

Ocean subsurface study from ICESat-2 mission

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Acknowledgments:

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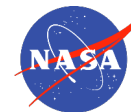
Outline

1. Framework of applying ATL03 for ocean subsurface study ([impulse response](#), [after pulses](#), [deconvolution](#))
2. Ocean phytoplankton examples ([validation/comparison](#))
3. Summary ([advantage of using ICESat-2 for ocean biology study](#))
4. Acknowledgment and References

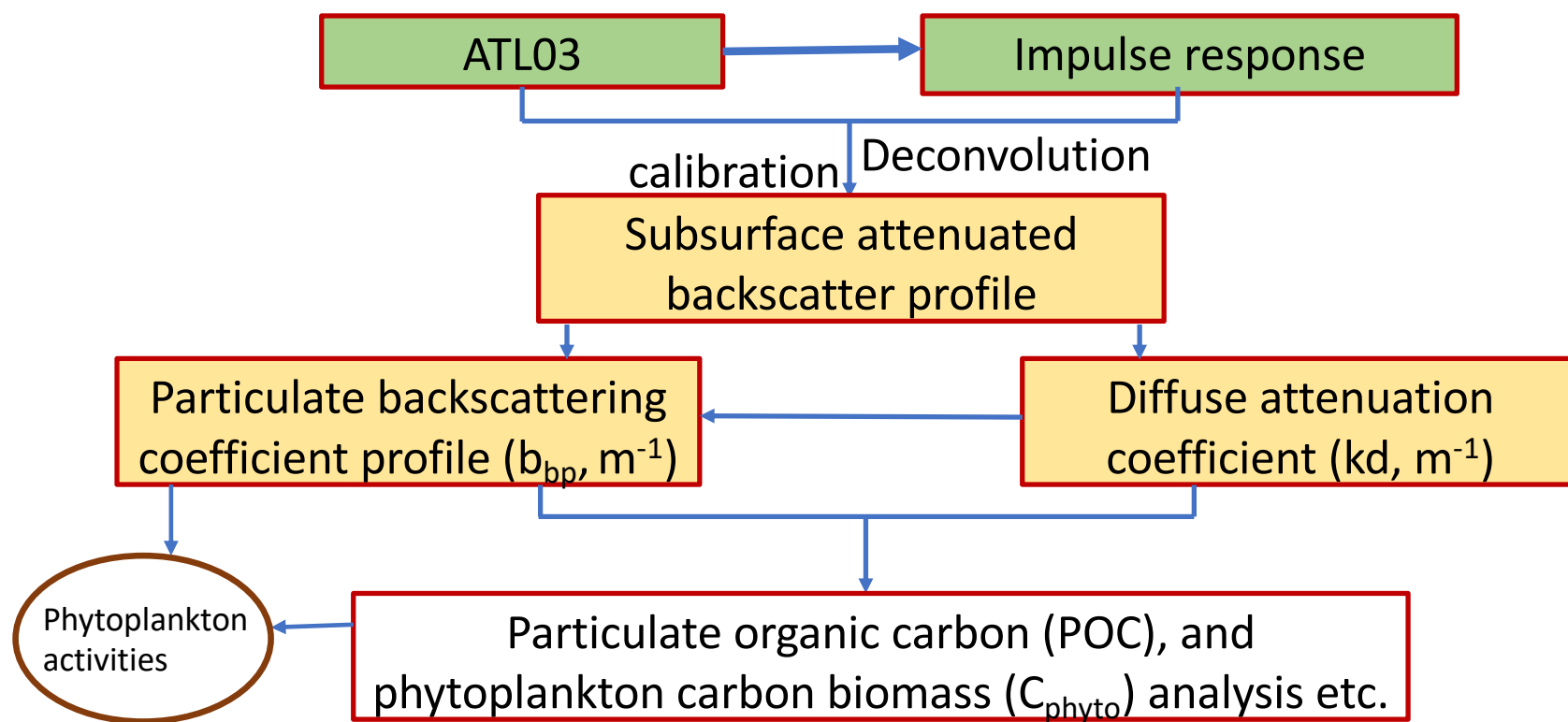


“Noise” photons are important too!

1. ICESat-2 **high, low, med and even “Noise” photons** are very useful and important!
2. ICESat-2 **impulse response**: the surface returns from **hard surface**, e.g., land surface, No subsurface return because laser at 532nm can not penetrate land surface.
3. ICESat-2 **Transient response**: the waveform of all kinds of lidar surface returns (e.g., ocean, sea ice, snow, etc.) during clear sky conditions (avoid cloud and aerosols impact).

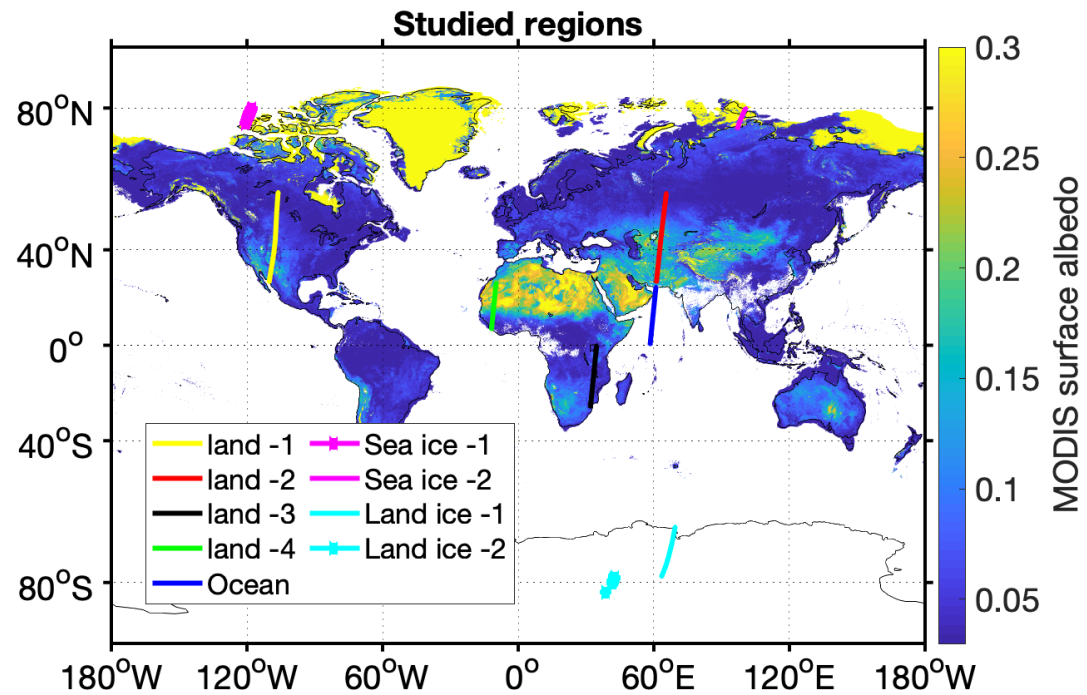


Framework of applying ATL03 for ocean study



Lu, et al. (2019, 2020, 2021a, b).

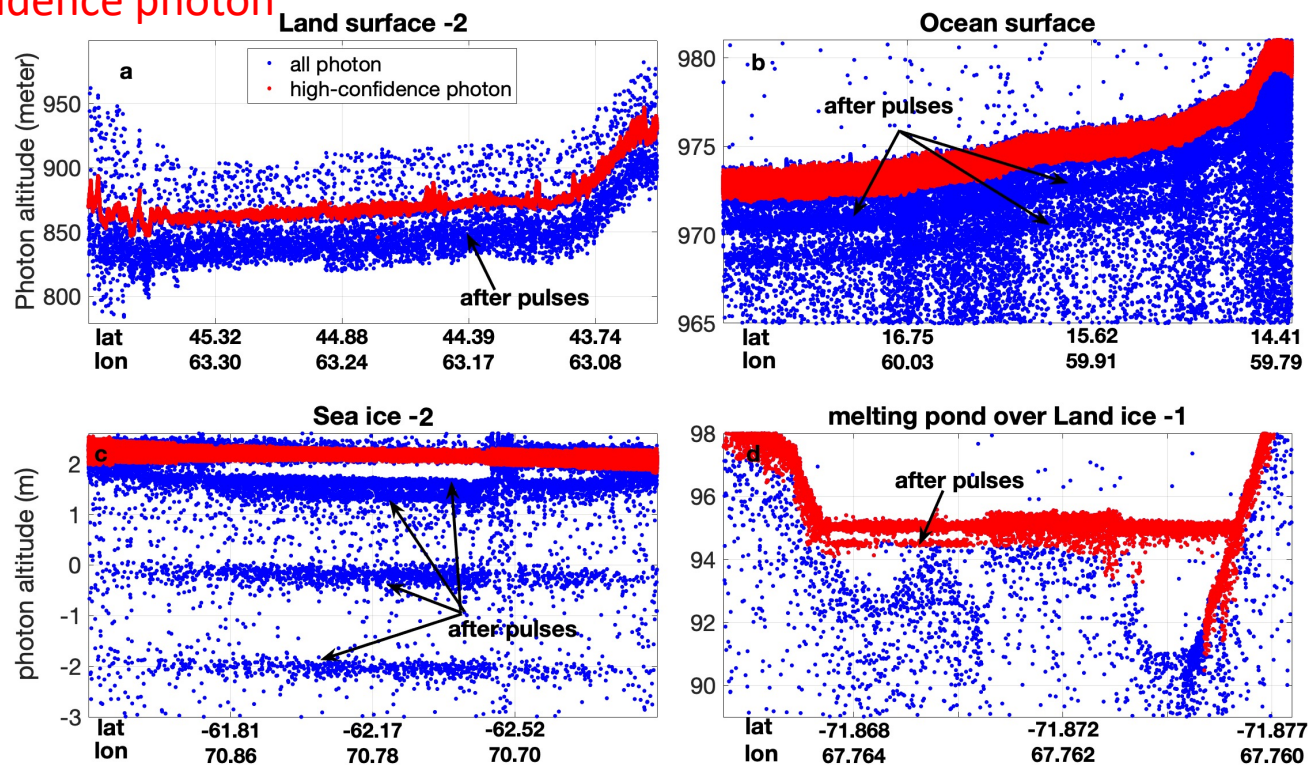
After pulsing effects – Studied regions



After pulses from different surfaces



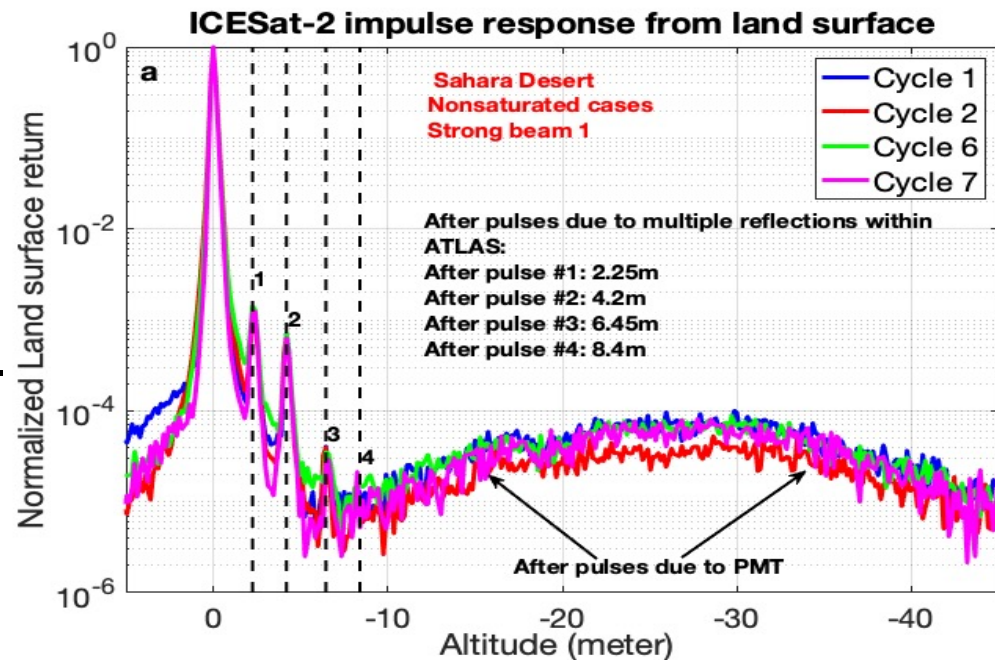
Red: high confidence photon



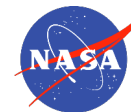
The impulse response is important



- No subsurface return.
- No solar background noise (Nighttime).
- No vegetation effect.
- No saturation effect.
(Removed saturated cases).
- No low cloud/aerosol effect
(clear sky conditions)

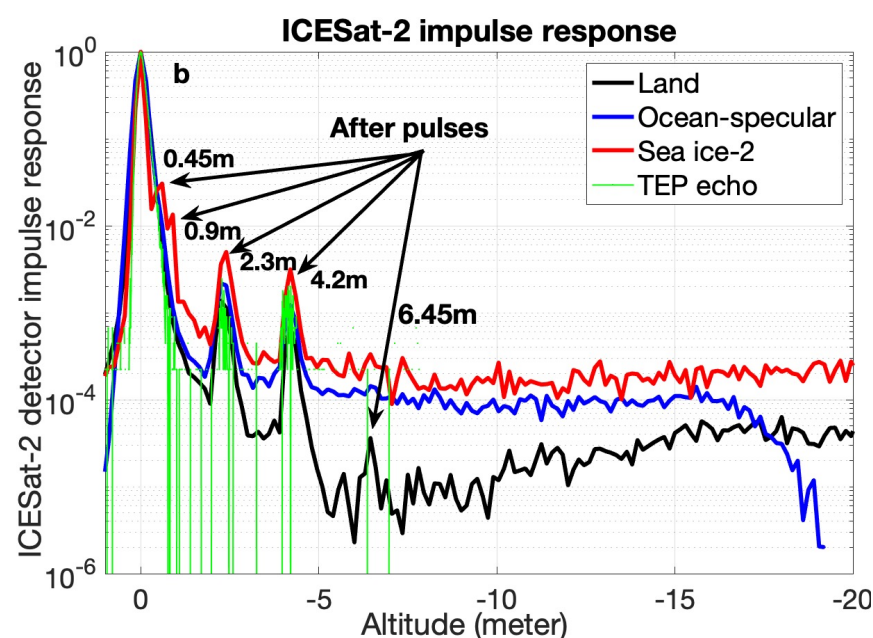
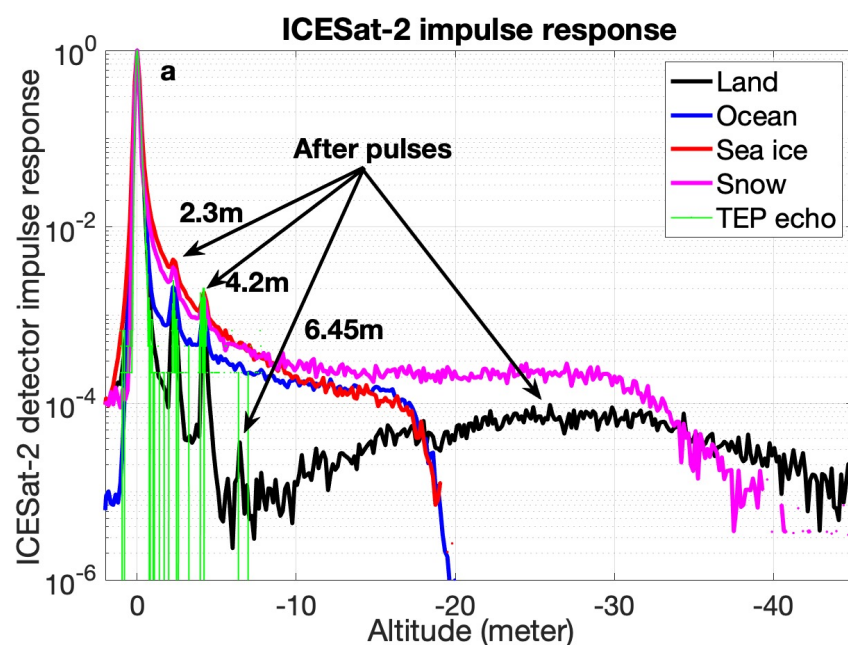


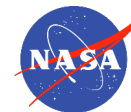
Lu, et al. (2021a)



ICESat-2 different surface returns

Different surface returns tell us: **ICESat-2 detects subsurface photons below sea ice, snow and ocean surfaces.**

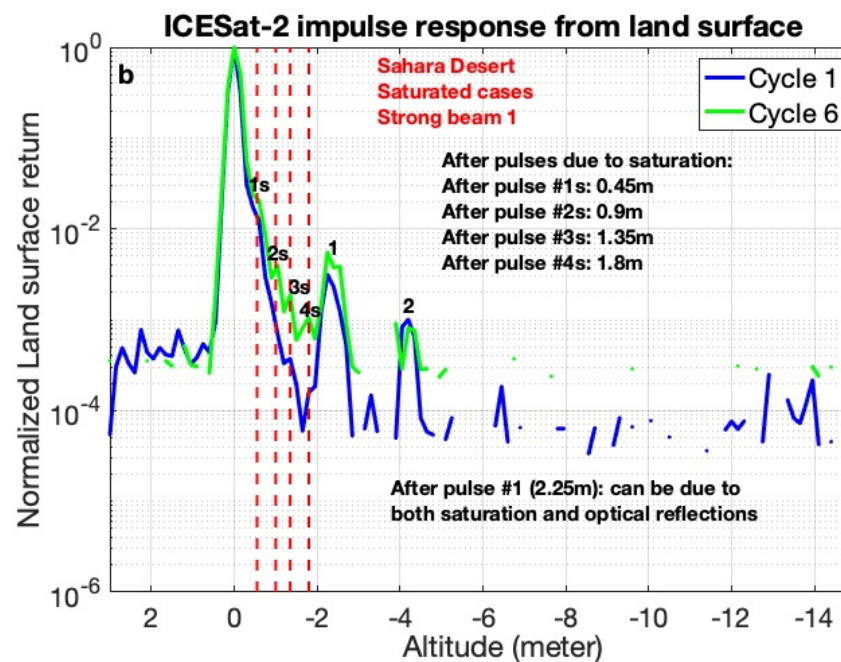




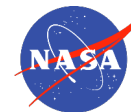
After pulses Summary

Afterpulses due to saturation

Afterpulses (AP)	Distance from primary surface to afterpulses	Ratio of afterpulse to surface	Reason
AP 1s	~ 0.45 m	~ 2×10^{-2}	PMT satur
AP 2s	~ 0.9 m	~ 4×10^{-3}	PMT satur
AP 3s	~ 1.35 m	~ 1.9×10^{-3}	PMT satur
AP 4s	~ 1.8 m	~ 1×10^{-3}	PMT satur



Lu, et al. (2021a)



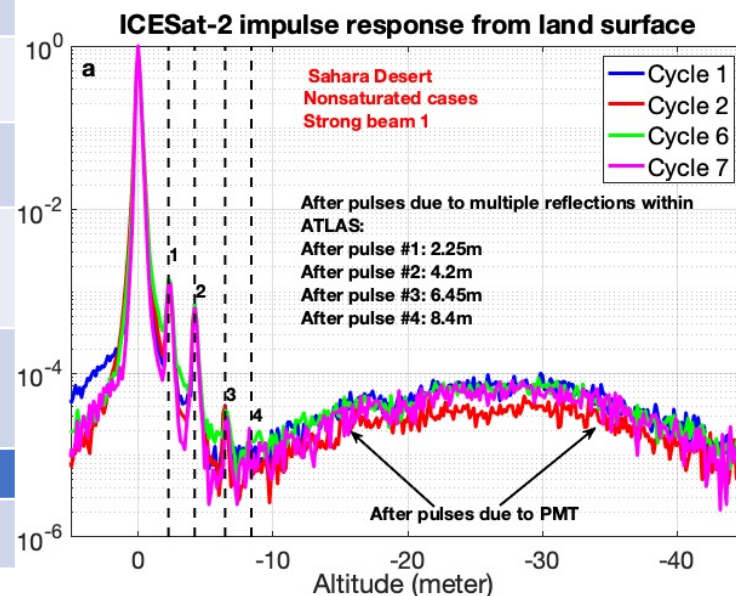
After pulses Summary

Afterpulses due to multiple reflections within ATLAS system

Afterpulses (AP) #	Distance from land surface to afterpulses	Ratio of afterpulse to surface	Reason: photons traveled extra times through the fibers due to reflections
AP 1	2.25m ($\approx$ EOPL of fiber 2)	$\sim 1.5e-3$	Photons traveled through fiber 2 a total of 3 times
AP 2	4.2m ($\approx$ EOPL of fiber 1)	$\sim 7.2e-4$	Photons traveled through fiber 1 a total of 3 times
AP 3	6.45m ($\approx$ EOPL of fiber 1 + EOPL of fiber 2)	$\sim 3e-5 - 4e-5$	Photons traveled through both fibers a total of 3 times
AP 4	8.4m ($\approx 2 \times$ EOPL of fiber 1)	$\sim 1.7e-5$	Photons traveled through fiber 1 a total of 5 times.

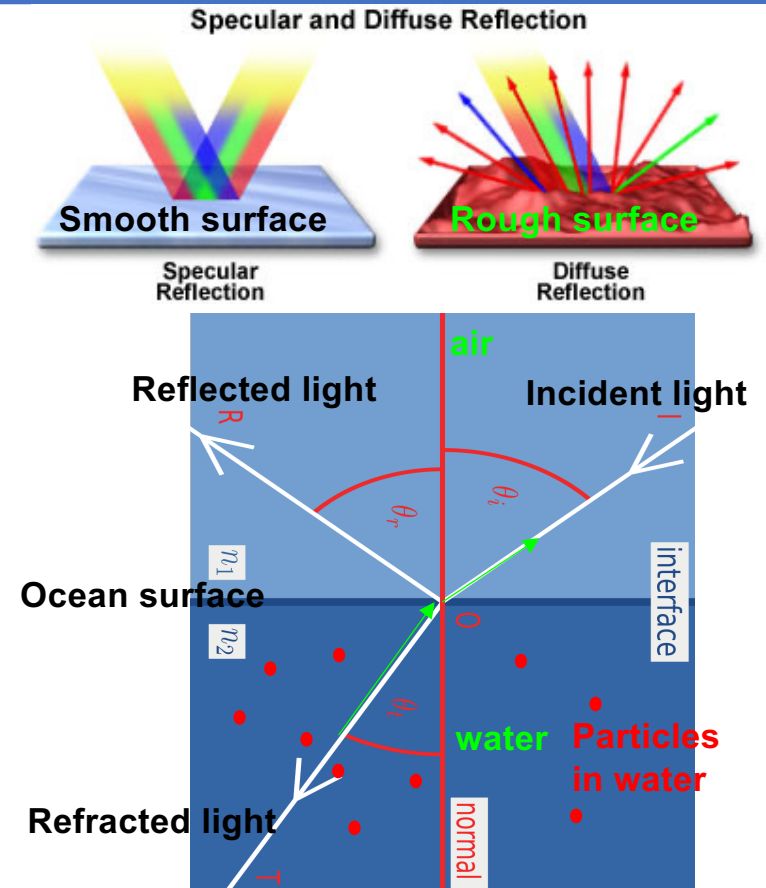
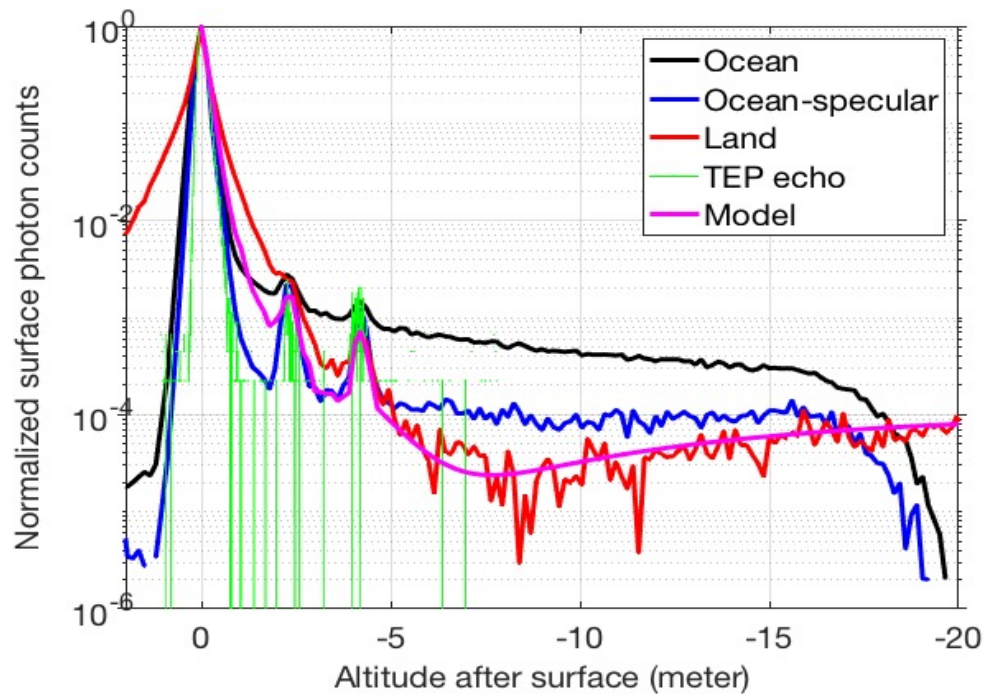
Afterpulses caused by PMT ionization effects

AP	$\sim 10 - 45$ m	$\sim 1.3e-5 - 1e-4$	Caused by PMT ionization effects
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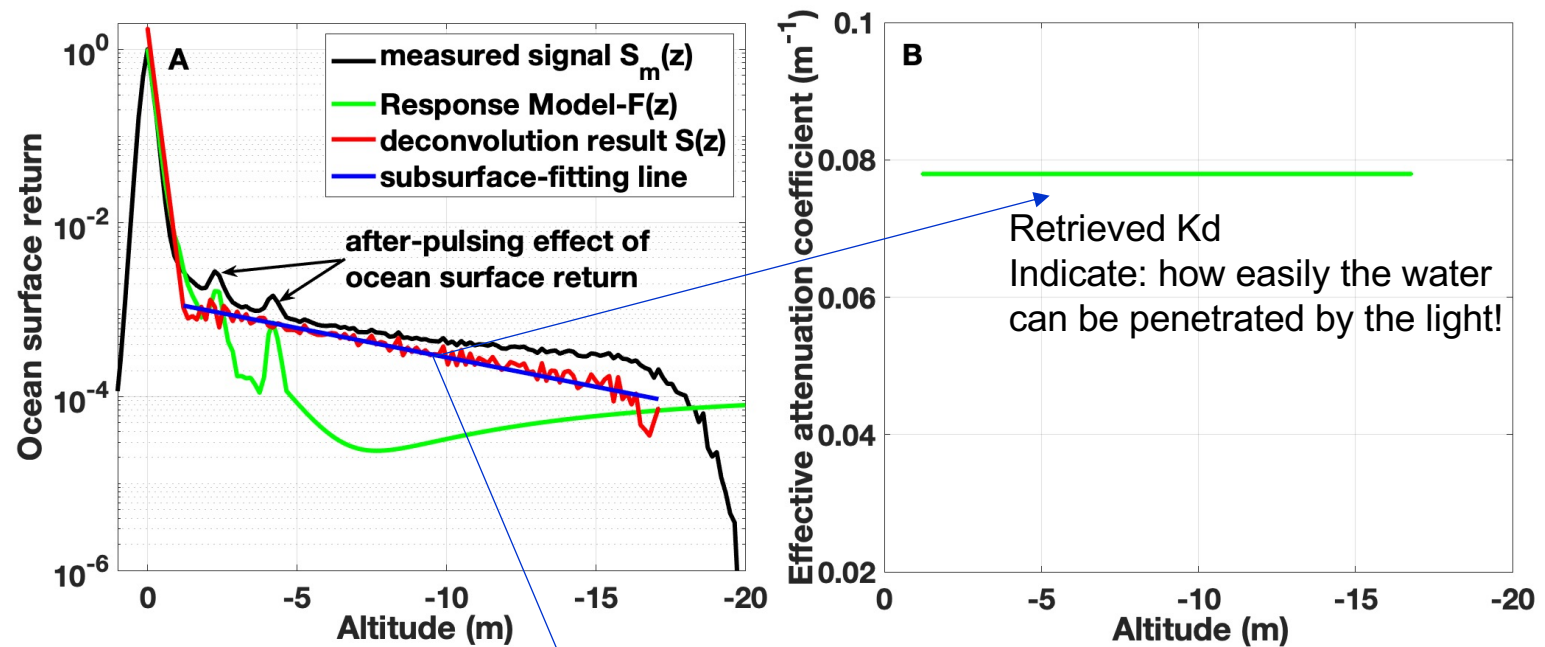


Lu, et al. (2021a)

Ocean subsurface profiles

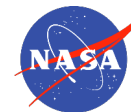


Ocean subsurface profiles

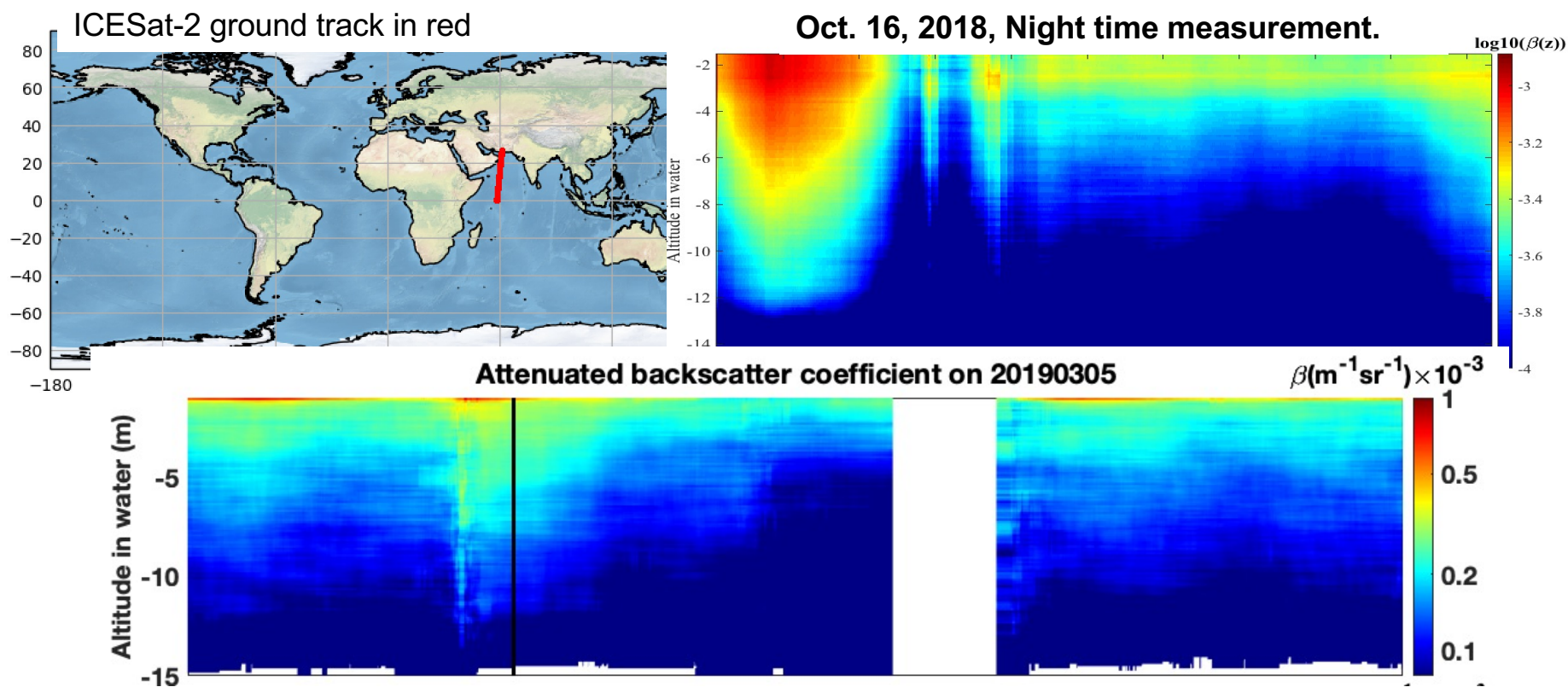


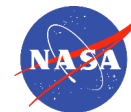
The subsurface profile indicate how fast the light attenuated through the water.

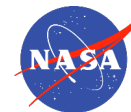
Lu, et al. (2020, 2021a)



Calibrated Ocean subsurface profiles

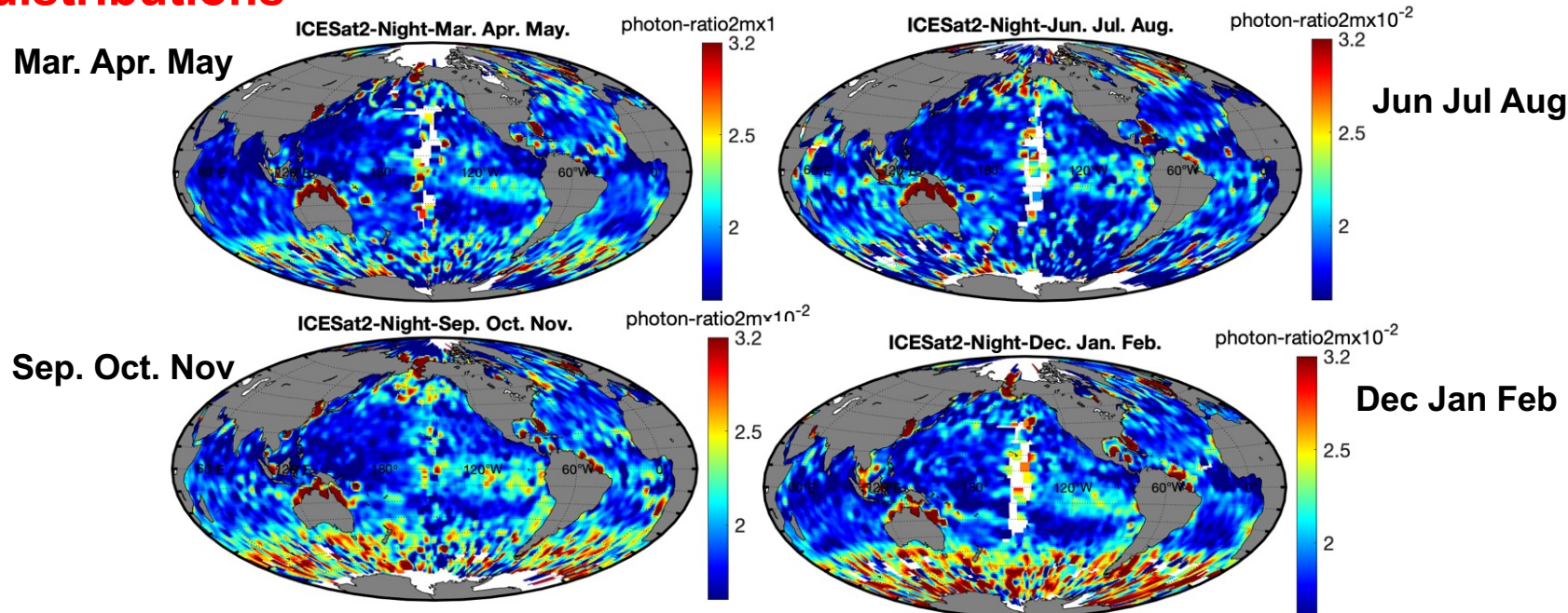




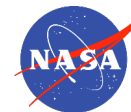


ICESat-2 global ocean subsurface photons

Subsurface photons directly indicates global phytoplankton distributions



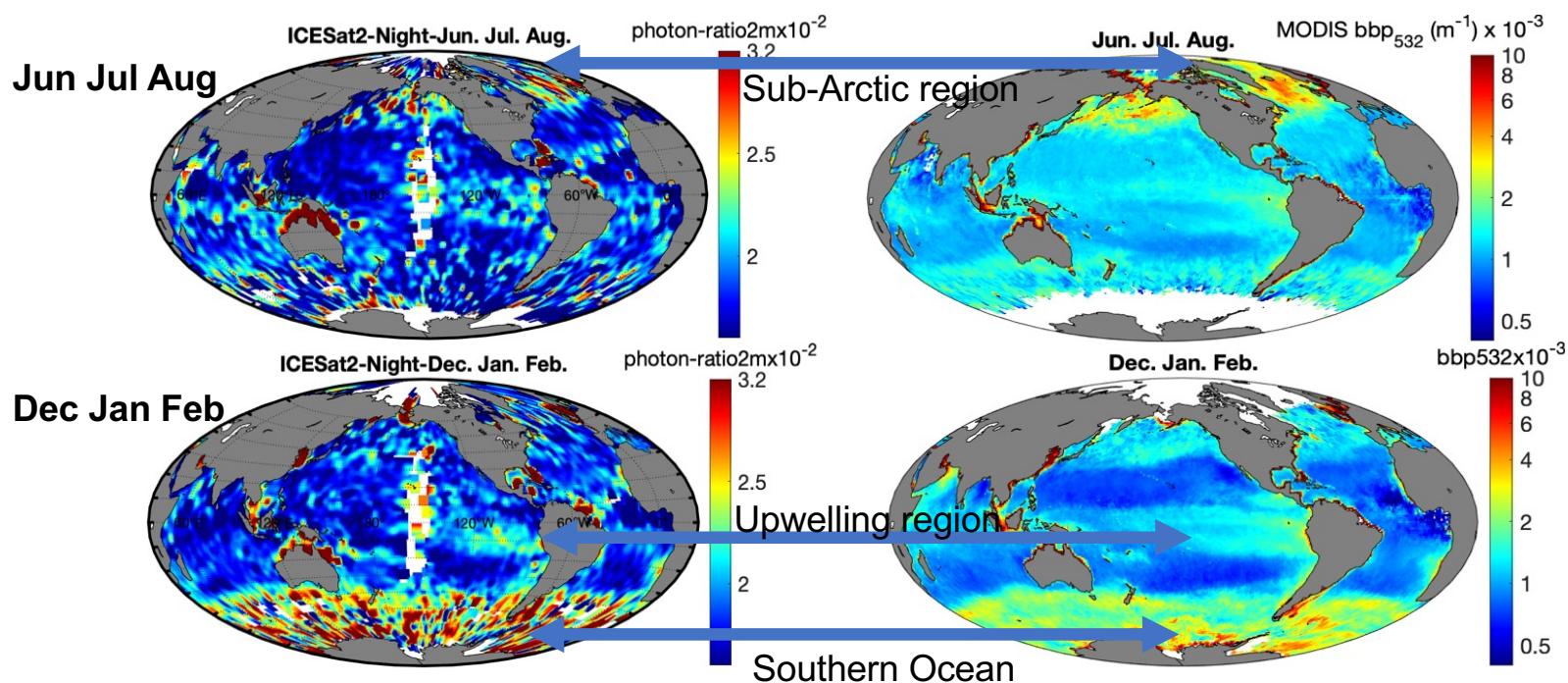
Paper in preparation



Photons indicate ocean biology

ATL03 subsurface photon

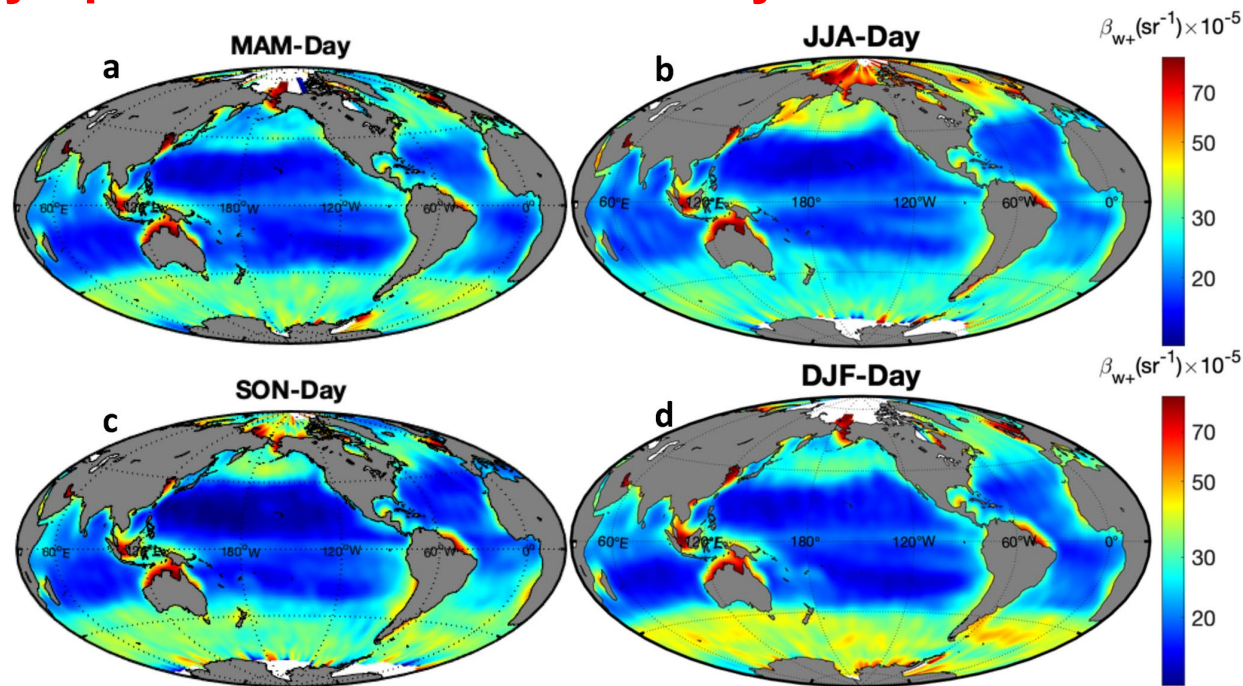
MODIS ocean color results



Global Ocean biology – seasonal distribution



Global phytoplankton distributions - Daytime



Lu, et al. (2021b)

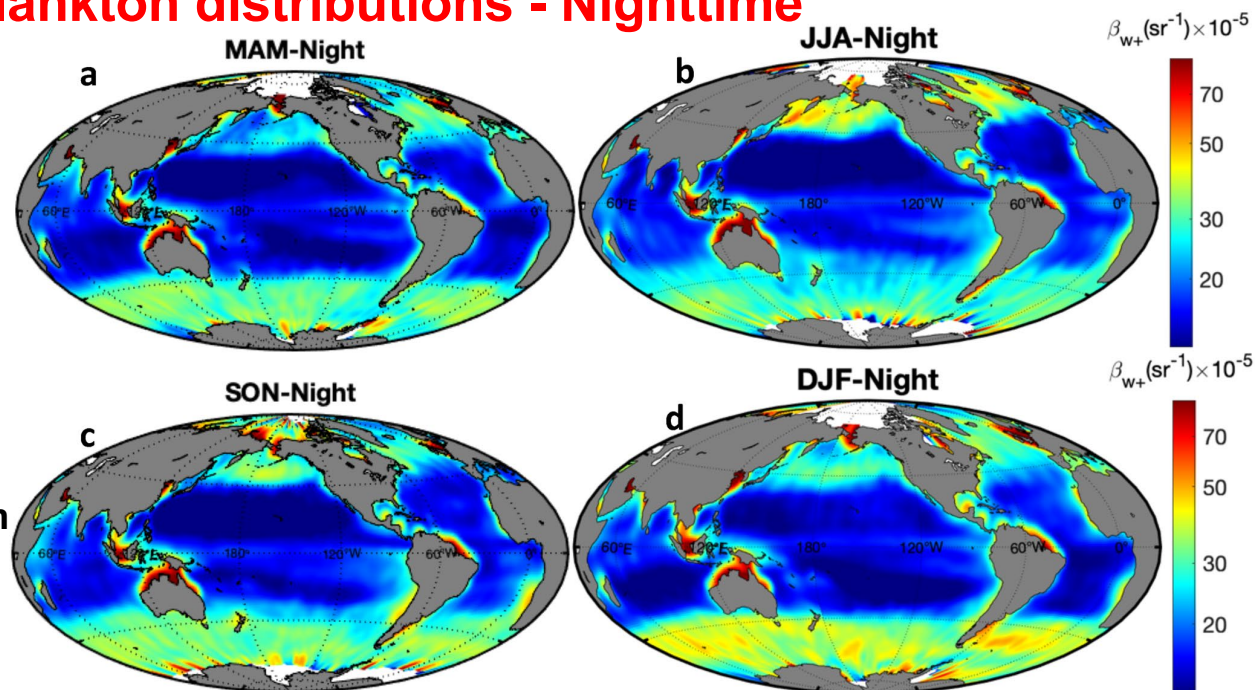
Global Ocean biology – seasonal distribution



Global phytoplankton distributions - Nighttime

Nighttime ocean biology distribution are not available from passive ocean color remote sensing (e.g., MODIS ocean color product)

Nighttime ocean biology distribution are only available from Space lidars: CALIOP and ICESat-2



Lu, et al. (2021b)



Summary

Advantage by combining ICESat-2/CALIOP Space lidar measurements

- **Space lidars provides both day and night global ocean biology observations, including measurements underneath aerosols and non-opaque clouds, measurements in polar regions during all seasons .**
- **Vertical distributions are not available from the traditional passive ocean color records (MODIS, CALIOP) in the upper 30m ocean.**



Summary

Great science can be done with ICESat-2/CALIOP lidar results

- Global phytoplankton seasonal and annual climatology.
- Cryosphere – Ocean biology – Cloud interaction.
- The impact of ocean biology on ice-albedo feedback.
- Sea ice vertical structure and light transmittance through sea ice.
- Estimate how much of SW radiation penetrating into the ocean through sea ice.

Acknowledgments



Tom Neumann

Anthony Martino

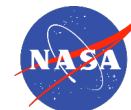
Christopher Field

For their help on ICESat-2 after pulses



References

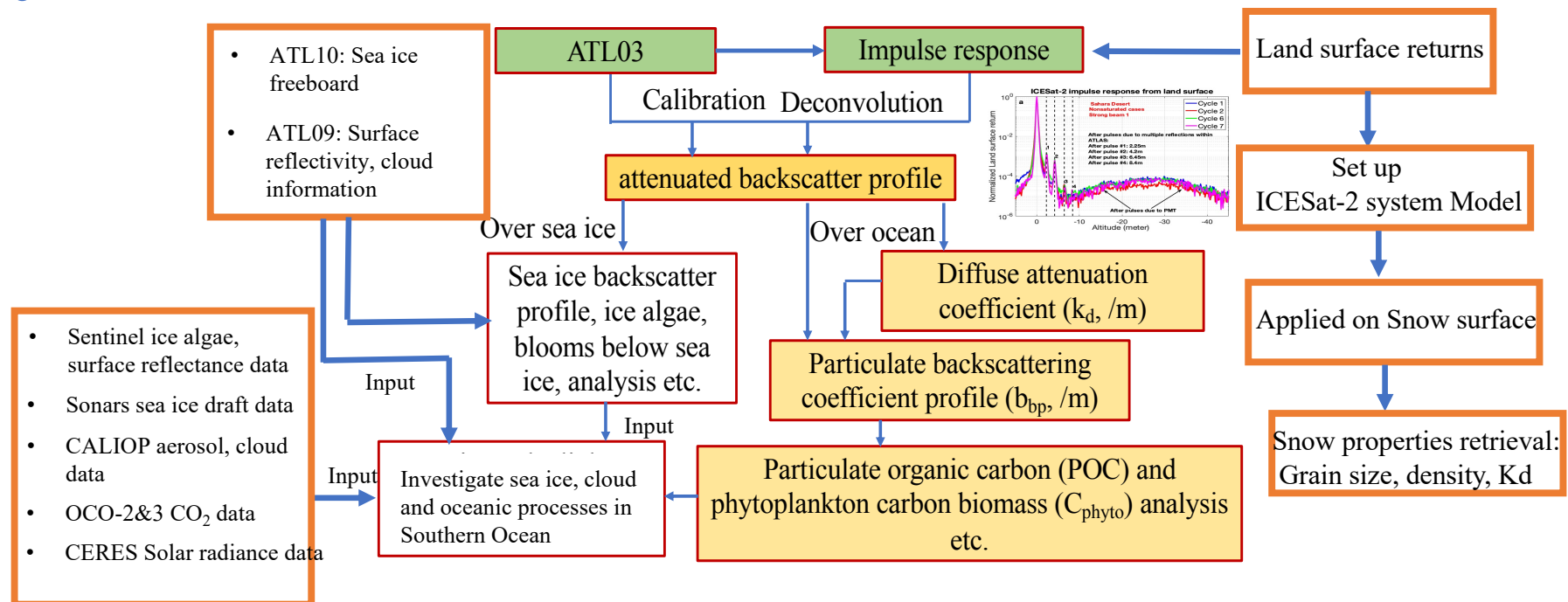
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- Lu, et al. (2019). Ocean subsurface study from ICESat-2 mission. In 2019 Photonics & Electromagnetics Research Symposium–Fall (PIERS–Fall) (pp. 910–918). <https://doi.org/10.1109/PIERS-Fall48861.2019.9021802>



PMT Transient Response

- Possible candidates for the cause of the transient response are:
 - PMT afterpulsing (ionization of residual gas). This effect is well documented in the literature for photon counting applications. The time scale of the effect is dependent on PMT voltage, gas species, and PMT internal geometry.
 - Signal induced noise...

ICESat-2 work



- Lu, et al. (2021a), "Enabling value added scientific applications of ICESat-2 data with effective removal of afterpulses", Earth and Space Science, Accepted.
- Lu, et al. (2021b). 'New ocean subsurface optical properties from space lidars: CALIOP/CALIPSO and ATLAS/ICESat-2', Earth and Space Science, under-review, <https://www.essoar.org/doi/10.1002/essoar.10507064.1>