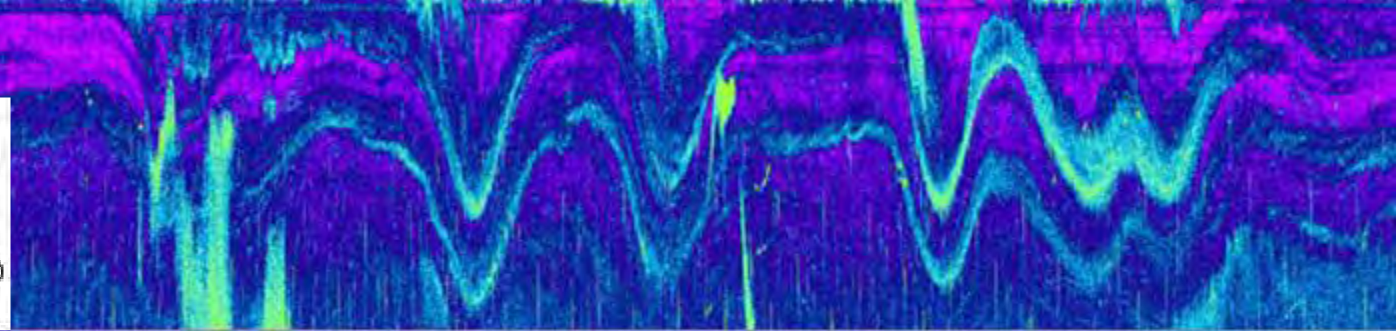

Wave-Current interaction [1]: Internal waves from space; Part I: Sentinel-3 RA3/ OLCI

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Centro Interdisciplinar de Investigação Marinha e Ambiental

Ocean Remote Sensing and Synergy, Porto, 13 September 2017

Outline of this Talk

- Introduction
  - Internal solitary waves (ISWs) and motivation to study them
  - How do we observe internal waves from space?
  - Theoretical considerations about observability of ISWs with altimeters

- Some case studies
  - Amazon Seas
  - Andaman Sea
  - Gibraltar (Alboran Sea)

- Conclusions

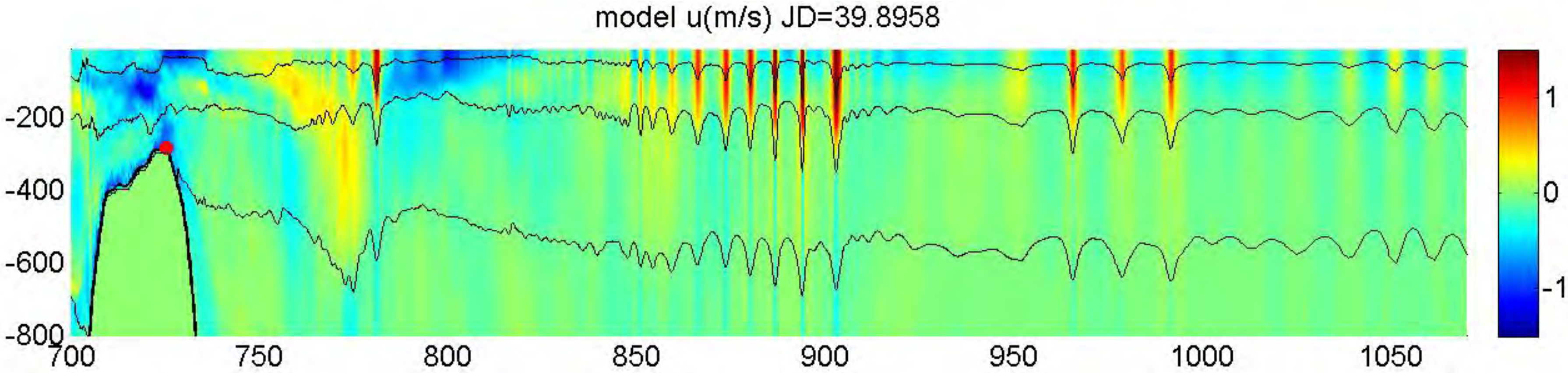
<u>Objective</u>:

- *Develop a novel synergetic approach that enables the identification of <u>large-amplitude, short-period ISWs</u> from high-rate satellite altimeter data*

Internal solitary waves (ISWs) and motivation to study them

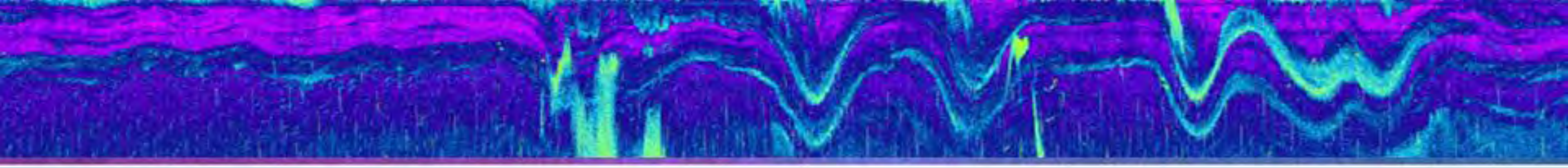
Internal waves: what are they?

- Waves that exist within the body of a density-stratified fluid
- During summer, the top 20-30m of the ocean can be up to 10 °C warmer than the water below and this gives rise to a thermocline along wich internal waves can travel
- The same is true -year round- in the tropical ocean, where the mixed top layer (100-200m) is more buoyant than the deeper, denser water.



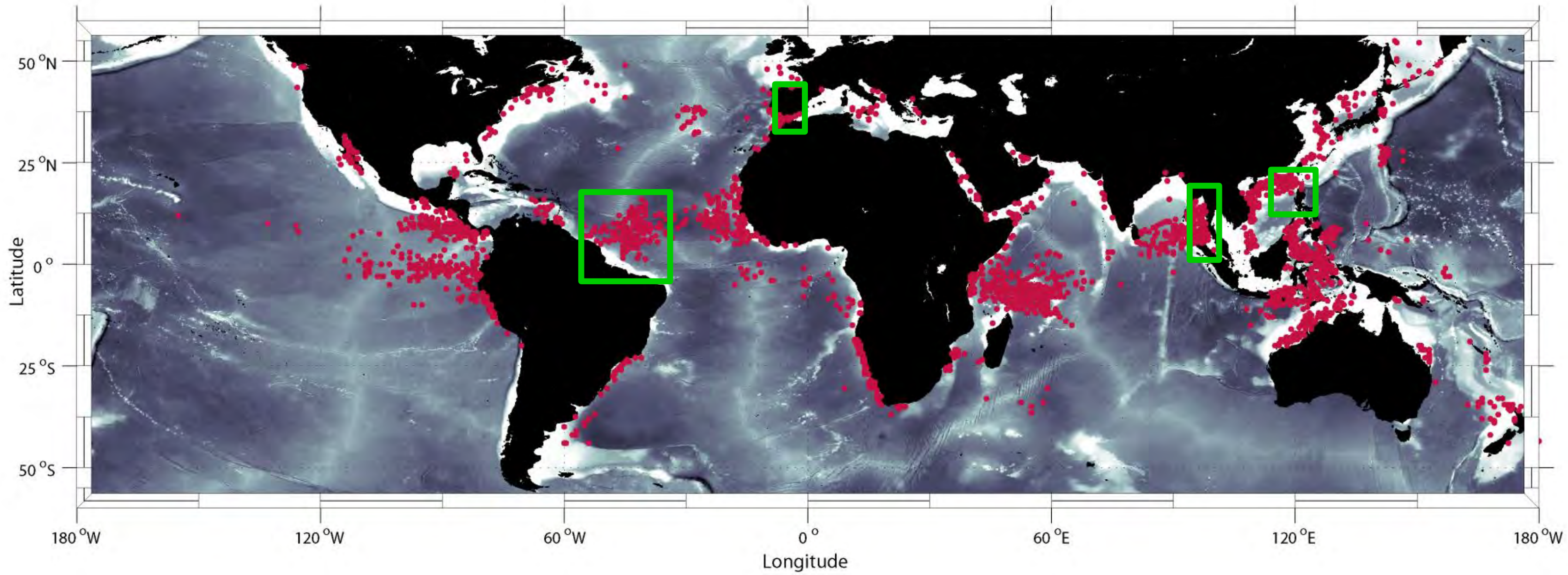
Horizontal velocity field within the water in the presence of IWs

da Silva et al. (2015)



Internal solitary waves (ISWs) and motivation to study them

Global Map of ISWs



The location of nonlinear internal waves observed in 250 m resolution MODIS (Moderate-Resolution Imaging Spectroradiometer) satellite sunglint imagery acquired from August 2002 through May 2004.

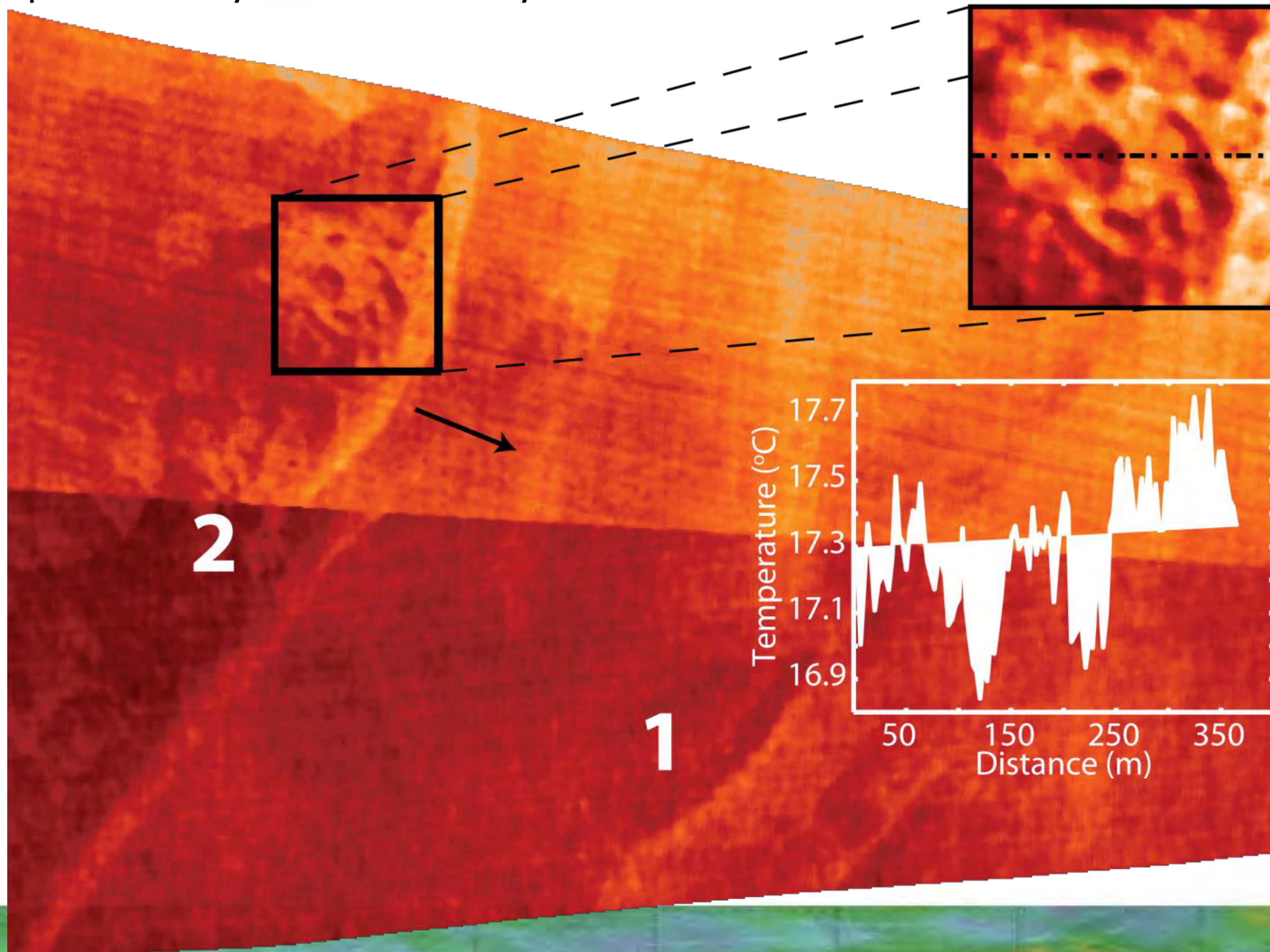
Jackson et al. (2012)

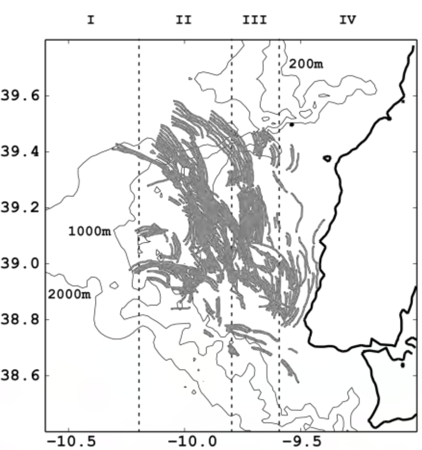
Internal solitary waves (ISWs) and motivation to study them

Thermal infrared image obtained from aircraft off Portugal:
“Boils” of cold water produced by internal solitary wave trains

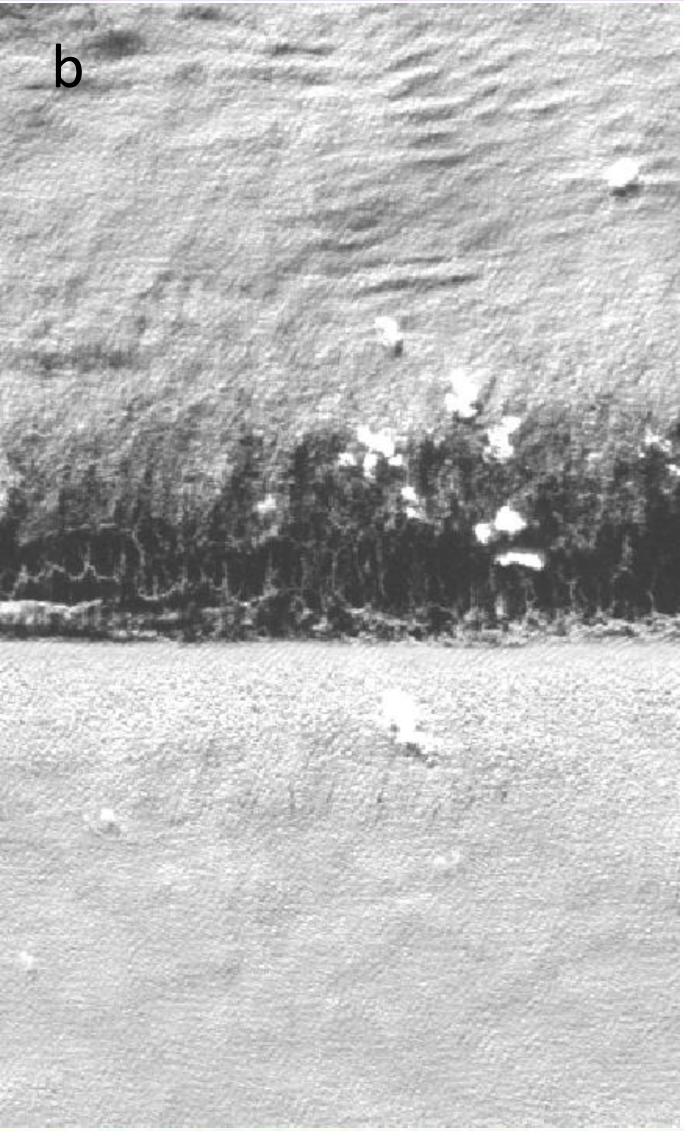
hence => mixing

European EUFAR project for airborne research





Internal solitary waves (ISWs) and motivation to study them

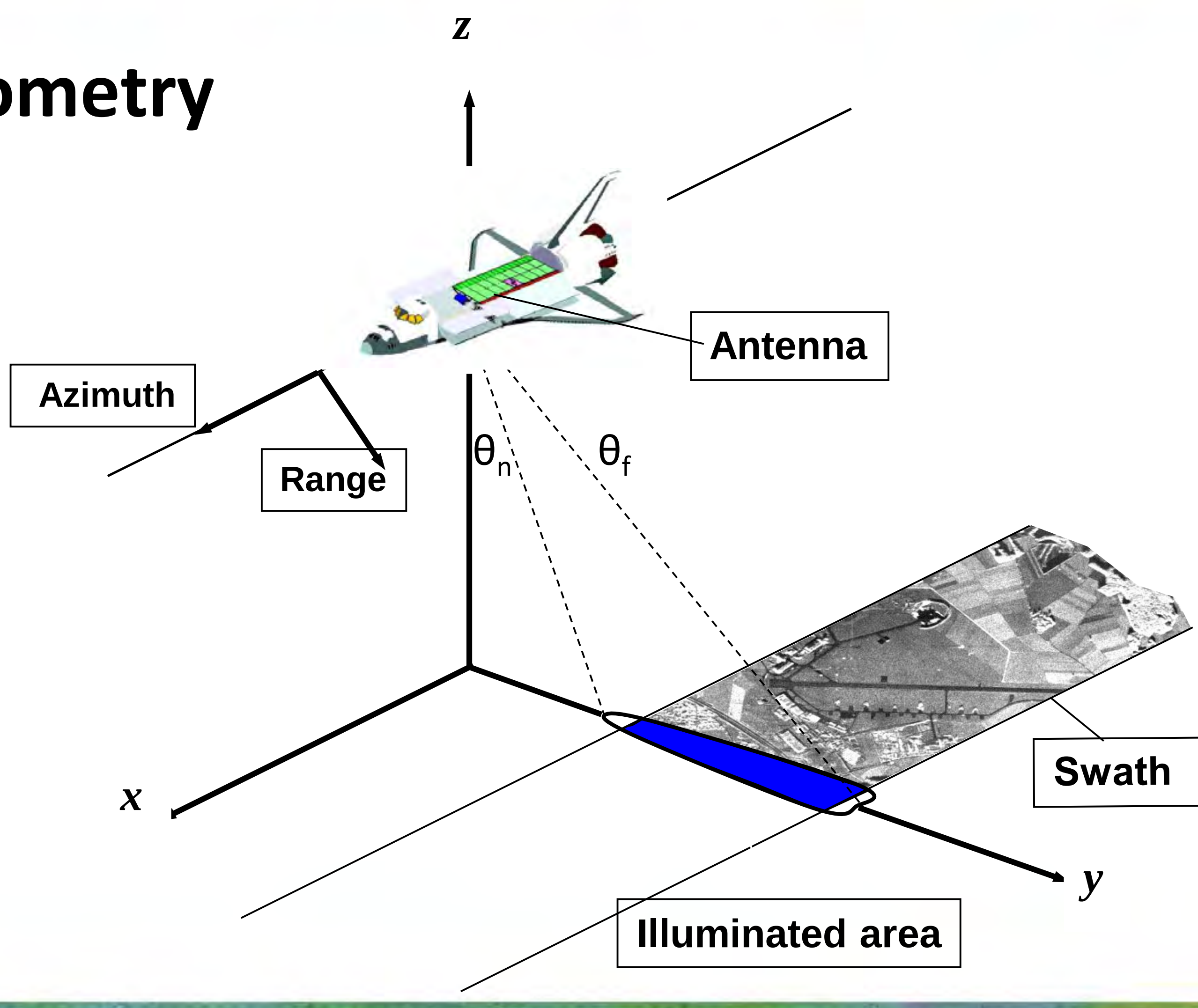


a. "boil" structure observed in the S. China S. by Farmer & Lien (2011)

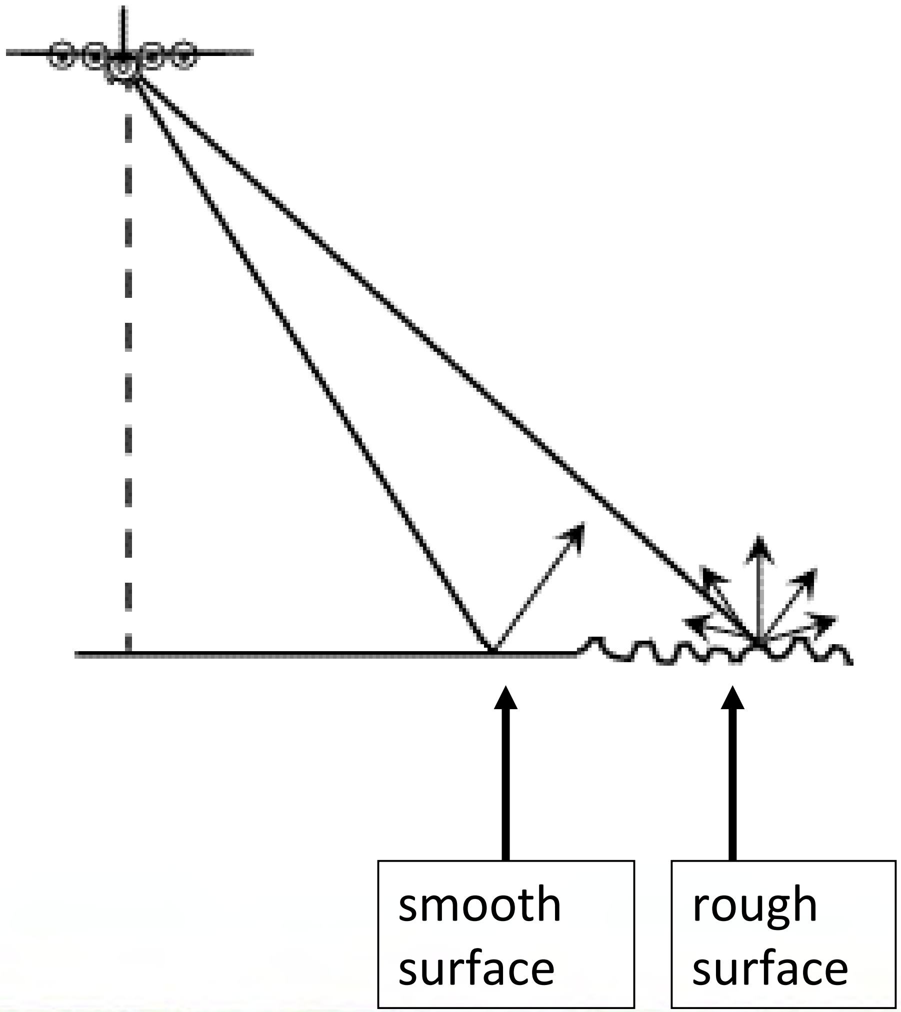
"O (10 m) diameter surface-renewal 'boils' that populate the Wake of the IWs"

b. Sentinel-2 MSI high resolution visible band (Band 6; red color) signature of an ISW front characterized by surface waves breaking, and a broad, trailing wake, associated to turbulent flow

SAR geometry

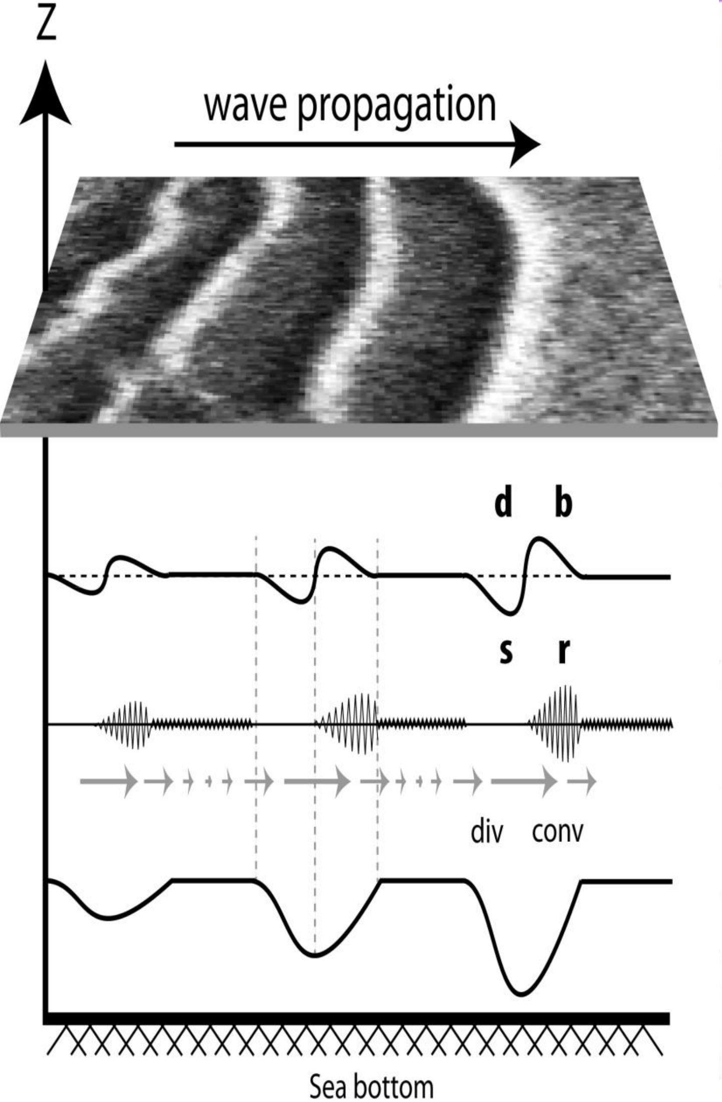


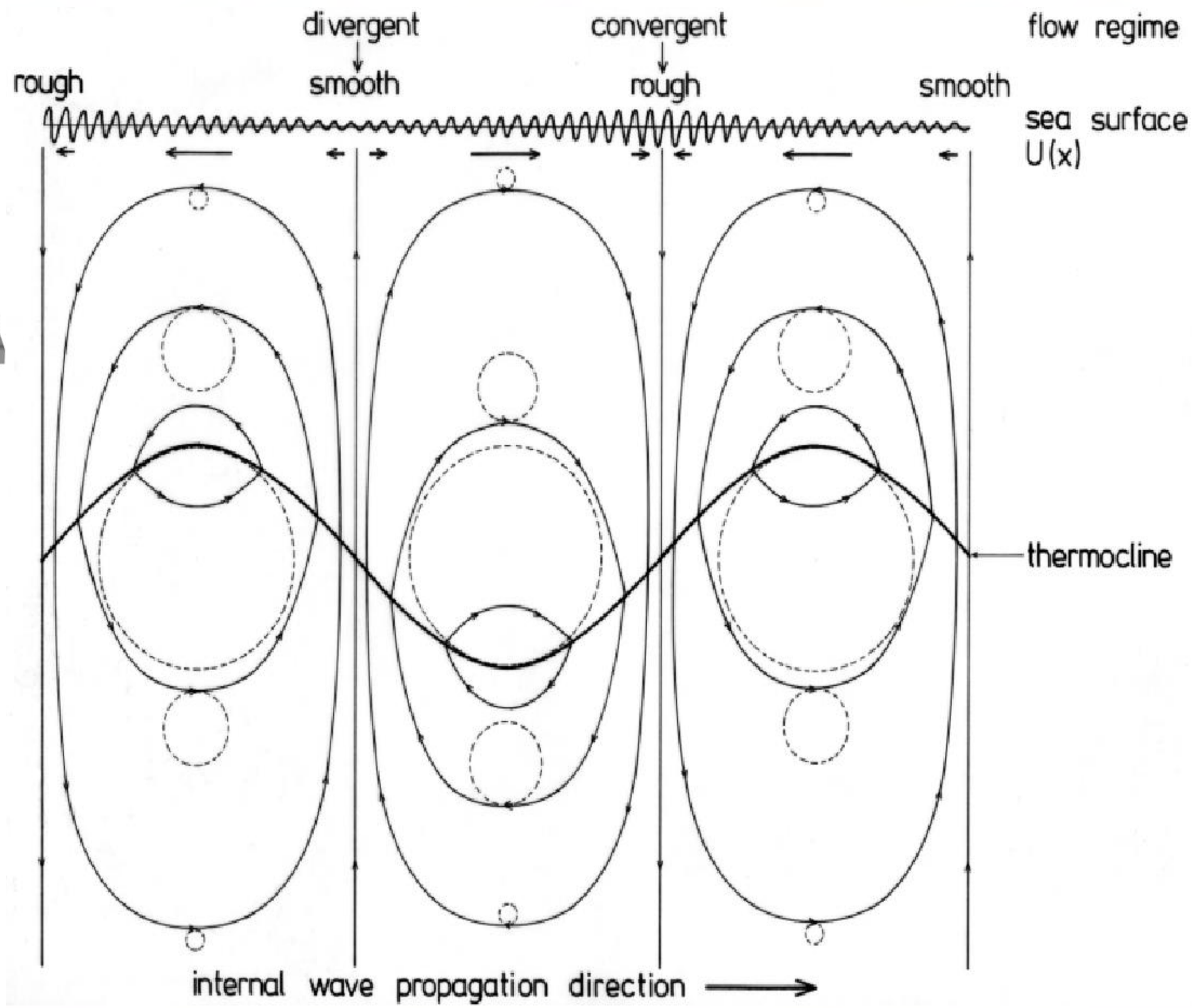
Radar backscattering from the sea surface



- The microwaves (radar waves) do not penetrate into the water.
- Thus, the radar senses only the sea surface roughness.

Introduction:
How does SAR see internal waves in the ocean?





Sea surface roughness pattern generated by a linear internal wave

Introduction:
How does SAR see internal waves in the ocean?

Weak hydrodynamic interaction theory together with (first order) radar Bragg scattering theory

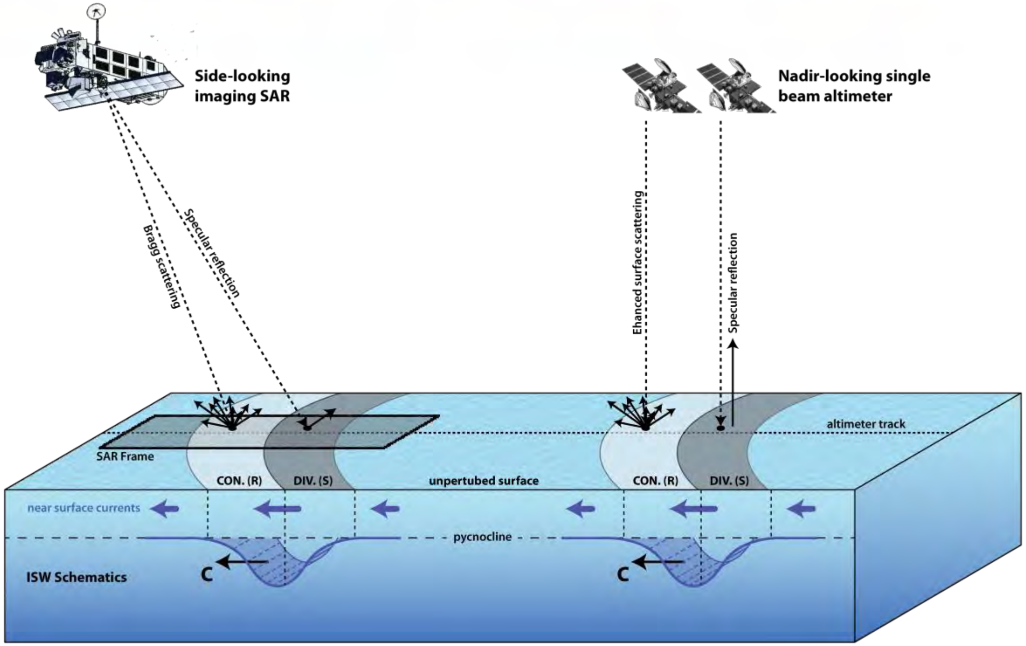
$$\boxed{\frac{\delta\sigma}{\sigma_0} = -A\frac{\partial u}{\partial x}}$$

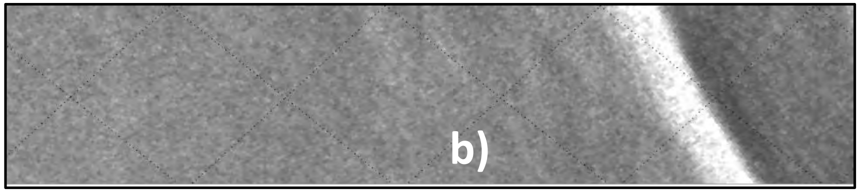
σ denotes the total NRCS ($\delta\sigma = \sigma - \sigma_0$), σ_0 is the NRCS of the background (unaffected by IWs), and A is a constant that depends on wind wave relaxation rate, radar wavelength, polarization and incidence angle. But, for a given image, mostly wind wave relaxation rate!, hence:

- IW image contrast inversely proportional to wind speed

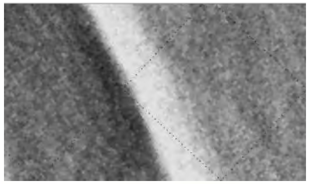
- ($\partial u/\partial x$) is the current gradient induced by the ISW, along the radar look direction (projected on the ground)

Introduction:
How does SRAL see internal waves in the ocean?





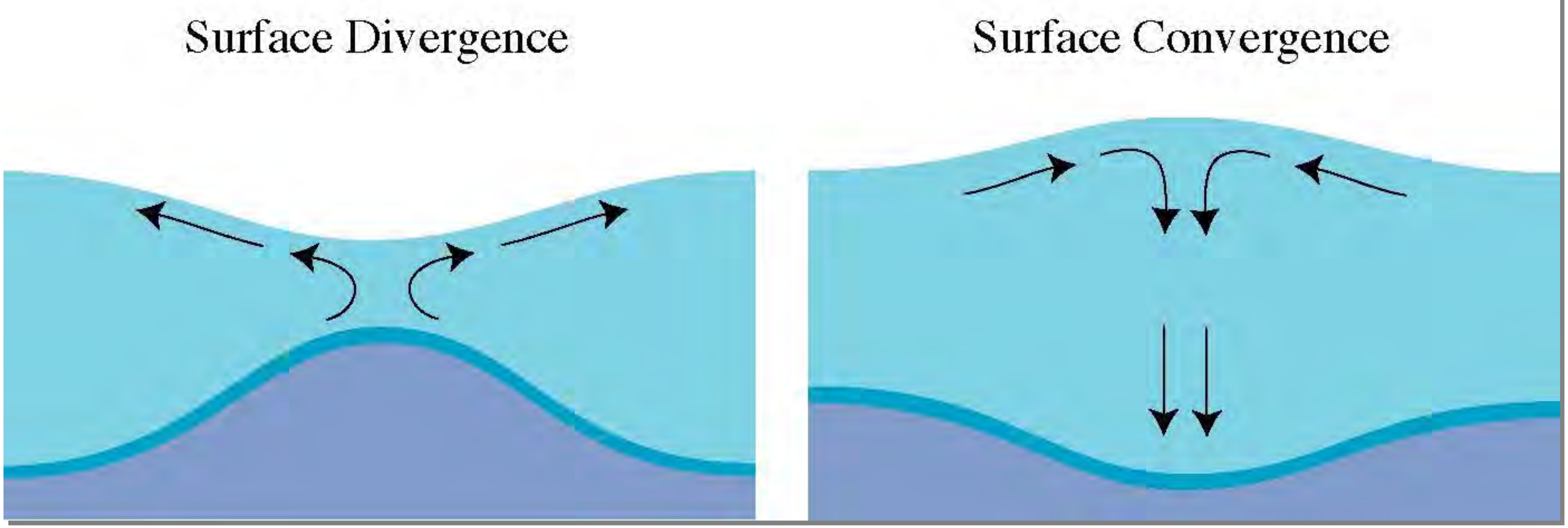
altimeter?



Altimeter
dark/bright

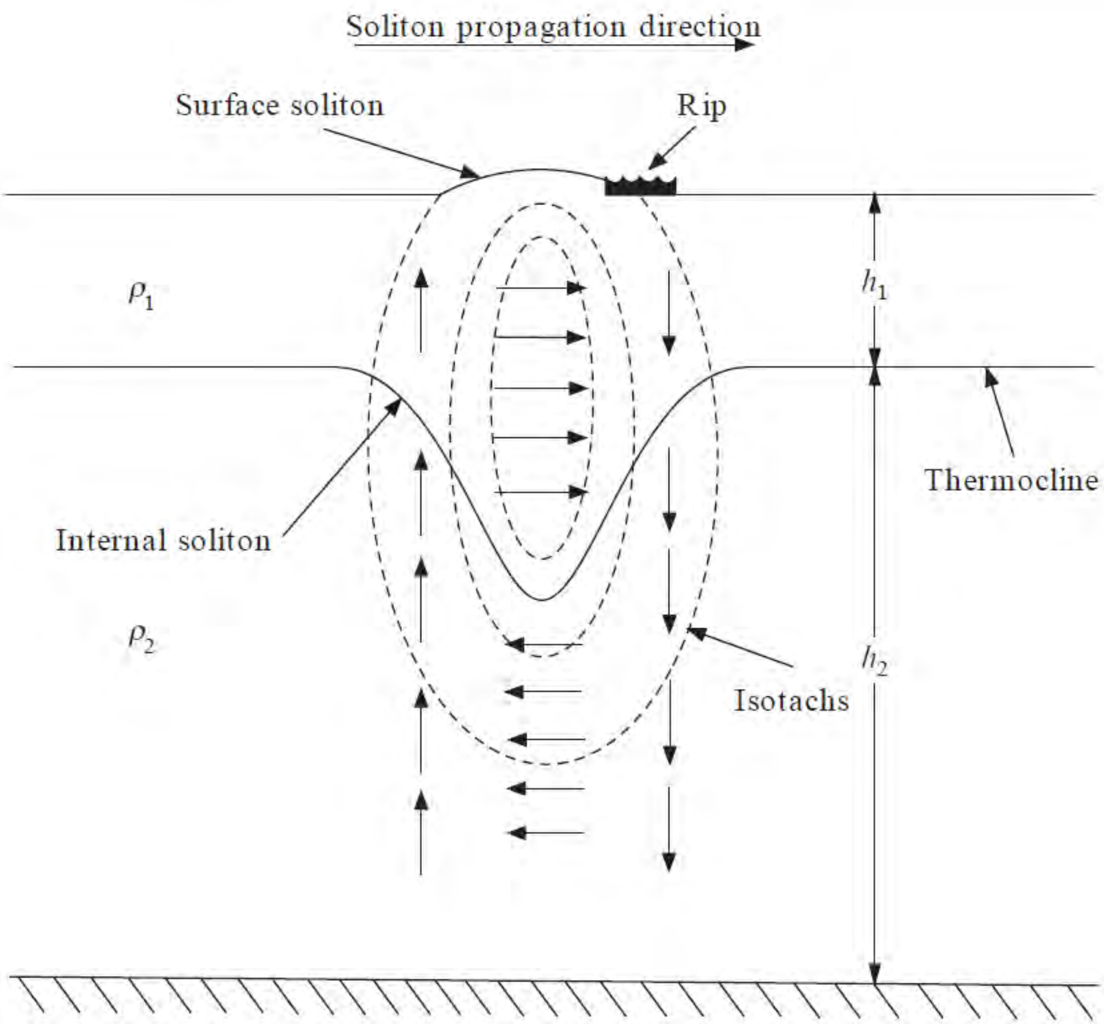
Introduction:
Theoretical considerations about observability of ISWs with altimeters

Thermocline Motion in Response to Surface Water Convergence and Divergence

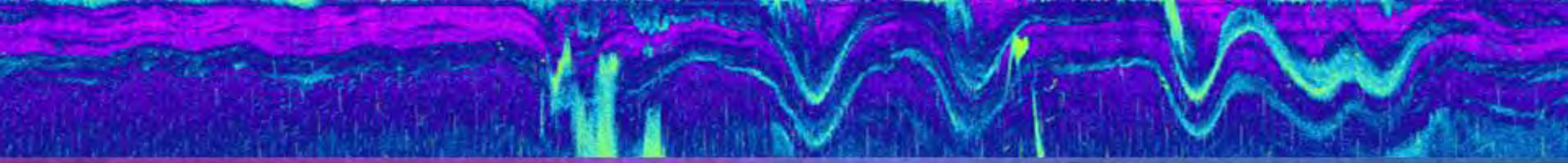


Hence, a **ssha is expected** in the presence of Internal Waves (both tidal frequency and short-period solitary waves!

Introduction:
Theoretical considerations about observability of ISWs with altimeters

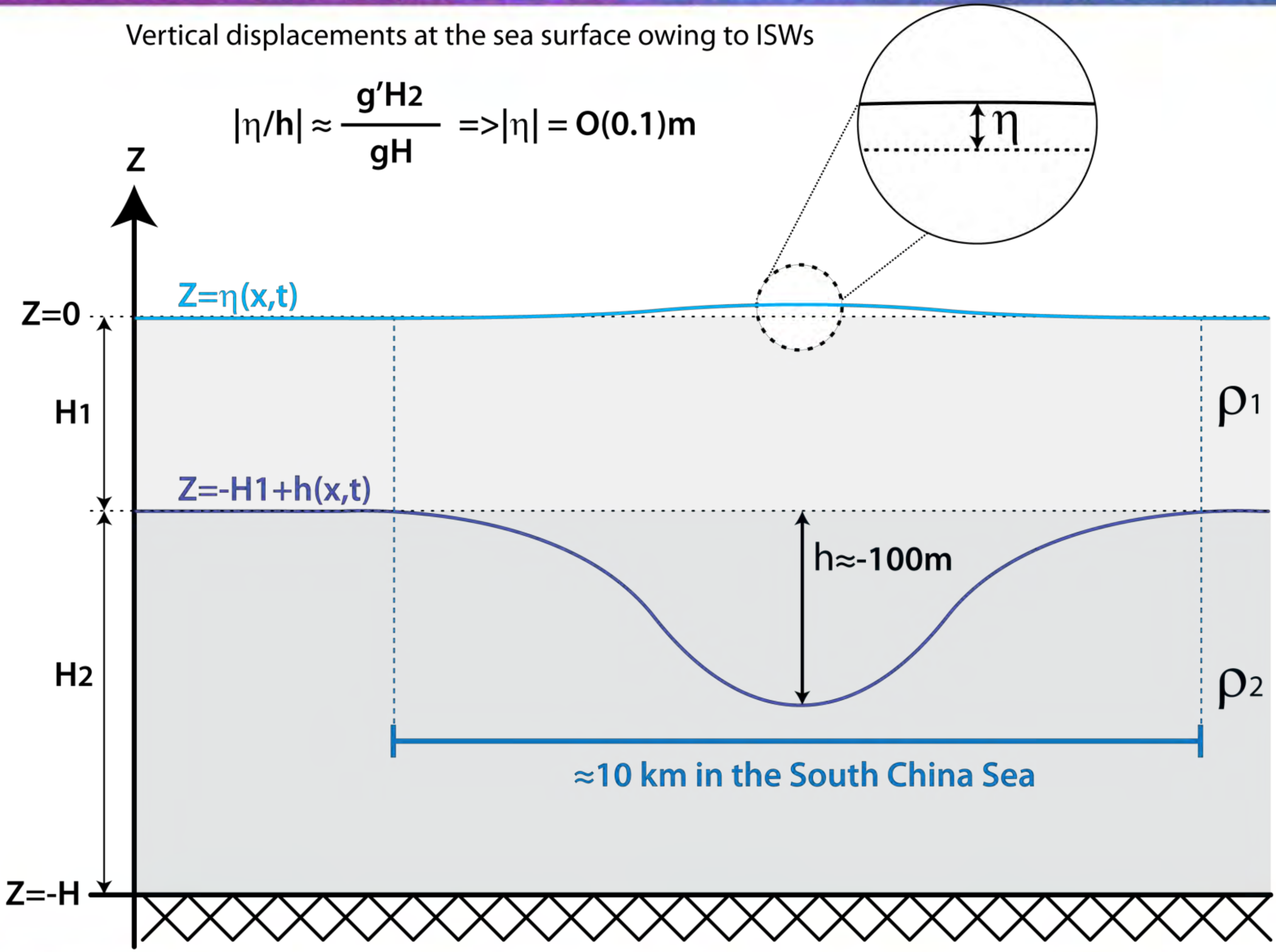


Osborne & Burch, 1980

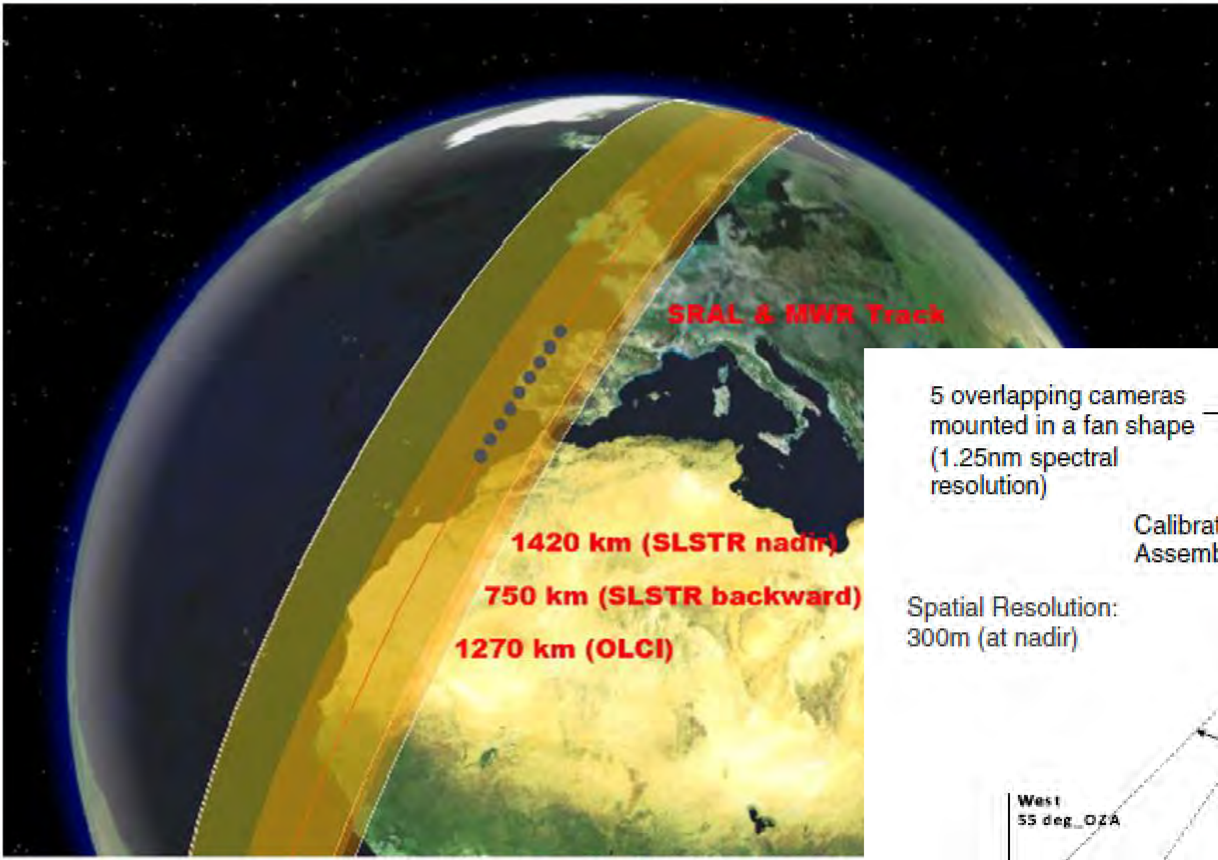


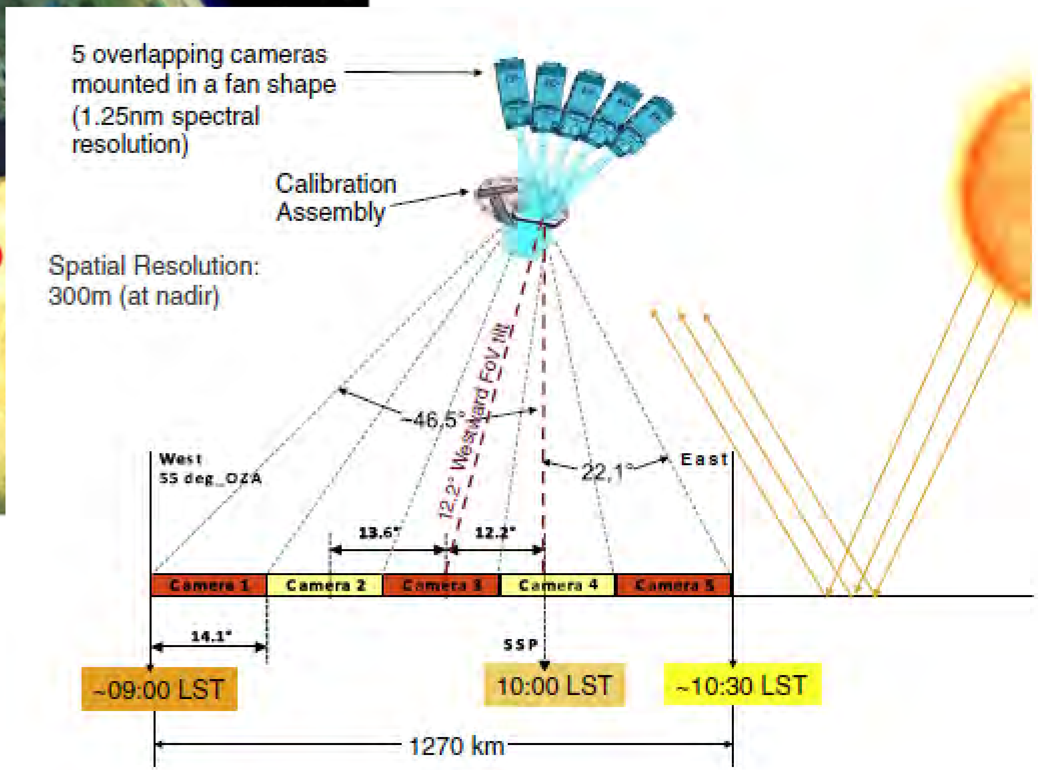
Vertical displacements at the sea surface owing to ISWs

$$|\eta/h| \approx \frac{g'H_2}{gH} \Rightarrow |\eta| = O(0.1)\mathrm{m}$$



Sentinel-3
SAR Altimeter / OLCI


SRAL & MWR Track
1420 km (SLSTR nadir)
750 km (SLSTR backward)
1270 km (OLCI)


5 overlapping cameras mounted in a fan shape (1.25nm spectral resolution)
Calibration Assembly
Spatial Resolution: 300m (at nadir)
~46.5°
12.2° Westward FoV tilt
West
55 deg_OZA
22.1°
East
13.6°
12.2°
Camera 1
Camera 2
Camera 3
Camera 4
Camera 5
14.1°
SSP
~09:00 LST
10:00 LST
~10:30 LST
1270 km

Andaman Sea

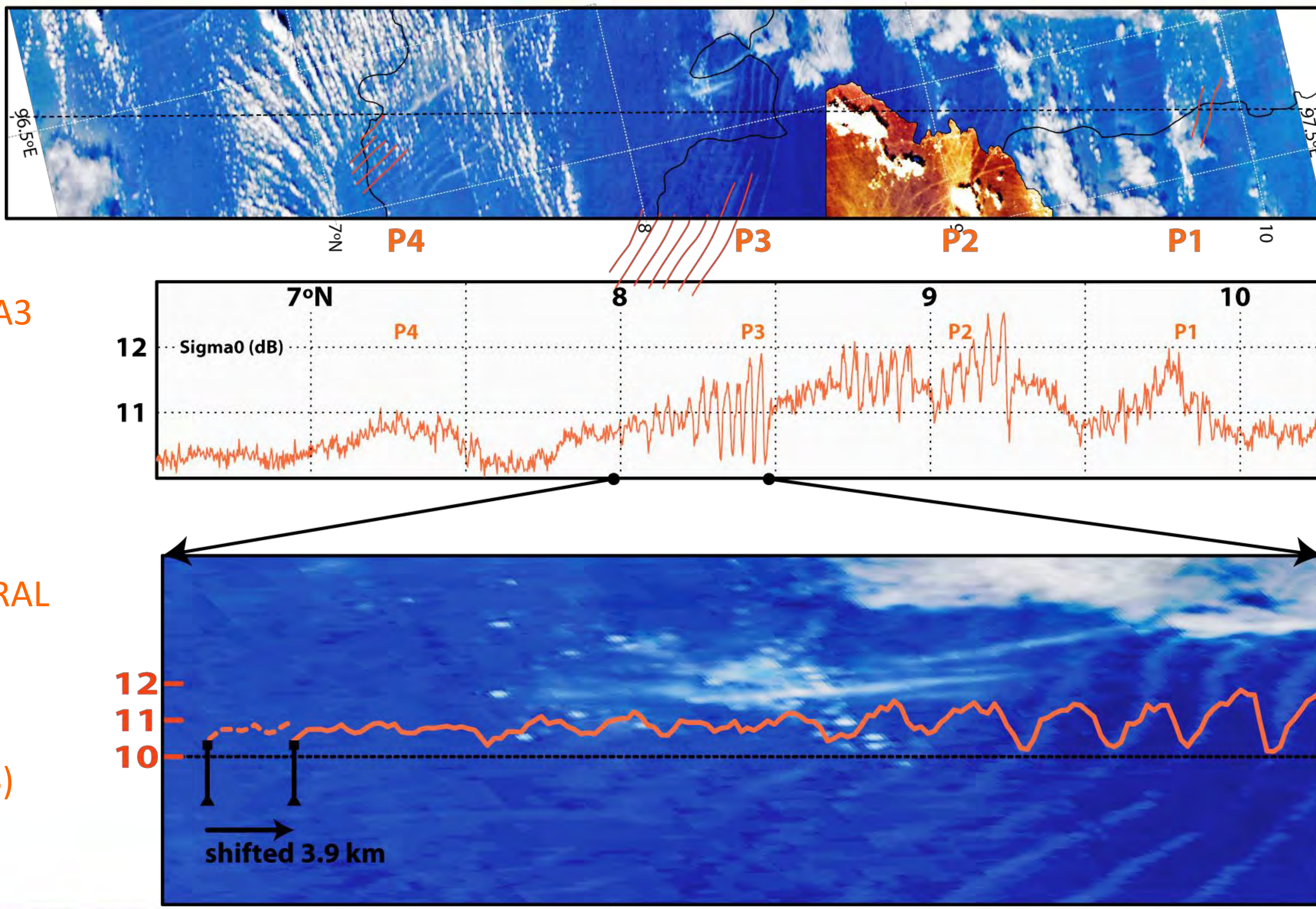
2017.02.12 03:16 UTC Andaman Sea

MODIS/
OLCI

Ku-band RA3
SARAL
Sentinel-3

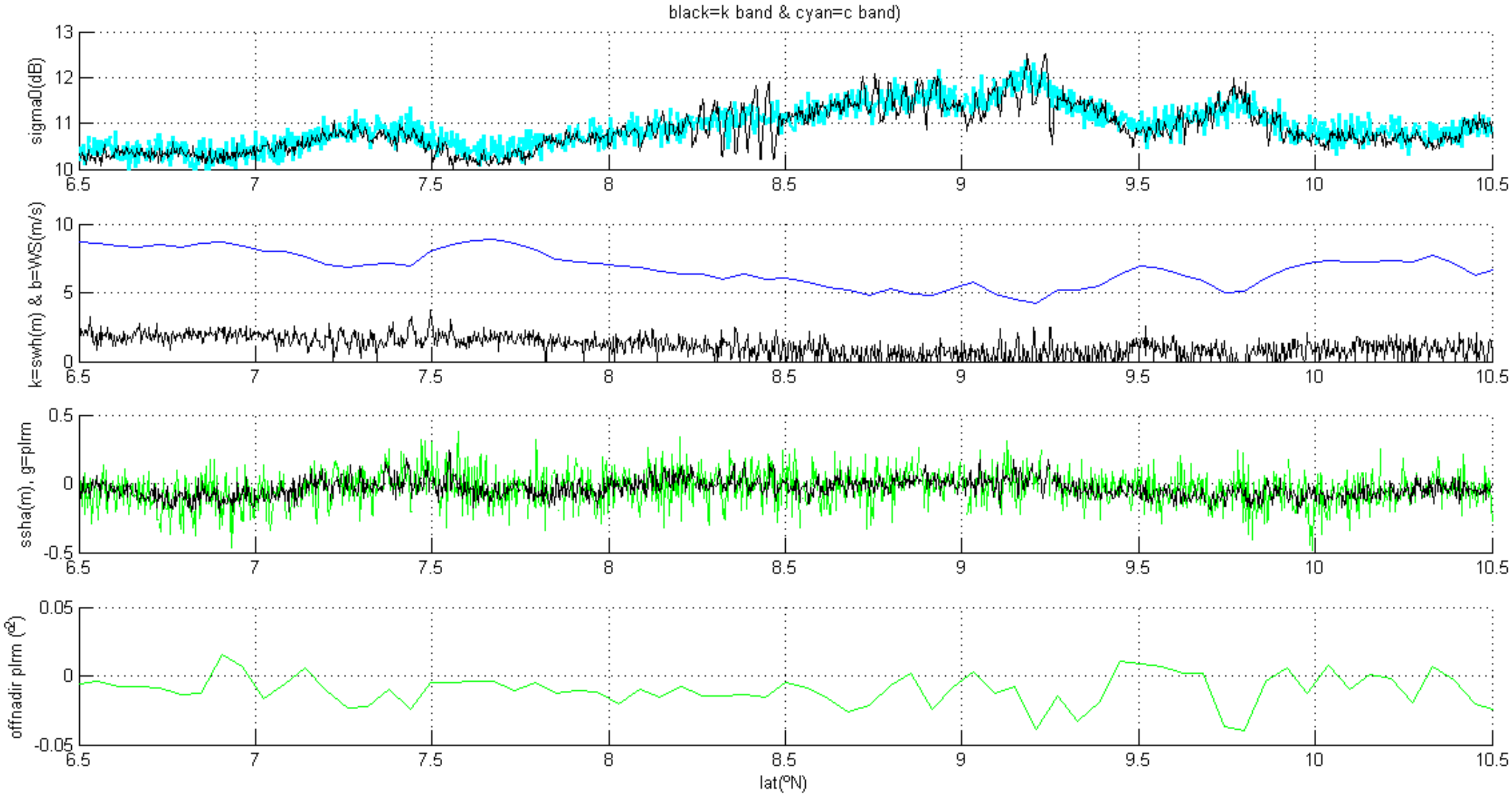
MODIS/ SRAL
Synergy

Ku-band
sigma0 (dB)



2017.02.12 03:16 UTC Andaman Sea

Radar Altimeter Product Level 2:
S3A_SR_2_WAT_20170212T031424_20170212T035906_20170309T222415_2682_014_175______MAR_O_NT_002.SEN3

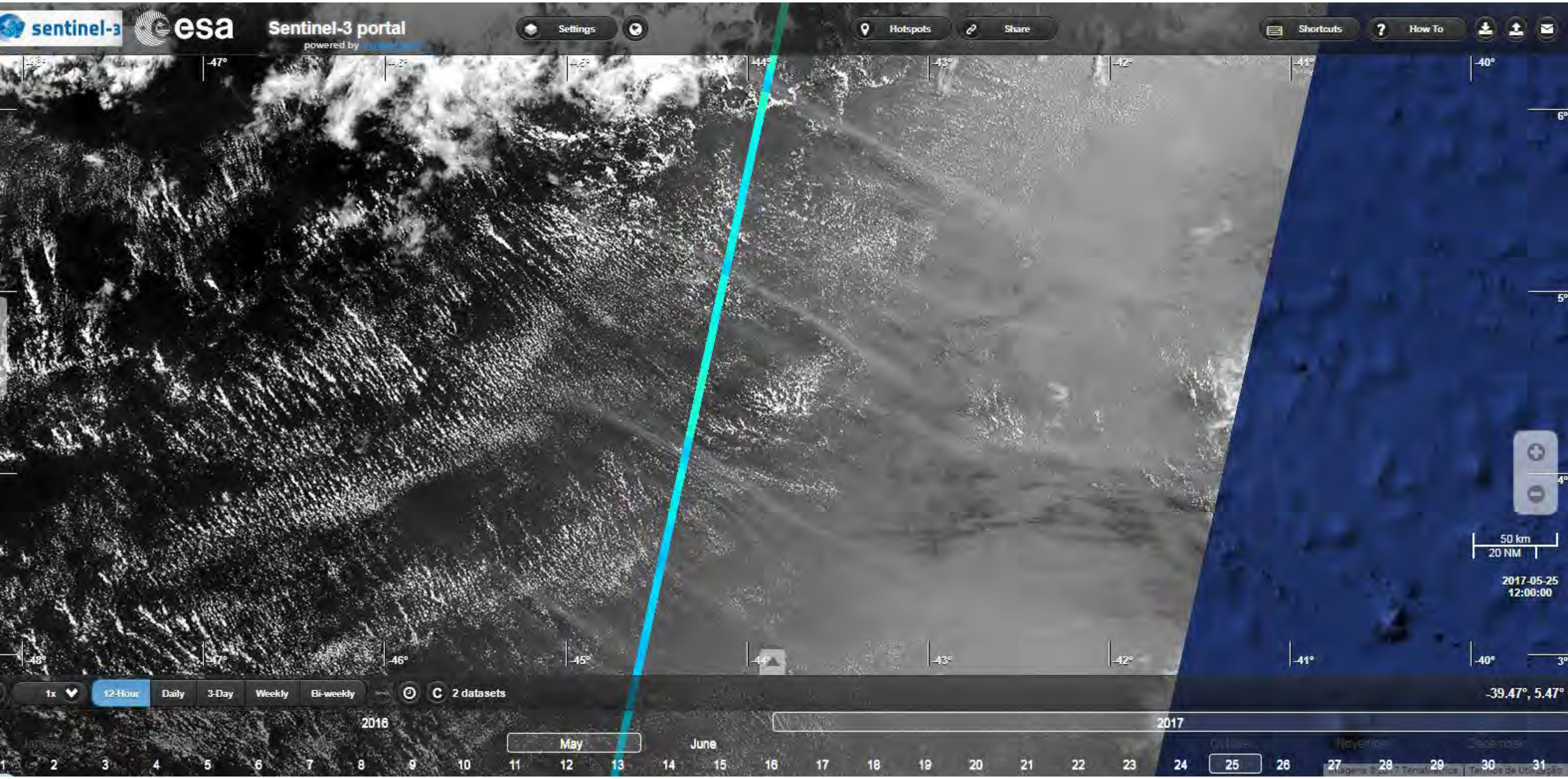


South China Sea

2017.05.25 12:35 UTC Tropical Atlantic (Amazon)

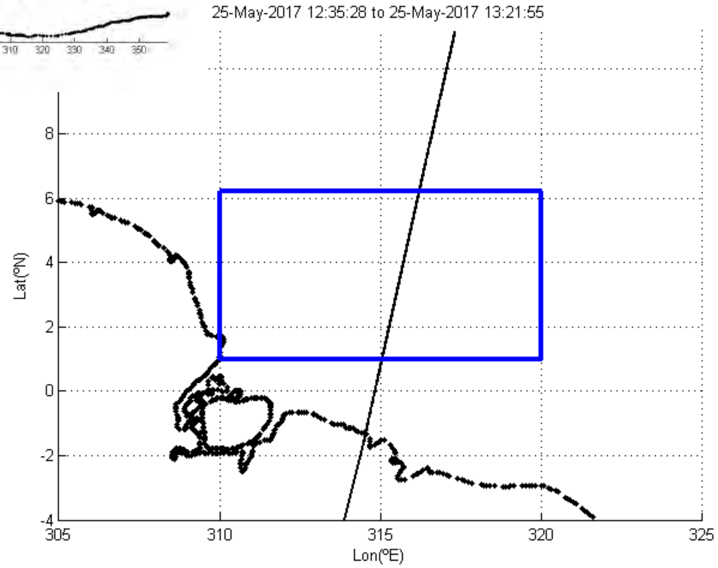
Radar Altimeter Product Level 2:

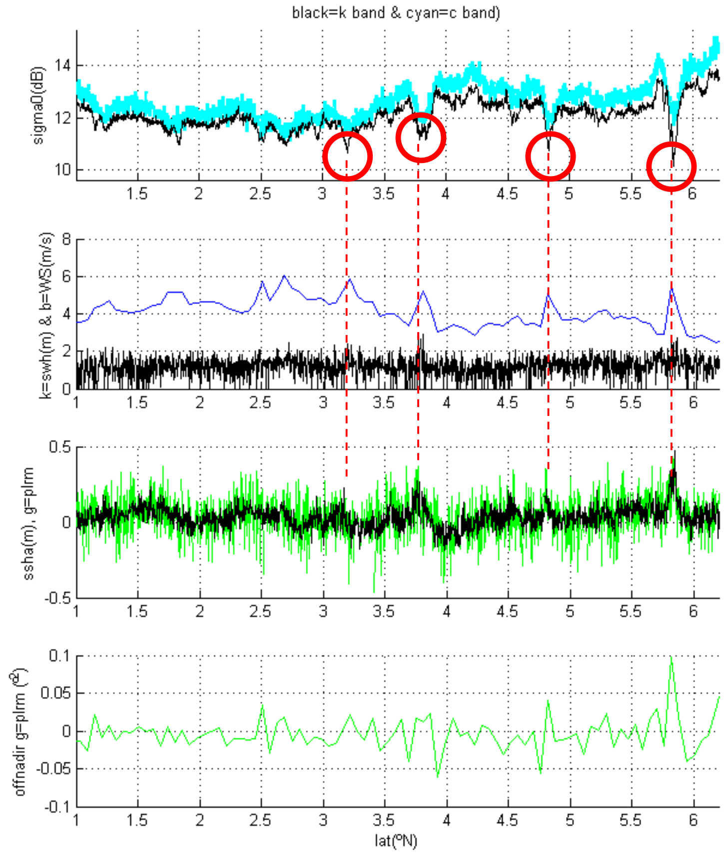
S3A_SR_2_WAT_20170525T123529_20170525T132155_20170620T073644_2786_018_095______MAR_O_NT_002.SEN3



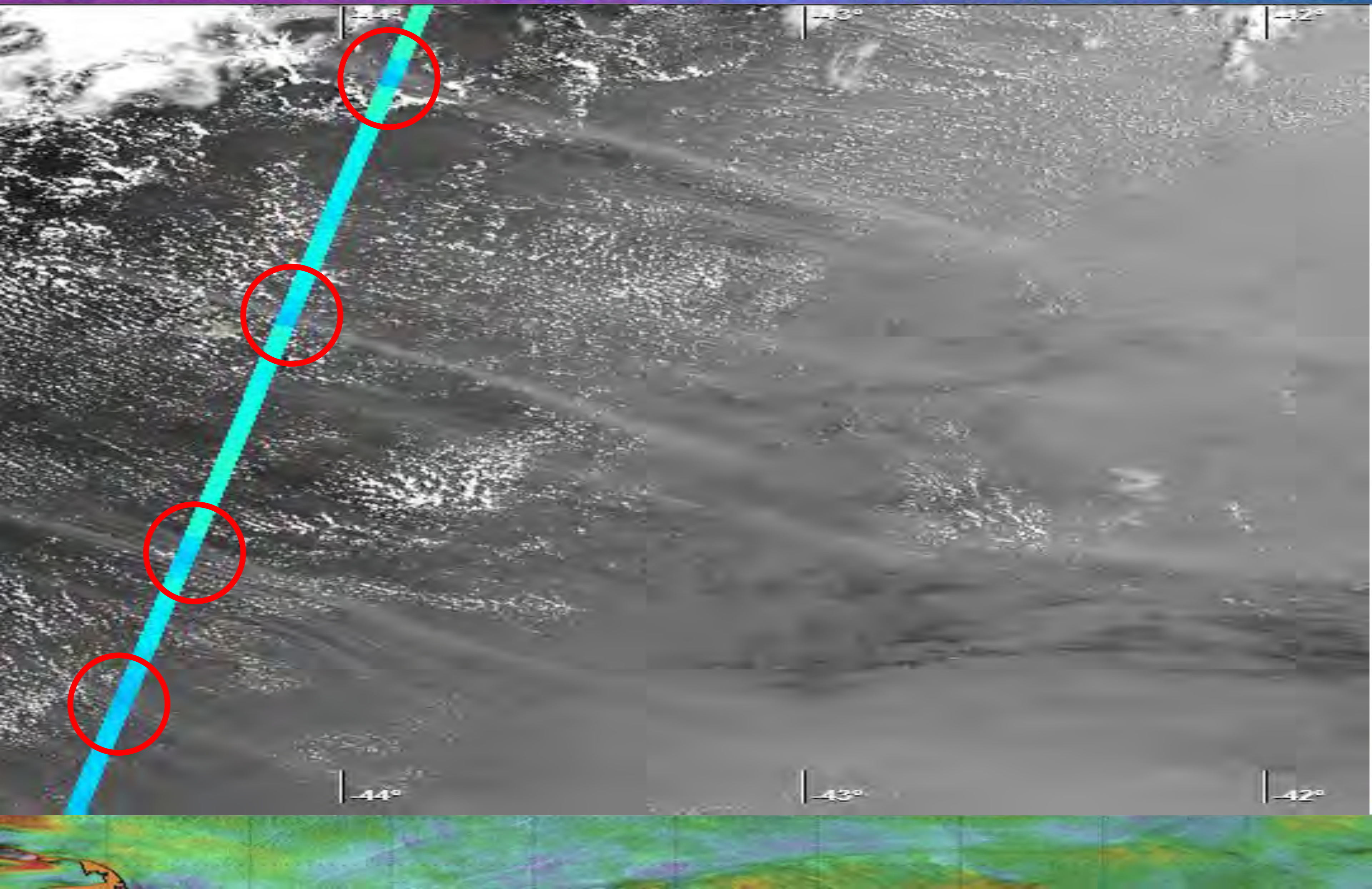
https://odl.bzh/gDKqdSzP

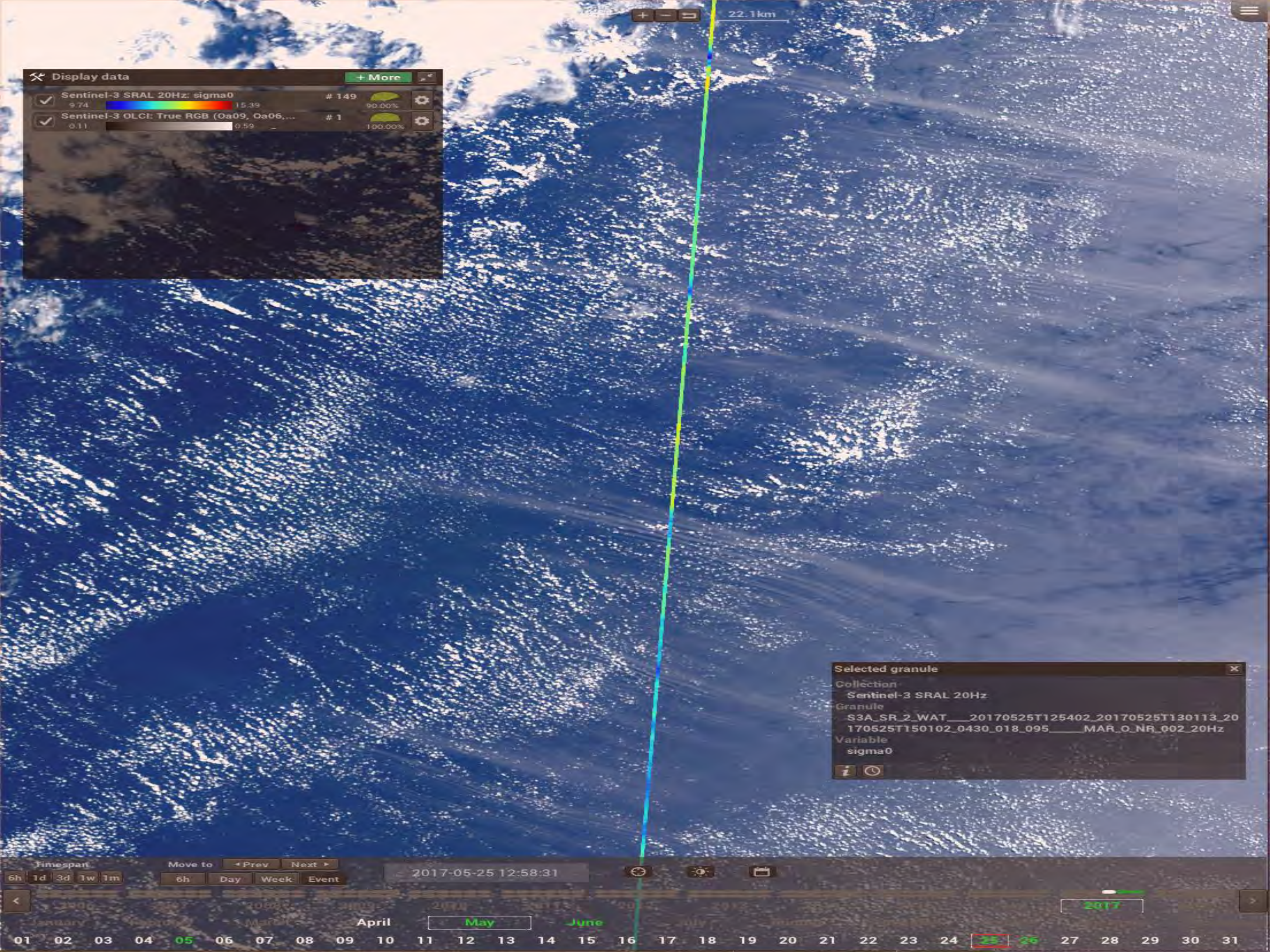
2017.05.25 12:35 UTC Tropical Atlantic (Amazon)





2017.05.25 12:35 UTC Tropical Atlantic (Amazon)





22.1km
Display data
+ More
Sentinel-3 SRAL 20Hz: sigma0
9.74
15.39
149
90.00%
Sentinel-3 OLCI: True RGB (Oa09, Oa06,...
0.11
0.59
1
100.00%
Selected granule
Collection
Sentinel-3 SRAL 20Hz
Granule
S3A_SR_2_WAT____20170525T125402_20170525T130113_20170525T150102_0430_018_095______MAR_O_NR_002_20Hz
Variable
sigma0
Timespan
6h 1d 3d 1w 1m
Move to
Prev
Next
6h Day Week Event
2017-05-25 12:58:31
2017
April
May
June
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

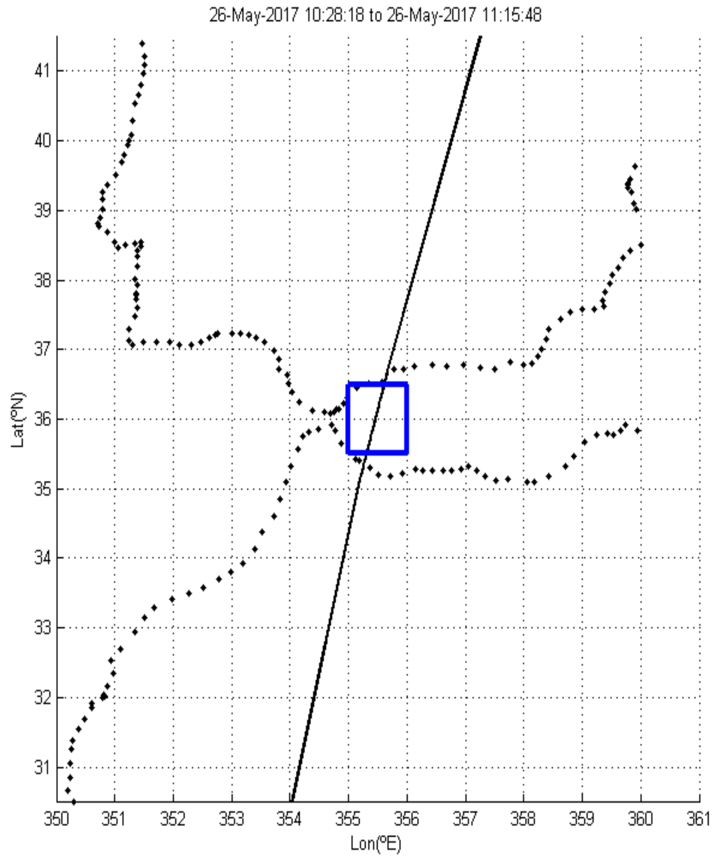
Strait of Gibraltar

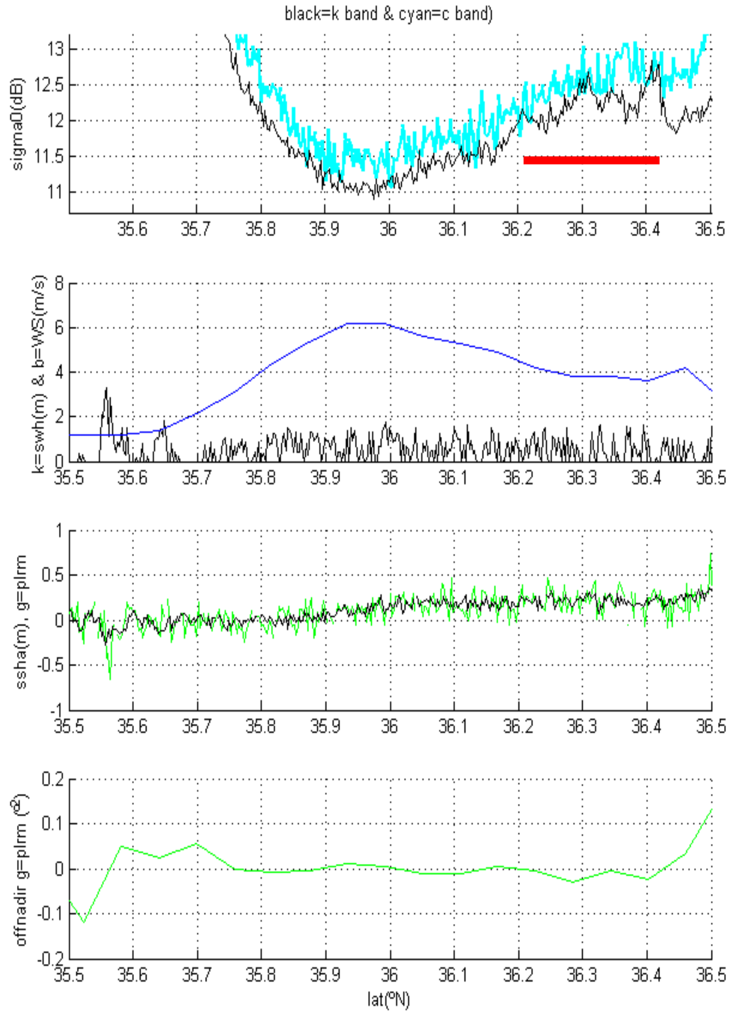
2017.05.26 12:28 UTC Str. Gibraltar (Mediteranean)

2017.05.26 12:28 UTC Str. Gibraltar (Mediteranean)

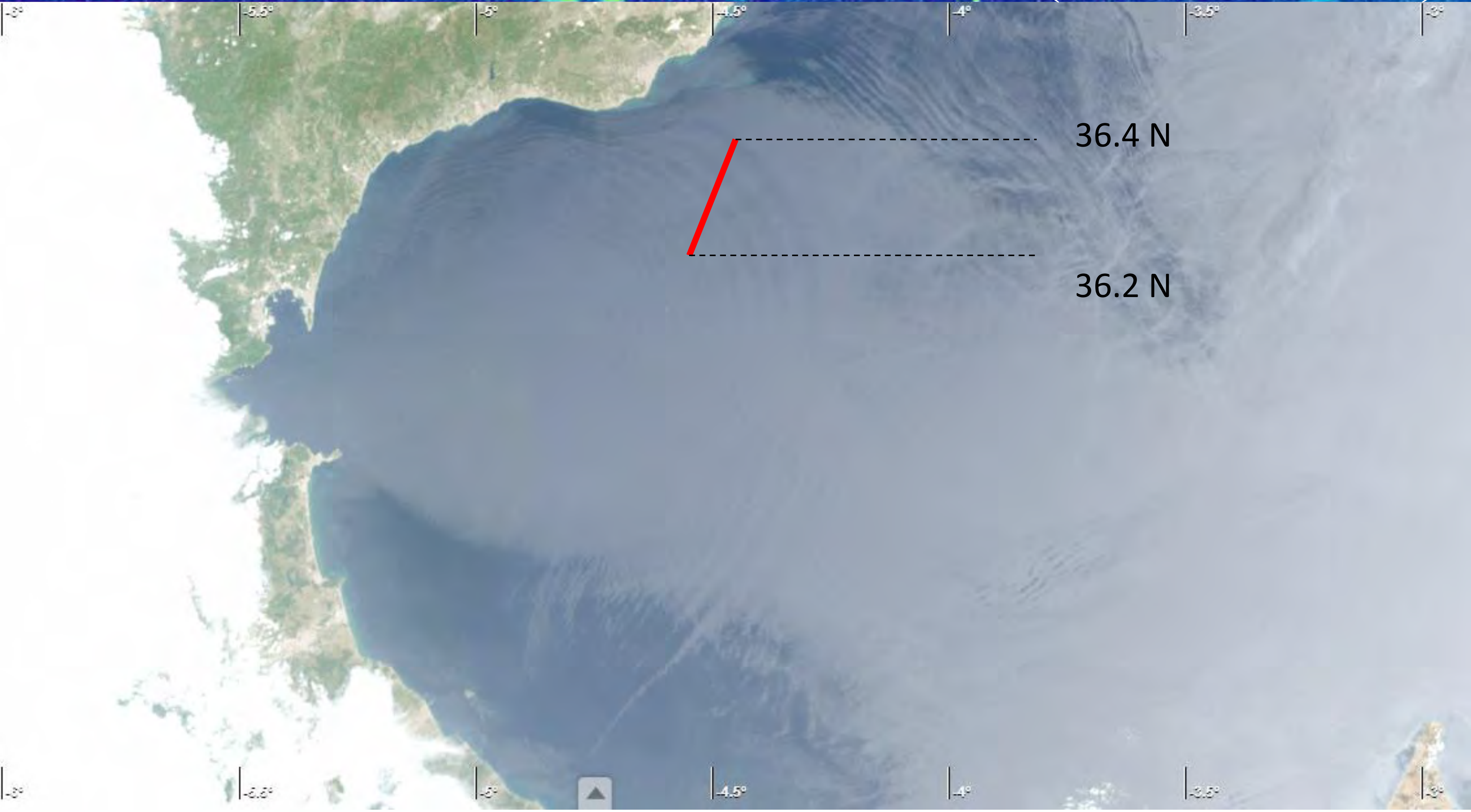
Altimeter ssha (1 Hz)
is colour coded

2017.05.26 12:28 UTC Str. Gibraltar (Mediteranean)



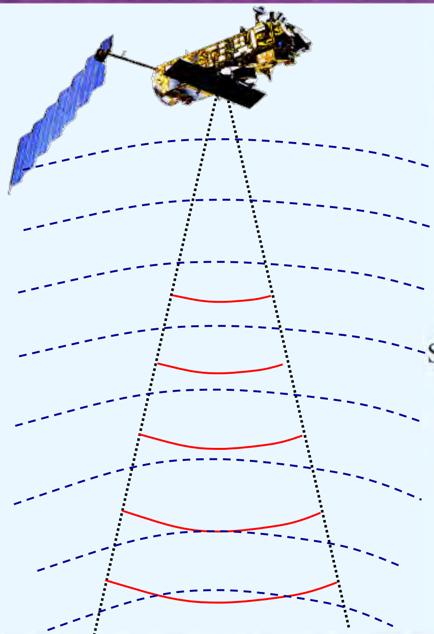


2017.05.26 12:28 UTC Str. Gibraltar (Mediteranean)



Pulse –limited high rate altimeters: Jason-2 /3

Introduction:
Theoretical considerations about observability of ISWs with altimeters



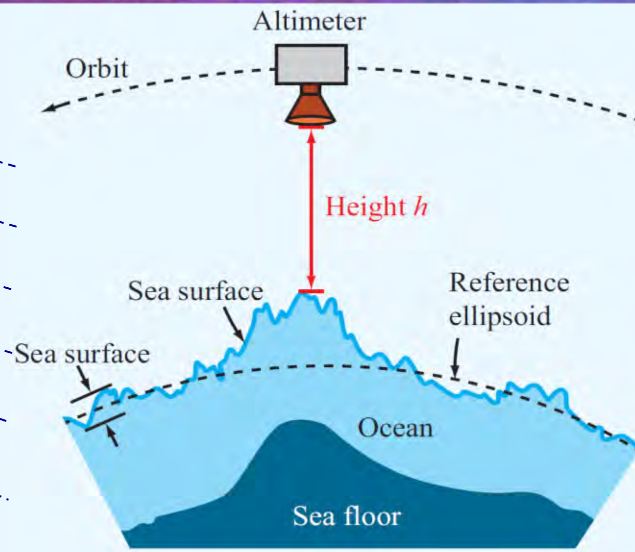
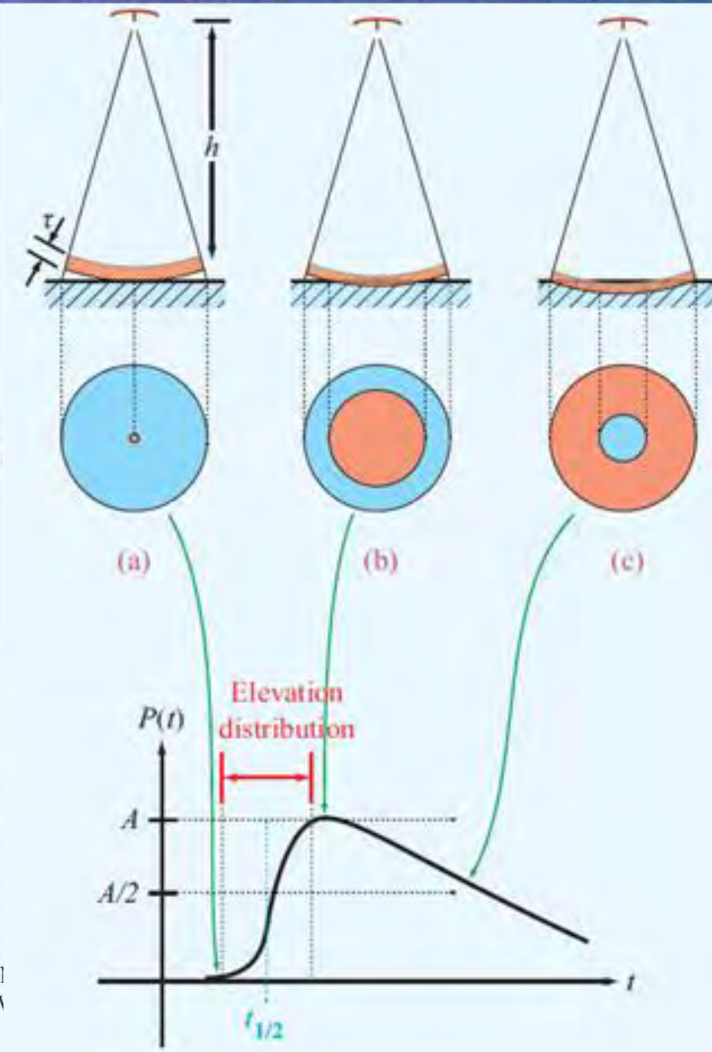


Figure 17-1: Spaceborne altimeter.



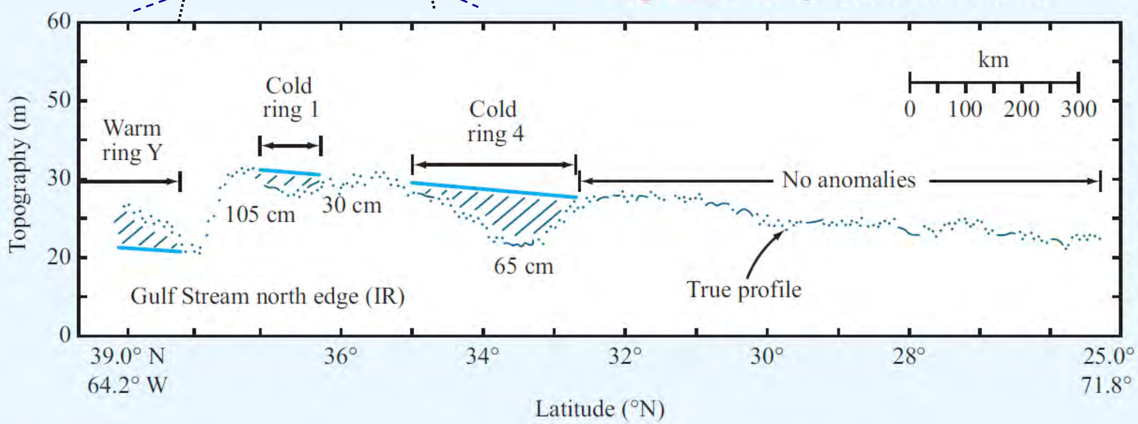
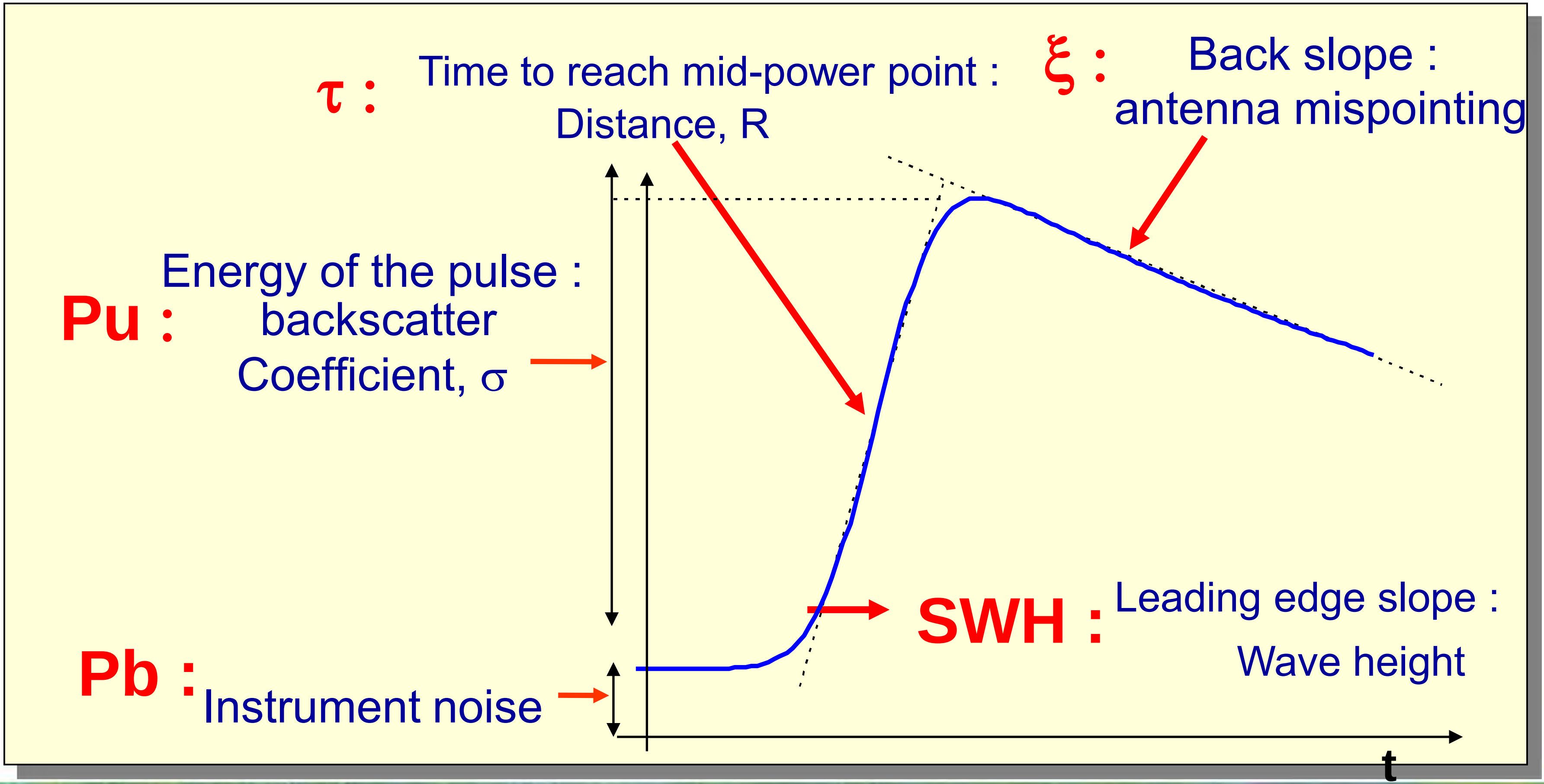


Figure 17-12: Ocean topography across the Gulf Stream. Small-scale eddies known as cold rings produce small-s variations. The Gulf Stream creates the slope. [Adapted from Cheney and Marsh, 1981.]

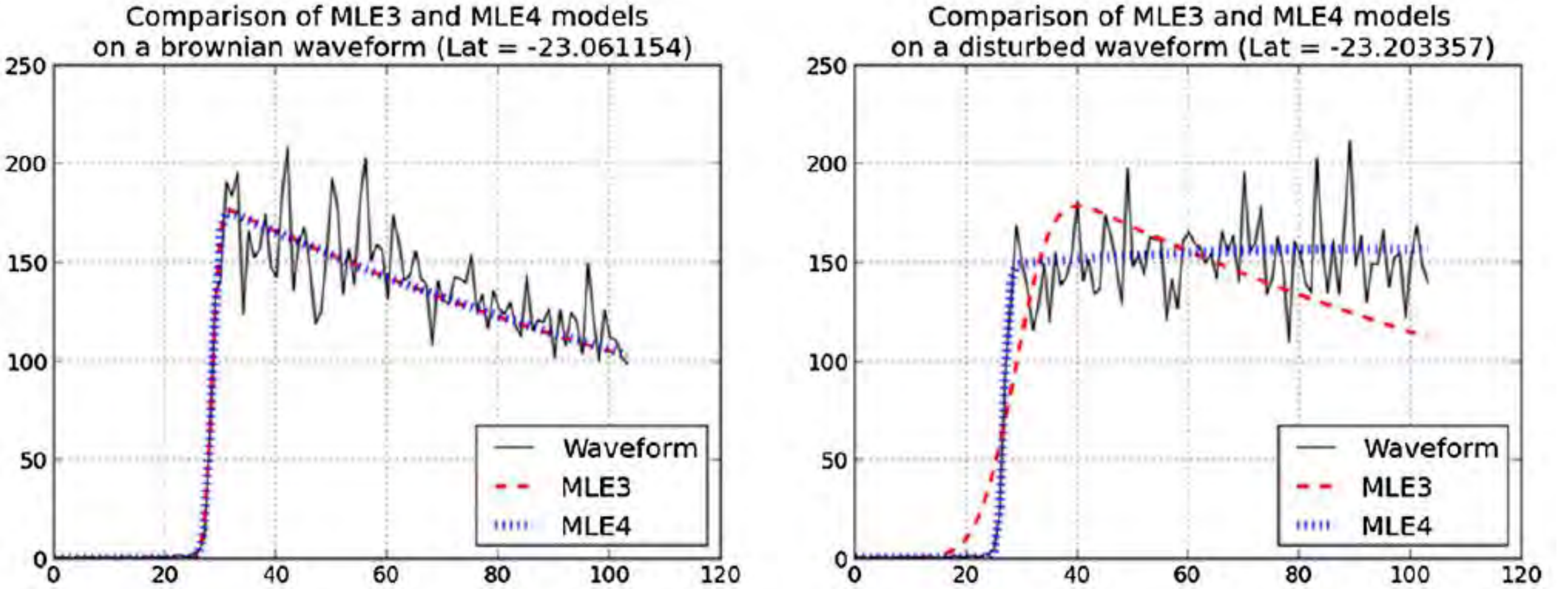
Physical parameters from the waveform



Introduction:
Theoretical considerations about observability of ISWs with altimeters

Retracking Algorithms: Maximum Likelihood Estimator MLE3 & MLE4

σ_0 and **off-nadir angle** affected by inhomogeneous surface and detected in MLE4



Standard ocean waveform

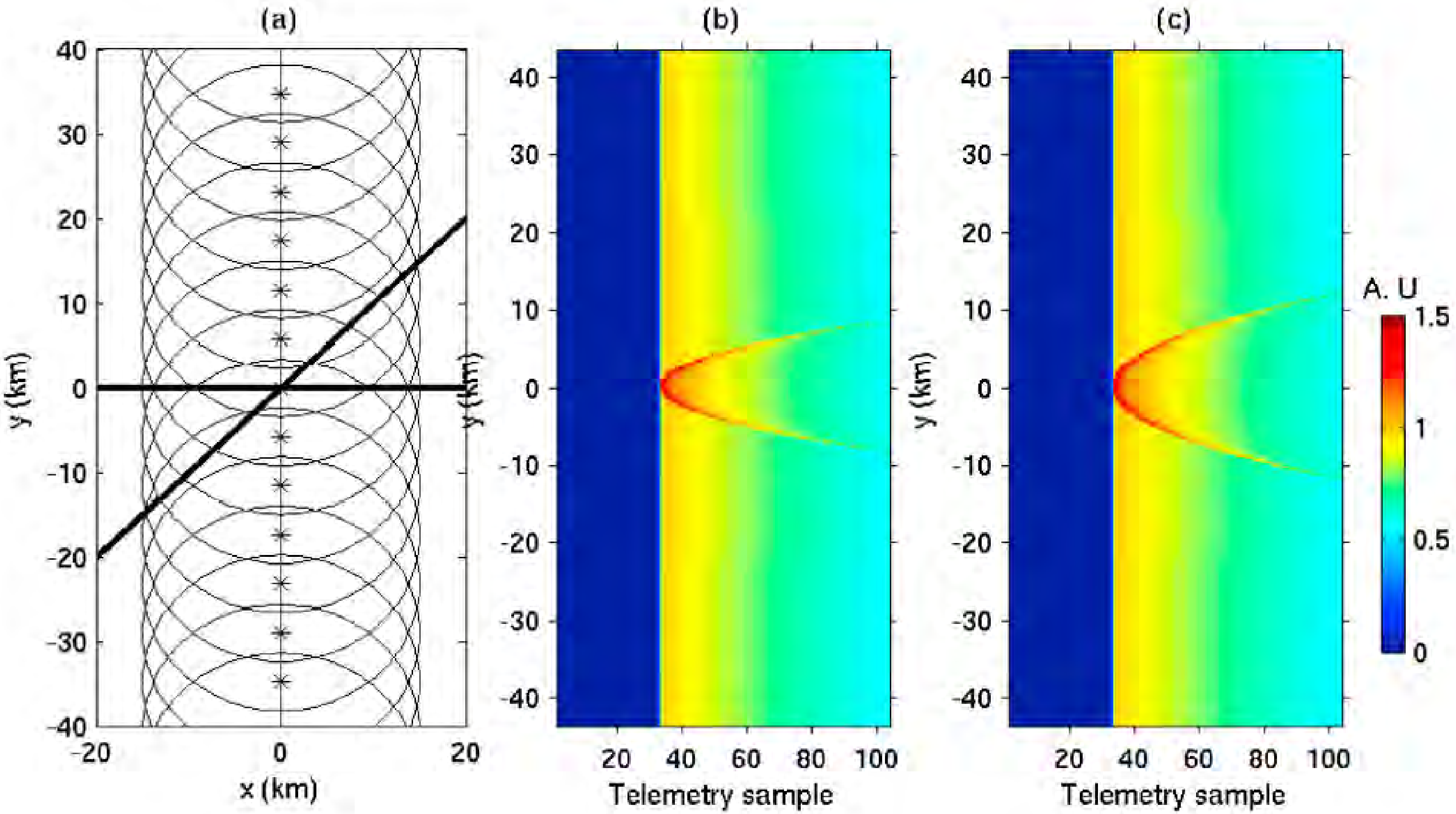
Waveform affected by a sigma0 bloom

➡ MLE4 performs better than MLE3 for inhomogeneous surfaces affetced by internal waves

from Dibarboure et al., 2014

Introduction:
Theoretical considerations about observability of ISWs with altimeters

Jason altimeter echo waveforms in presence of Dirac-type surface slicks of +10 dB relative brightness and 100 m width (Tournadre et al., 2006).



(a) slicks bands (thick solid lines) and the altimeter footprint (circles, 1 per second). Modeled waveforms for (b) perpendicular slick and (c) the 45° oblique slick.

Introduction:
Theoretical considerations about observability of ISWs with altimeters

1) Roughness of the water surface with wind-driven waves may be “measured” with the mean square surface slope (mss), defined as,

$$\langle s^2 \rangle = \int_0^\infty S(\kappa)\ \kappa d\kappa$$

where S(κ) is the omnidirectional, one-sided wave number slope spectrum and κ is the wave number.

2) Apply the geometrical optics (Kirchhoff method) form of the integrated microwave backscatter cross section according to the expression,

$$\sigma_0^{GO} = \left(\rho_g \sec^4 \theta / \langle s_g^2 \rangle\right) e^{\left(-\tan^2 \theta / \langle s_g^2 \rangle\right)}$$

where ρ_g is an effective reflectivity, $<s_g^2>$ is an effective mean square slope estimate and θ is the pulse illumination incidence angle.

Introduction:
Theoretical considerations about observability of ISWs with altimeters

For satellite altimeter observations (near-nadir, i.e. θ~0), the mss is given by,

$$\langle s_n^2 \rangle = \frac{\rho_n'}{\sigma_0}$$

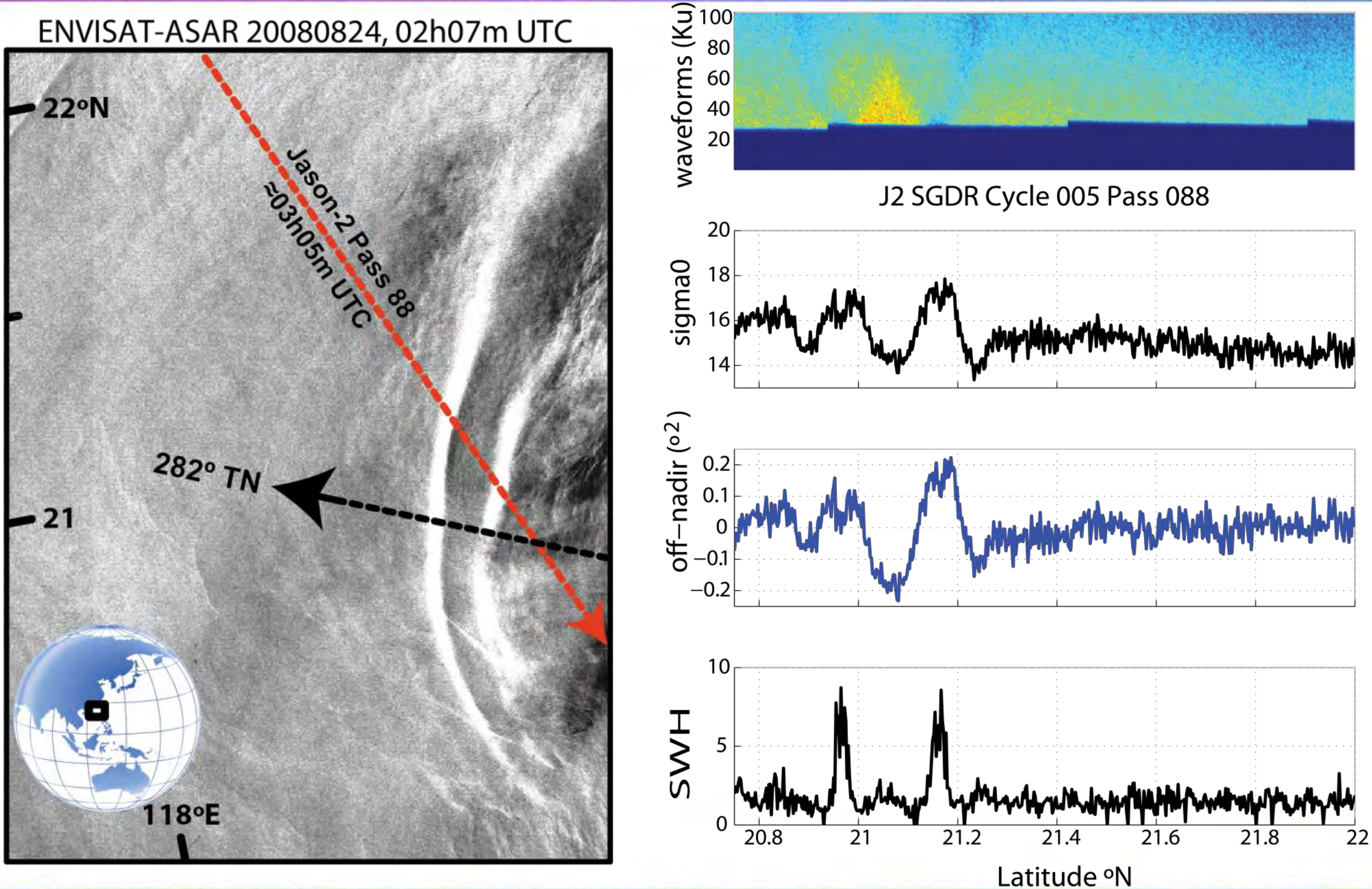
where the subscript n is used to indicate nadir and $\rho_{n'}$ is understood to differ from a pure Fresnel reflectivity coefficient in that it may include diffraction effects.

3) Isolation of the mean square slope contribution of the small-scale waves between 6.3 cm and 16.5 cm is possible by differencing the estimates from the two frequency bands of Jason-2 altimeter (Ku and C bands).

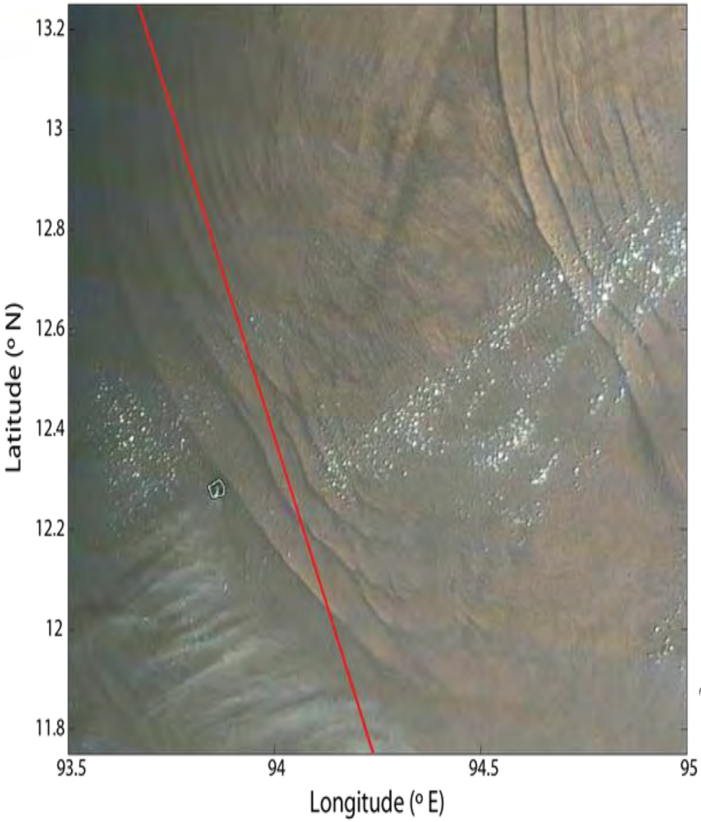
$$\langle s^2 \rangle = \int_{k1}^{k2} S(\kappa)\, \kappa d\kappa$$

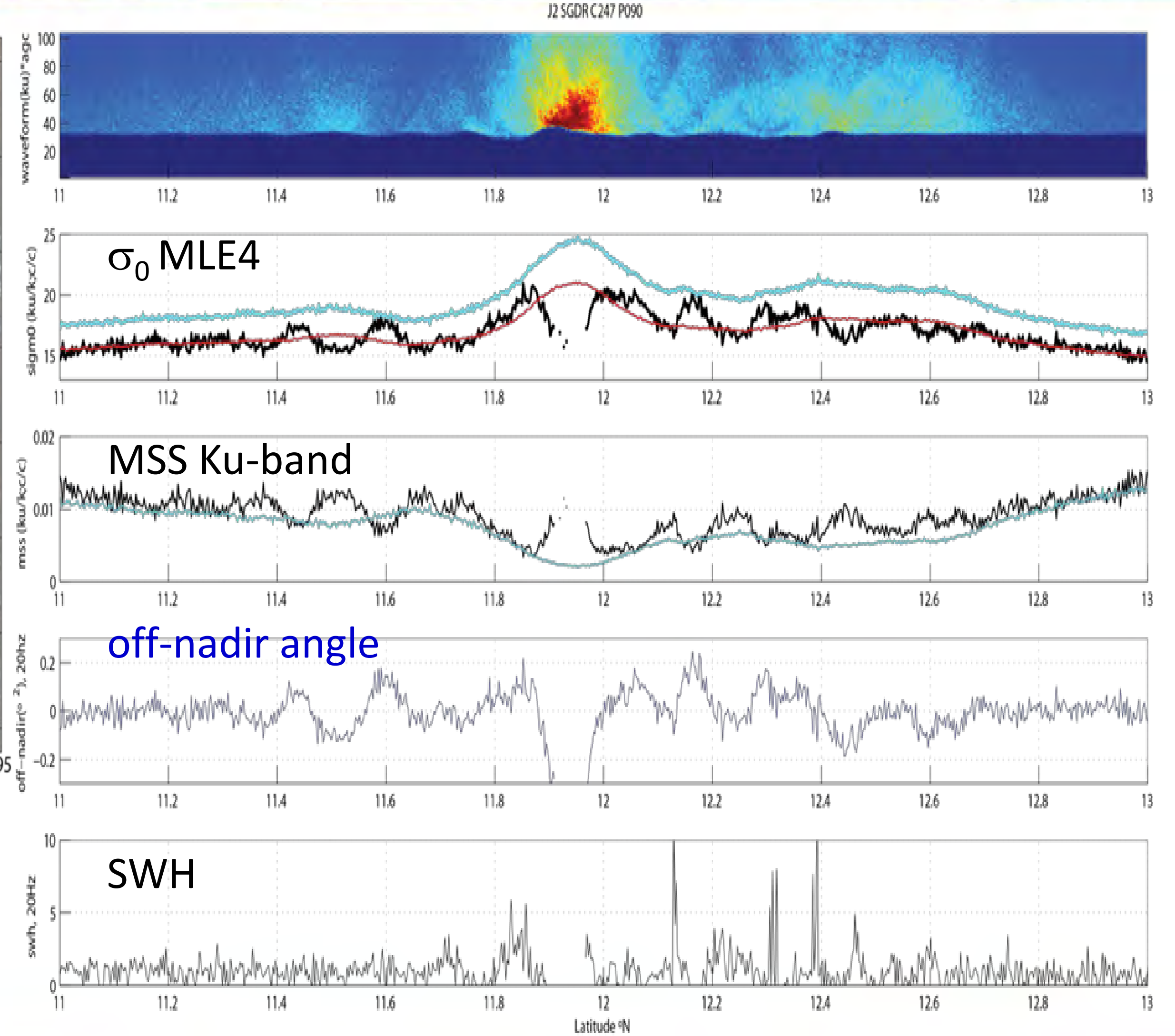
[k1, k2] = [40, 100] rad/m
[6.3, 16.5] cm

Some case studies: South China Sea



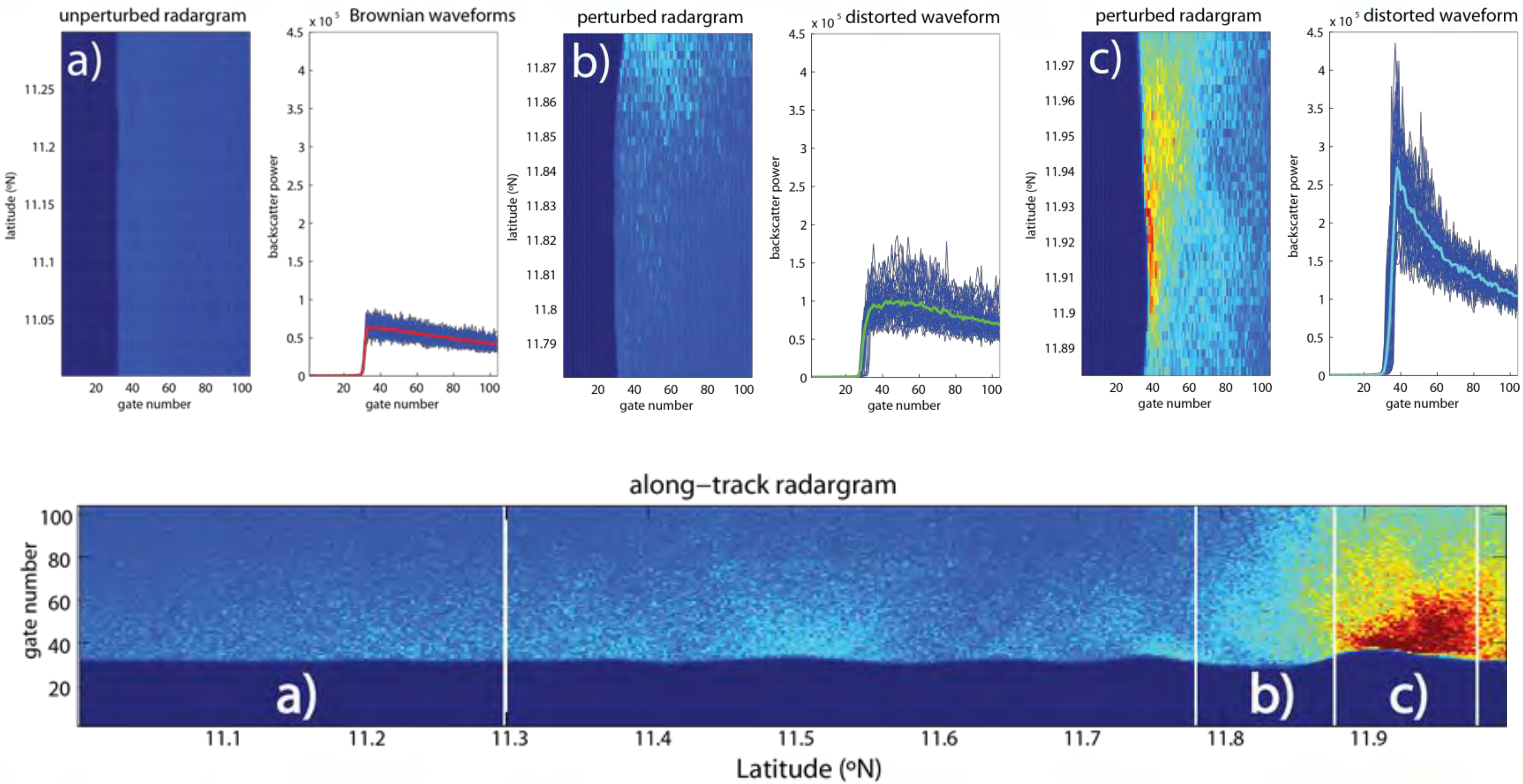
Some case studies: Andaman Sea



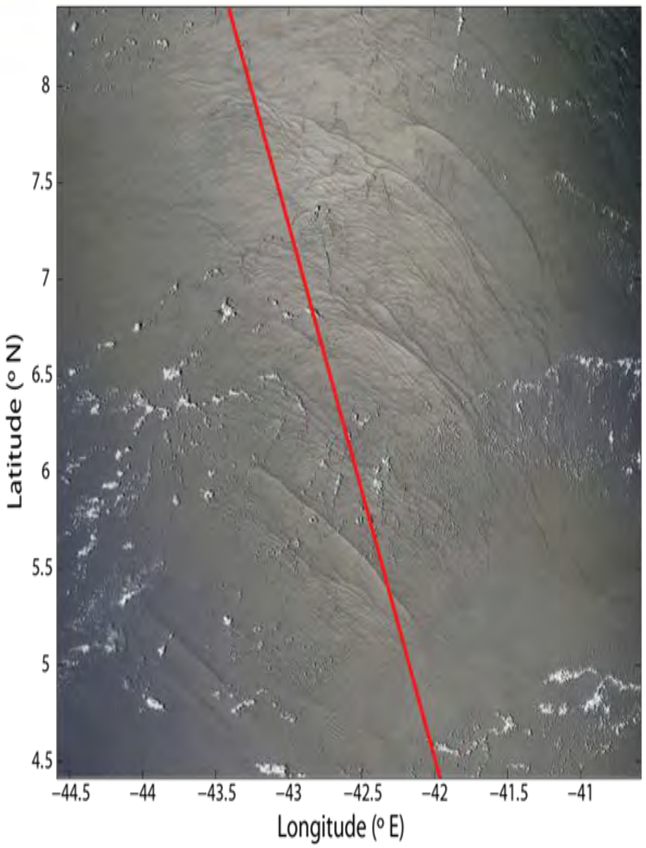


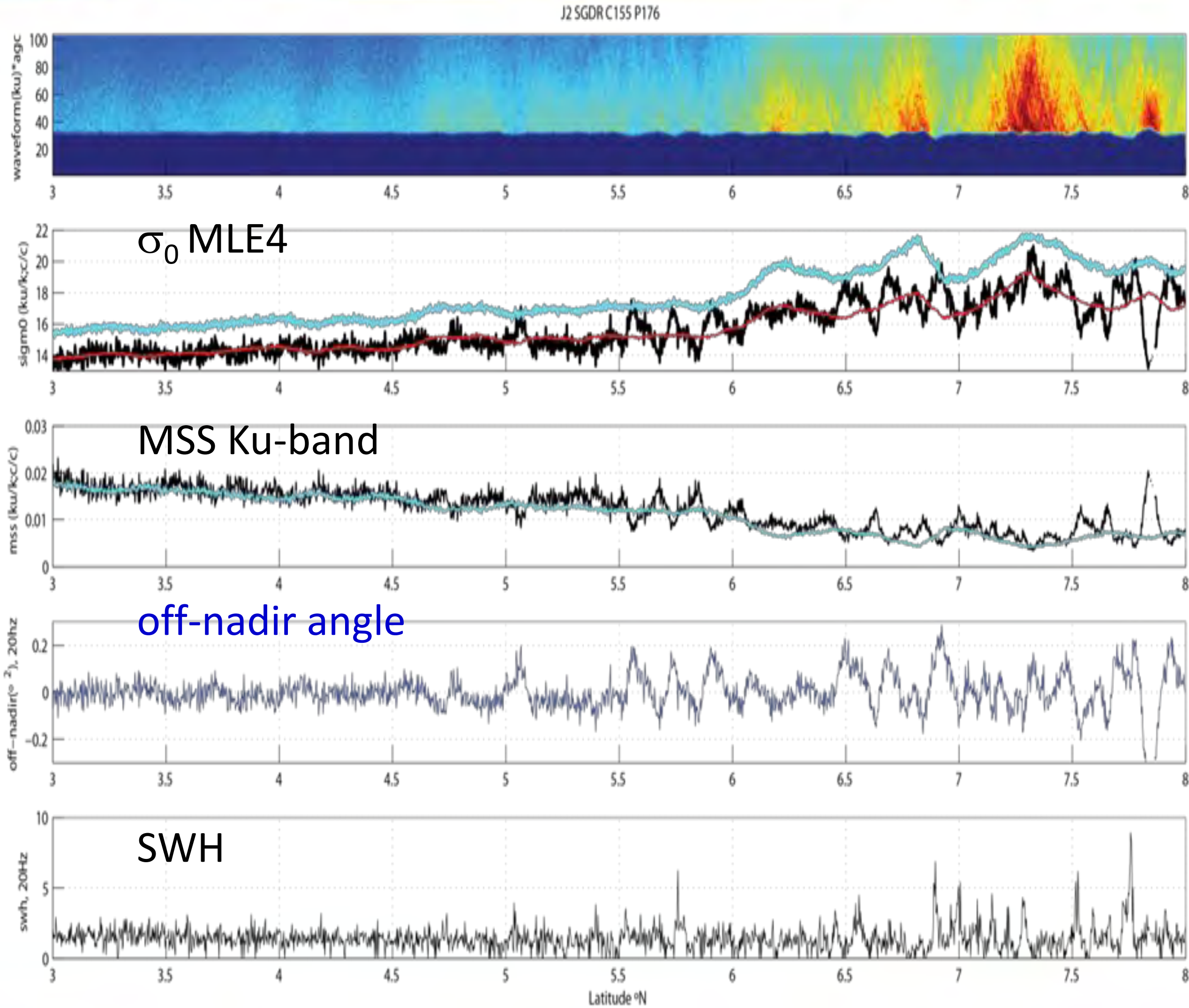
Jason-2 pass 90 cycle 247 on 20 March, 2015 (retrieved geophysical parameters)

Some case studies: Andaman Sea



Some case studies: Amazon Seas





Jason-2 pass 176 cycle 155 on 22 September, 2012 (retrieved geophysical parameters)

Conclusions

- A novel synergetic approach enables the identification of large-amplitude, short-period internal waves from high-rate satellite altimeters

- Oceanographers interested in short-period internal wave signals may find useful information in the 20Hz-rate Jason-2/3 and Sentinel-3 SRAL altimeter products currently being generated

- ISW signatures apparent in parabolic-like features in the radargram (Jason-2/3, radar power (sigma0), with a significant modulation in the off-nadir angle, and occasionally in SWH

Thank you!