Introduction to Satellite Waves Remote sensing

Fabrice COLLARD (OceanDataLab)

With inputs from
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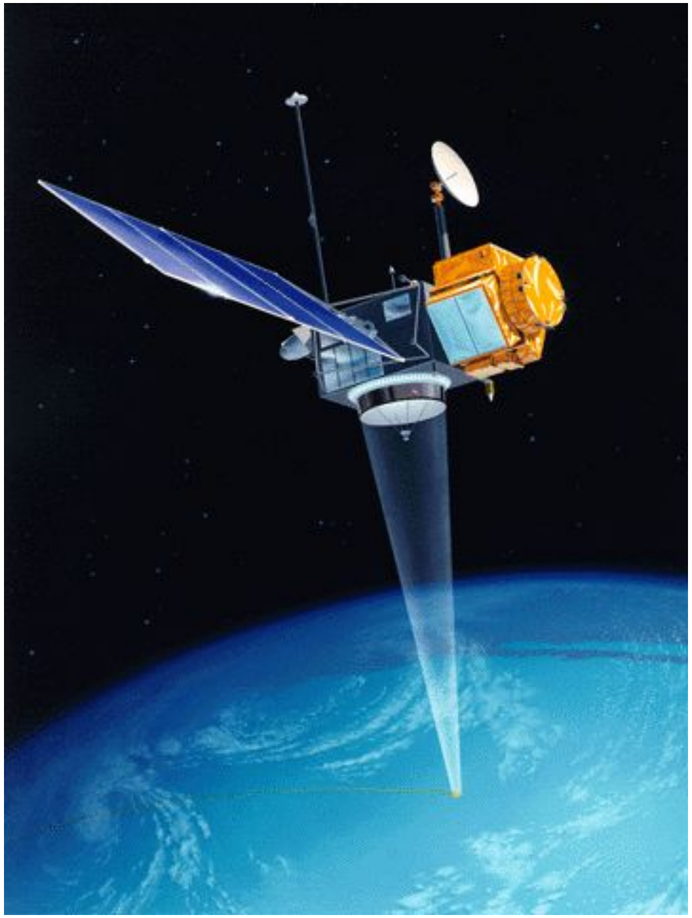
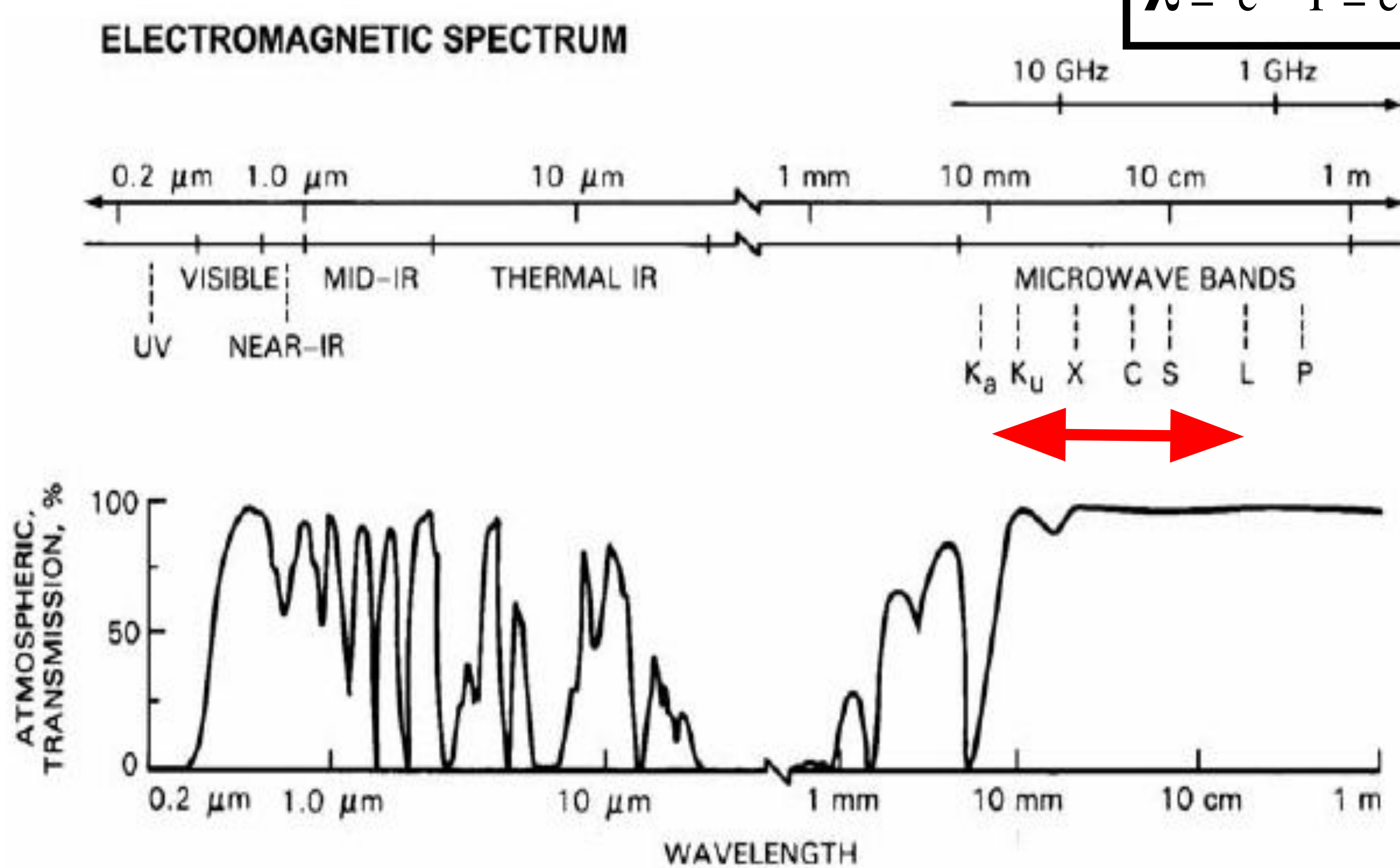
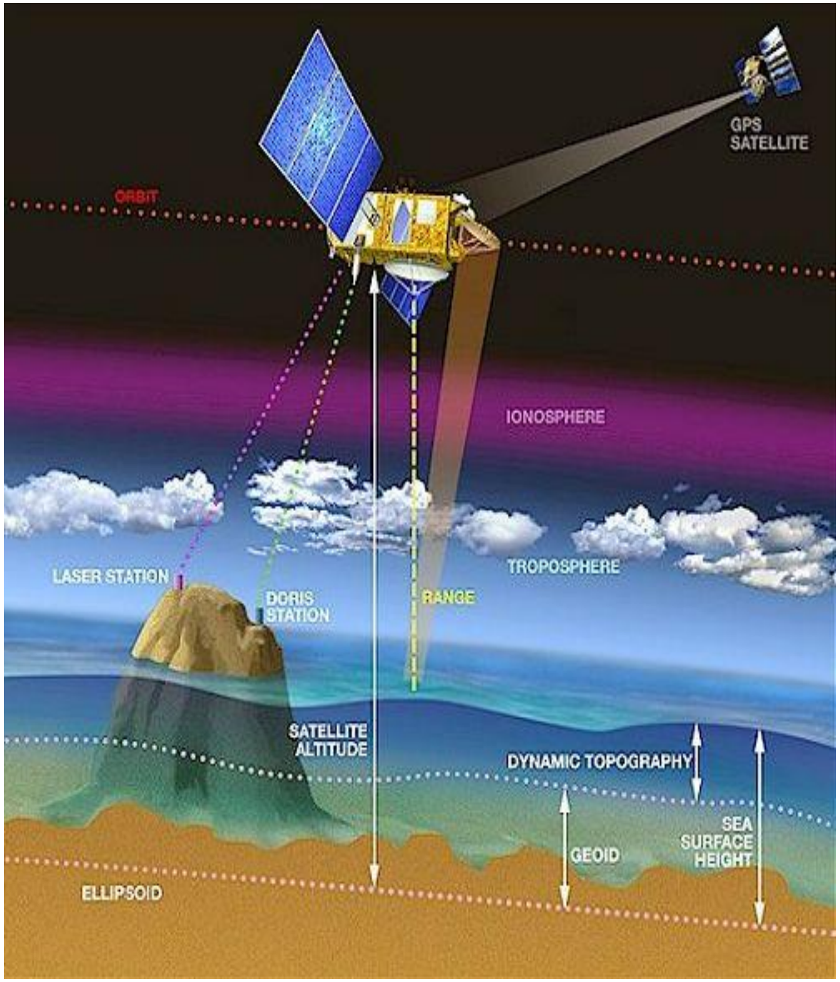
Satellite altimetry



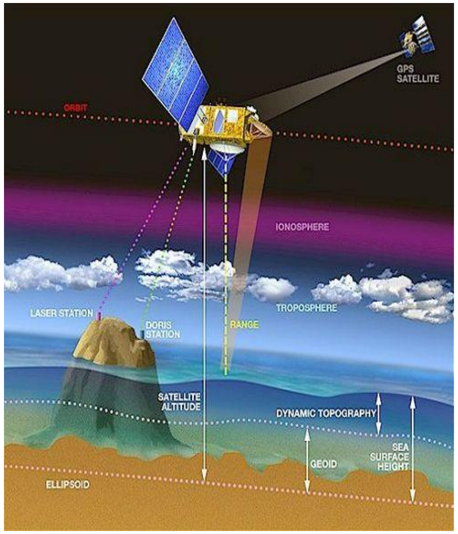
Satellite altimeters are radars, which transmit short pulses toward the earth beneath them. The return time of the pulse after reflection at the earth's surface is measured, and this yields the height of the satellite. The most important are ERS-1, ERS-2, TOPEX/Poseidon, Jason-series and Sentinel-3

$$\lambda = c * T = c * 1/f$$



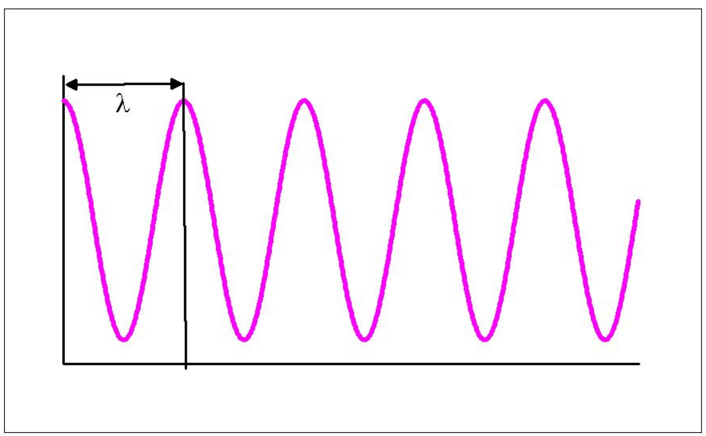


Radar altimeters on board the satellite permanently transmit signals at high frequency (Topex-Poseidon - over 1700 pulses per second) to Earth, and receive the echo from the sea surface. This is analyzed to derive a precise measurement of the round-trip time between the satellite and the sea surface. The time measurement, scaled by the speed of light (at which electromagnetic waves travel), yields a measurement of the satellite-to-ocean range.

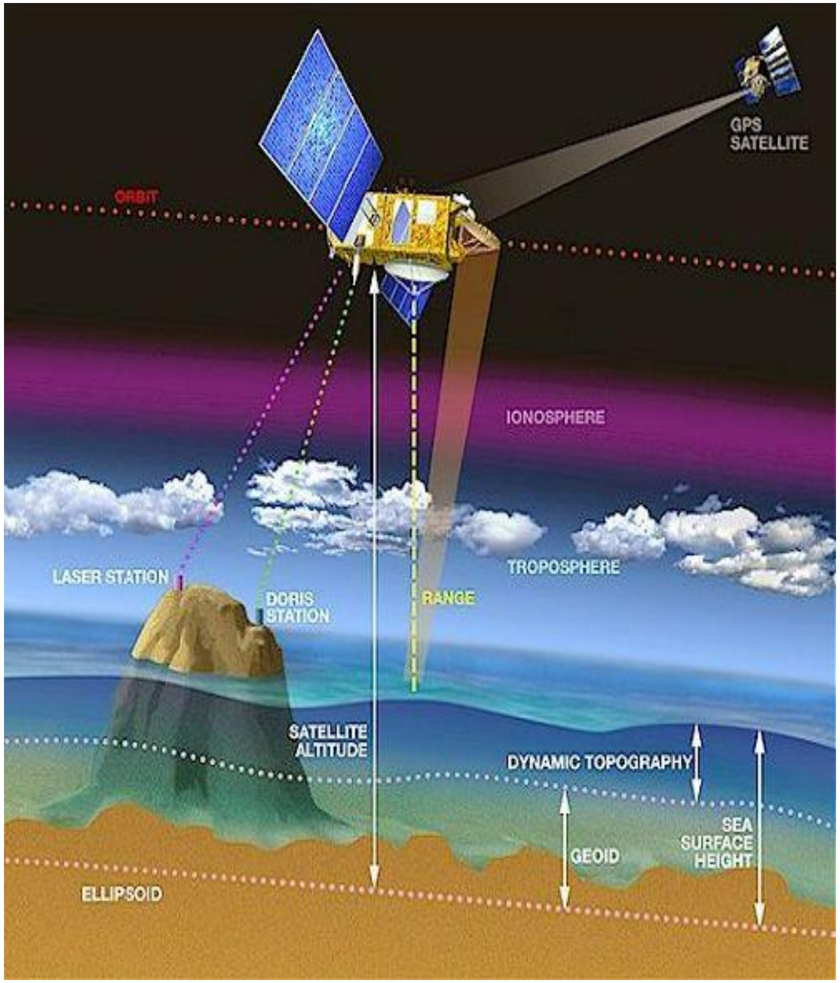


Each signal pulse produced by a radar altimeter consists of coherent electromagnetic energy.

Receiving the echo signal, the sensor measures not only the amplitude but also the phase of the reflected signal and the travel time of the pulse.



Measuring the phase of the signal reflected from the earth surface enables measuring the travel time with very high accuracy.

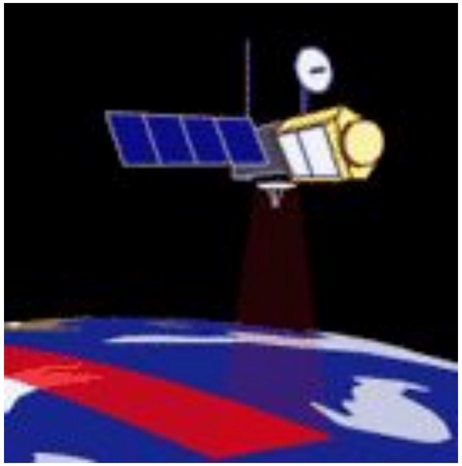


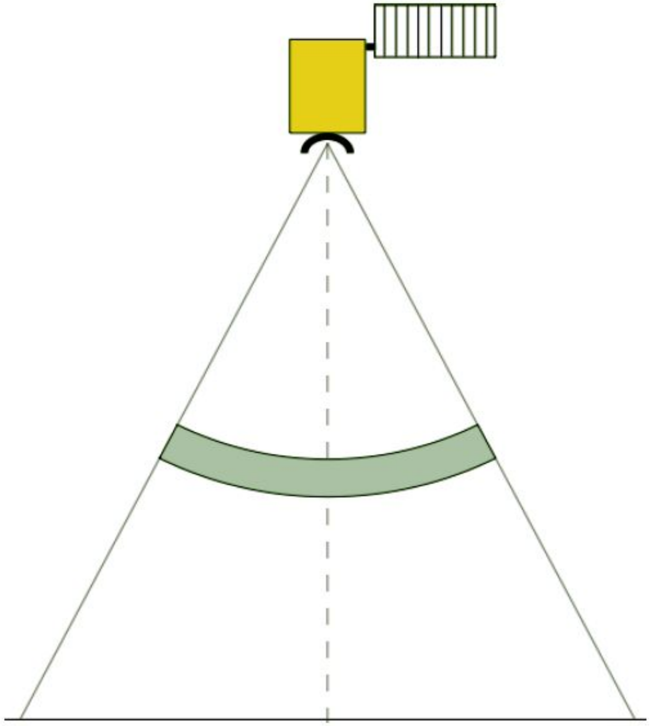
As electromagnetic waves travel through the atmosphere, they can be decelerated by water vapor or by ionization. Once these phenomena are corrected for, the final range R is estimated within 2 cm.

The ultimate aim is to measure the sea level. This requires independent measurements of the satellite orbital trajectory, i.e. exact latitude, longitude and altitude coordinates.

Pulse Limited Altimeter

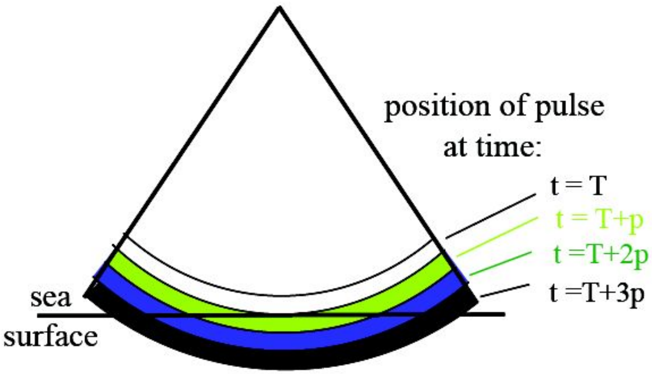
- In a pulse limited altimeter the shape of the return is dictated by the length (width) of the pulse

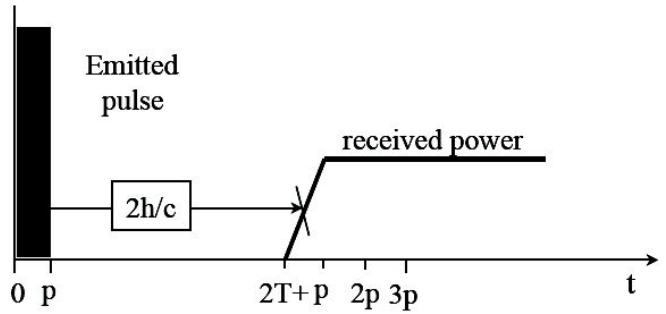


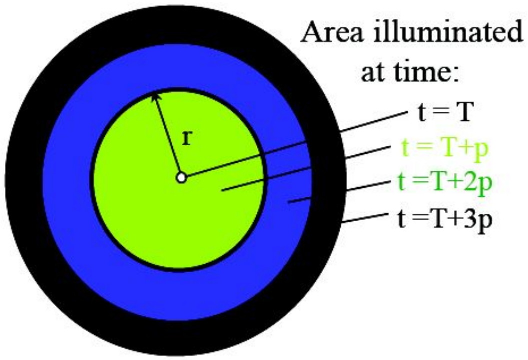


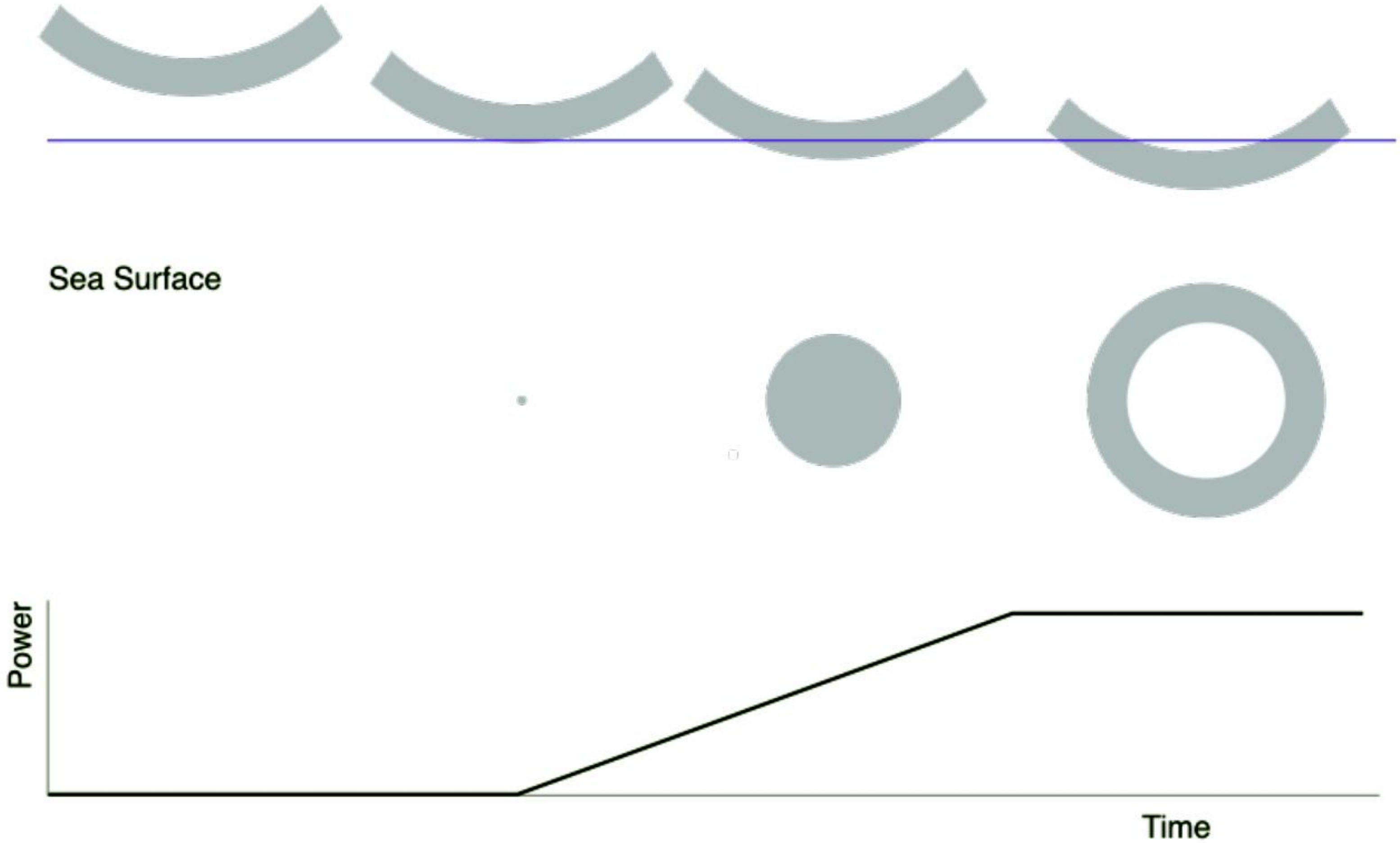
The "pulse-limited" footprint

- Full illumination when rear of pulse reaches the sea – then area illuminated stays constant
- Area illuminated has radius $r = \sqrt{(2hcp)}$
- Measure interval between mid-pulse emission and time to reach half full height

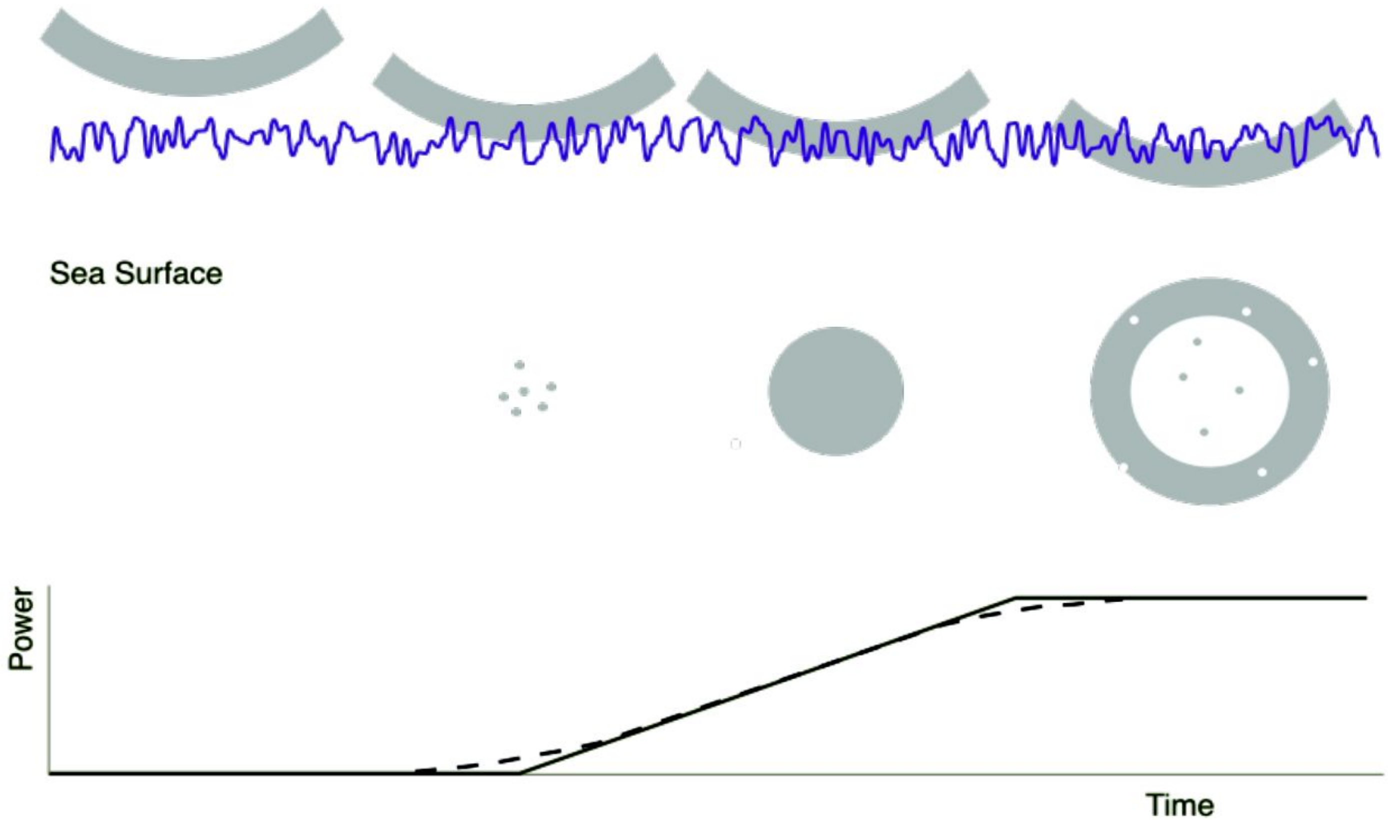


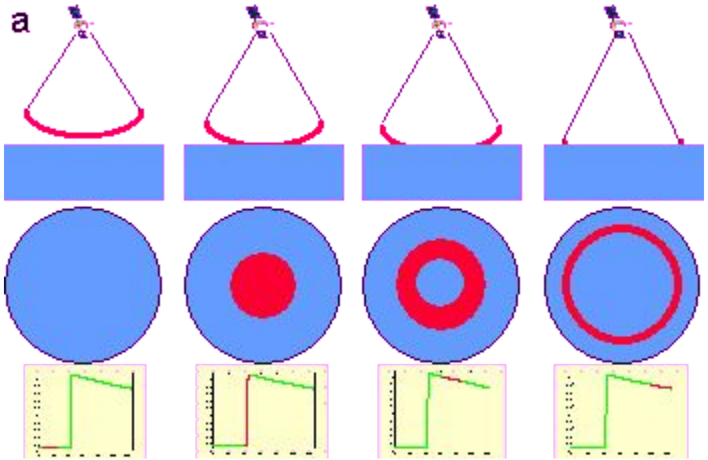




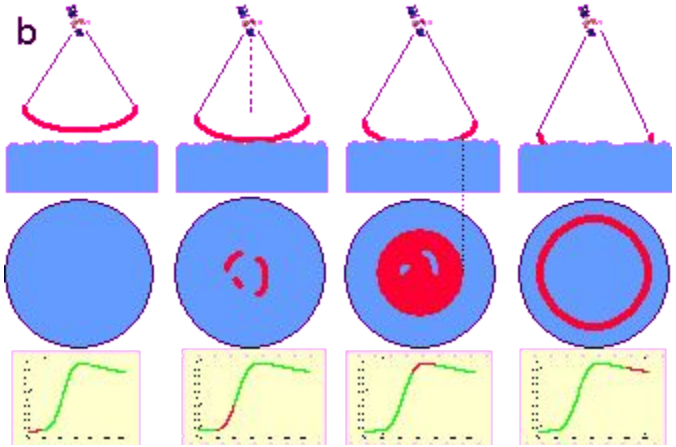

Sea Surface
Power
Time

If we add waves ...



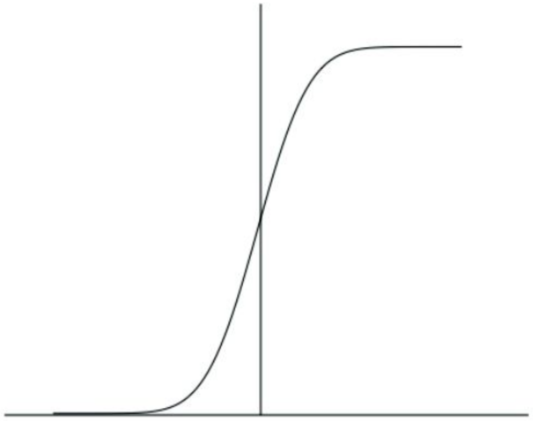


Flat surface



Wavy surface

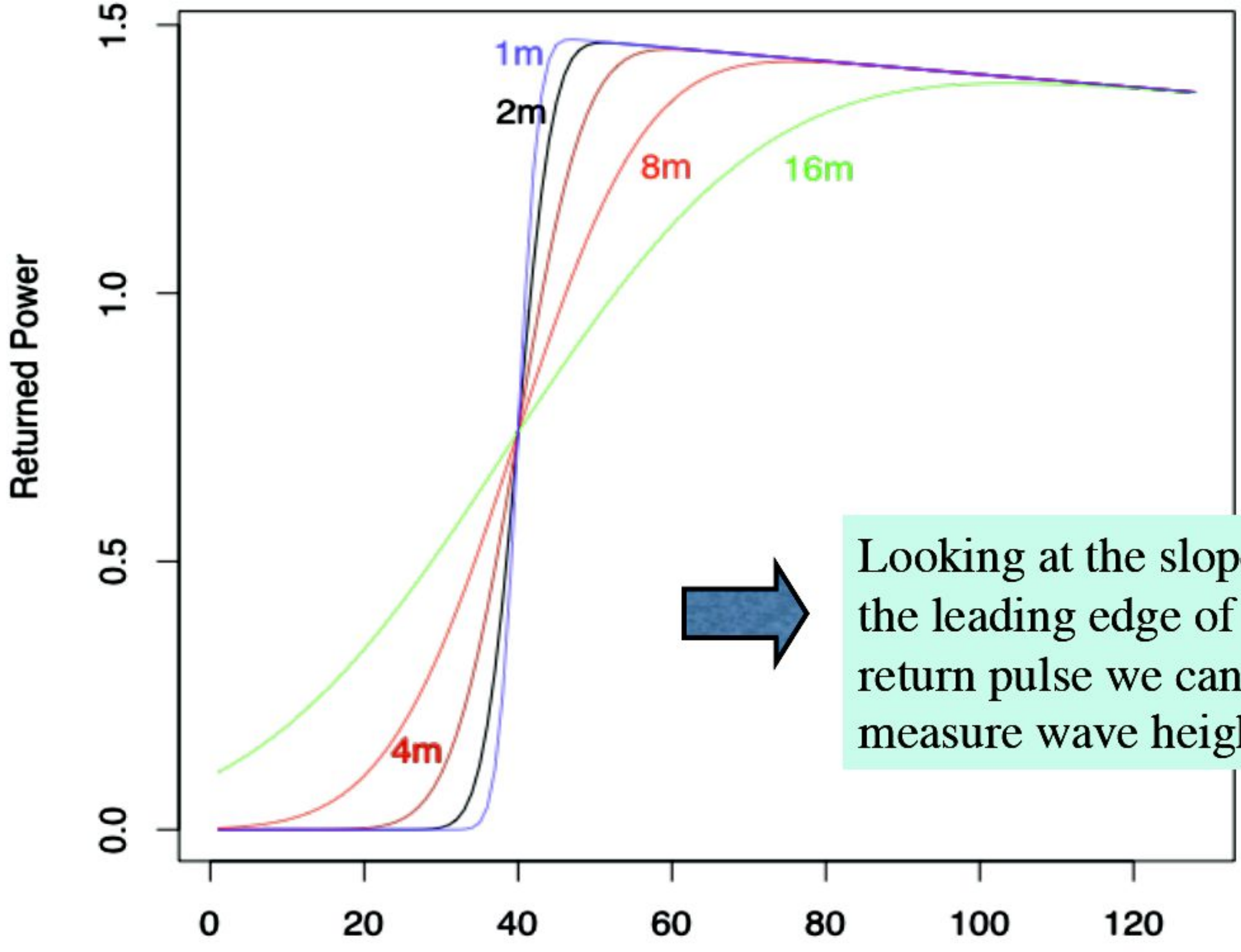
- A plot of return power versus time for a pulse limited altimeter looks like the integral of the heights of the specular points, i.e. the cumulative distribution function (cdf) of the specular scatterers



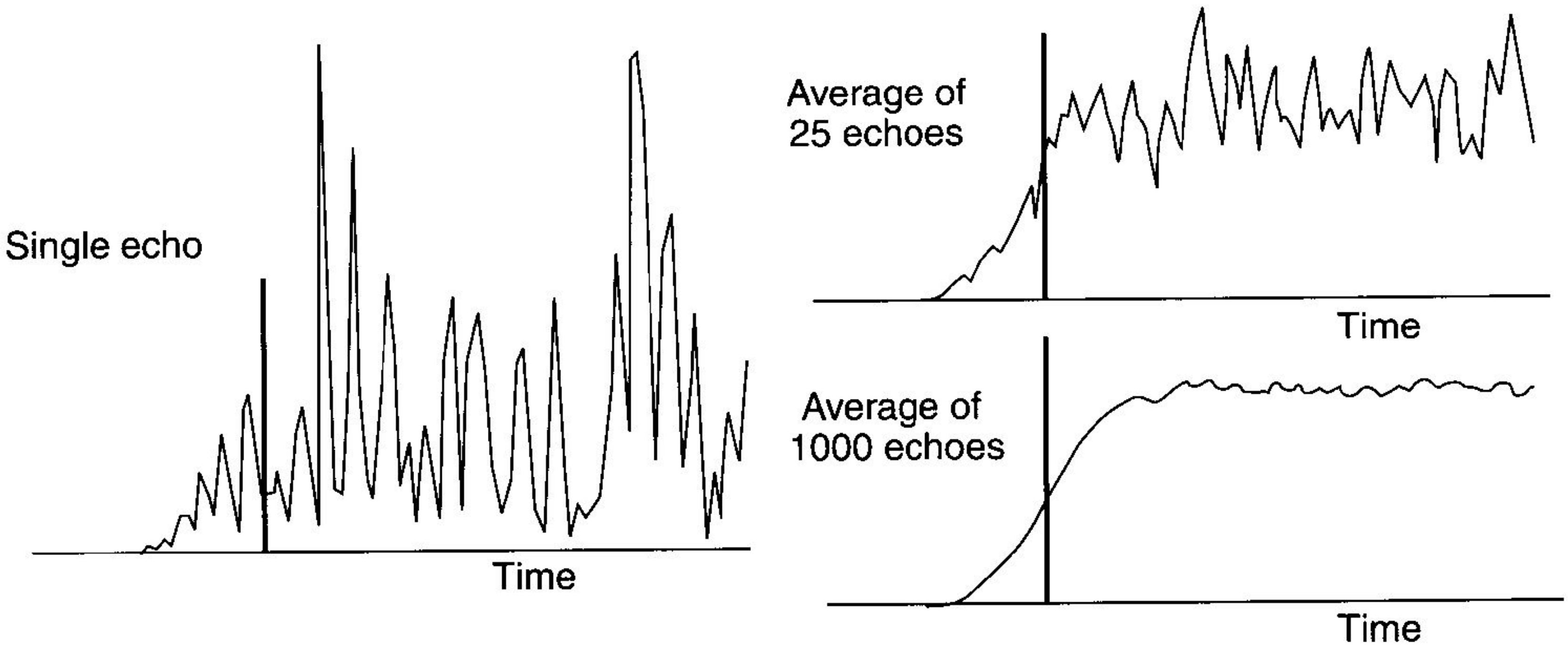
The tracking point is the half power point of the curve

Hs (m)	Effective footprint (km) (800 km altitude)	Effective footprint (km) (1335 km altitude)
0	1.6	2.0
1	2.9	3.6
3	4.4	5.5
5	5.6	6.9
10	7.7	9.6
15	9.4	11.7
20	10.8	13.4

Some example waveforms



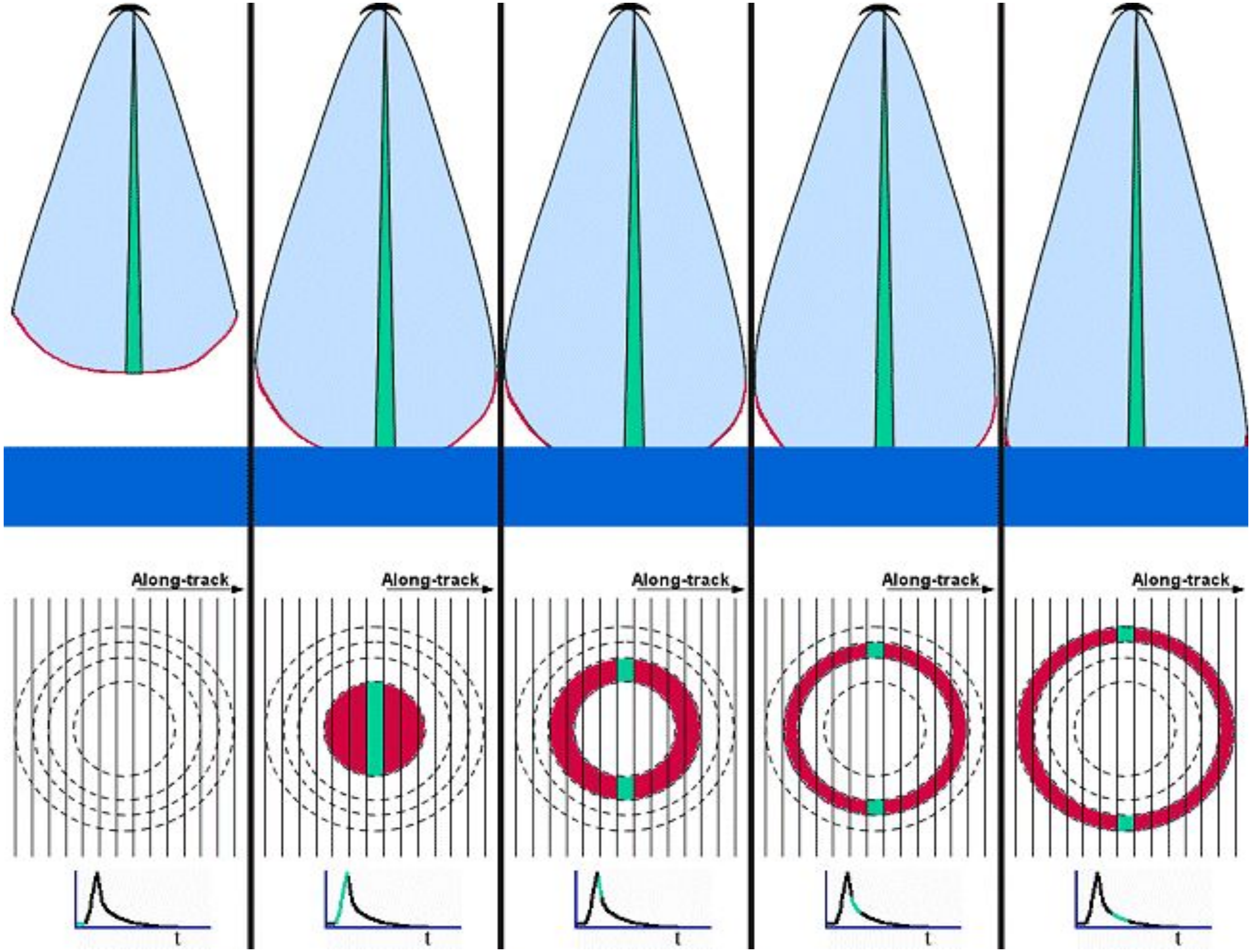
Looking at the slope of the leading edge of the return pulse we can measure wave height!



As a result of random distribution of the ocean wave facets at any instant, each individual return signal is very noisy, but averaging many successive pulses can reduce this.

12h of SAR Altimeters constellation (8 today)

SAR Altimeters (New generation of altimeters)

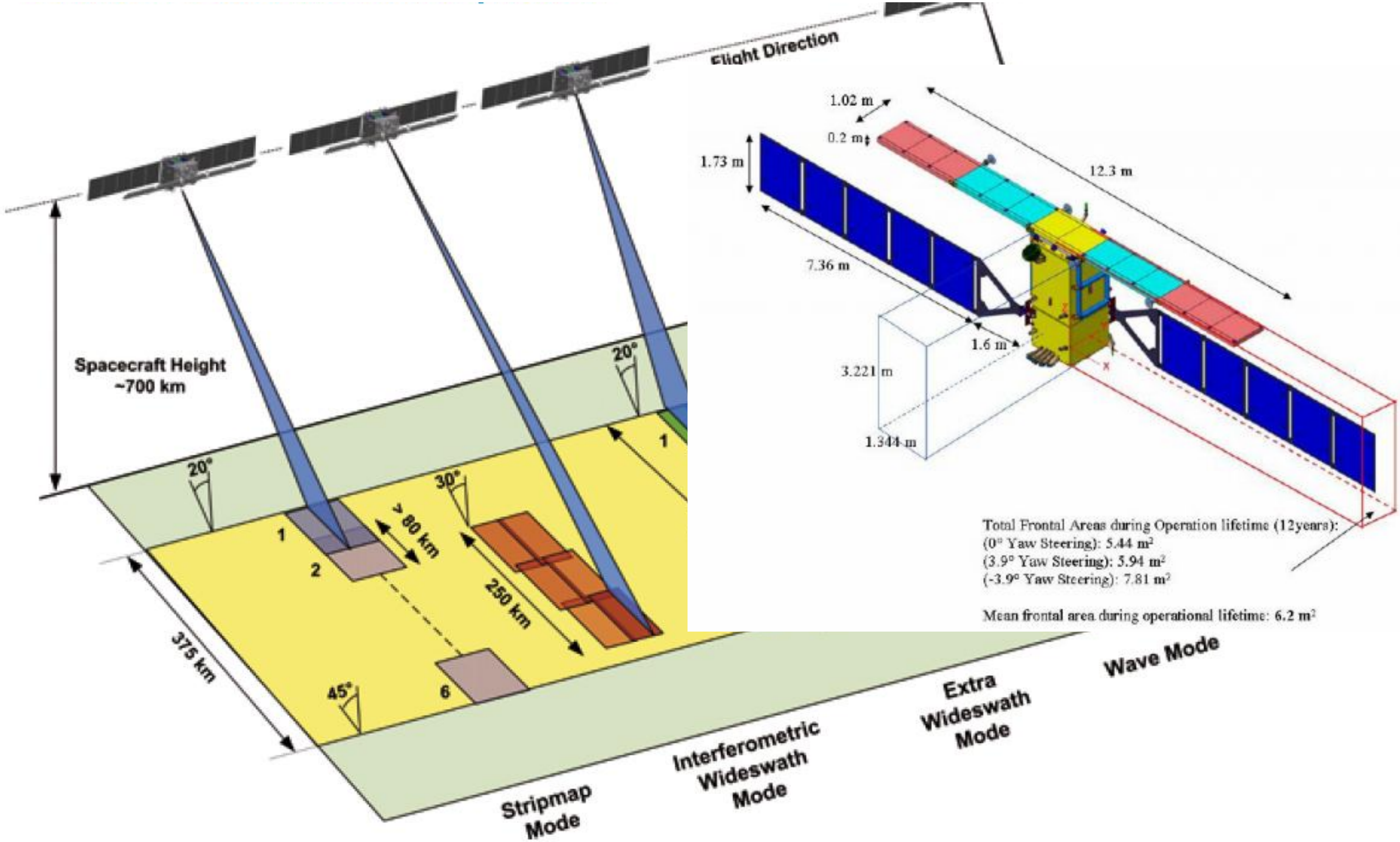


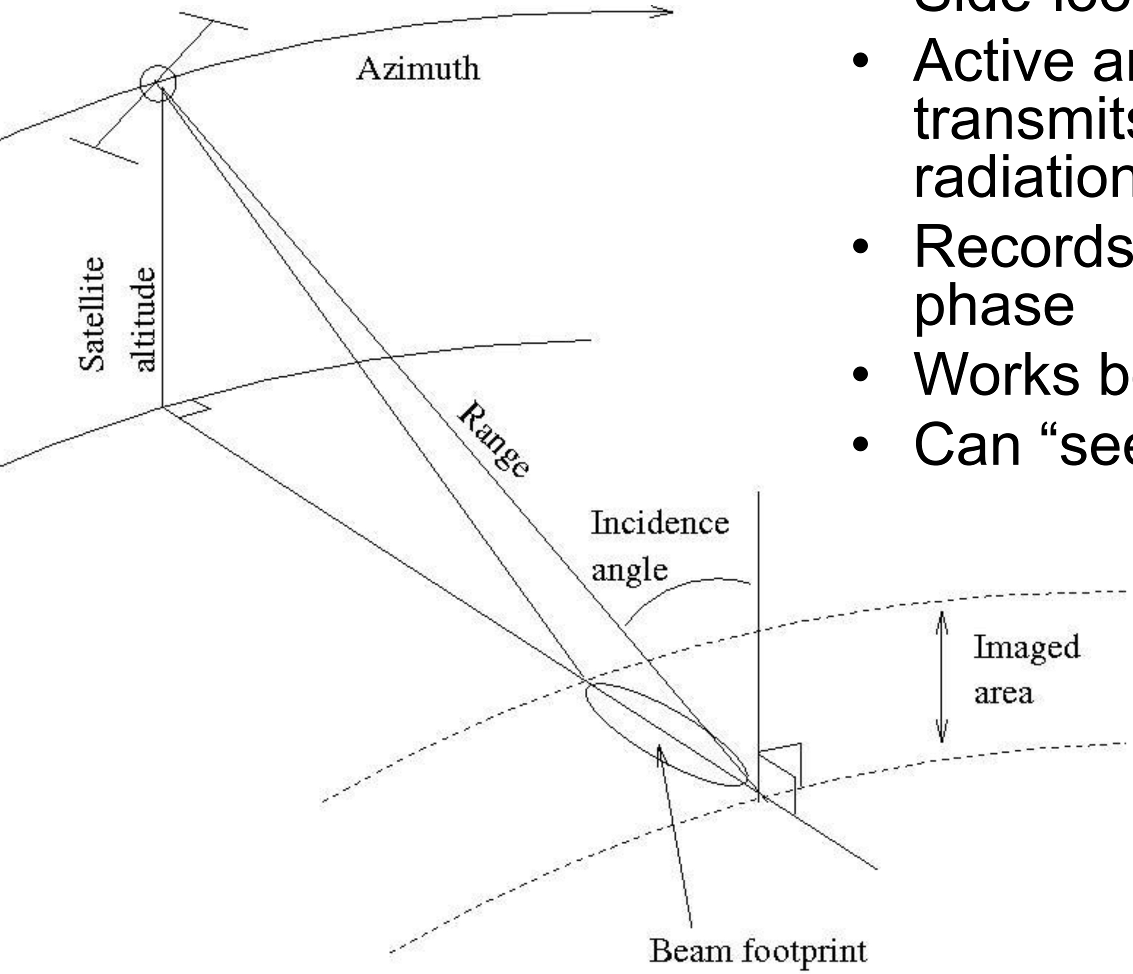
Waves Remote Sensing by Synthetic Aperture Radar (SAR)

OceanDataLab

OVL Workshop, Brest, June 2022

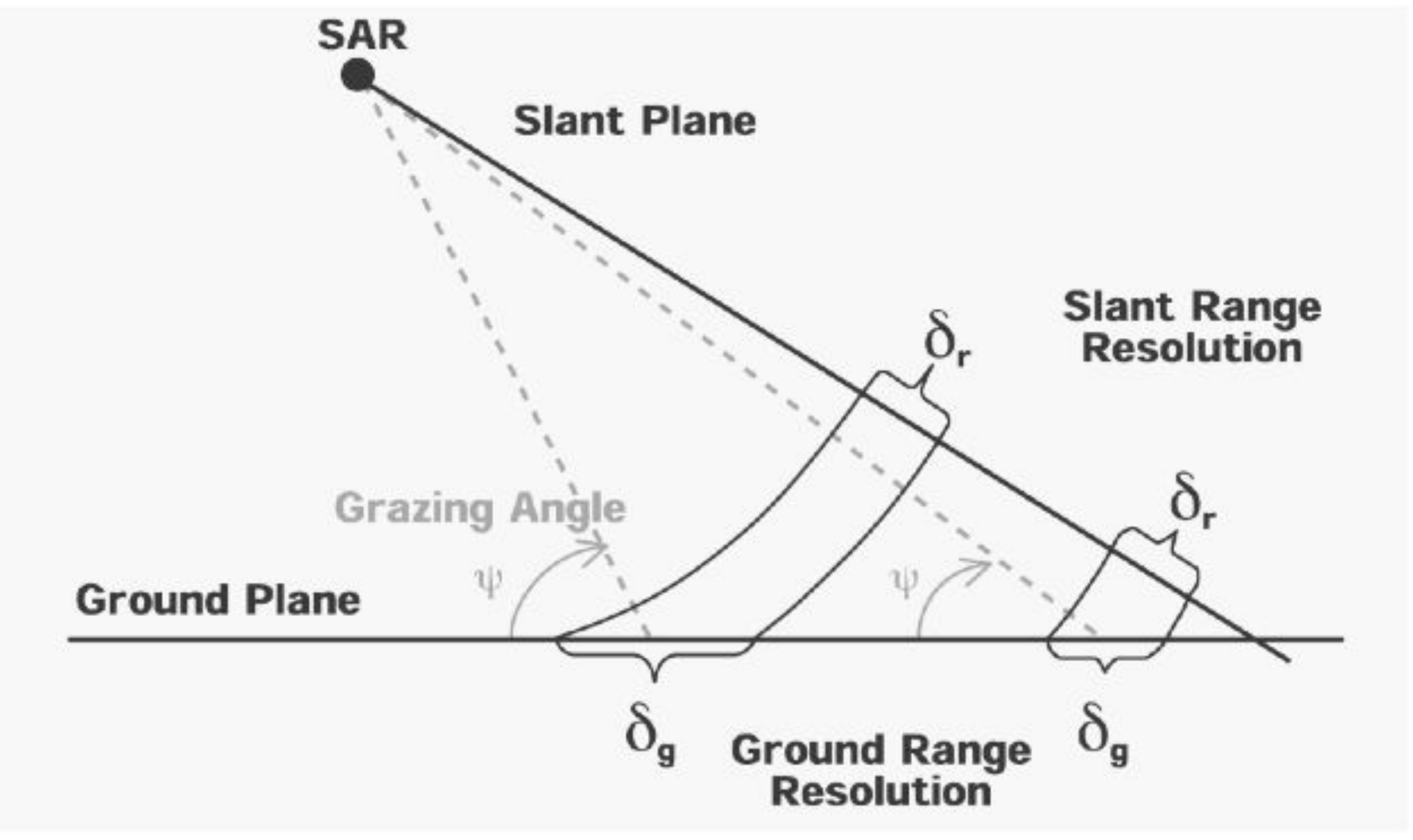
Sentinel-1 A&B (ESA,Copernicus)





- Side-looking
- Active antenna that transmits/receives electromagnetic radiation in VV, HH, VH, HV pol
- Records both signal amplitude and phase
- Works both day and night
- Can “see” through clouds

Ranges

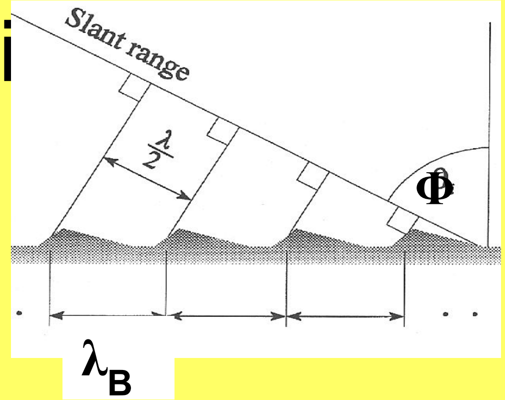


SAR
Slant Plane
Slant Range
Resolution
δr
δr
Grazing Angle
ψ
ψ
Ground Plane
δg
Ground Range
Resolution
δg

Scattering

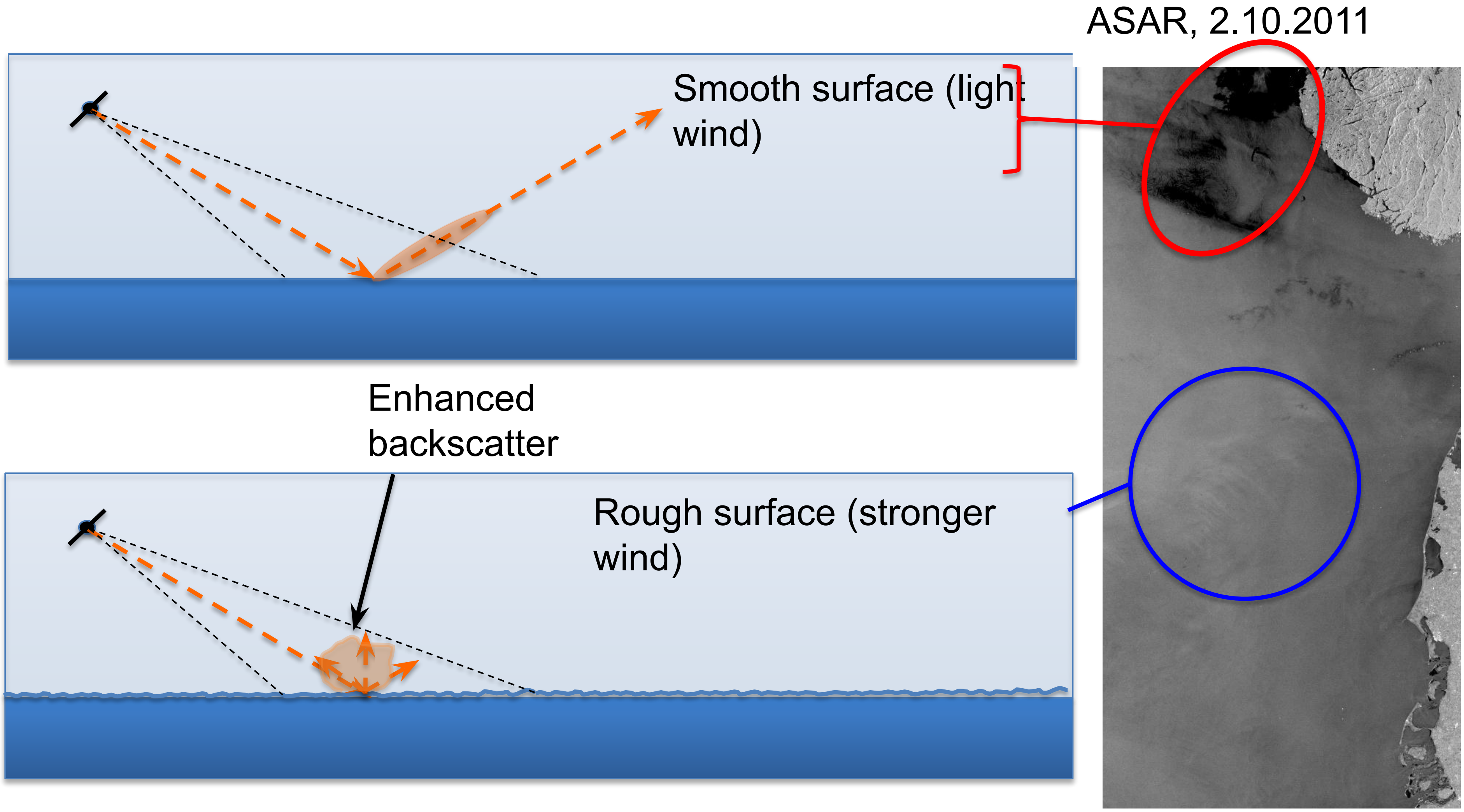
At oblique incidence angles, the SAR backscattering arising from the sea surface is caused by surface waves of the order of the radar wavelength.

These waves are called “ Bragg waves“. They obey the “ Bragg resonance conditi



$$\lambda_B = \lambda_r / 2 \sin\Phi$$

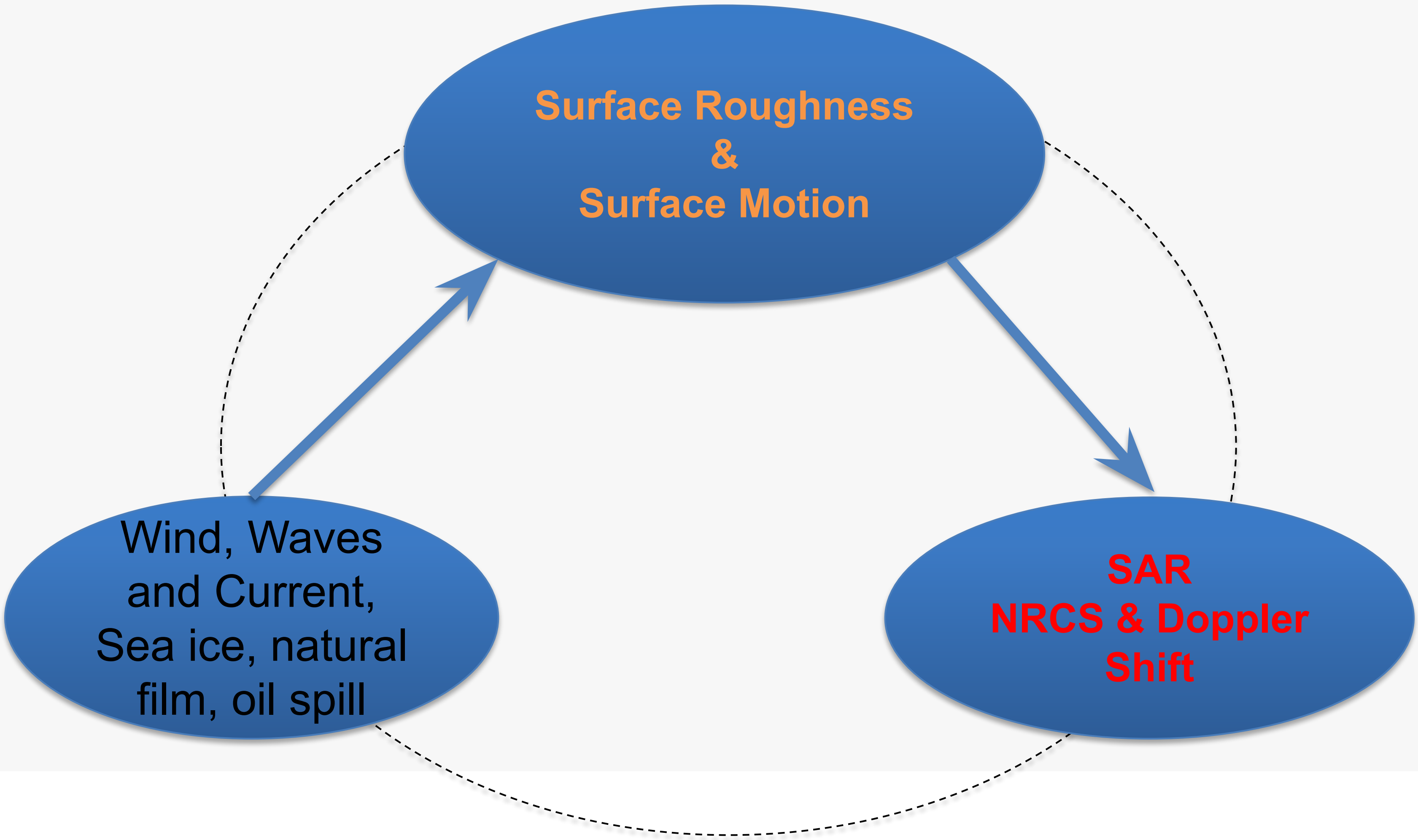
where λ_B = Bragg wavelength, λ_r = radar wavelength, and Φ= incidence angle


ASAR, 2.10.2011
Smooth surface (light wind)
Enhanced backscatter
Rough surface (stronger wind)

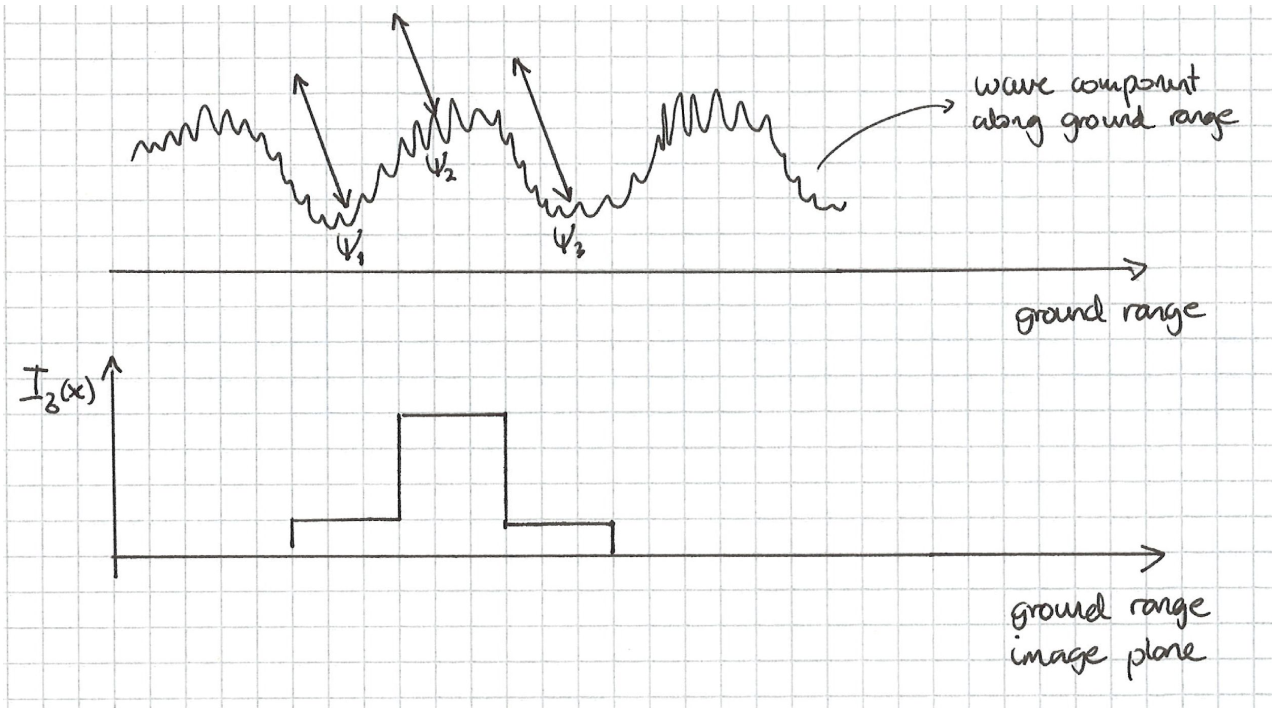
The ocean surface roughness is influenced by wind and waves, currents, surface slicks and sea ice and is often different in open ocean versus coastal or ice covered regions due to fetch effects

The surface roughness is the source for the backscatter of the SAR signal.

The signal that arrives at the antenna is registered both in *Amplitude and Phase*.


Surface Roughness
&
Surface Motion
Wind, Waves
and Current,
Sea ice, natural
film, oil spill
SAR
NRCS & Doppler
Shift

The Hydrodynamic Effect:

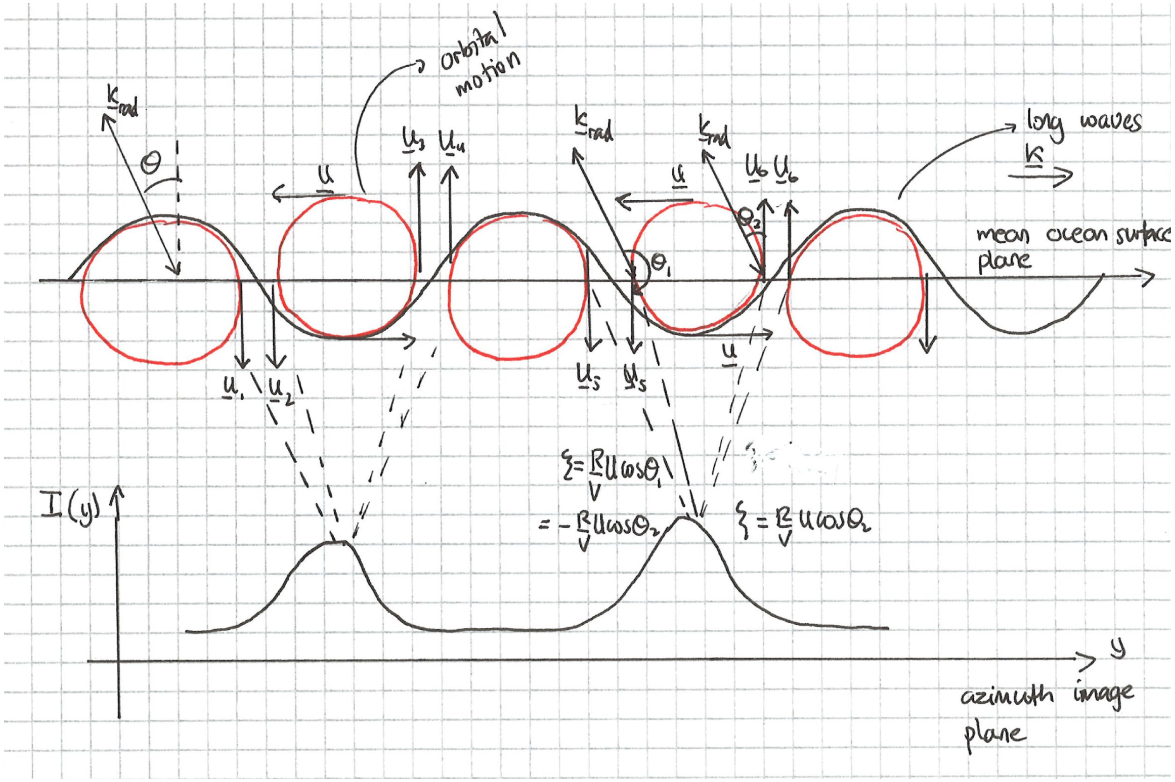


Backscattered energy density of radar resonant capillary waves spatially modulated by longer waves due to wave/wave and wave/wind interactions. The result is a spatial modulation in the backscatter image intensity

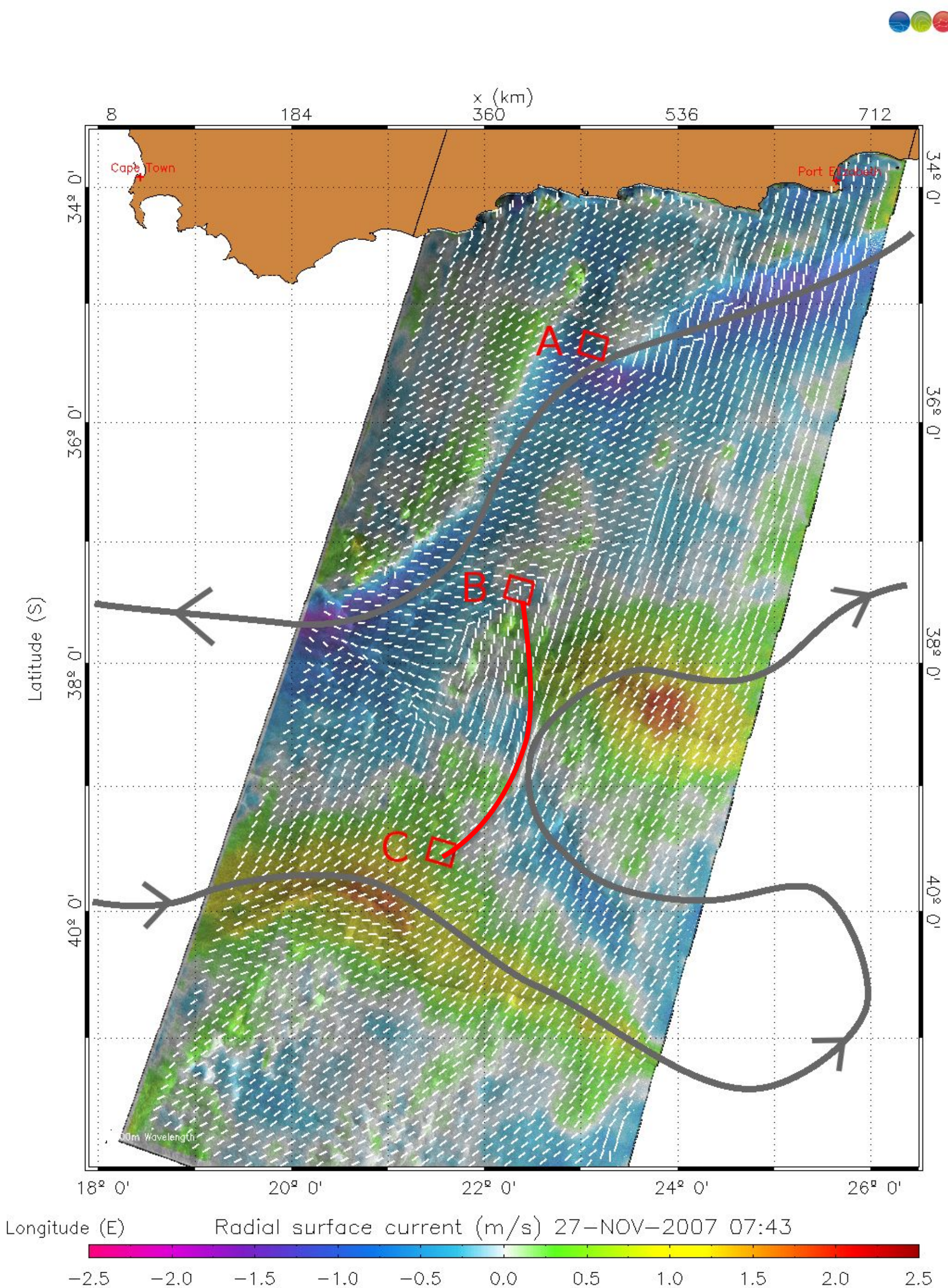
The Tilt Effect:

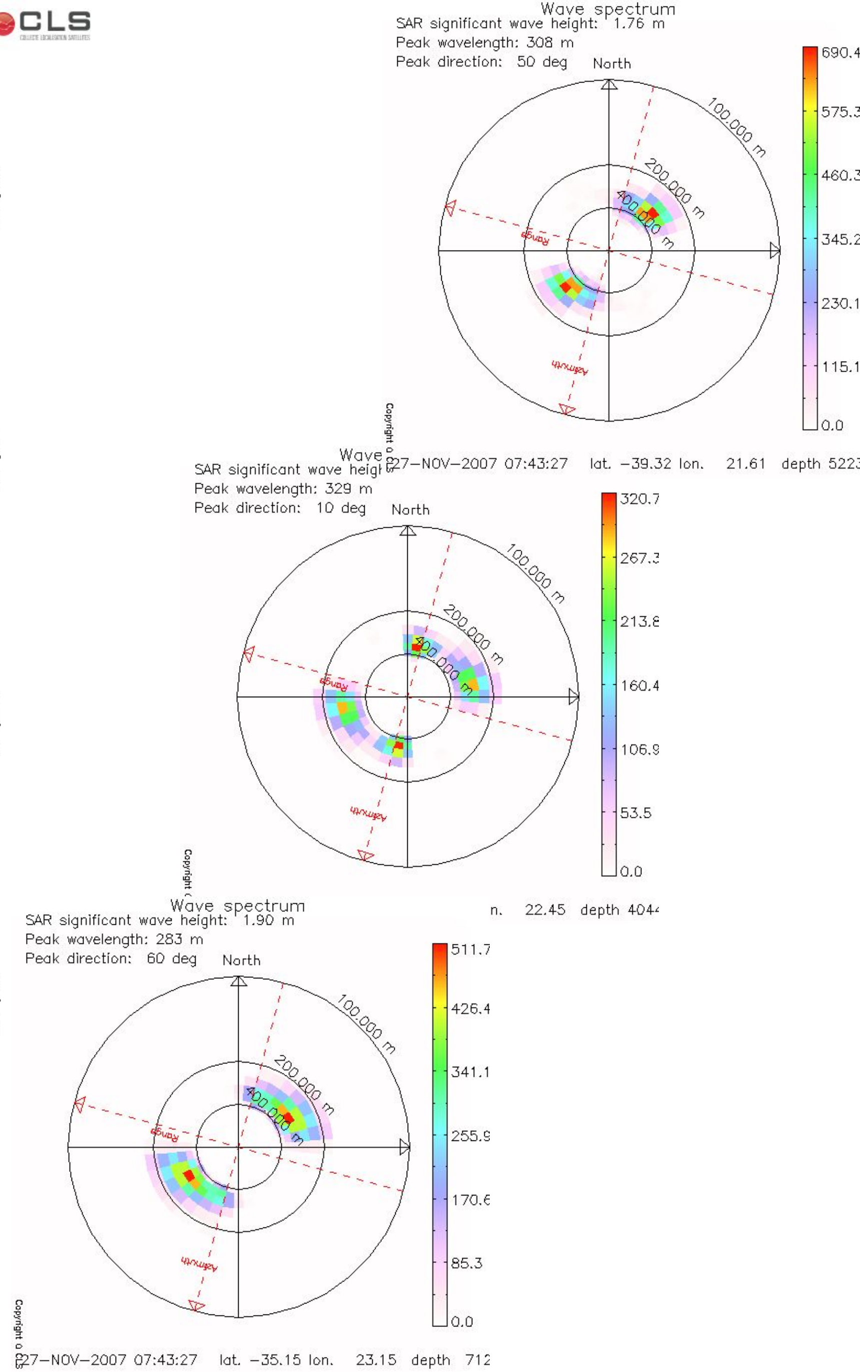
Backscattered energy density of radar resonant capillary waves spatially modulated by longer waves due to change in local incidence angle. The result is a spatial modulation in the backscatter image intensity

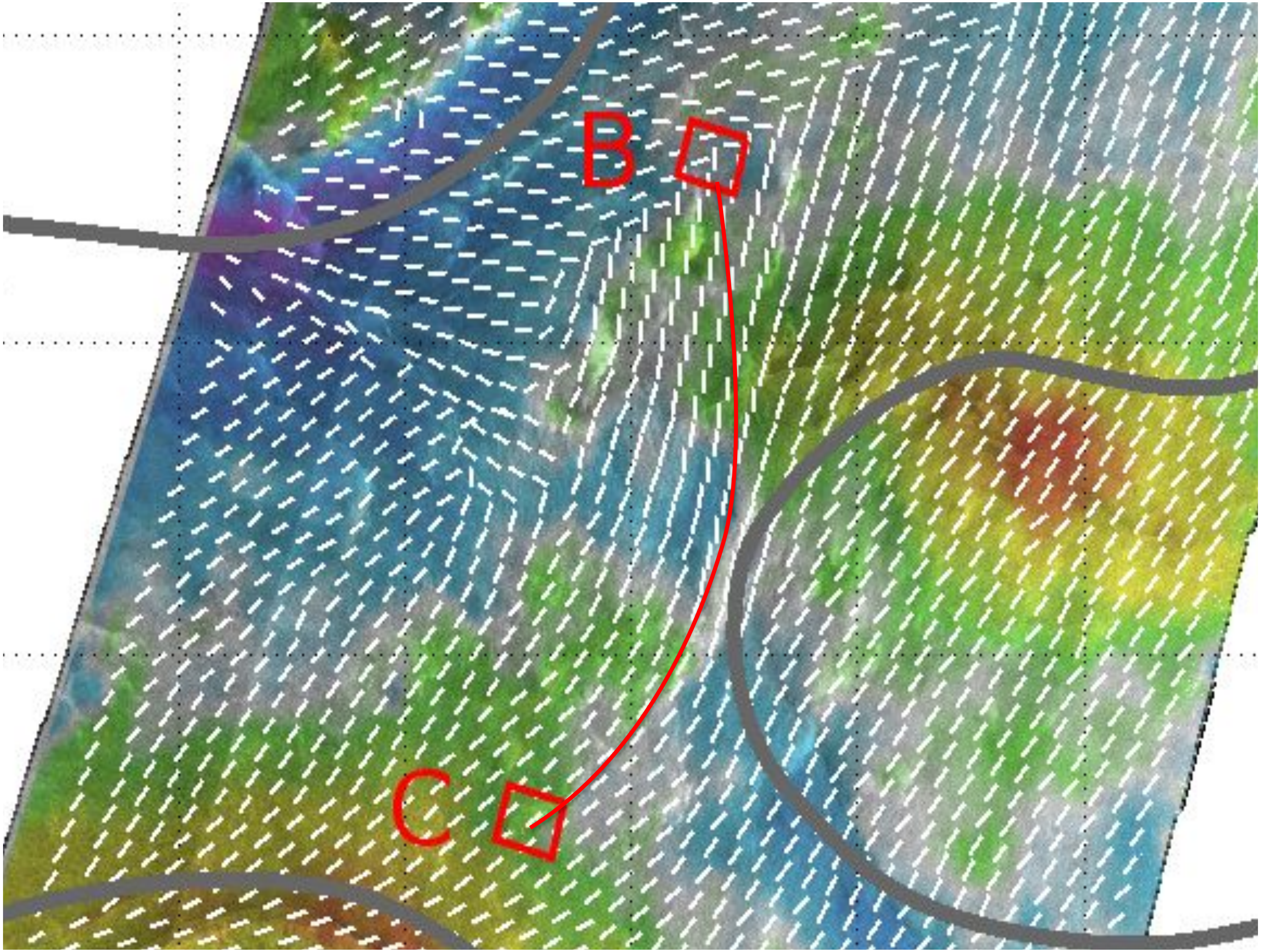
The Velocity Bunching (SAR) Effect:



The backscattered energy of the radar resonant capillary waves are shifted in azimuth by the Doppler effect due to the orbital motion of the scatterer on the longer waves. The result is a spatial modulation in azimuth in the SAR image intensity


CLS
x (km)
8
184
360
536
712
Cape Town
Port Elizabeth
A
B
C
34° 0'
36° 0'
38° 0'
40° 0'
Latitude (S)
18° 0'
20° 0'
22° 0'
24° 0'
26° 0'
Longitude (E)
Radial surface current (m/s) 27–NOV–2007 07:43
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5

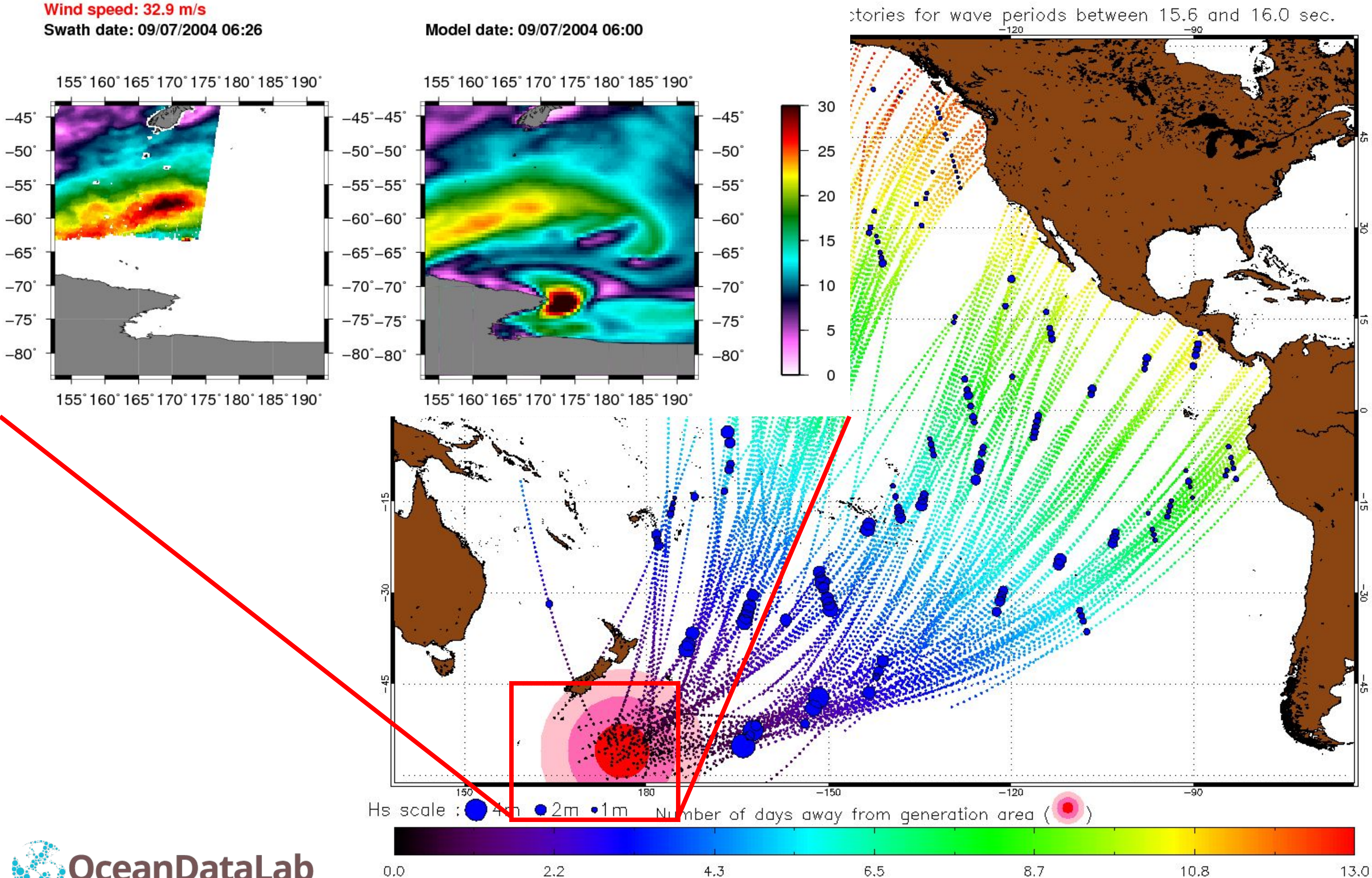

Wave spectrum
SAR significant wave height: 1.76 m
Peak wavelength: 308 m
Peak direction: 50 deg
North
100.000 m
200.000 m
400.000 m
Range
Azimuth
690.4
575.3
460.3
345.2
230.1
115.1
0.0
27–NOV–2007 07:43:27 lat. −39.32 lon. 21.61 depth 5223
Wave
SAR significant wave heigh
Peak wavelength: 329 m
Peak direction: 10 deg
320.7
267.3
213.8
160.4
106.9
53.5
0.0
n. 22.45 depth 4044
Wave spectrum
SAR significant wave height: 1.90 m
Peak wavelength: 283 m
Peak direction: 60 deg
511.7
426.4
341.1
255.9
170.6
85.3
0.0
27–NOV–2007 07:43:27 lat. −35.15 lon. 23.15 depth 712


B
C

Firework analysis : Principle

- Extraction of swell systems parameters from SAR WAVE MODE level2 products.
- Backward propagation to identify the swell origin (Storm source)
- Identification of all swell observations relative to a given Storm source.
- Determination of the propagation path by forward and backward propagation between observations (dispersion relationship).

Propagation of 15-16s swell from July 8 to July 20, 2004



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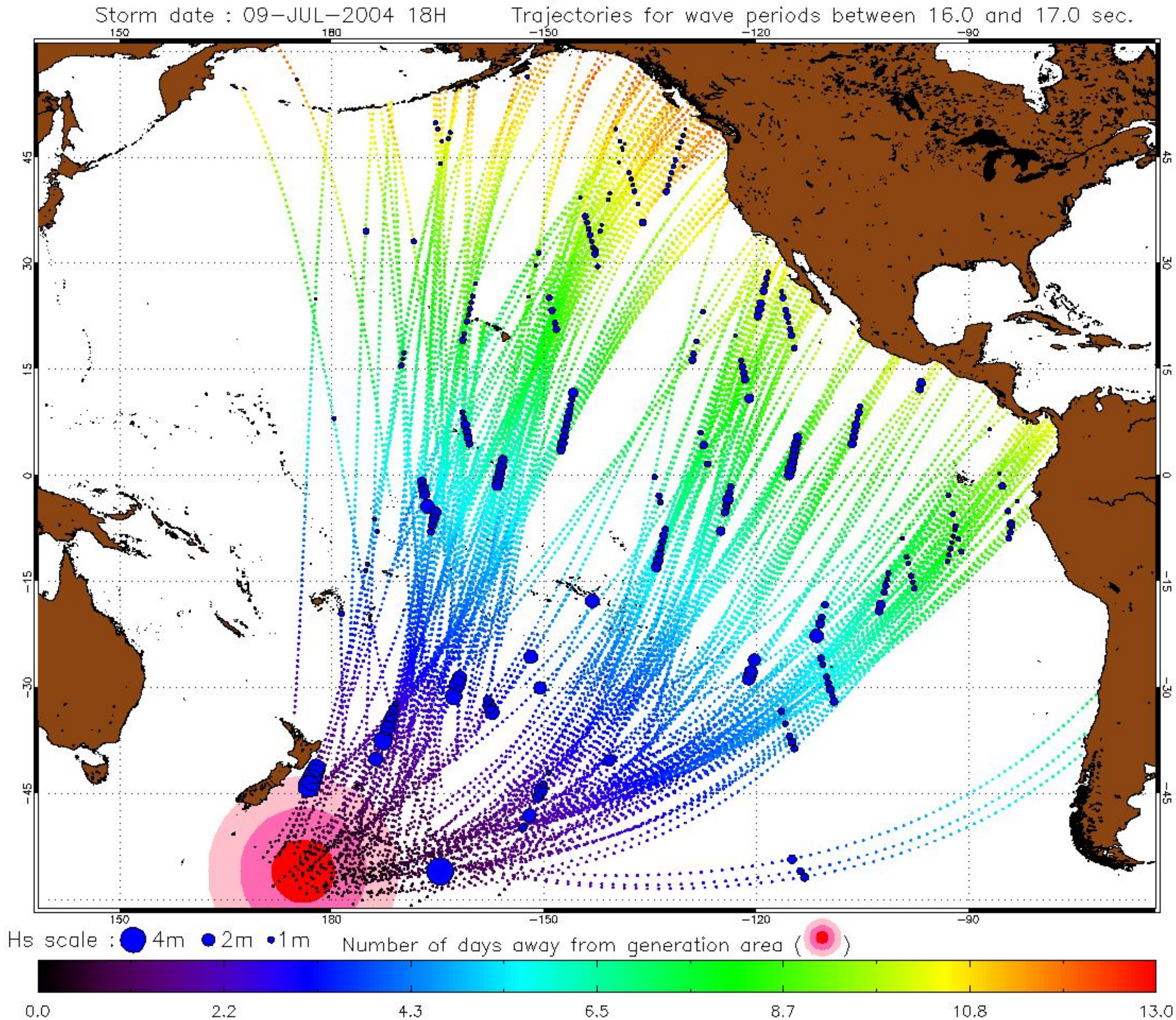
Propagation of 16-17s swell from July 8 to July 20, 2004



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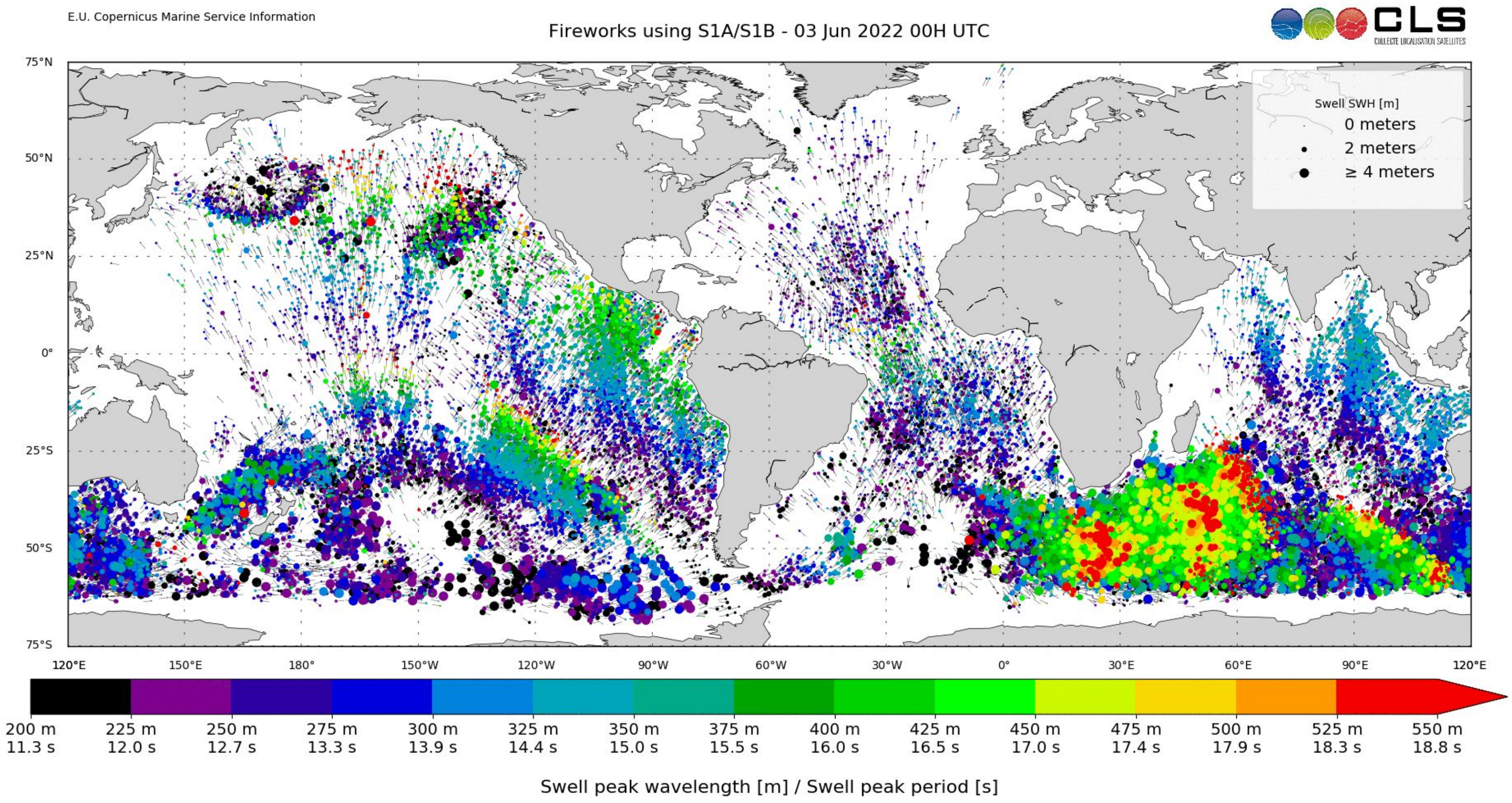
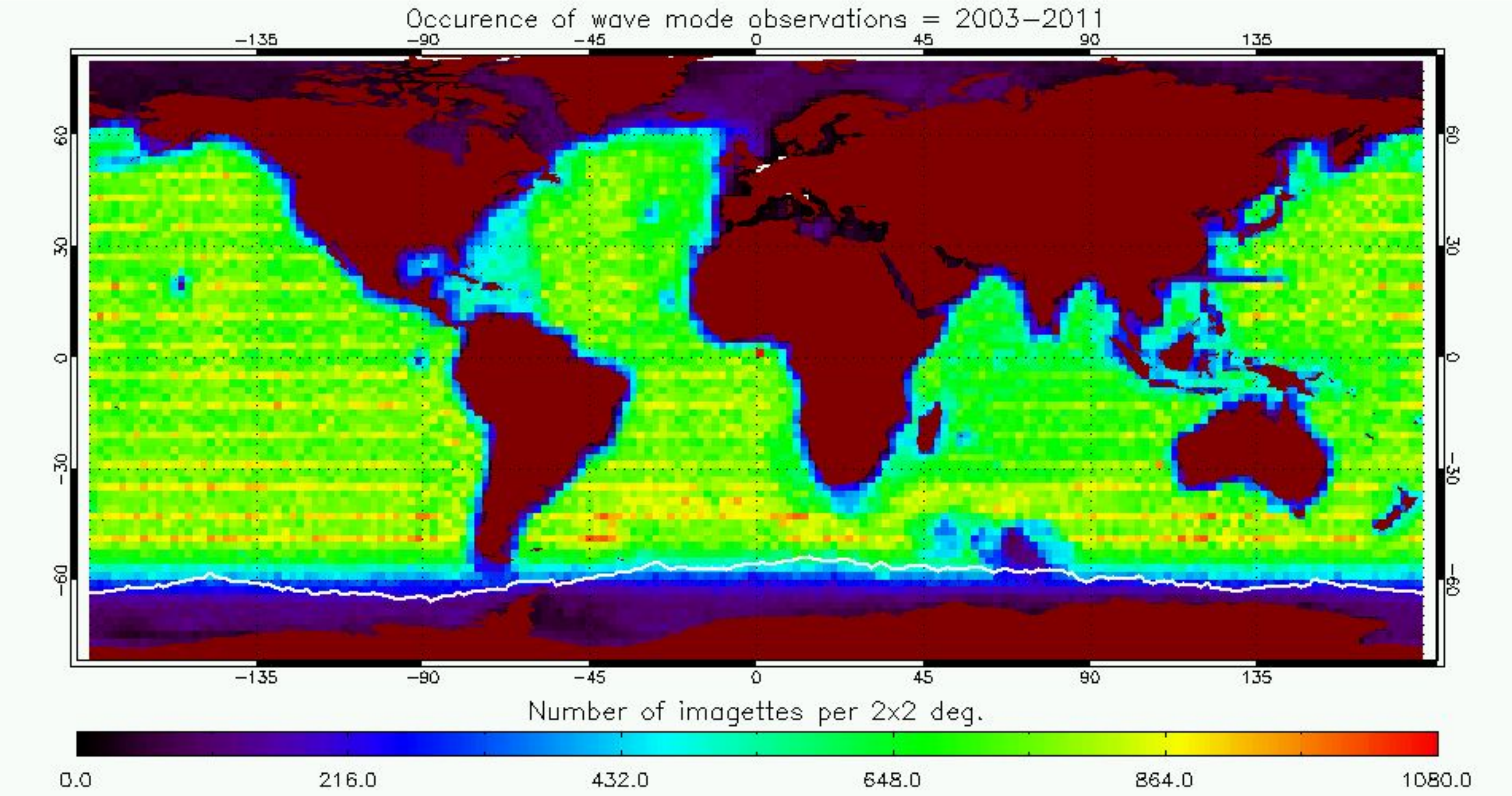
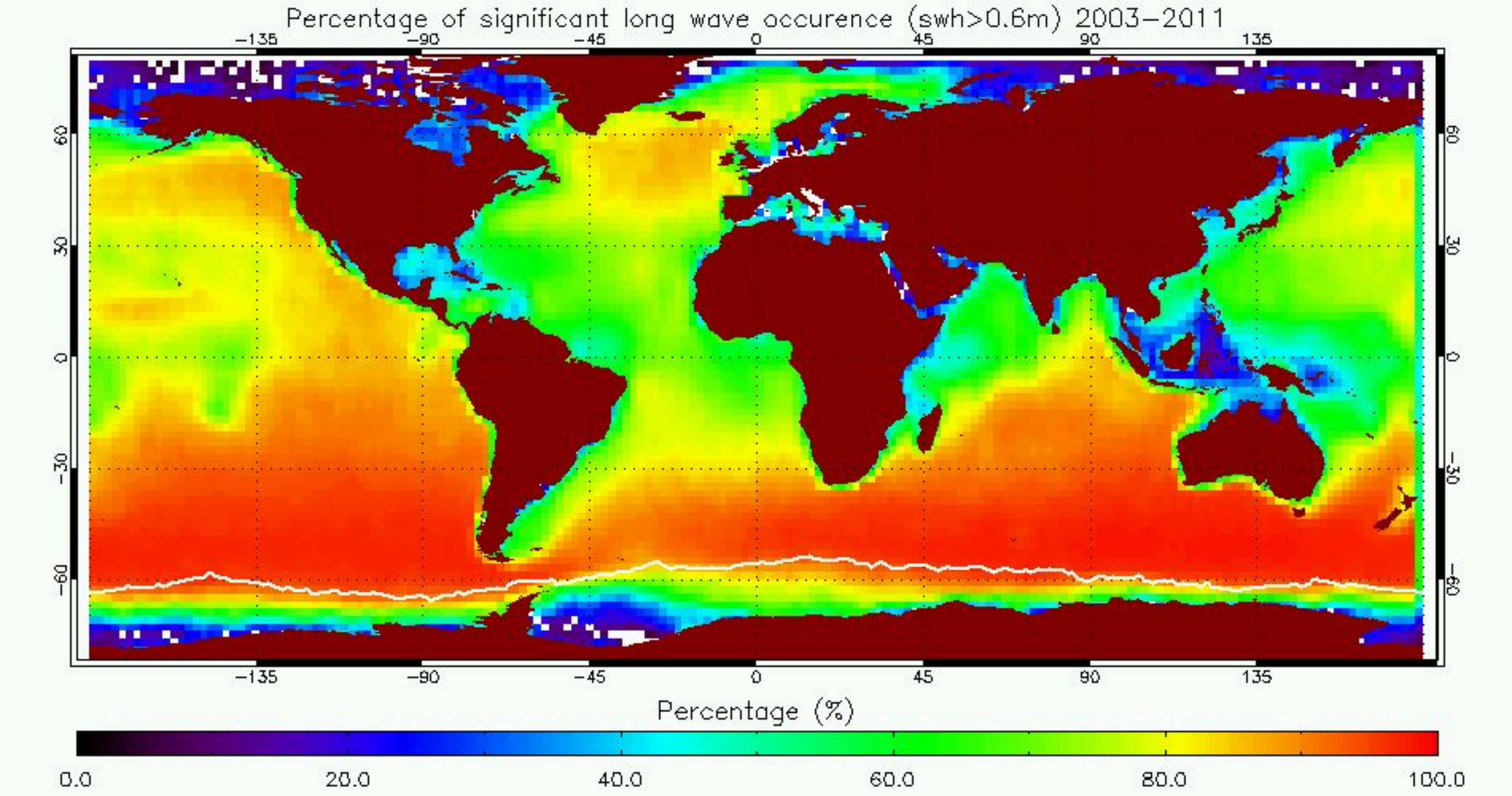
Today with Sentinel-1A&B Wave mode



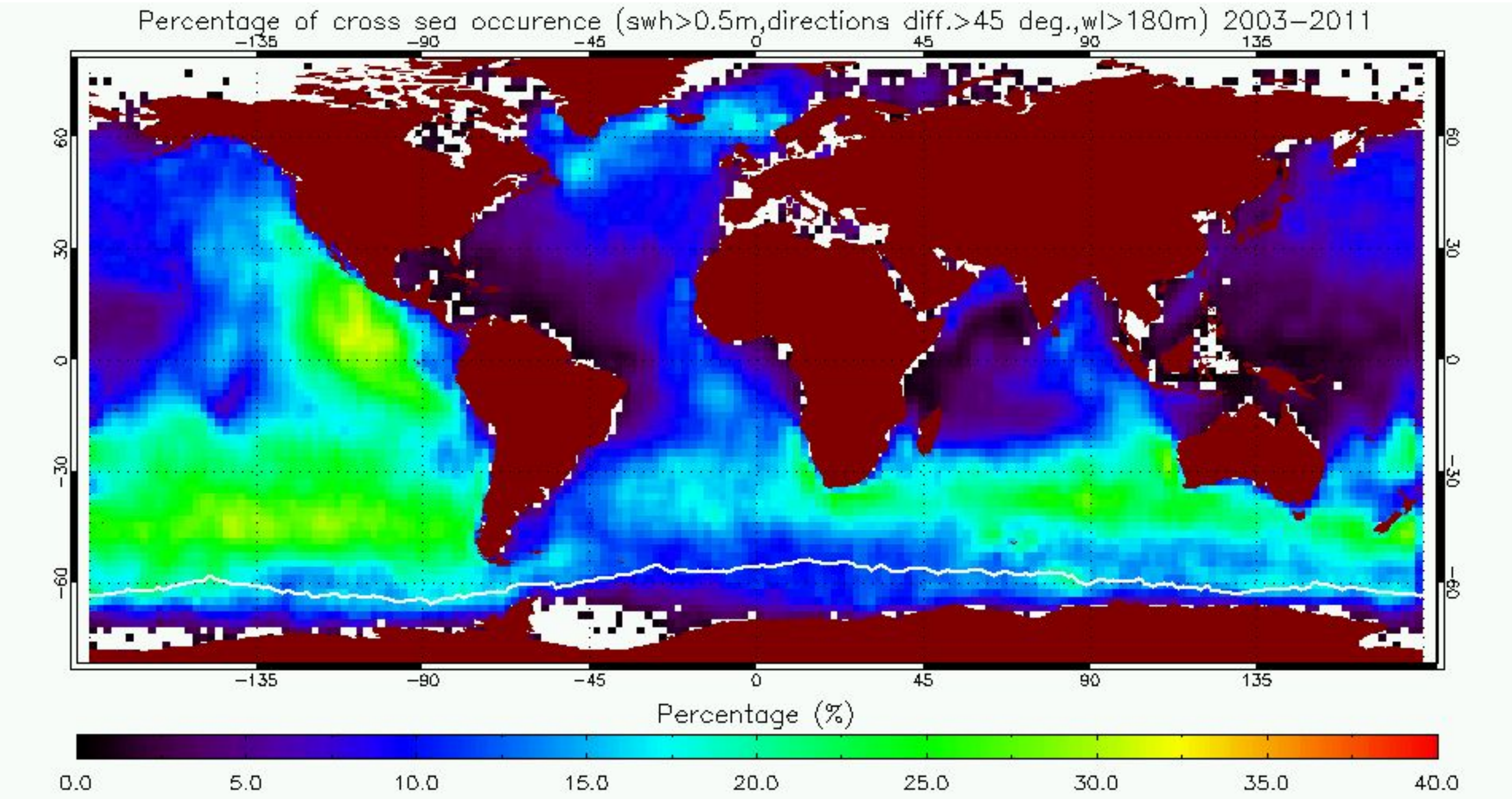
Statistical analysis ENVISAT ASAR Wave mode



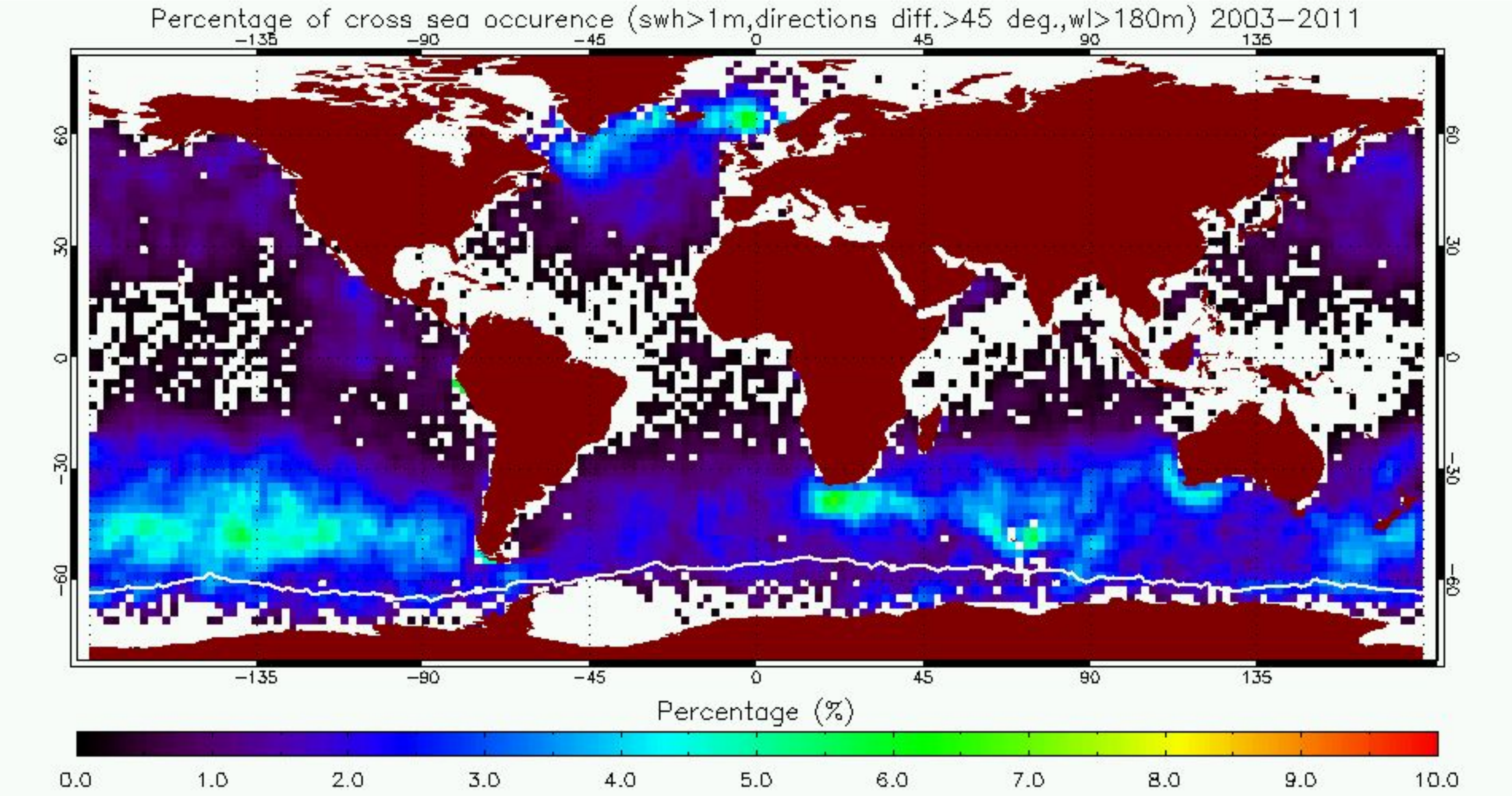
Percentage of detected long waves/swell



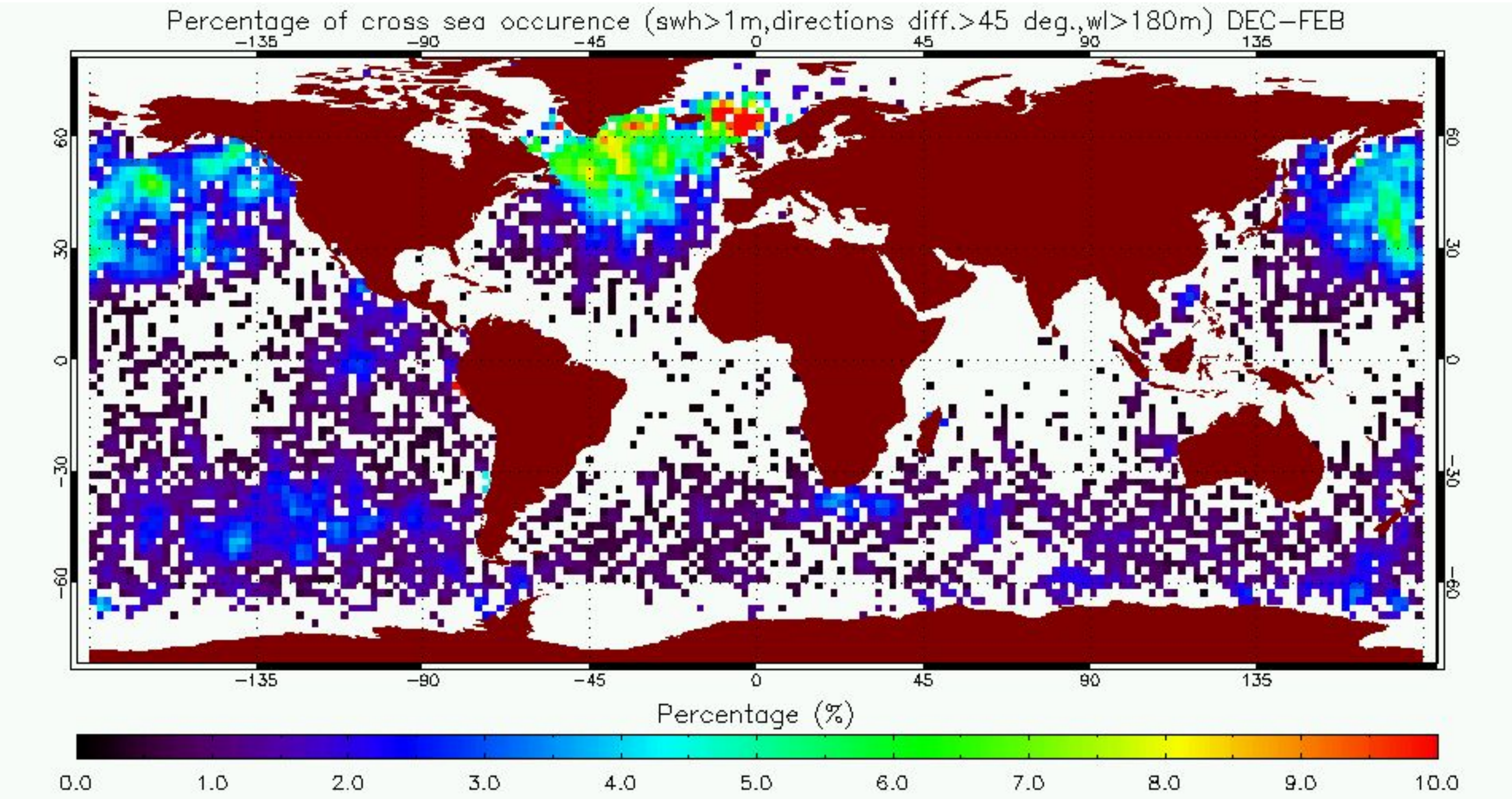
Percentage of detected cross swells

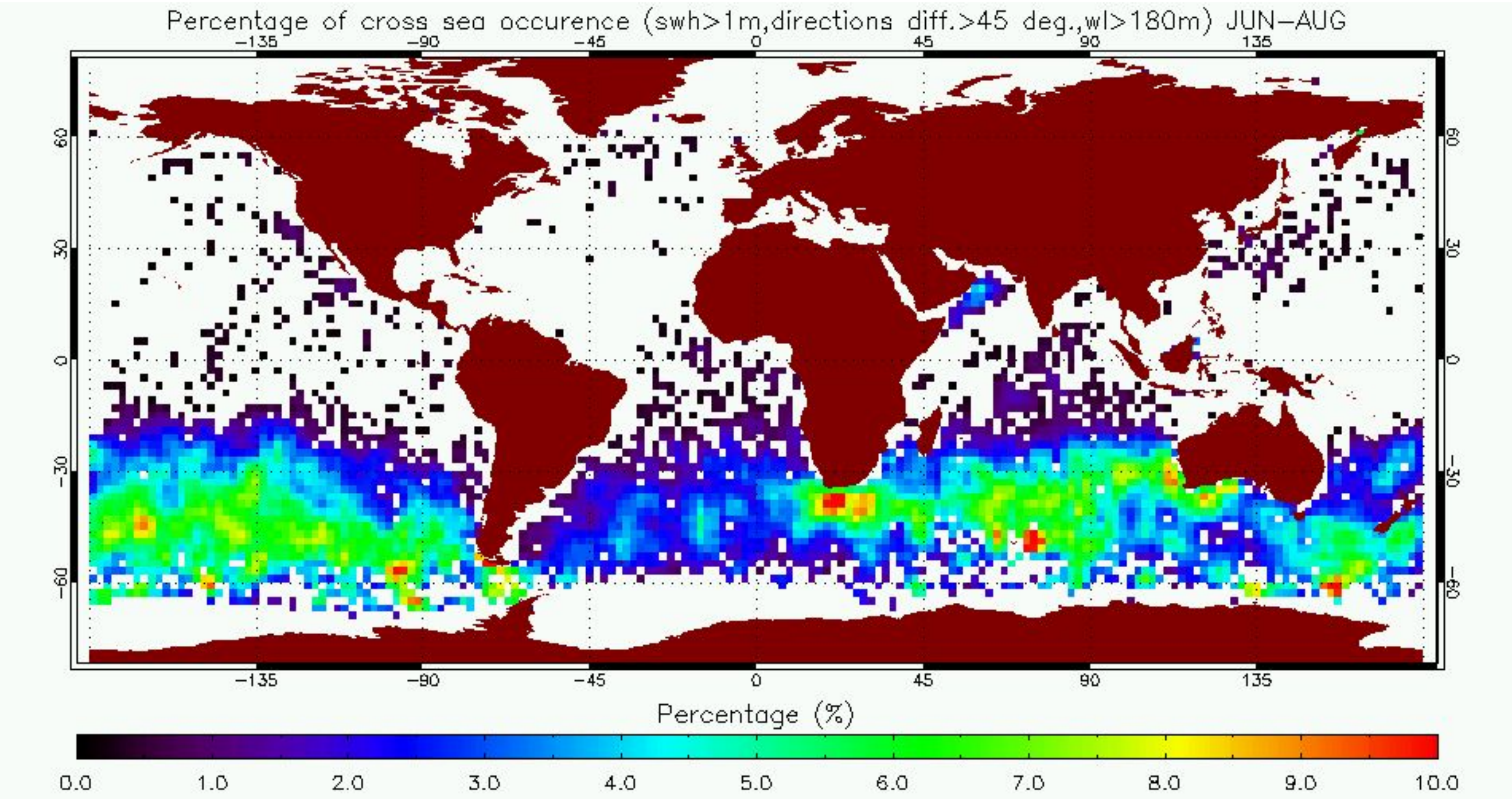


Percentage of detected cross swells > 1m Hs



Seasonal variability of cross swells > 1m Hs





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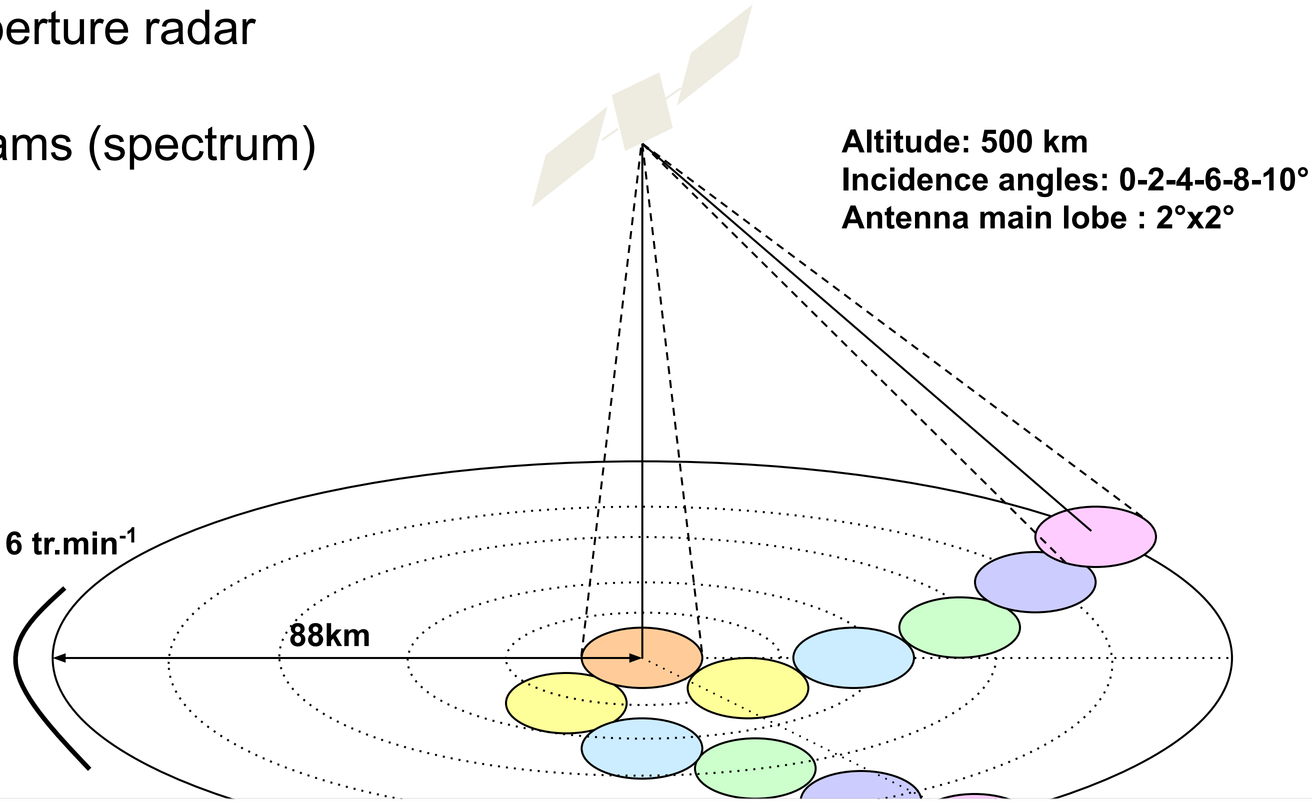
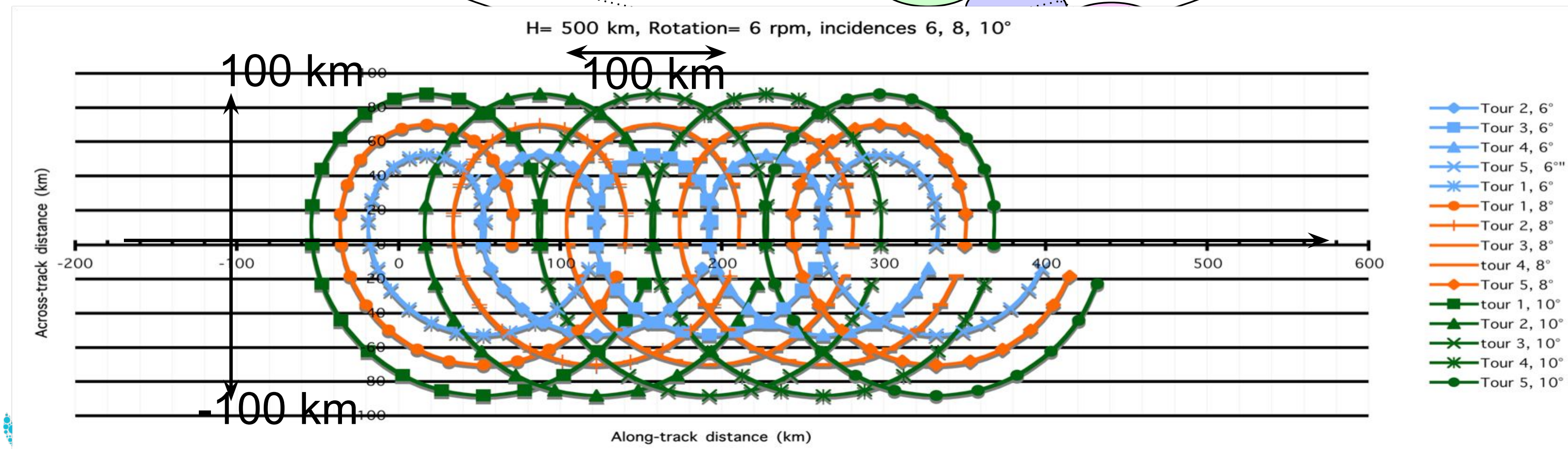
CFOSAT (launched in 2018) Wind and wave observations from space: A French-Chinese mission

Scientific Pis:
Lotfi Aouf (France): Météo-France (previously Danièle Hauser)
Liu Jianqiang (China): NSOA
and the Mission and Technical Team

SWIM instrument

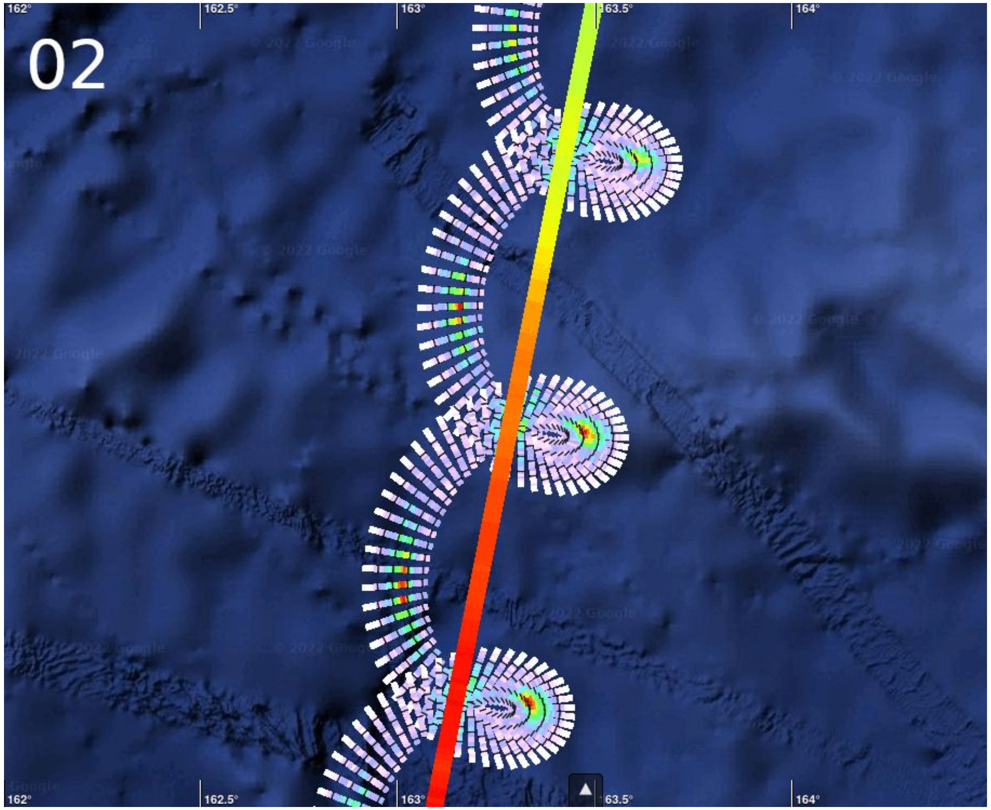
SWIM: real aperture radar
1 nadir beam
5 off-nadir beams (spectrum)





SWIM instrument

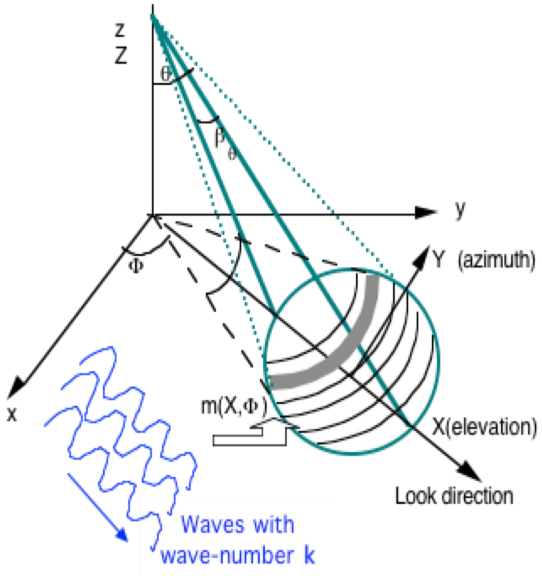
- SWIM (Surface Wave Investigation and Monitoring) measures the ocean surface wave related modulations in Ku band using a rotating instrument
- In nominal macrocycle mode, it provides a directional 1D wave spectra
    - every ~7 degrees
    - for each of its 5 beams at 2, 4, 6, 8, and 10° incidence angle
    - resulting in a very special cycloid ground footprint geometry.



Example of 1D raw spectra projected over range footprint With nadir Hs

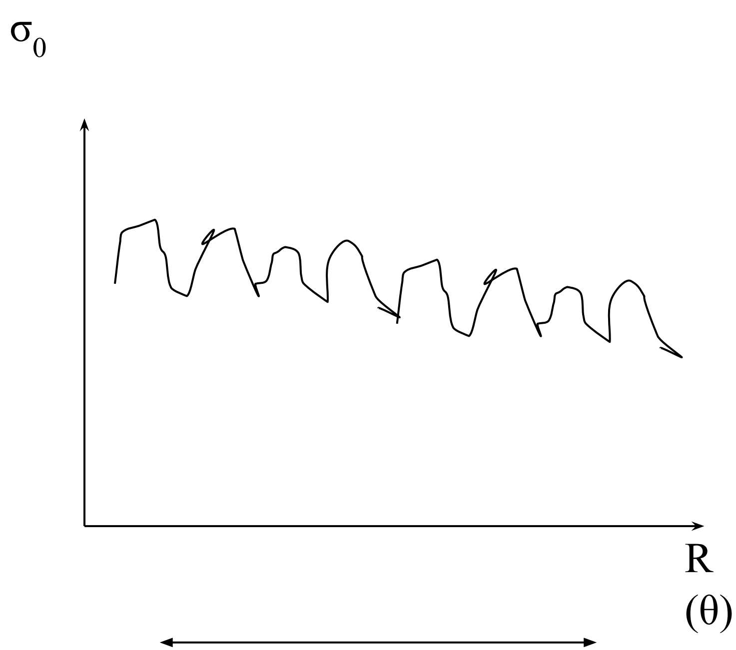
-Near Real time transmission of data (within 3 hours)

Principle for estimating wave spectra

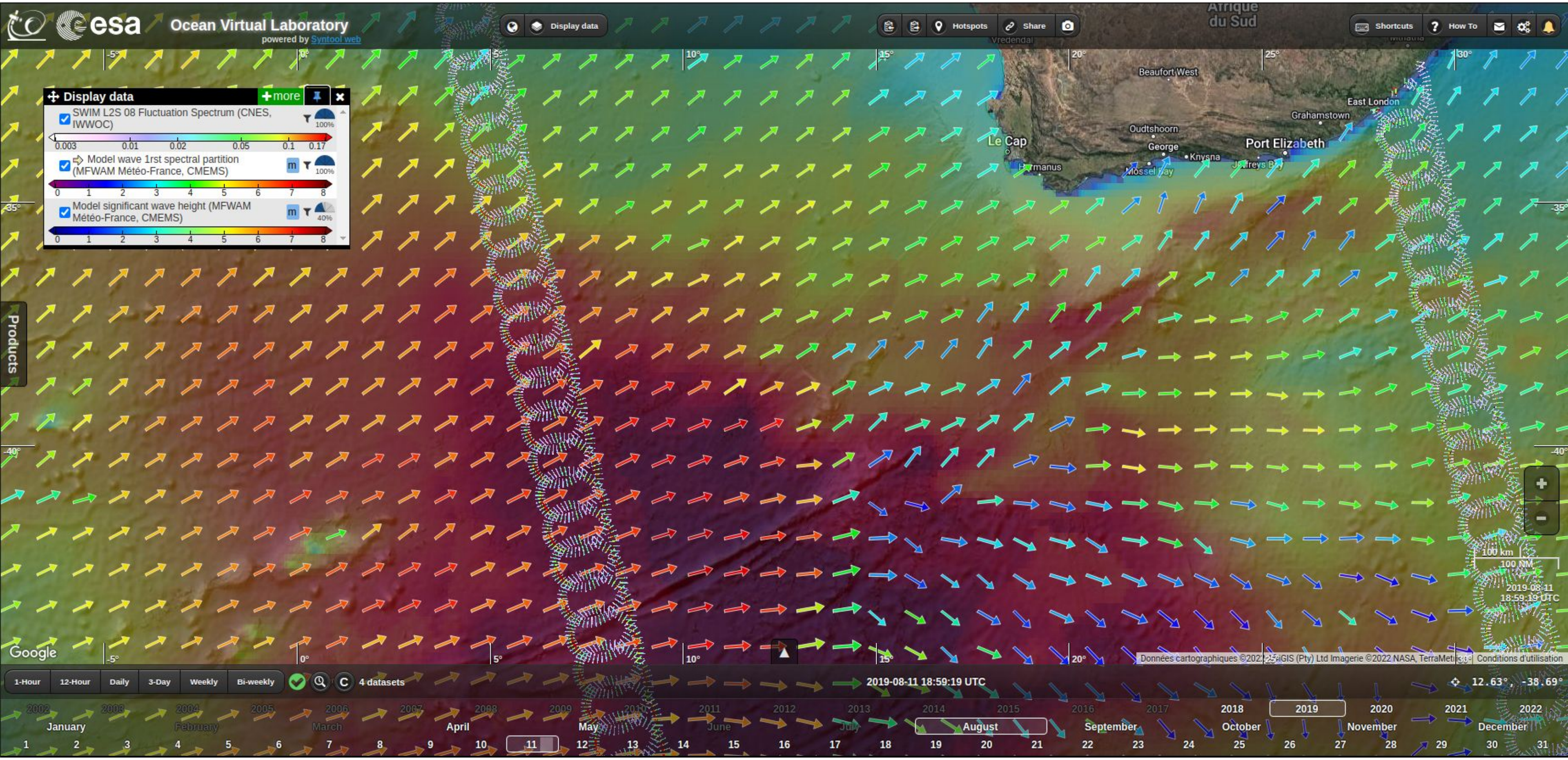


- In each azimuth direction, the normalized radar cross-section σ_0 is modulated by the tilt of the long waves

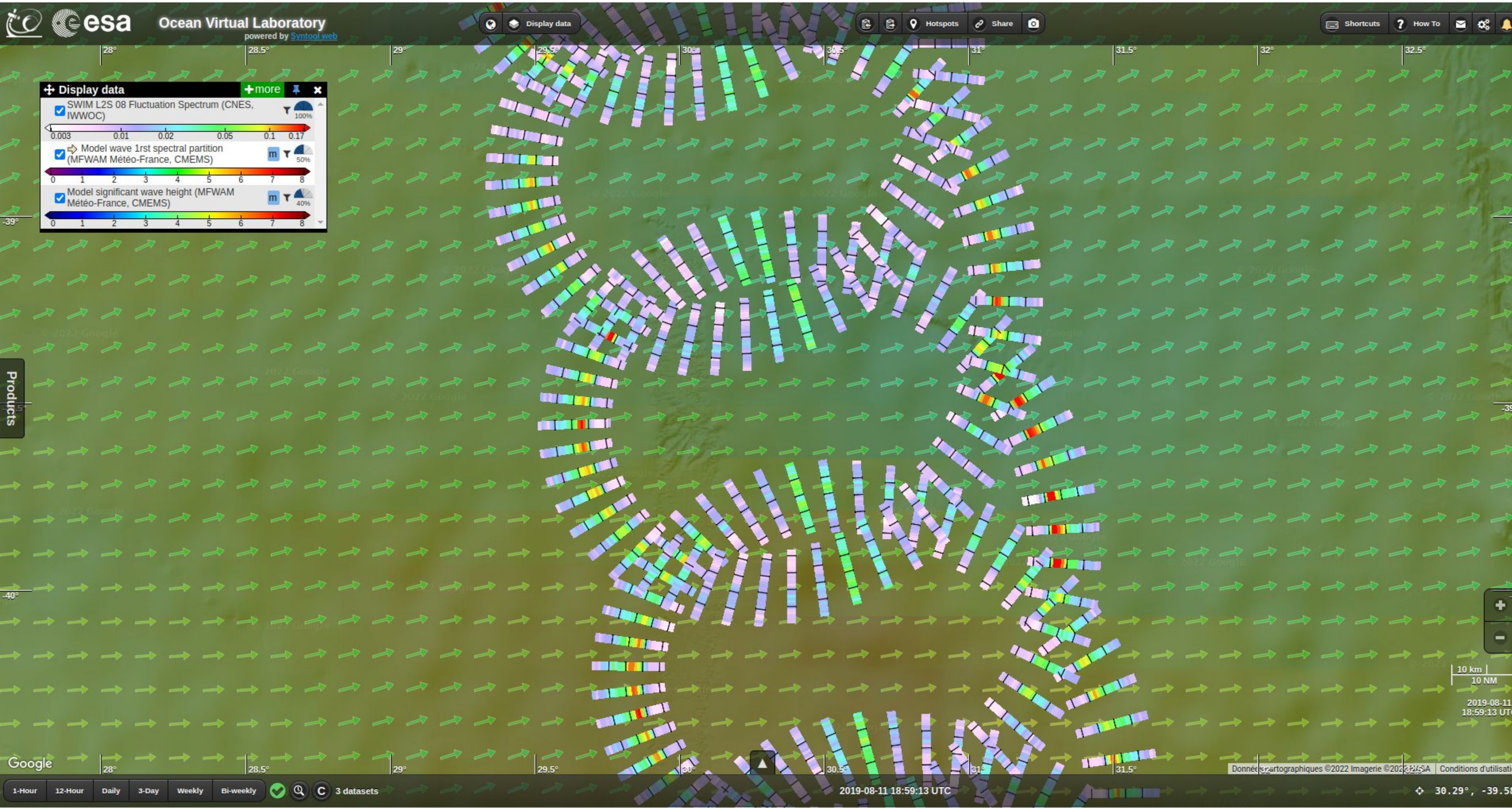
=> Measurement of these modulations m(x,φ), calculation of their spectrum $P_m(k,\varphi)$



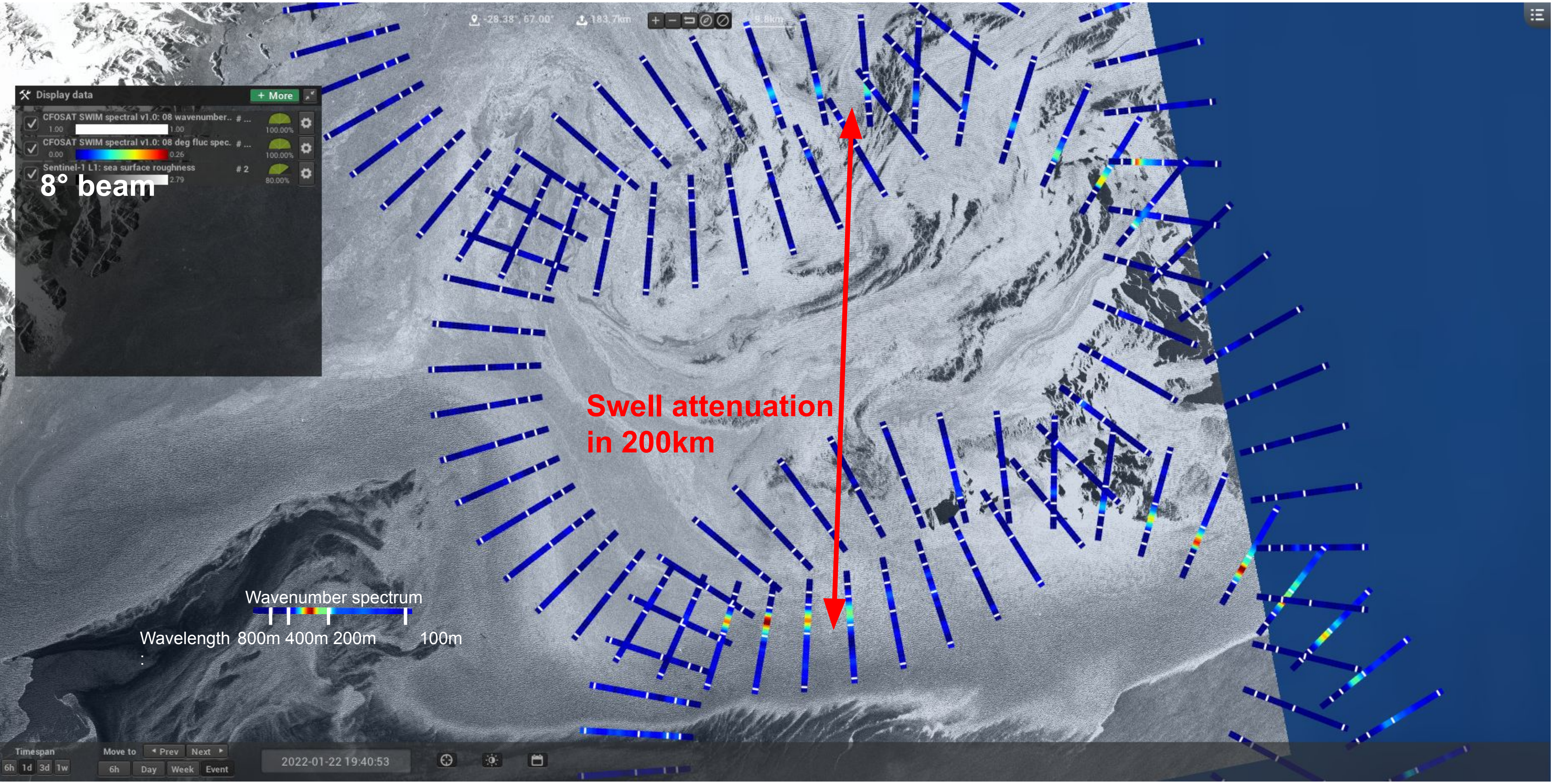
Swath covering 2° incidence range



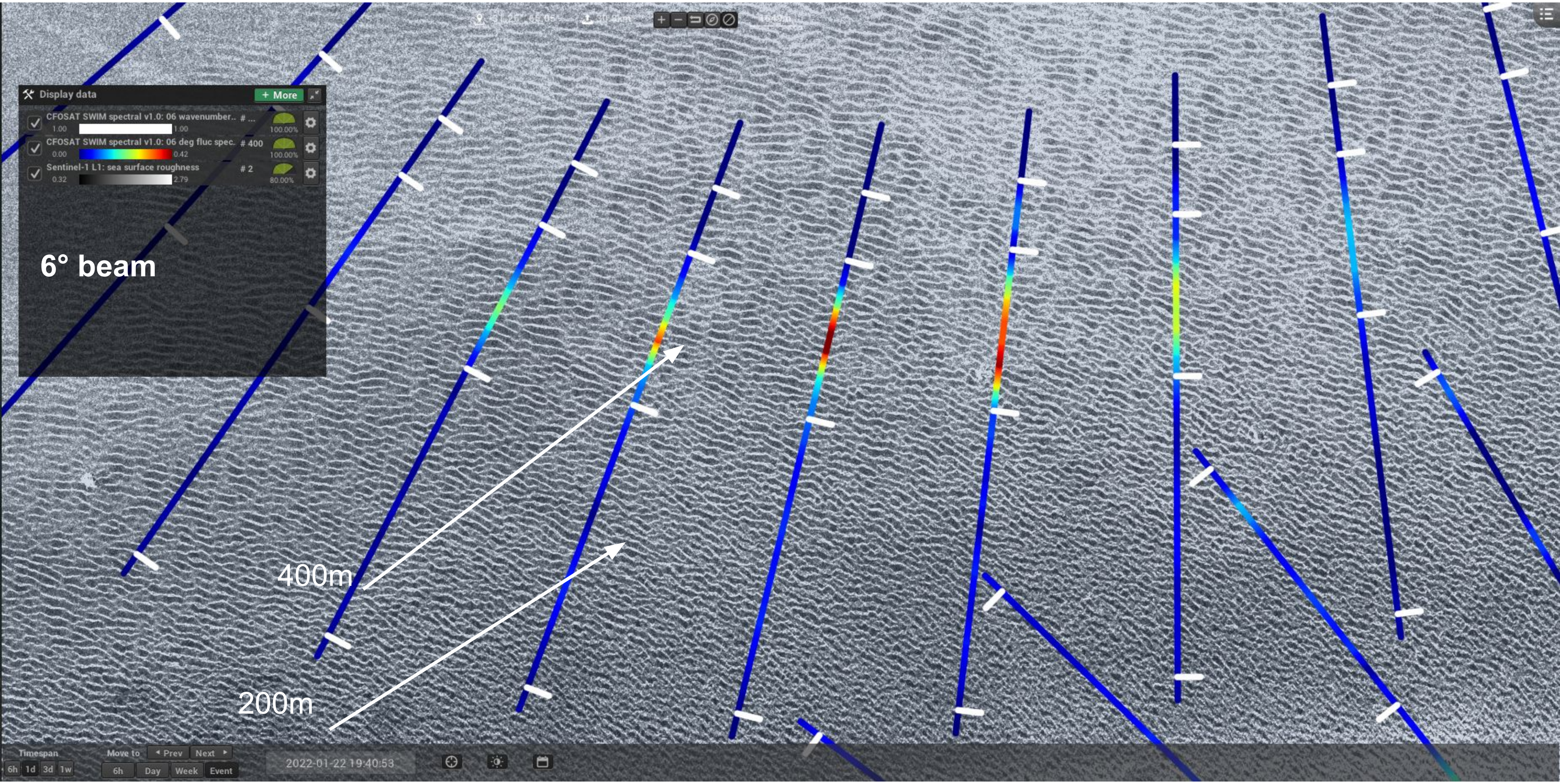
esa
Ocean Virtual Laboratory
powered by Syntool web
Display data
Hotspots
Share
Shortcuts
How To
Display data
SWIM L2S 08 Fluctuation Spectrum (CNES, IWWOC)
Model wave 1rst spectral partition (MFWAM Météo-France, CMEMS)
Model significant wave height (MFWAM Météo-France, CMEMS)
Le Cap
Beaufort West
Oudtshoorn
George
Knysna
Port Elizabeth
Grahamstown
East London
Products
1-Hour
12-Hour
Daily
3-Day
Weekly
Bi-weekly
4 datasets
2019-08-11 18:59:19 UTC

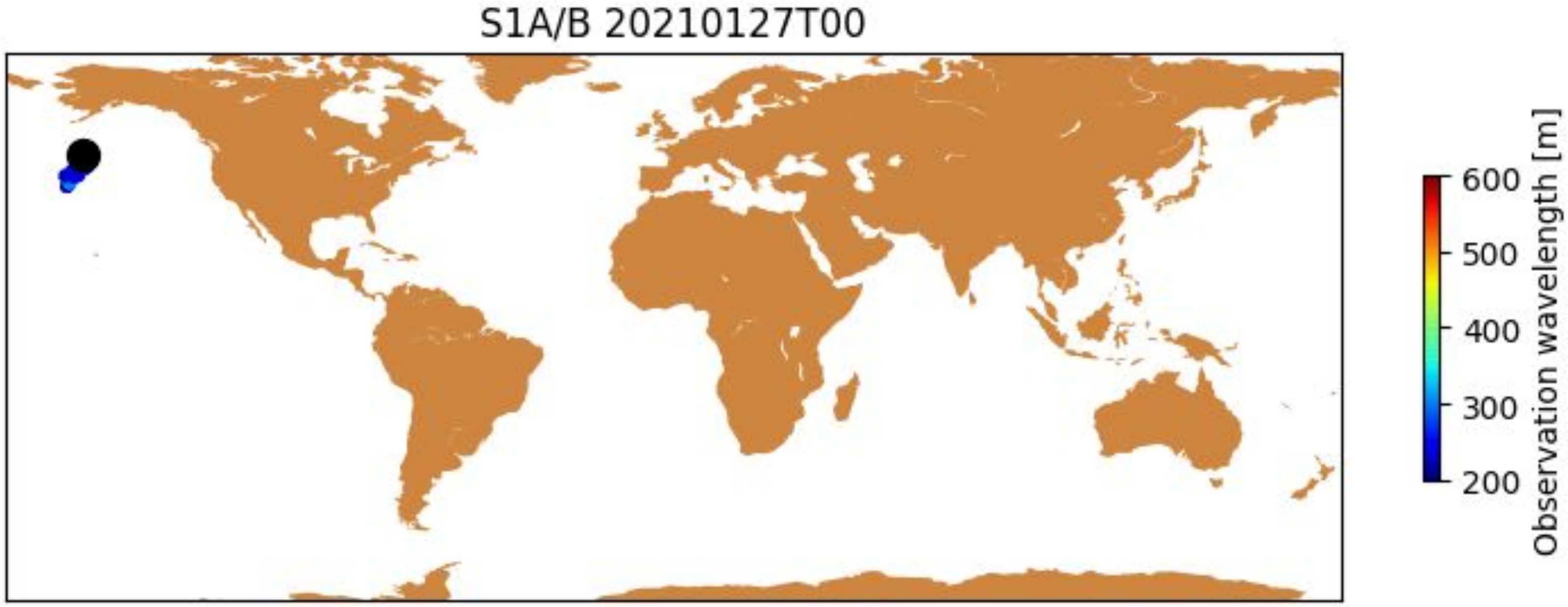

esa
Ocean Virtual Laboratory
powered by Syntool web
Display data
Hotspots
Share
Shortcuts
How To
Display data
+more
SWIM L2S 08 Fluctuation Spectrum (CNES, IWWOC)
0.003 0.01 0.02 0.05 0.1 0.17
Model wave 1rst spectral partition (MFWAM Météo-France, CMEMS)
0 1 2 3 4 5 6 7 8
Model significant wave height (MFWAM Météo-France, CMEMS)
0 1 2 3 4 5 6 7 8
Products
28° 28.5° 29° 29.5° 30° 30.5° 31° 31.5° 32° 32.5°
-39° -39.5° -40°
10 km
10 NM
2019-08-11 18:59:13 UTC
Google
1-Hour 12-Hour Daily 3-Day Weekly Bi-weekly
3 datasets
2019-08-11 18:59:13 UTC
30.29°, -39.58°
Conditions d'utilisation

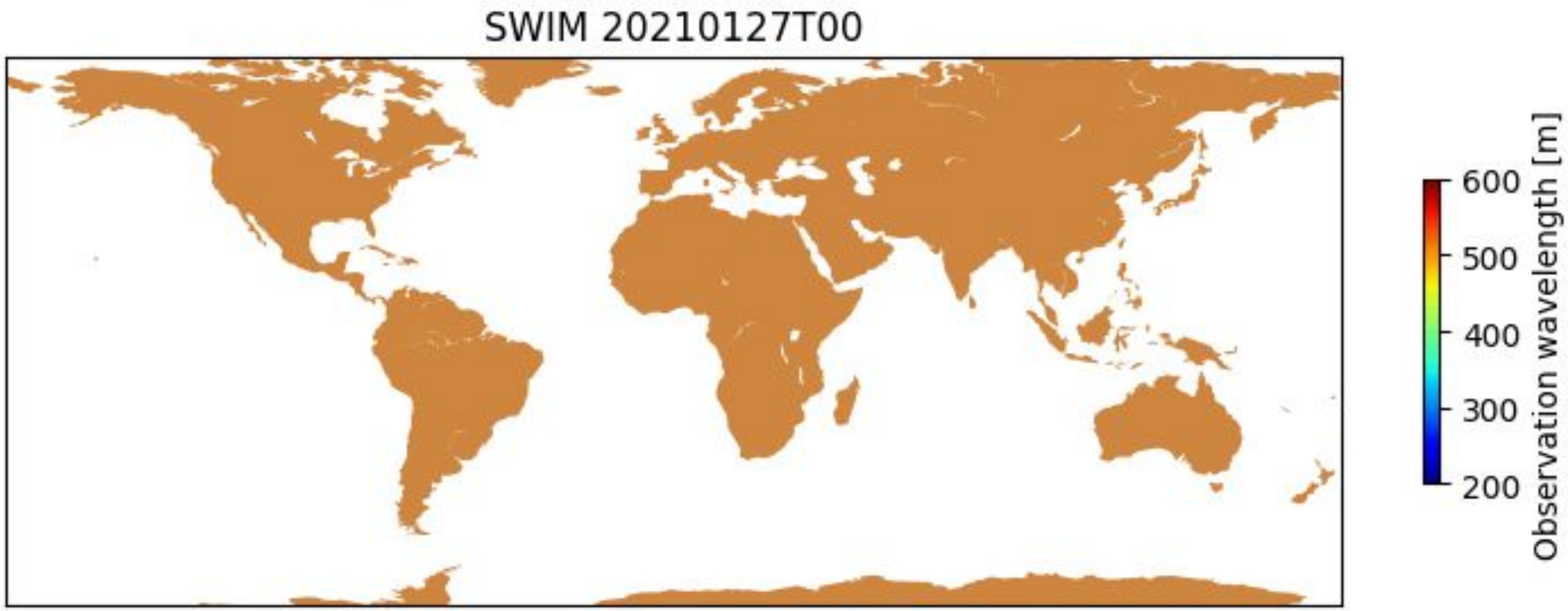
5. Last sensor: CFOSAT's SWIM instrument



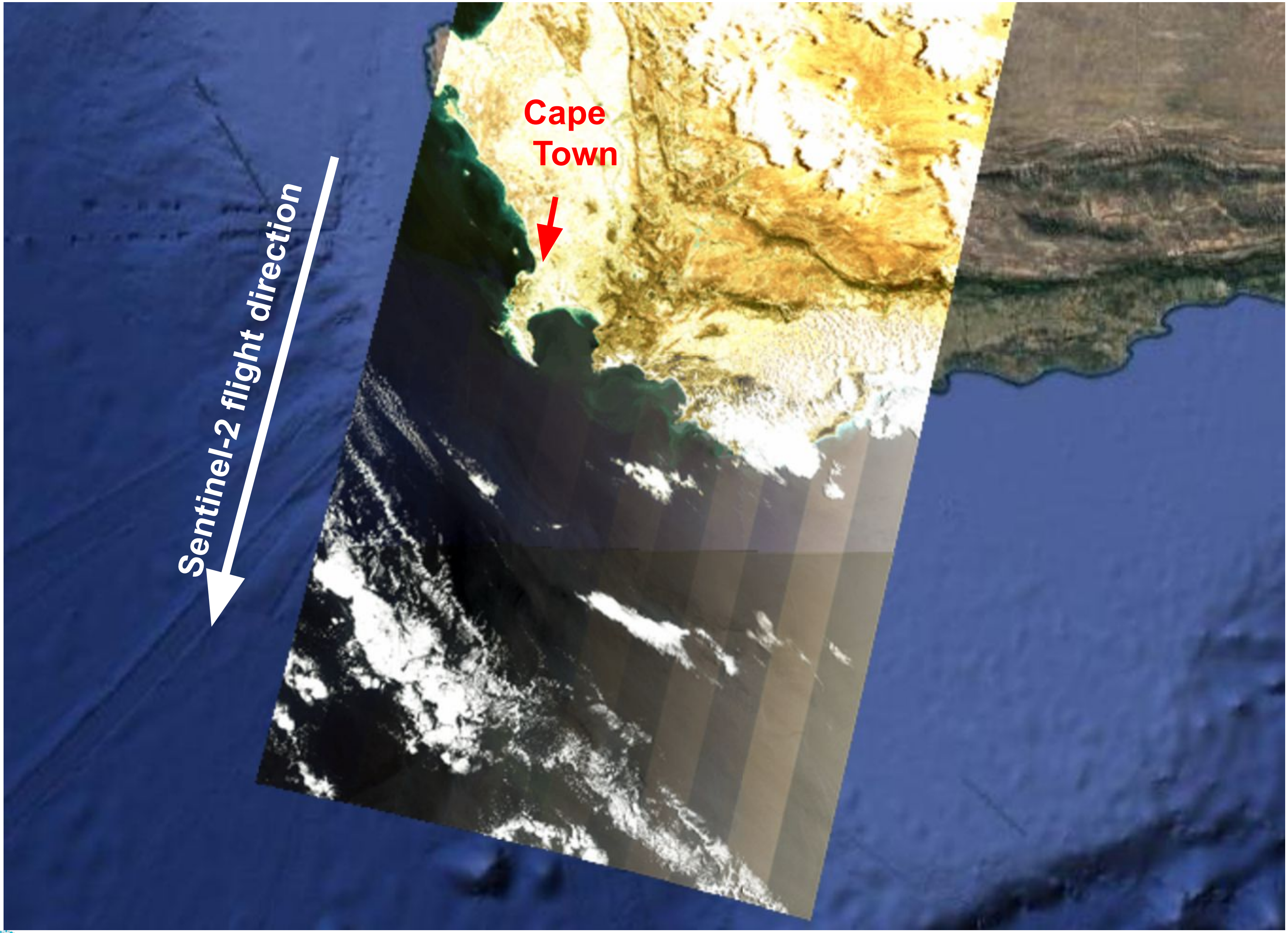
5. Last sensor: CFOSAT's SWIM instrument

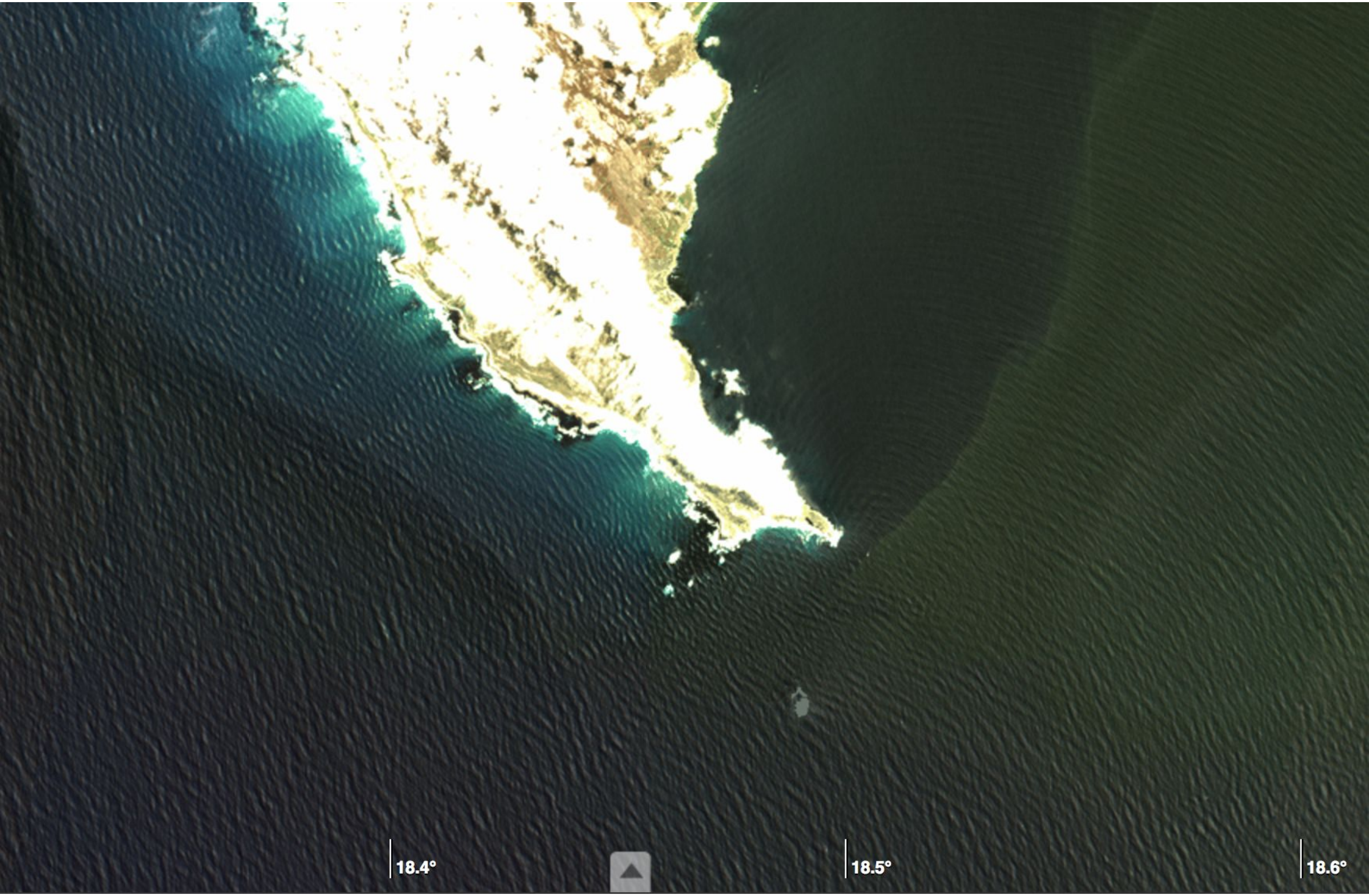



S1A/B 20210127T00
600
500
400
300
200
Observation wavelength [m]

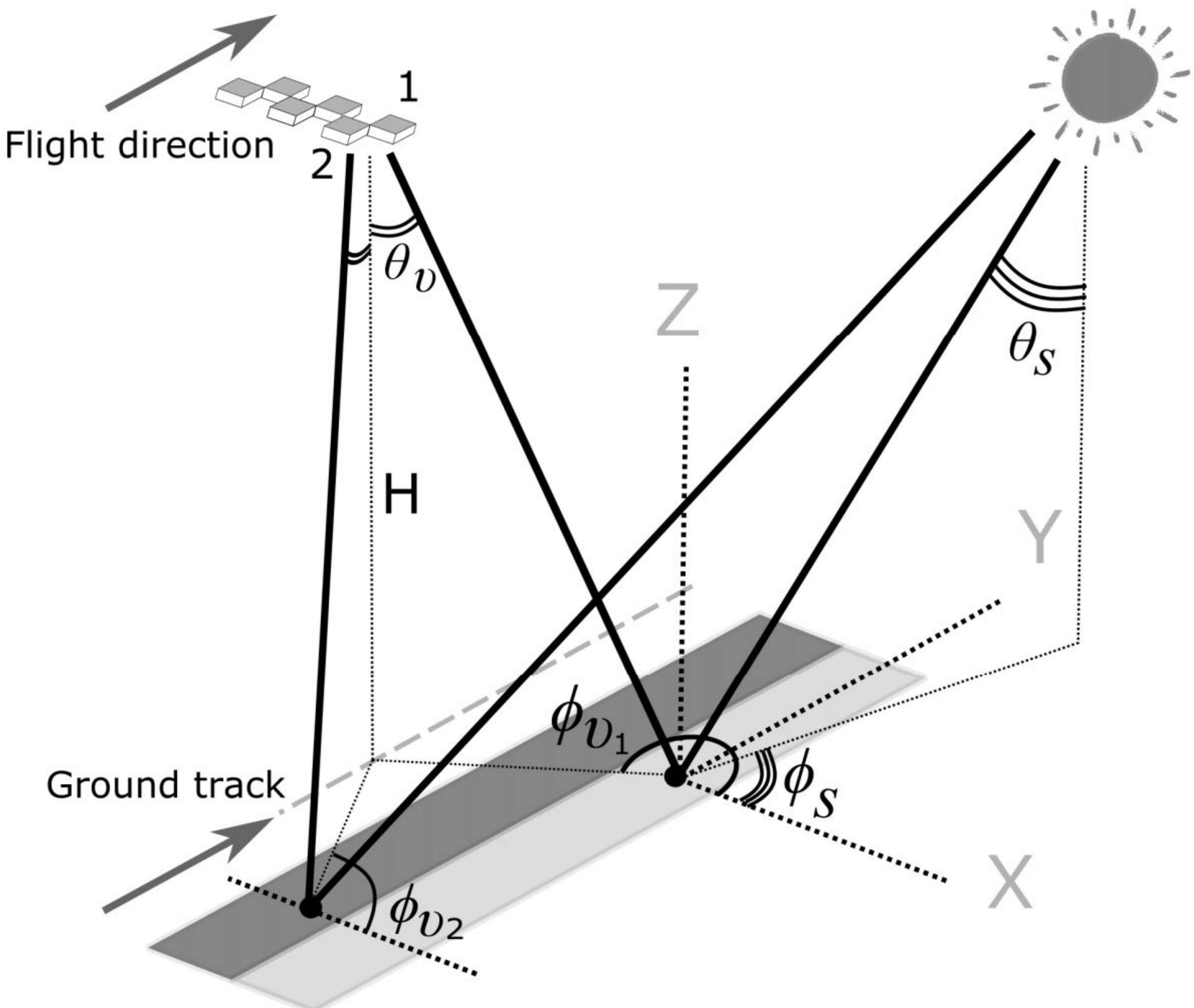

SWIM 20210127T00
600
500
400
300
200
Observation wavelength [m]

Optical waves remote sensing with Sentinel-2 (ESA-Copernicus) and Landsat-8 (NASA-USGS)

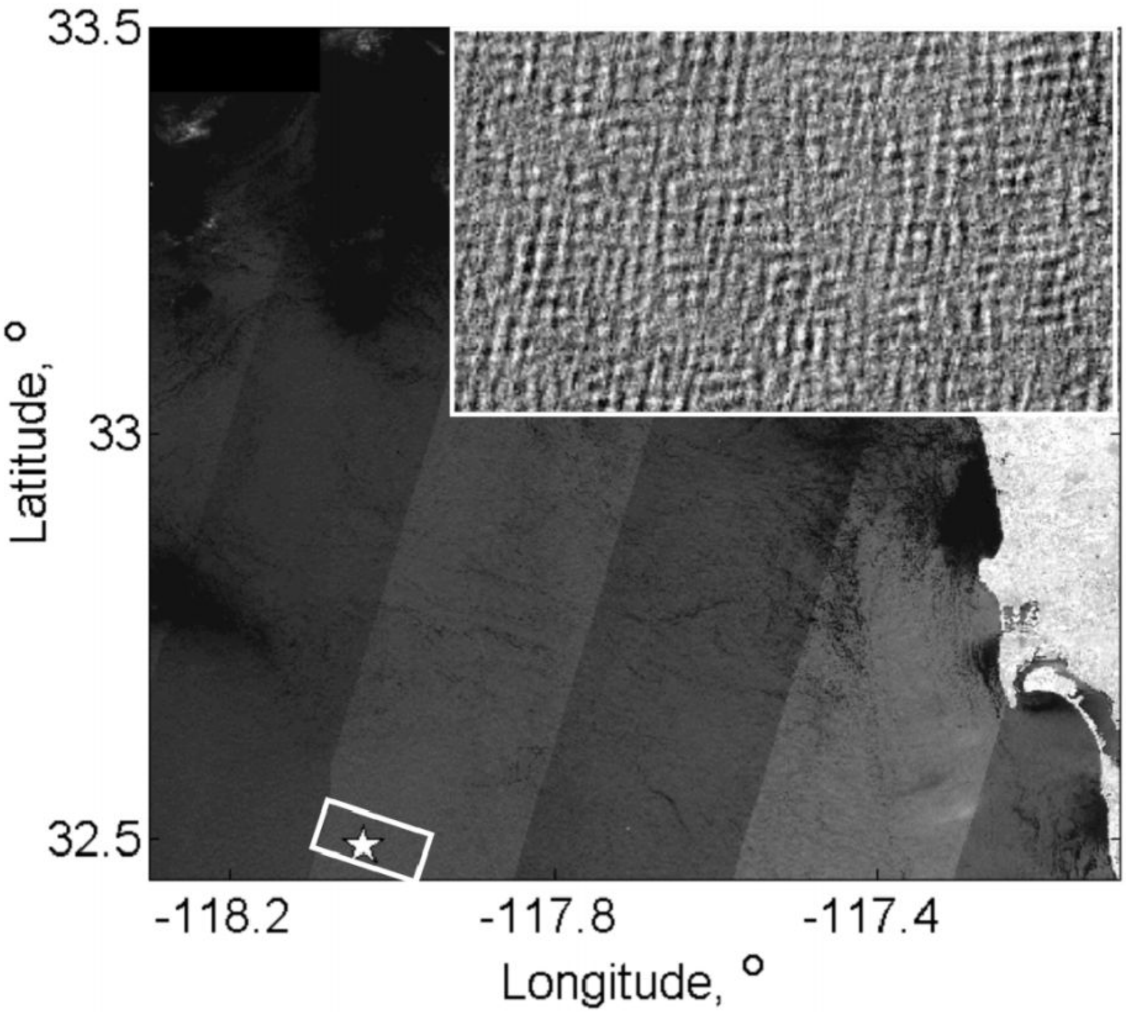

Cape
Town
Sentinel-2 flight direction


18.4°
18.5°
18.6°

Sentinel-2

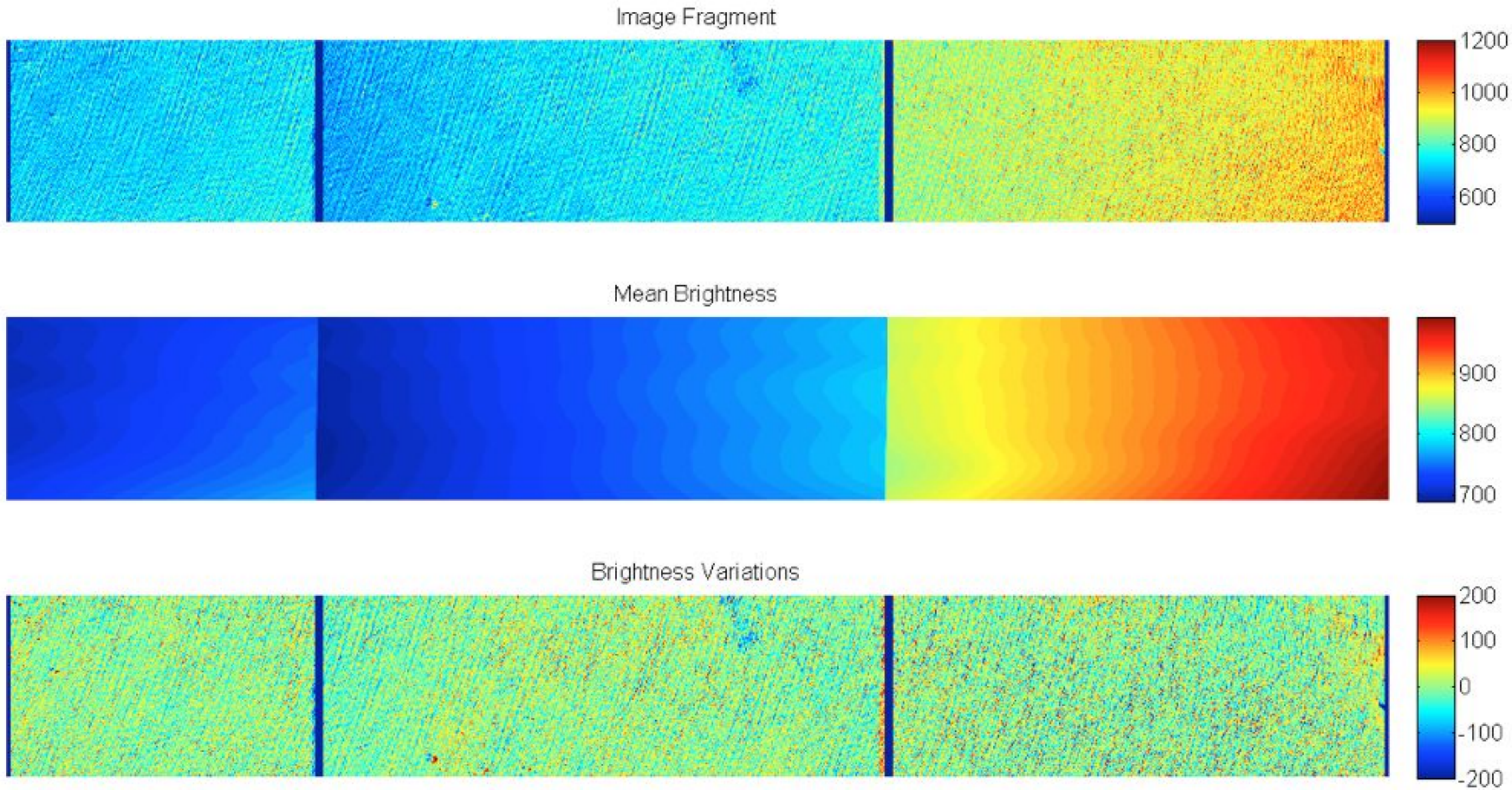

Flight direction
1
2
θ_v
Z
θ_s
H
Y
ϕ_{v_1}
ϕ_s
Ground track
X
ϕ_{v_2}

Sentinel-2

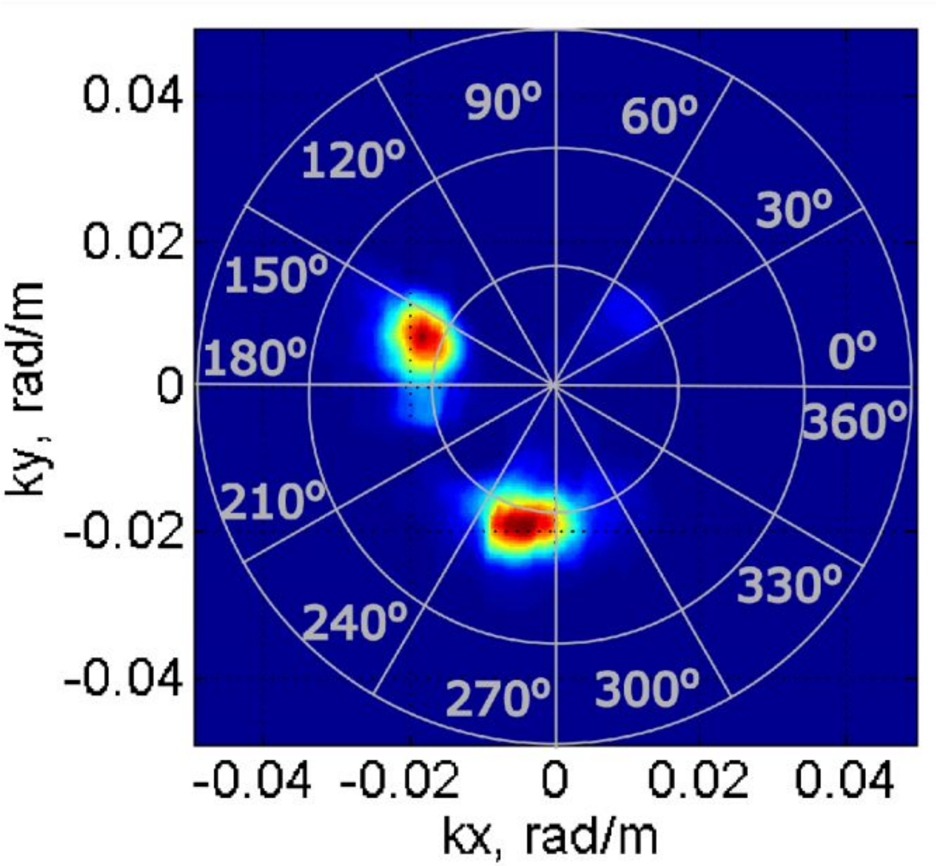


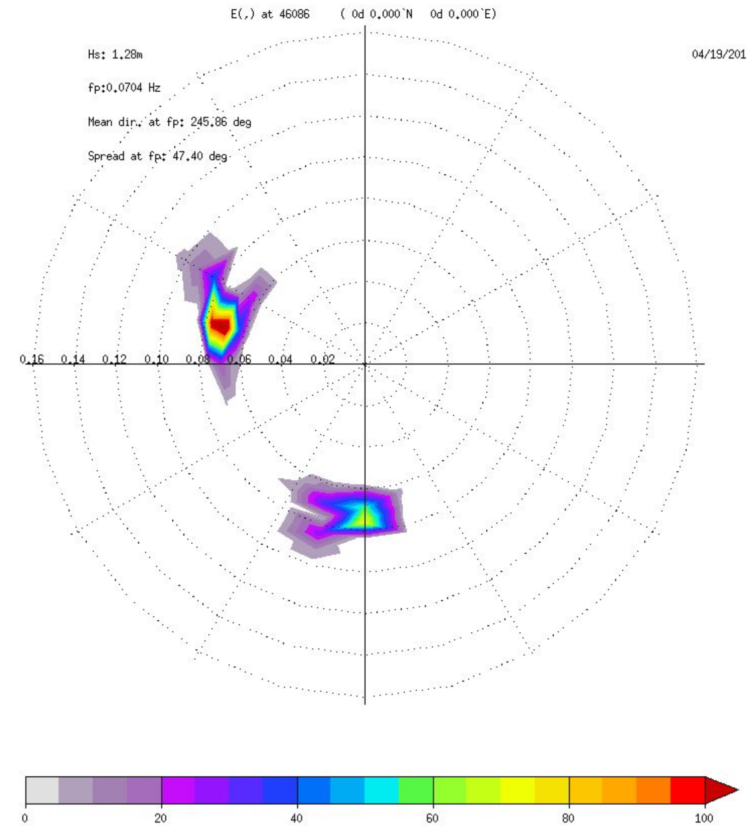
Sentinel-2 MSI image channel B04 off the California coast, 2016-04-19 627 18:44. The white star indicates location of the buoy 46086 - San Clemente Basin, 628 National Data Buoy Center (NDBC).

From brightness to slope



Comparison with buoy





Kudryavtsev, V., Yurovskaya, M., Chapron, B., Collard, F. and Donlon, C. (2017), Sun glitter imagery of ocean surface waves: 1. Directional spectrum retrieval and validation. J. Geophys. Res. Oceans. Accepted Author Manuscript. doi:10.1002/2016JC012425