Seasonal Effects on the Pitch Measurements for Cryosat-2

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Presentation Outline

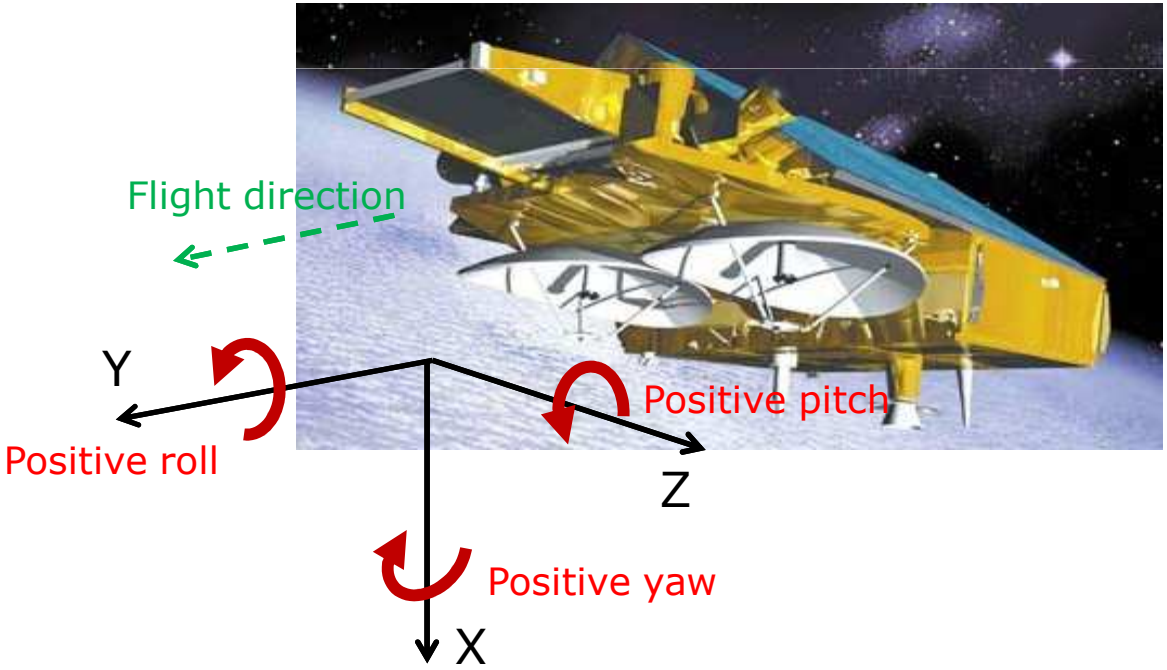
- Pitch & Roll Mispointing Angles
- Methodology for Pitch Estimation
- Experimental results with CryoSat-2 data over ocean
- Error Impact
- Conclusions

Introduction and Rationale

- As standard de facto, in SAR Altimetry, pitch and roll mispointing angles are not estimated from the SAR waveform but are computed from Star Tracker and fed as input in the SAR Waveform model
- Consequently, any error in pitch and roll measurement will end up in a potential source of error in estimation of the sea surface geophysical parameters (SSH, SWH, U10)
- It becomes hence essential that mispointing angles, that are obtained on ground processing the quaternions provided by the Star Trackers, be validated against indipendent measurements of pitch/roll (i.e., calibration of the off-nadir mispointing angles)

CryoSat-2 Pitch and Roll

	Convention from Cryosat-2 Product Handbook
Pitch	Positive pitch: Nose down
Yaw	Positive yaw: Nose right
Roll	Positive roll: Right antenna down



CryoSat-2 Processing Reference Frame

On ground the off-nadir mispointing angles are computed from one Star Tracker at a time.

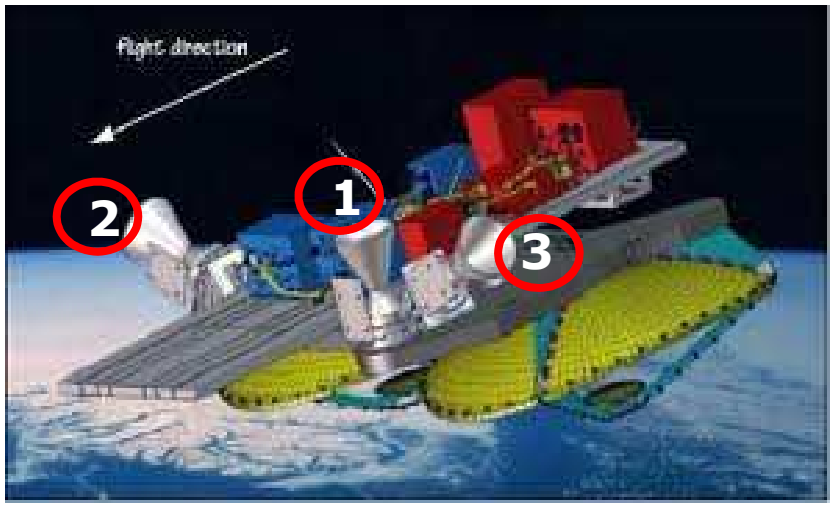
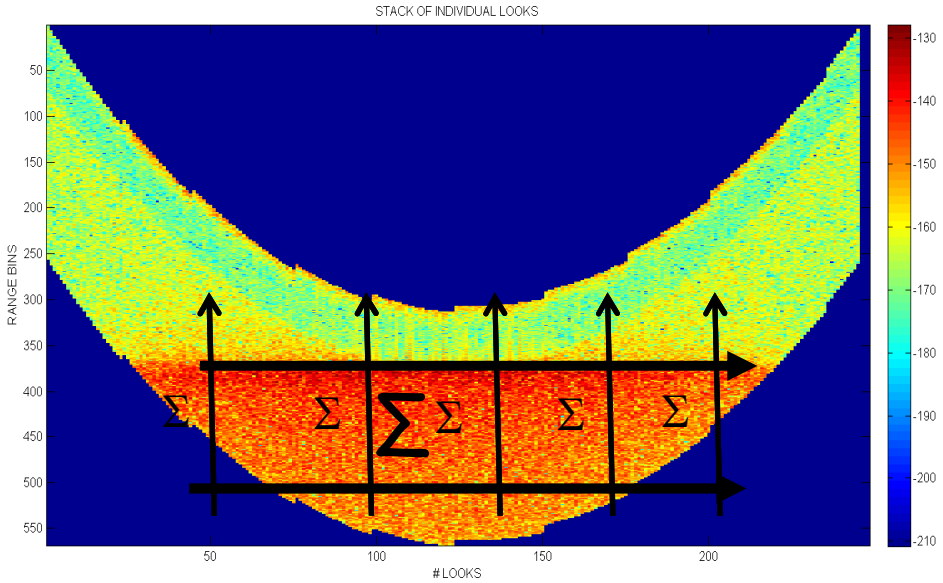


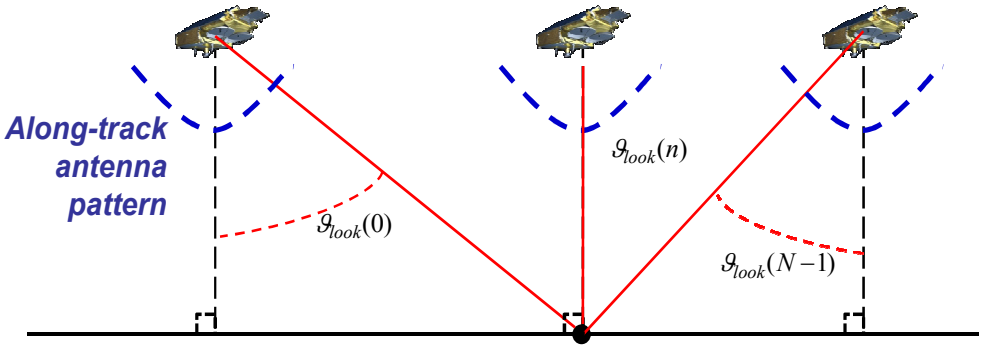
Figure courtesy of Thales Alenia Space.

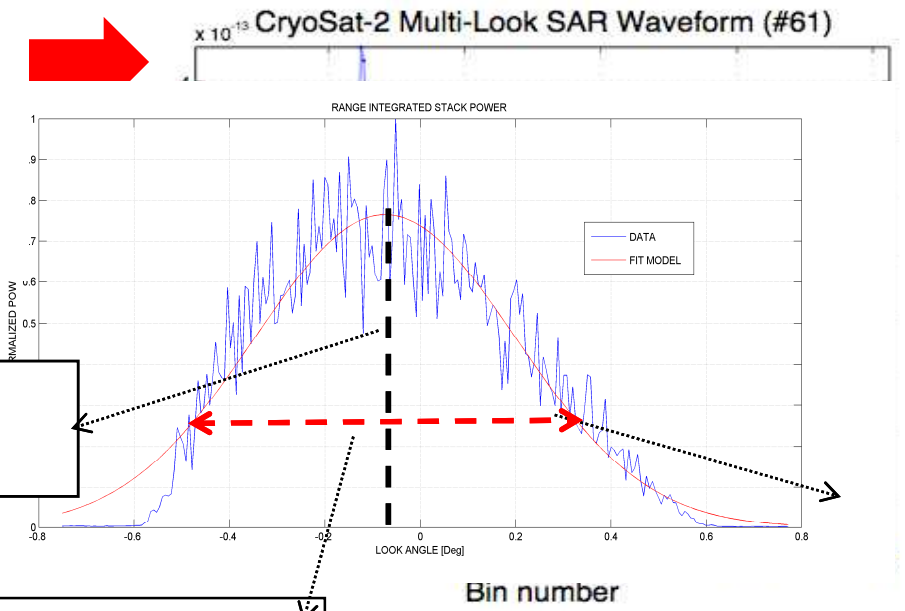
METHODOLOGY

For more info, refer to:
M. Scagliola, M. Fornari, and N. Tagliani, "*Pitch estimation for CryoSat-2 by analysis of stacks of single-look echoes*," IEEE Geosci. Remote Sens. Letters, vol. PP, no. 99, pp. 1–5, 2015.

RIP (Range Integrated Power) Building





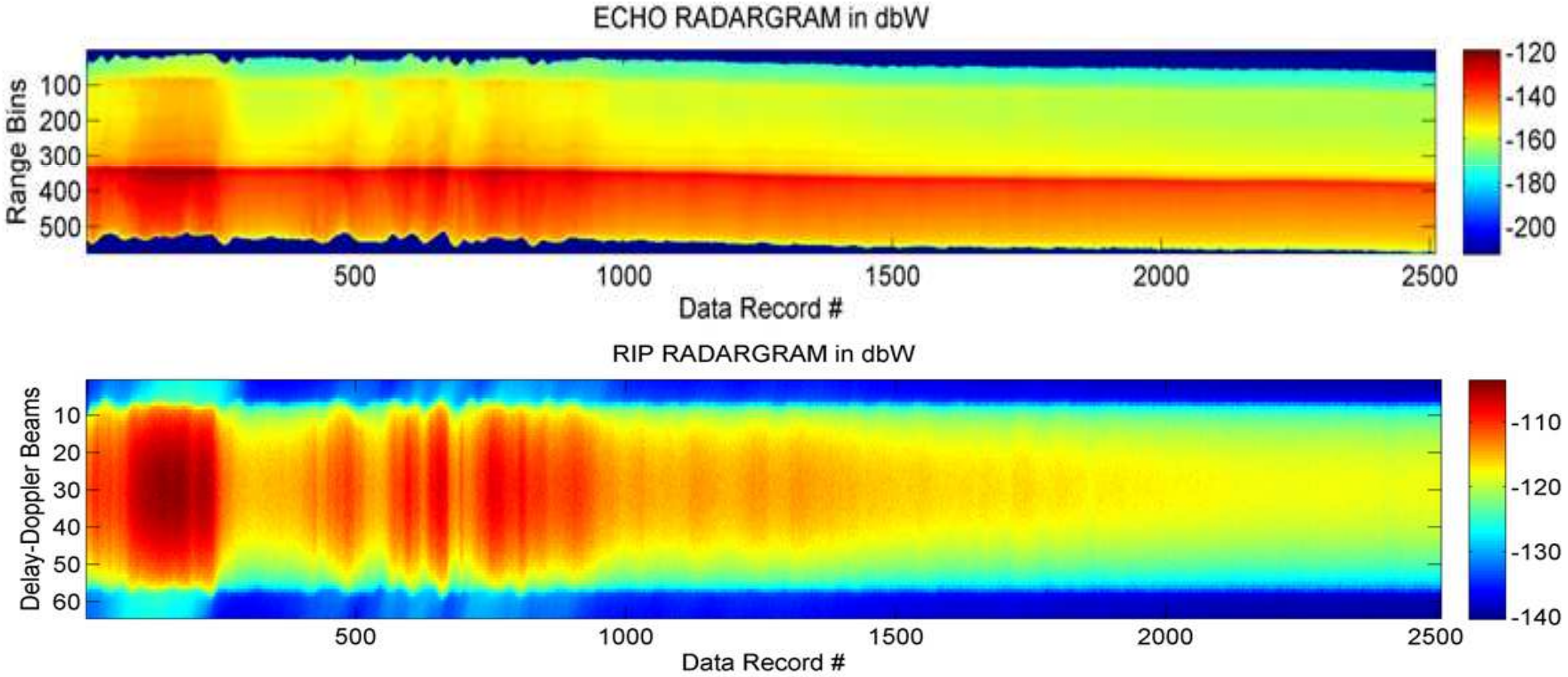


RIP Offset depending on pitch mispointing (but not only)

RIP 3db aperture depending on mean square slope of sea surface

ECHO RADARGRAM & RIP RADARGRAM

We use RIP just to estimate the pitch but it worth to notice that RIP holds much more geophysical information that currently is not exploited fully over ocean

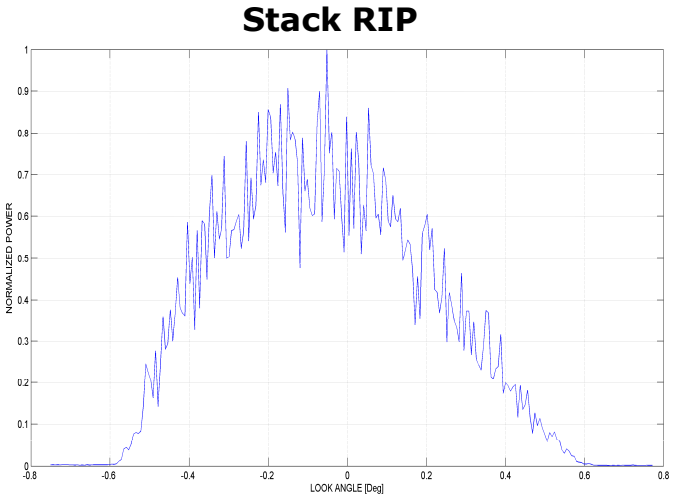


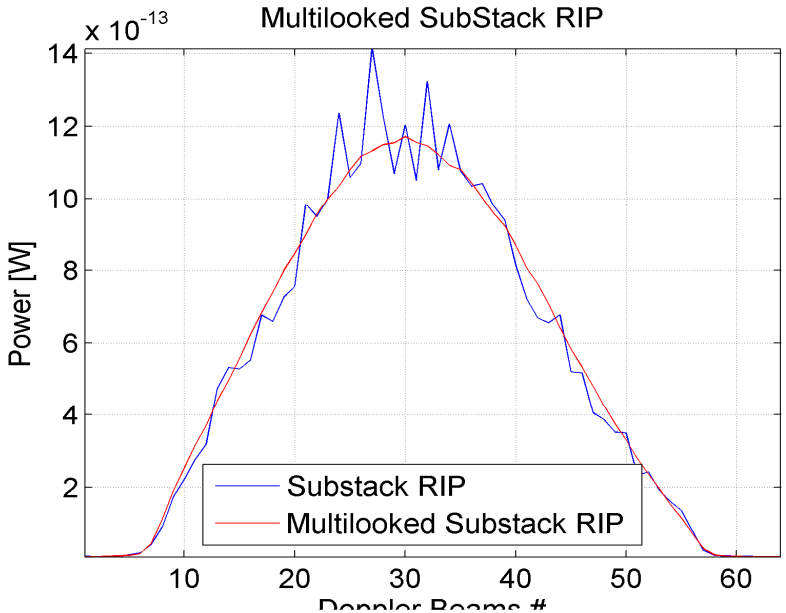
Sub Stack RIP & RIP MULTILOOKING

Individual Stack RIPs are pretty **noisy**
In order to make the pitch estimation more robust and knock down the noise, we:

❑ From the stack RIP, we build the substack RIP (a simple moving average along the RIP with size of 4 beams)

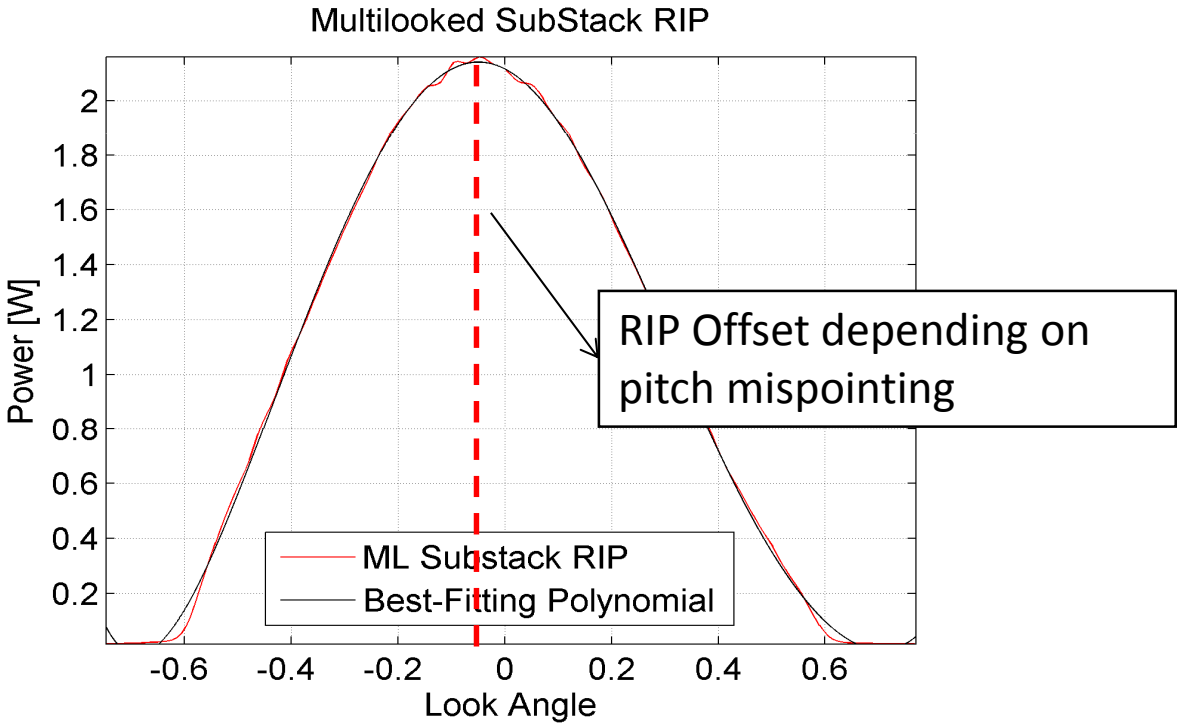
❑ 100 consecutive Substack RIPs were multilooked togheter (integrated)
(assumption is that the attitude of the satellite is slowly varying in time)





RIP FITTING

Once build the Multilooked Substack RIP, we fit the RIP power against a 9th degree polynomial.
Then, we oversample the polynomial: the estimated stack pitch will be the maximum of the oversampled polynomial



RIP can be modeled as

$$RIP(\xi) \approx K \cdot \exp\left(-\frac{2(\xi - \eta - \varsigma/\mu)^2}{\gamma_1^2} \right)$$

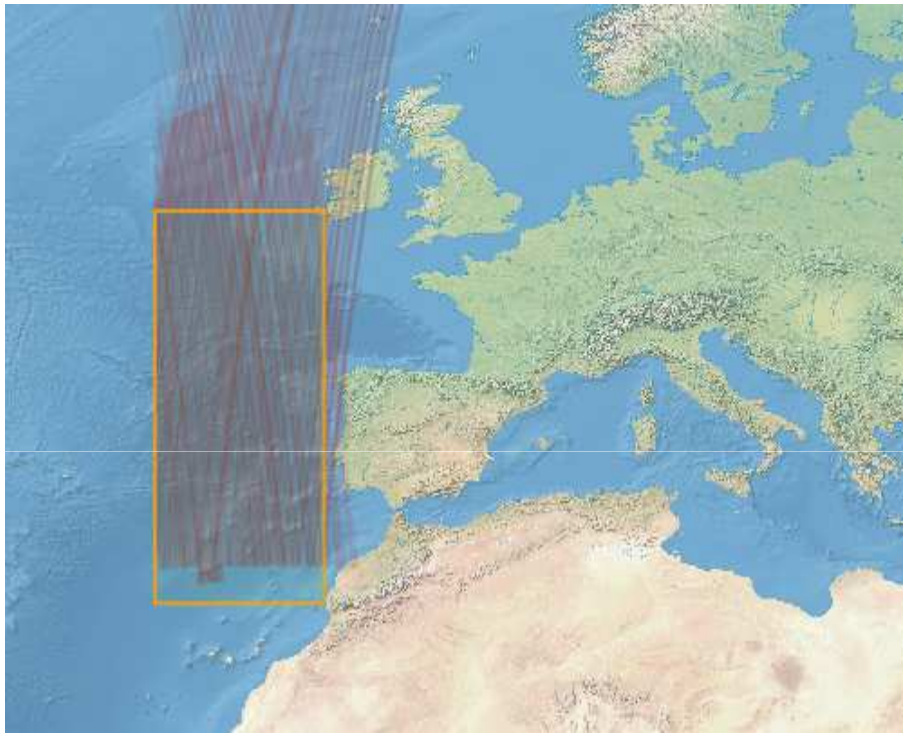
ξ : Look angle

η : pitch mispointing

ς / μ : along-track slope of ocean surface

Region and Time of Interest

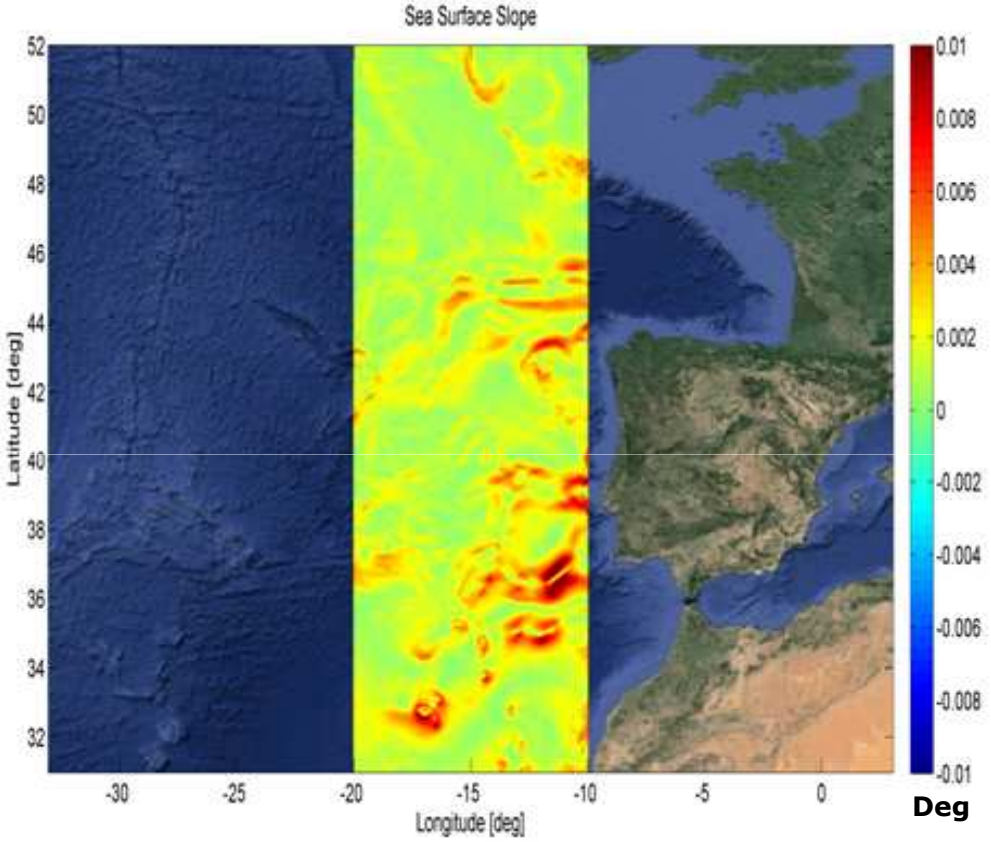
1620 CryoSat-2 SAR acquisitions for a long time span (**5 years:** 2010/04 to 2015/08) over North-East Atlantic Ocean (no coastal data) have been processed and extracted from ESA-ESRIN GPOD CryoSat-2 Service.
We have used Baseline A, B, C FBR data.



It is worth recalling here that the mispointing angles in FBR products comes from all the three Star Trackers, each of them is differently oriented.

Each Star Tracker can have different accuracy as function of its orientation with respect sun/moon and as function of its temperature.

OCEAN SLOPE Is Neglected

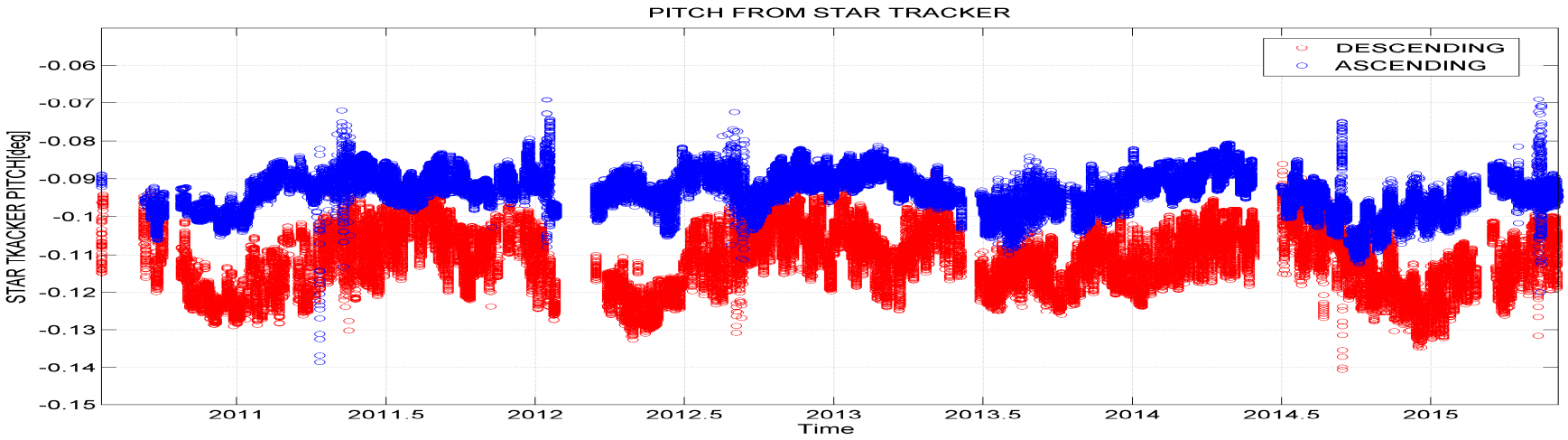


RIP Center depends also on ocean surface slope (not only pitch mispointing)

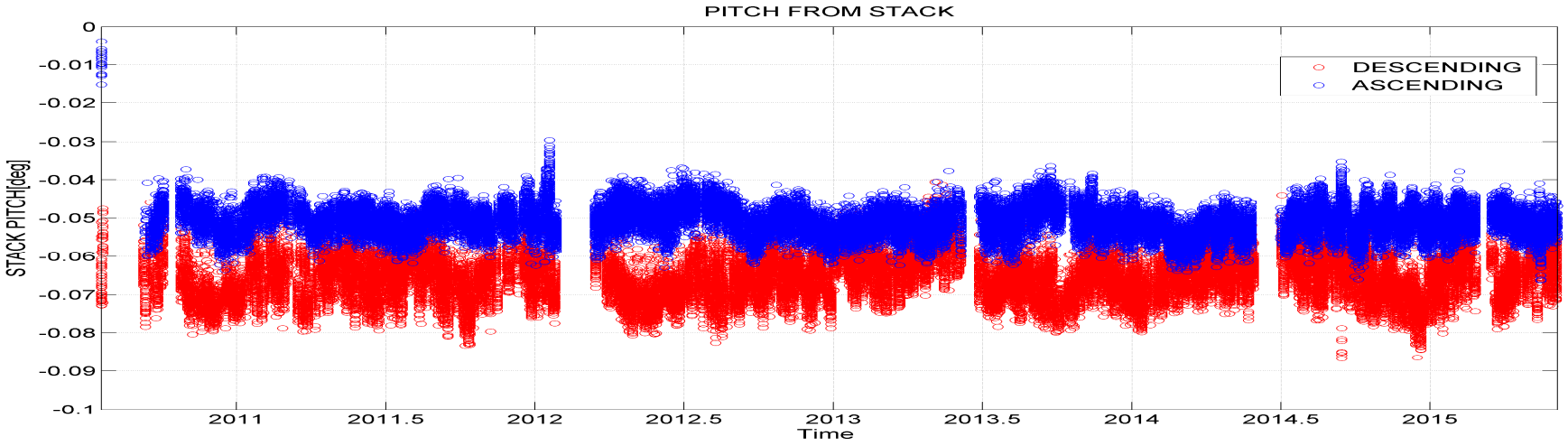
In the area of interest (North-East Atlantic), the surface slope takes a maximum value of 10 millideg with a mean value of 2 millideg.
In the current analysis ocean slope is considered small and it will be neglected.

Pitch from Star Tracker and Pitch from Stack

PITCH from STAR TKR, ASC. and DESC. Case

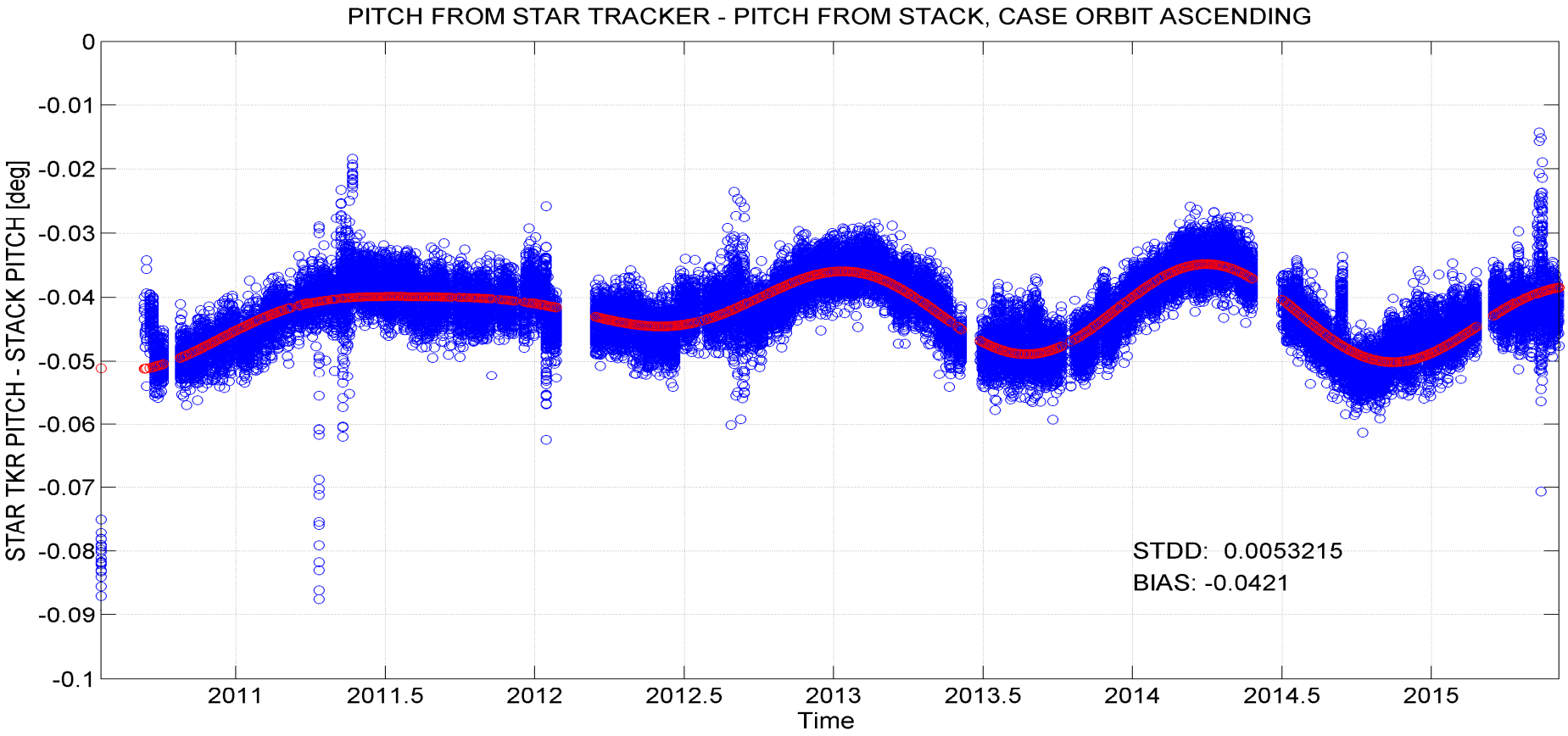


PITCH from STACK, ASC. and DESC. Case



Pitch Mispointing Bias very close to the value estimated by N. Galin and M. Scagliola (0.053 deg) even if their datasets were more geographically spread but on a shorter time interval.

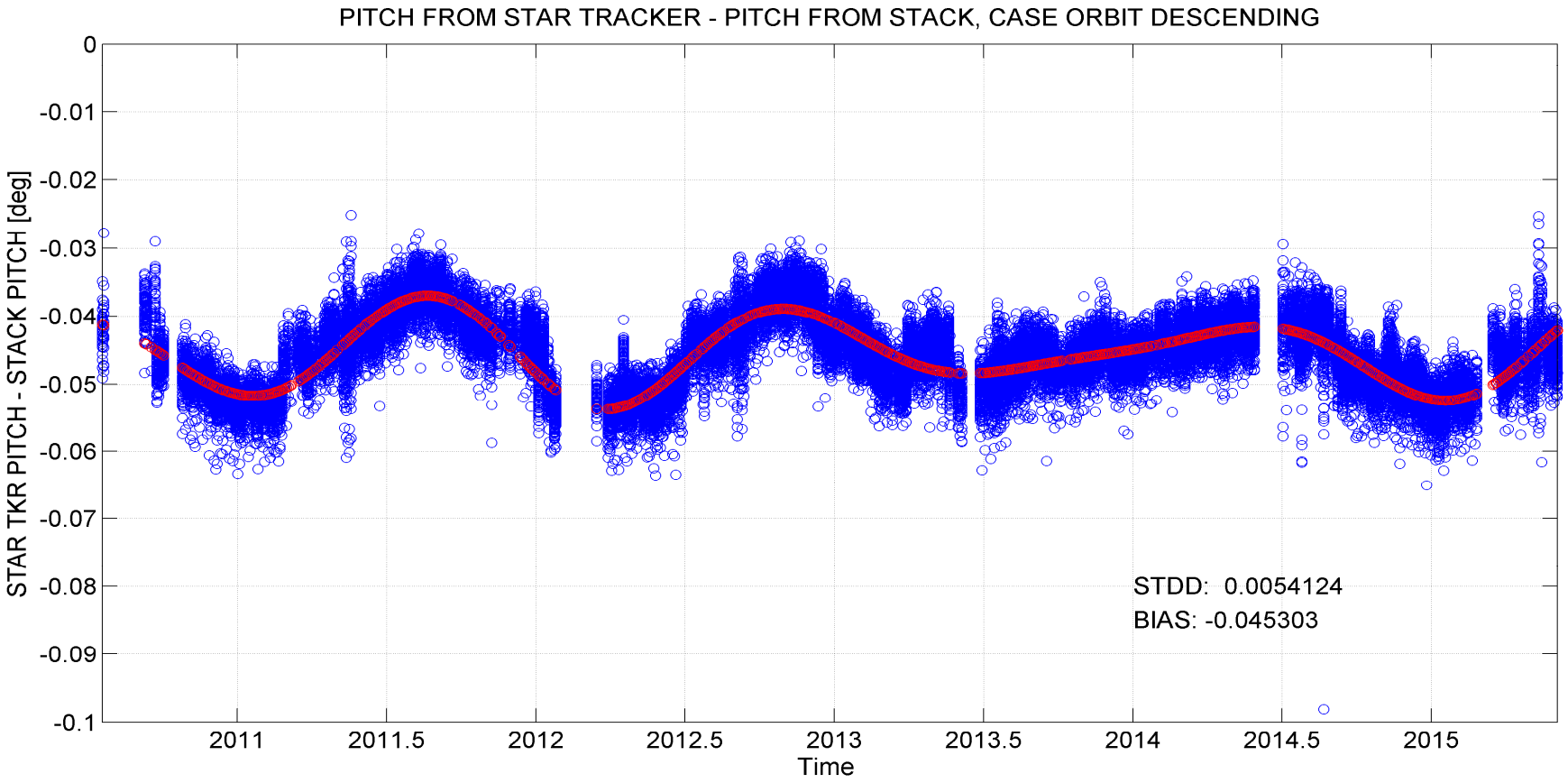
Pitch from STAR Tracker – Pitch from STACK vs. Time



CASE ASCENDING

Bias= -0.042 deg

Pitch from STAR Tracker – Pitch from STACK vs. Time

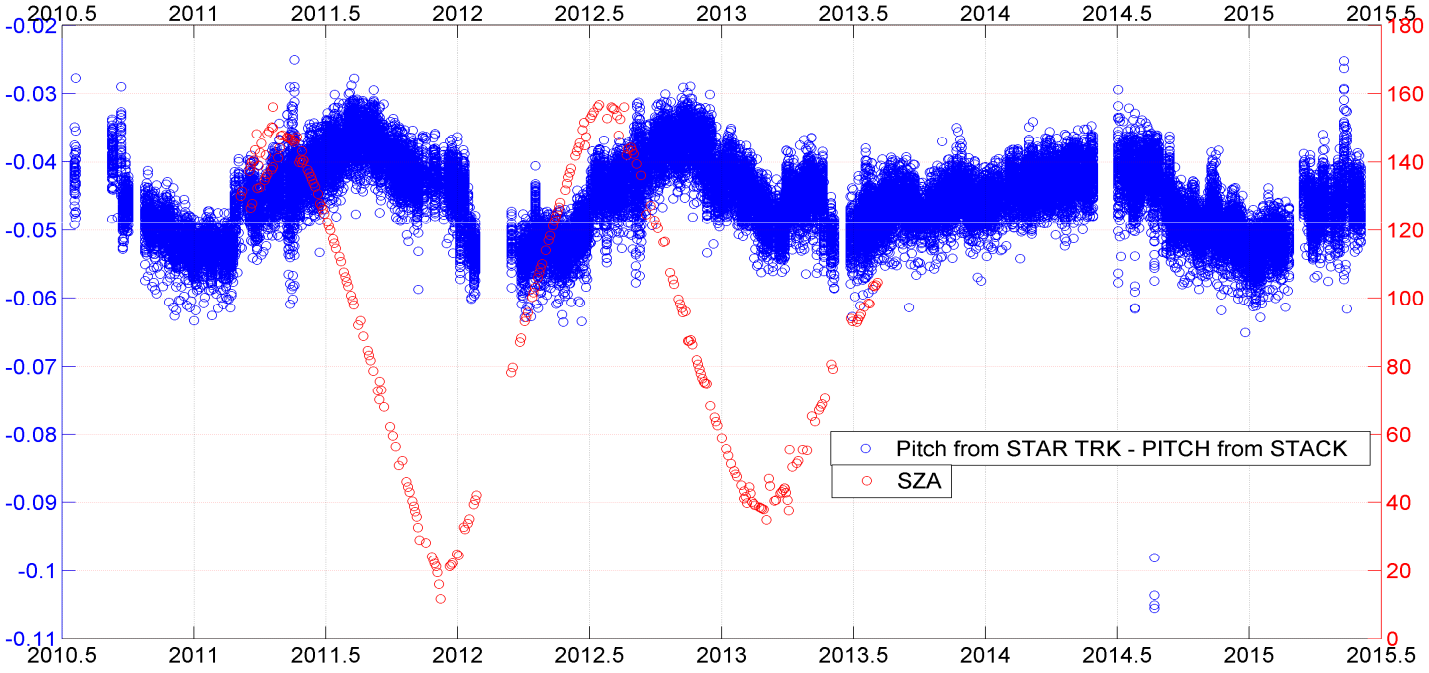


CASE DISCENDING

Bias= -0.045 deg

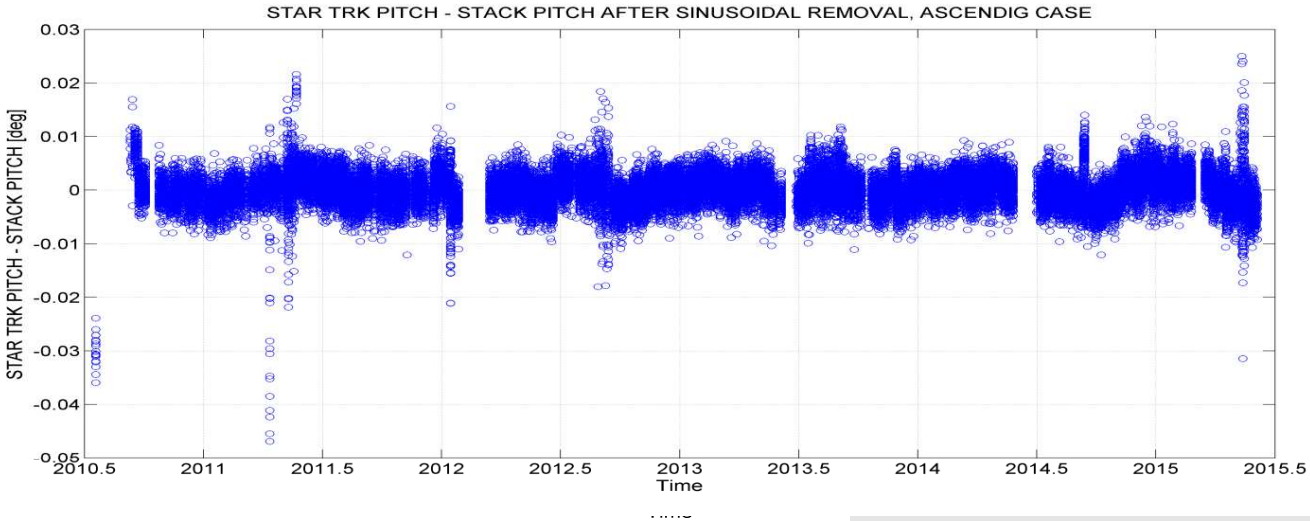
Rationale for this ondulatory pattern in time

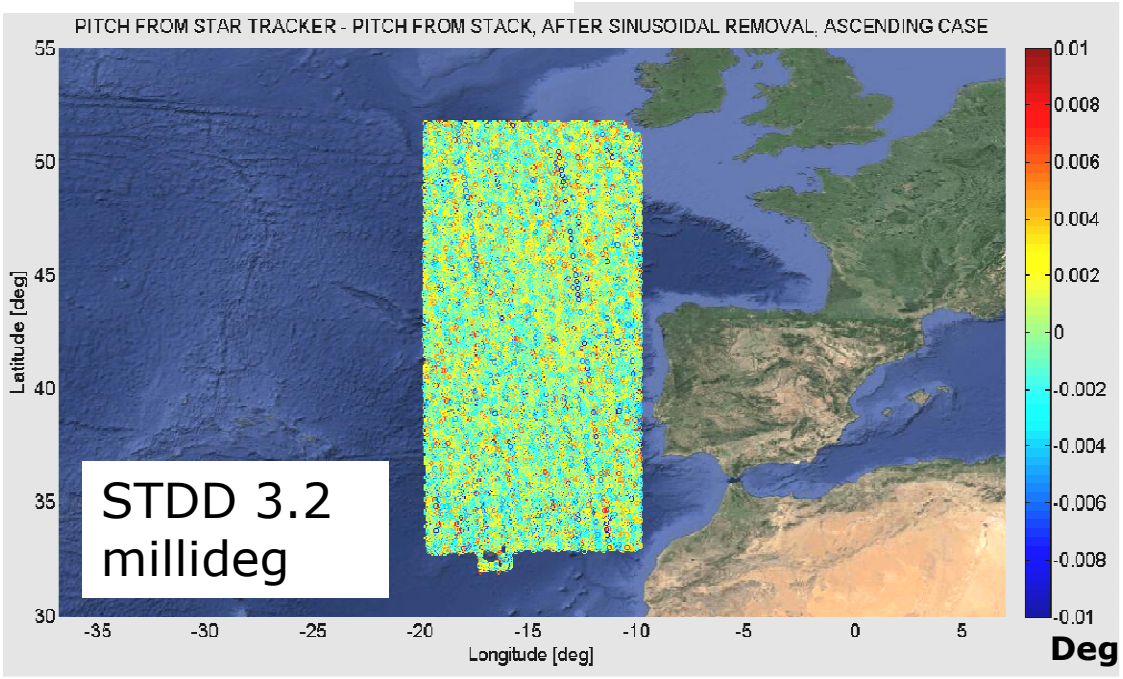
One of the responsible for the sinusoidal temporal pattern might be the sun illumination



Sun illumination is expected to affect differently each Star Tracker and their temperature recalling that the CryoSat orbit is not sun-synchronous.

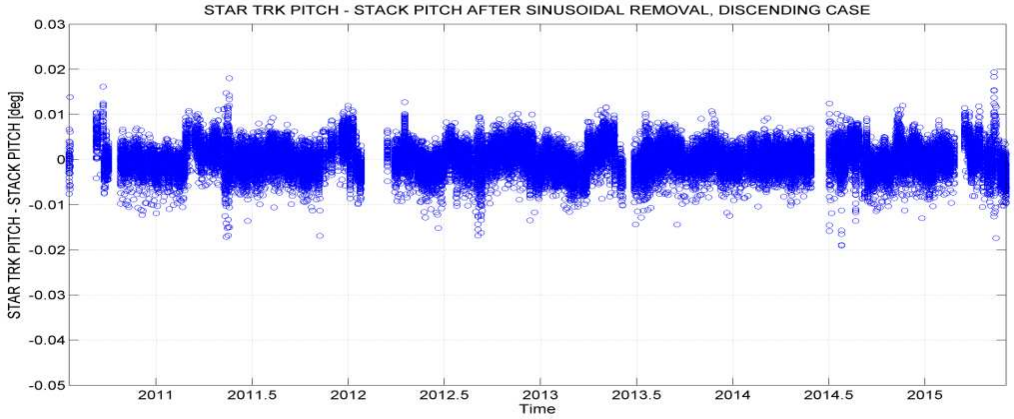
Trying to remove sinusoidal pattern...

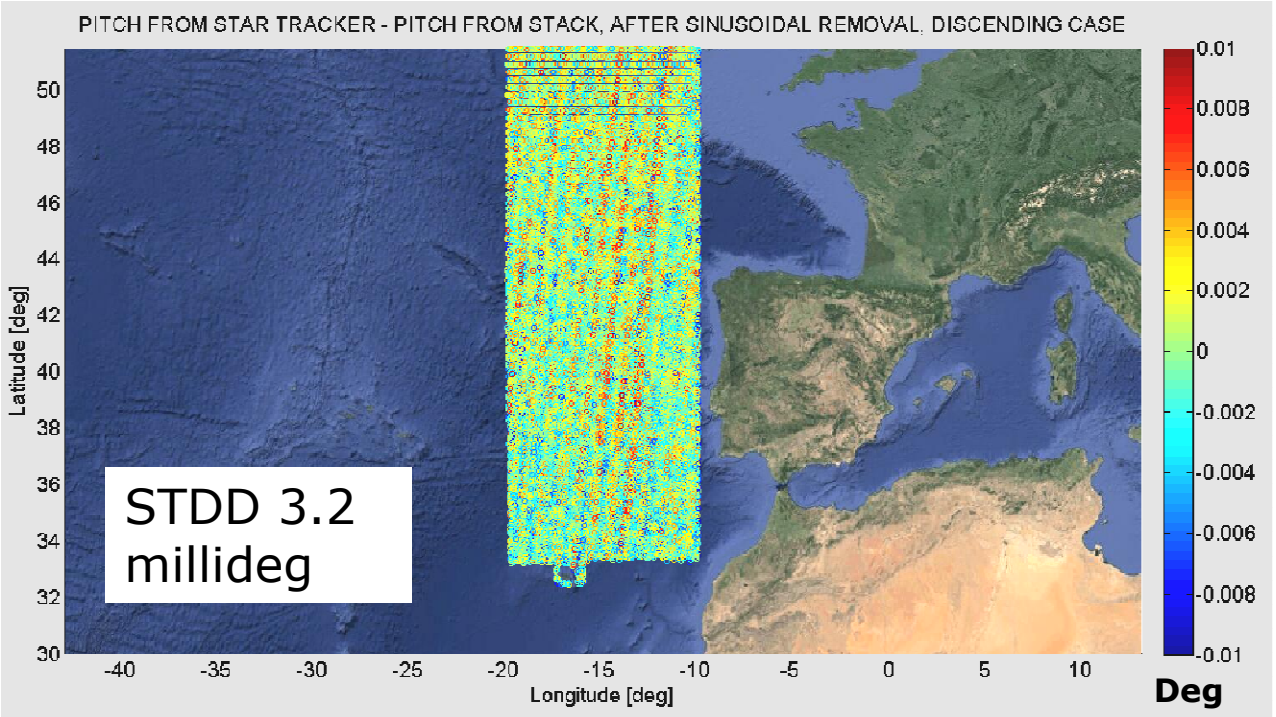




CASE ASCENDING

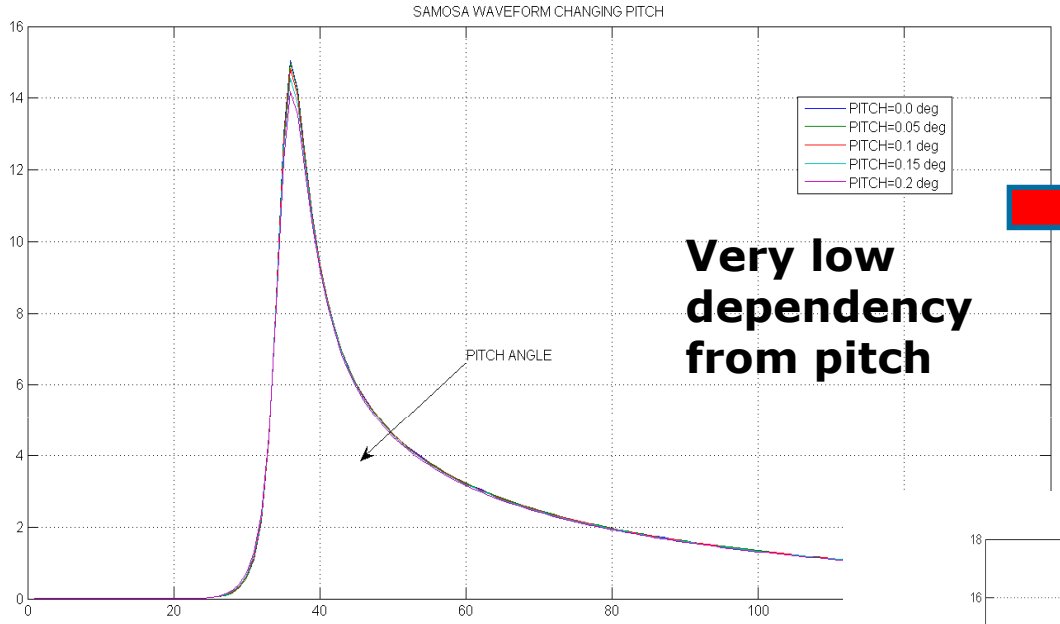
Trying to remove sinusoidal pattern...





CASE DESCENDING

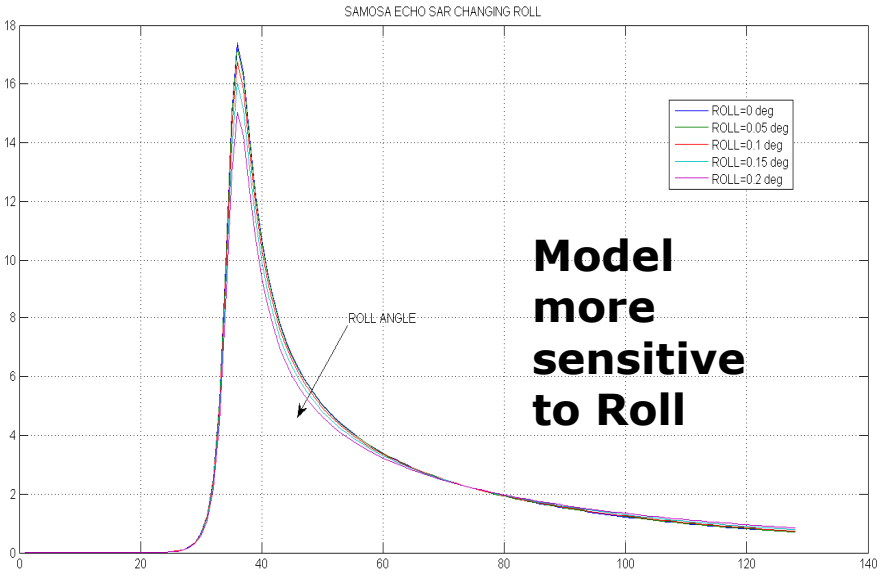
Error Impact



Very low dependency from pitch

Errors in pitch mispointings translate essentially in errors in estimated amplitude (Power)

SAR Echo Shape more sensitive to roll, errors in roll mispointings cn translate in error in SWH and range



Model more sensitive to Roll

Conclusions and Way Forward

- Since the next generation SAR altimetry will take in input the pitch and roll mispointing angles from Star Tracker, it's quite important to ensure the accuracy of the mispointing angles as computed on ground.
- We have carried out an analysis of the Cryosat-2 Pitch Mispointing (from Star Trackers and from Stack) in a long time span and on a limited geographical area.
- Thanks to pitch mispointing computed from Stack, we have identified a sinusoidal pattern in the Star Tracker estimation of the pitch mispointing (potentially correlated to sun illumination conditions).
- After removal of the sinusoidal pattern, the estimation of the pitch from Star Tracker and Stack are pretty consistent (around 3 millideg).
- The outcomes of this analysis are strictly related to the geographycal area here considered: they cannot be extrapolated to other zones.
- It is essential to calibrate also the roll mispointing (that can be affected in the same way by solar illumination).
- We recommend to perform the same exercise routinely for Sentinel-3, as long as for the roll.