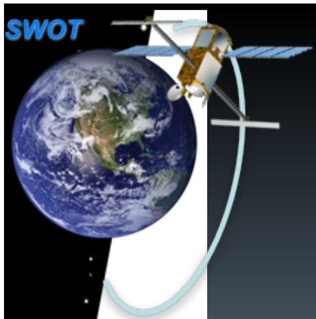
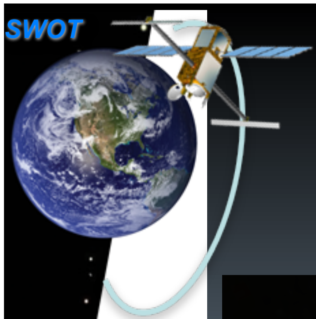


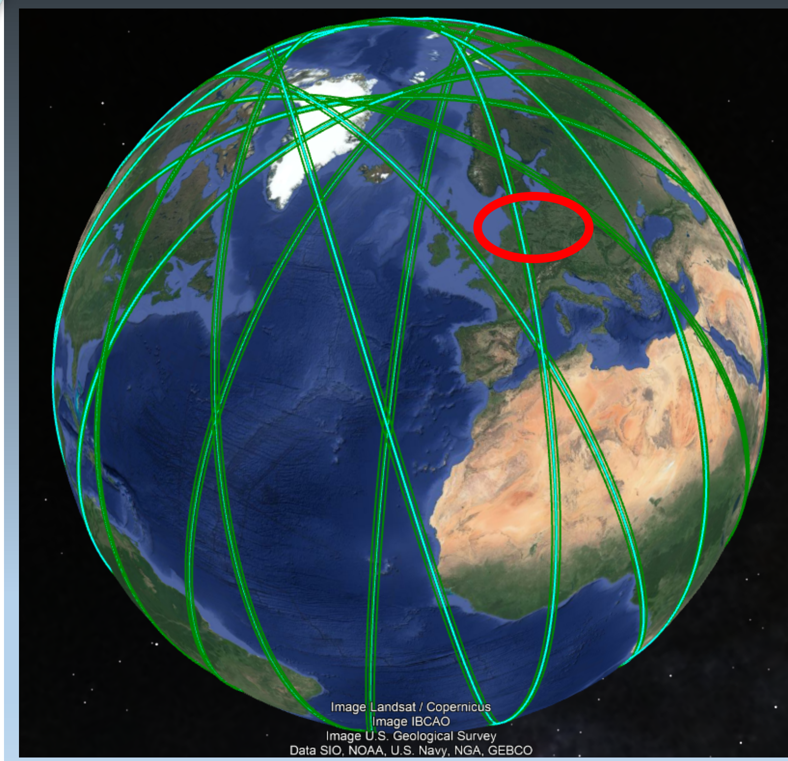
Spectral Approaches to investigate the Coastal Hydrodynamic Altimetry measurements

Spatial and Temporal coverage of measurements and Some insights in SWOT errors

Imen TURKI, Benoit LAIGNEL, Frederic FRAPPARD



Spectral Approaches to investigate the Coastal Hydrodynamic Altimetry measurements



English Channel: Normandy Coasts

Numerical Approaches
Hydrodynamic modelling
Waves, wind: SWAN
Sea level, currents: DELFT3D-FLOW
250m of resolution; Forcing limits: WW3

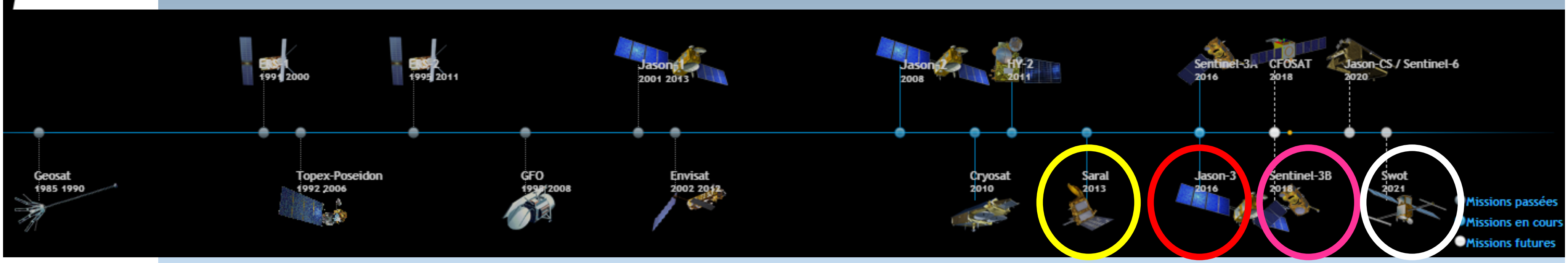
Altimetry Approaches
Use of wave and wind measurements

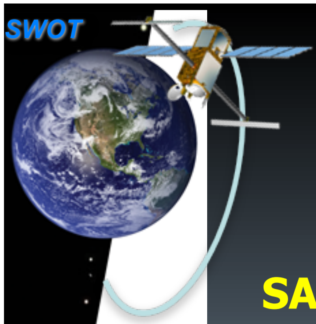
Statistical and Spectral Approaches
Analyse the error evolution in space and time

Spatial and Temporal coverage of measurements

Combining altimetry measurements is required for : the full coverage and Data Assimilation

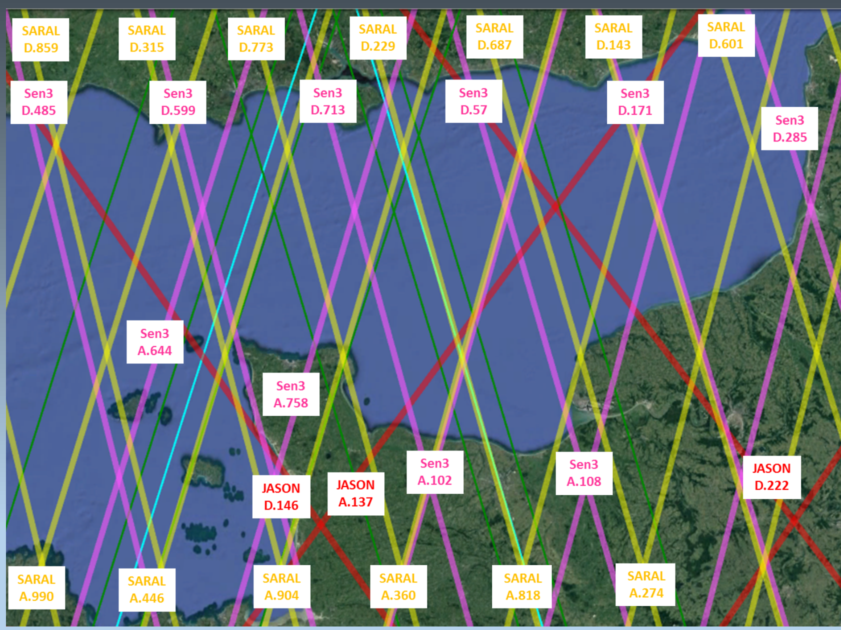
SARAL	35 days	Current Missions
Jason 3	10 days	
Sentinel 3	27 days	
SWOT	21 days	Further Mission



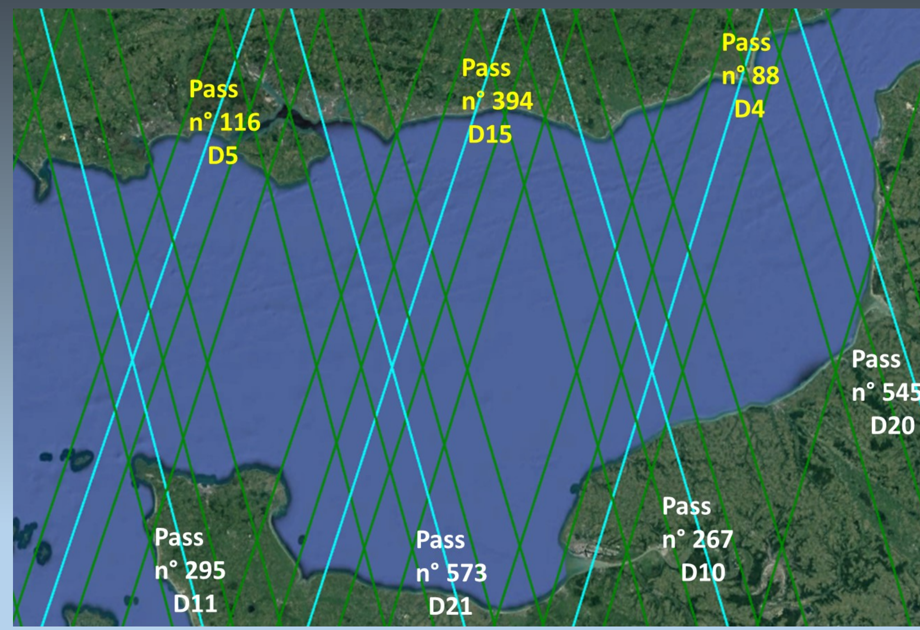


Spatial and Temporal coverage of measurements

SARAL, Sentinel 3 and Jason 3 Tracks



SWOT Tracks



More than 34 Altimetry passes covering the Northern side of French Coastal Zones + Large distribution in space and time

Spatial and Temporal coverage of measurements

To what extent these passes can cover the spatial and temporal variability?

SARAL, Sentinel 3, Jason 3 and SWOT Tracks

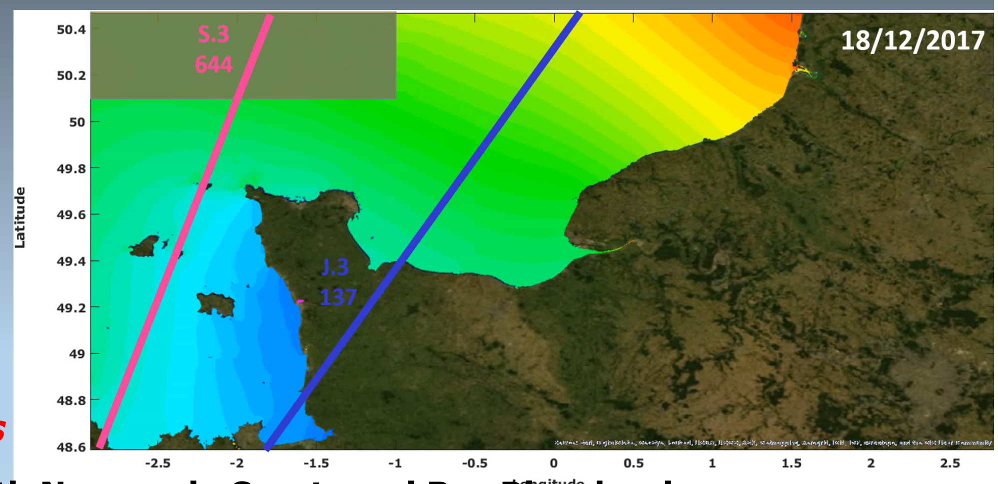
35 Days: 18 December 2017 – 21 January 2018

6 STORMY EVENTS

Bruno	27 Dec 2017
Carmen	29 Dec 2017
Eleanor	2-3 Jan 2018
Fionn	16 Jan 2018
David	17-18 Jan 2018

Same day of starting for cycles

Day 10 — Day 21 — Day — Day 35



2 days with 3 passes: 6 measurements
7 days with 2 Passes : 14 measurements
13 days with 1 pass: 13 measurements
12 days with 0 pass: 0 measurements
1-3 tracks each day for more than 20 days

➡ **spatial coverage+ time coverage is higher in North Normandy Coasts and Raz Blanchard**

Combining altimeter data is strongly required during high energy seasons where the succession of stormy events is important

Some insights in SWOT errors

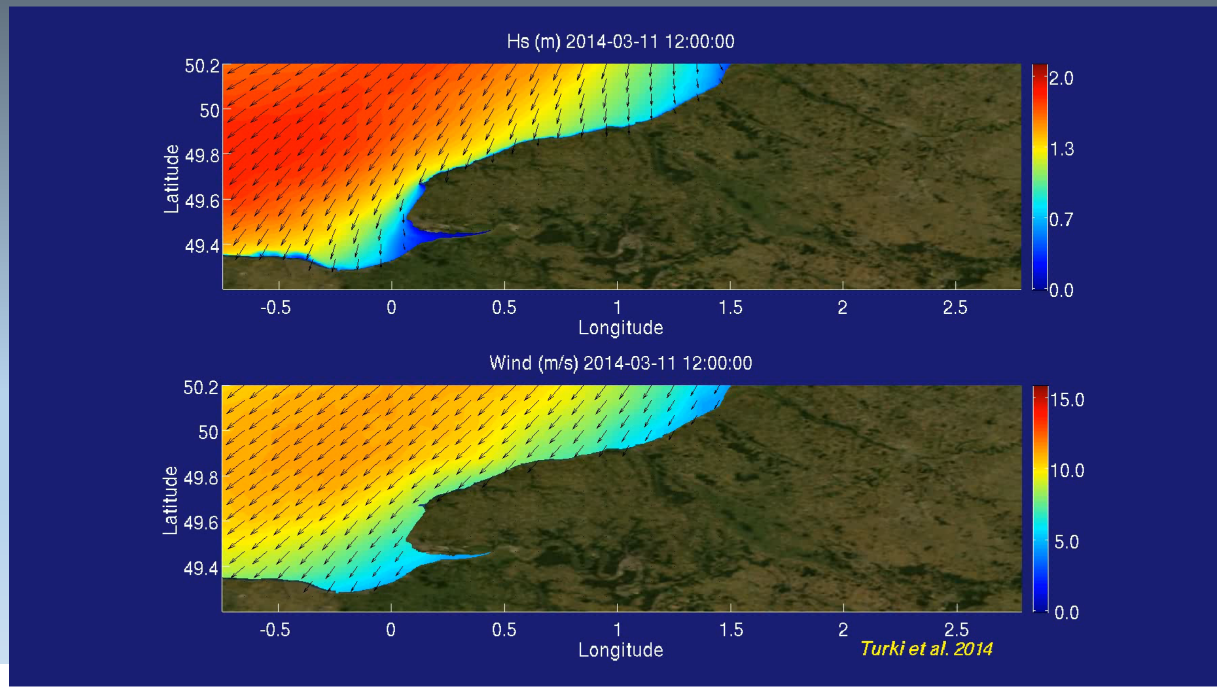
$$SSH = Altitude - Altimeter\ Range - \sum Corr$$

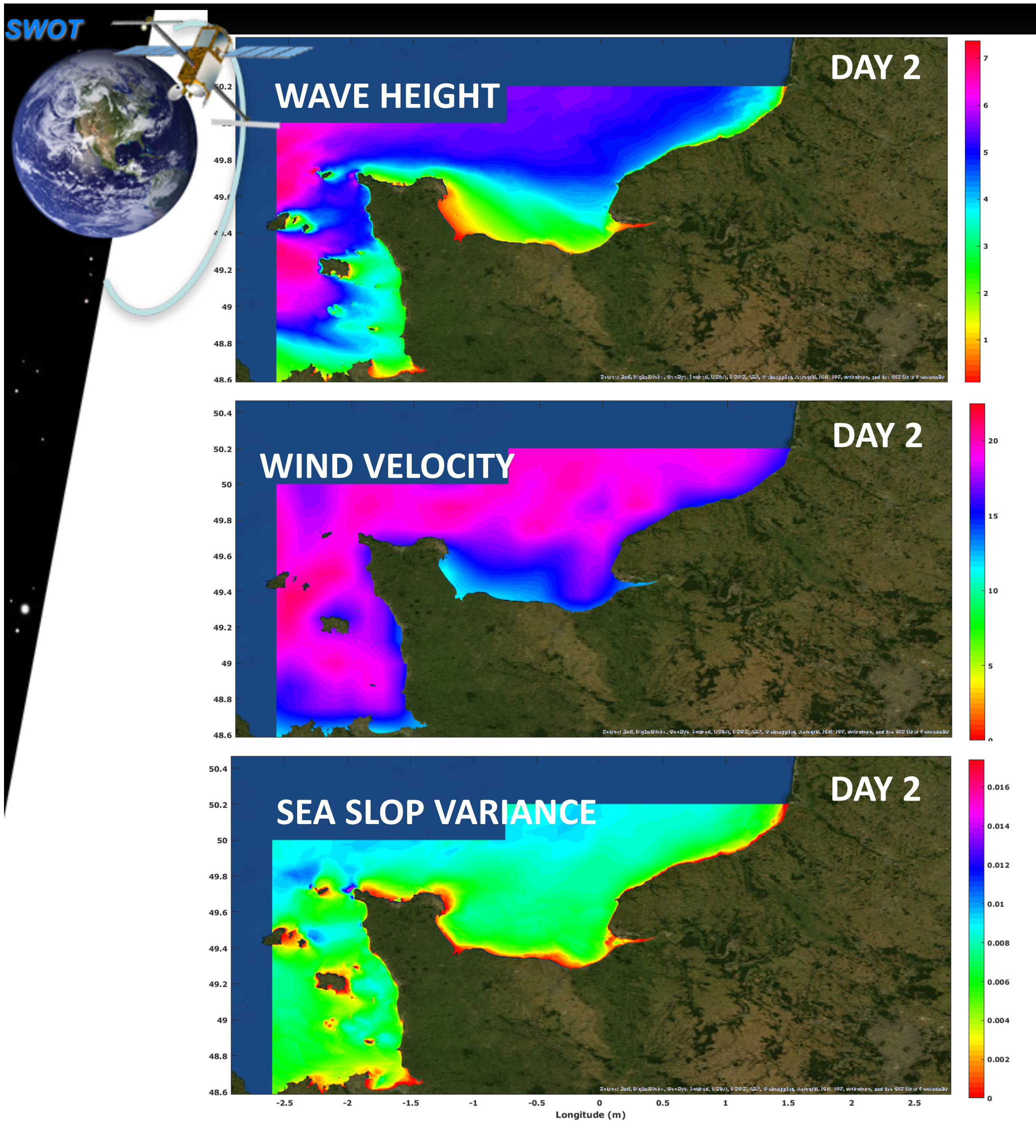
Environmental Corrections | **Sea State Corrections** | Geophysical Corrections

Sensitivity of error signal ?

Several resources of errors limit the accuracy of the final products:

1- Physical origin (wave height , wind velocity, sea slope, …..)
2- other Characteristics related to altimeters (look angle, k-band, …….)





Some insights in SWOT errors

What about altimetry errors in littoral zone near to the coastline ?
To what extent are ocean and coastal errors similar ?

Focus

Wave- Related Errors

Random errors

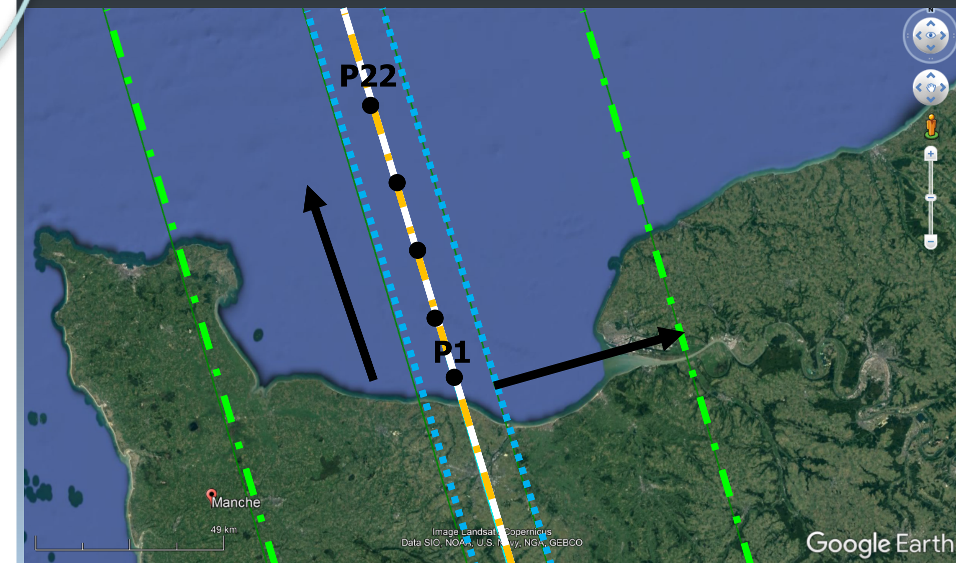
Strong variations of meteorological and physical conditions at small scales impacts :

1. **In time : days to seasons**
2. **In space : many km,**

(local topography conditions control this variation)

Some insights in SWOT errors

Descending SWOT Pass : 573



Swath Far Range
Swath Near Range

Descending SARAL track 229

Wave- Related Errors

Random errors

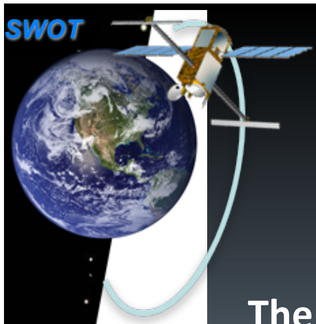
P1: 5 km from the coast
P22: 110 km from the coast

How errors vary in the space ?

Along the track? **Cross the track?**

How errors vary in the time ?

Monthly scales ? **Seasonal scales ?**



Some insights in SWOT errors

Wave- Related Errors

The spatial and temporal variability of wave and wind fields introduces height biases

Sea State Bias: SSB

$$SSB = f(U, SWH) \qquad SSB = a + b\,U + c\,U^2 + d\,SWH)\,SWH$$

$$SWOT:\ a = -0.21; b = -0.035; c = 0.00014; d = 0.0027$$

Average Brightness-modulated sea surface height: hs (σ_0)

Height Biases due to mean velocity shifts

$$hs(\sigma_0) = f(SWH)$$

Related to the look angle

$$hs(\sigma_0) = \frac{SHW\ \ m_H \cos\emptyset_m}{4\sqrt{2}}$$

Phase of Modulation

Some insights in SWOT errors

Random errors

The variance of the height/phase measurements; intrinsic noise of the interferometer….. Destructive errors increasing the variance

Ocean Backscatter

Backscatter at K-band is derived from Vandermark Model

$$\sigma_0 = \frac{|R(\theta)2|}{mss'_{Ka}} \sec^4(\theta)\, e^{\frac{\tan\theta^2}{mss'Ka}}$$

Radar derived estimate of surface wave slope variance

$$mss'_{ka} = 0.019 \log(8.35\sqrt{-\log(1-p)})$$

Wind velocity Percentile

Approximated Angular Decorrelation

Non linear mixing of wavelength at shallow water far from the coast And surf-board effects

f(Probability function de SWH)

SWH=4σ_h

σ_h : height standard deviation

f(Look Angle)

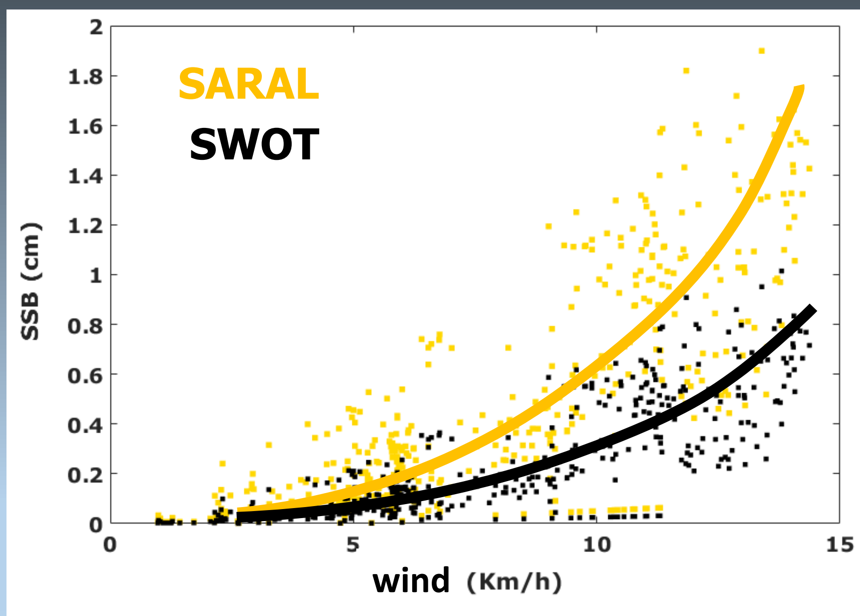
Empirical expressions have been used to compute error signals from modelling data in passes between 2013 and 2016;

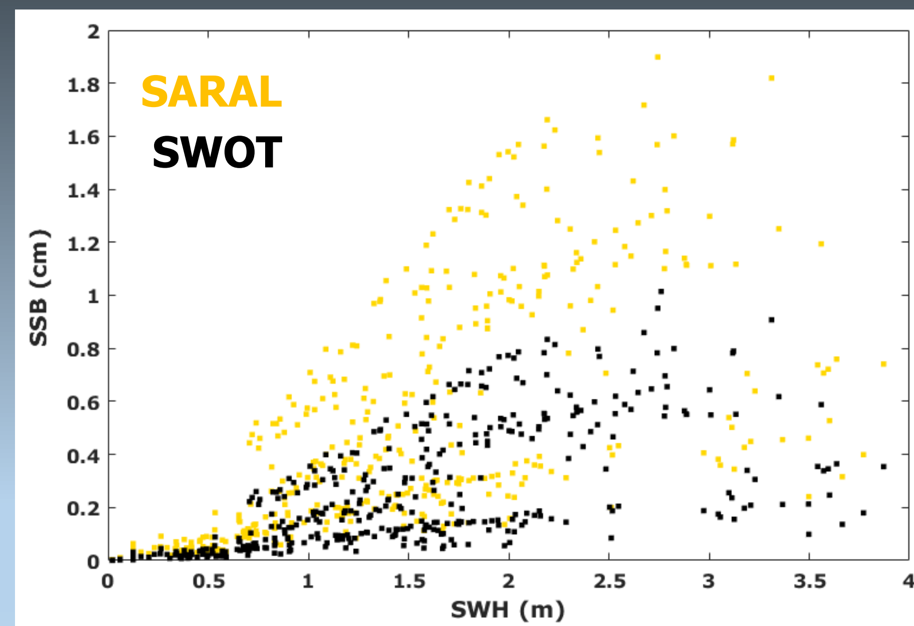
Some insights in SWOT errors

Wave- Related Errors: Sea State Bias 'SSB'

How is the dependence of SSB in SWH and Wind Velocity?

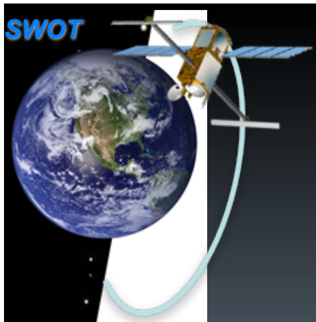
Descending SARAL track 229;
Descending SWOT Pass : 573





Increasing SSB with wind velocity/wave height , less important for SWOT computed bias

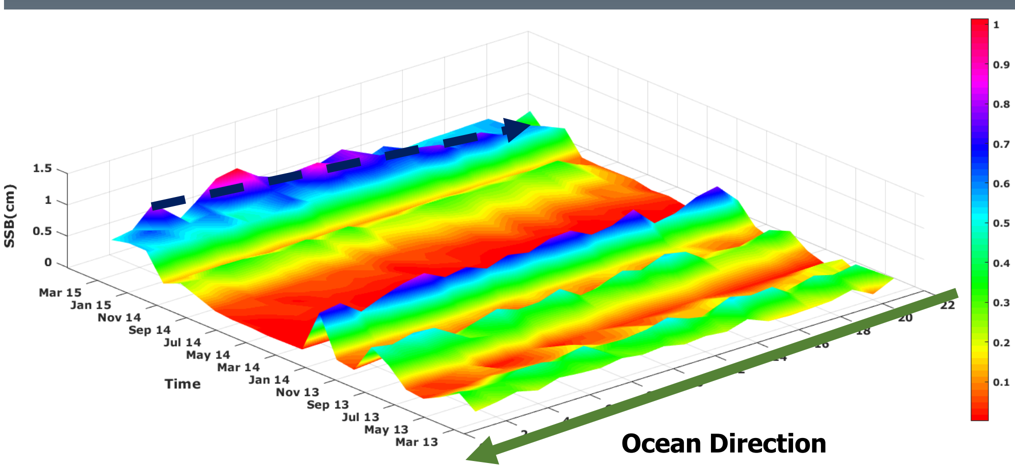
How is the dependence of SSB

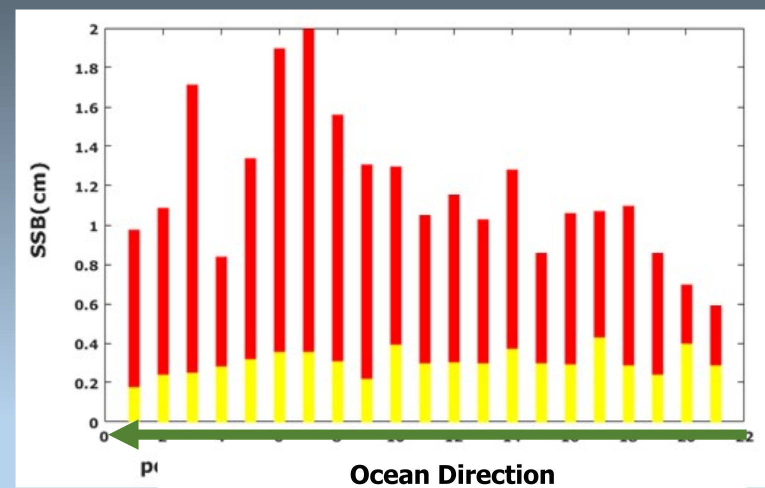


Some insights in SWOT errors

Wave- Related Errors: Sea State Bias ‘SSB’

Temporal and Spatial Dependence of SSB





* Variation in time with high and low values corresponding to high and low energy conditions.

* Along the track, SBB decreases close to coastal areas

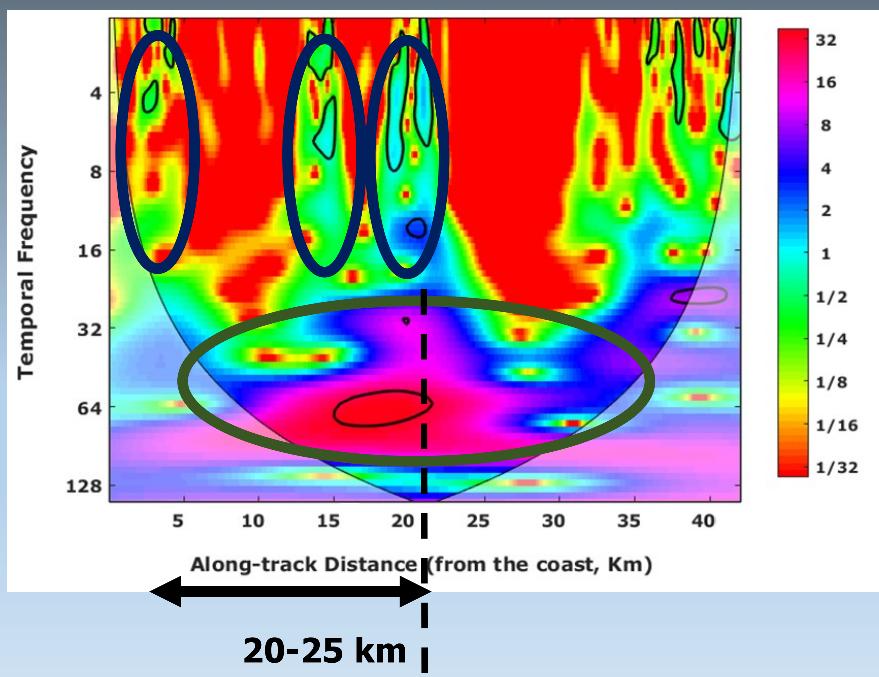
High and low patterns of SSB during high energy conditions along the track.
No significant changes during moderate conditions.

Some insights in SWOT errors

Wave- Related Errors: Sea State Bias 'SSB'

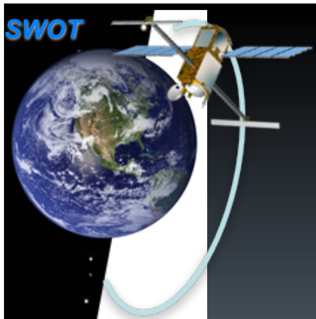
Spectral Approach of SWOT SSB signal: Continuum Wavelet transform

CWT diagram : spectrum power distribution



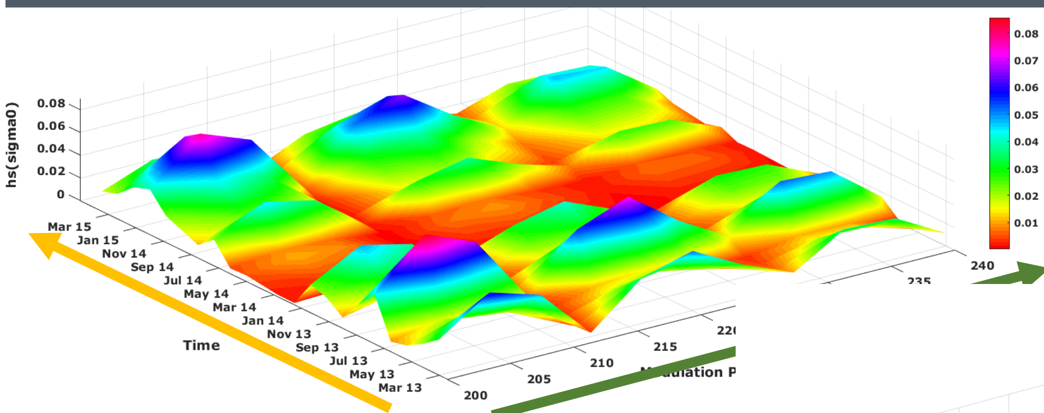
Scales of Days : 10 -30 days
High Frequencies until 20 Km from the Coast

Scales of Months and Seasons: 45-130 days
High Energy Spectrum along the track

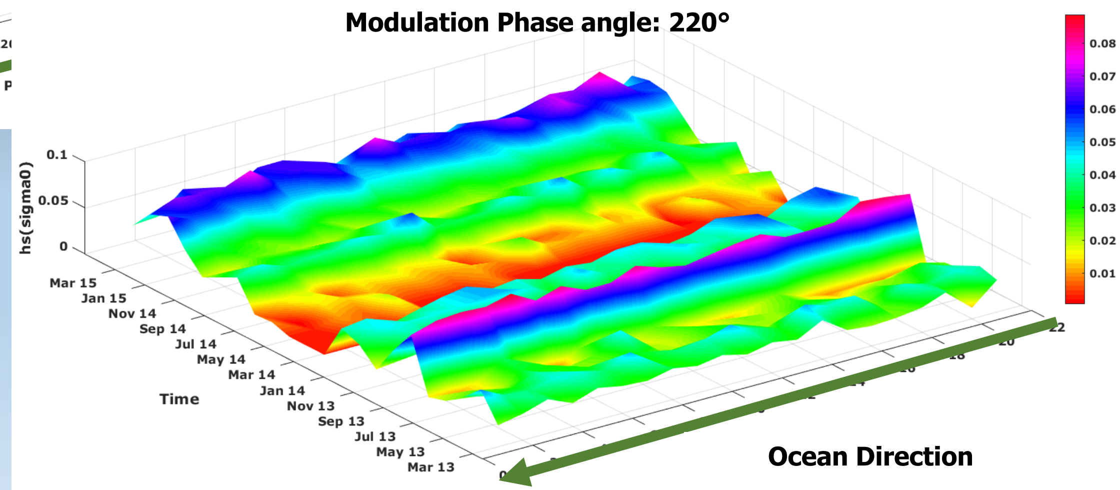


Some insights in SWOT errors

Wave- Related Errors: Motion Effects: Height Biases due to mean velocity shifts
'Average Brightness-modulated sea surface height: hs(σ0)'



The dependence of hs(σ0) on:
1- SWH
2- Modulation Phase angle

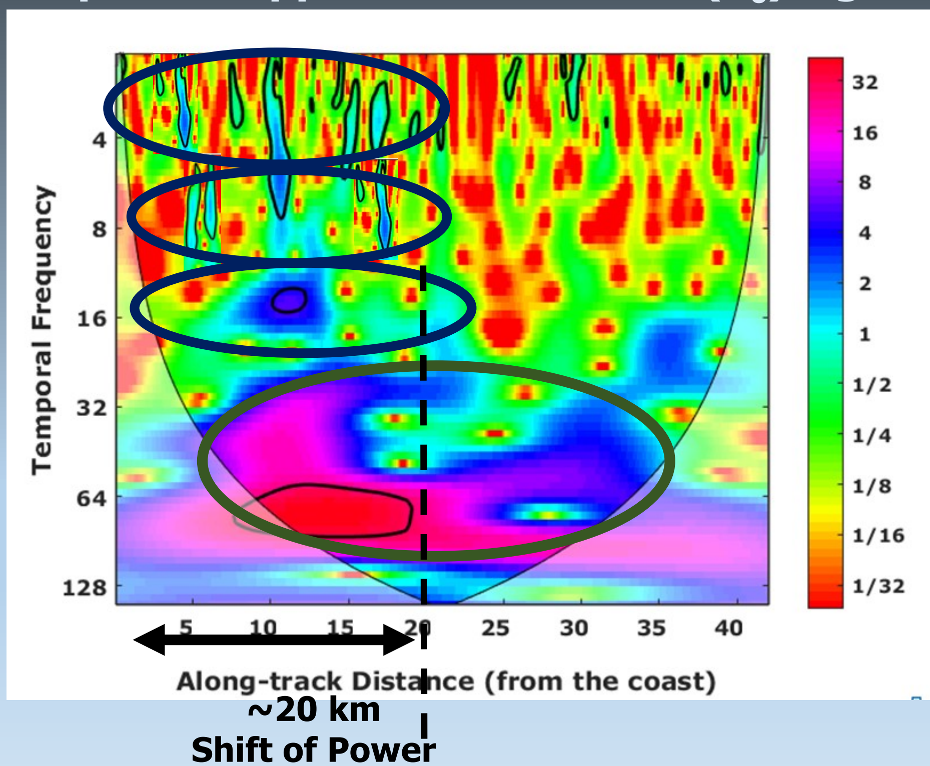


$hs(\sigma_0)$ is very dependent on the use of the modulation phase angle in space and time.
The sensitivity of $hs(\sigma_0)$ to the modulation angle increases close to the coast

Some insights in SWOT errors

Wave- Related Errors: Motion Effects: Height Biases due to mean velocity shifts
'Average Brightness-modulated sea surface height: hs(σ_0)'

Spectral Approach of SWOT hs(σ_0) signal: Continuum Wavelet transform



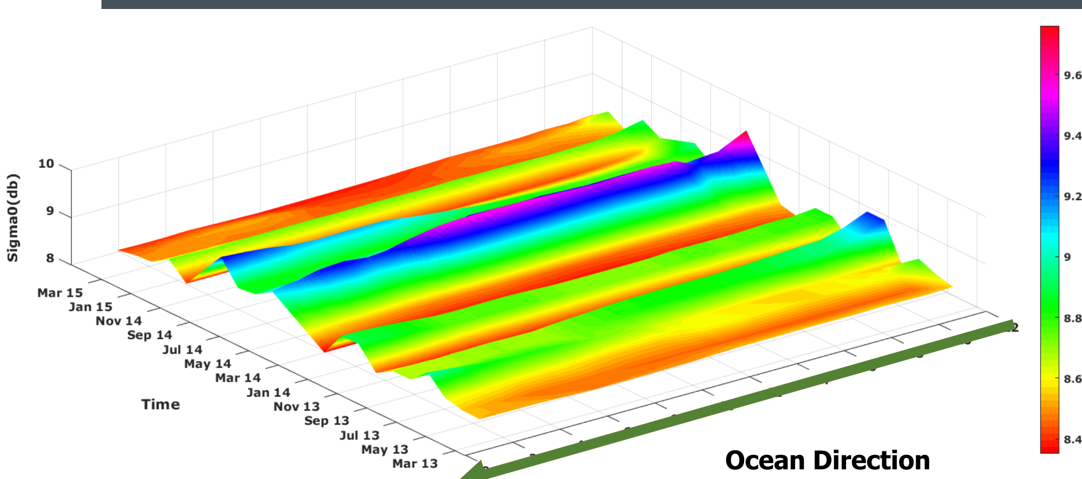
Scales of Days : 10-30 days
High Frequencies until 15 -20 km from the Coast

Scales of Months and Seasons: 45 - 130 days
High Energy Spectrum along the track

hs(σ_0) signal varies from the coast to the ocean with high frequency power close to the coast

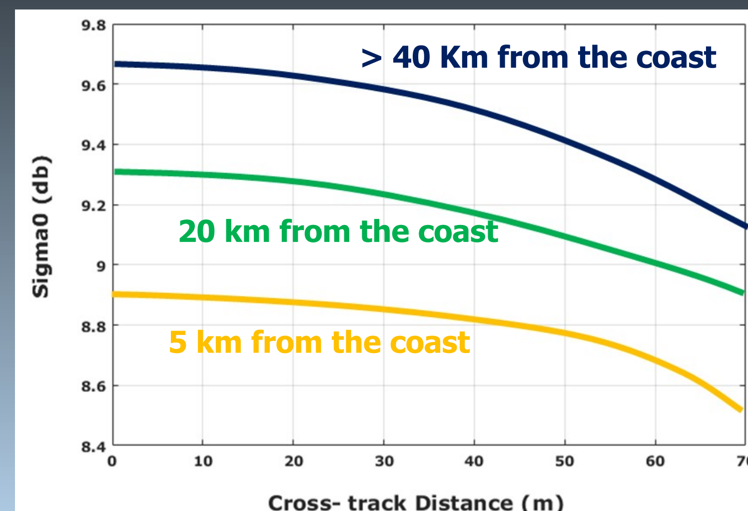
Some insights in SWOT errors

Random Errors: Ocean Backscatter: σ_0



Using the wind Percentile extracted in each location along track distance from a series of time-computed data: Strong variations in time ; **σ_0 shows different patterns along the track;**

The wind changes in time, then the percentile varies with the track distance.



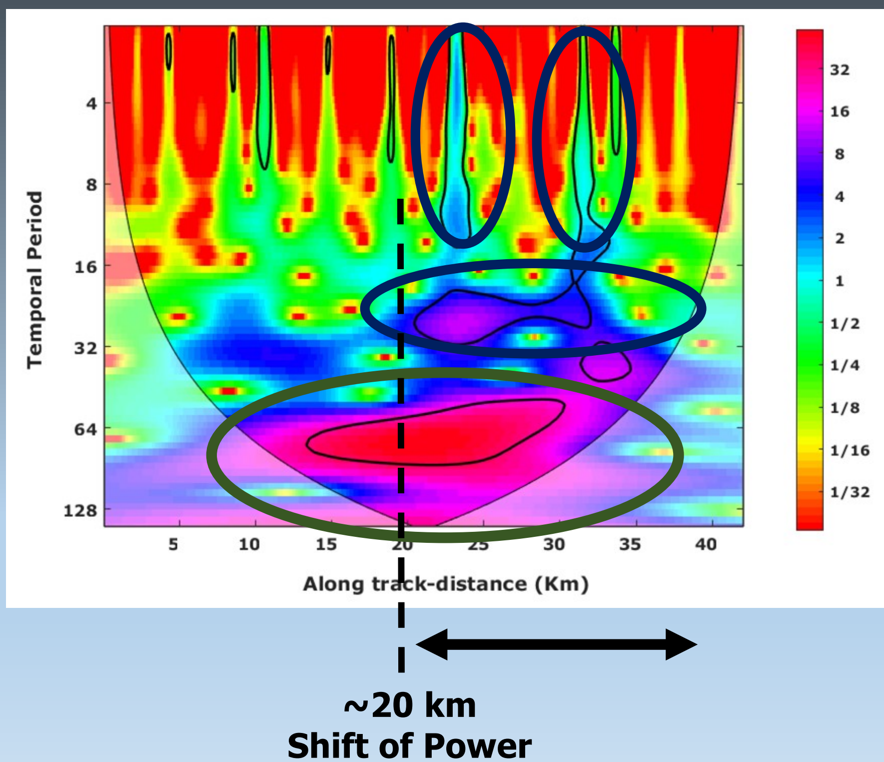
σ_0 evolution changes in the cross track direction from SWOT nadir to the Swath near range and far range

Changes are not similar along-track distance in particular close to Swath far range

Some insights in SWOT errors

Random Errors: Ocean Backscatter: σ0

Spectral Approach of SWOT σ0 signal: Continuum Wavelet transform



Scales of Days : 10-30 days
High Frequencies from 20 km far the Coast

Scales of Months and Seasons: 45-130 days
High Energy Spectrum along the track

σ_0 signal varies from the coast to the ocean with high frequency from 20 km where a shift of power is clearly illustrated : Important roughness patterns

Some insights in SWOT errors

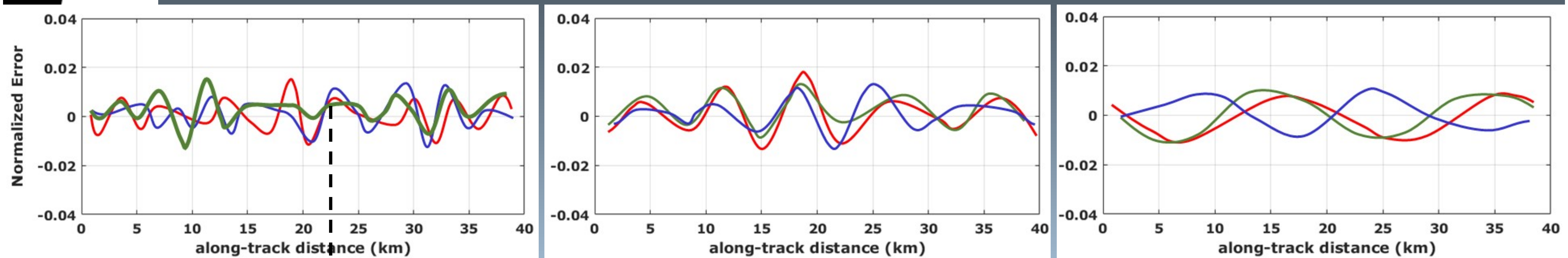
Random Errors: Ocean Backscatter: σ0

Spectral Approach of SWOT SSB signal: Discrete Wavelet transform

C1: Component of 42 days — Mean Variance < 20% of the total signal

C2: Component of 84 days — Mean Variance 20 -25% of the total signal

C3: Component of 210 days — Mean Variance > 30% of the total signal



$R^2 < 0.6$ $R^2 \sim 0.6$

$R^2 \sim 0.6$-0.7

$R^2 > 0.7$

Out of phase of σ_0

SSB Brightness modulated hs(σ_0) backscatter σ_0

The most variability of the error signal can be explained by C1+C2+C3

A certain dependence between Analysed errors. This dependence is more illustrated for low time frequencies
The ocean backscatter is better correlated with wave-related errors for low time-frequencies

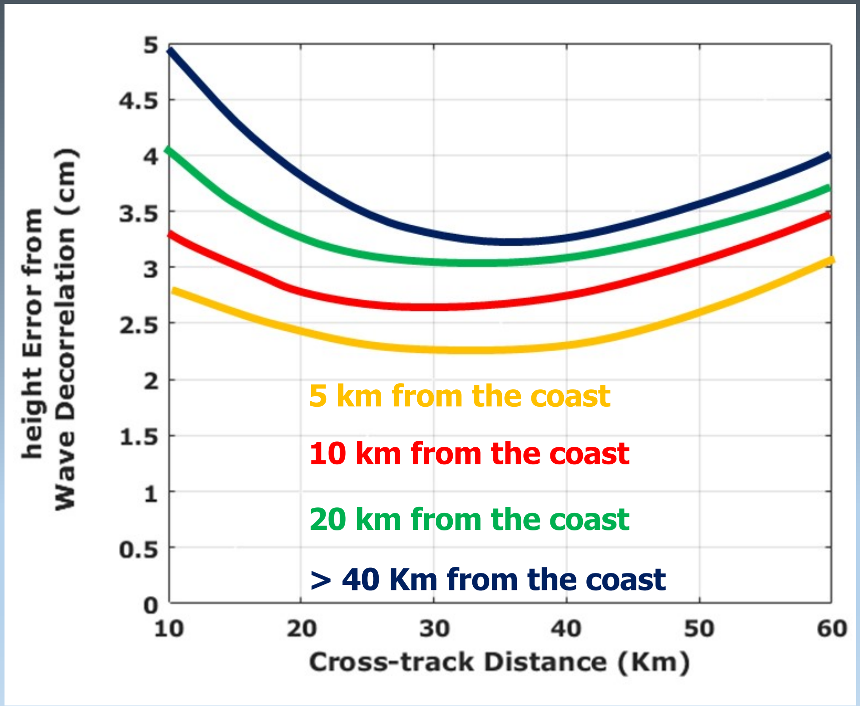
Some insights in SWOT errors

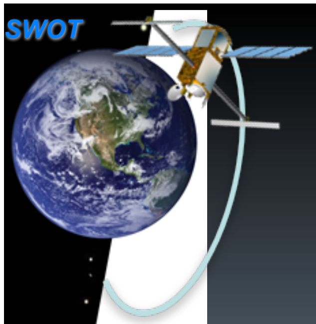
Random Errors: Angular Decorrelation

Approximation in the littoral zone

The total height increases in the Swath near range and seems to be reduced in the Swath far range

The error grows with the along-track distance and also for high energy conditions





Spectral Approaches to investigate the Coastal Hydrodynamic Altimetry measurements

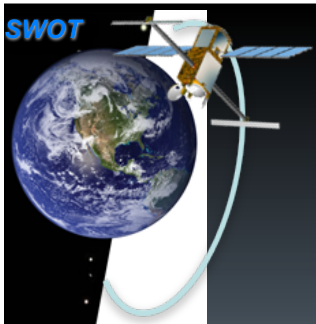
Concluding Remarks

The combining altimetry passes in strongly required for the spatial and the temporal coverage of the hydrodynamic conditions in coastal zones; in particular during successive stormy periods.

Wave-related errors (Sea State Bias SSB and Brightness-modulated sea surface height hs (σ0)) show strong changes along- and cross-track distance; and also in time when the evolution of the energy conditions is important.
The monthly and the seasonal scales should be considered for the error analyses.

The spectral approach has shown that the power energy spectrum of the error signal emphasis a shift along track- distance, approximately 20-25 km from the coast.

The dependence between the different errors has been clearly illustrated by the frequency analysis; which should be deeply considered in further studies of altimetry errors.



Spectral Approaches to investigate the Coastal Hydrodynamic Altimetry measurements

MANY THANKS !!!!

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