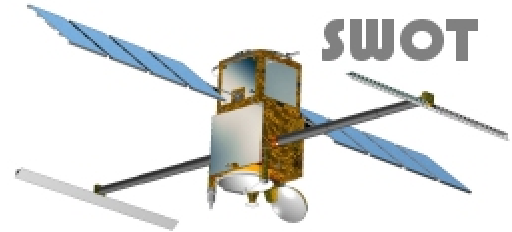

SWOT

ADVANCES ON SWOT SEA STATE BIAS

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SWOT-ST / OCEAN SPLINTER

Toulouse, June 28, 2017

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SWOT BASICS: TOPOGRAPHY ESTIMATION

The ideal model for interferometric product is

$$(v_1 v_2^*) \propto \int_{x_0 - \frac{\text{cell extension}}{2}}^{x_0 + \frac{\text{cell extension}}{2}} \sigma_{0;x} . \mathrm{e}^{\mathrm{j}2\pi k_0 (R_{2,x} - R_{1,x})} . \mathrm{d}x$$

$\sigma_{0;x}$ is the NRCS at x

The topography estimation is based on the inversion of the interferometric phase

$$h_{topo\ ,x_0} = \text{InversionFunction}[\text{angle}(v_1 v_2^*)]$$

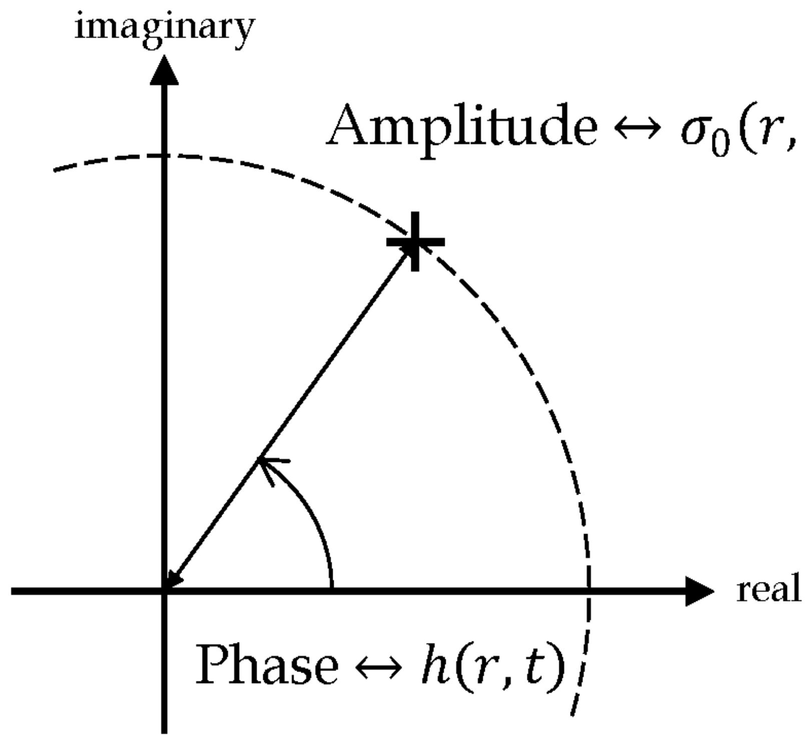
Thus, every term in angle$(v_1 v_2^*)$ that is not topography but that is not correctly removed will be incorrectly interpreted as topography

→ Here stands the origin of height bias in SWOT SSH estimation

SSB for KaRIn with the hands

The sea surface being a **collection of facets**, each one having its own inclination and roughness.

contribution of one surface facet in the complex plan: the phase is related to the heights and the amplitude to the NRCS

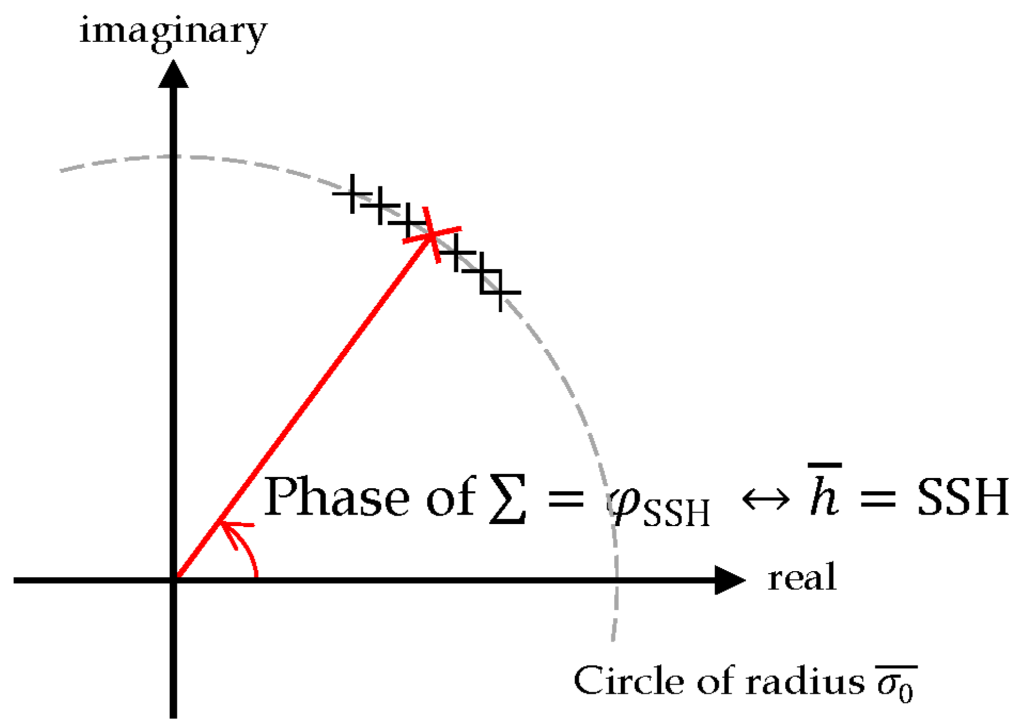


1 weighted facet in the complex plan

$$\sigma_0(r,t)\,\exp[\mathrm{i}.\,\kappa.\,h(r,t)]$$

SSB for KaRIn with the hands

phase of a SWOT pixel under the hypothesis of **uniform NRCS and Gaussian distribution of the waves heights**: the resulting phase is the one related to the topography (SSH) only.

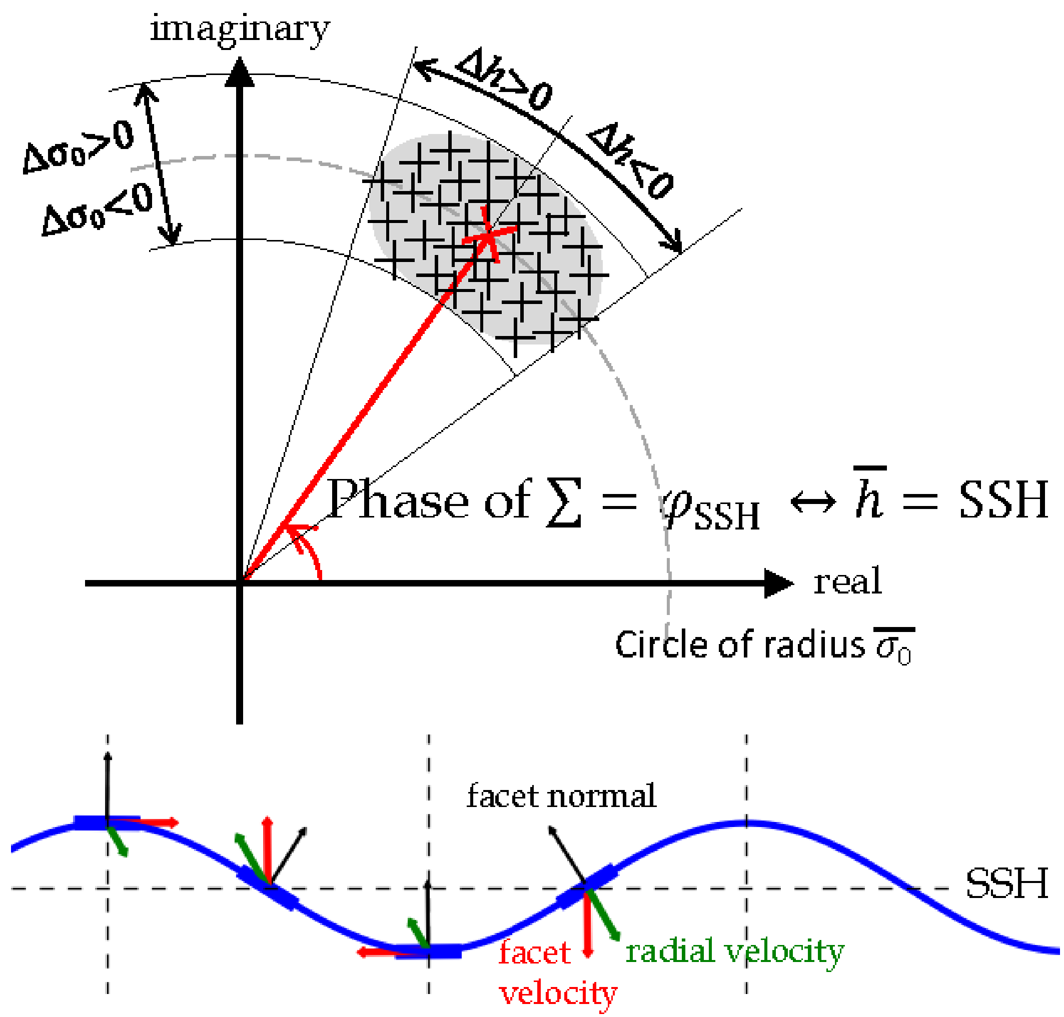


All weighted facets contributing to 1 SWOT pixel

$$\sum \sigma_0(r,t)\exp[\mathrm{i}.\kappa.h(r,t)]$$

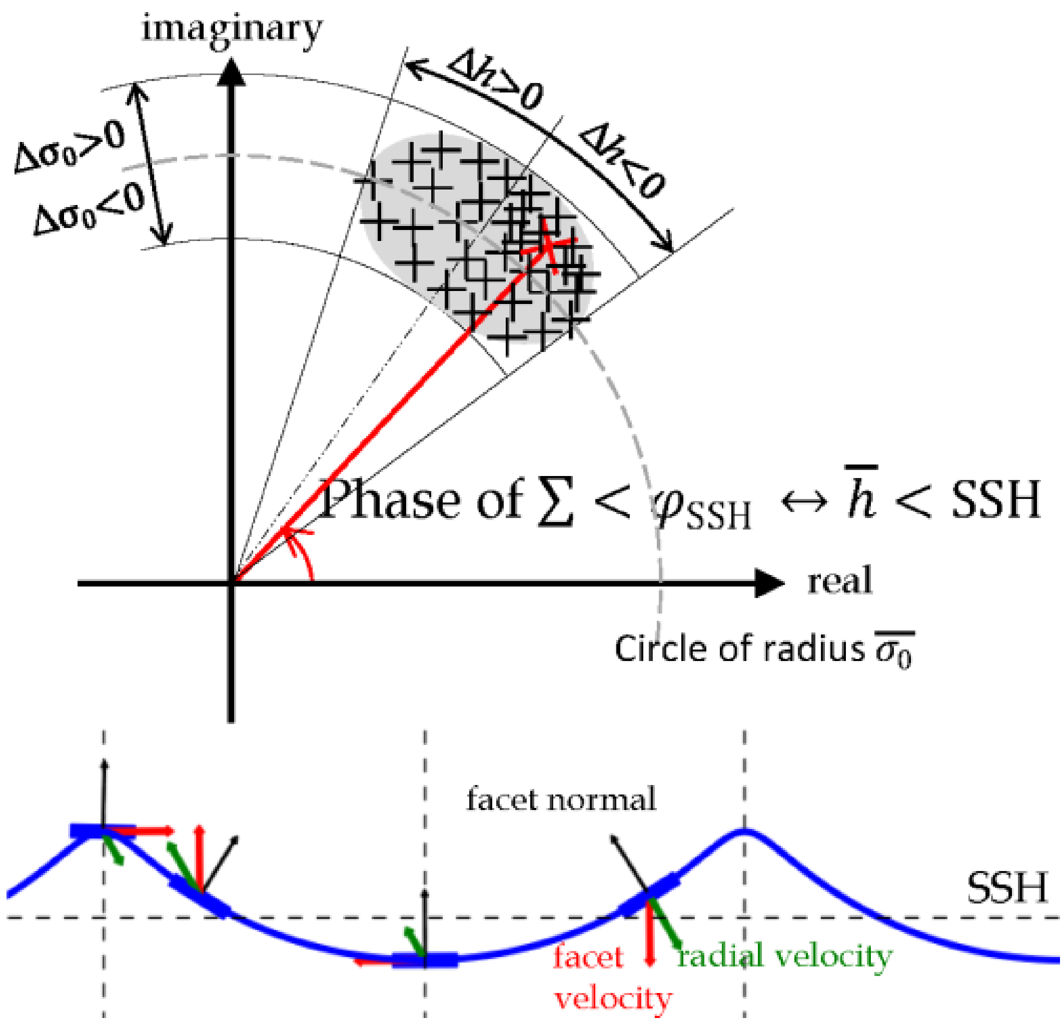
SSB for KaRIn with the hands

Phase of a SWOT pixel under the hypothesis of **tilted dependent NRCS and linear waves height profile**: the phase is the one related to the topography (SSH) only



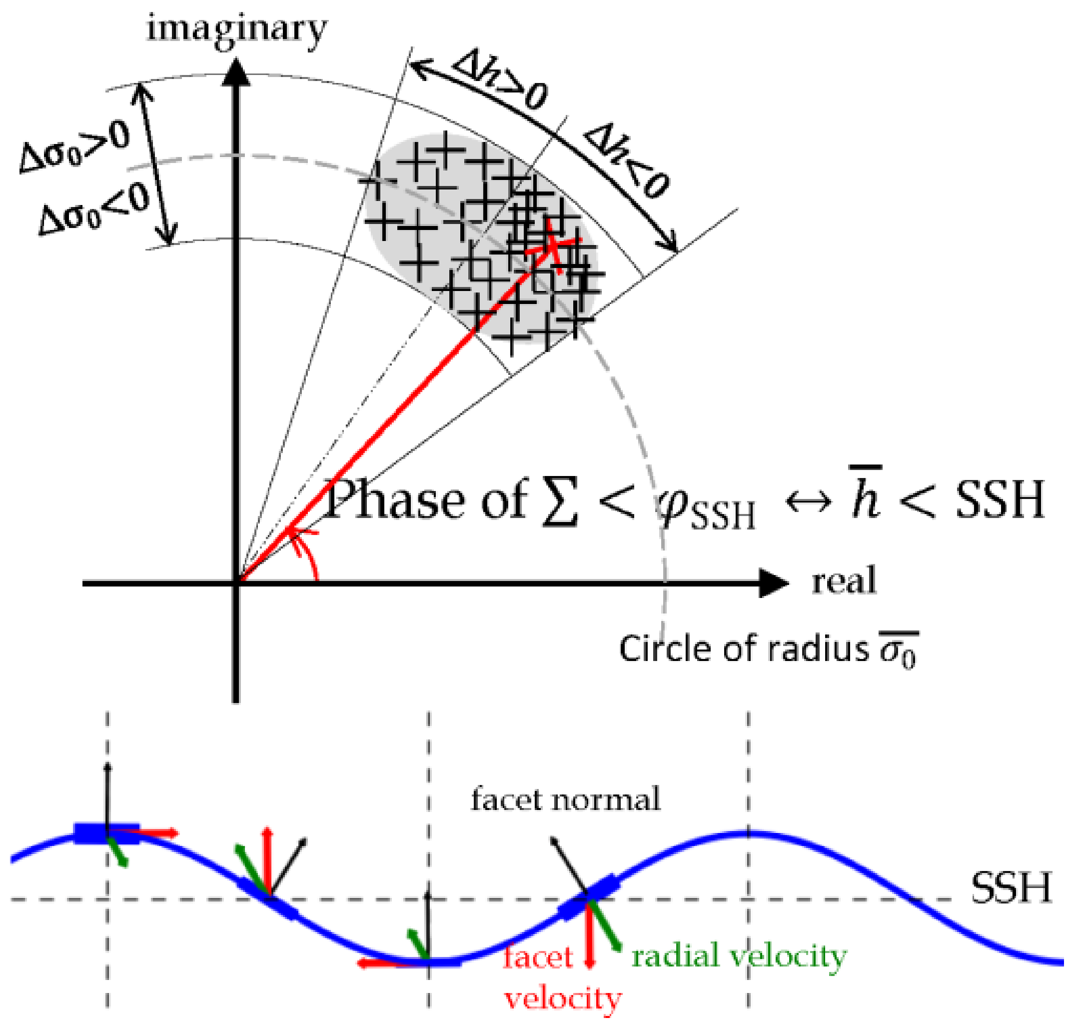
SSB for KaRIn with the hands

Phase of a SWOT pixel under the hypothesis of **tilted dependent NRCS and nonlinear (Stokes like) waves height profile**: we observe an excess of points in the $\Delta\sigma_0 > 0$ and $\Delta h < 0$ area, the estimated phase is $<$ of the phase of SSH. A negative bias is observed



SSB for KaRIn with the hands

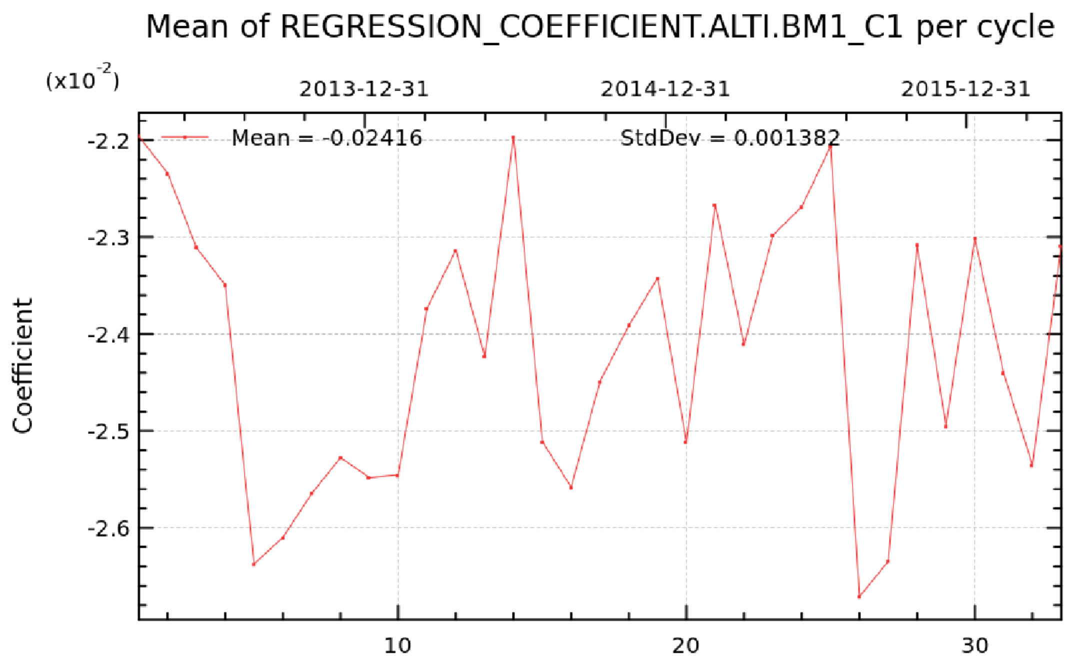
Phase of a SWOT pixel under the hypothesis of **tilted dependent NRCS, roughness modulation (the thicker the facet, the less the roughness) and linear waves height profile**: we observe an excess of points in the $\Delta\sigma_0 > 0$ and $\Delta h < 0$ area, the estimated phase is $<$ of the phase of SSH. A negative bias is observed



SSB CORRECTION BASELINE

Algorithm Description Document v2.0

“SWOT will use the same EM bias algorithm as used by SARAL/AltiKa […].”



From [CLS, 2016], p.252: coefficient C1 of the regression that estimates bias BM1. (SSH = C1 SWH).

Mean value is -2.4%.

Improving our interferometric SSB understanding

While setting SWOT SSB = Conventionnal SSB, we consider its causes to be heights/NRCS correlation, $\langle h\sigma_0 \rangle$, only.

<u>Some legitimate questions:</u>

- What is the impact of the KaRIn instrument transfer function ? (vs. conventional altimeter transfer function)
- OBP SAR processing: is there any impact due to wave movement/currents ?
- Beyond baseline rationale: are other correlation implied, other than $\langle h\sigma_0 \rangle$?

Seeking for a SSB Model

1/ Derivation of the KaRIn transfer function in time domain (2-scales approach)

- it accounts for
  - slant range sampling geometry (see surfboard effects)
  - ocean surface velocities
  - ocean waves spectral features (peak wavelength, direction,…)
- limitations
  - Flat earth (to ease computations. Round earth can be accounted for « easily »)
  - NRCS correlation time = the OBP azimuth integration time

2/ Identification of implied cross-correlations using probability density function integration.

Seeking for a SSB Model

The master (@t_m) and slave (@t_n) range difference is

$$R_{2,x,t_n} - R_{1,x,t_m} \cong \underbrace{-\frac{B}{2}\sin\theta_0}_{\text{effect of reference topography at cell center}} + \underbrace{\alpha.(r_x - r_0)}_{\text{expansion around cell center}} + \underbrace{\beta.\boldsymbol{h}_{\boldsymbol{x},\boldsymbol{t_m}}}_{\text{effect of topography over reference}} + \underbrace{\gamma(\boldsymbol{h}_{\boldsymbol{x},\boldsymbol{t_n}} - \boldsymbol{h}_{\boldsymbol{x},\boldsymbol{t_m}})}_{\text{effect of moving topography}}$$

The phase terms are spatially and temporarly integrated while being weighted by surface refelectivity.

The model shows cross-correlations of

- surface velocities and NRCS
- height and surface velocities

Seeking for a SSB Model

Work still in progress.

$$\text{SSB} = \langle h\sigma_0 \rangle + \text{extra terms}$$

So far, we have not identified any clue of major discrepancy with the proposed first order approximation:

$$\text{SSB} \sim \text{Conventionnal SSB}$$

Peer-reviewed paper is expected.

Note that particular care is taken to link our methodology/results to the ones of Peral, E., E. Rodriguez, and D. Esteban-Fernandez (2015), “Impact of surface waves on SWOTs projected ocean accuracy”, Remote Sensing, 7, 14,509–14,529.

BEYOND THE NOMINAL CASE: SWH VARIABILITY

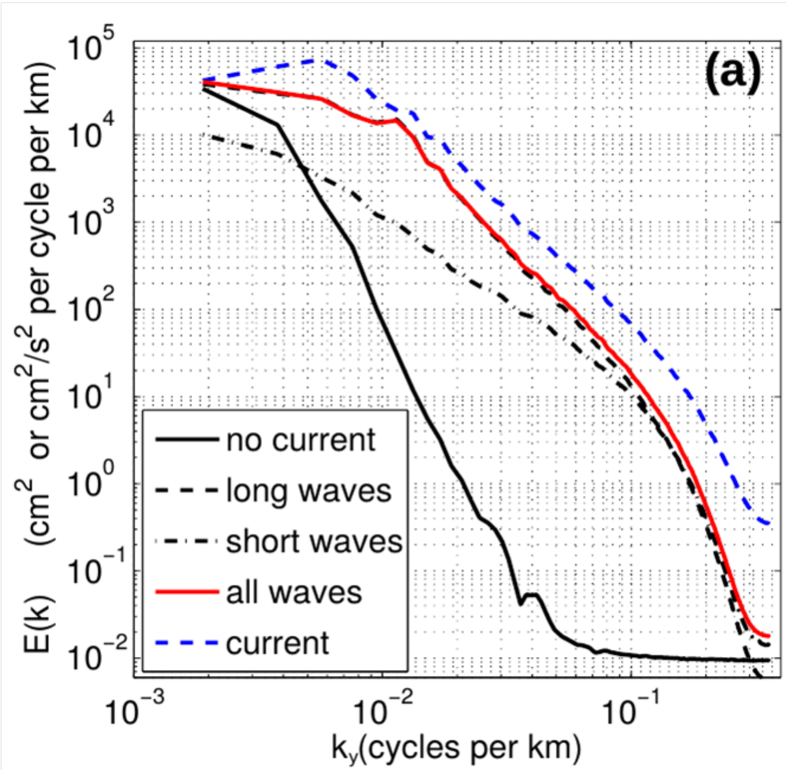
Because of estimator characteristic
⟶ only on estimate per swath
⟶ Probable mis-estimation of SWH at far range
⟶ equivalent to using mis-located SWH estimates in nadir altimetry

The mis-location can be as large as 50 to 60 km:
⟶ a simple SSB algorithm using nadir+near-range SWH may not properly correct wave-induced effects for scales smaller than 40 to 80 km.

Only the larger scales of the SSB would be corrected, especially in the outer edges of the swath.

BEYOND THE NOMINAL CASE: SWH VARIABILITY

Conclusions of [Ardhuin et al., 2017]



- (SSB) in Ka-band of the order of 2.5% of SWH
- If no information on the cross-track variations in Hs
- Assuming that the SSB is fully determined by SWH alone

→ the spectrum of range error at 50 km away from the nadir would be 0.025^2 times the wave height spectrum.

Over the Gulf Stream, this can be 1 cm^2 /(cycle/km) for Hs = 2 m at 50 km wavelength.

This value should be compared to the baseline total error level of 5 cm^2(cycle/km)

SSB CORRECTION: ADDITIONAL ALGORITHMS

On Board Additionnal algorithm has been proposed to help for cases of low scale SWH/SSB variability.

High resolution Doppler Centroid

Doppler centroid estimates:

- @2.5 km posting and resolution in along-track direction
- @2.5 km posting and resolution in across-track direction, from 30 to 60km

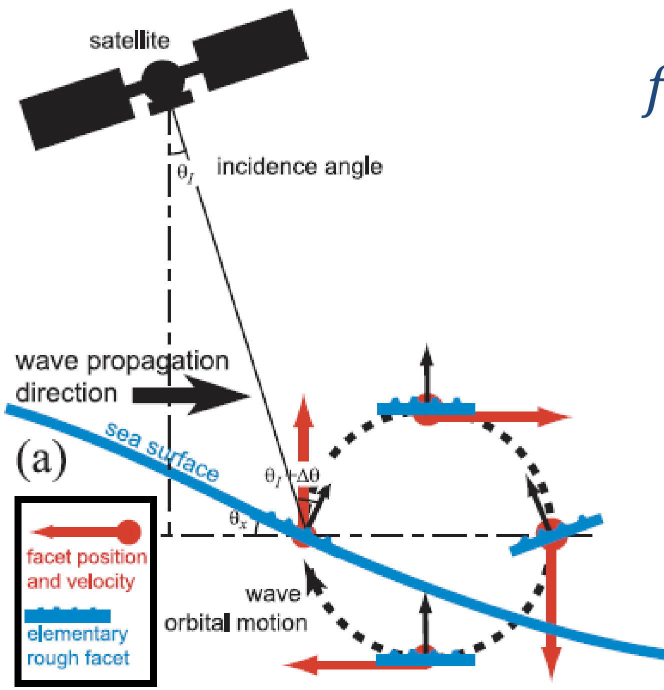
Doppler Centroid and Surface Velocities

In satellite measurements, the centroid f_{Dc} of the measured Doppler spectrum is composed of effect of instrument acquisition geometry f_{Dcm} and a centroid anomaly f_{Dcm} related to ocean surface motions only:

$$f_{Dca} = f_{Dc} - f_{Dcm}$$

The Doppler shift of the radar backscatter from a moving target is given by:

$$f_{Dca} = \frac{k_e U_d}{2\pi}$$



Orbital velocities and Sea State

[Longuet-Higgins 1963], [Srokosz,1986] + dispersion relation
→ SWH correlated with the squared orbital velocity variance

Doppler centroid anomaly (velocity effect) *may* give access to a proxy of the SWH (or be a direct proxy to SSB)

<u>Other proof</u>

- SSB primarily related to the long wave orbital velocity variance rather than to SWH [Chapron et al 2001]
- Altimeter SSB algorithms based upon SWH have been shown to be efficient

→ Explained by the correlation between the variance of orbital velocities and SWH

Using the new parameters in ground algorithms

A look at the variability of Ud (corrected from projection angle) will teach us about small scale* variability of the wave field, not catched by the SWH estimate.

→**new sea-state quality flag** : raised when the algorithm suspects an underestimation of the sea-state induced error due to small scale variability of the wave field.

*Ud are HR data w.r.t. to estimated SWH,

Using the new parameters in ground algorithms

$$\mathrm{SSB} = \langle \tilde{\sigma}_0 \, h \rangle = \int_k M_k^{H+T} \, \Psi(k).\, \mathrm{d}k$$

If we consider the monochromatic wave (amplitude A, wave number K_L, direction φ, and c_{K_L} its phase velocity), then

$$\mathrm{SSB} = \langle \tilde{\sigma}_0 \, h \rangle = c^{H+T} .\, \mathrm{T}_{K_L}$$

with the long wave period $\mathrm{T}_{K_L} = 1/\left(K_L .\, c_{K_L}\right)$.

c is the mean range velocity of scattering facets, **c^{T+H} is the contribution of long waves through tilt and hydrodynamic modulation of facets**

An SSB estimation scheme can be obtained with the parameter Ud and auxiliary data (e.g., WW3 spectra) to approximate the spectral peak of the modulating waves.

Back-up slides

Bibliography

Ardhuin, F., S. T. Gille, D. Menemenlis, C. Rocha, N. Rascle, B. Chapron, J. Gula, and J. Molemaker (submitted), Small scale currents have large effects on ocean wave heights, Geophysical Research Letters.

Pedersen, I. F., Engen, G., and Johnsen, H. (2004). Polarization Dependency in Sea Surface Doppler Frequency and its Applications to Envisat ASAR Alt-Pol Data. In Proc. of ERS/Envisat Symposium, ESA Publication SP-572.

Mouche, A., Chapron, B., Reul, N., and Collard, F. (2008). Predicted doppler shifts induced by ocean surface wave displacements using asymptotic electromagnetic wave scattering theories. Waves in Random Media, 18(1):185–196

Peral, E., E. Rodriguez, and D. Esteban-Fernandez (2015), Impact of surface waves on SWOTs projected ocean accuracy, Remote Sensing, 7, 14,509–14,529.

Dubois P. (2011) Impact de l'état de mer sur la mesure d'élévations des futurs instruments altimétriques, Phd Thesis.

Vandemark, D. et al., (2016), Sea surface reflectivity variation with ocean temperature at Ka-band using near-nadir satellite radar data, IEEE Geoscience and Remote Sensing Letters

Bibliography

Vandemark, D., N. Tran, B. D. Beckley, B. Chapron, and P. Gaspar (2002), Direct estimation of sea state impacts on radar altimeter sea level measurements, Geophys. Res. Lett.,29 (24), 2148

Longuet-Higgins, M. S. (1963). The effect of non-linearities on statistical distributions in the theory of sea waves. Journal of Fluid Mechanics, 17:459–480.

Srokosz, M. A. (1986). On the joint distribution of surface elevation and slopes for a non linear random sea, with an application to radar altimetry. Journal of Geophysical Research, 91(C1):995–1006.

Chapron, B., Vandemark, D., Elfouhaily, T., Thompson, D. R., Gaspar, P., and LaBroue, S. (2001). Altimeter sea state bias: A new look at global range error estimates. Geophysical Research Letters, 28(20).

Status : Conventional altimetry: EM BIAS for KA BAND

From Vandemark et al. “Impact of high-frequency waves on the ocean altimeter range

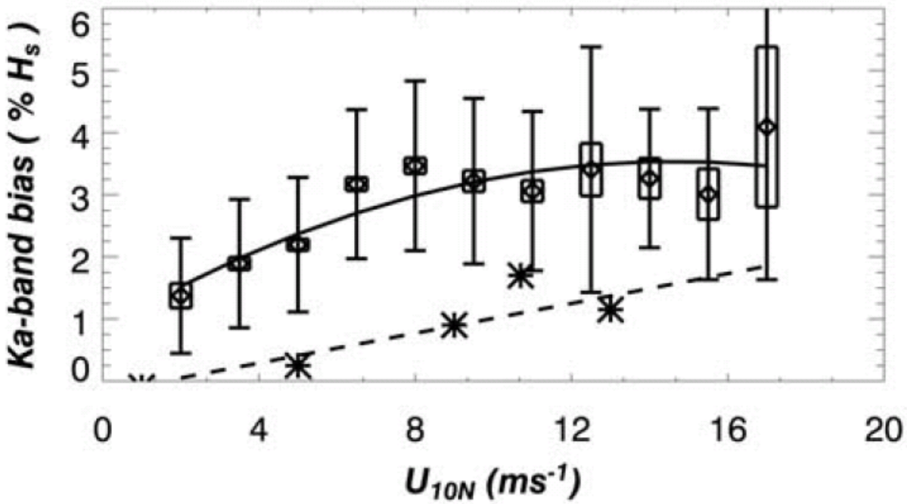


Figure 4. Relative radar bias measurements versus wind speed. The symbols are the observed relative electromagnetic bias (β_t) for a Ka-band radar. Points represent averages over 1.5 m s^{-1} wind speed bins and the whisker plot provides 50% and 95% confidence intervals. The solid curve represents a quadratic fit through the data. The lower curve (dashed line) represents a linear model obtained from the Ka-band data (∗) of *Walsh et al.* [1991].

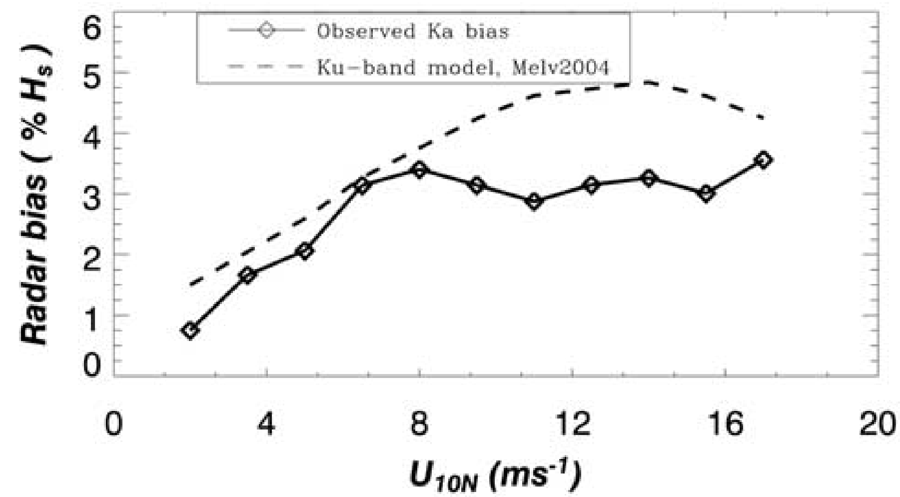


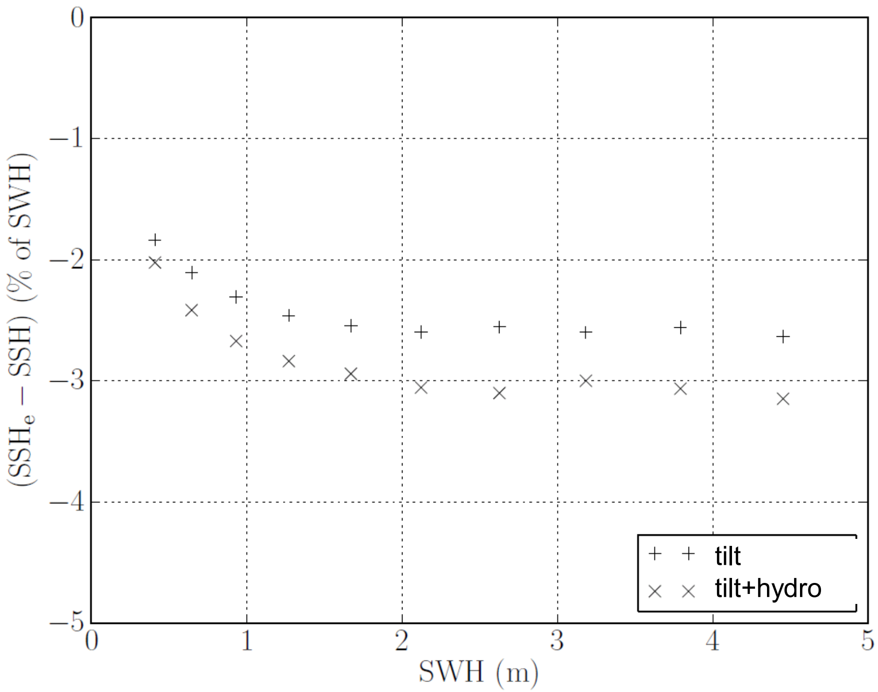
Figure 8. Ka-band bias results as seen in Figure 4 and experiment-derived Ku-band model results using equation (16) of *Melville et al.* [2004].

SSB FOR SWOT: PREVIOUS STUDIES

[Dubois, 2011] studied the SSB for SWOT under the assumptions:

- ✓ infinite coherence time
- ✓ no wave movement
- ✓ purely wind waves surfaces (no decoupling of wind/SWH)

$$\mathrm{SSB} \cong \frac{1}{k\beta}\,\mathrm{angle}\left(\langle \sigma_{0;x}.\, e^{jk[\beta.\xi_x]} \rangle\right)$$



Difference between the estimated SSH and the true SSH versus the SWH

The SSH is obtained by averaging on all the swath. The large scales non linearities are computed with the Choppy Waves Model theory.

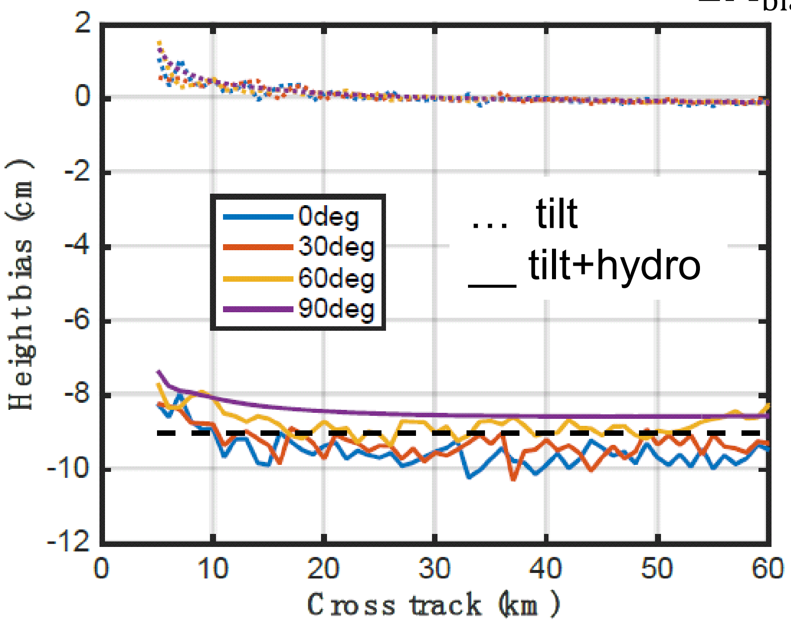
P. Dubois et al. “Design of a multi-configurations altimeter simulator for the study of the Sea State Bias”, 2011, Submitted to IEEE Trans. Geoscience and Remote Sensing.

SSB FOR SWOT: PREVIOUS STUDIES

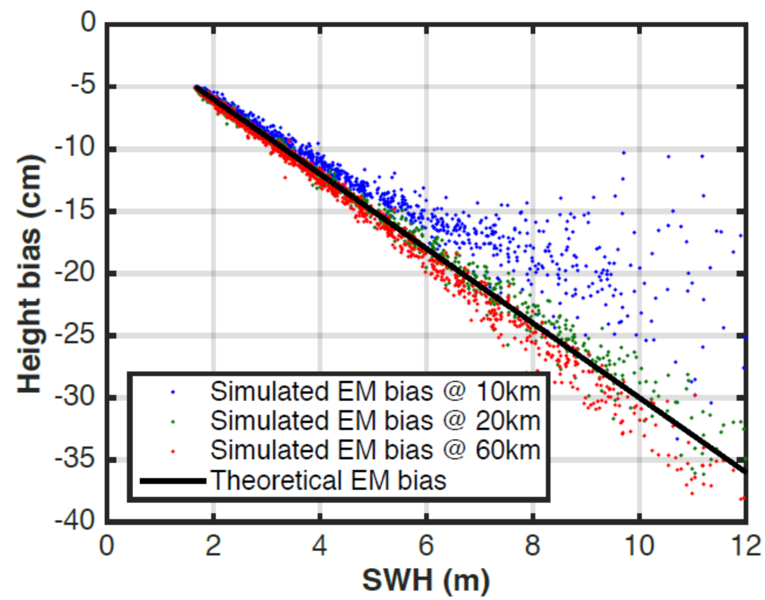
[Peral et al., 2015] studied the SSB for SWOT under the assumptions

- ✓ $k\beta.\xi_{x,t} \ll 1$, which is particularly true
  - when sea state is low
  - at far range
- ✓ infinite coherence time
- ✓ no wave movement
- ✓ no "long waves" non linearities

$$\mathrm{EM_{bias}} = [1-3\%].\mathrm{SWH}$$



EM bias for a Pierson ocean surface of SWH=3m as a function of Cross-track distance.



EM bias at 10km (blue), 20km (green) and 60km (red) as a function of SWH

SWH variability

How fast does SWH varie spatially ?

Small scale gradients of SWH are due to currents.

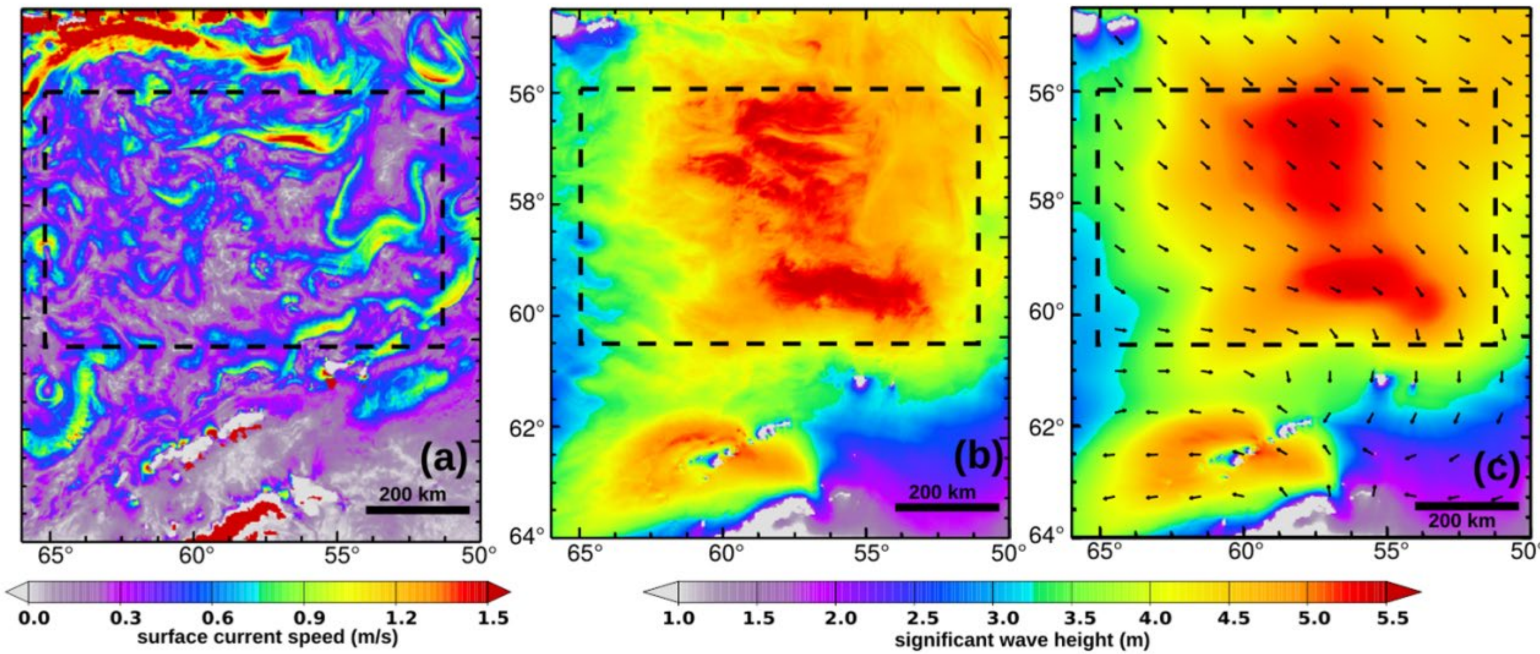
→ Non local (propagative) effect, colocated SWH and currents uncorrelated

SWH and SSH uncorrelated (good news!)

(a) Current from MITgcm

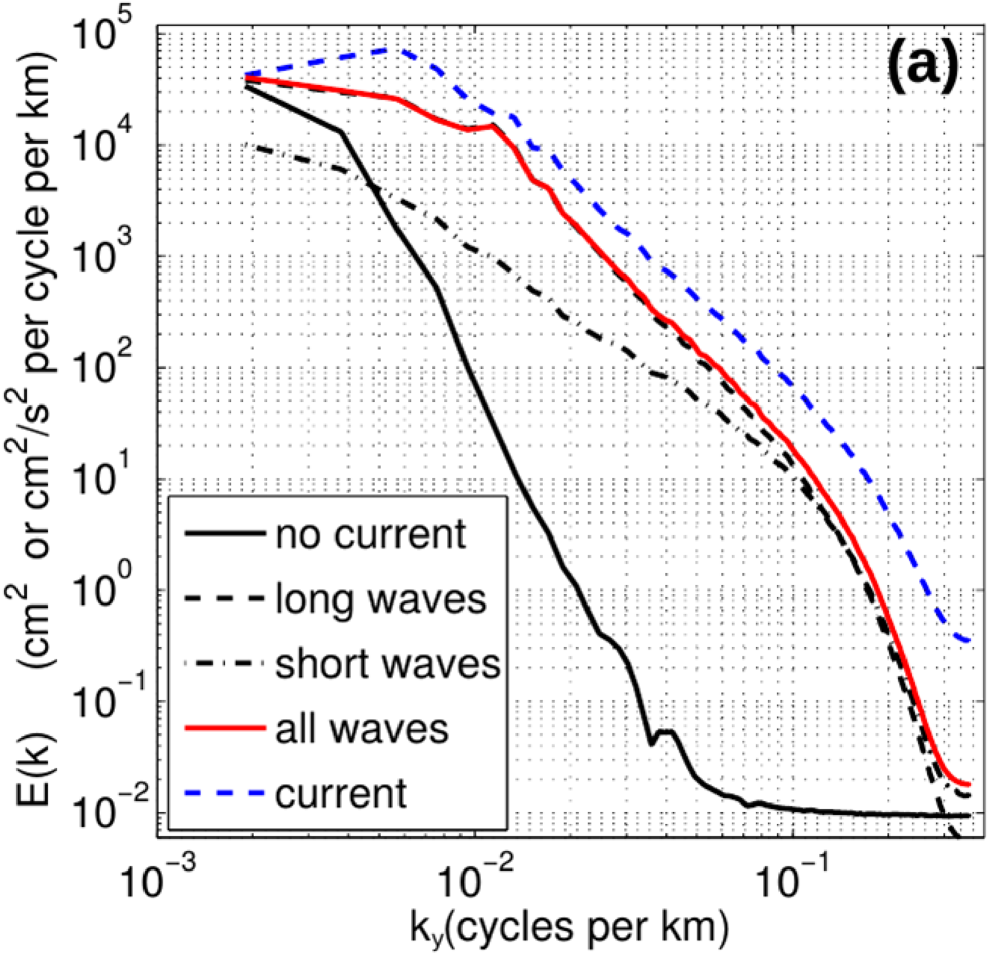
(b) SWH from WW3 using current

(c) SWH from WW3 : no current



From [Ardhuin et al., Submitted]

SWH variability



<u>black plain curve (cm²/(cy/km)):</u>
Spectra Hs from WW3 : no current (c)

<u>red plain curve (cm²/(cy/km)):</u>
Spectra Hs from WW3 : currents (b)

<u>dotted blue curve (cm²/ s²/(cy/km)):</u>
Spectra Current from MITgcm

The SWH spectrum with currents follows the currents spectrum (in $k^{-2.5}$).

Note that at periods <$(g.2\pi.[ky\times10^{-3}])^{-1/2}$=6. s, the short waves exceed the long waves.

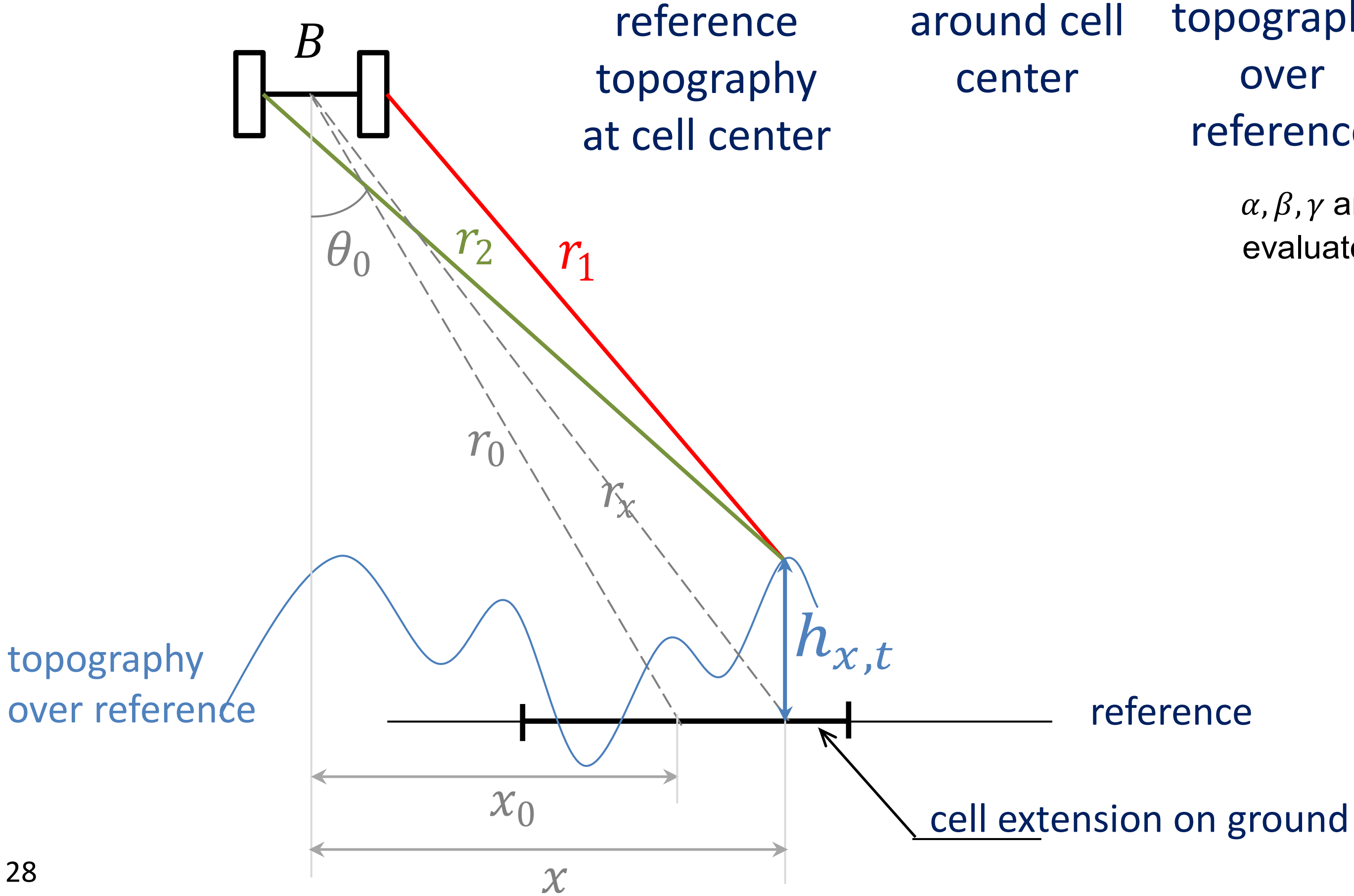
From [Ardhuin et al., Submitted]

KaRIn transfer function : GEOMETRY

The master ($@t_m$) and slave ($@t_n$) range difference is

$$R_{2,x,t_n} - R_{1,x,t_m} \cong \underbrace{-\frac{B}{2}\sin\theta_0}_{\text{effect of reference topography at cell center}} + \underbrace{\alpha.(r_x - r_0)}_{\text{expansion around cell center}} + \underbrace{\beta.\boldsymbol{h}_{\boldsymbol{x},\boldsymbol{t_m}}}_{\text{effect of topography over reference}} + \underbrace{\gamma(\boldsymbol{h}_{\boldsymbol{x},\boldsymbol{t_n}} - \boldsymbol{h}_{\boldsymbol{x},\boldsymbol{t_m}})}_{\text{effect of moving topography}}$$

α, β, γ are purely geometric coefficients evaluated at range cell center.



SWOT BASICS: TOPOGRAPHY

The topography over reference, is compound with $h_{x,t} = h_{topo\ ,x_0} + \xi_{x,t}$

- ✓ $\boldsymbol{h_{topo,x_0}}$: the mean topography → **SSH** (what we want to measure !)
- ✓ $\boldsymbol{\xi_{x,t}}$: the topography variability → **SEA STATE**

The moving contribution can be expressed at first order with

$$h_{x,t_n} - h_{x,t_m} = \underbrace{\left(\frac{\partial \xi_{x,t}}{\partial t}\bigg|_{t_m} + \frac{\partial x}{\partial t}\bigg|_{t_m}\right)}_{\substack{\text{orbital velocity} \\ U_{x,t_m}}} (t_n - t_m)$$

$$\boxed{R_{2,x,t_m} - R_{1,x,t_n} \cong -\frac{B}{2}\sin\theta_0 + \frac{\alpha}{\sin\theta_0}.(x - x_0) + \beta.\boldsymbol{h_{topo,x_0}} + \beta.\boldsymbol{\xi_{x,t_m}} + \underbrace{\gamma.\boldsymbol{U_{x,t_m}}}_{\substack{\text{projected} \\ \text{orbital} \\ \text{velocity}}}(t_n - t_m)}$$

NB: If the master and slave acquisitions are taken at different satellite positions (m and n, say) the range difference contains an extra term that can be **neglected under unfocused SAR processing conditions**

SWOT BASICS: TOPOGRAPHY ESTIMATION

The ideal model for interferometric product (including azimuth processing for beam J) is

$$(v_1 v_2^*)^{(J)} \propto \int_{x_0-\frac{\text{cell extension}}{2}}^{x_0+\frac{\text{cell extension}}{2}} \sum_{m,n} \mathrm{e}^{\mathrm{j}\phi_{J,m,n}} \sigma_{0;x,t_m} \, \mathrm{e}^{-\frac{(t_n-t_m)^2}{\tau_x^2}} . \mathrm{e}^{\mathrm{j}\left(R_{2,x,t_m}-R_{1,x,t_n}\right)} . \mathrm{d}x$$

$\sigma_{0;x,t_m}$ is the NRCS at x and t

τ_x is the NRCS coherence time

k is the radar wave number

$\phi_{J,m,n}$ is the ramp phase for azimuth processing

The topography estimation is based on the inversion of the interferometric phase

$$\begin{aligned} h_{topo,x_0} &= \text{InversionFunction}[\text{angle}(v_1 v_2^*)] \\ &\cong \frac{1}{k\beta} \text{angle}(v_1 v_2^*) \end{aligned}$$

Thus, every term in $\text{angle}(v_1 v_2^*)$ that is not topography but that is not correctly removed will be incorrectly interpreted as topography

→ Here stands the origin of height bias in SWOT SSH estimation

SSB FOR SWOT

We evaluate the ensemble average of the interferometric product, thus integrating the varying processes.

$$\langle (v_1 v_2^*)^{(J)} \rangle \propto \int_{x_0 - \frac{\text{cell extension}}{2}}^{x_0 + \frac{\text{cell extension}}{2}} \sum_{m,n} \langle \sigma_{0;x,t_m} . \mathrm{e}^{\mathrm{j}\left(R_{2,x,t_m} - R_{1,x,t_n}\right)} . \mathrm{e}^{-\frac{(t_n - t_m)^2}{\tau_x^2}} \rangle \, \mathrm{e}^{\mathrm{j}\phi_{J,m,n}} . \mathrm{d}x$$

In range difference expression, <u>only the sea state</u> contribution part is a spatial varying process

$$\langle \sigma_{0;x,t_m} . \mathrm{e}^{\mathrm{j}\left(R_{2,x,t_m} - R_{1,x,t_n}\right)} . \mathrm{e}^{-\frac{(t_n - t_m)^2}{\tau_x^2}} \rangle$$

$$= \langle \boldsymbol{\sigma}_{\mathbf{0};\boldsymbol{x},\boldsymbol{t_m}} . \mathrm{e}^{\mathrm{j}\boldsymbol{k}\left[\boldsymbol{\beta}.\boldsymbol{\xi}_{\boldsymbol{x},\boldsymbol{t_m}} + \boldsymbol{\gamma}.\boldsymbol{U}_{\boldsymbol{x},\boldsymbol{t_m}}(\boldsymbol{t_n} - \boldsymbol{t_m})\right]} \mathrm{e}^{-\frac{(\boldsymbol{t_n} - \boldsymbol{t_m})^2}{\boldsymbol{\tau_x^2}}} \rangle . \mathrm{e}^{\mathrm{j}k\left[-\frac{B}{2}\sin\,\theta_0 + \frac{\alpha}{\sin\,\theta_0}.(x - x_0) + \beta.\boldsymbol{h_{topo,x_0}}\right]}$$

The EM bias writes

$$\mathbf{EM_{bias}} \cong \frac{\mathbf{1}}{\boldsymbol{k\beta}} \mathbf{angle}\left(\langle \sum_{\boldsymbol{m,n}} \boldsymbol{\sigma}_{\mathbf{0};\boldsymbol{x},\boldsymbol{t_m}} . \mathrm{e}^{\mathrm{j}\boldsymbol{k}\left[\boldsymbol{\beta}.\boldsymbol{\xi}_{\boldsymbol{x},\boldsymbol{t_m}} + \boldsymbol{\gamma}.\boldsymbol{U}_{\boldsymbol{x},\boldsymbol{t_m}}(\boldsymbol{t_n} - \boldsymbol{t_m})\right]} \mathrm{e}^{-\frac{(\boldsymbol{t_n} - \boldsymbol{t_m})^2}{\boldsymbol{\tau_x^2}}} \rangle \right)$$

SSB FOR SWOT W.R.T. conventional altimetry

$$\mathrm{EM_{bias}} = \frac{1}{k\beta}\,\mathrm{angle}\left(\left\langle \sum_{m,n} \sigma_{0;x,t_m}.\, \mathrm{e}^{\mathrm{j}k\left[\beta.\xi_{x,t_m}+\gamma.U_{x,t_m}(t_n-t_m)\right]}\mathrm{e}^{-\frac{(t_n-t_m)^2}{\tau_x^2}} \right\rangle\right)$$

Making the assumptions

- ✓ $k\beta.\xi_{x,t} \ll 1$, which is particularly true
  - when sea state is low
  - at far range
- ✓ no coherence time variability
- ✓ no orbital velocity variability
- ✓ no surfboard effect

$$\mathrm{EM_{bias}} \cong \frac{1}{k\beta}\,\mathrm{angle}\left(\langle \sigma_{0;x}\left(1+\mathrm{j}k\beta.\,\xi_x\right)\rangle\right)$$

Under certain reasonable assumptions:

$$\mathbf{EM_{bias}} \cong \frac{\langle \boldsymbol{\sigma_0}.\,\boldsymbol{\xi} \rangle}{\langle \boldsymbol{\sigma_0} \rangle}$$

EM bias in SWOT is equivalent to EM bias in conventional altimetry

Slant range sampling effect on SWOT SSB

A more realistic model for interferometric product (including azimuth processing) is:

$$v_1 v_2^* \propto \underbrace{\int_{x_0 - \frac{\text{cell extension}}{2}}^{x_0 + \frac{\text{cell extension}}{2}}}_{\text{(too) rough conversion of slant range to ground range values}} \sum_{m,n} \mathrm{e}^{\mathrm{j}\phi_{m,n}} \left[\int \sigma_{0;x',t_m} \, \mathrm{e}^{-\frac{(t_n - t_m)^2}{\tau_{x'}^2}} . \, \mathrm{e}^{\mathrm{j}\left(R_{2,x',t_m} - R_{1,x',t_n}\right)} . \underbrace{\delta\left(x' + \frac{\xi}{\tan\theta_0} - x\right)}_{\text{true sampling considering waves and tilted plan}} . \, \mathrm{d}x' \right] . \, \mathrm{d}x$$

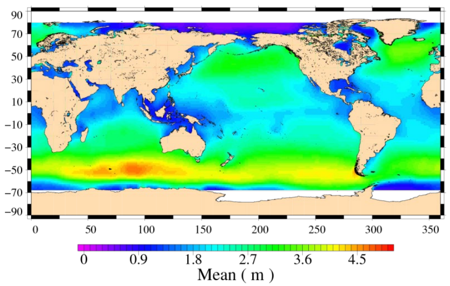
When effective (@near range, high sea state…), the surfboard effect will tend to toss the antinomic effects of peaks and troughs on EM bias.

→ **EM bias may be lowered by surfboard effects.**

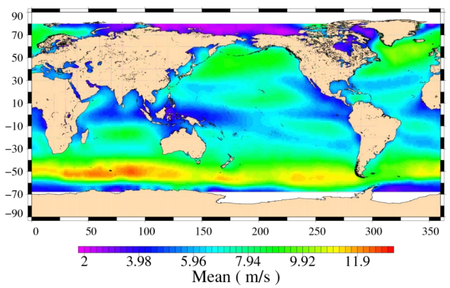
Status Conventional altimetry: SSB 3D ALGORITHM AltiKA

Development of 3D SSB (SWH, wind speed, Tm) to better model SSB behavior with improved description of the sea state. Direct approach based on SLA [Vandemark et al, 2002].

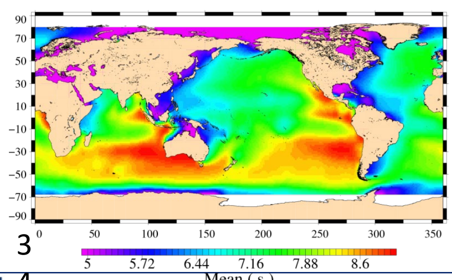
- Tm : mean wave period from a numerical wave model (WAVEWATCH-3 (F. Ardhuin), used operationally at NOAA/NCEP)



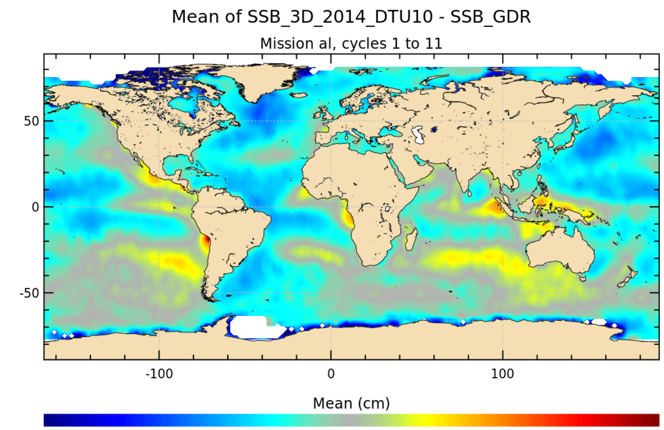
SWH

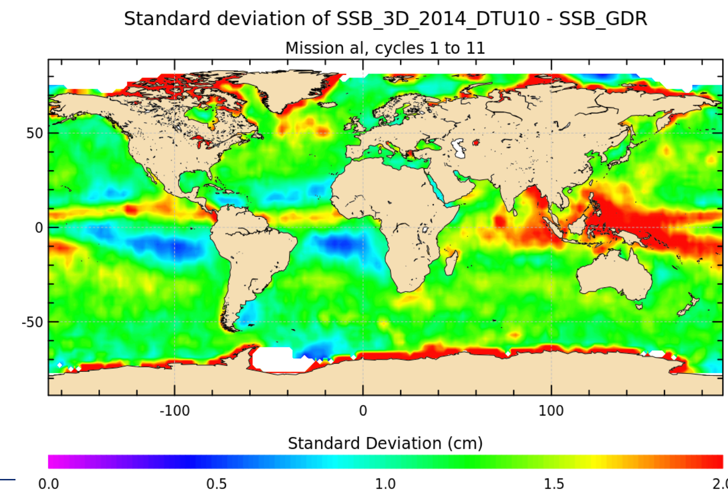


Wind speed



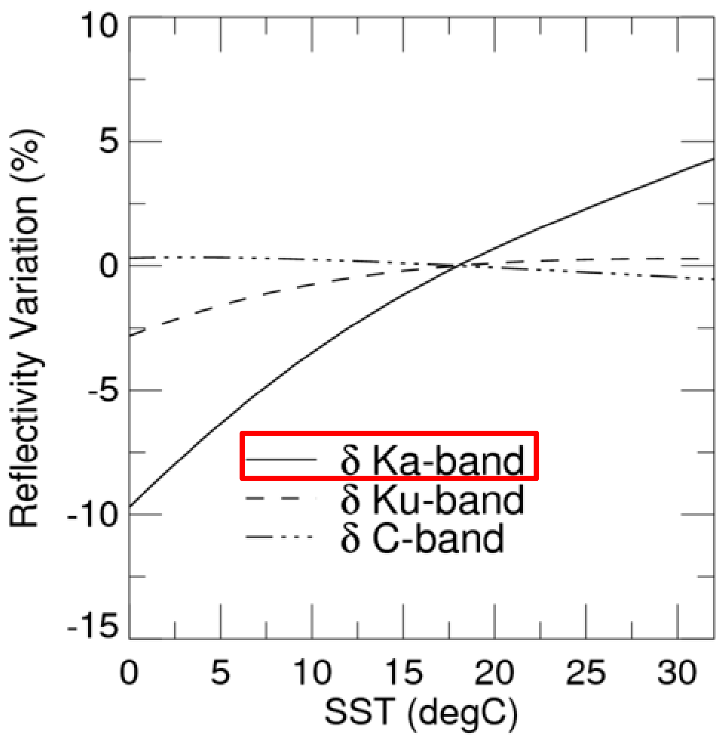
Tm



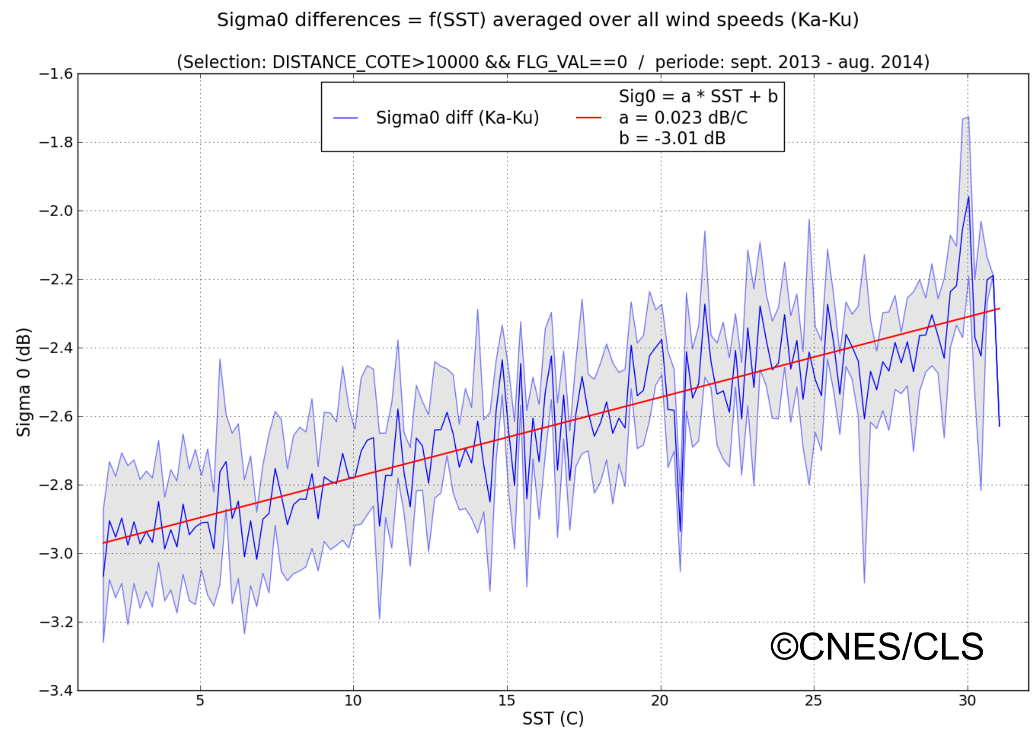


Conventional altimetry: NRCS dependance in SST

Vandemark et al. have shown that the sea surface reflectivity has a strong dependency to the surface temperature. This phenomenon is also present in Ku-band but to a lesser extent (only for cold temperatures).

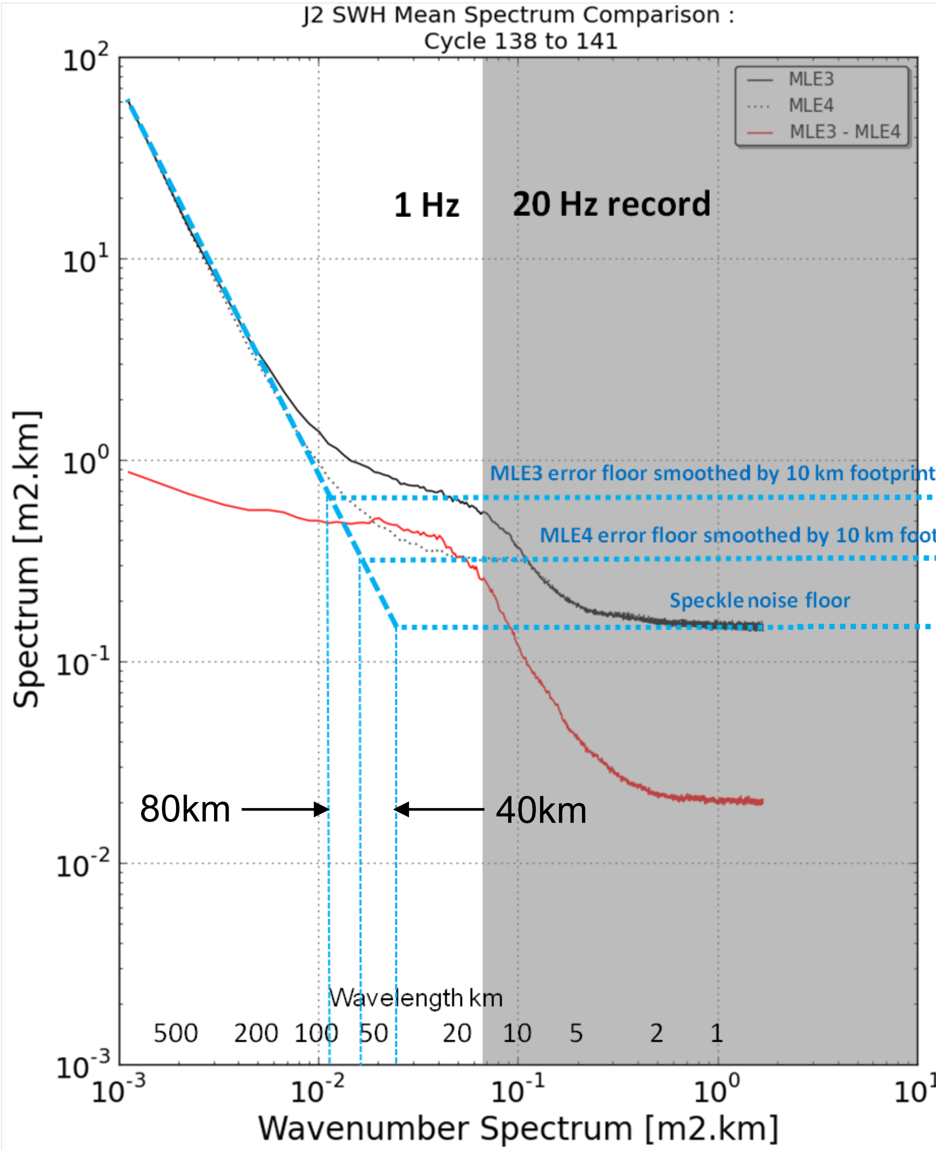


Vandemark, D. et al., (2016),



Difference of Sigma0 between Jason-2 and AltiKa computed at crossovers (Δt < 1h) as a function of the Reynolds SST.

BASELINE: THE LIMITATIONS



Assuming that KaRIN's SSB use the SWH parameter as a proxy

<u>Limitation</u>: due to the noise of altimetry-derived SWH, the SSB solution will be unable to correct for wavelengths smaller than 40-80 km (global average).

Legend: Global mean PSD of the SWH from Jason-2 estimated with MLE3 and MLE4 retrackers (from [Dibarboure et al., 2014]). The blue lines illustrate the small-scales noise floor: speckle noise, MLE3 retracker estimation noise, and MLE4 retracker estimation noise. On average SWH observability (SNR=1) is limited to scales larger than 40 to 80 km.

BEYOND THE NOMINAL CASE: SWH VARIABILITY

Access to the SWH parameter with:

- 1 nadir altimeter SWH estimation
- 1 KaRIn SWH estimation per swath. The SWH estimate is primarily representative of near-range sea-state conditions.

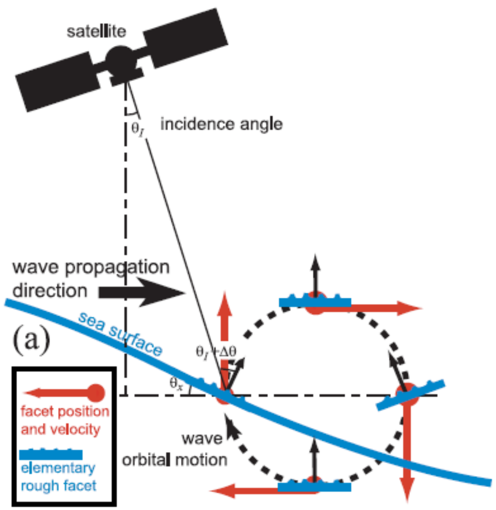
→ Probable mis-estimation of SWH in far range.

Impact of using nadir+near-range SWH estimation to correct SSB at far range is equivalent to using mis-located SWH estimates in nadir altimetry

The mis-location can be as large as 50 to 60 km (nadir to far-range pixels): in other words, a simple SSB algorithm using nadir+near-range SWH may not properly correct wave-induced effects for scales smaller than 40 to 80 km.

Only the larger scales of the SSB would be corrected, especially in the outer edges of the swath.

Orbital velocities and modulation



Reminder: relating modulation and velocity [Elfouhaily 2001]

$$\Omega = \tilde{\omega}(\boldsymbol{k}_{\mathrm{s}}, \boldsymbol{x}, t) + \boldsymbol{k}_{\mathrm{s}} \cdot \boldsymbol{U}_{\mathrm{L}}(\boldsymbol{x}, t),$$

$\boldsymbol{U_L}(\boldsymbol{x},t)$ is the horizontal component of the orbital velocity induced by the presence of long, linear or nonlinear, modulating waves. The local acceleration vector is according to Longuet-Higgins [1985, 1987]

$$\tilde{\boldsymbol{g}}(\boldsymbol{x}, t) = \boldsymbol{g} - \boldsymbol{a},$$

with $\boldsymbol{g}$ being the (constant) acceleration due to gravity, and $\boldsymbol{a}$ being the real, or lagrangian, acceleration due to the orbital motion of the underlying field