Starlab Space

Wavemill Primary Scientific Products E2E Simulator

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Starlab Living Science

esa

WAPA Final Review Meeting
25th Nov. 2014

Objectives

- **To validate the outputs of the Wavemill End-to-End Simulator.**

- **To asses the correct behavior of the simulator, checking some relevant features of the simulated SAR images.**

Outline

- **Validation Models Definition.**
- **Tests implementation and results.**
- **PCC scenario simulation.**
- **Conclusions.**

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Validation Models

Seed Questions

- Q1: What is the spatial spacing you considered ? 1 m, 30 cm.

- Q2:Did you assign for each facet, the resulting local orbital velocity components, with local tilt angles ?

- Q3:What is then the solution you considered within the non-resolved patches?

- Q4: Did you evaluate the relative sensitivity of this solution to the local tilt changes?

- Q5:Whatever the EM model, the fact that modulations are expected (at least from orientation changes) will contribute to change the cross section statistics from exponential (Rayleigh in amplitude) to heavier-tail distribution. Is that the case?

- Q6:One aspect is certainly to take into account some modulations associated to hydro/aero effects. Even considering a 'toy' model, is it feasible to apply some modulation (on top of the tilt ones) to the cross section: correlation with the elevations and slopes of the dominant scales?

- Q7:On the Doppler part: did you check that your mean Doppler (centroid or interferometric) is affected by the relative line-of-sight wind direction?

Validation Models

Test number	Key variable	Test set-up
TST-SIM-01	Simulation of ocean surface with **different wind speed.**	The test will be executed for wind speed equal to [3,7,14,20] m/s and across track direction.
TST-SIM-02	Simulation of ocean surface for **different wind directions.**	The test will be executed for wind directions equal to [90o (up wind), 135o,180o (cross wind), 225o, 270o(down wind)]
TST-SIM-03	Simulation of SAR images at **different incidence angles**.	The test will be executed for a fixed wind speed (5 m/s) and direction (across track), and for incidence angle (at scene center) of [20º,30º,40º].
TST-SIM-04	Simulation of ocean surface with **different swell (tilts).**	The test will be executed for a fixed wind speed (5 *m/s*) and direction (across track), and for for swell wavelength of [50,100,150,200] *m*.
TST-SIM-05	Simulation of ocean surface with **different wind speed.**	For this test will be used the result of TST-SIM-01
TST-SIM-06	Simulation of ocean surface for **different wind speed and swell.**	For this test will be used the result of TST-SIM-02.
TST-SIM-07	Simulation of ocean surface for **different wind speed**.	The test will be executed for wind speeds equal to [3,7,14,20] *m/s* and across track direction and for along/across track directions.

Simulator Configuration

ERS like

Parameter	Value
PRF	1680.0 [Hz]
TX_BANDWIDTH	15549900.0 [Hz]
PULSE_DURATION	3.71200e-05 [ms]
CARRIER_FREQ	5.2966865e+09 [Hz]
SAMPLING_FREQUENCY	18963103.0 [Hz]
AZIMUTH ANGLE	0.0º
NOMINAL_ALTITUDE	777828.71 [m]
NOMINAL_VELOCITY	7480.9116
IMAGE SIZE	4.5 Km x 4.5 Km

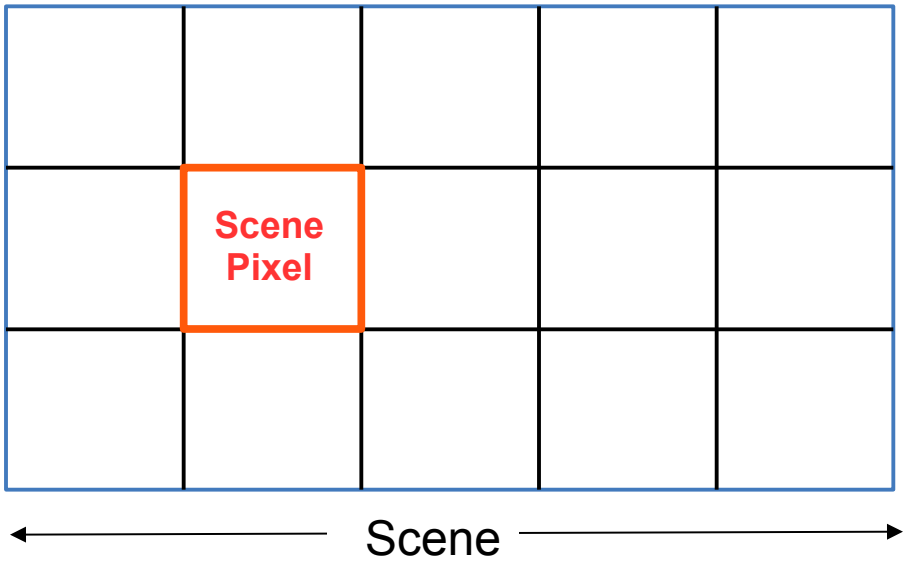
Raw data generation

Answer yo questions Q1,Q2

Scene Sampling

Scene dimensions (x,y) and resolution(dx,dy) are user defined

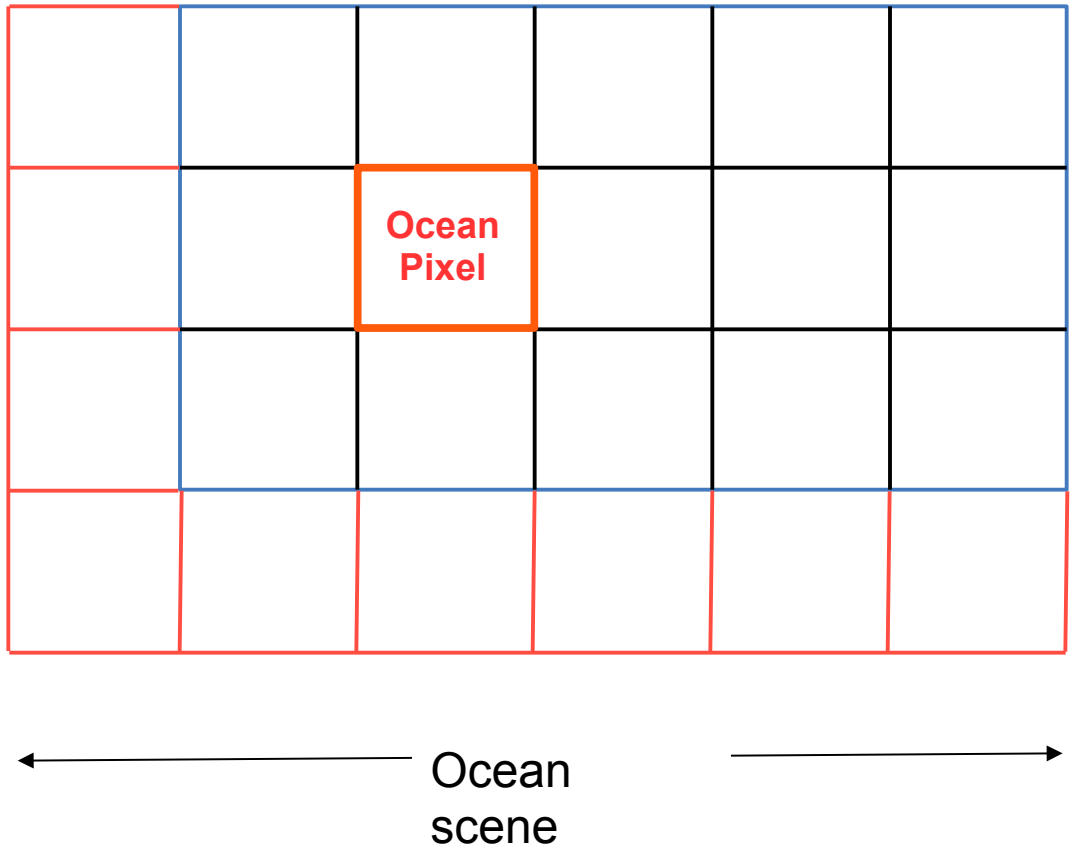
- (dx, dy) < SAR resolution



Raw data generation

Ocean Sampling

- **Scene dimensions are expanded to the next power of 2**



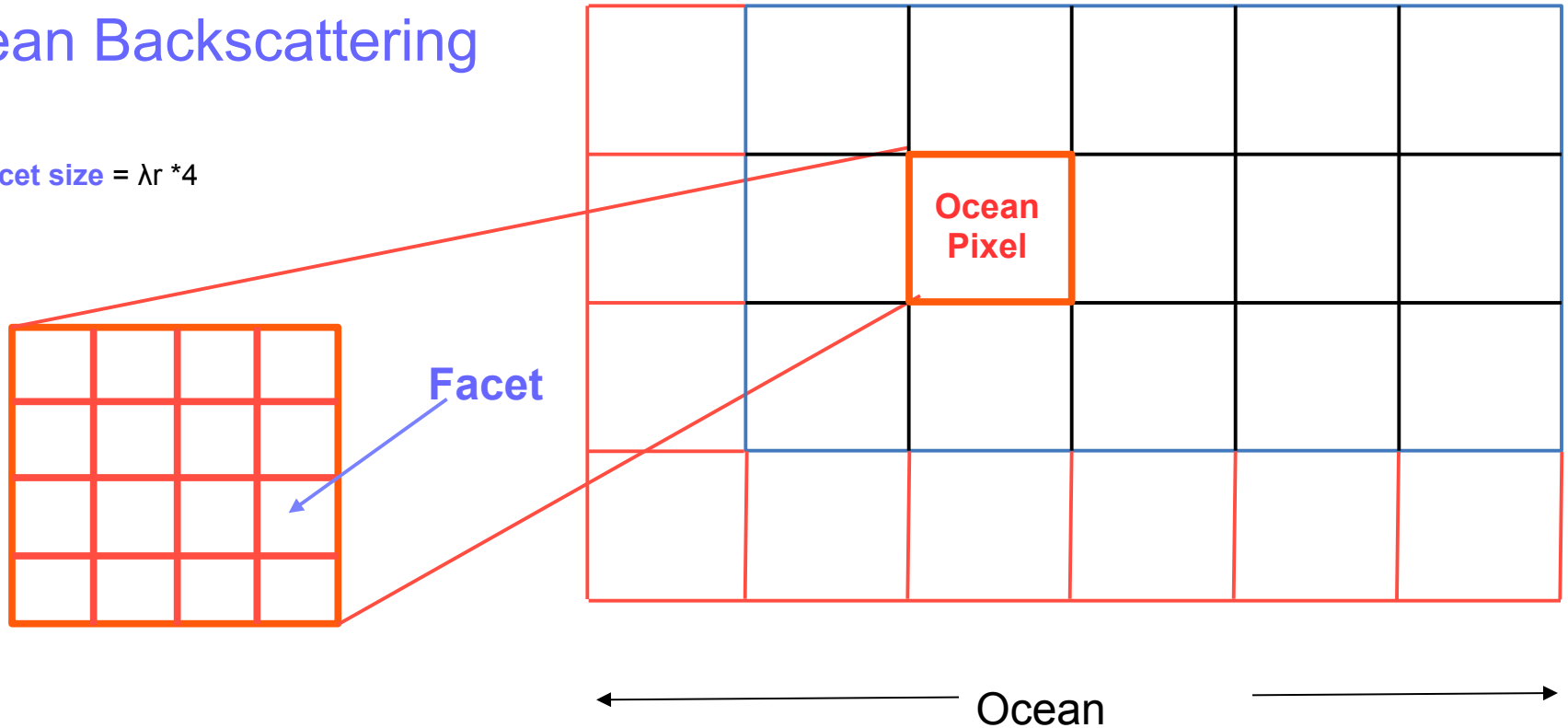
For each Ocean pixel the following parameters are computed (and updated every radar pulse):

- Local incidence angle.
- Position (x, y, z ECEF)
- Velocity (x, y, z ECEF)

Raw data generation

Ocean Backscattering

- **Facet size** = λr *4



$$\sigma(x,t) = \pi R^2 sec^4(\theta) P(\eta_i,\eta_n)_{\eta_i=\tan\theta;\eta_n=0} + \int \sigma_{0br}(\theta-\eta_i) P(\eta_i) d\eta_i$$

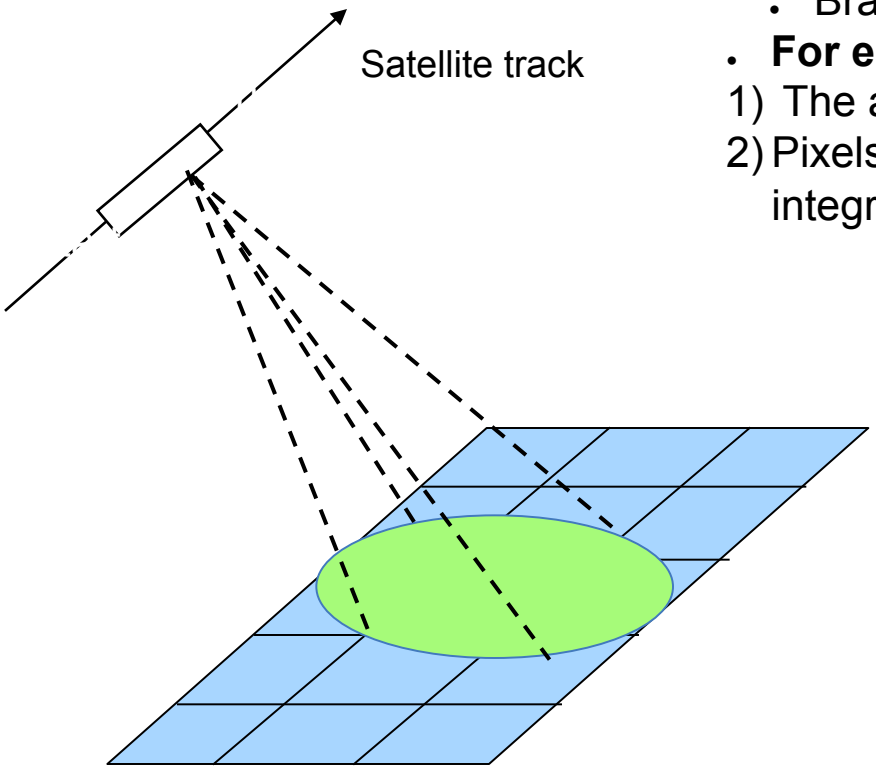
- ***P(η$_i$)*** one dimensional probability density functions of the sea surface slope in the direction of the incidence plane(η_i).

- ***P(η$_i$,η$_n$)*** are the one and two dimensional probability density functions of the sea surface slope in the direction of the incidence plane (η_i) and in the orthogonal direction (η_n).

Kudryavtsev, V. et al. , **On radar imaging of current features: 1, Model and comparison with observations.** JGR, vol 110, 2005

Raw data generation

SAR Sampling



- A **“Raw data” matrix** is defined with dimensions and spacing dictated by the instrument configuration
- The following parameters are considered in the **phase computation**:
  - Pixel position
  - Pixel velocity
  - Bragg phase speed
- **For each radar pulse:**

1) The antenna pattern is projected over the scene
2) Pixels that fall within the antenna pattern are integrated and stored in the “Raw data” matrix

Outline

- Validation Models Definition.
- **Tests implementation and results.**
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Tests Implementation and Results

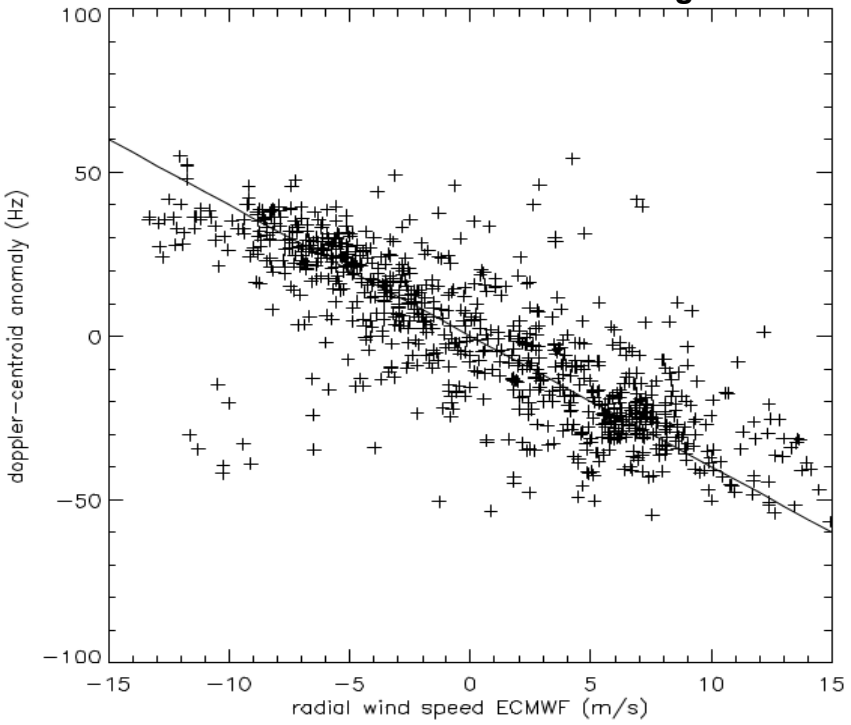
Induced Doppler Bias

TST-SIM-02:Simulation of ocean surface for different wind speed.

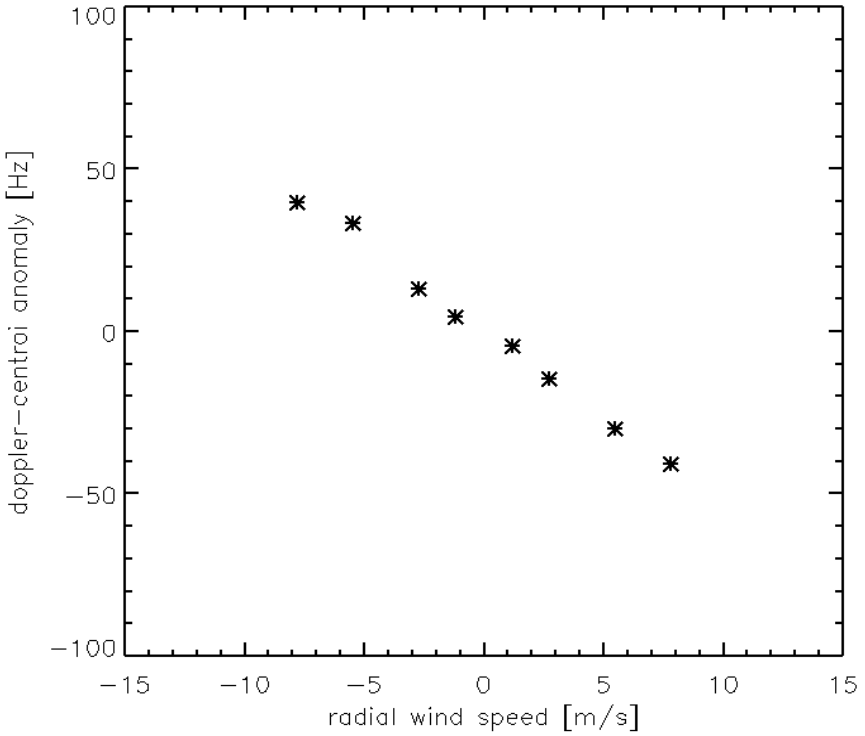
Answer yo questions Q2,Q7

- Wind speed = [3, 7, 14, 20] *m/s*
- Wind direction = 90º (up wind), 270º(down wind)

After B. Chapron, et al., 2002, ENVISAT Calibration Review meeting.



E2E Simulations



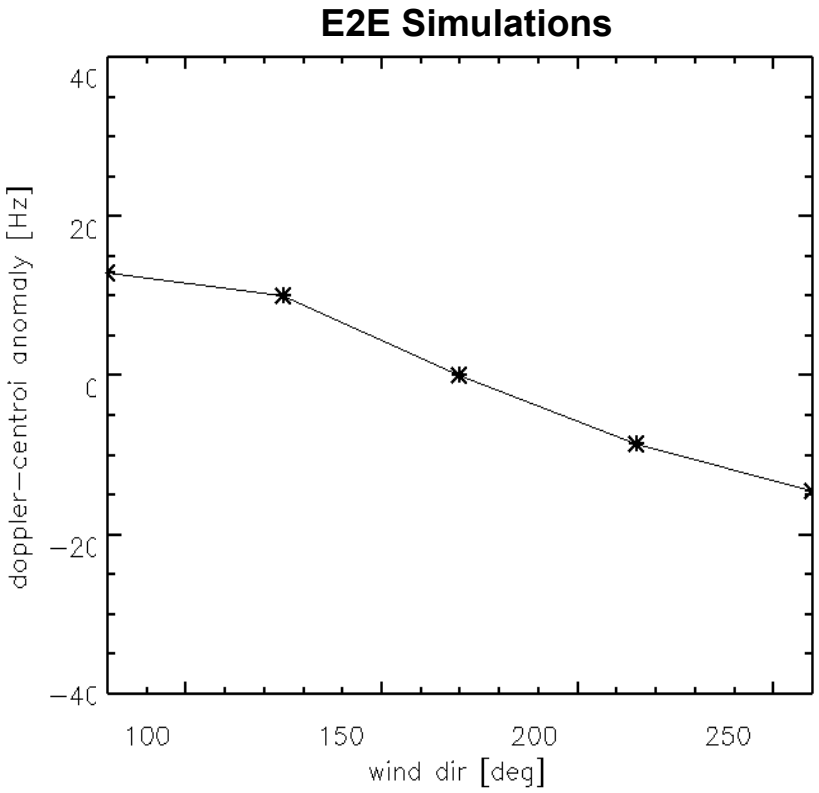
Tests Implementation and Results

Induced Doppler Bias

Answer yo questions Q2,Q7

Simulation of ocean surface for different wind direction.

- Wind speed = 7 *m/s*
- Wind direction = [90º (up wind), 135º,180º (cross wind), 225º, 270º(down wind)



Tests Implementation and Results

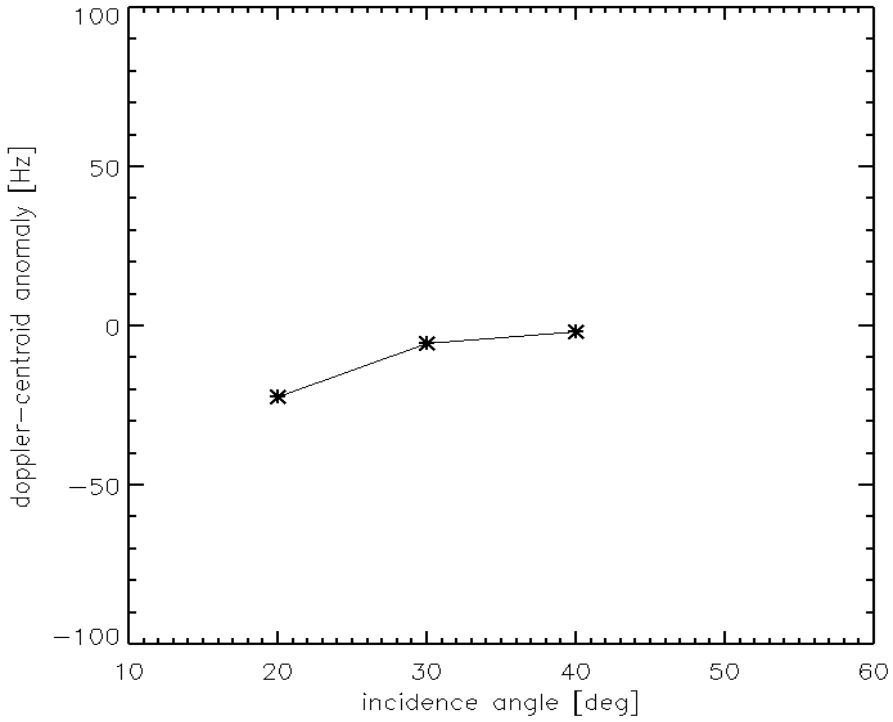
Induced Doppler Bias

TST-SIM-03:Simulation of SAR images at different incidence angles.

Answer yo questions Q2,Q7

- Wind speed = 5 m/s
- Wind direction = 180º (down wind)
- Incidence angle (at scene centre) of [20º,30º,40º]

E2E Simulations



Tests Implementation and Results

Induced Doppler Bias

TST-SIM-04:Simulation of ocean surface with different swell (tilts).

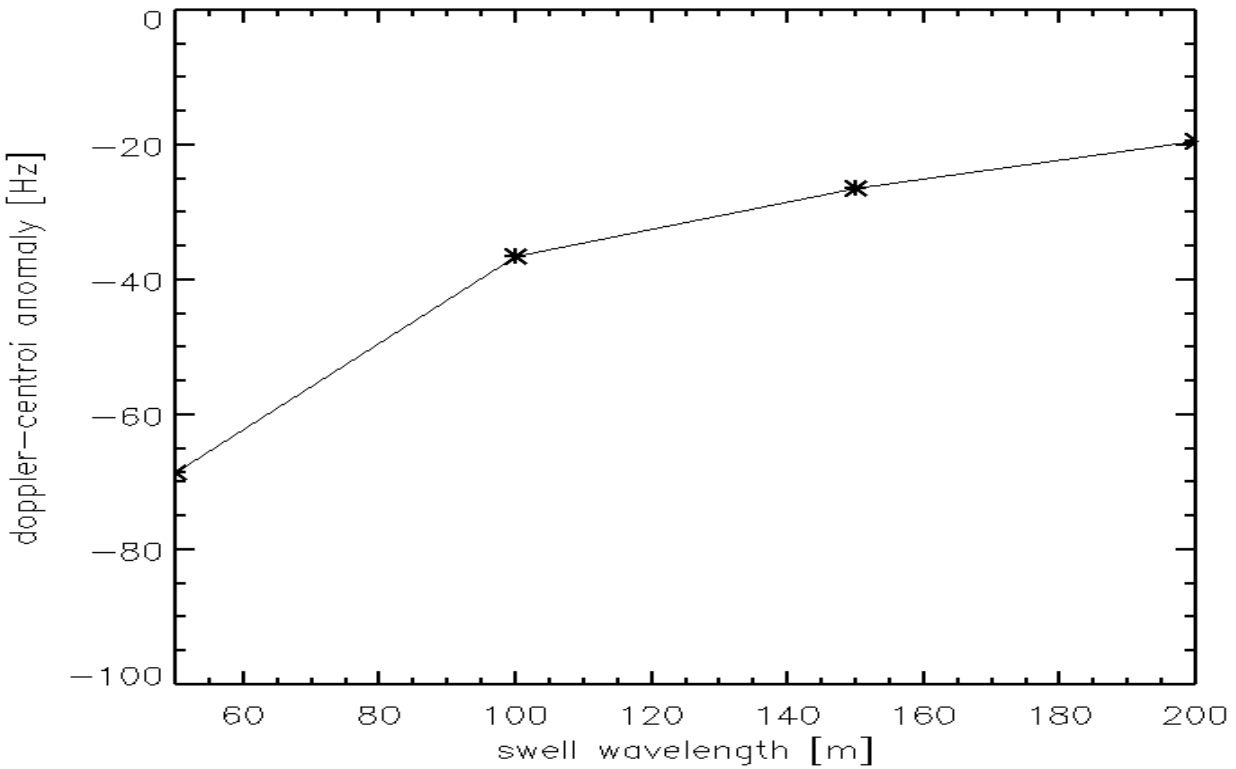
Answer yo questions Q2,Q7

- Wind speed = 5 m/s
- Wind direction = 180º (down wind)

Swell wavelength : [50, 100, 150, 200] *m*

- Swell Amp.: 2 *m*

E2E Simulations



Tests Implementation and Results

Sensitivity of distribution's tail to wind and waves

TST-SIM-05:Simulation of ocean surface with different titls

Answer yo questions Q5

- Wind speed = [5, 20] *m/s*
- Wind direction = 90º (up wind)
- Swell wavelength : [50, 200] *m*
- Swell Amp.: 2 *m*

Wind Speed 5 m/s

Swell wavelength	Mean	std	S/N (Mean^2/Var)
50 m	1.9e-5	1.2e-5	3.05
200 m	6.1e-6	3.5e-6	2.69

Wind Speed 20 m/s

Swell wavelength	Mean	std	S/N (Mean^2/Var)
50m	2.6e-5	1.6e-5	2.65
200 m	1.5e-5	1.0e-5	2.43

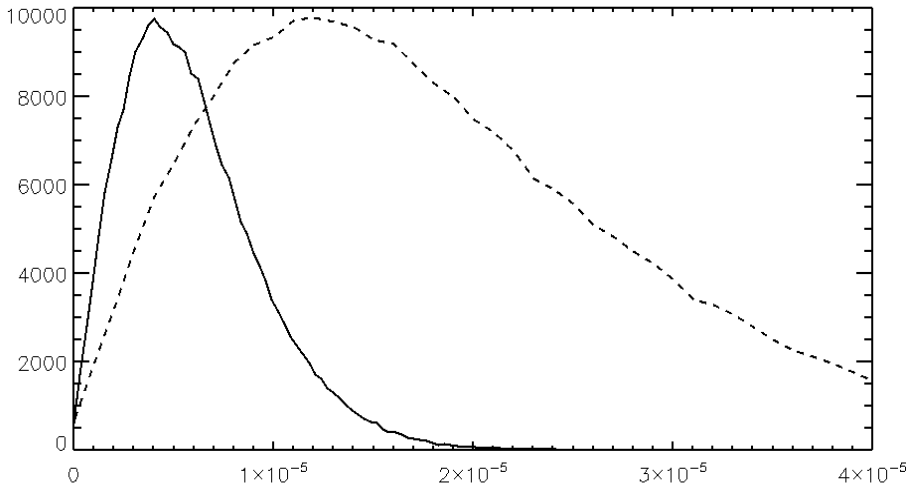
Tests Implementation and Results

Sensitivity of distribution's tail to wind and waves

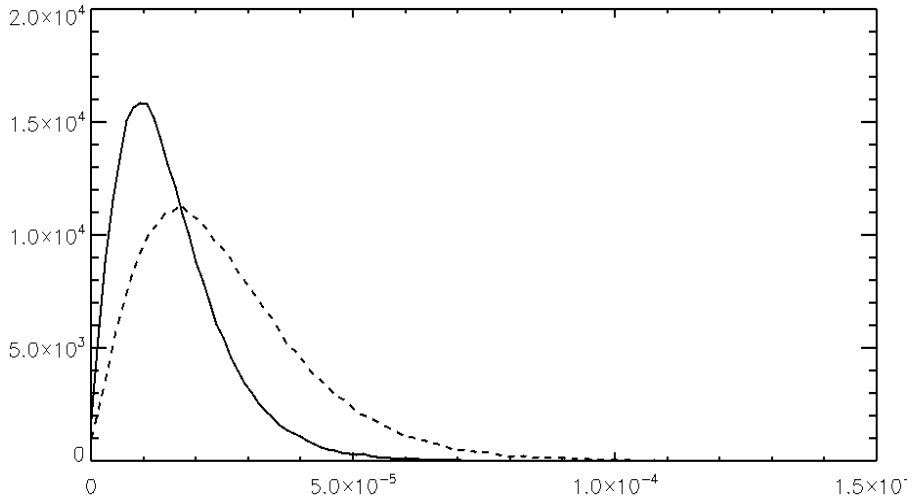
TST-SIM-05:Simulation of ocean surface with different tilts

Answer yo questions Q5

- Wind speed = [5, 20] *m/s*
- Wind direction = 90º (up wind)
- Swell wavelength : [50, 200] *m*
- Swell Amp.: 2 *m*



Wind Speed 5 m/s



Wind Speed 20 m/s

Tests Implementation and Results

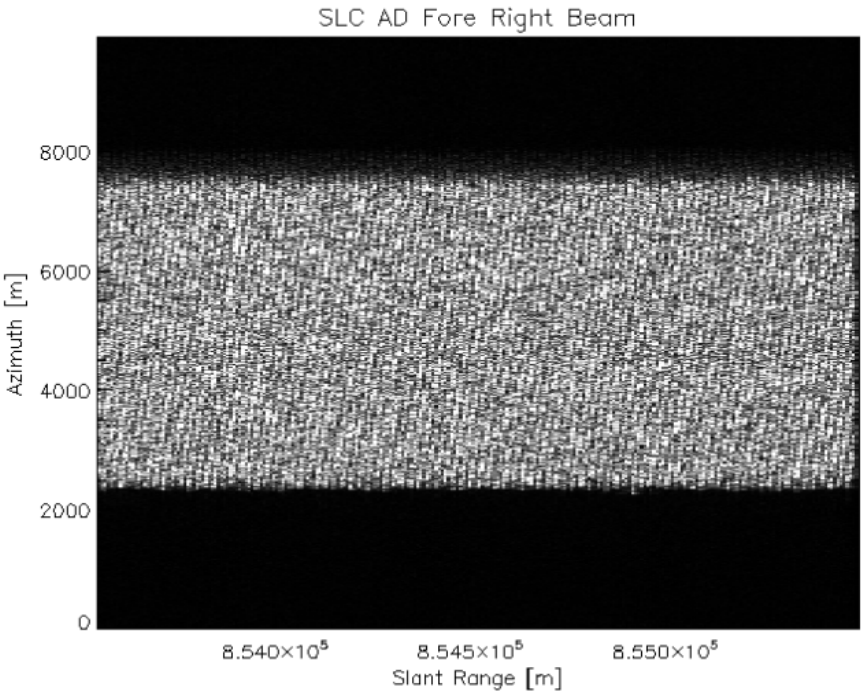
Sensitivity of distribution's tail to wind and waves

TST-SIM-05:Simulation of ocean surface with different tilts

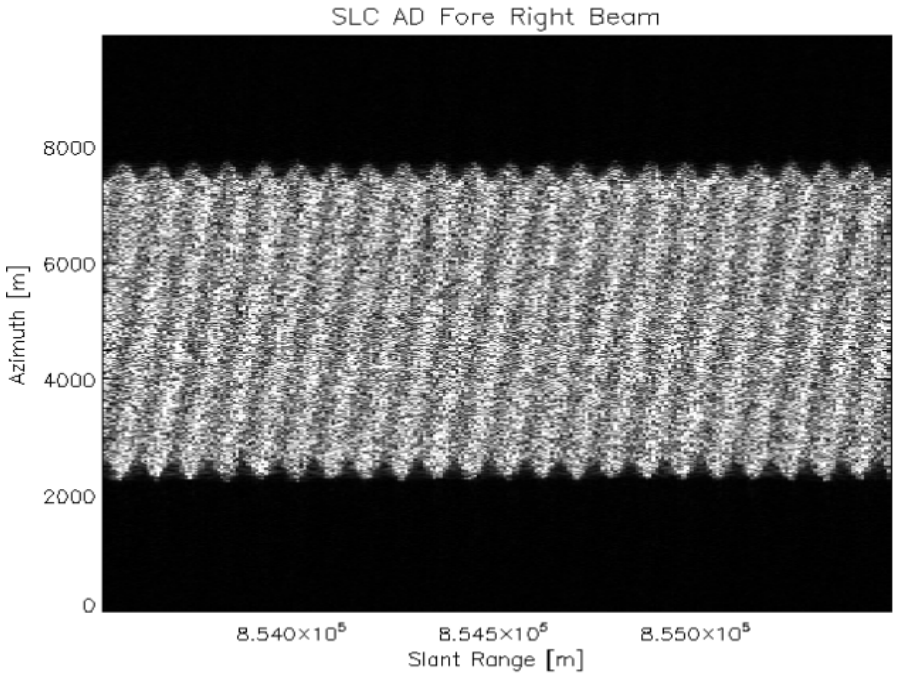
Answer yo questions Q5

- Wind speed = [5, 20] *m/s*
- Wind direction = 90º (up wind)
- Swell wavelength : [50, 200] *m*
- Swell Amp.: 2 *m*

Wind Speed 5 m/s



Swell 50 m



Swell 200 m

Tests Implementation and Results

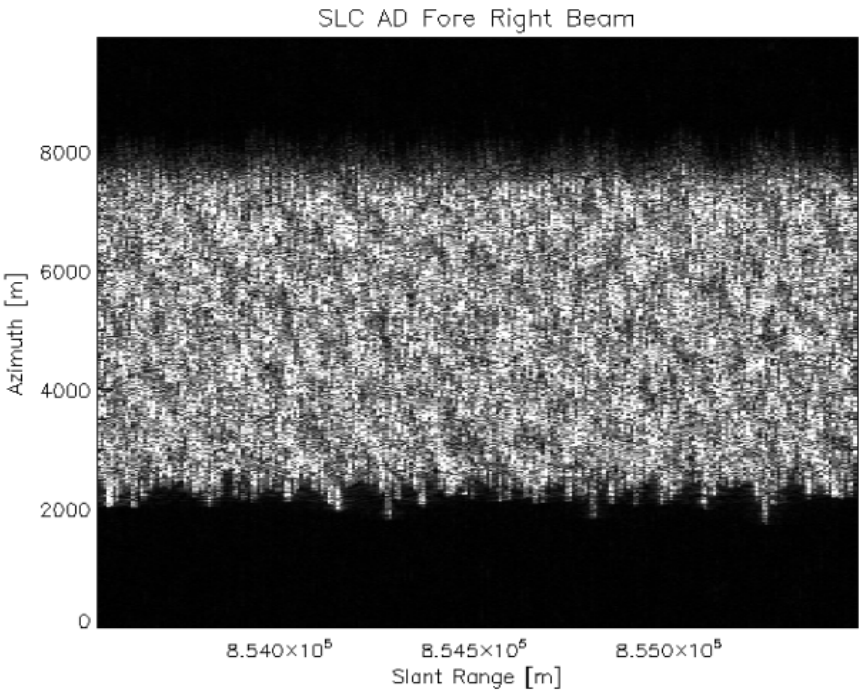
Sensitivity of distribution's tail to wind and waves

TST-SIM-05:Simulation of ocean surface with different tilts

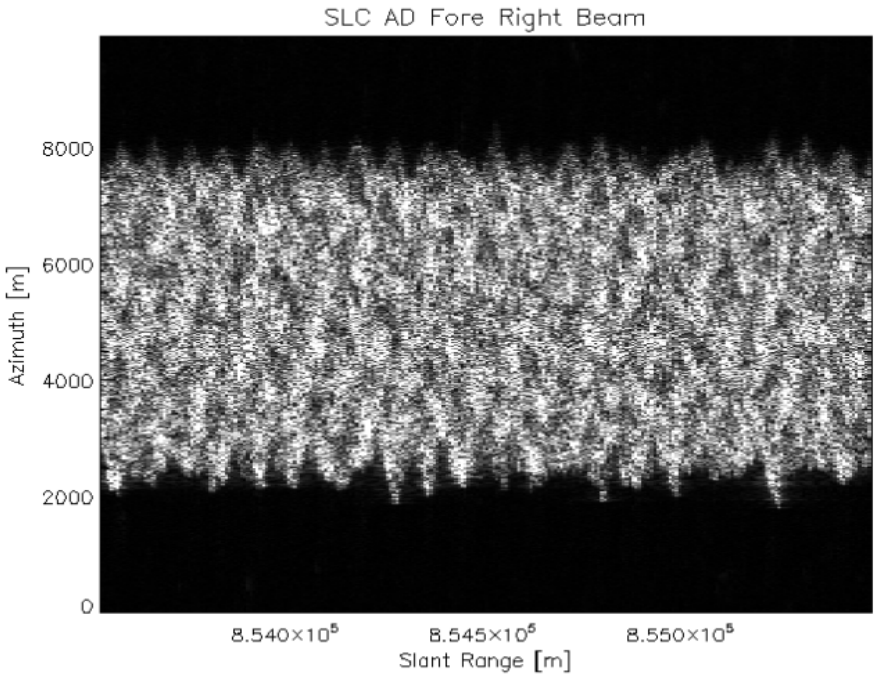
Answer yo questions Q5

- Wind speed = [5, 20] *m/s*
- Wind direction = 90º (up wind)
- Swell wavelength : [50, 200] *m*
- Swell Amp.: 2 *m*

Wind Speed 20 m/s



Swell 50 m



Swell 200 m

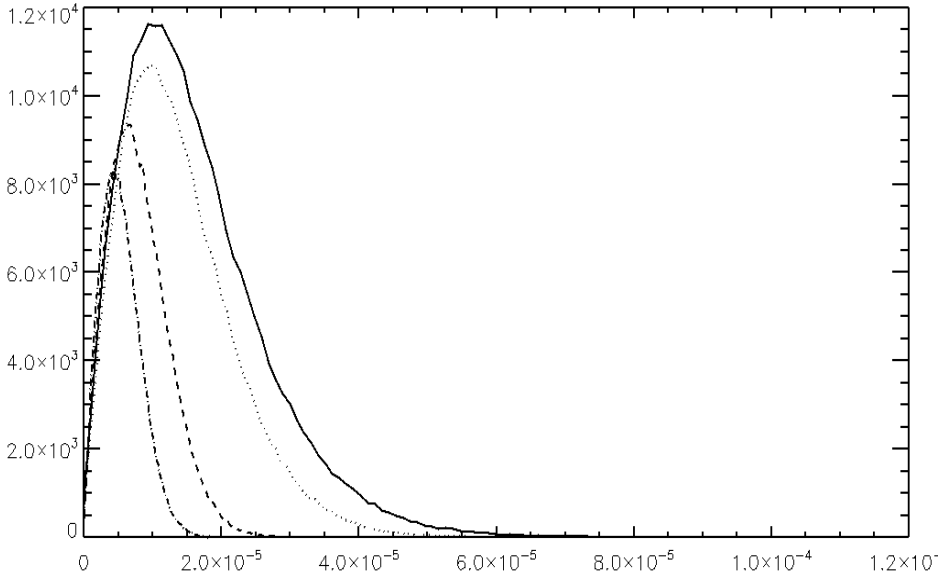
Tests Implementation and Results

Sensitivity of distribution to wind

TST-SIM-06:Simulation of ocean surface for different wind speed

Answer yo questions Q5

- Wind speed = [3, 7, 14, 20] *m/s*
- Wind direction = 90º (up wind)



Wind speed	Mean	std	S/N (Mean^2/Var)
3 m/s	5.54e-6	2.9e-6	3.63
7 m/s	8.24e-6	4.42e-6	3.47
14 m/s	1.41e-5	8.22e-6	2.97
20 m/s	1.66e-5	1.03e-5	2.61

Tests Implementation and Results

Hydrodynamic modulation

TST-SIM-07:Simulation of waves profiles

Answer yo questions Q6

NRCS = NRCS_0*(1+x*h)

- First we decompose the elevation (h) into harmonic modes:

- Then x*h is generalized as follows:

$$x * h = \int x(k) h(k)^{ik(x-\omega t)+} \, dk$$

with

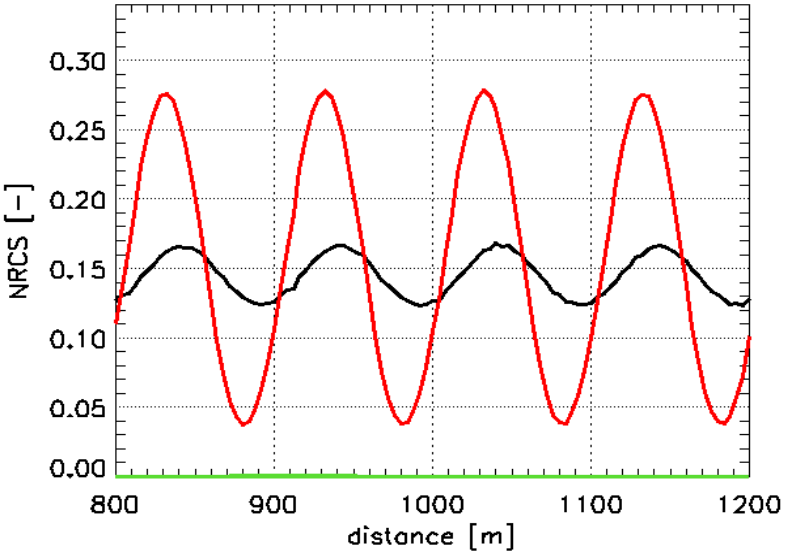
→ X_0 = const. and For *K* around the peak wavelength

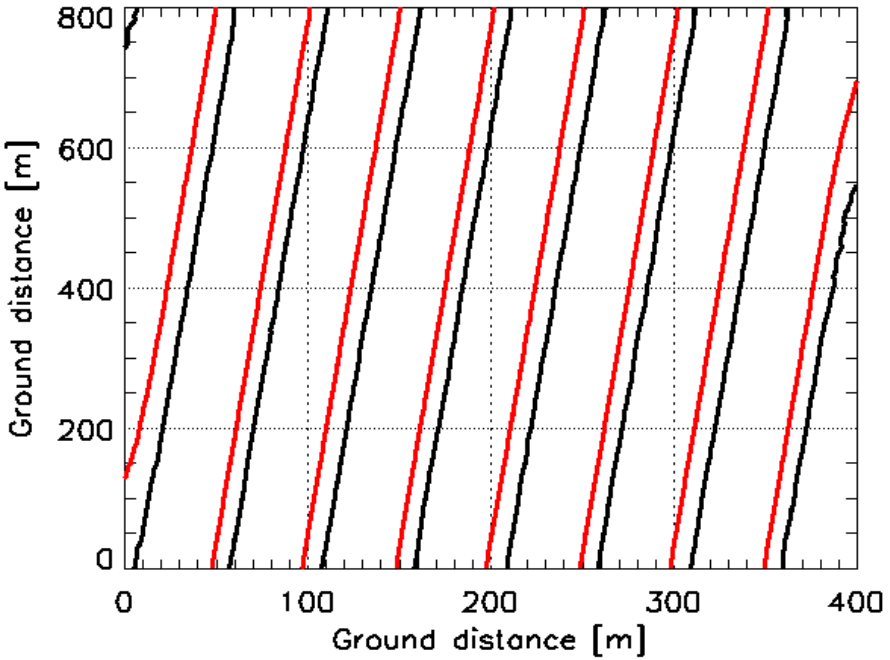
Tests Implementation and Results

Hydrodynamic modulation

TST-SIM-07:Simulation of waves profiles

Answer yo questions Q6





Azimuth cut-off

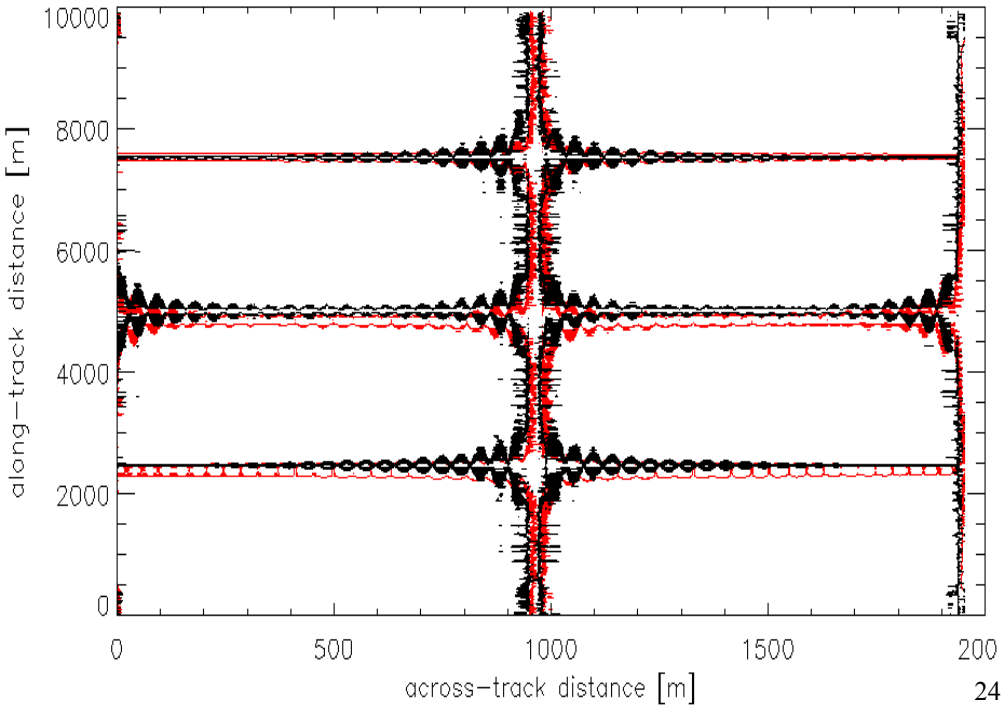
Input parameters:

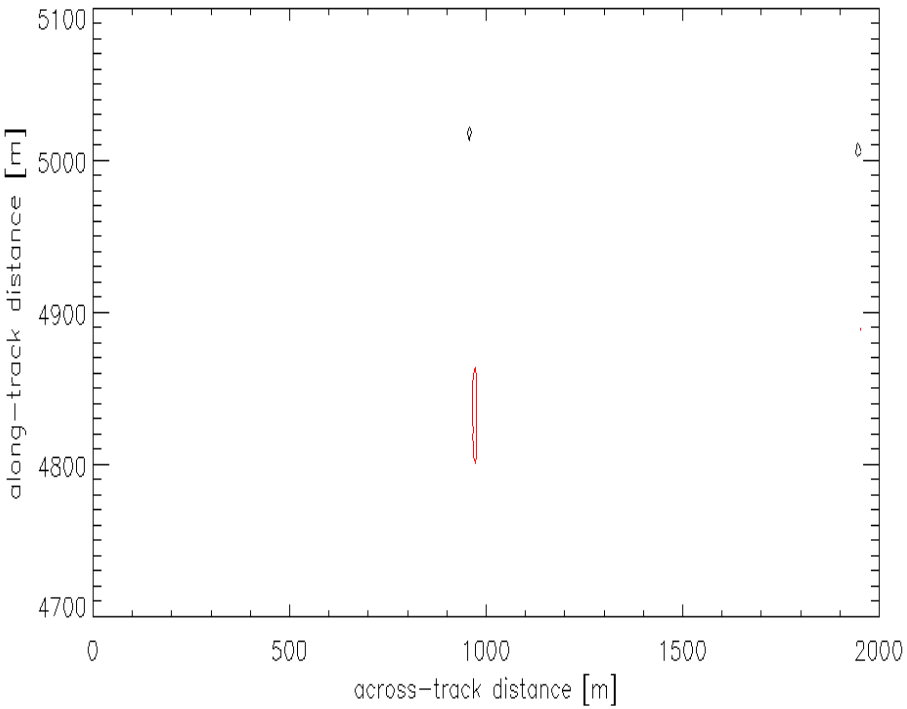
- Wind speed 14 m/s
- Wind direction 90º

STD Line of sight orbital velocity = 1.04 m/s

Assuming an R/V = 120 s

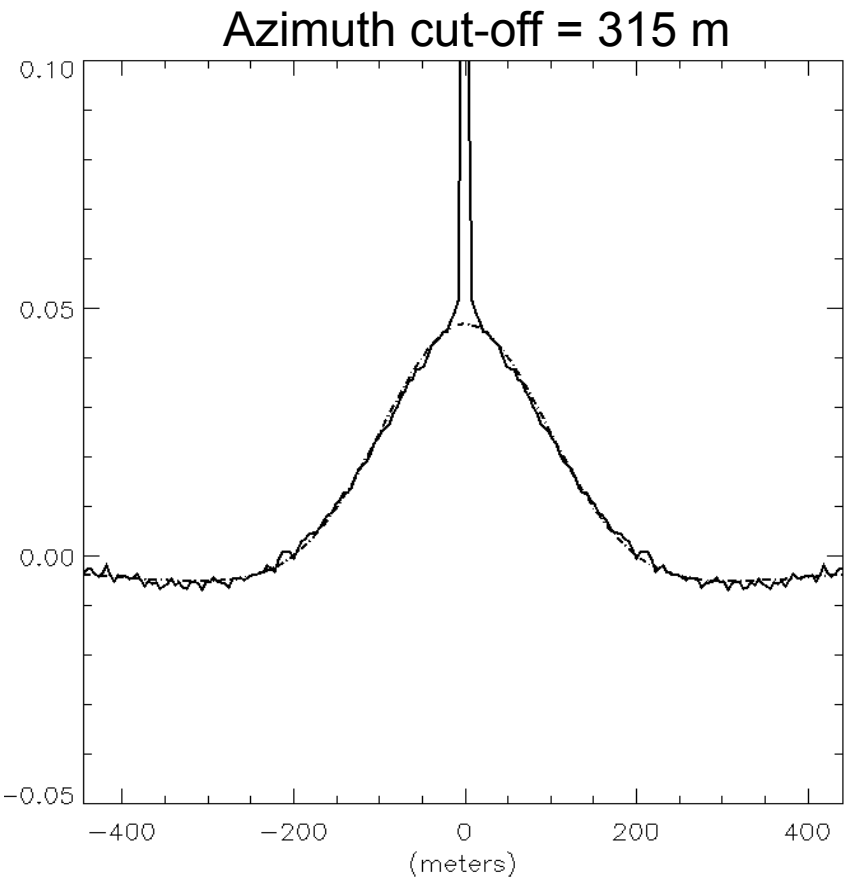
Average shift = 124 m

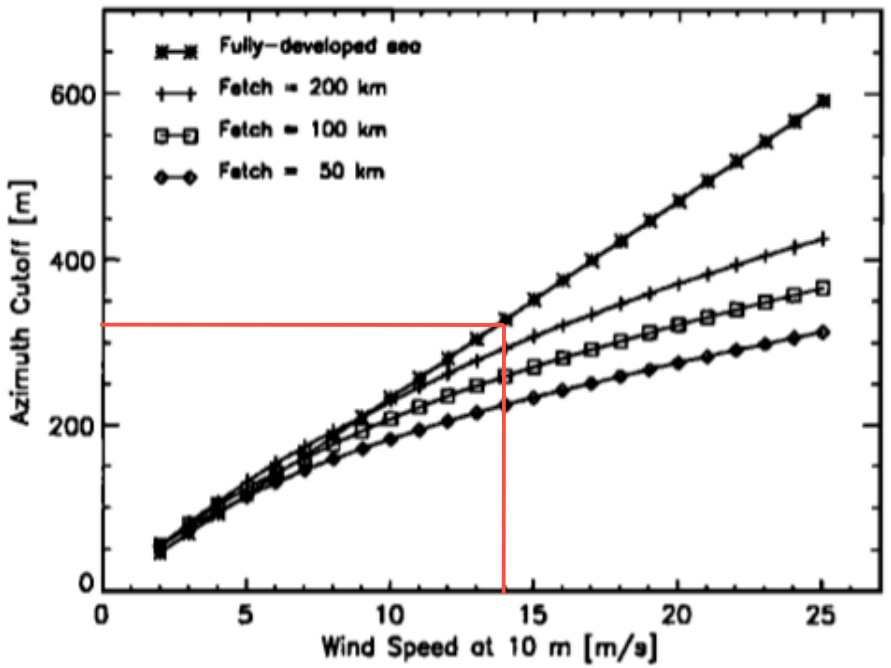




Azimuth cut-off

SLC autocorrelation function





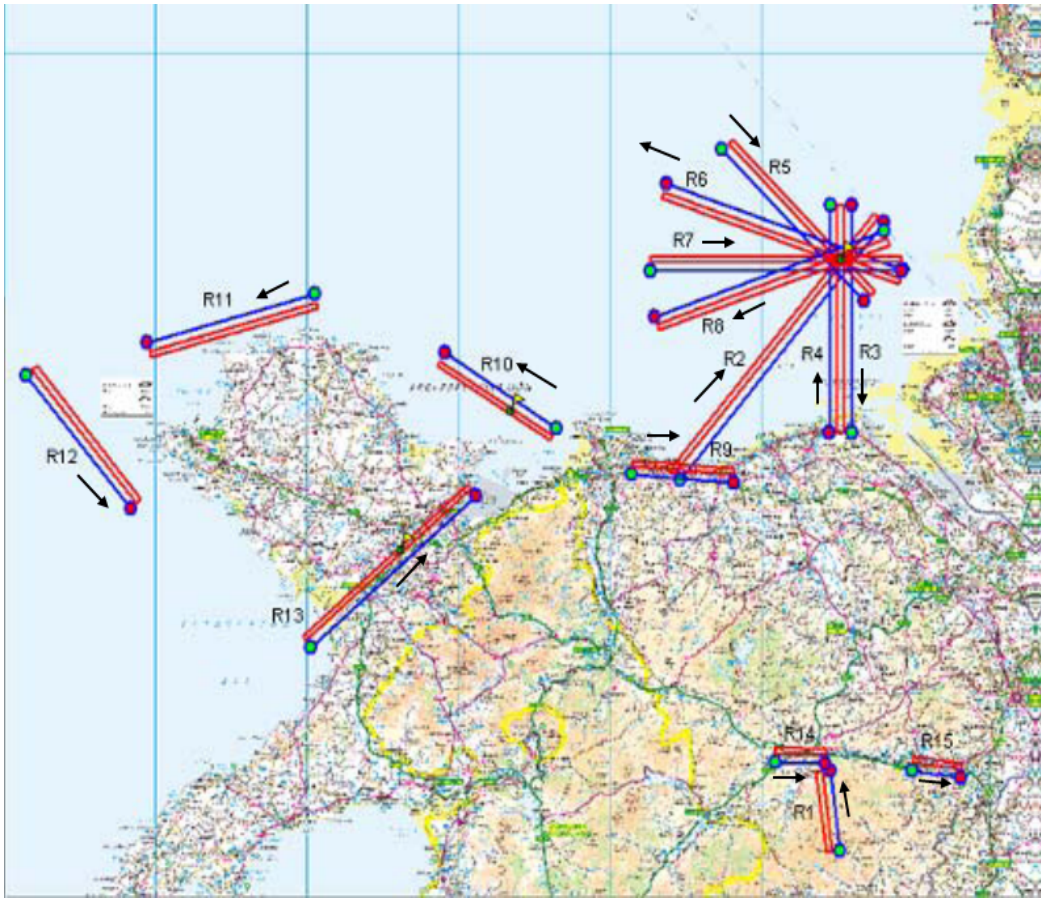
(After Kerbaol et Chapron, JGR, 1998)

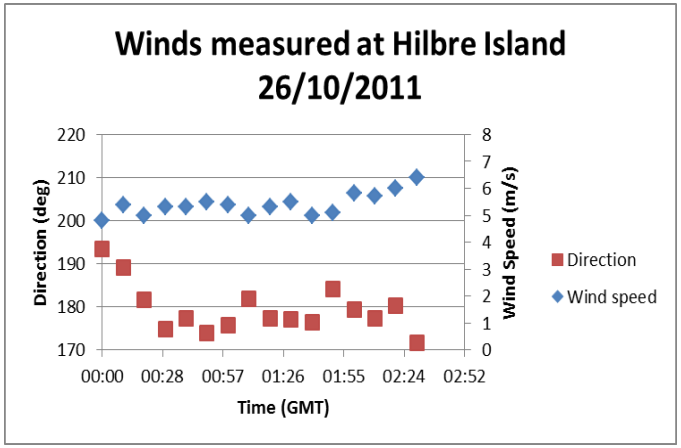
Outline

- Validation Models Definition.
- Tests implementation and results.
- **PCC scenario simulation.**
- Conclusions.

PCC scenario

- **Trials sites:**
  - **Liverpool Bay**
  - **Anglesey**
- **Flights done on Oct. 26 (R), 27(M) 2011**





Run	Speed (m s^{-1})	Direction
	ADCP	ADCP
R2	0.69	269.5
R3	0.68	267.5
R4	0.70	267.4
R5	0.72	273.2
R6	0.72	273.2
R7	0.75	275.5
R8	0.77	274.3
Average	***0.72***	***271.6***

PCC scenario Simulation

Aircraft configuration settings

Parameter	Value
PRF	700.0 [Hz]
TX_BANDWIDTH	1.3000000e+08 [Hz]
PULSE_DURATION	1.20000e-06 [ms]
CARRIER_FREQ	9.9999999e+09 [Hz]
SAMPLING_FREQUENCY	1.4950000e+08 [Hz]
RANGE RESOLUTION	1.1530479 [m]
AZIMUTH RESOLUTION	0.5 [m]
AZIMUTH ANGLE	45.0º
NOMINAL_ALTITUDE	3000.0 [m]
NOMINAL_VELOCITY	250 [m/s]
INCIDENCE ANGLE	25º

PCC scenario Simulation

Ocean Conditions Simulation Settings

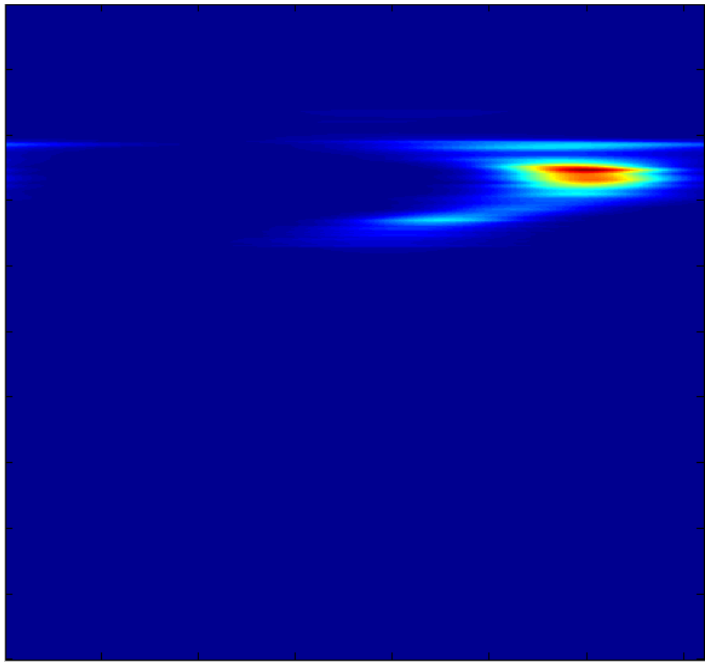
Parameter	Value
Wind speed	5 [m/s]
Wind direction	180 [deg]
Currents speed	0.7 [m/s]
Currents direction	270 [deg]

- **Wind speed and direction have been used to simulate NRCS**
- **Ocean Surface has been simulated using the spectrum provided by NOC.**

PCC scenario Simulation

NOC Sea Spectrum

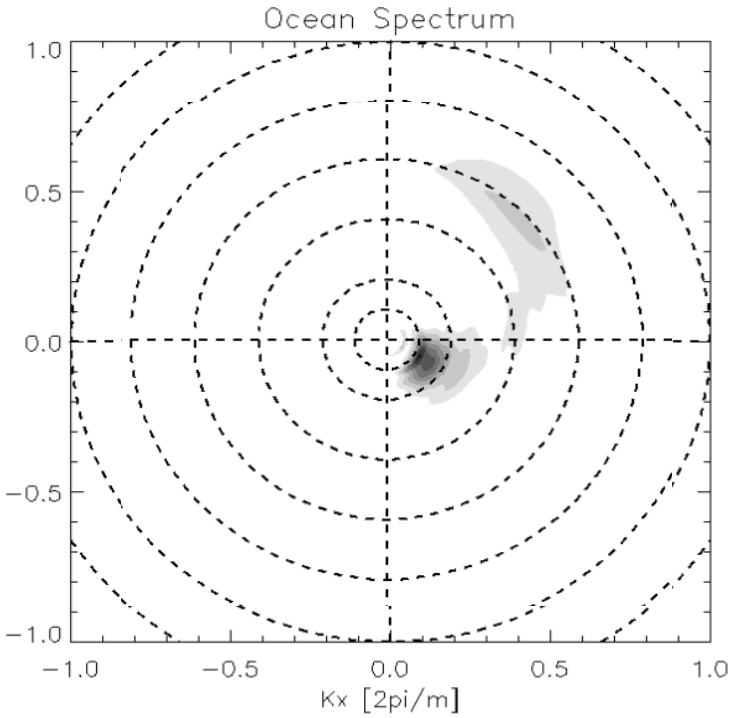
Wave spectrum at the buoy + Kudryatsev fit for small waves (wave spectral density (m2). Circular coordinates with K in log scale)



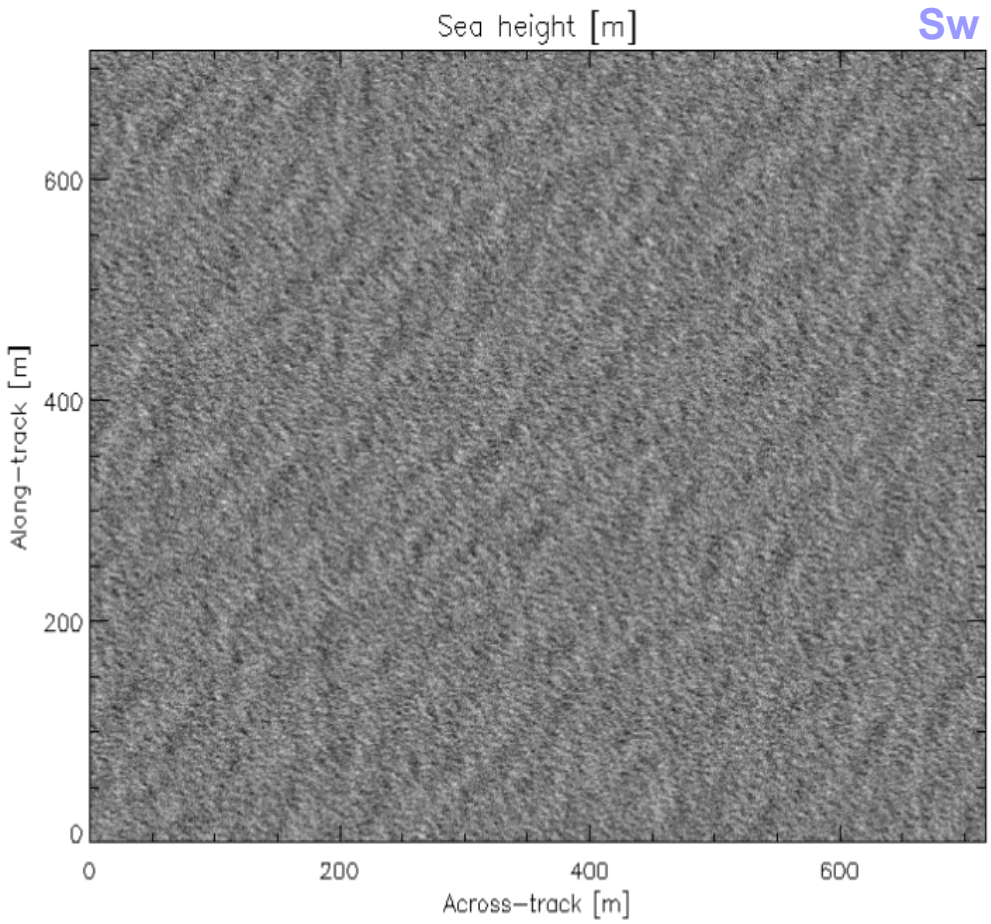
K

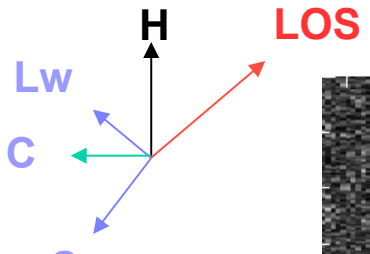
Direction

Interpolation to a regular linear grid

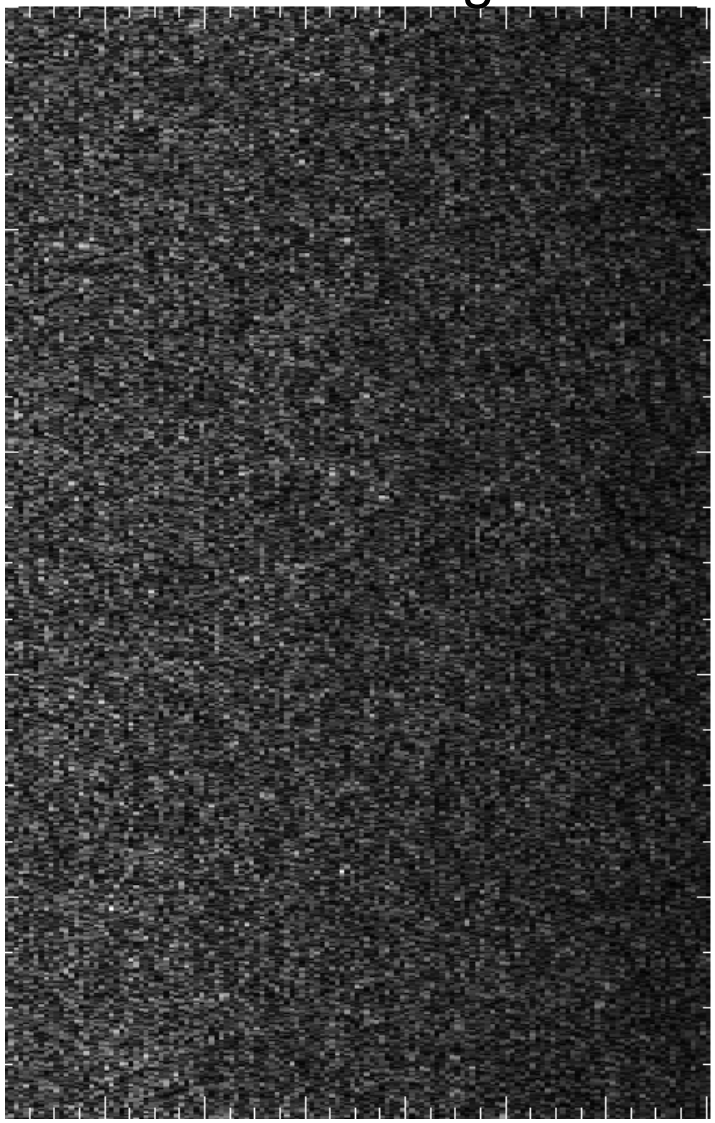


PCC scenario Simulation





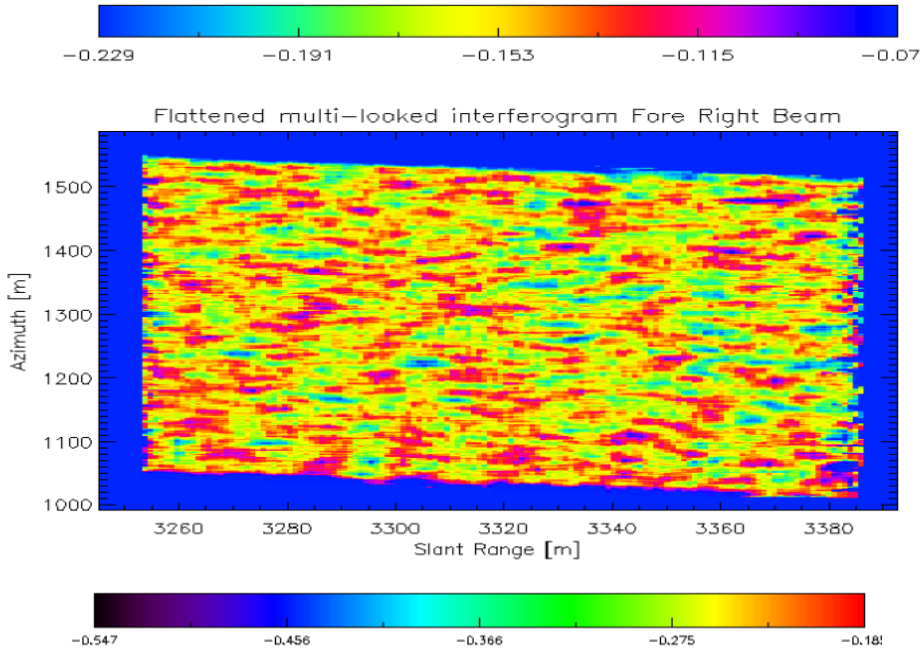
SLC fore-right

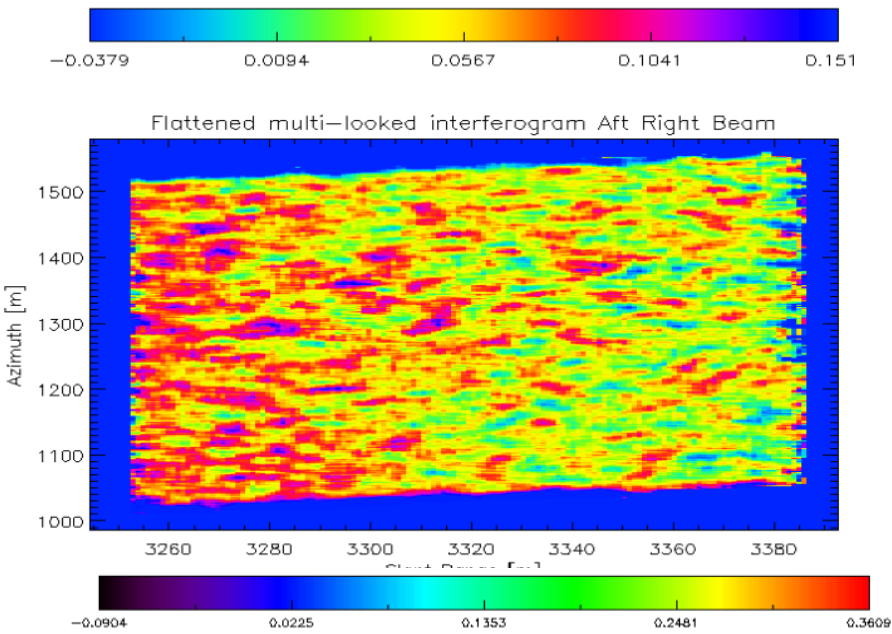


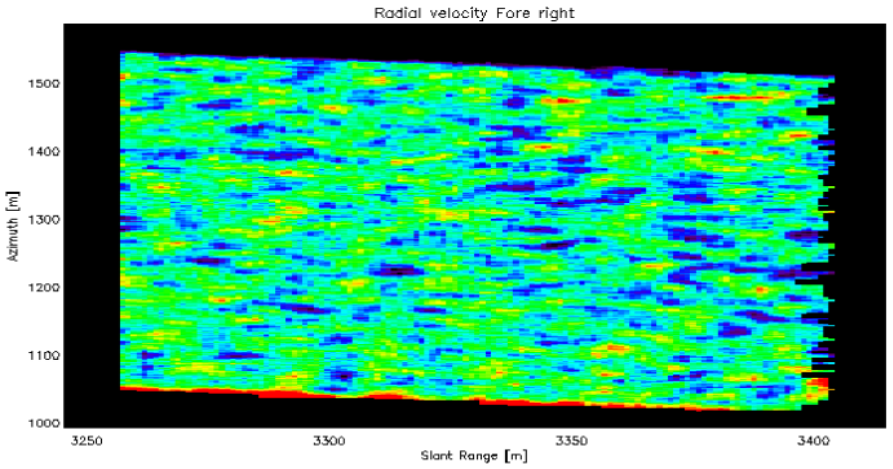
Azimuth

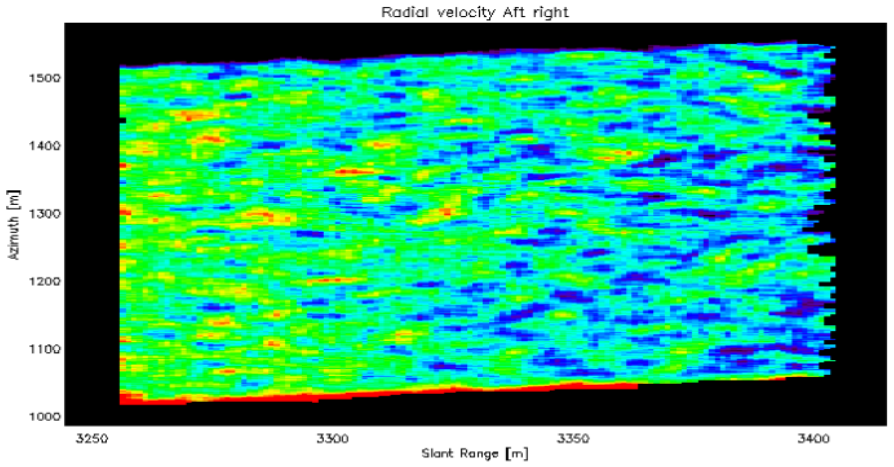
Range

PCC scenario Simulation





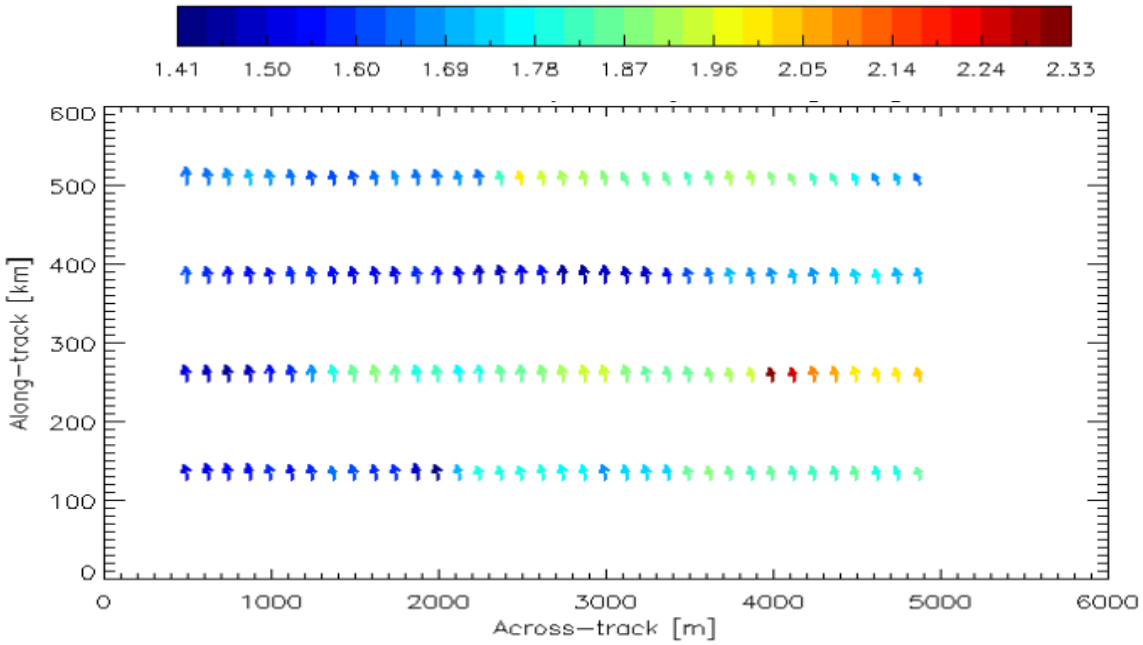




Dual Beam Interferometry

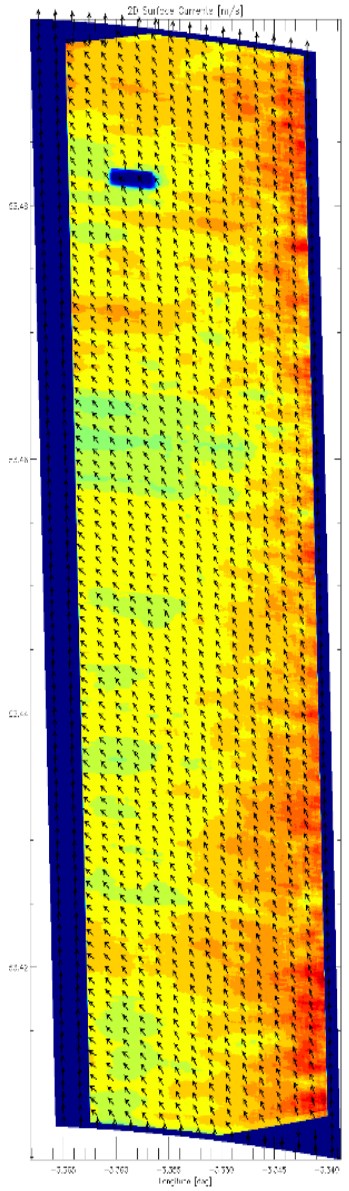
Proof of Concept Campaign

Simulated Data



	Mean Dir.	Mean Vel.
Real Data	326	1.12
Simulated Data	318	1.7

Real Data

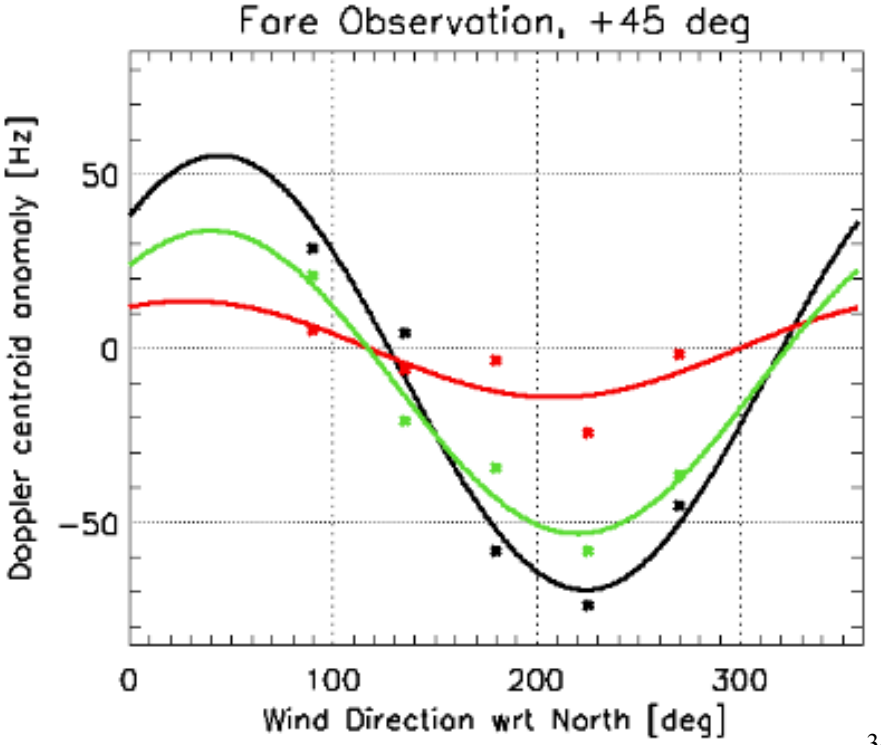


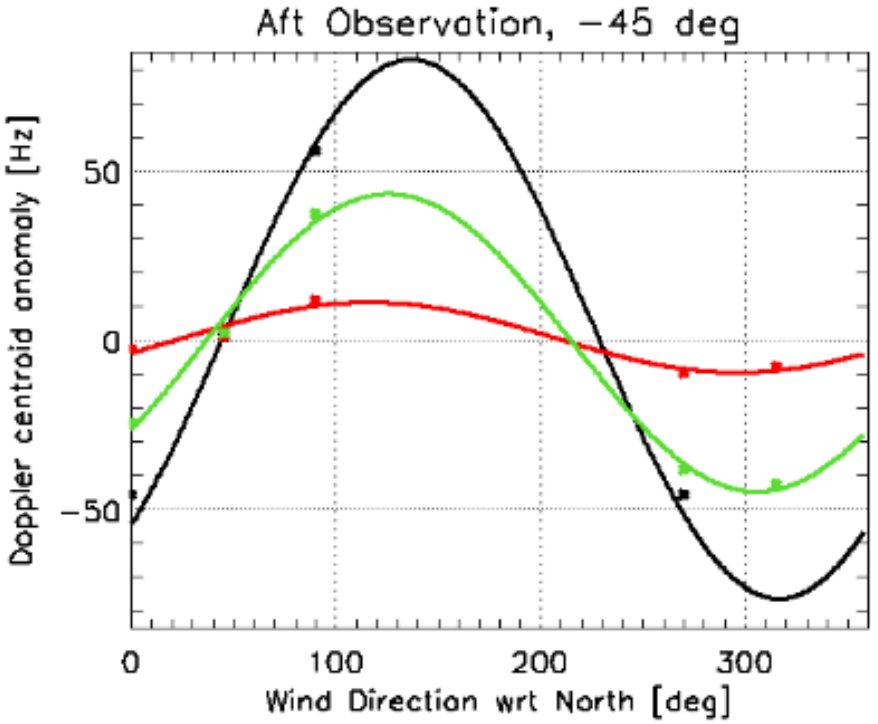
Induced Doppler anomaly for Wavemill

The results represent a Wavemill space-borne scenario:

- Only wind included waves for U10 = [3, 7, 14] m/s
- Incidence angle = 20°
- Azimuth angle = 45°
- Centre frequency = 13.3 GHz
- Doppler estimates computed from generated raw data

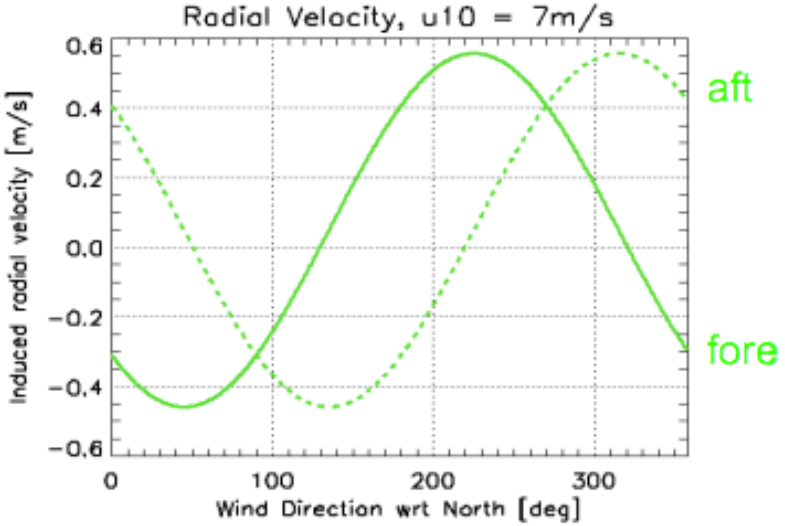
3 m/s
7 m/s
14 m/s

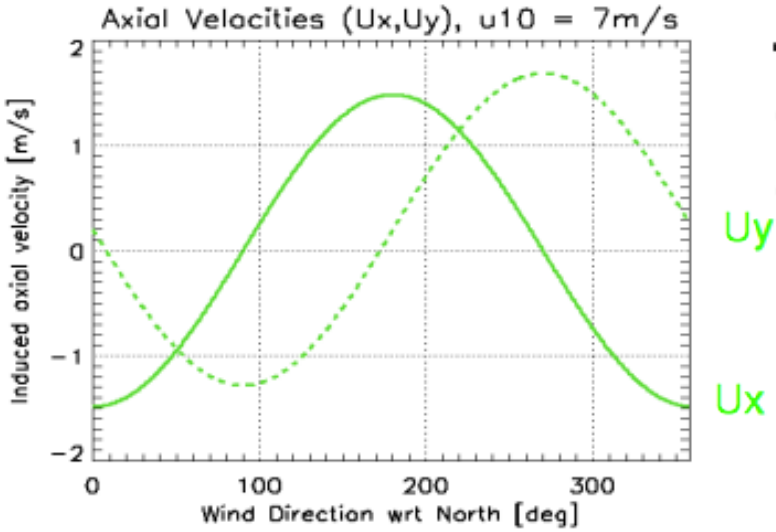


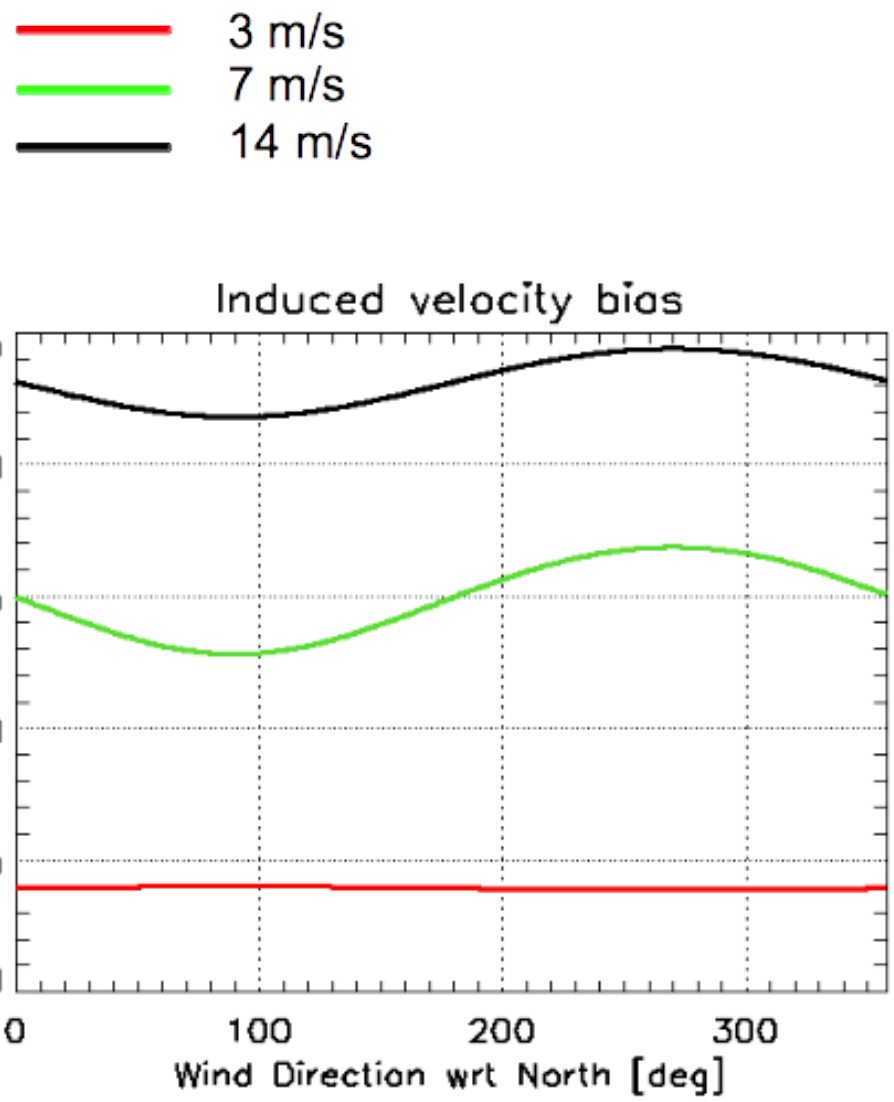


Error budget for wind induced waves

- For an average sea state, u10 = 7m/s, the induced waves will produce a bias of ~1.5m/s in the velocity budget (incidence angle 20º, azimuth 45º).







Outline

- Validation Models Definition.
- Tests implementation and results.
- PCC scenario simulation.
- **Conclusions.**

Conclusion

●Relevant features linked to SAR ocean surface imaging have been validated using several simulations.

- **Doppler Bias**

●**Sensitivity of distribution's tail to wind and waves**

●**Hydrodynamic modulation**
Only if swell and wind are aligned

●**Azimuth Cutoff**

●The test have been compared to literature results, when possible, showing agreement.

●Results show that the software is correctly simulating the Wavemill primary products

●Simulation of a PCC scenario gives results with same order of magnitude.

●A preliminary geophysical error budget has been estimated for wind induced waves.

Thanks for Your Attention