Satellite Observations of the Ocean Surface

Swell in the open ocean derived from SAR

Alli Ho

06-04-2019

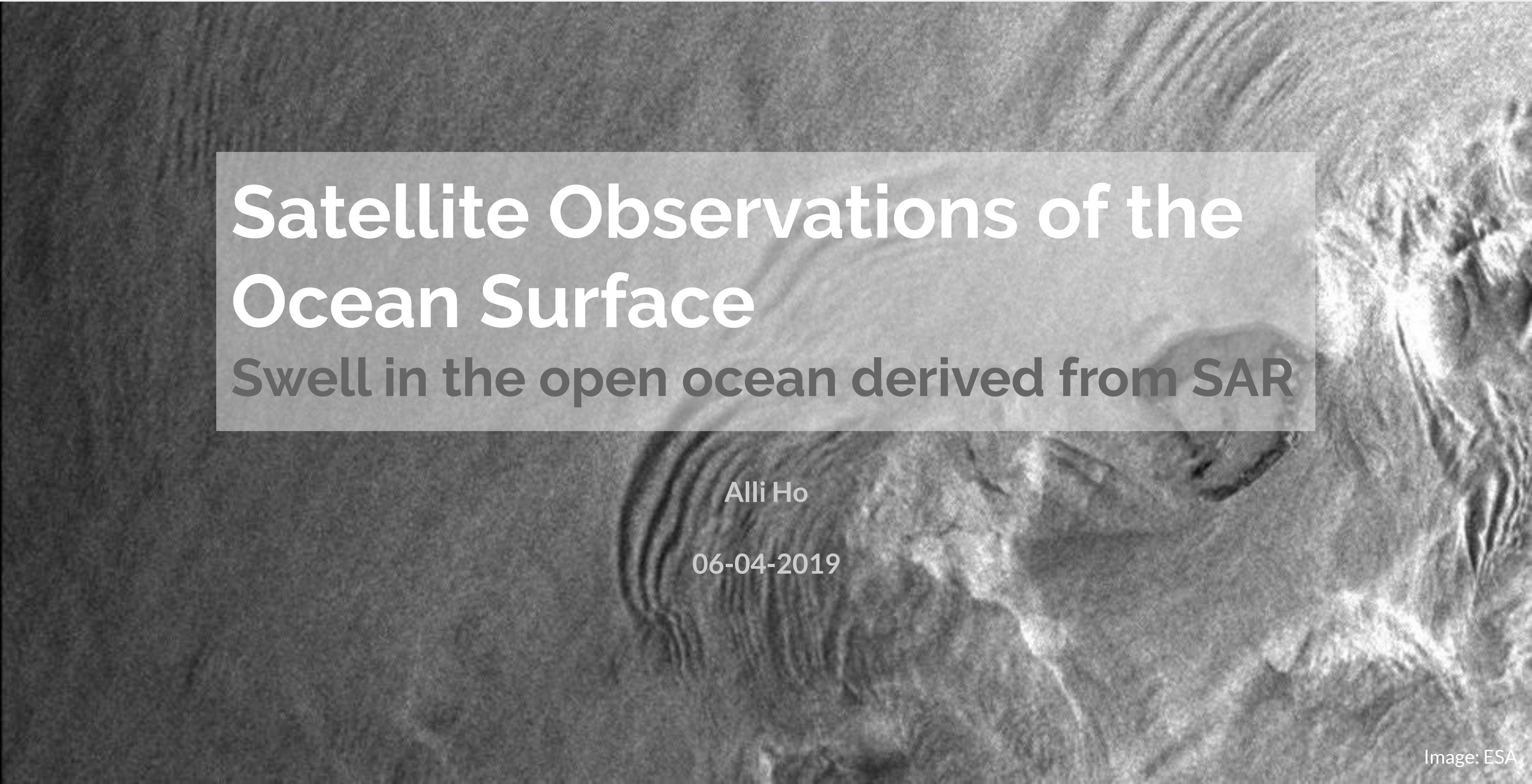

Image: ESA

OUTLINE

1. Ocean wave field
2. Scatterometry, relationship between wind and backscatter
3. SAR as it applies to ocean waves
4. Using Sentinel-1 SAR in wave mode to compare satellite obvs with in-situ measurements (CDIP)
5. Swell dissipation and tracking

KEY POINT | Wind is the primary mechanism of wave growth. Wind transfers momentum from the atmosphere into the ocean, and creates waves which act to increase the roughness of the ocean surface. Surface waves have periods from 5-20 seconds

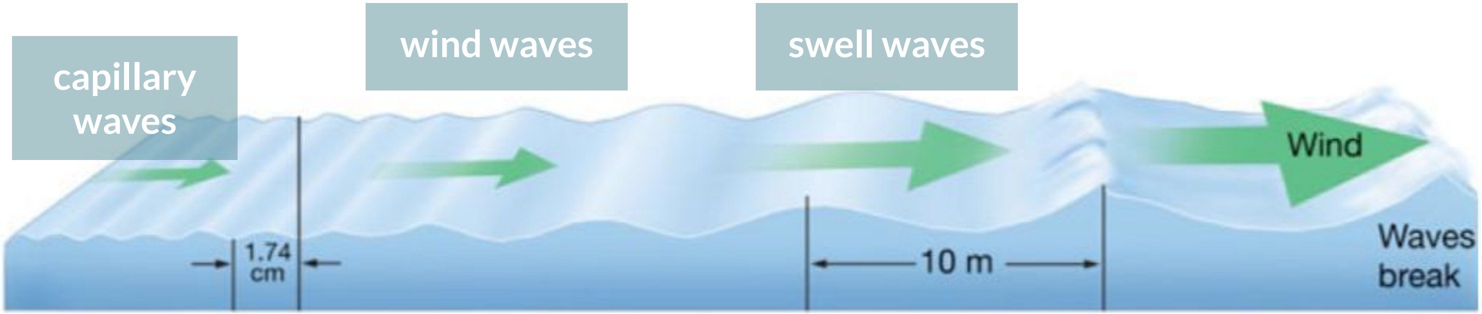

Image credit: Pearson Prentice Hall Inc (2008)
Video credit: Sophia Merrifield

KEY POINT | A sea state is a superposition of capillary waves, wind waves, swell waves, and breaking waves.

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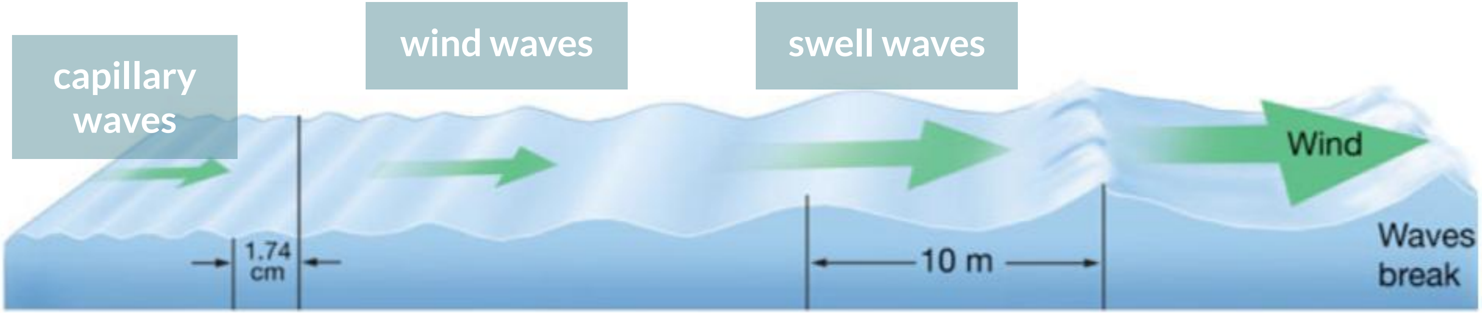

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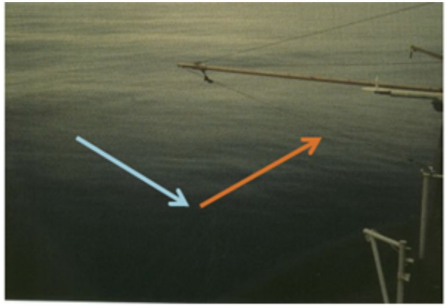
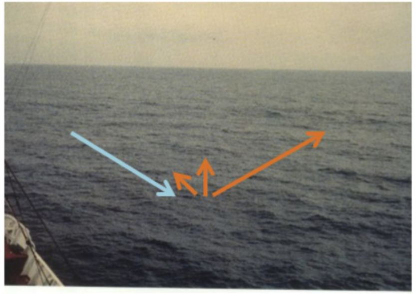
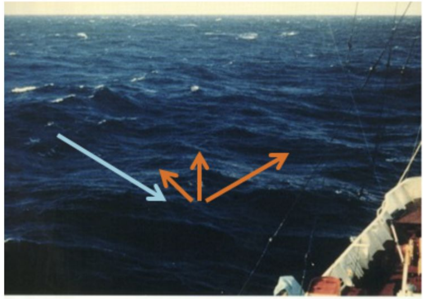
BACKGROUND | ocean waves



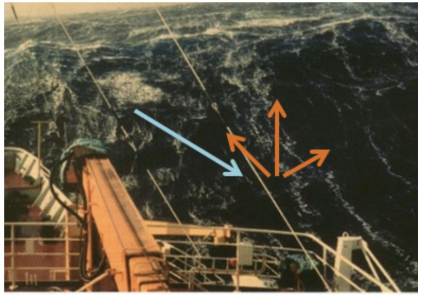
BEAUFORT FORCE 0
WIND SPEED: LESS THAN 1 KNOT
SEA: SEA LIKE A MIRROR



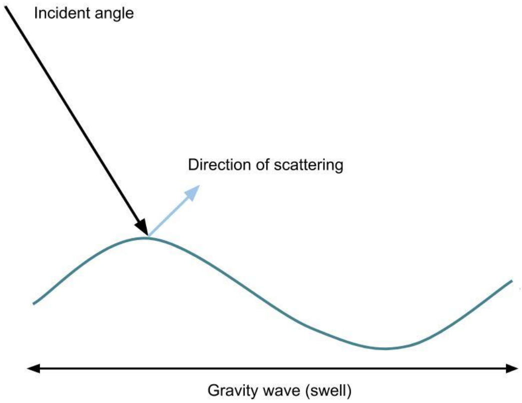
BEAUFORT FORCE 3
WIND SPEED: 7-10 KNOTS
SEA: WAVE HEIGHT 2-3 FT, LARGE WAVELETS, CRESTS BEGIN TO BREAK, ANY FORM HAS GLASSY APPEARANCE, SCATTERED WHITE CAPS

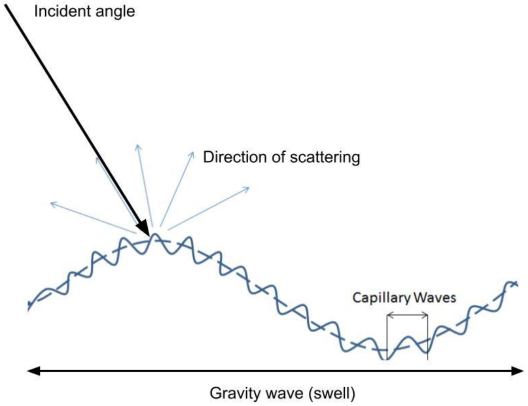


BEAUFORT FORCE 6
WIND SPEED: 22-27 KNOTS
SEA: WAVE HEIGHT 9.5-13 FT, LARGER WAVES BEGIN TO FORM, SPRAY IS PRESENT, WHITE FOAM CRESTS ARE EVERYWHERE

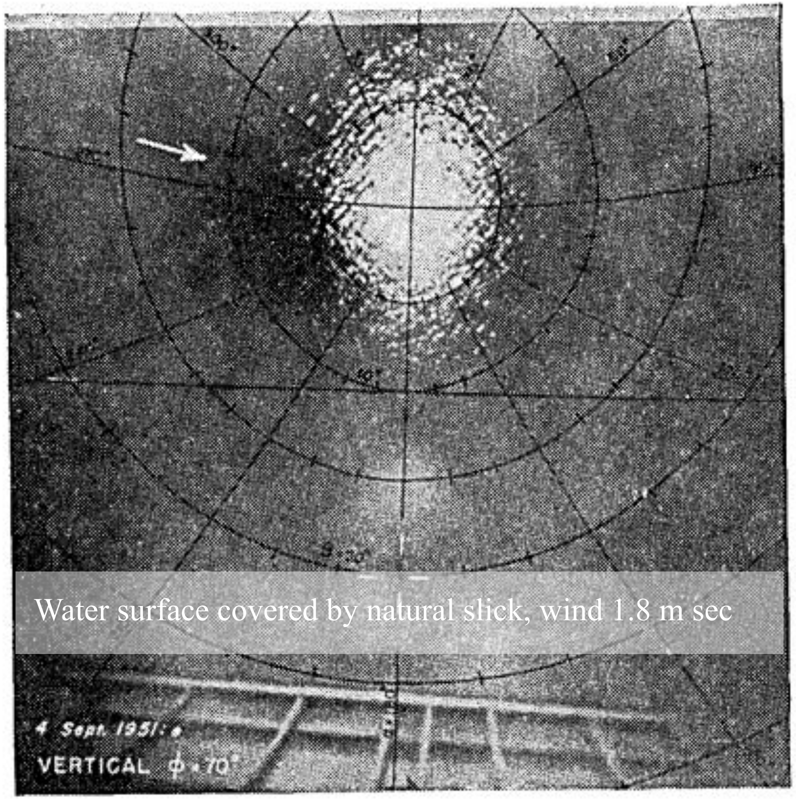


BEAUFORT FORCE 9
WIND SPEED: 41-47 KNOTS
SEA: WAVE HEIGHT 23-32 FT, HIGH WAVES, DENSE STREAKS OF FOAM ALONG DIRECTION OF THE WIND, WAVE CRESTS BEGIN TO TOPPLE, TUMBLE AND ROLL OVER. SPRAY MAY AFFECT VISIBILITY

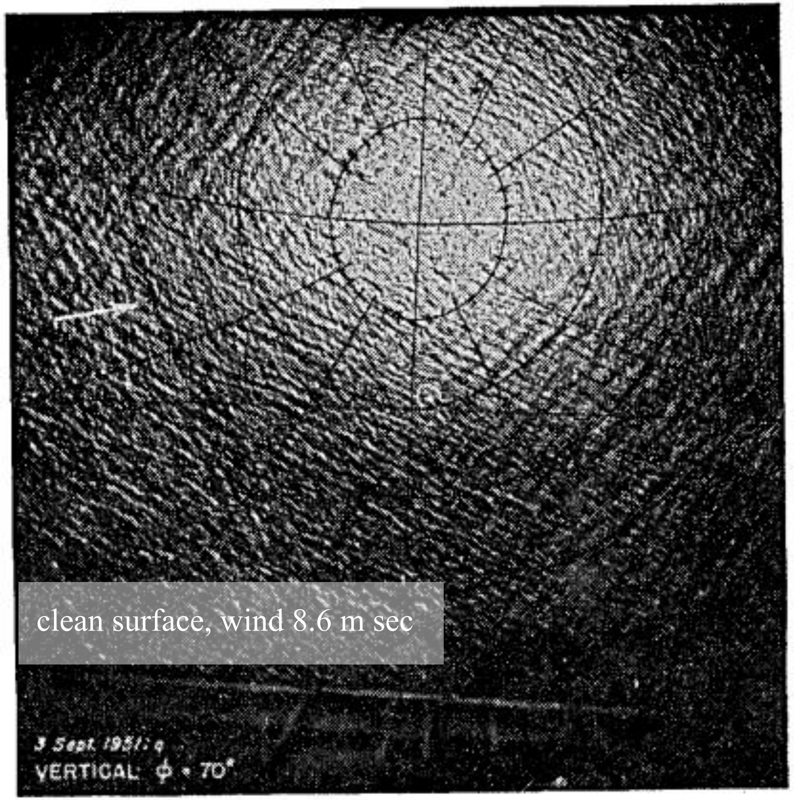




Measurement of the Roughness of the Sea Surface from Photographs of the Sun's Glitter, Cox and Munk (1954)



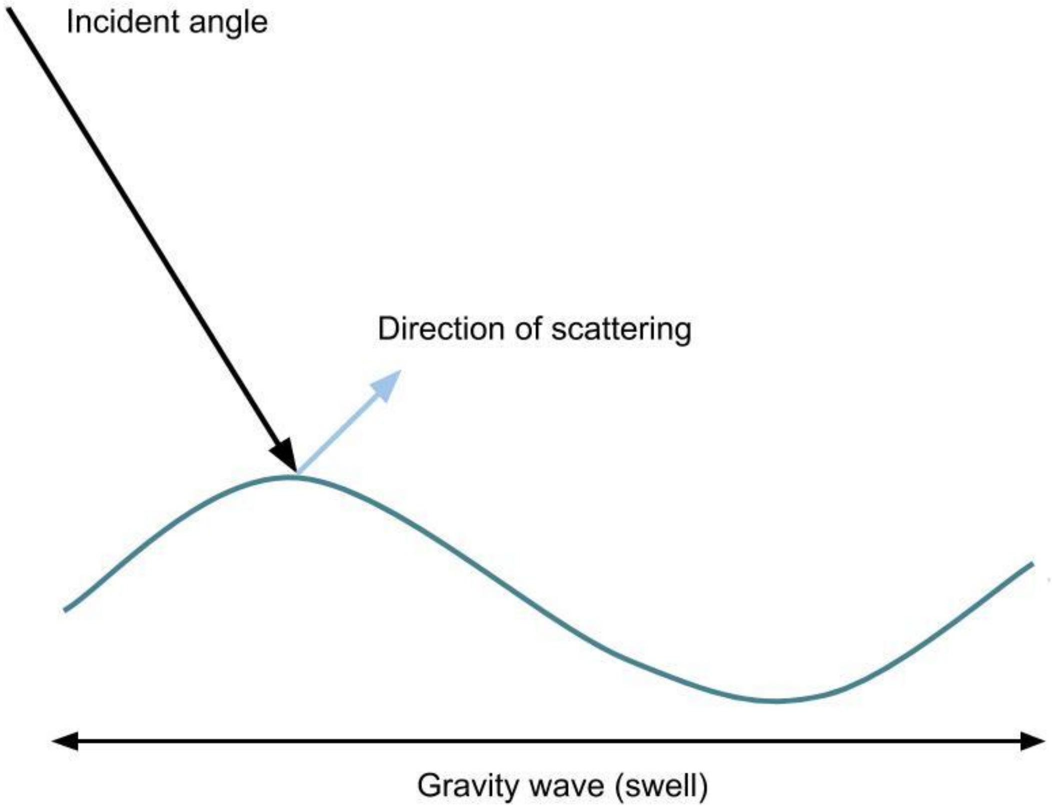
Water surface covered by natural slick, wind 1.8 m sec



clean surface, wind 8.6 m sec

Cox & Munk (1954)

BACKGROUND | Bragg scattering review



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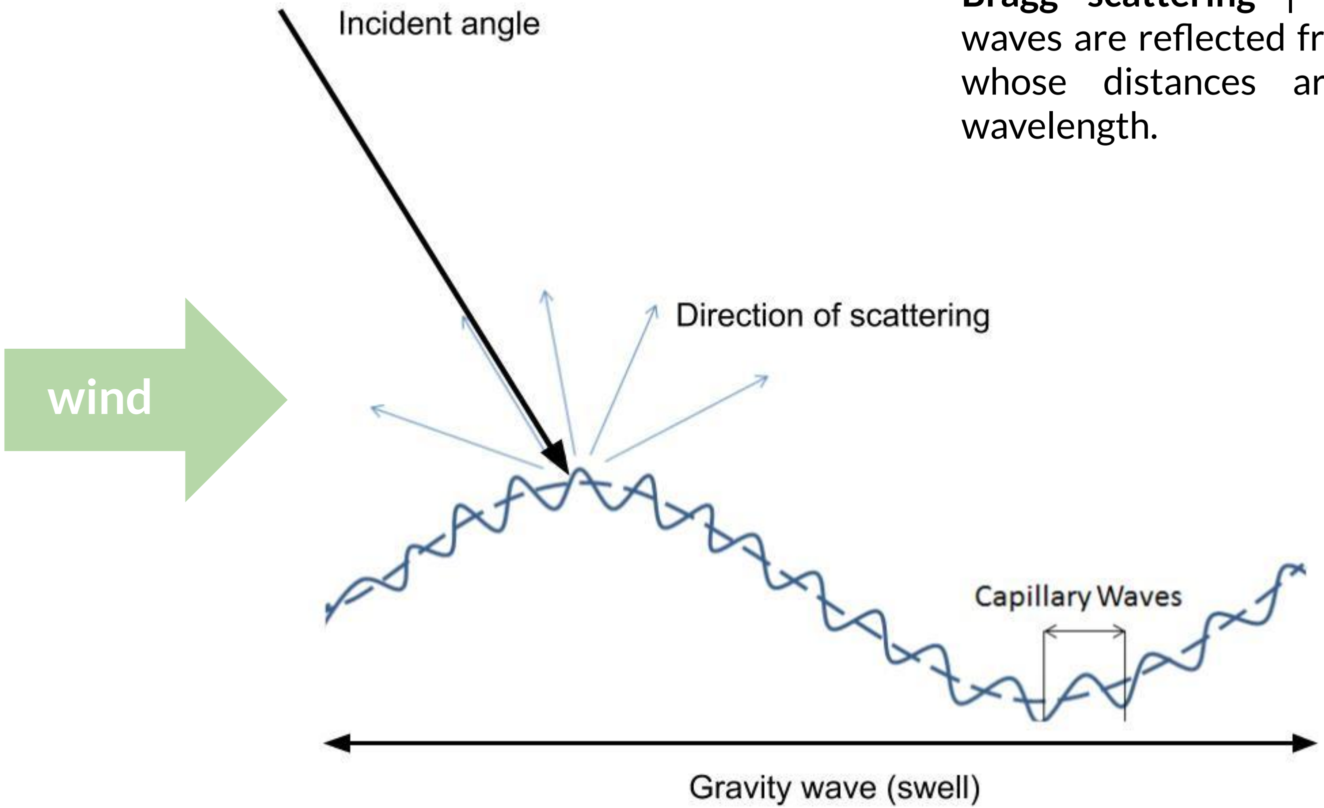
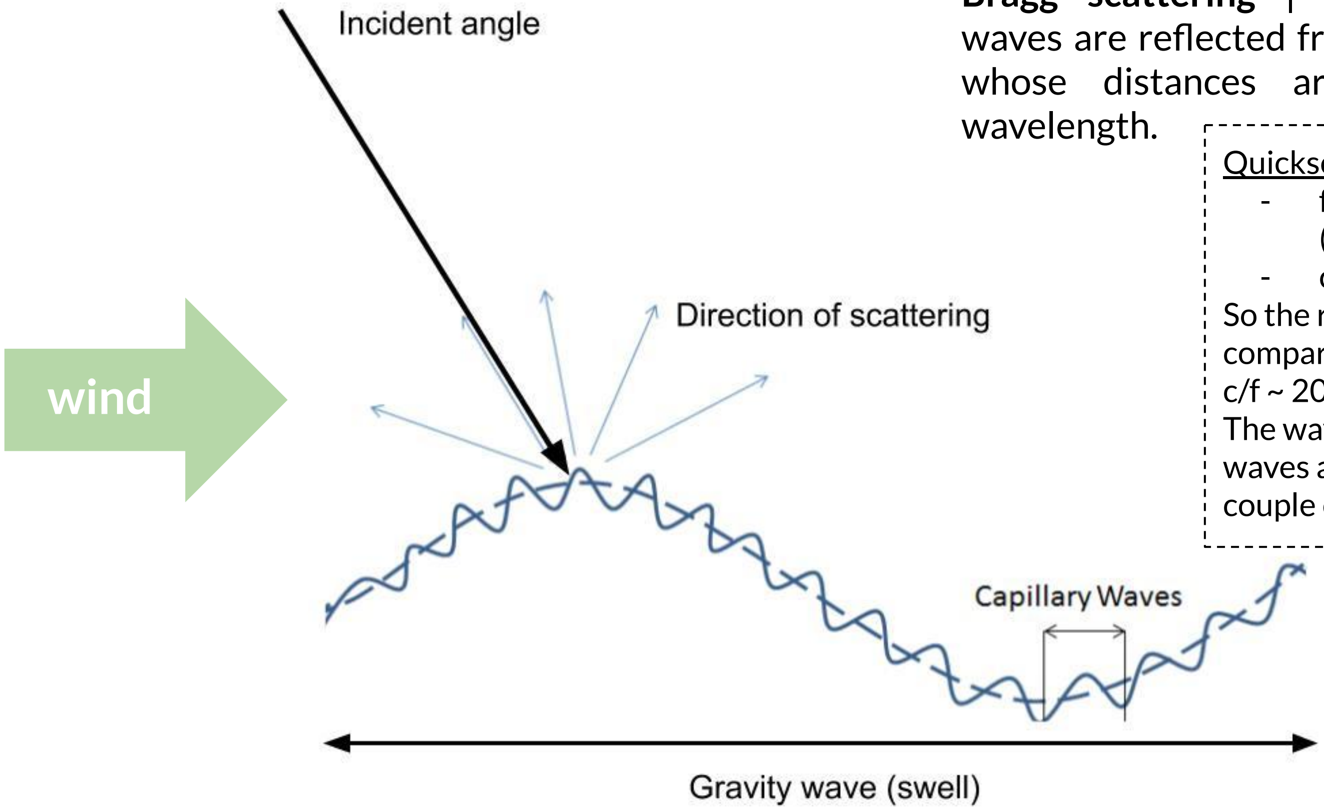


Bragg scattering | how electromagnetic waves are reflected from periodic structures whose distances are in the range of wavelength.

BACKGROUND | Bragg scattering & scatterometry



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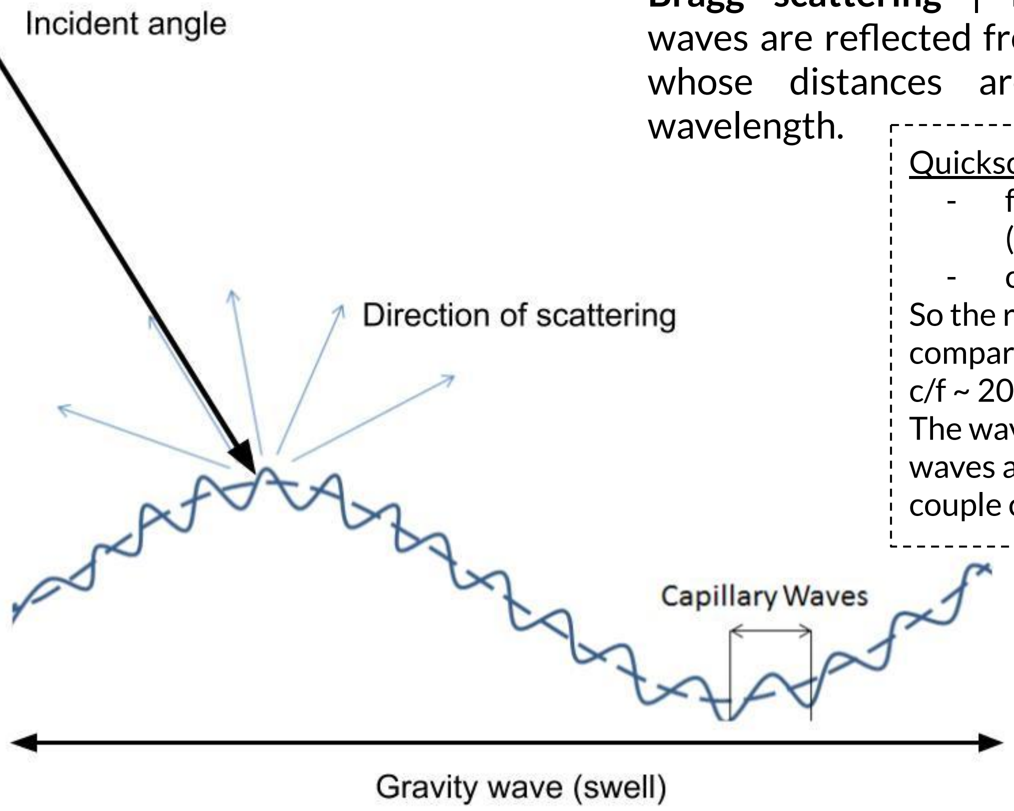
<u>Quickscat Example</u>

- frequency = 13.4 GHz ($10^9\ s^{-1}$)
- c = 2.99 x 10^9 m/s

So the relevant structures are comparable to the wavelength c/f ~ 20 mm.
The wavelength of capillary waves are typically less than a couple centimeters.

BACKGROUND | Bragg scattering & scatterometry

more wind
→
more backscatter



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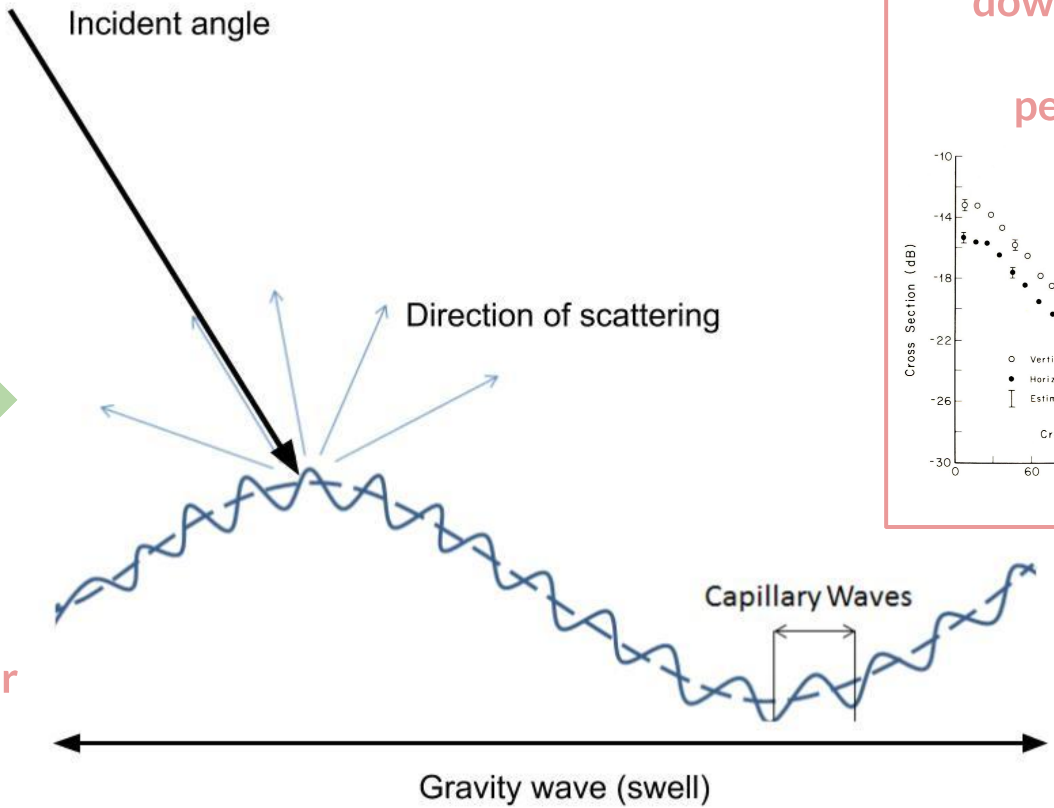
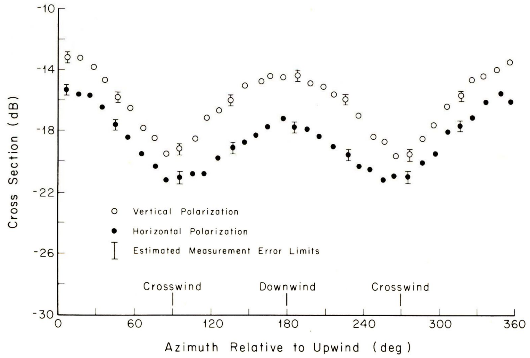
wind



more wind
→
more backscatter

downwind or upwind
→
peak backscatter

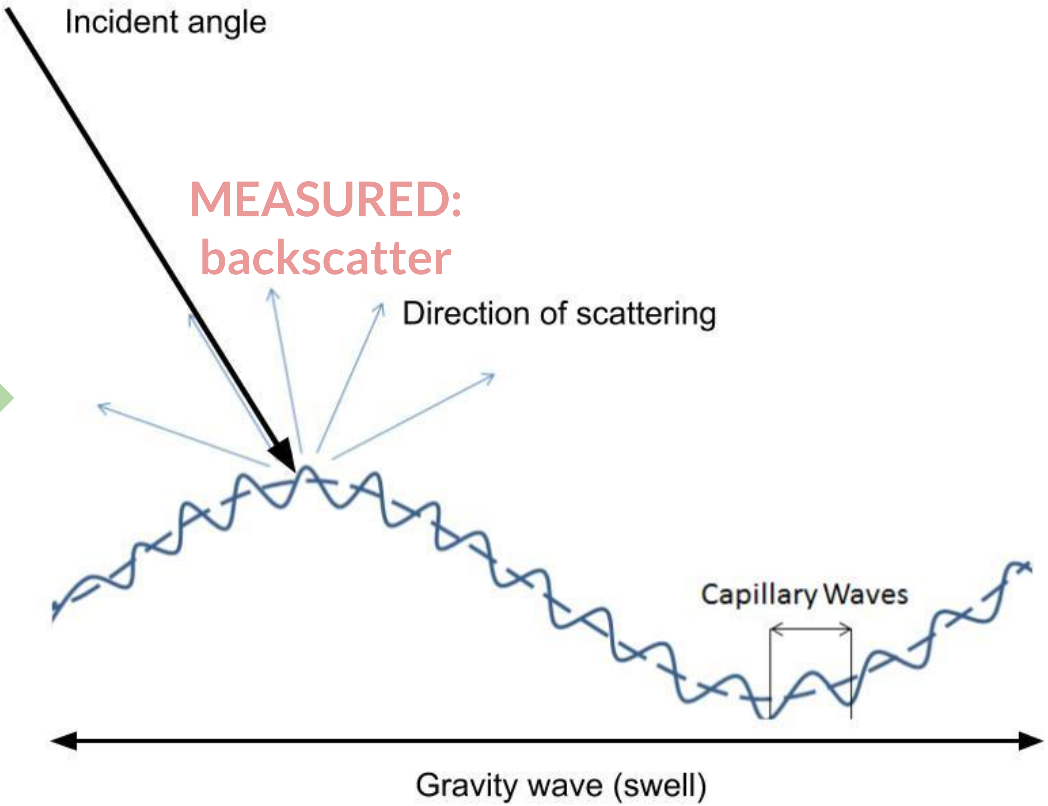


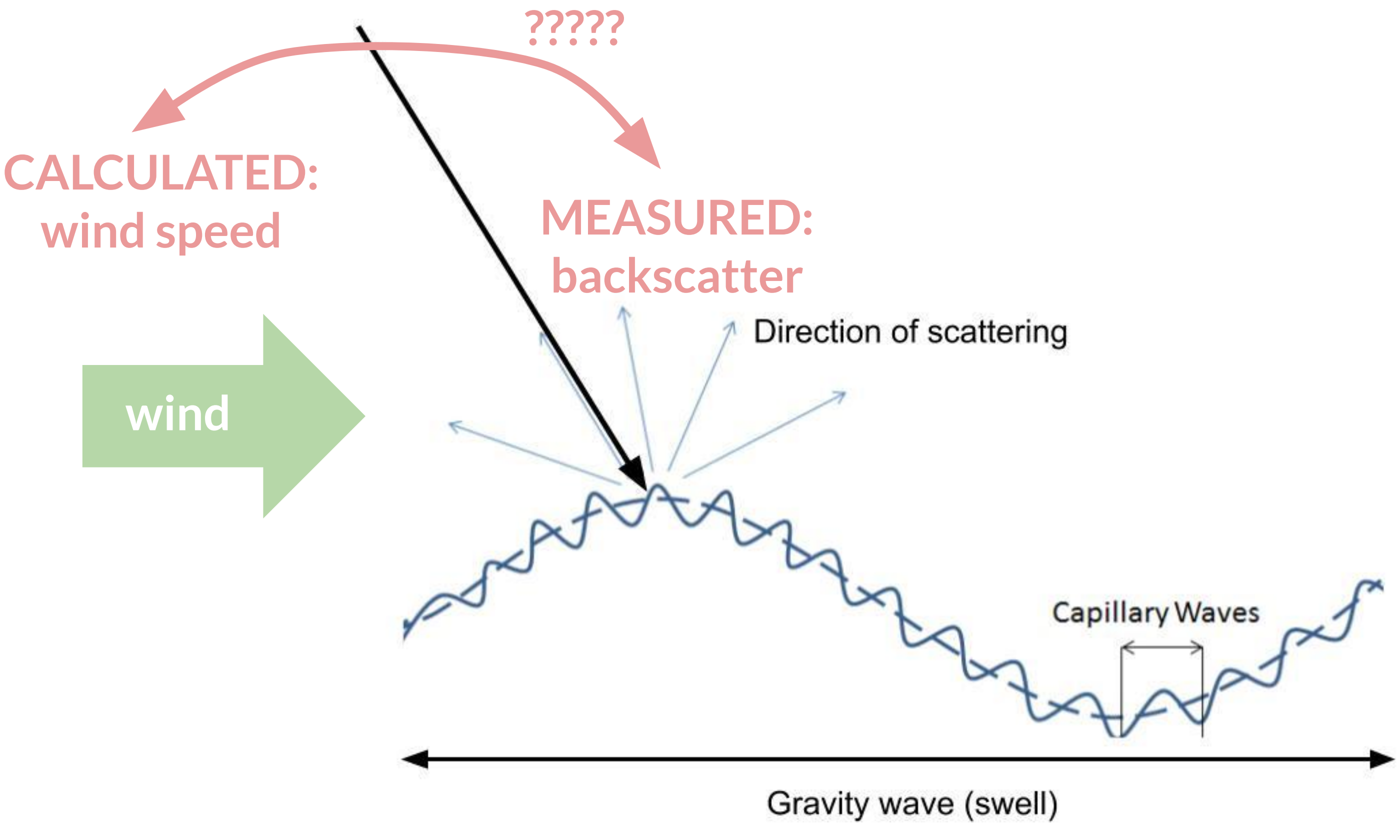
SAR Marine User's Manual, CH2 (Holt, 2004)

CALCULATED:
wind speed

wind

MEASURED:
backscatter




?????
CALCULATED:
wind speed
MEASURED:
backscatter
wind
Direction of scattering
Capillary Waves
Gravity wave (swell)

Geophysical Model Functions (GMFs)

Relate amount of backscatter detected by satellite sensors to wind speed

$$\sigma_0 = GMF(U_{10N}, \phi, \theta, p, \lambda)$$

Typically a function of wind speed, incident angles, polarization, and wavelength. Usually empirically determined.

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- From observational data from Joint Air-Sea Interaction Experiment (1978)

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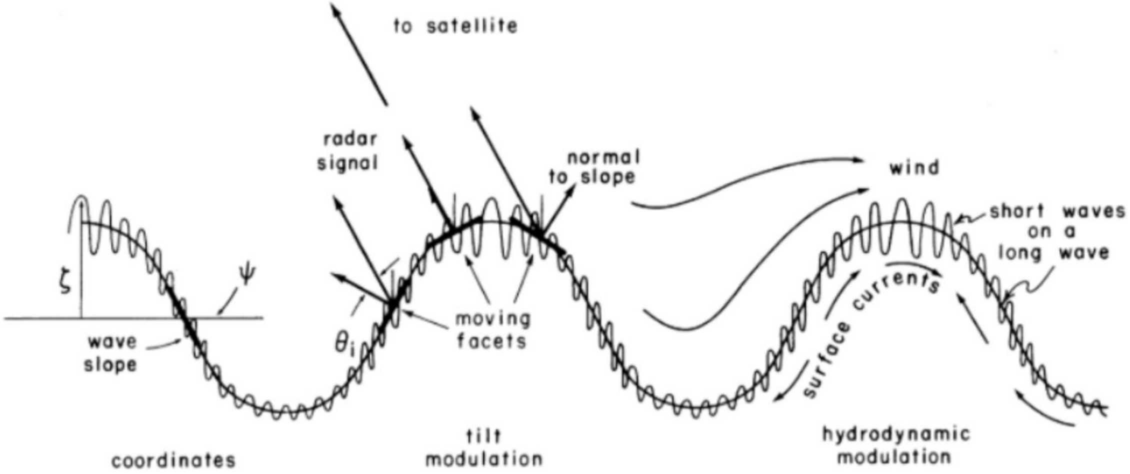
- temperature by affecting the viscous dissipation of short waves for low winds
- Saturation state at high winds
- tilt and modulation of short capillary-gravity waves by longer gravity waves
- longer gravity waves are affected by:
    - coastal topography ○ non-local storms ○ bathymetry ○ currents



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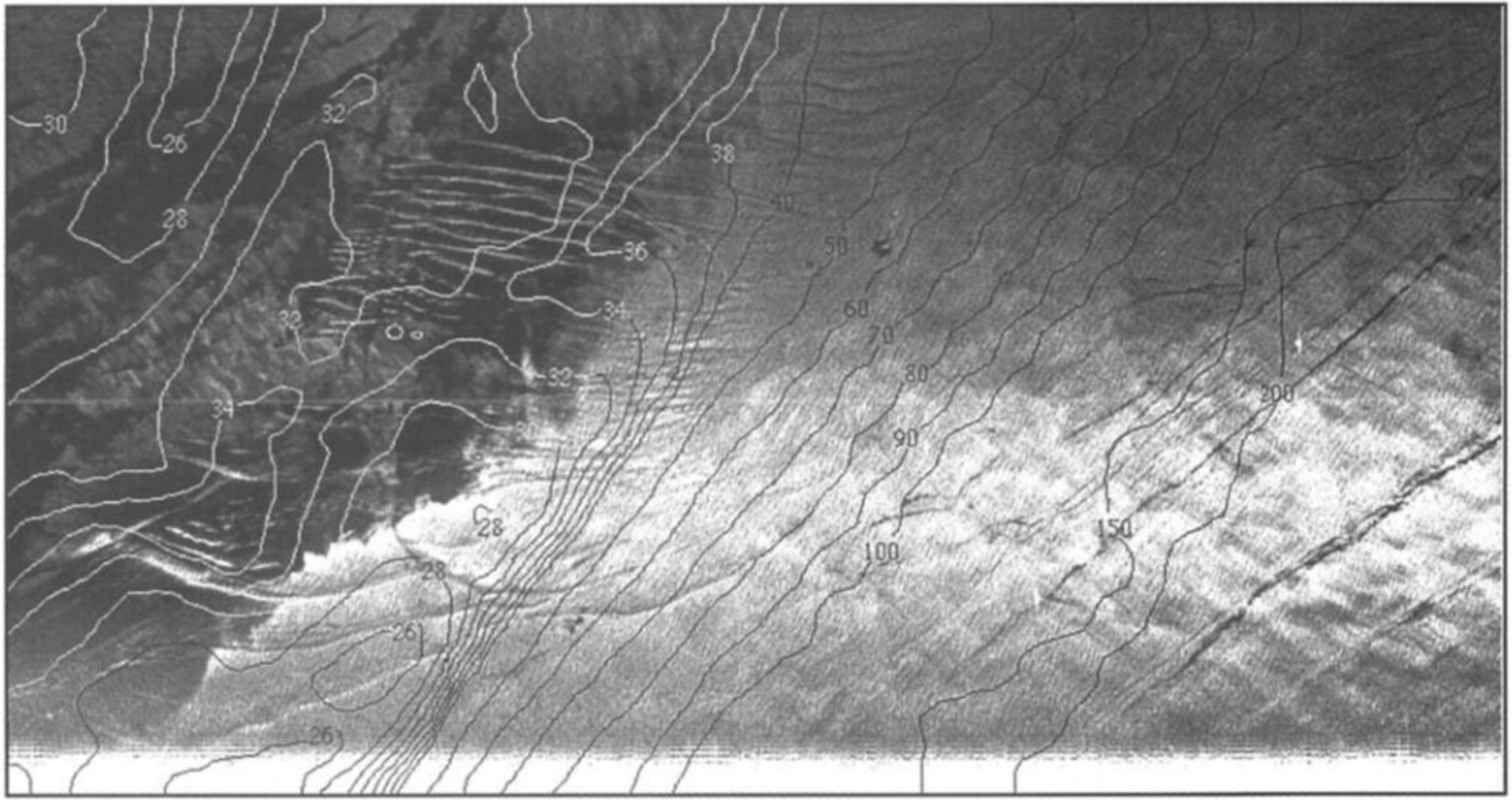
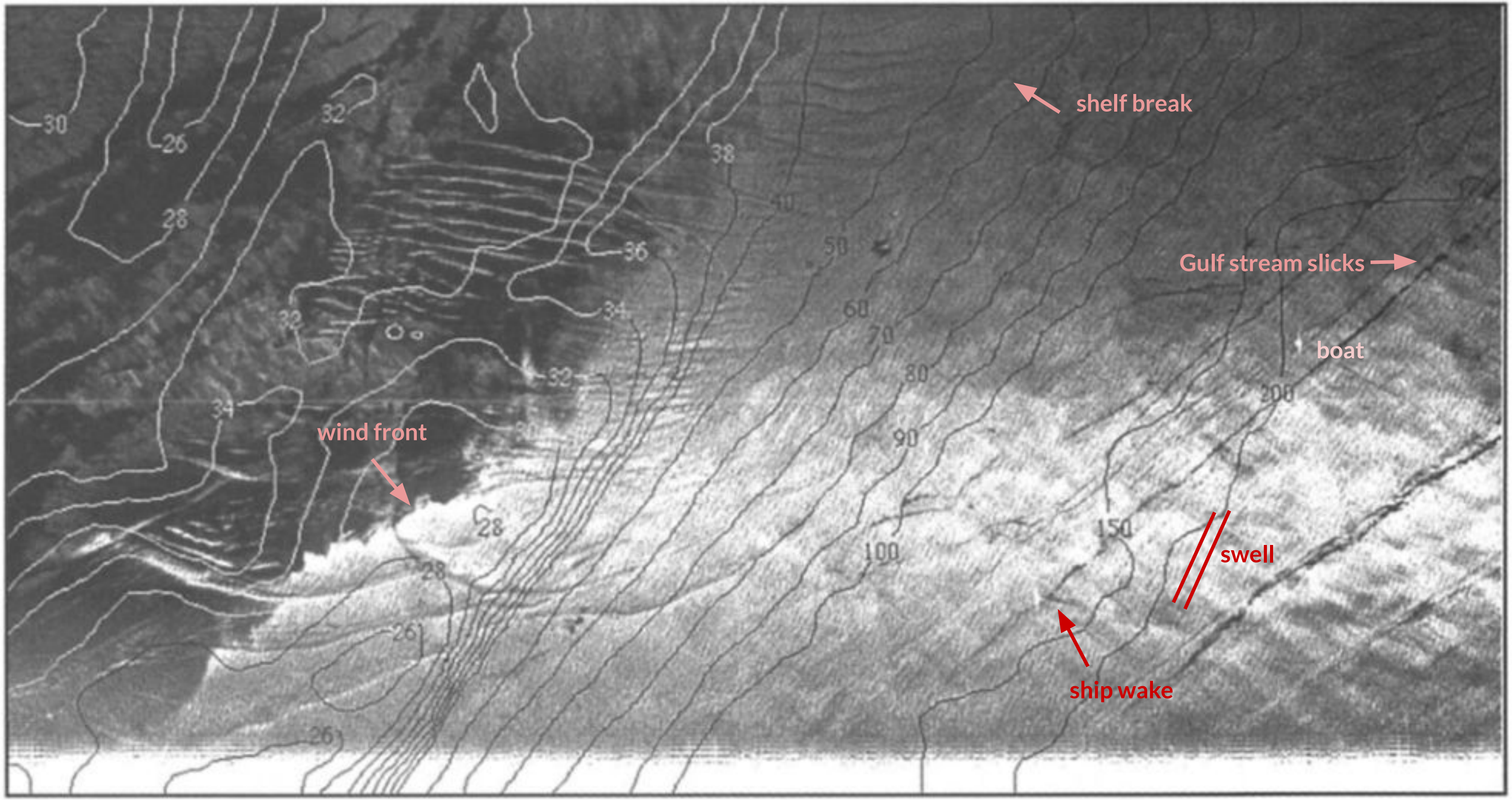


Marimo et al. (2002)

SAR observations of the ocean surface



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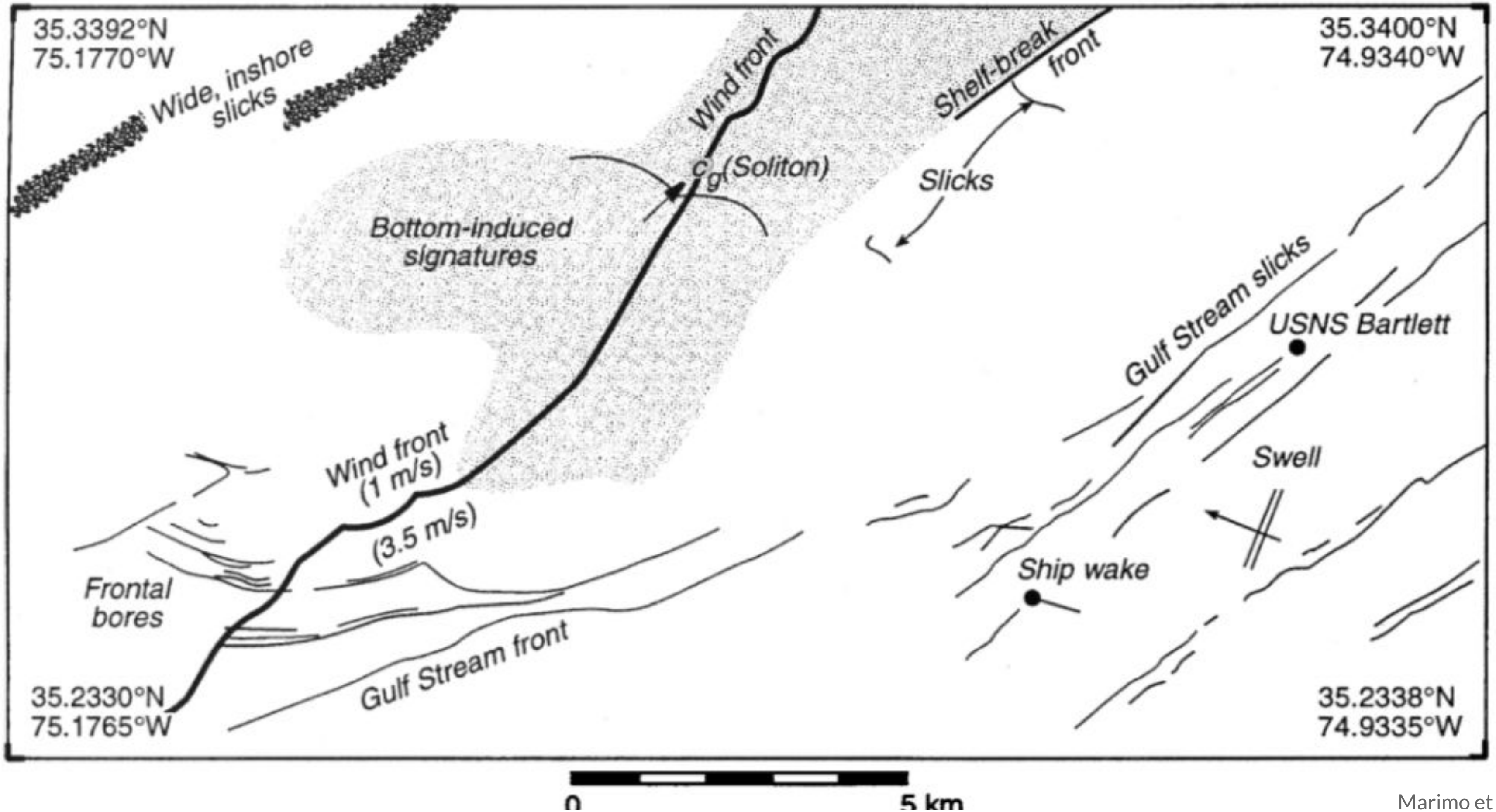

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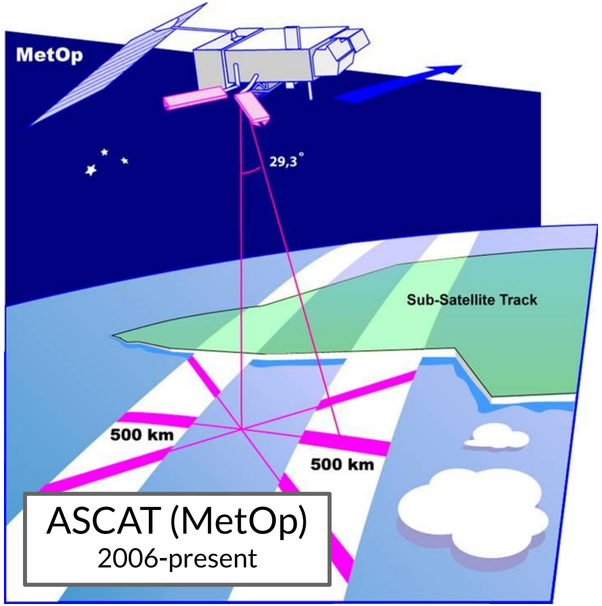
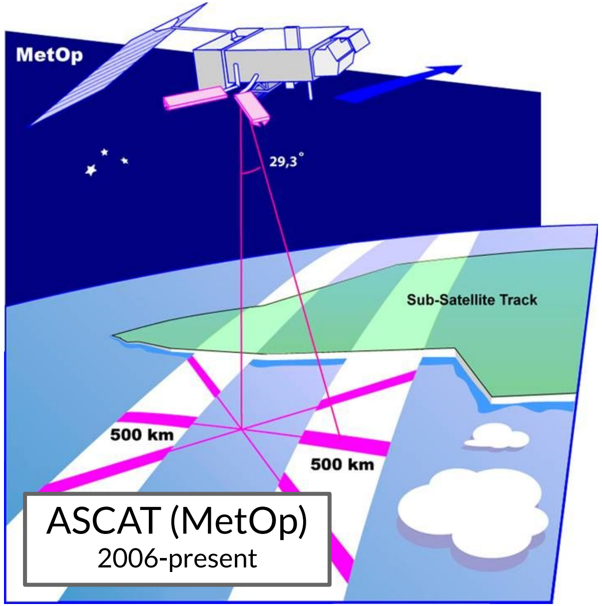
Scatterometry

- Satellite
- Wind via GMF and backscatter from Bragg scattering off capillary waves
- ~25km resolution



ESA

Scatterometry	Synthetic Aperture Radar (SAR)
• Satellite • Wind via GMF and backscatter from Bragg scattering off capillary waves • ~25km resolution	• Satellite or aircraft • Backscatter from Bragg scattering off capillary waves • Images with ~5m resolution, ~400km wide swath • ~12 day repeat cycle

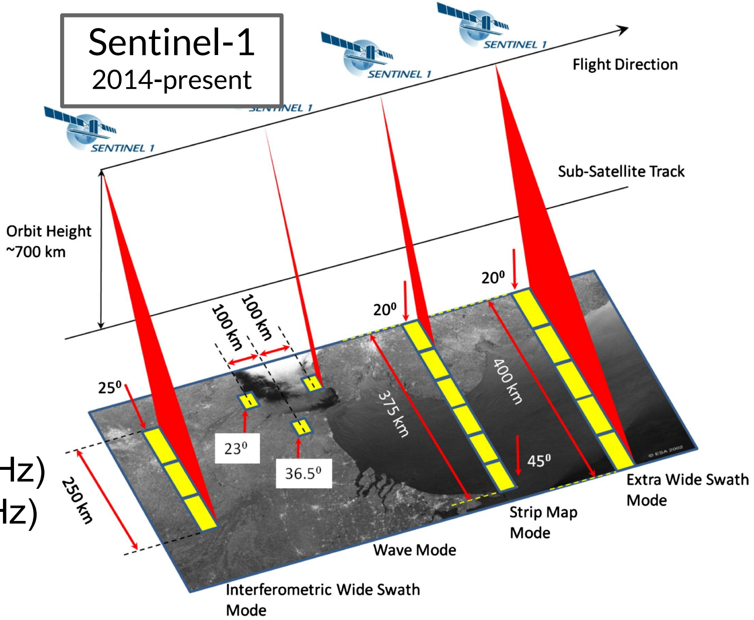


ASCAT (MetOp)
2006-present

ERS-1 & ERS-2
1991-2000, 1995-2011

Both:

- operate in band:
  - Ku-band (14 GHz)
  - C-band (5.6 GHz)
- Active sensors



Sentinel-1
2014-present

ESA

SCATTEROMETRY vs SAR

Scatterometry	Synthetic Aperture Radar (SAR)
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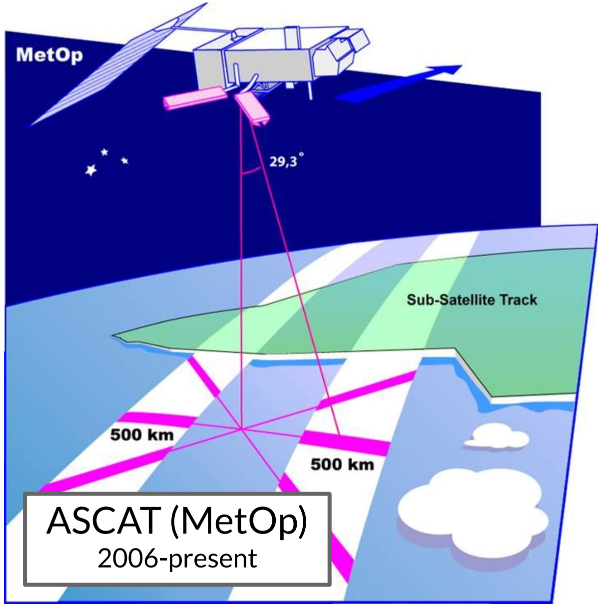

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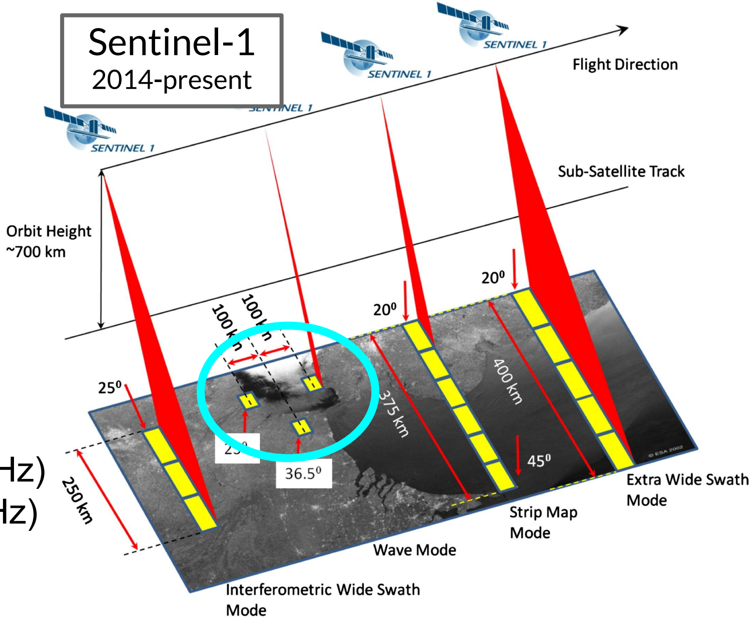
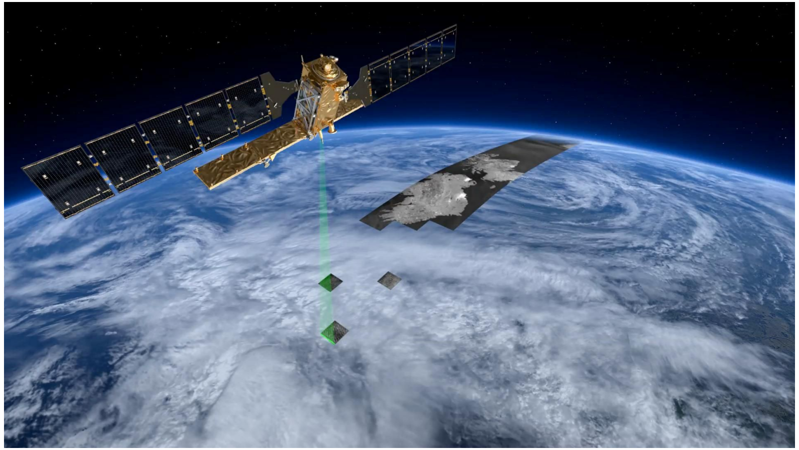


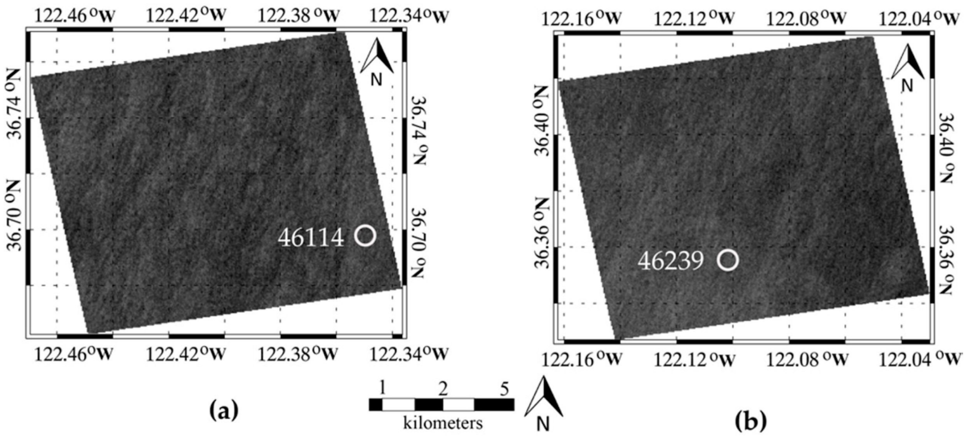
Sentinel-1
2014-present

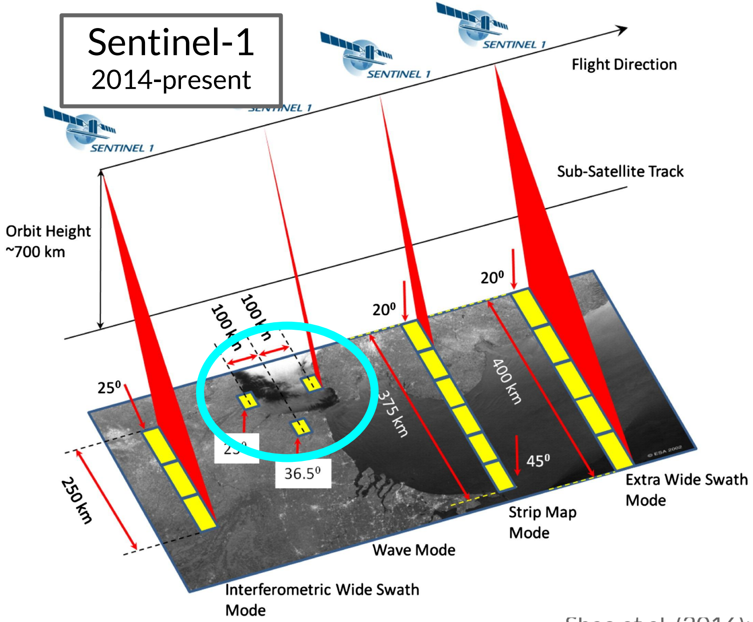
ESA

S A R | ocean swell spectra



Wave mode is operated over oceans, composed of 20km by 20km stripmap imagettes (5m by 5m resolution) every 100km.

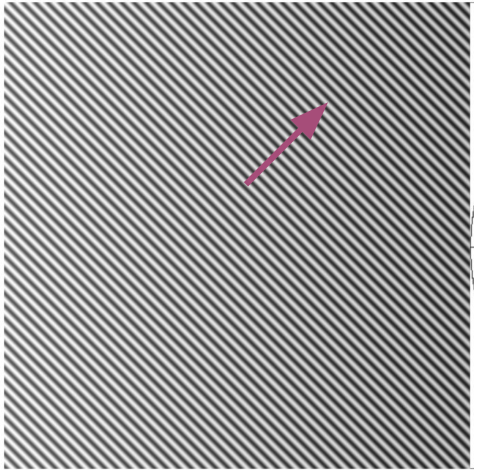




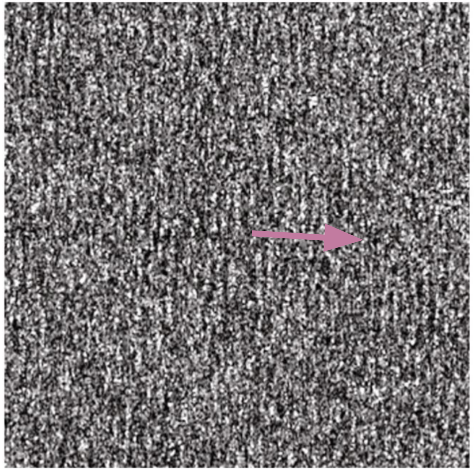
Shao et al. (2016); ESA

S A R | ocean swell spectra

THEORETICAL
(artificially generated)



OBSERVED
(from RADARSAT-1 SAR)



SAR Marine User's Manual, CH5 - Vachon et al. (2004)

S A R | ocean swell spectra

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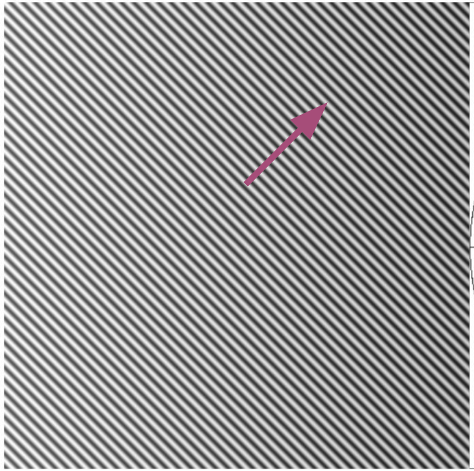

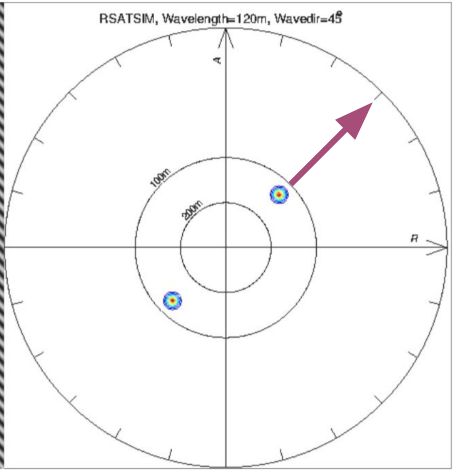

WAIT: What is this???
Apply FFT to the wave field to represent size/# of waves in terms of wavenumbers or frequencies.
Here our wave field looks only like one size of wave, so produces a single peak in the 2-dimensional spectrum (direction corresponding to angle of propagation).

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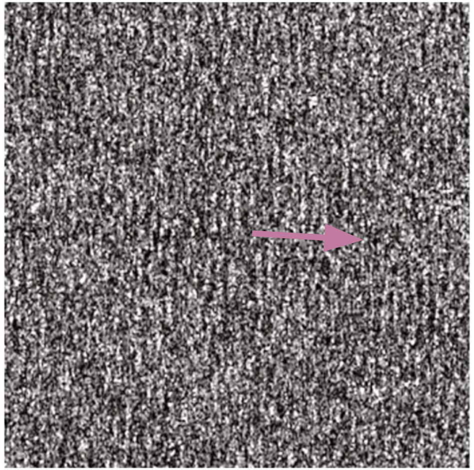

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S A R | ocean swell spectra

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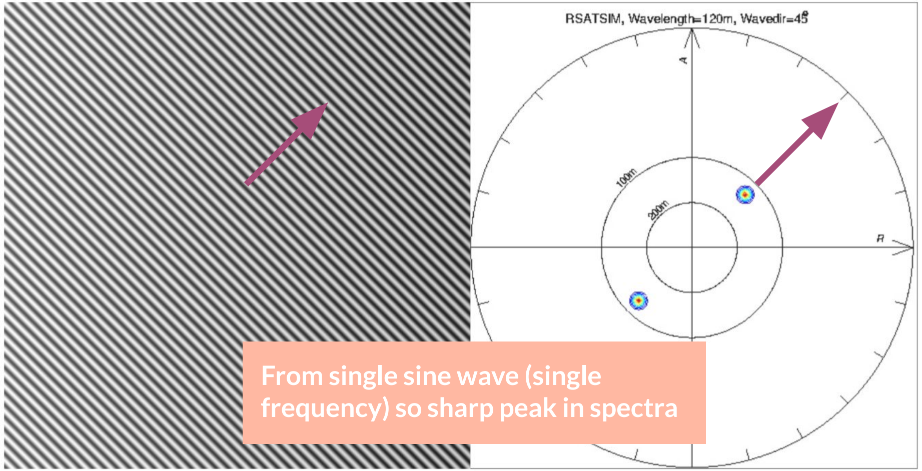

From single sine wave (single frequency) so sharp peak in spectra

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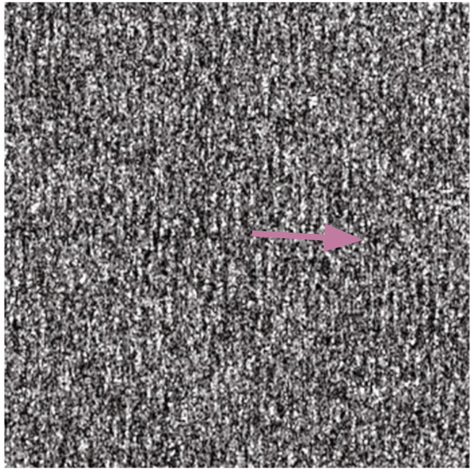

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S A R | ocean swell spectra

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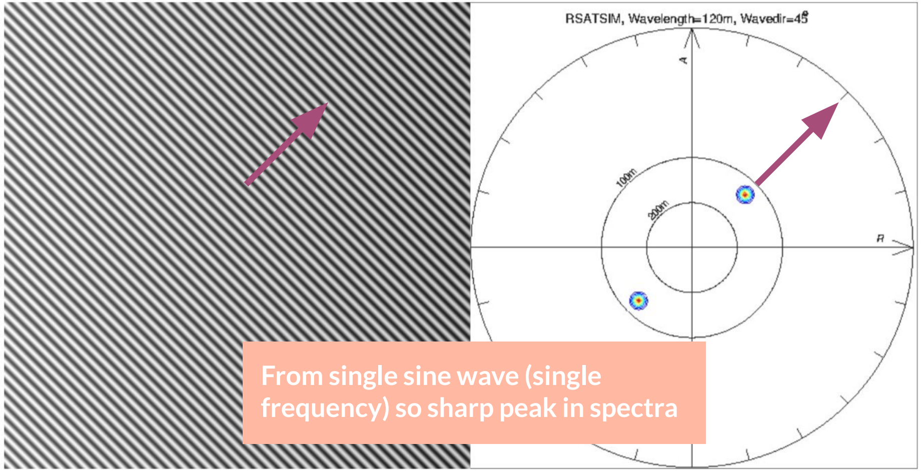

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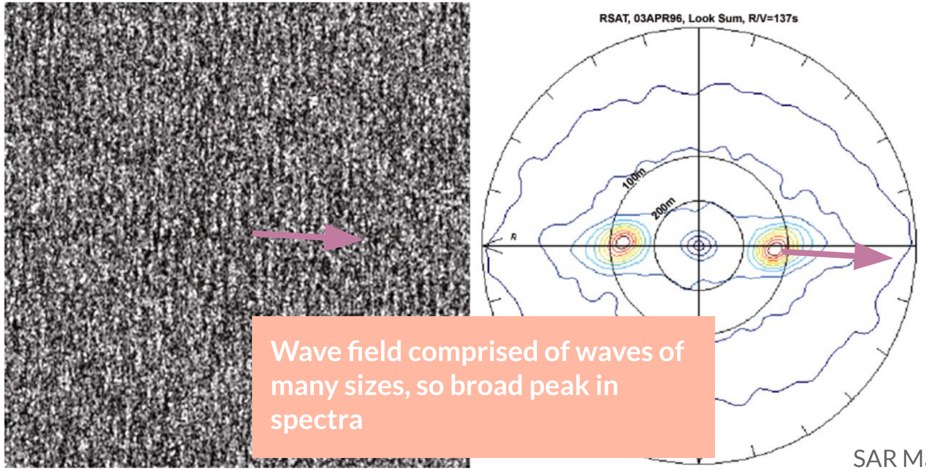
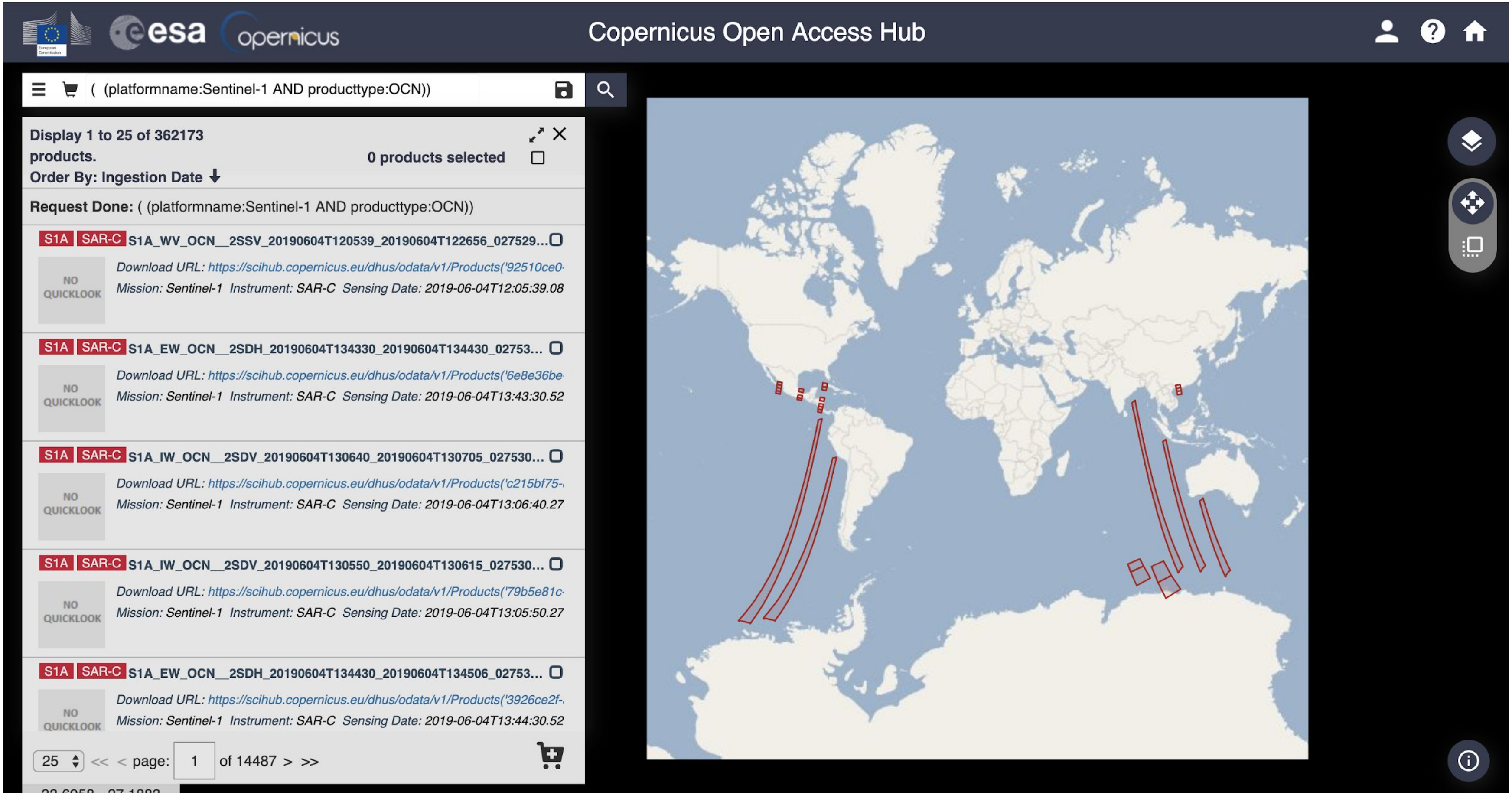


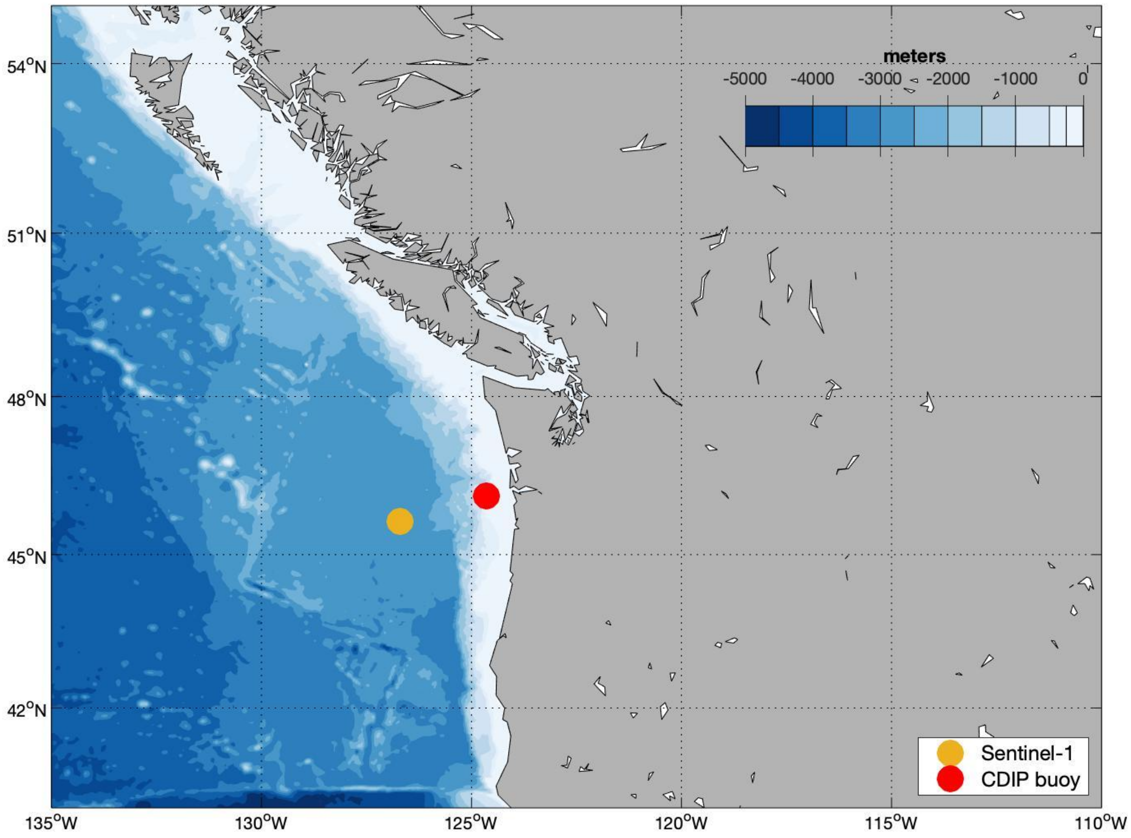
Wave field comprised of waves of many sizes, so broad peak in spectra

SAR Marine User's Manual, CH5 - Vachon et al. (2004)

INSIGHTS | Comparing CDIP to OSW product



 | Comparing CDIP to OSW product



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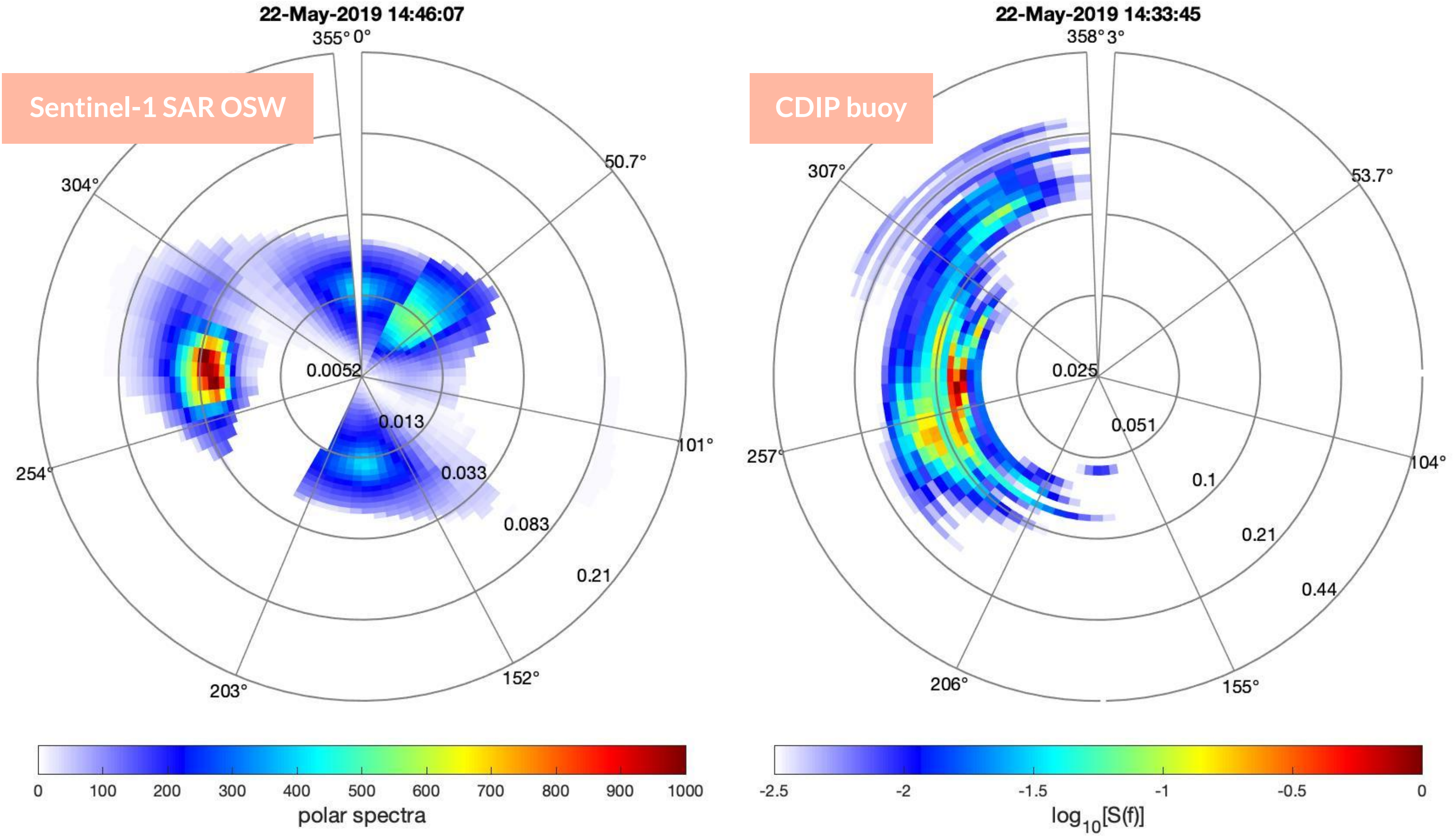
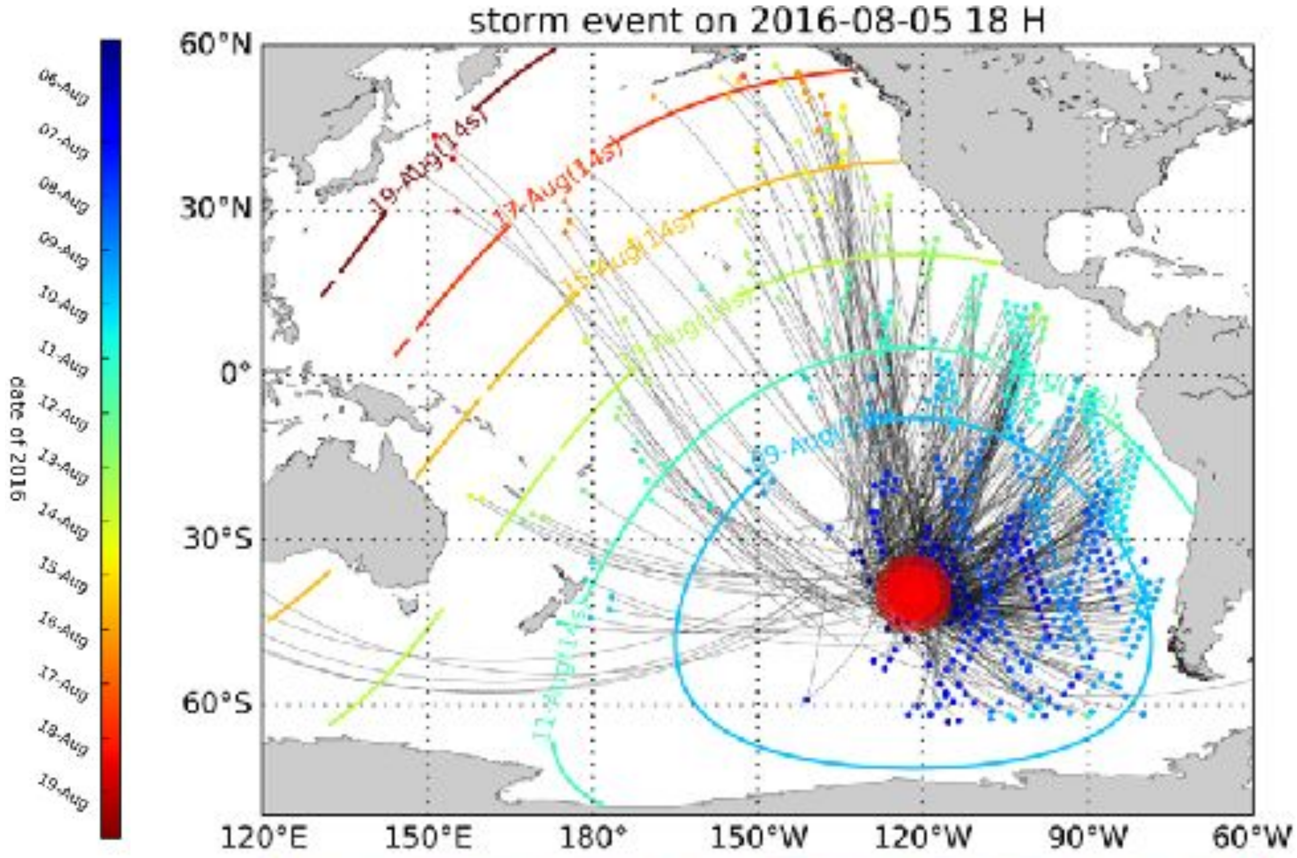
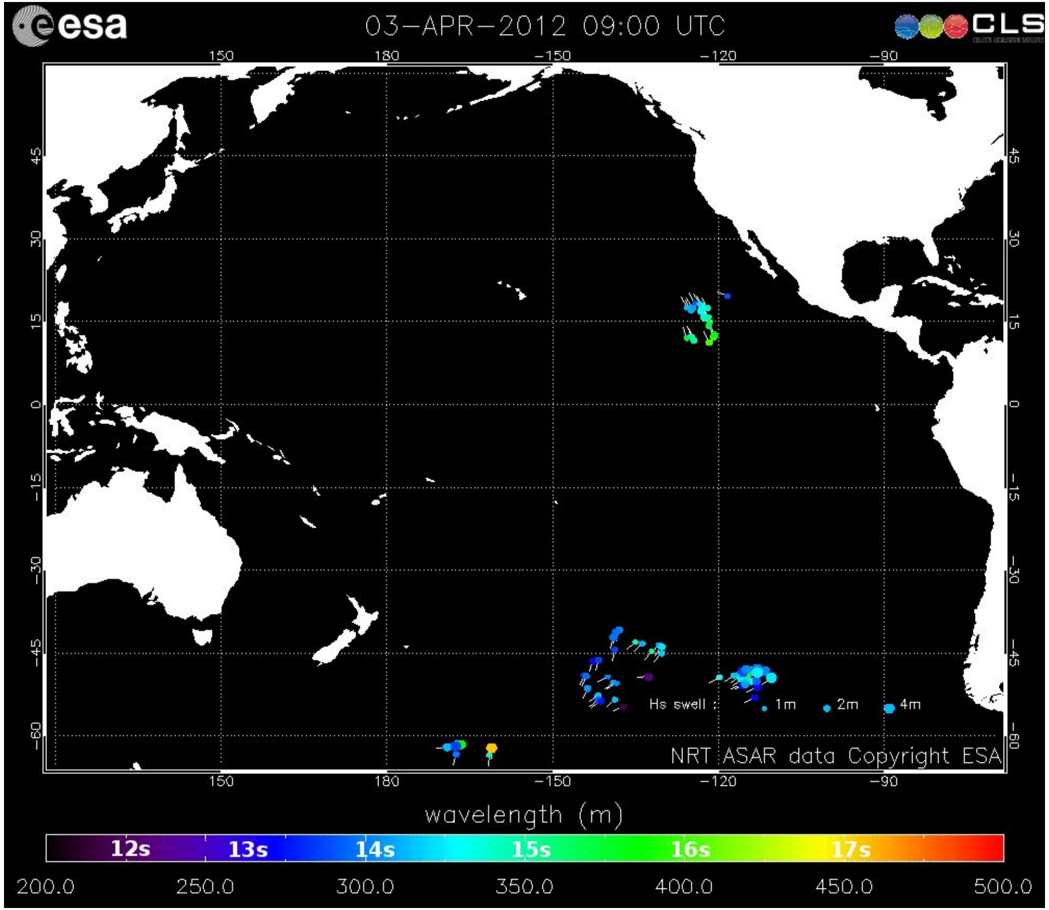


“fireworks”


storm event on 2016-08-05 18 H
60°N
30°N
0°
30°S
60°S
120°E
150°E
180°
150°W
120°W
90°W
60°W
date of 2016
06-Aug
07-Aug
08-Aug
09-Aug
10-Aug
11-Aug
12-Aug
13-Aug
14-Aug
15-Aug
16-Aug
17-Aug
18-Aug
19-Aug
19-Aug(14s)
17-Aug(14s)

APPLICATIONS | swell trajectories and dissipation

http://www.boost-technologies.com/esa/images/nrt_pac.gif



"Monitoring and analysis of ocean swell fields from space: New methods for routine observations." Fabrice Collard, Fabrice Ardhuin, and Bertrand Chapron (2009)

Collard et al. (2009)

APPLICATIONS | swell trajectories and dissipation

http://www.boost-technologies.com/esa/images/pacific_20040709_20040721.gif

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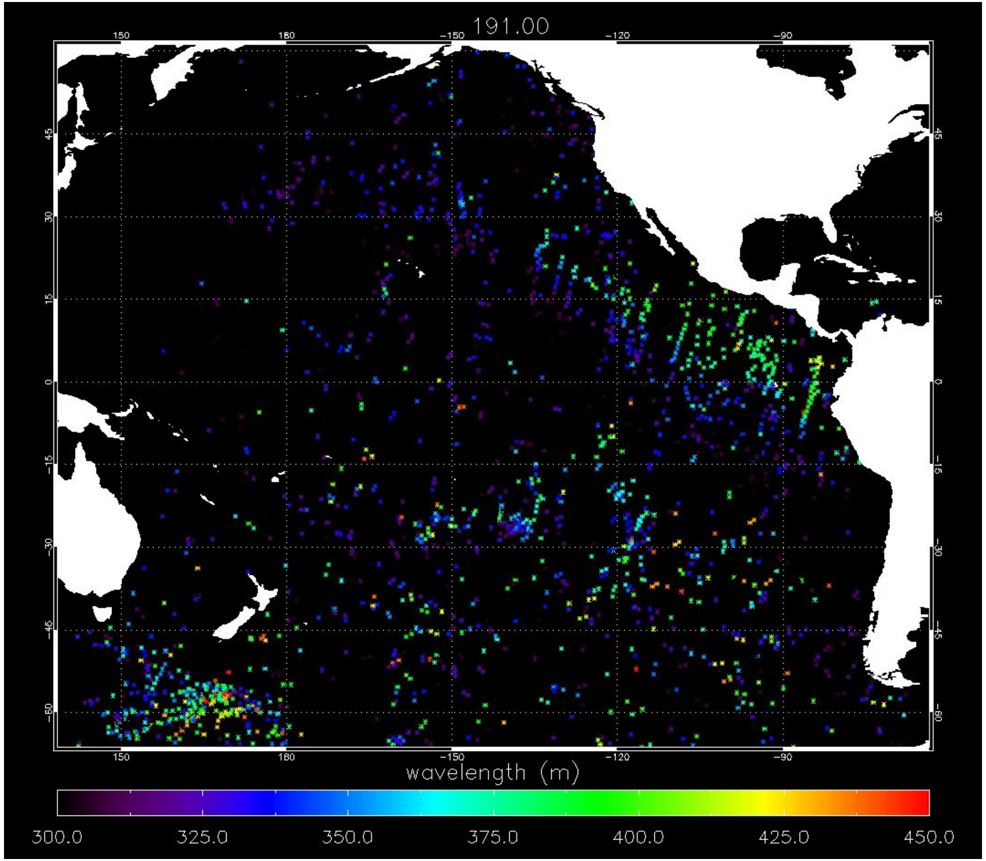

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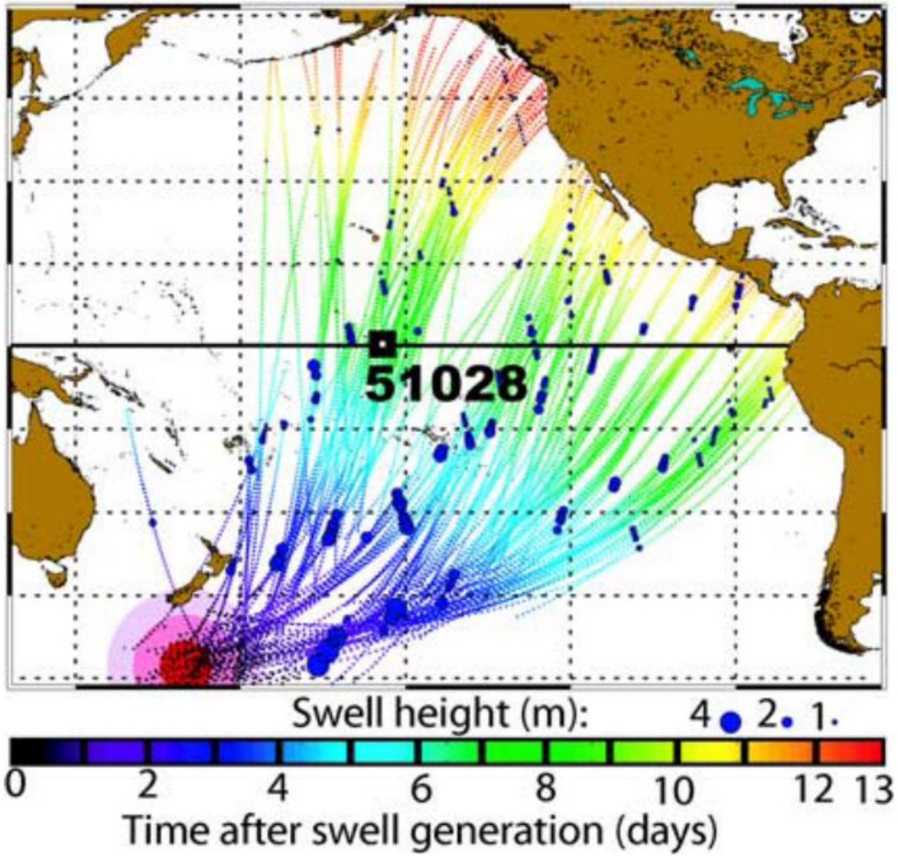

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