Improved SAR-mode ocean retrievals from new Cryosat-2 processing schemes

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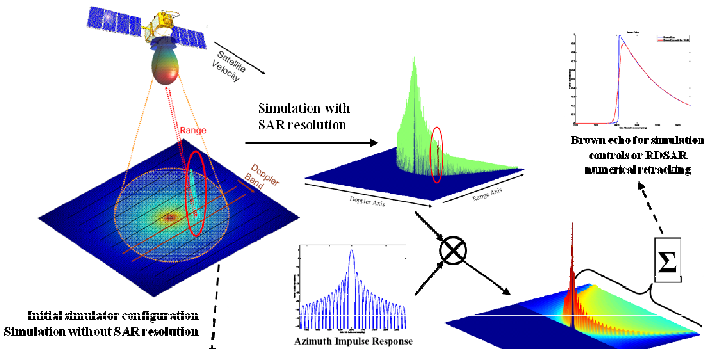
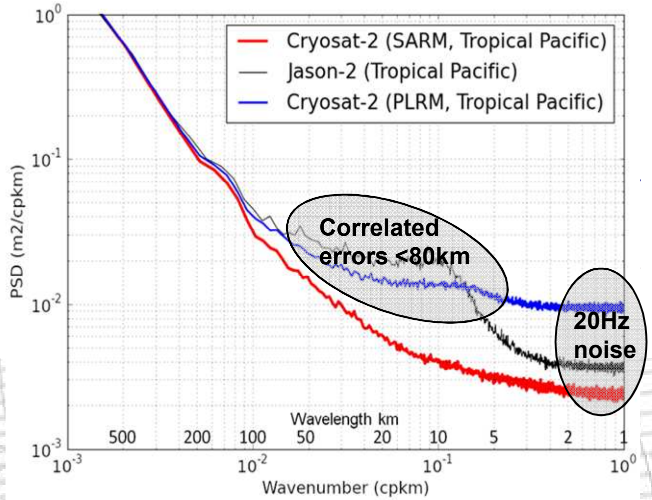
CONTEXT

- CNES/CLS have undertaken several studies aiming at developing **alternative SARM processing** schemes that would enable **to take maximum advantage of SAR mode capabilities** over ocean

  ➔ in preparation for S-3, S-6 and other SARM missions

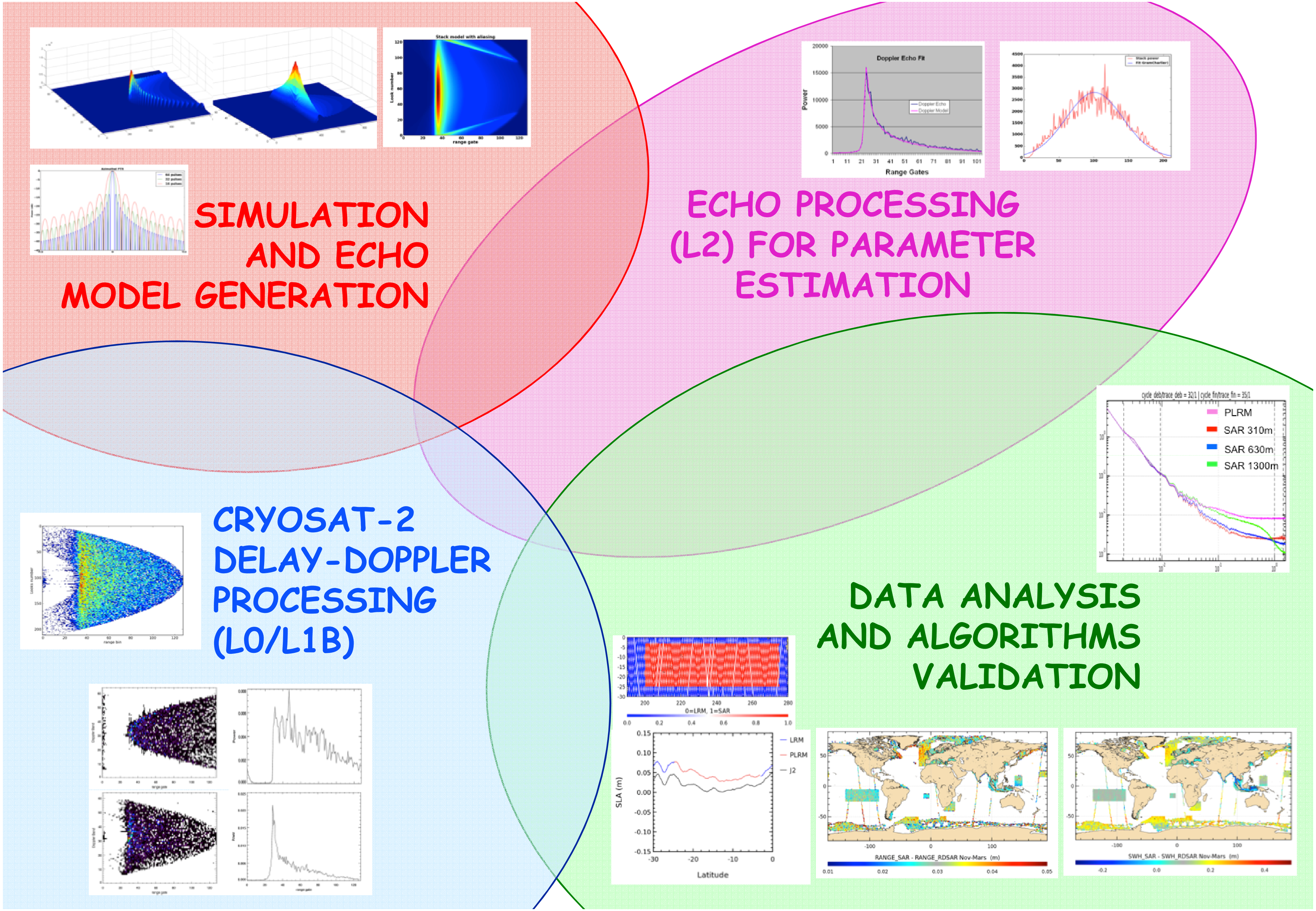
- To perform these studies, we take benefits of the availability of Cryosat-2 data and the existing tools:
  - the easy-to-use and versatile **L0 to L2 SAR CNES Cryosat-2 processor** (CPP),
  - the **SAR altimeter simulator** to generate SAR echo models that mimic the altimeter response of any configurations (without the need to modify any analytical model formulation and with no approximations)



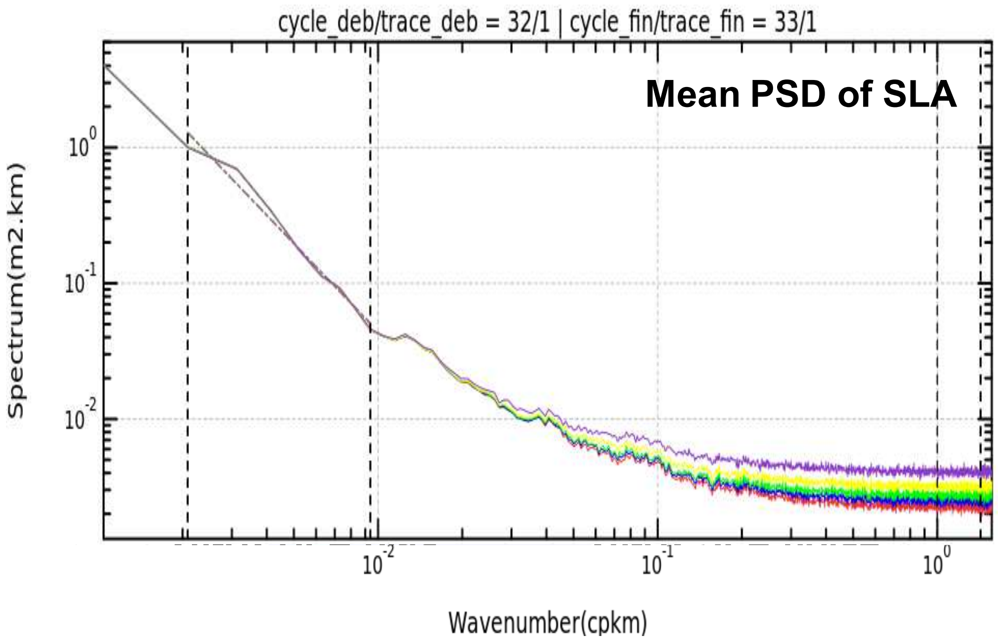


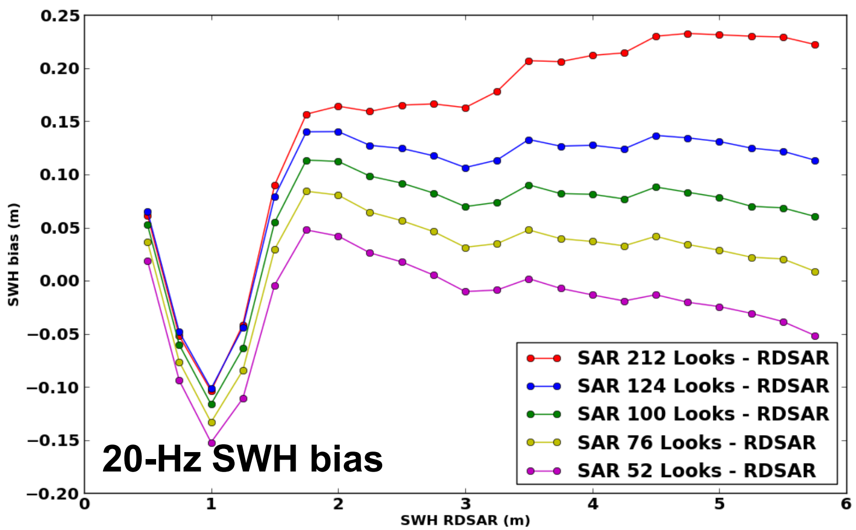
Objectives :

- To improve the noise reduction performance
- To ensure data quality continuity with LRM while not degrading small-scales signal (<100km)

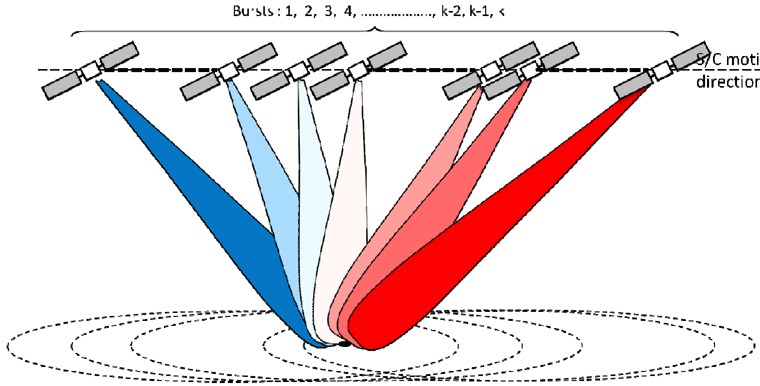

SIMULATION AND ECHO MODEL GENERATION
ECHO PROCESSING (L2) FOR PARAMETER ESTIMATION
CRYOSAT-2 DELAY-DOPPLER PROCESSING (L0/L1B)
DATA ANALYSIS AND ALGORITHMS VALIDATION
Doppler Echo Fit
Range Gates
Power
PLRM
SAR 310m
SAR 630m
SAR 1300m
0=LRM, 1=SAR
SLA (m)
Latitude
LRM
PLRM
J2
RANGE_SAR - RANGE_RDSAR Nov-Mars (m)
SWH_SAR - SWH_RDSAR Nov-Mars (m)

RETRIEVAL OF SAR OCEAN PARAMETERS





- SAR-mode measurements consist of:



- Averaging of co-localised Doppler beams (looks) in the stack
  - ➔ **SAR power echo (multilooked)**
- Averaged waveform retracking
  - ➔ **Model fitted with waveform**
  - ➔ **Range, swh and sigma0 estimation**

- No-degraded performances with 100 looks (even lower if no-mispointing)
  - ➢ Similar 20-Hz noise levels
  - ➢ No SLA bias and reduced SWH bias with PLRM
  - ➢ Same oceanic signal content (from spectra analysis)

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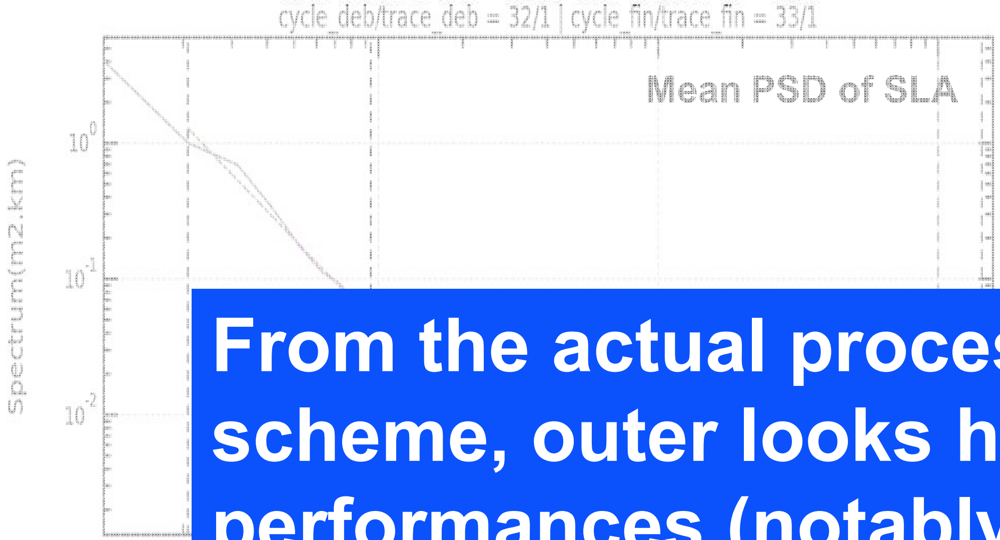

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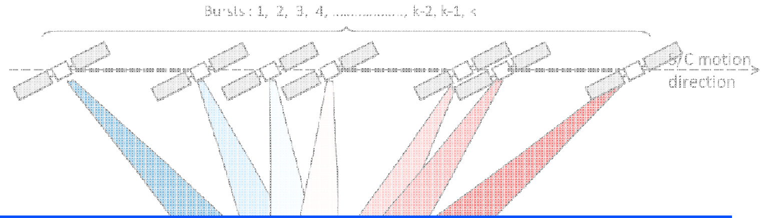

beams

l)

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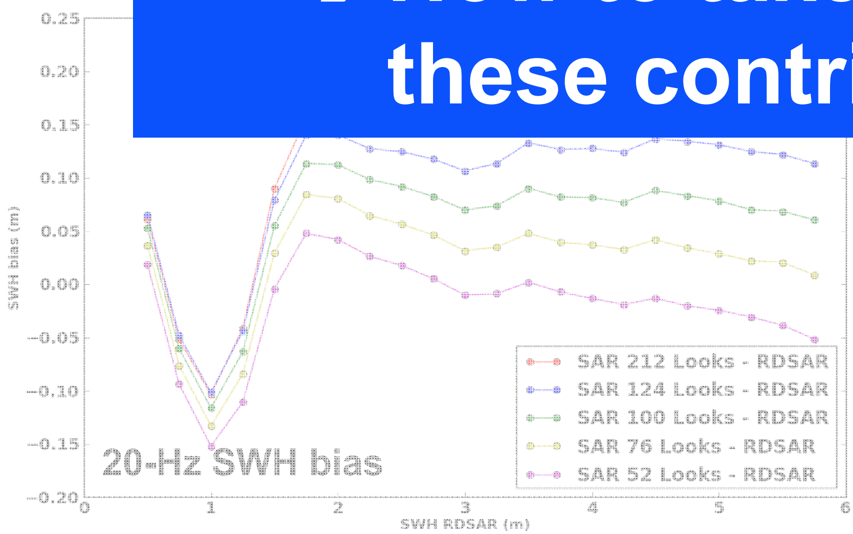
From the actual processing/retracking scheme, outer looks have no impact on SAR performances (notably range)

➔How to take advantage from these contributions ?



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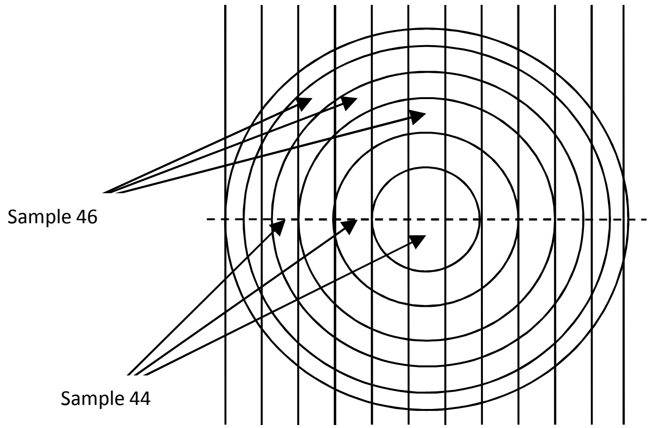
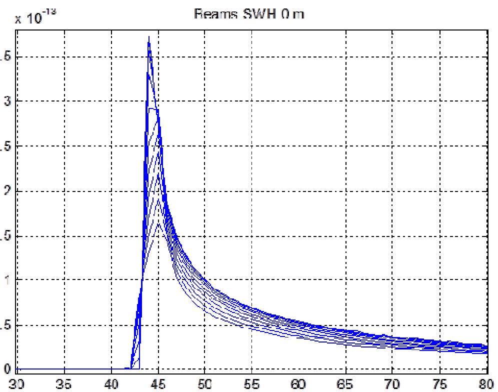
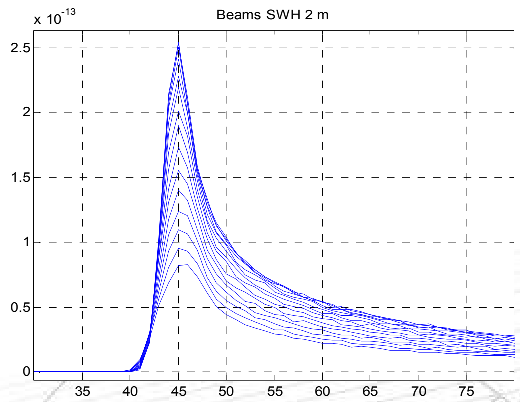
THEORETICAL STUDY OF SARM SPECKLE NOISE

L.Amarouche, SAR Altimetry Expert Group Meeting, Southampton, June 2013

- High inhomogeneity between Doppler beams in a stack
  - Along-track variation in amplitude from beam to beam due to antenna gain
  - Different mean shapes in range due to inaccurate migration corrections







- Expected speckle noise reduction:
- √N in conventional altimetry since individual echoes are quite similar in amplitude α_i=0 and incoherently cumulated

$$\frac{a}{\sqrt{v}} = \frac{\sqrt{N}}{\sqrt{1+\frac{1}{N}\sum_{i=1}^{N}\left(\frac{\alpha_i}{a}\right)^2}}$$

Number of looks

mean power variations within the stacked beams

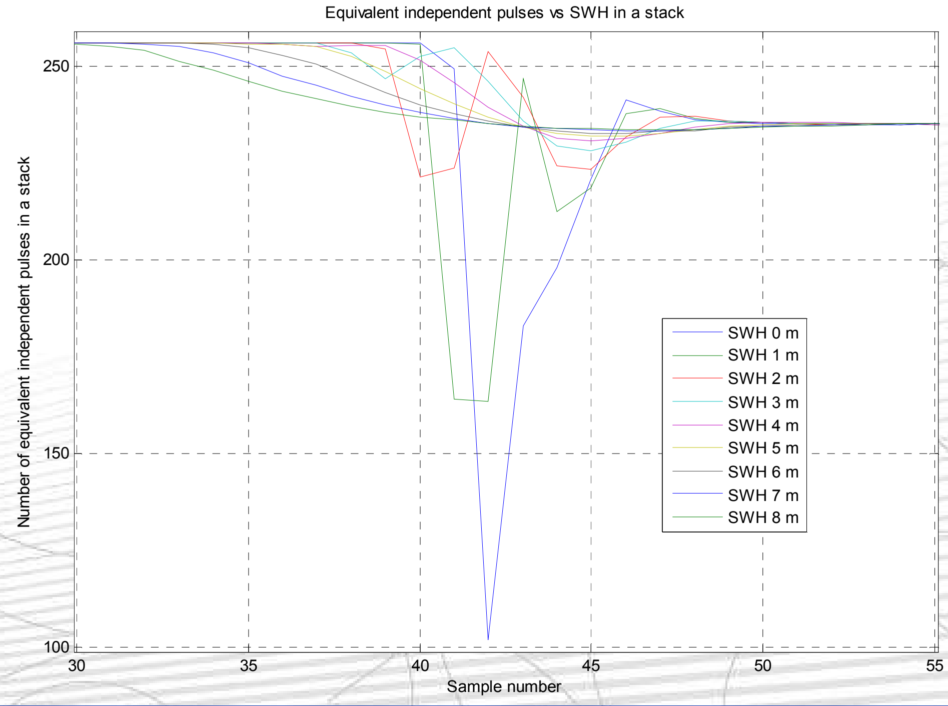
Effective number of looks is lower than the number of beams

NEW SARM PROCESSING METHOD

L.Amarouche, SAR Altimetry Expert Group Meeting, Southampton, June 2013

- Number of effective Doppler beams
  - High speckle reduction for samples whose beam-to-beam discrepancies are low
  - Low speckle reduction for large variation of echo amplitude
  - Lowest values in the leading edge for low swh

    ➔ **increased noise level while retracking Doppler echoes at low wave height**



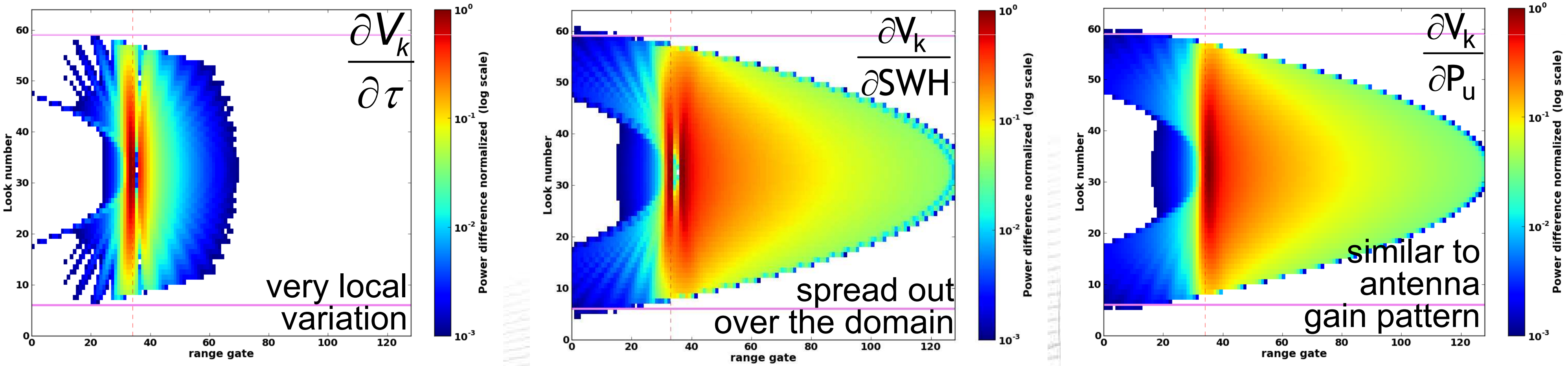
OPTIMISED SAR OCEAN NUMERICAL RETRACKING

- **CPP retrieval algorithm** (MLE3) is based on a **Newton-Raphson iterative least squares method** which uses partial numerical derivatives of the multilooked model to solve the system (as for Levenberg-Marquardt method)

$$\theta_n = \theta_{n-1} - g(BB^T)^{-1}_{\theta_{n-1}} (BD)_{\theta_{n-1}}$$

θ_n ocean parameters vector
B derivatives matrix
D residuals matrix

- Un-weighted least-square estimator gives more importance to samples of high amplitude (given by antenna gain) and constrains the echo model to fit mostly with those samples (from the centered Doppler beams)



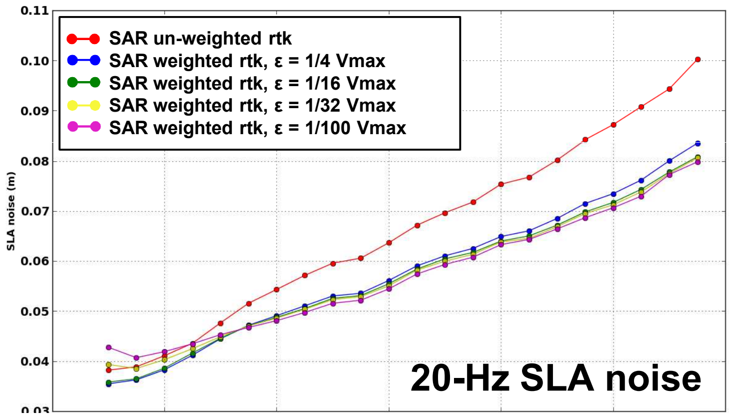
- More weight has to be assigned to low power samples of the waveform to constrain the model to fit those portions that originate from outer beams (toe)

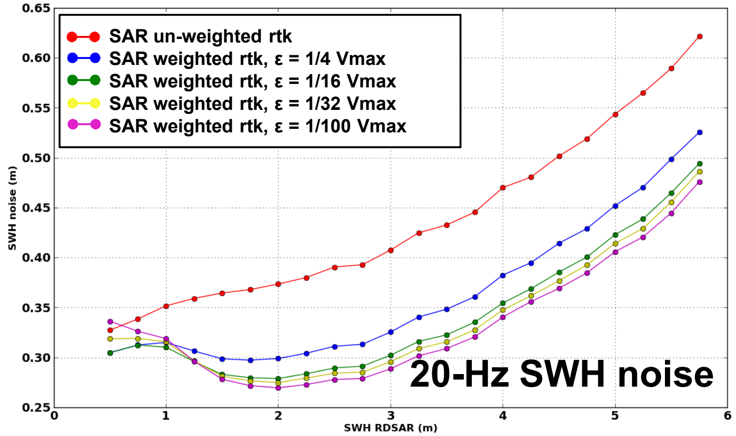
OPTIMISED SAR OCEAN NUMERICAL RETRACKING

- A weighted MLE3 retracking (aka **Maximum-likehood estimator algorithm**) gives more importance to portions of the waveform with low power

$$B_{mk} = \frac{1}{P_u}\frac{\partial V_k}{\partial \theta_m} \qquad D_k = \frac{V_k - \tilde{V}_k}{P_u} \quad \Rightarrow \quad B_{mk} = \frac{1}{V_k + \varepsilon}\frac{\partial V_k}{\partial \theta_m} \qquad D_k = \frac{V_k - \tilde{V}_k}{V_k + \varepsilon}$$

V_k echo model in power
$\bar{V}_k$ measured waveform
ε positive constant to prevent instabilities and numerical convergence issues
k samples from 0 to 127
m parameters (τ, swh, P_u)



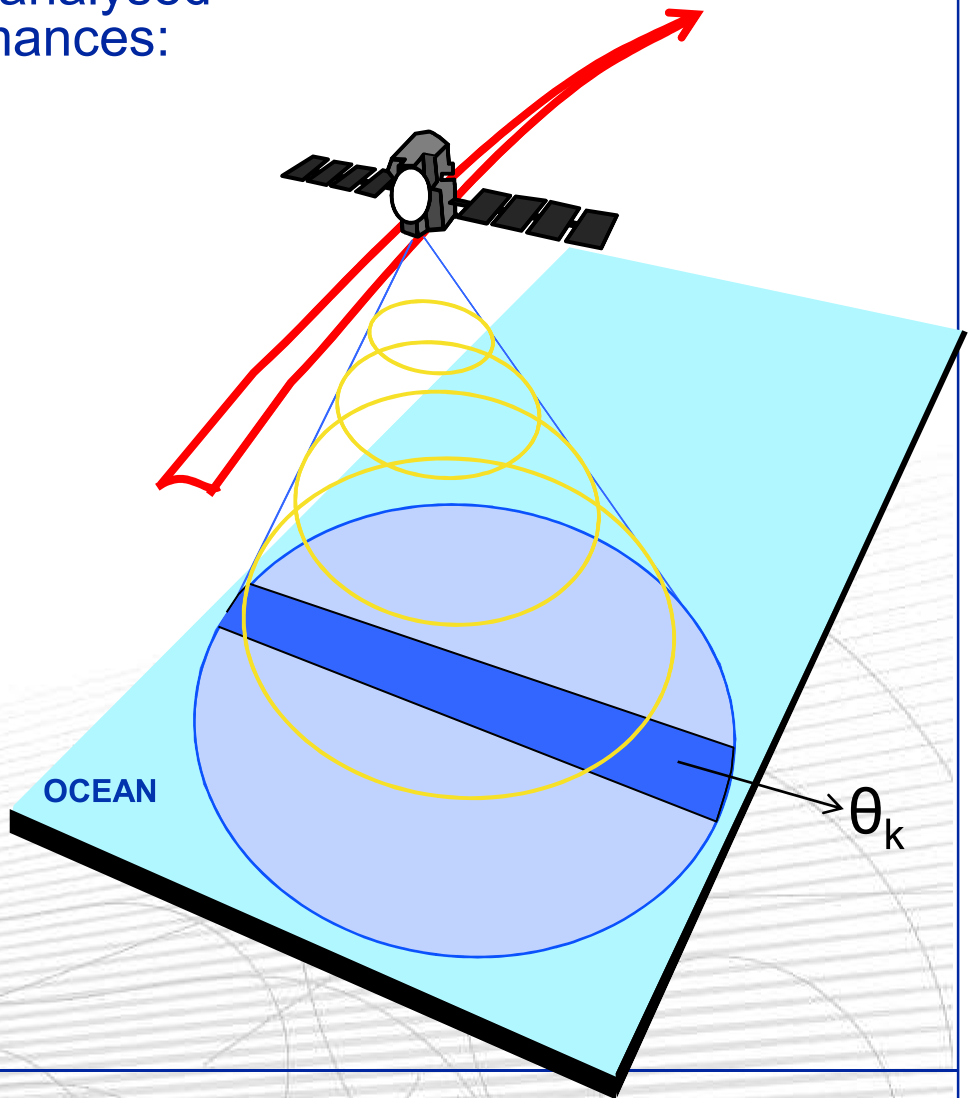


- **Analysis of 1-month Cryosat-2 data**
  - Higher bias for low ε
  - No significant bias for ε = ¼ Vmax
  - 20-Hz noise reduction (ε = ¼ Vmax)
    - SLA 10% (SWH @2m)
    - SWH 20% (SWH @2m)
    - Sigma0 25% (SWH @2m)
  - Same oceanic signal content (from spectra analysis)

➔ A likehood estimator weighted in Doppler beams would provide more improvements

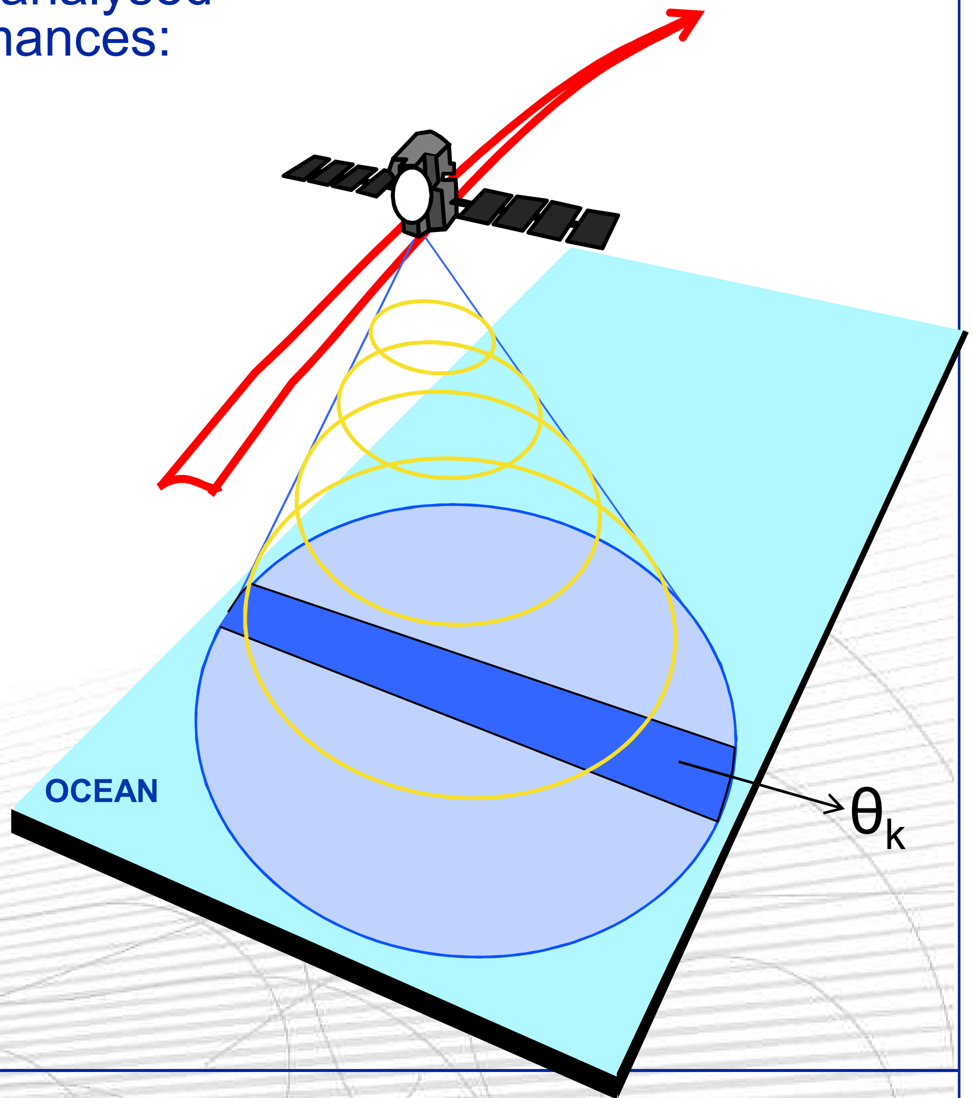
INDIVIDUAL DOPPLER BEAMS RETRACKER

- An alternative processing method will be analysed that would further improve SARM performances:



INDIVIDUAL DOPPLER BEAMS RETRACKER

- An alternative processing method will be analysed that would further improve SARM performances:
  - To process each individual look



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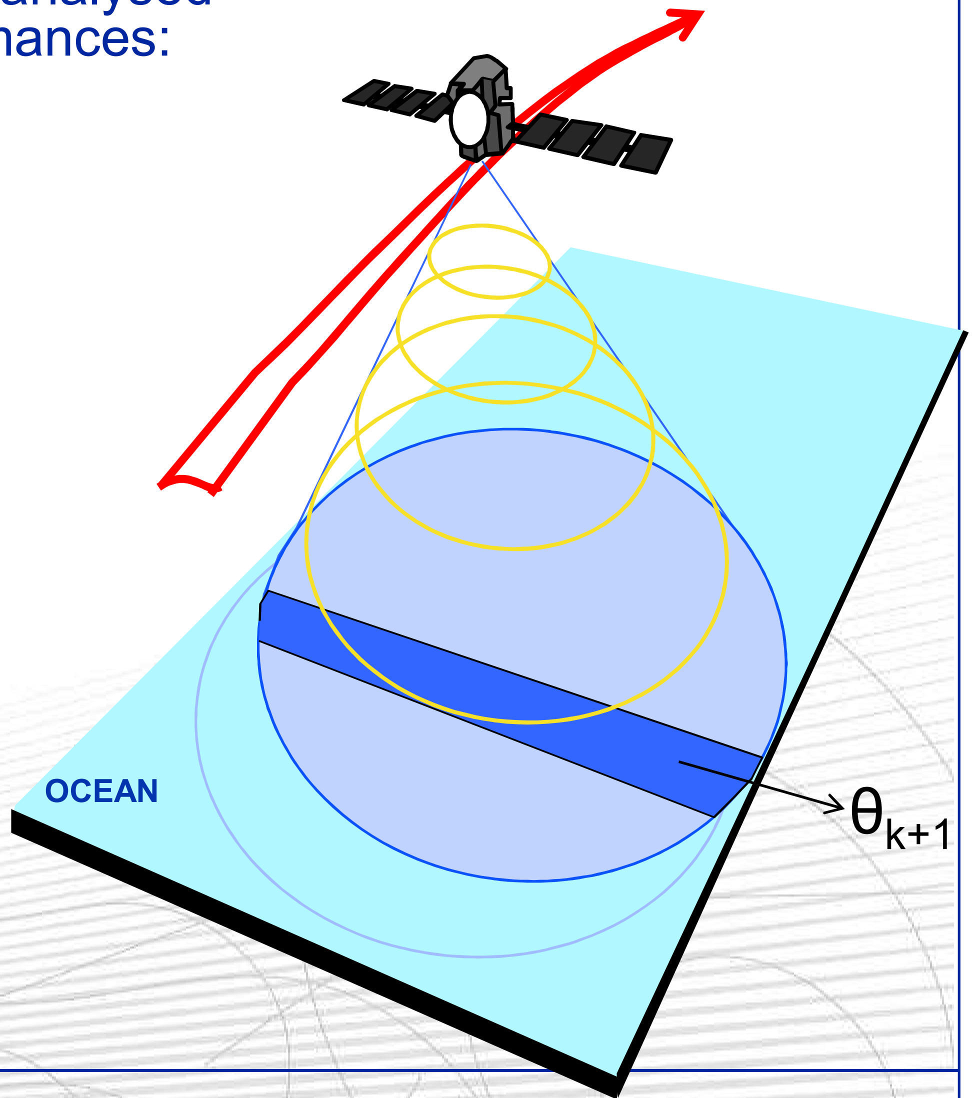

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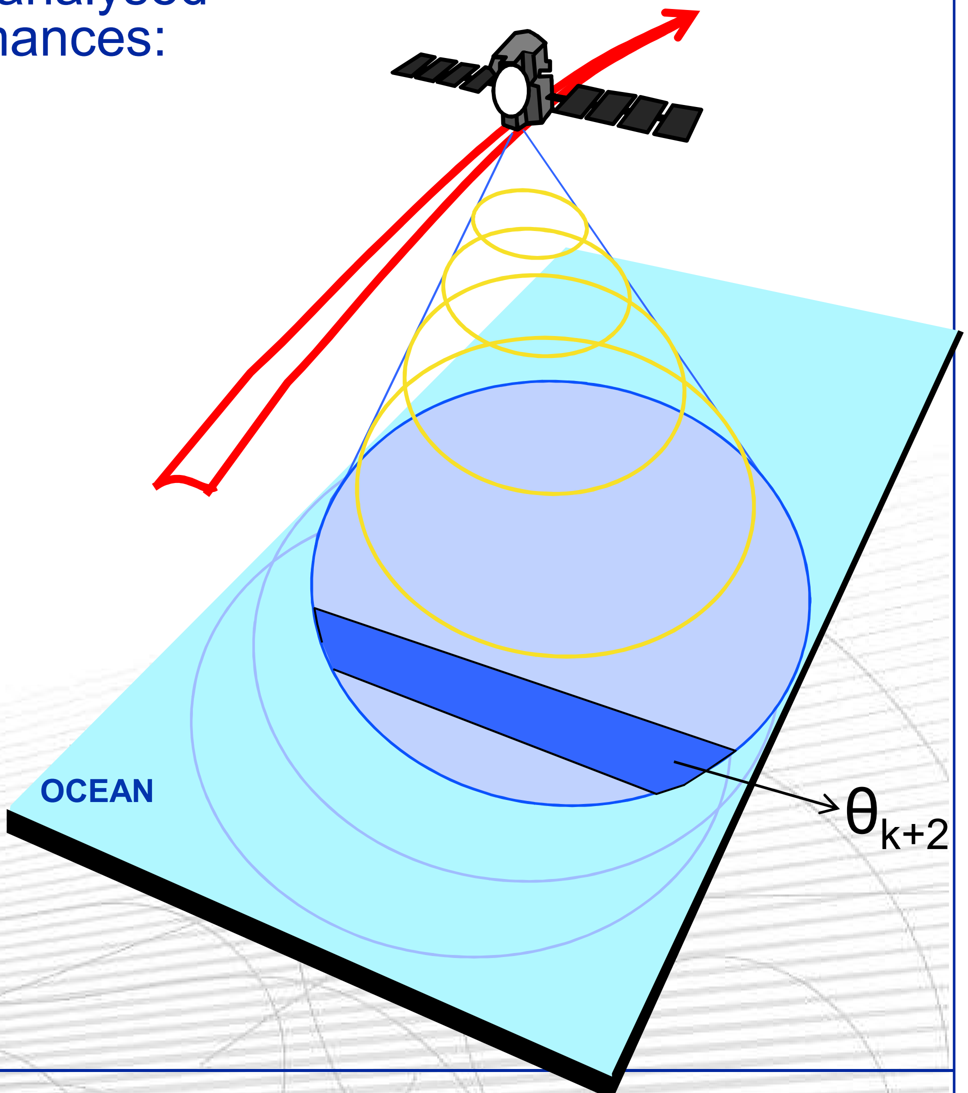

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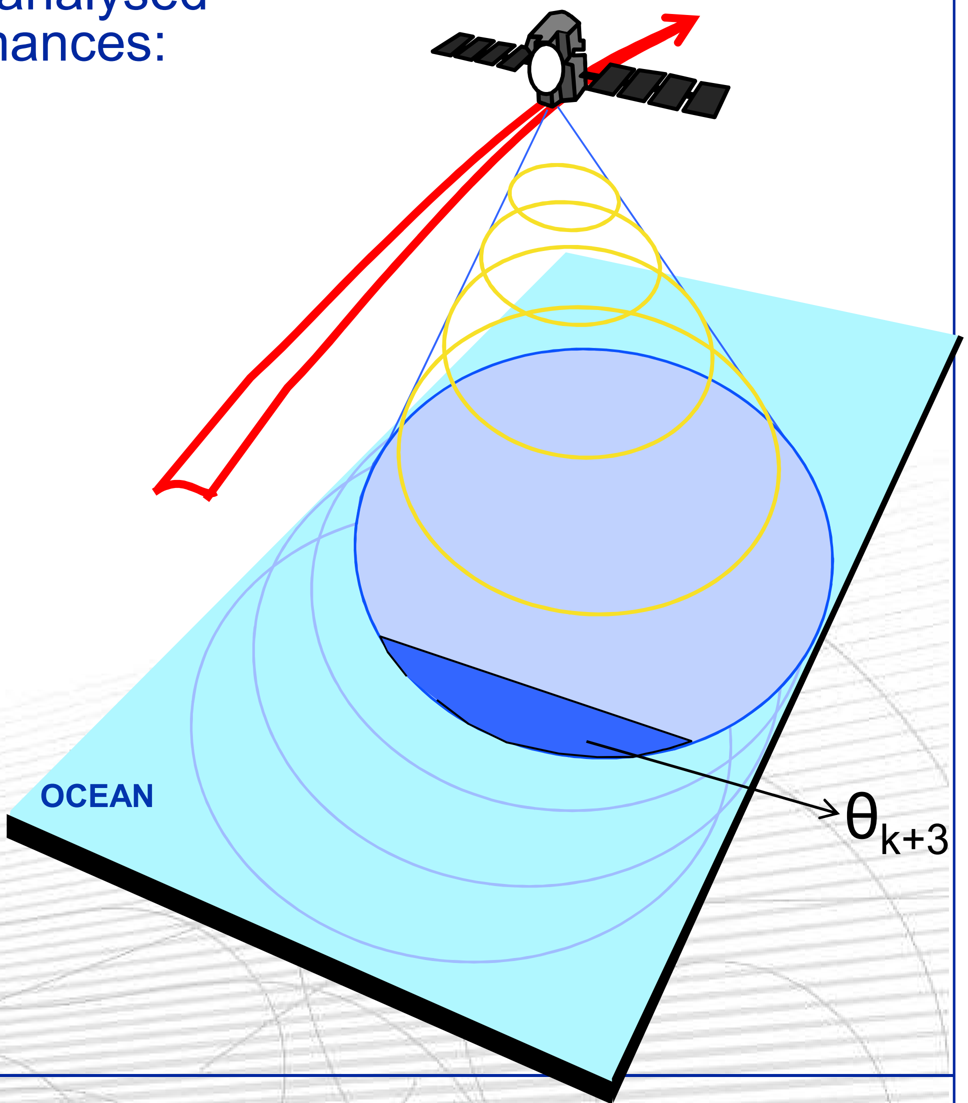

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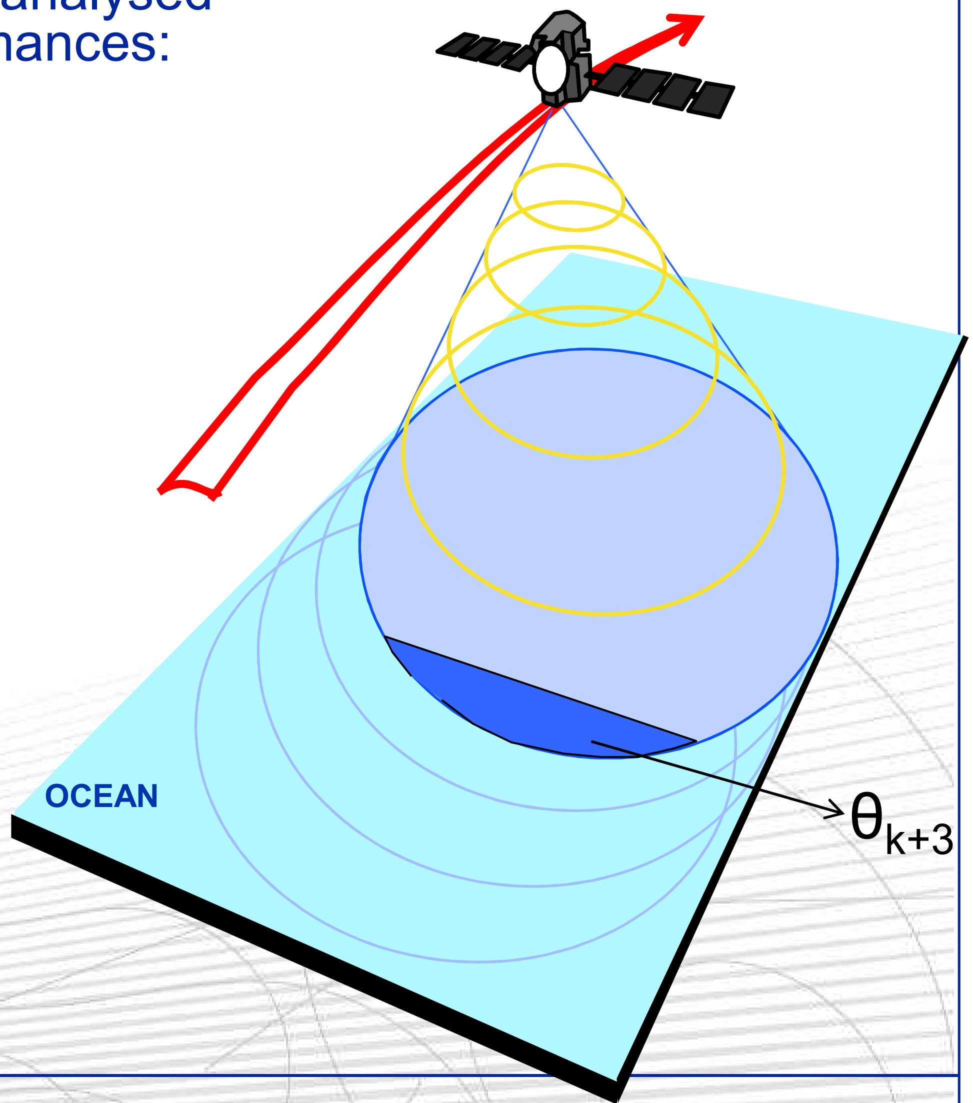
- An alternative processing method will be analysed that would further improve SARM performances:
  - To process each individual look
  - Then “average” their estimates θ_k
    $\theta = 1/L\ \Sigma(..\ +\theta_k+\theta_{k+1}+\theta_{k+2}+\theta_{k+3})$



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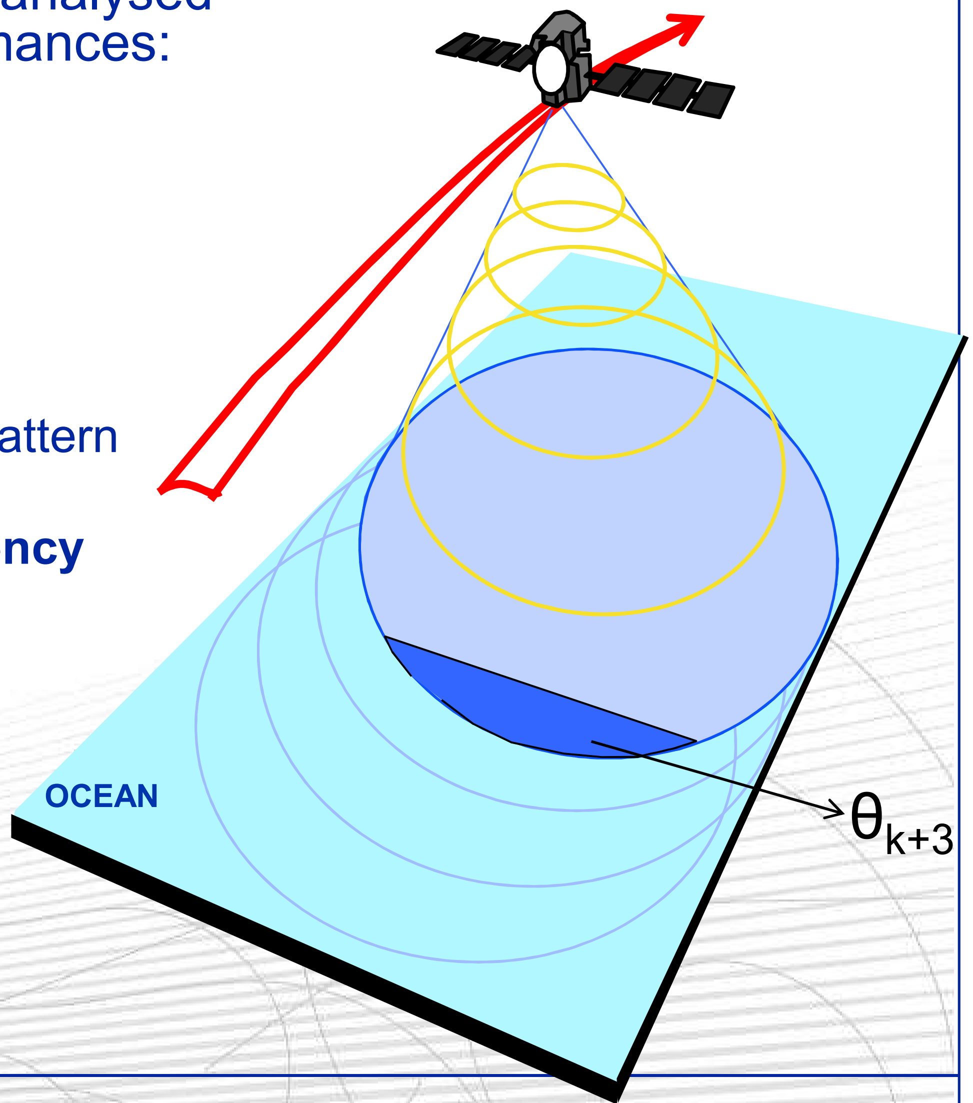
  ➔ Making all Doppler beams with equal contribution to the noise reduction

  - With no beams weighting (e.g., antenna pattern compensation, stack beam weighting)

  ➔ Enabling to assess the model consistency (checking any discrepancies between nadir/off-nadir look estimates)



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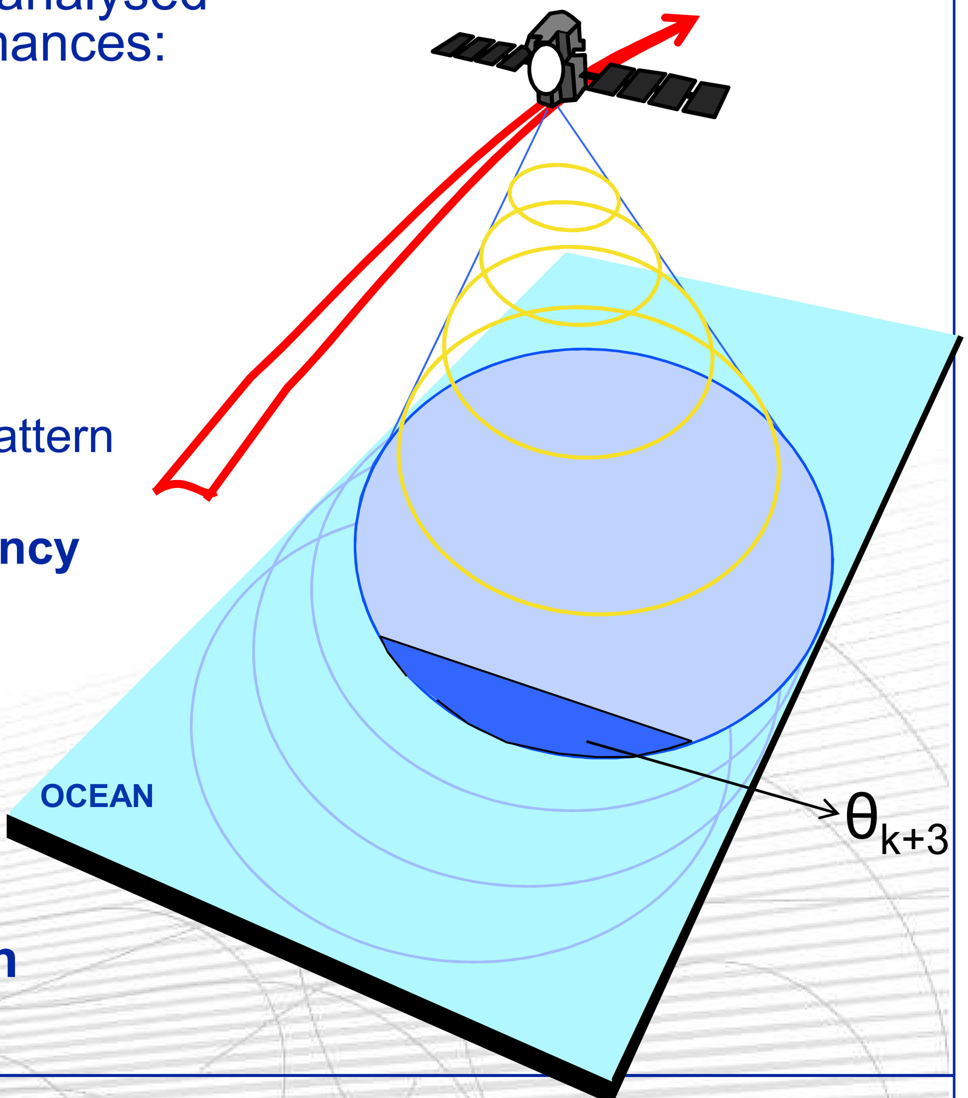
- Beams alignment before multilooking can be disrupted by inaccurate COR2 command (computed on-board)

  ➔ Tracker range alignment is not applied herein (only distance migration correction) mitigating possible errors



INDIVIDUAL DOPPLER BEAMS RETRACKER

- No valuable data for tracks perpendicular to the coast line at distance < 4-5km despite its high along-track resolution
  ➔ To edit inconsistent looks (after along-track Hamming weighting) still contaminated by land / calm sea

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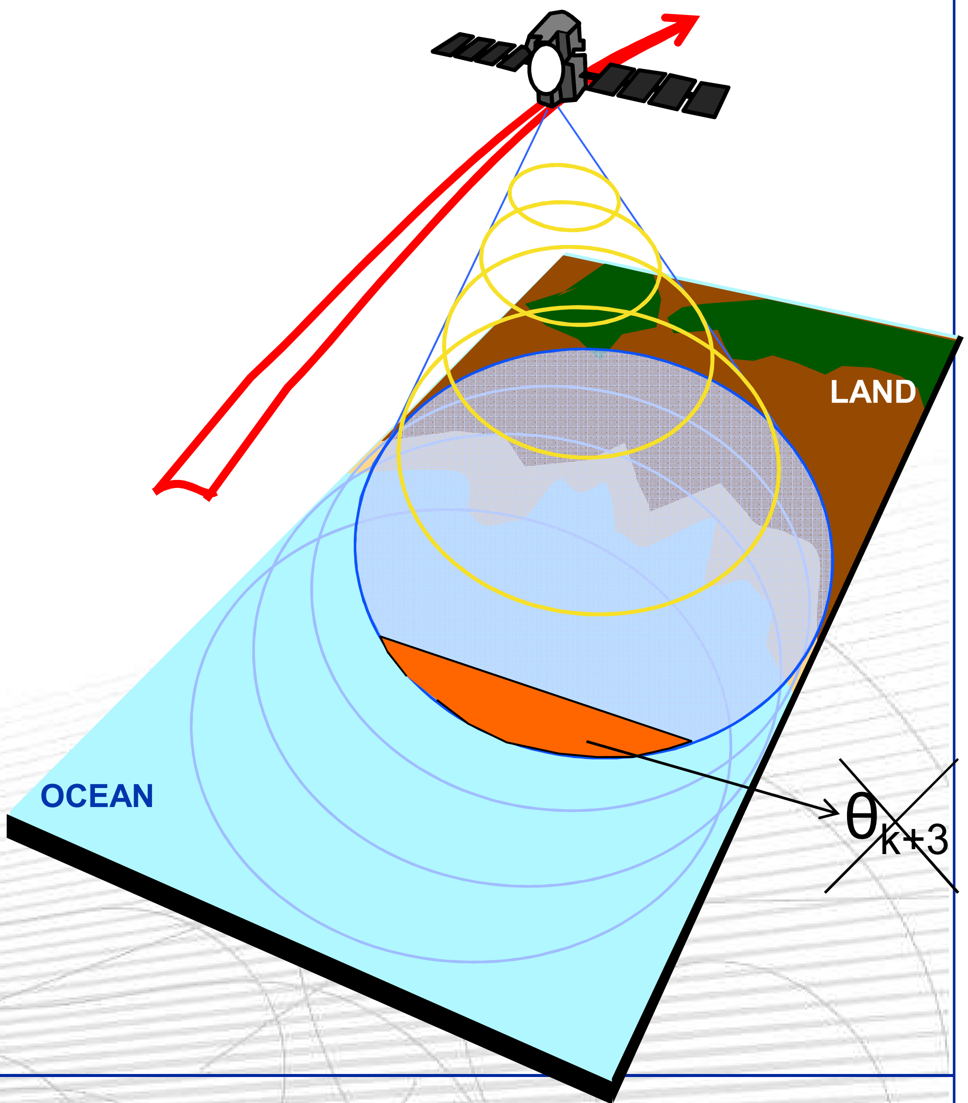

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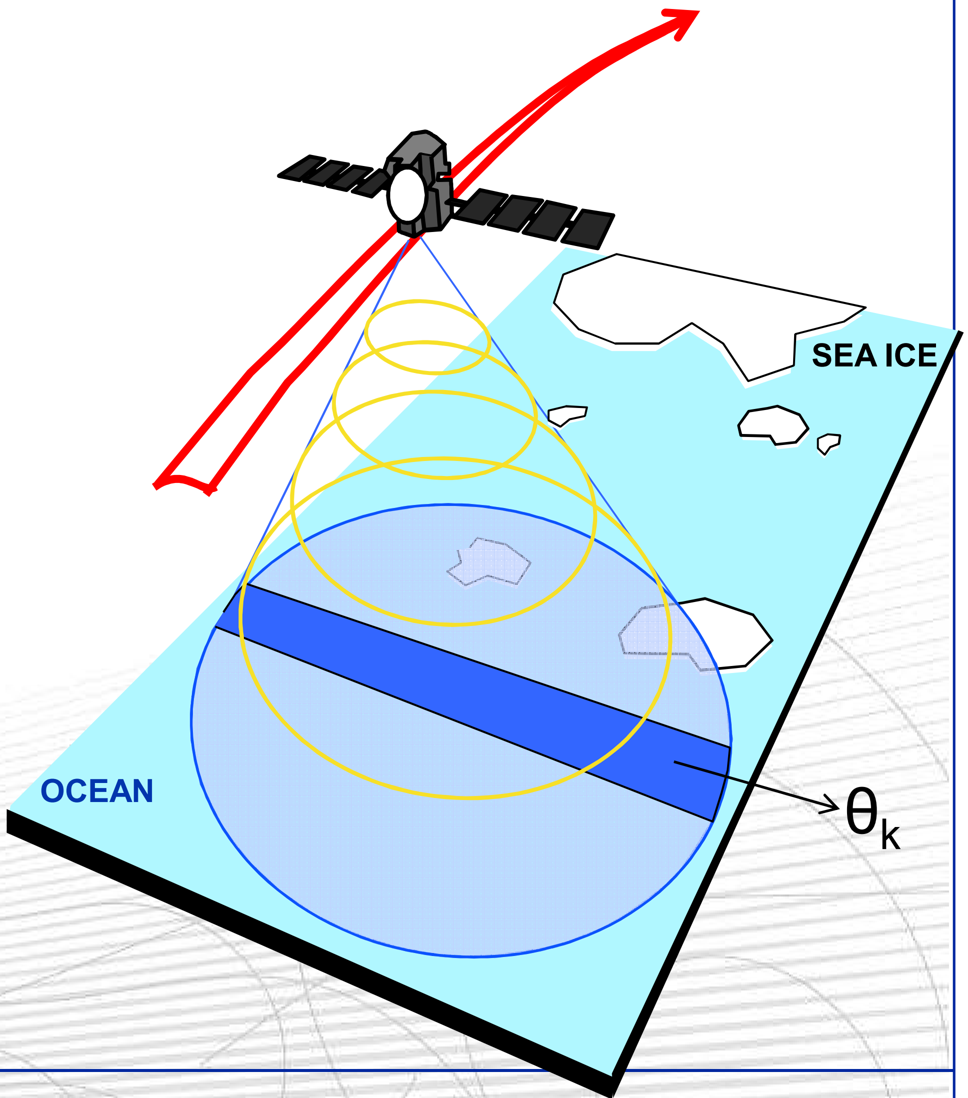

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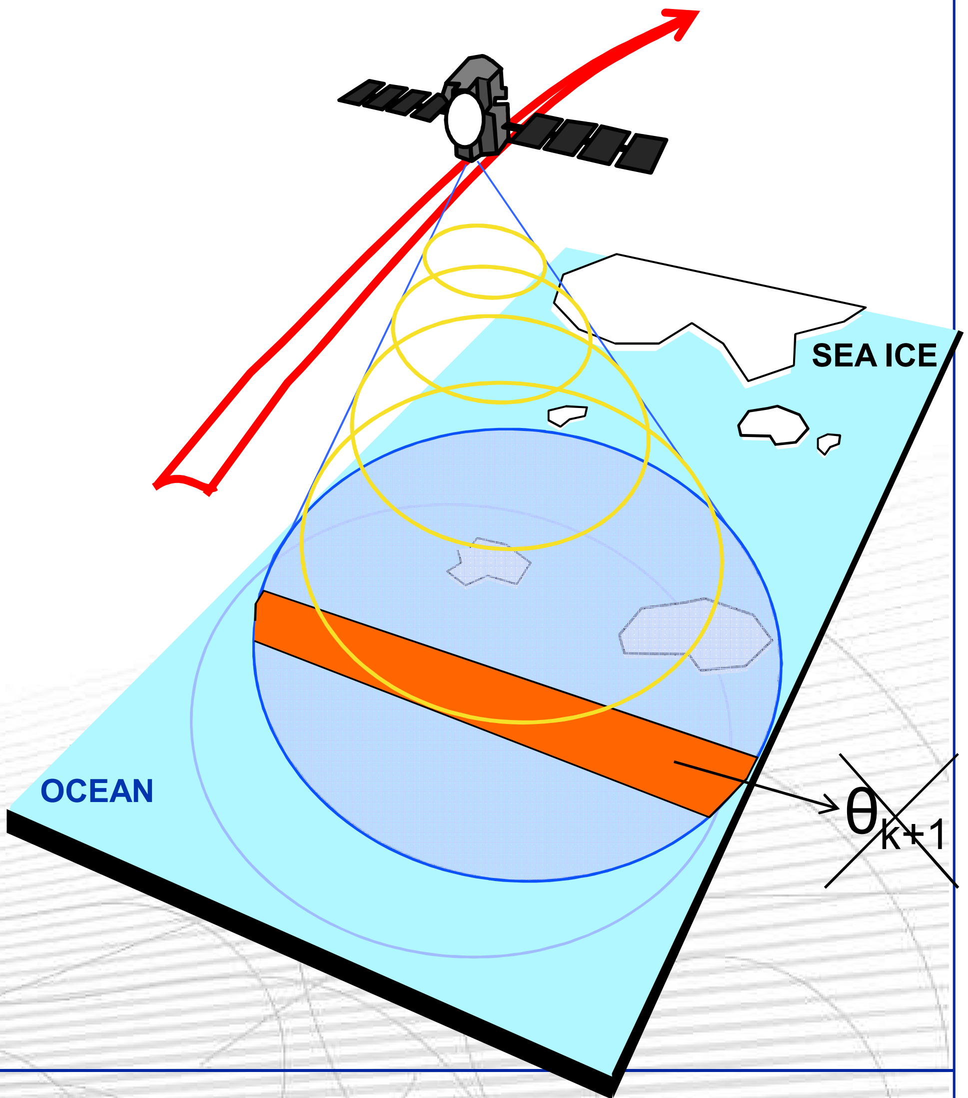

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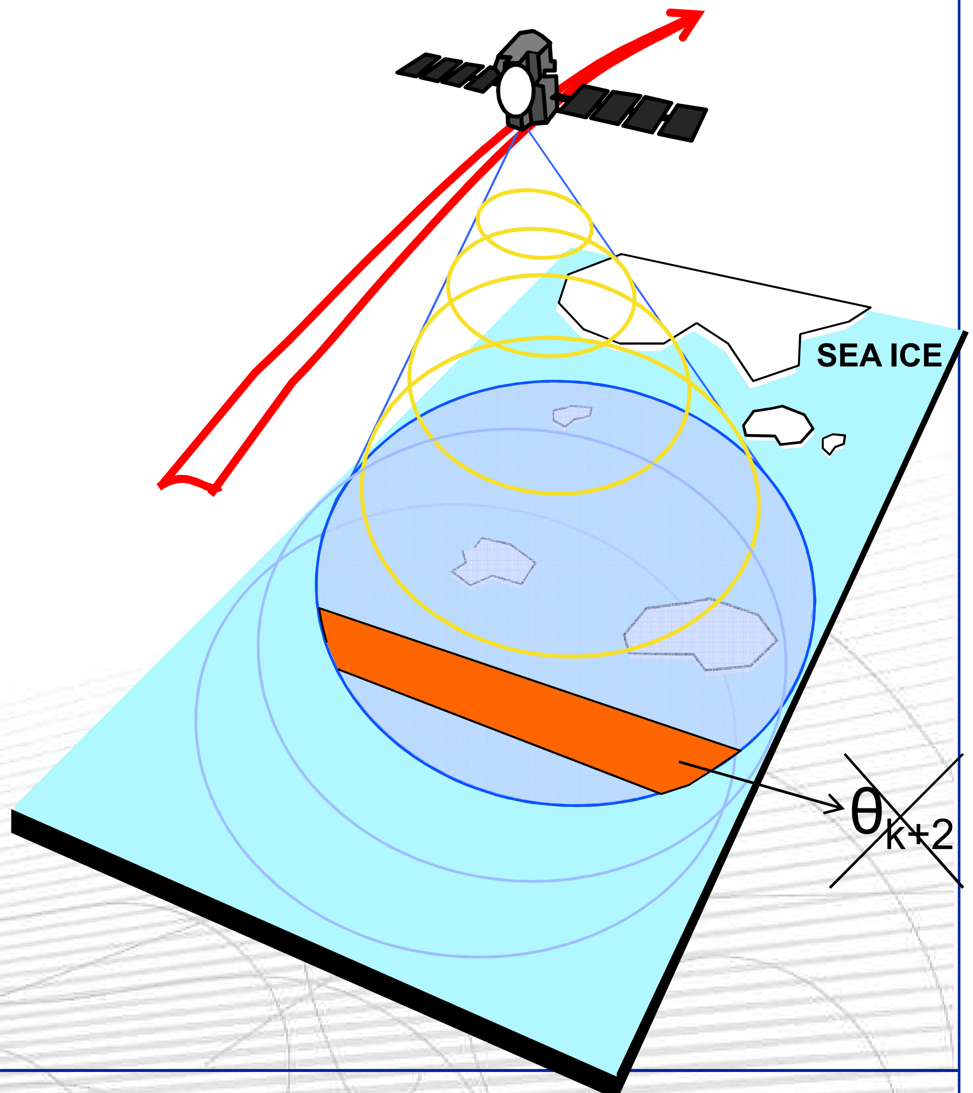

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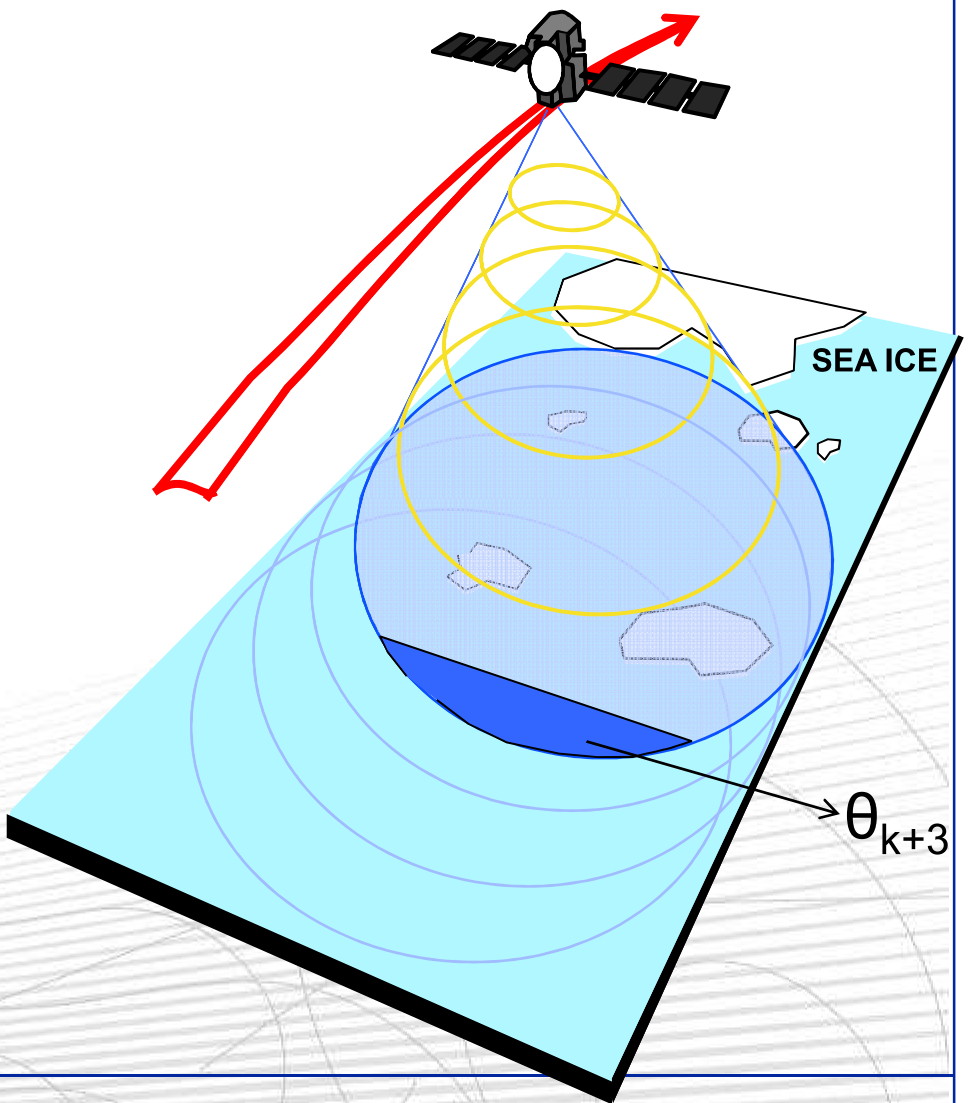

CONCLUSIONS & PERSPECTIVES

- Different configurations of Doppler processing have been studied showing potential improvement of SAR-mode performances
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- **Major interest for SAR-mode missions (S-3, S-6, ..)**
- **On-going investigations applied to S-3 data with CNES Processor**
- The existing tools (Processing Prototype, simulator and validation tools) are also used to study ice regions and in-land waters in SAR mode

THANK YOU !!

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