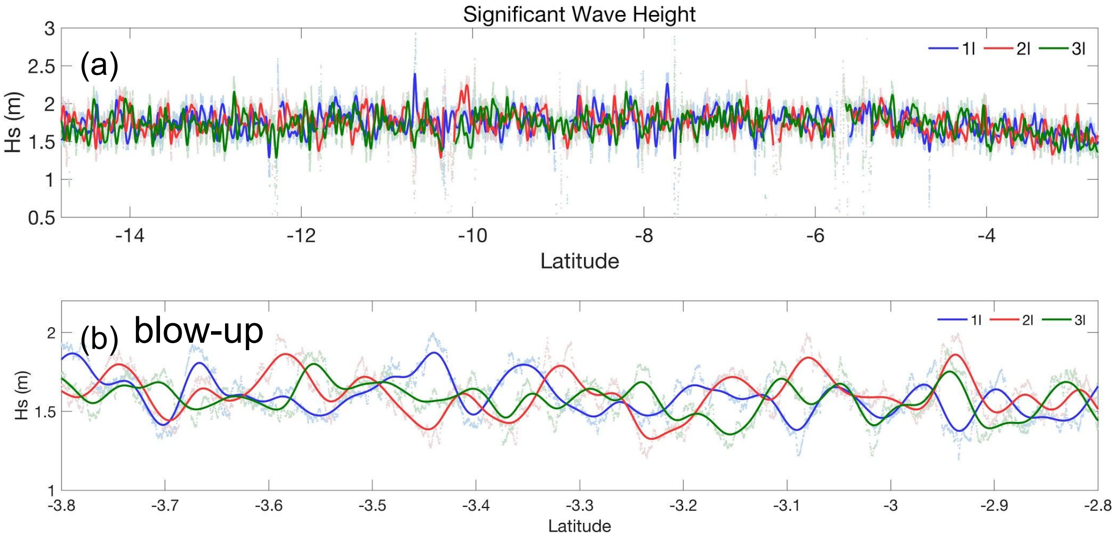


Figure 4. (a) SLA of ICESat-2 3 strong beams (ground track: 0394, cycle: 02). (b) a shorter segment of (a) showing peak to trough variations having wavelengths of a few hundreds of meters. Tracks run almost N-S so 1° corresponds to ~110 km along track and each 0.002° grid in (b) is about 200 m.

Significant Wave Height



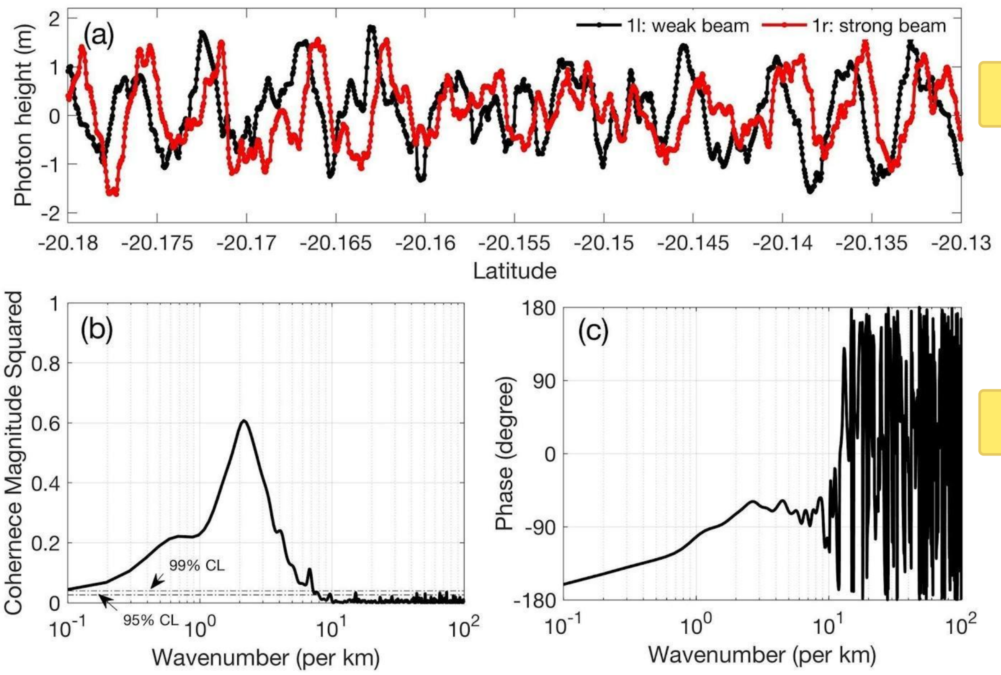
Data processing:

- Remove MSS from SSH to get SLA
- 4 × 3km-running standard deviation of SLA
- Low-pass filter at 3km

Figure 5. (a) SWH calculated from 3km-running standard deviation of SLA from ICESat-2 3 strong beams (ground track: 0394, cycle: 02). Background light dots are significant wave height before filtering and darker lines are low-pass filtered at 6 km so that they resemble the 1Hz averaged SWH in radar altimetry. (b) a shorter segment of (a). Tracks run almost N-S so 1° corresponds to ~110 km along track.

Space domain: surface waves

Dominant ocean wave reconstruction: an example



(date:2018/10/20, ground track: 0326, cycle: 01, 1l & 1r).

Observed wavelength: 465.5m
Phase shift: :-70.3 °.

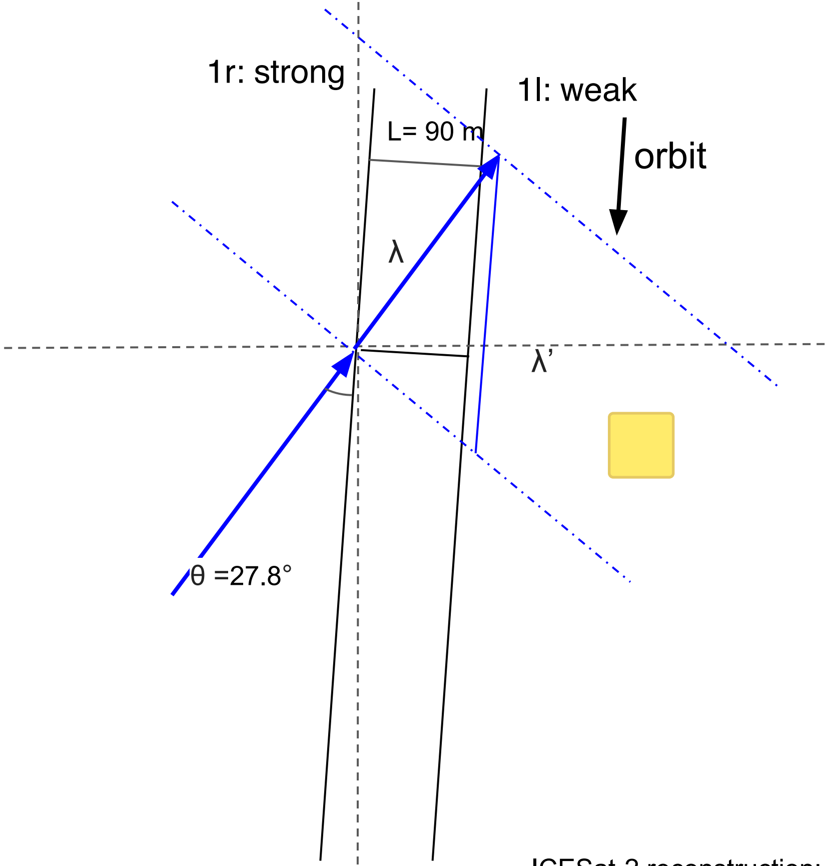
Phase shift sources:

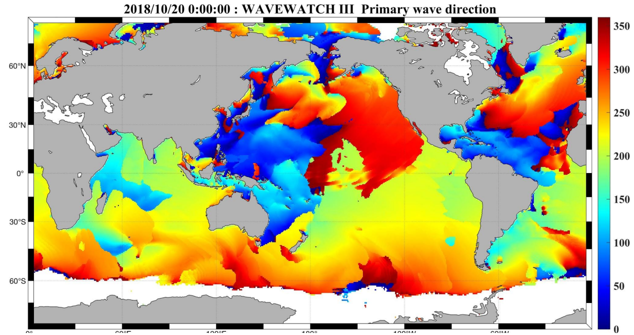
- Angle between orbit and wave
- Weak beams leads by 2.5km (error)

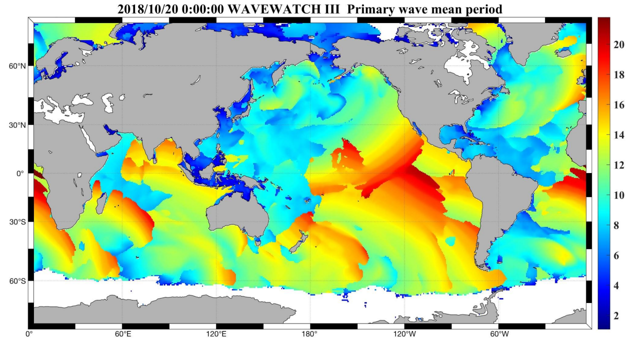
Figure 6. (a) a small segment of ICESat-2 photon height data w.r.t WGS 84. (ground track: 0326, cycle: 01). The strong and weak beams are separated by 90 m and both are low-pass filtered at 30 m. (b) Coherence and (c) phase between beams 1l and 1r. Coherence peaks around 465 m and the corresponding phase shift is -70.3°. The 95% and 99% CL are labeled.

Dominant ocean wave reconstruction: an example

i.e. 0 deg => coming from North; 90 deg => coming from East







WAVEWATCH III
Lat: -21
Lon:-138
T = 14.68 s
λ = 336 m
Direction: 209.8 °

λ' = λ/cos(θ) = 380 m
Phase shift = L*tan(θ)/λ'*360°

ICESat-2 reconstruction:

λ = 327 m
Direction: 223.3°

Space domain: surface waves

Dominant ocean wave reconstruction: result

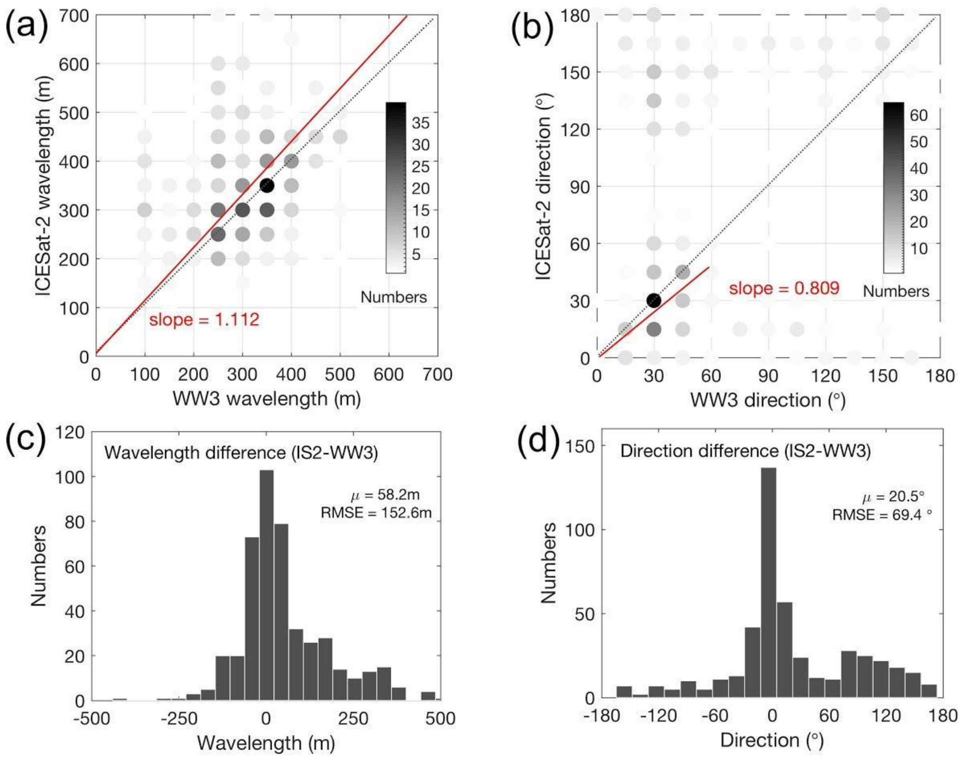


Figure 7. Joint probability histograms for wavelength (a) and wave directions (b) of WAVEWATCH III (WW3) predictions and ICESat-2 (IS2) reconstructions. The black dotted line is the 1:1 relationship and the red line is the best fitted slope. Histogram of (c) wavelength and (d) direction differences between IS2 reconstructions and WW3 predictions.

Space domain: intermediate band

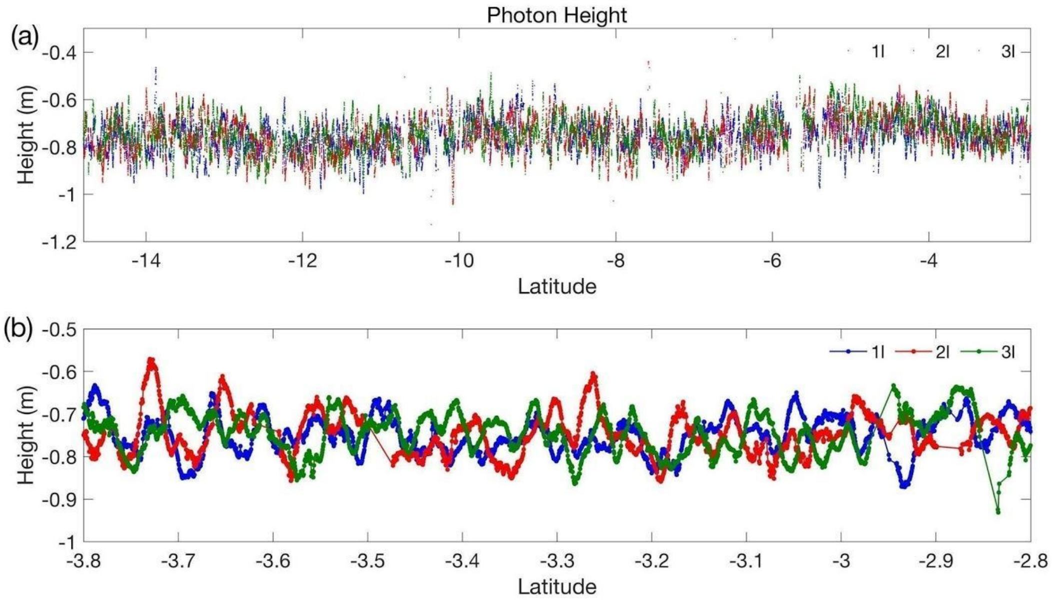


Figure 8. (a) Low-pass filtered (3 km and sampled at 50 m) SLA. Missing data were not included in the filter. (b) a shorter segment of (a). Tracks run almost N-S so 1° corresponds to ~110 km along track.

large signals (0.1-0.2 m) with wavelengths of 5-10 km: what are they?

Synthetic test using CDIP wave model

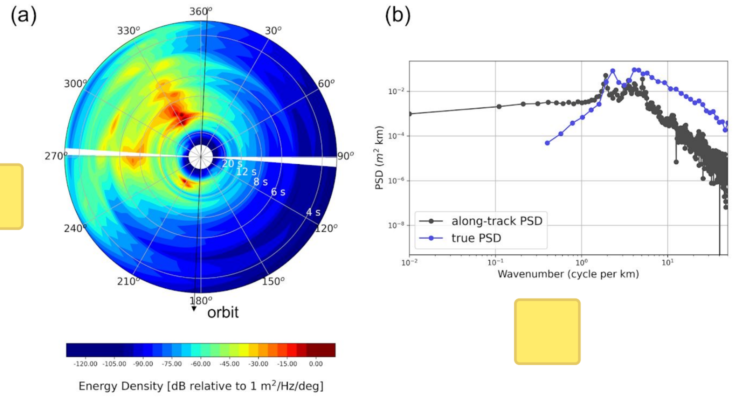


Figure 9. (a) Directional spectrum from CDIP station Point Reyes at time: 2019-09-29, 19:00 UTC. Energy density is in dB so as to show a large range of energy levels. The directional spectrum was computed using the maximum entropy method (Lygre et al., 1986). ICESat-2 orbit inclination is 92° and here we show a synthetic descending track. (b) grey: along-track PSD; blue: true PSD. Both are derived from the directional spectrum in (a).

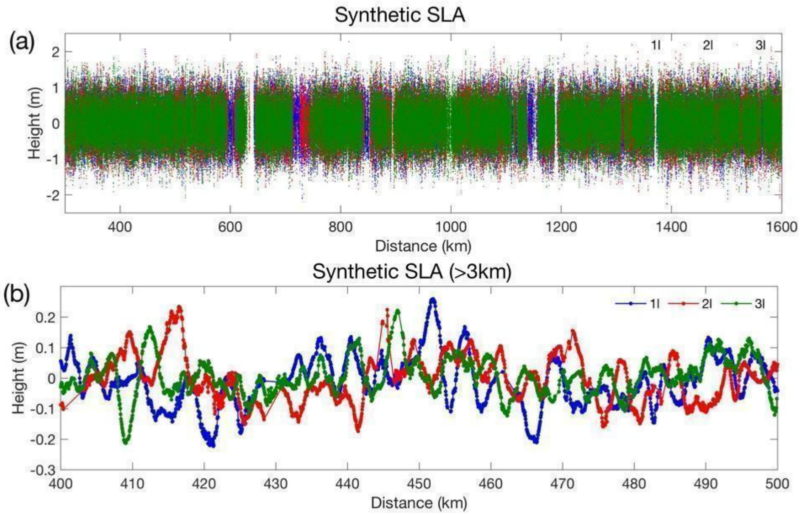


Figure 10. (a) Synthetic SLA using CDIP directional spectrum in Figure 8 (a) and the positions of ICESat-2 track (ground track: 0394, cycle: 02). The SWH is 2.8m for all three beams. (b) 3km low-pass filtered synthetic SLA for a 100-km segment.

Conclusions

- ICESat-2 will not provide major improvements to the geoid in the open ocean.
- Surface waves will be projected to longer wavelength in the 1-D sampling of ICESat-2;
- The higher than expected signals in 3-20km wavelength come from aliasing from short-wavelength surface waves.
- A pair of strong and weak beams can be used to reconstruct the dominant surface wave.

Resources :

NSIDC: https://nsidc.org/data/icesat-2/data-sets ◄- - - - - - - - - - - - - - *Download data*

Open altimetry: https://openaltimetry.org/data/icesat2/ ◄- - - - - - - - *Visualize single (file)*