Swell detection from fully-focused SAR altimetry data

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OSTST 2022 · 31 October – 4 November 2022, Venice

First I would like to acknowledge the contribution of the co-authors to this work which is also part of my PhD project

Outline

Introduction

Method

Results

Summary

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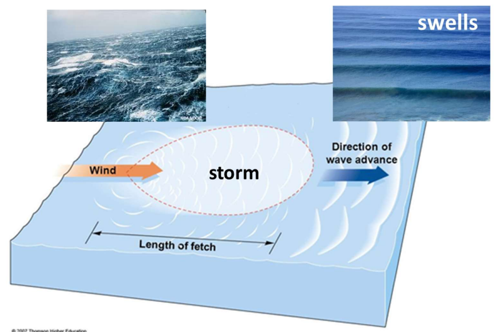
- A short introduction about ocean waves and how they are imaged by a Synthetic Aperture Radar (SAR) instrument
- Method description: how to compute a two-dimensional modulation spectrum using fully-focused SAR altimetry data
- First results - comparison with buoy measurements
- Summary with the key messages

Swell detection from fully-focused SAR altimetry data

long crested waves generated by storms in deep water but can propagate up to coasts

https://www.surfertoday.com/surfing/

How do ocean waves develop?



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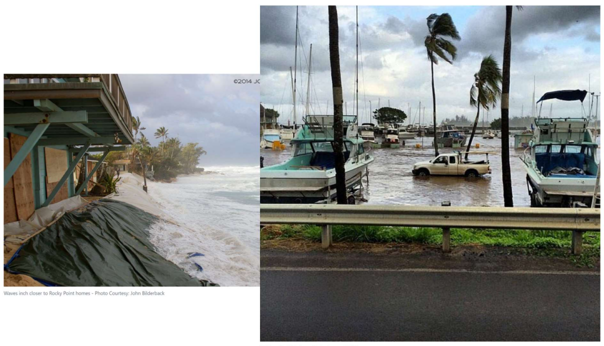
Swell detection from fully-focused SAR altimetry data

What's the importance of monitoring swells?

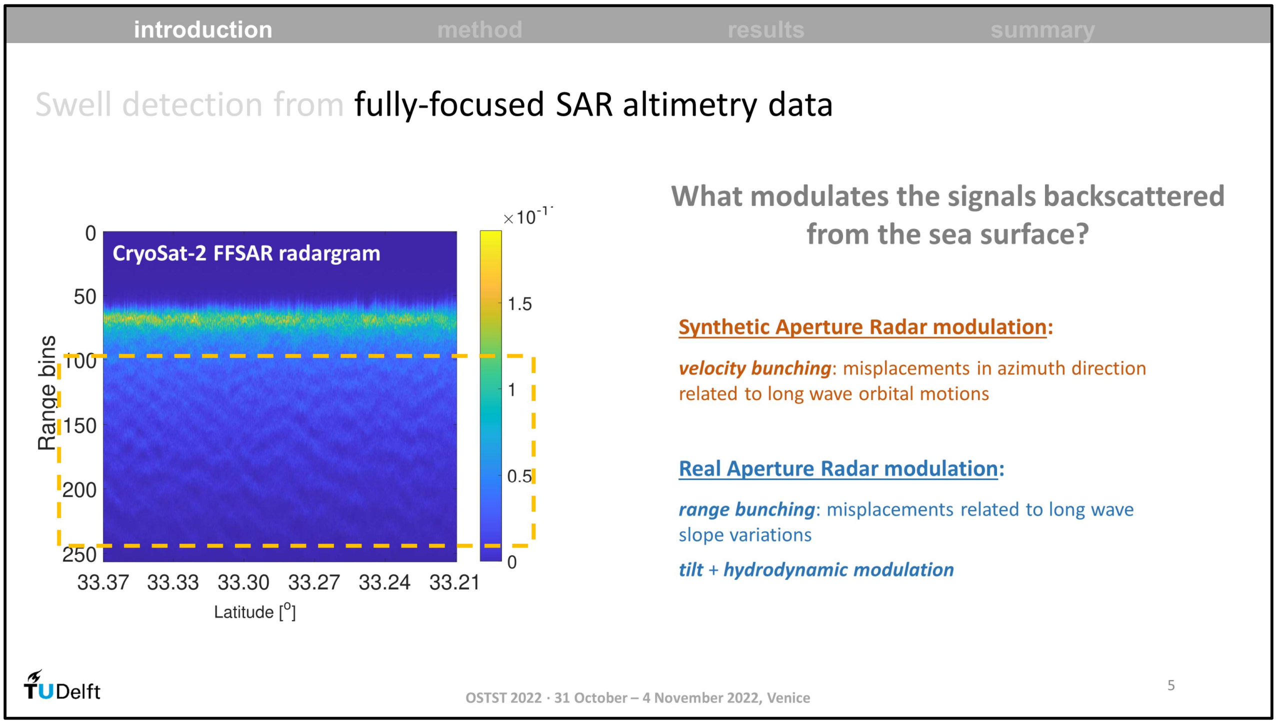


long propagation distance → important reference for storm disaster prediction and marine safety

How do we monitor swells?

- ✓ Wave models
- ✓ In-situ measurements
- ✓ Satellites (Sentinel-1, CFOSAT, GF-3)

Swells can affect operations at open sea and remote shores. Because of their long propagation distance and fast propagation speed, they are an important reference for storm disaster prediction and marine safety.

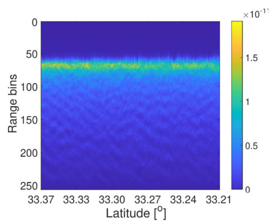


In the left side of this slide, you see a fully-focused SAR (FFSAR) radargram representing power variations over time. We have confirmed the presence of swells using buoy derived ocean wave spectra from the NOAA NDBC network. Focusing on the tail of the waveforms (yellow dashed box), we can see how the SAR altimeter images the long ocean waves. Recent studies have reported that there are characteristic undulations in the trailing edge of the waveforms where swells occur.

In the right side of this slide the main imaging mechanisms for a SAR system are described. For near-nadir looking systems, such as SAR altimeters, it has been reported that both velocity and range bunching mechanisms dominate. The Real Aperture Radar (RAR) modulation is known to be dominant for cross-track propagating waves while the SAR modulation for along-track propagating waves.

2D SAR altimetry spectrum

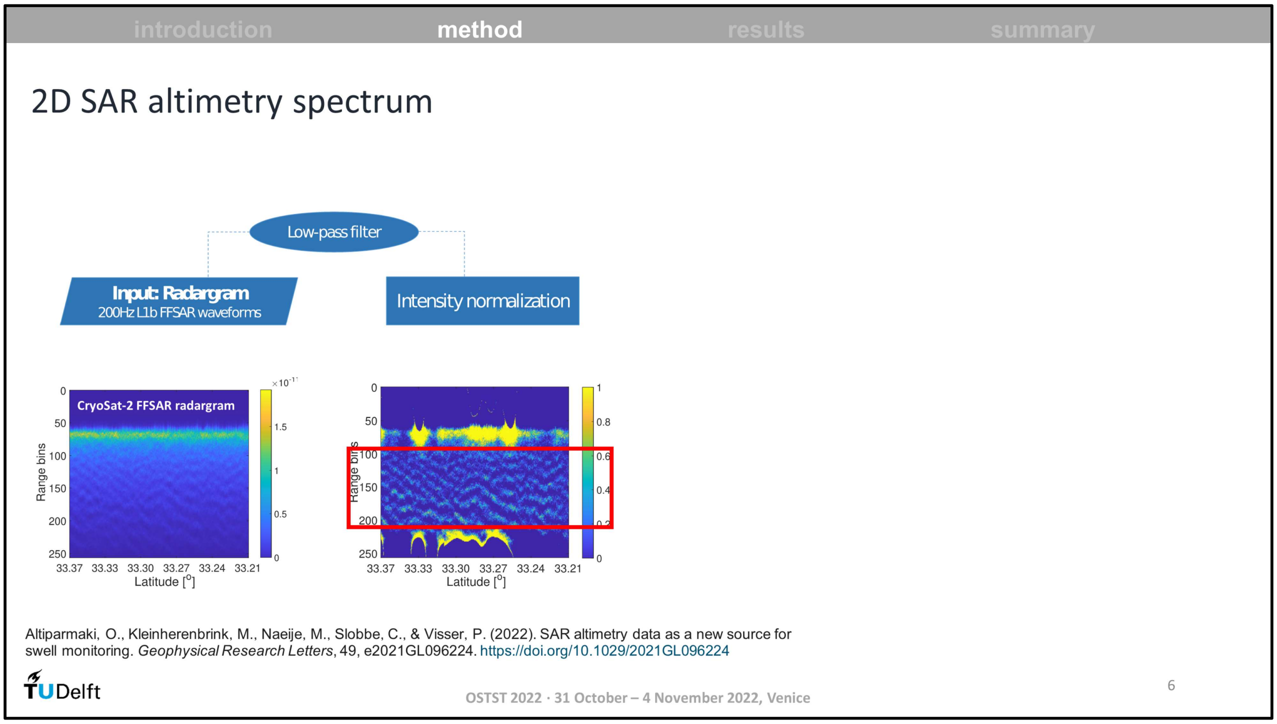
Input: Radargram
200Hz L1b FFSAR waveforms



Altiparmaki, O., Kleinherenbrink, M., Naeije, M., Slobbe, C., & Visser, P. (2022). SAR altimetry data as a new source for swell monitoring. *Geophysical Research Letters*, 49, e2021GL096224. https://doi.org/10.1029/2021GL096224

Let’s see how we can compute a two-dimensional spectrum from SAR altimetry. This method can be used for all SAR altimeters that are currently in orbit (Sentinel-3A/B, Sentinel-6 and CryoSat-2; here we use CryoSat-2 data).

Input: L1b fully-focused SAR waveforms. For this analysis, we use multilooked waveforms with an along-track spacing of approximately 35m.



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Step 1: Normalize the waveforms to get the backscatter contrast:

1a. Apply a low-pass filter in along-track direction

1b. Retrack the waveforms

1c. Fit a polynomial model of degree 4 to the tail of each waveforms, including all bins between 4 km and 7 km across track (for CryoSat-2)

1d. Normalize the waveforms using the ratio of the high-to-low backscatter variations

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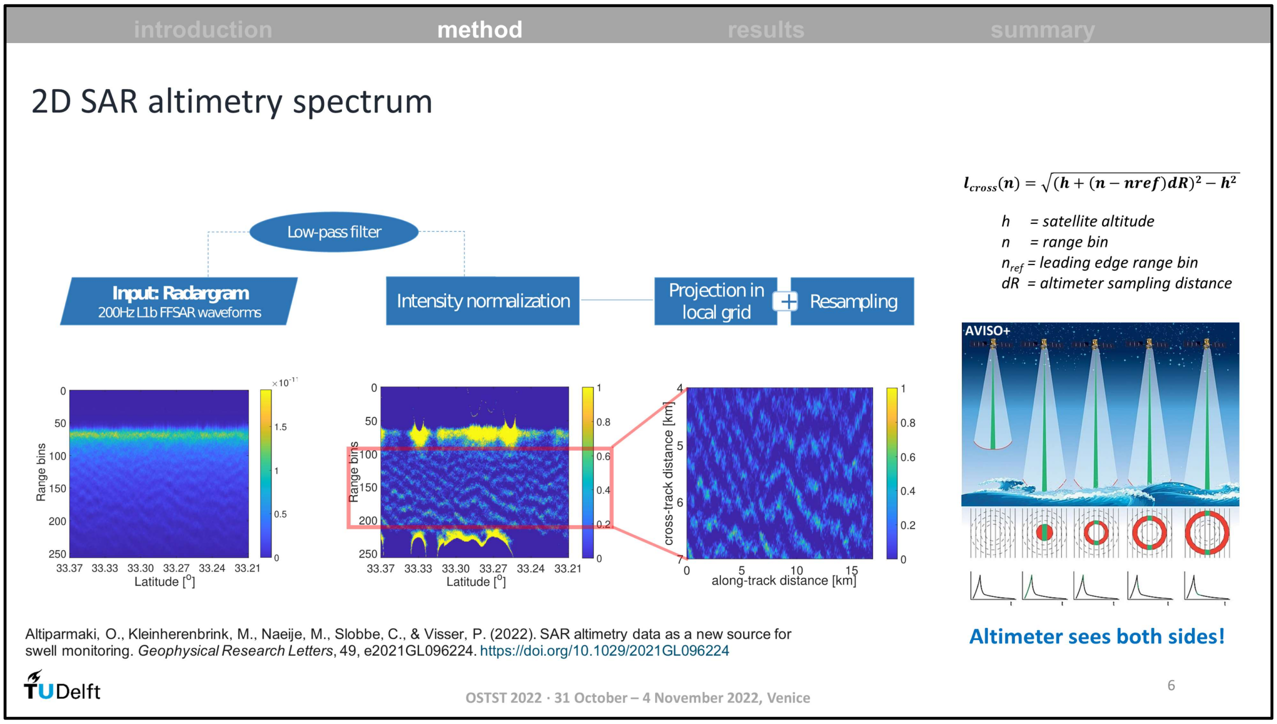

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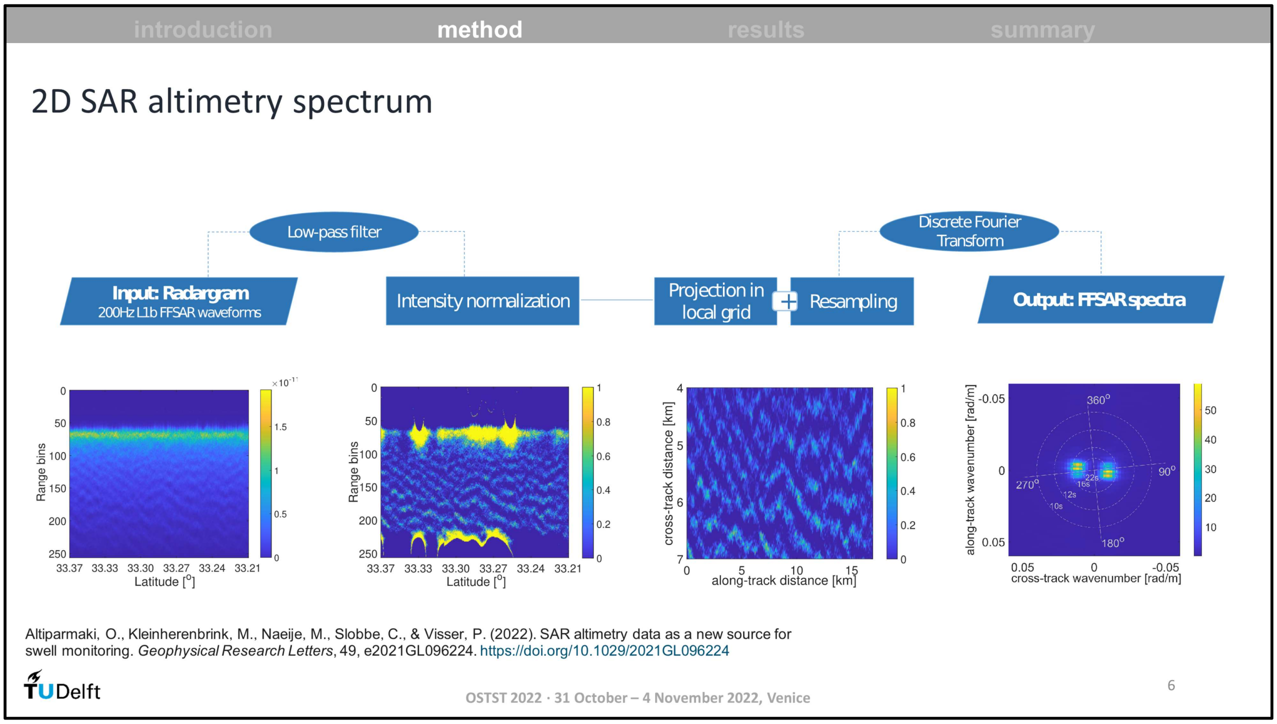
Step 2: Ground projection:

2a. Relate each range bin to a unique cross-track location by projecting them as a function of cross-track distance $l_{cross}(n)$. To do so, we assume that all backscatters are received from one side. As shown in the illustration in the right side, the waveform is sampled considering signals coming from both left and right sides in the trailing edge.

2b. Resample to get an equally spaced grid



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Step 3: Use Fourier Transform to compute the two-dimensional (modulation or FFSAR) spectrum that represents the distribution of the returned power at different frequencies and directions.

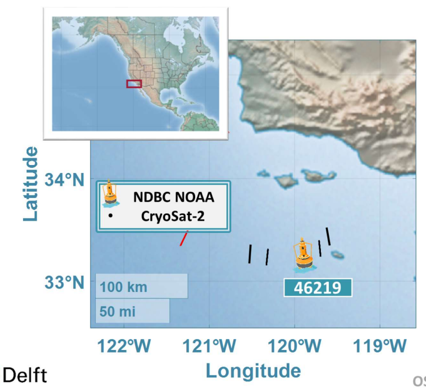
introduction method **results** summary

Case study: CryoSat-2

Data: L1b products acquired by the ESA G-POD service

Processing configuration: 200Hz multilook posting rate

Study area: Channel Islands of California



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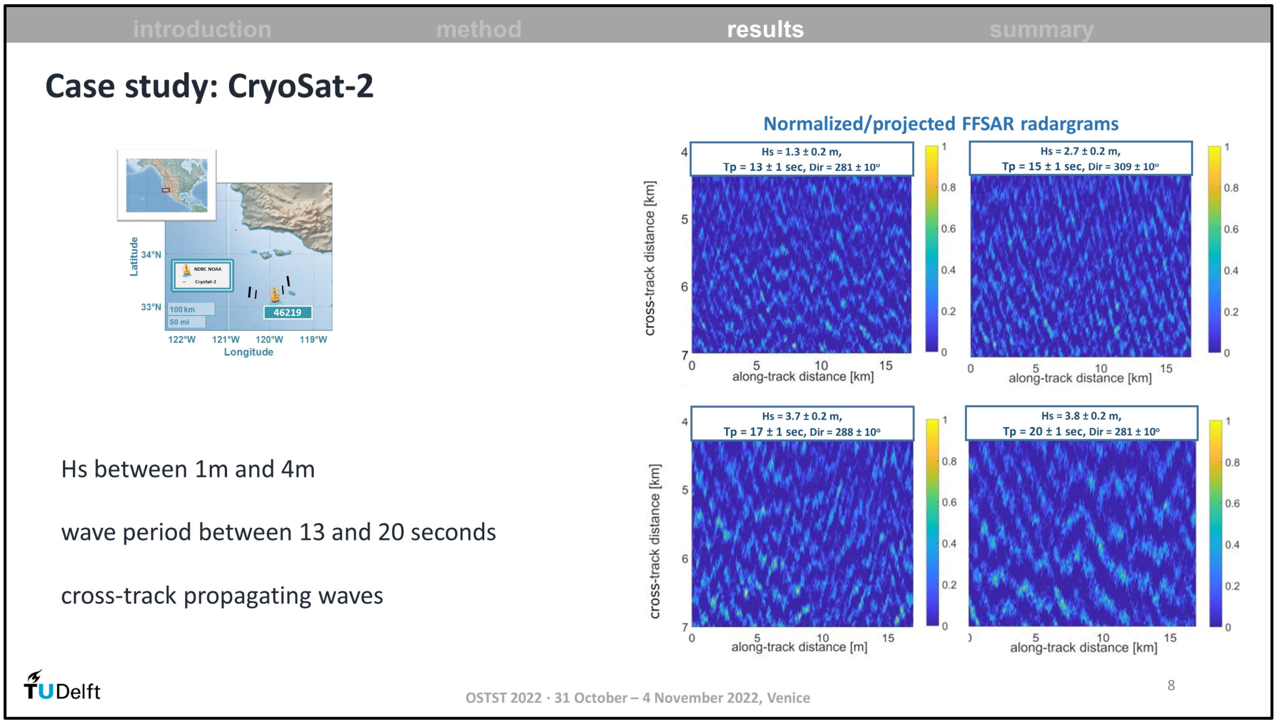
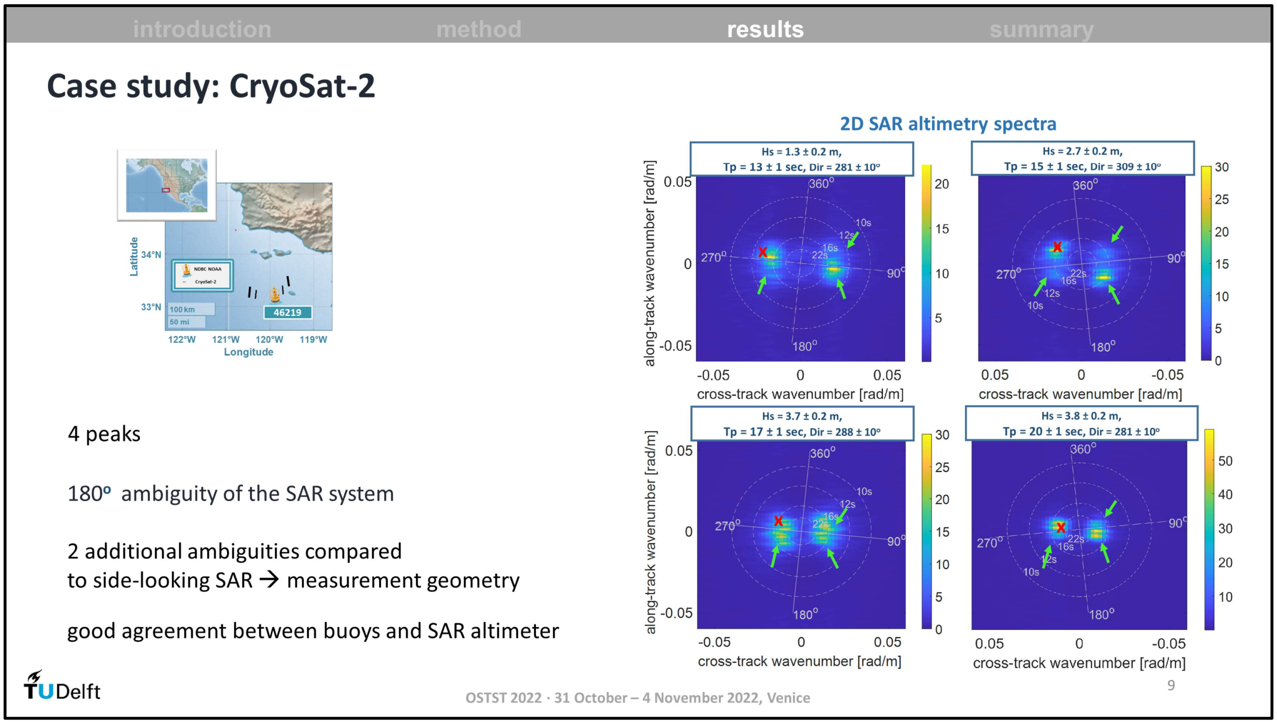
We focus on the North Pacific zone where swells dominate throughout the year and their presence can be verified by NOAA buoys. CryoSat-2 data are used for this analysis.



Four different acquisitions representing different wave conditions are shown here. The wavy patterns vary with different wave conditions: Hs (significant wave height) represents both wind waves and swells.



The corresponding SAR spectra are shown in this slide. The red crosses represent the position where maximum wave energy is expected based on the wave directional spectrum (NOAA-NDBC).

- Four peaks are observed in the modulation spectrum, two of the same order of magnitude and two weaker for at least three of the four cases.

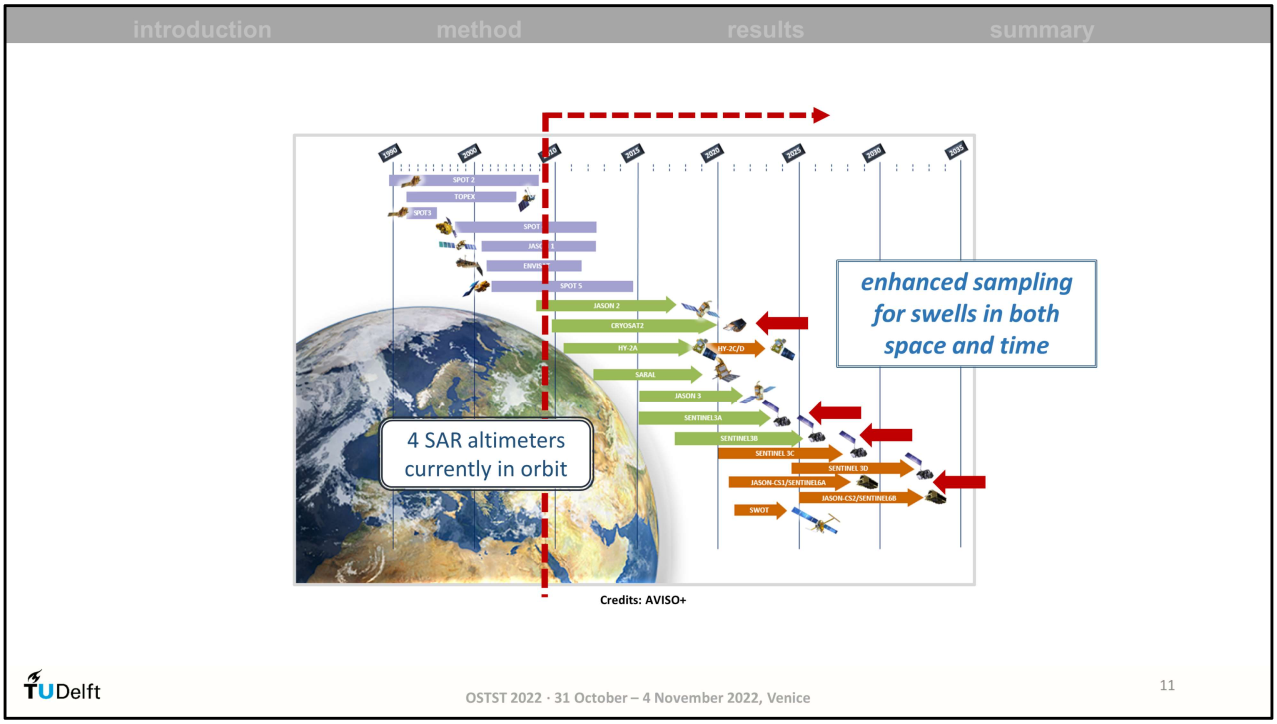
- One 180◦ ambiguity is already known from the SAR side-looking system (Sentinel-1).

- The two additional ambiguities, compared to a SAR side-looking system, are due to the left-right folded projected backscatter signals, which is a result of the measurement geometry as in the projection step (2) we make the assumption that all signals come from one side. The varying magnitude of those peaks reveals a difference of the spectral responses from signal coming from left and right side.

- To invert from a SAR spectrum into an ocean wave spectrum we need the modulation transfer functions to describe properly all the effects that modulate the backscattered signal.

Key messages

- We propose a method to compute a two-dimensional SAR altimetry spectrum: it can be applied to all SAR altimeters currently in orbit (CryoSat-2, Sentinel-3A/B and Sentinel-6A)
- Main spectral responses are related to the long wave orbital motions and the measurement geometry
- The first results show a good agreement between buoys and SAR altimetry data: potential for future estimation of the wave directional spectrum



SAR altimeters show potential to significantly enrich the existing swell wave data sources but also to be used complementary with other satellite instruments (such as CFOSAT and Sentinel-1) for a wide range of applications (such as marine safety, ocean wave forecasting).

Are you interested in more details?

You can find them in our recently published article:
Altiparmaki, O., Kleinherenbrink, M., Naeije, M., Slobbe, C., & Visser, P. (2022). SAR altimetry data as a new source for swell monitoring. Geophysical Research Letters, 49, e2021GL096224. https://doi.org/10.1029/2021GL096224

…. or please ask me any questions online or contact me by email (given on the bottom left side of this slide) in case you have any comments/feedback.

Thank you very much in advance ☺