→ 10th COASTAL ALTIMETRY WORKSHOP

SAR Altimetry Training Course

SAR Altimetry Processing for Coastal Oceanography

L. Fenoglio, University Bonn

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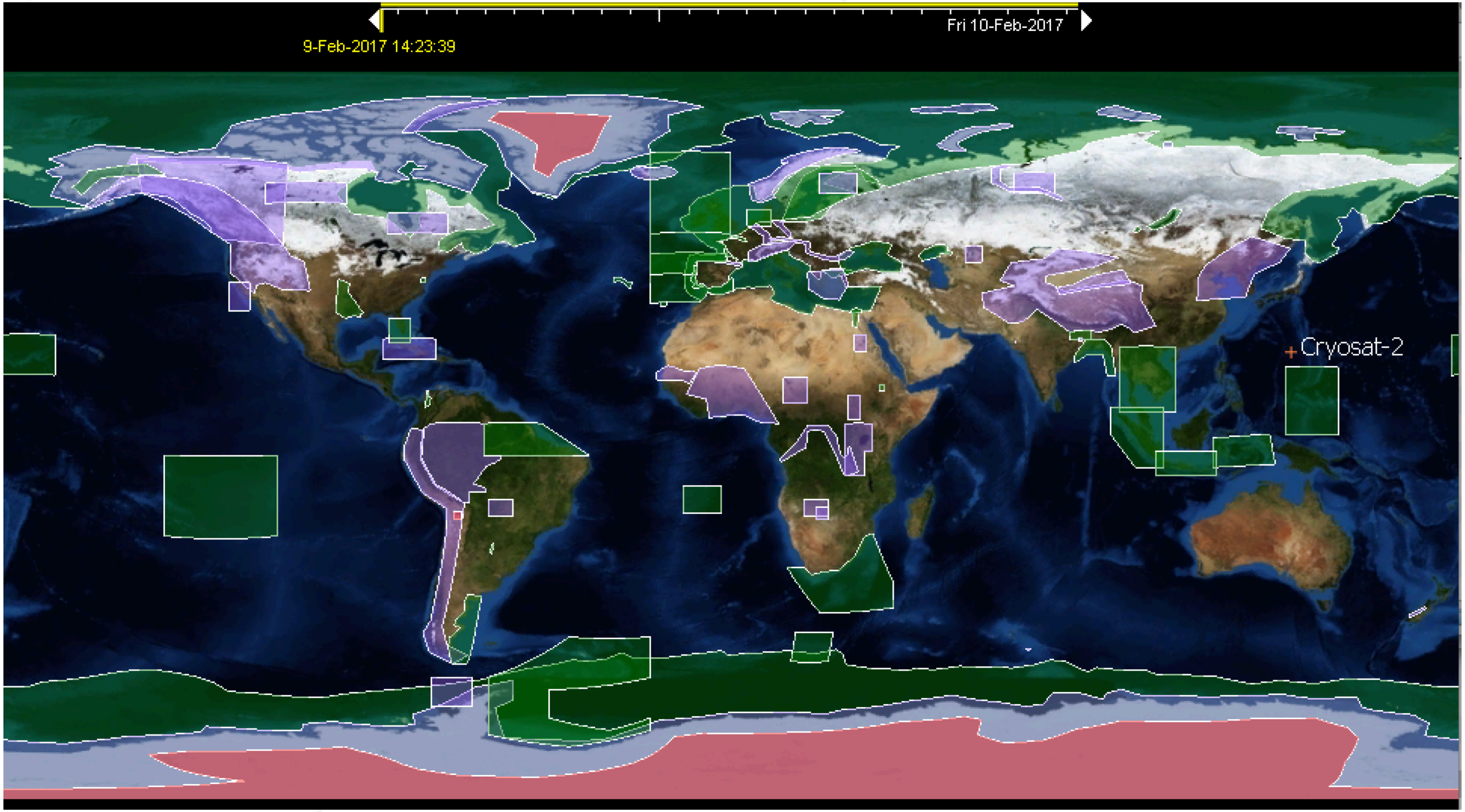
Outline

- SAR Altimetry Processing for Coastal Oceanography
  - Novelty in SAR for sea level monitoring
  - Improvement assessment / validation
  - Applications of SAR data to coastal zone

CryoSat-2 MASK 3.9



Definitions

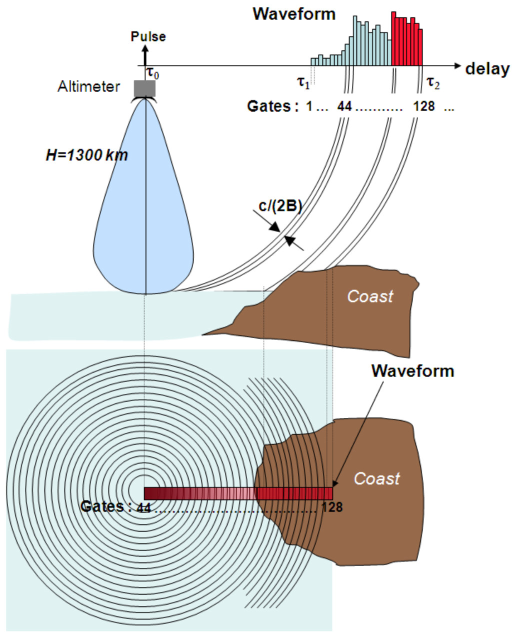
- What is „coastal zone“ ?
  - Here is defined at „less than 10 Kilometers from coast“

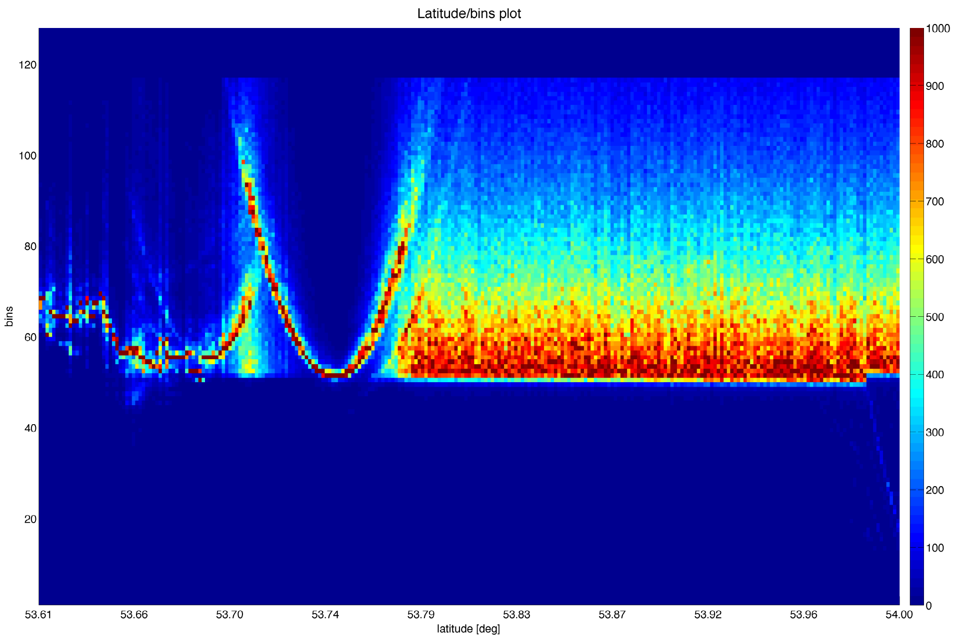
Sea level for comparison with in-situ and model data

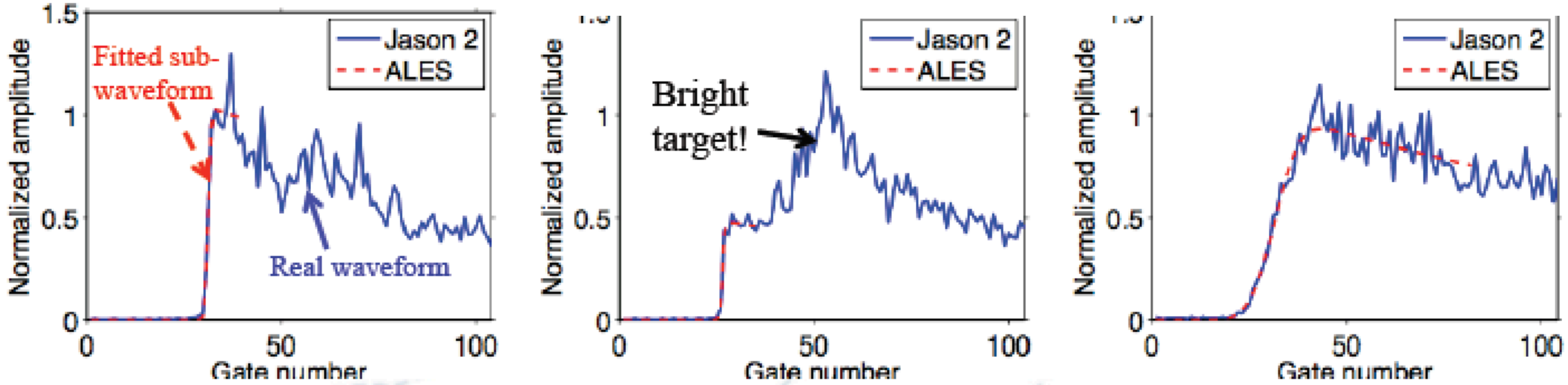
h_{unc}	$= H - R - \Delta R_{bias}$		(Eq.1)
Δh_{appx}	$= \Delta h_{iono} + \Delta h_{dry} + \Delta h_{wet} + \Delta h_{earth} + 0.468\ \Delta h_{pole} + \Delta h_{load} + \Delta h_{SSB}$		(Eq.2)
h_{SSHi}	$= h_{unc} - \Delta h_{appx}$	in-situ height (sea level as measured by Tide gauges)	(Eq.3)
Δh_{SSB_C2}	$= 0.05\ SWH$		(Eq.4)
Δh_{tf2mt}	$= 0.099\ h2(1 - 3\ sin^2\varphi)\ [m]$		(Eq.5)
h_{TGiMT}	$= h_{TGiTF} + \Delta h_{tf2mt}$		(Eq.6)
SLA_i	$= h_{SSHi} - h_{MSL}$	Correction of height from tide free to mean tide system	(Eq.7)
Δh_{tot}	$= \Delta h_{iono} + \Delta h_{dry} + \Delta h_{wet} + \Delta h_{earth} + \Delta h_{pole} + \Delta h_{load} + \Delta h_{SSB} + \Delta h_{DAC} + \Delta h_{otide}$		(Eq.8)
h_{SSH}	$= h_{unc} - \Delta h_{tot}$		(Eq.9)
SLA	$= h_{SSH} - h_{MSL}$		(Eq.10)

Fenoglio-Marc et al. (2015), Advances in Space Research

Störungen

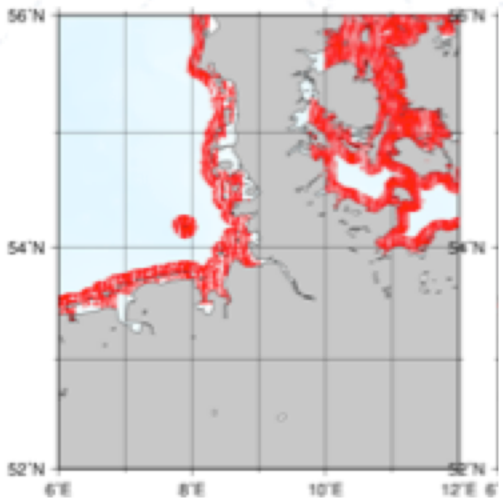




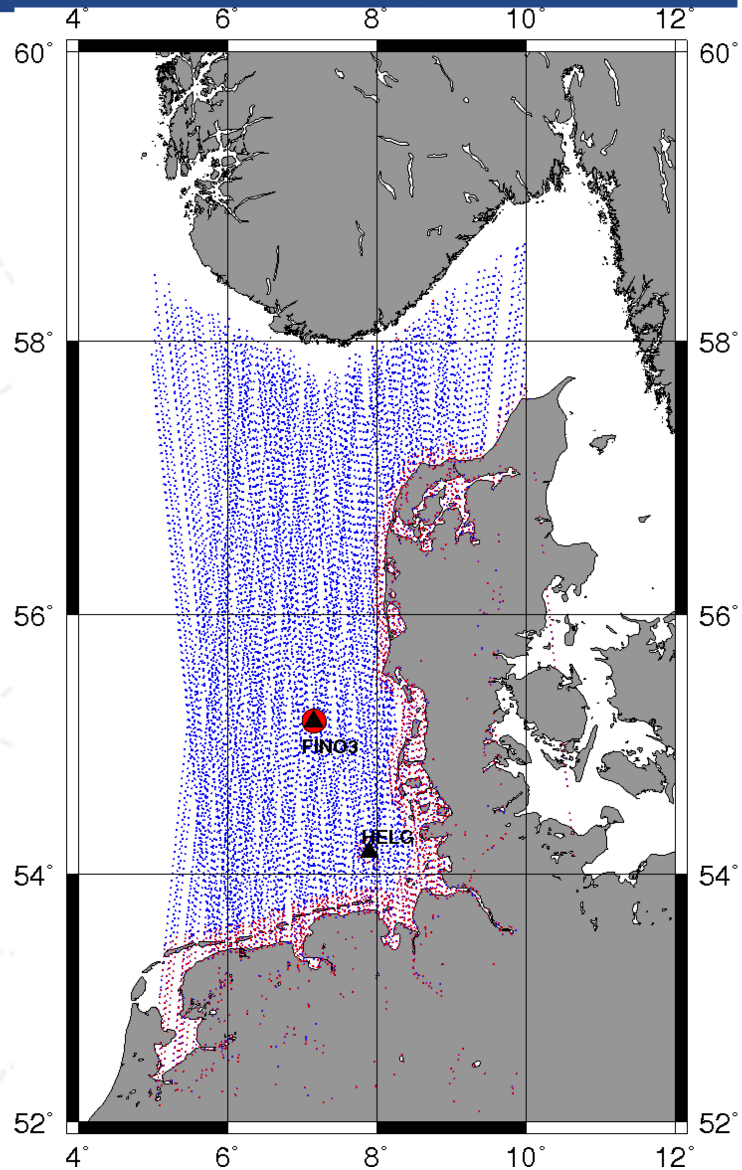


(Passaro et al., 2015)

- **150 m < D2C < 10 km:**



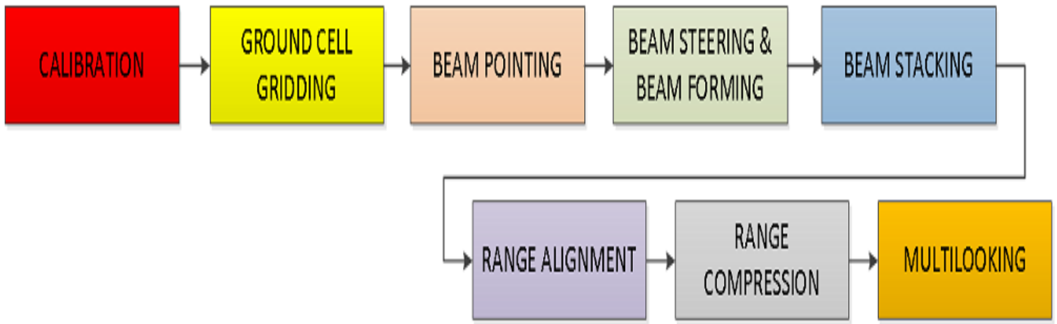
20 Hz



Coastal zone

DELAY DOPPLER SAR L1B Processing from L1a to L1b

1. **Calibration Correction** (of SAR FBR waveforms, e.g. Path delay etc.)
2. **Ground Cell Gridding** (identify surface locations on sub-sat elevation)
3. **Beam Pointing** (vectors, angles, ranges)
4. **Beam Steering & Beam Forming: FFT** of the pulse burst **in azimuth (along track)** (synthetize a set of 64 Doppler beams per burst), weighting function, FFT→ 64 Doppler Beams equally spaced, 4.1 Approximated Beam Forming & 4.2 Exact Beam Forming
5. **Beam Stacking**
6. **Range Alignment** (correct mis-alignement between beams same stack)
   6.1 Slant Range C., 6.2 Tracker Range Correction, 6.3 Doppler Range Correction
7. **Range Compression** (compress Doppler Beam Echoes in a stack)
8. **Multi Looking** (single SAR echo in power) (summation in azimuth (along-track) to reduce noise)



How is the processing done ?

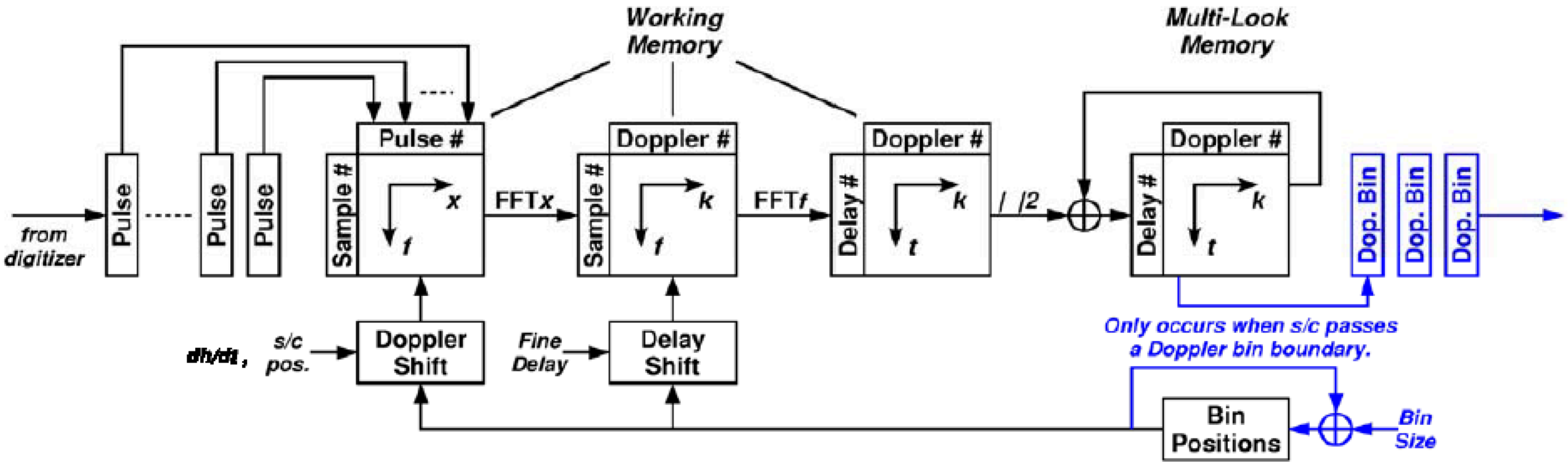
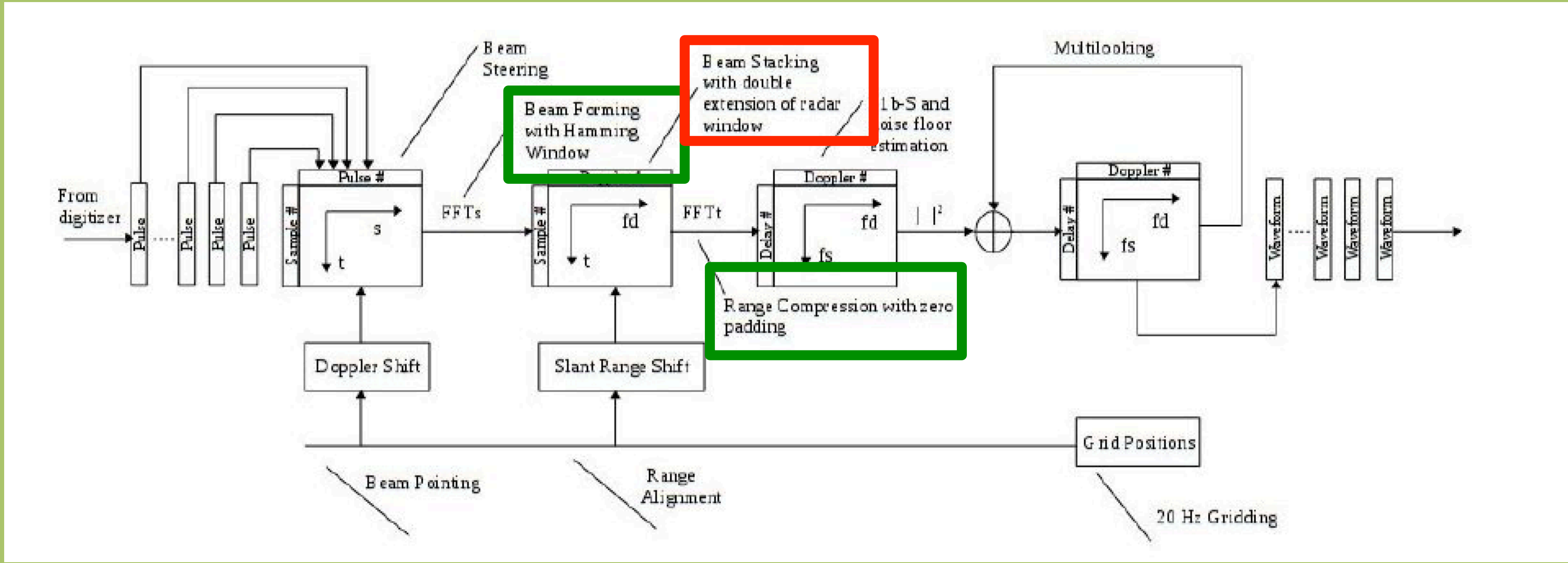


Fig. 4 Signal manipulations operated during the Delay-Doppler Processing.
The range compression and range alignment stages are performed before the stacking stage.
Image courtesy of Keith Russel Raney. From Dinardo „Guideline for SAR DD L1b Processing v2.2

Processing Schema

Additional steps in SAM+ wrt SAM2 (the 3 boxes)



Data

- **CryoSat-2 :**

  SAR: 2 x GPOD

  GPODO : ocean option selection

  GPODC : coastal option selection

  PLRM : 2 x TUDa+Ubonn

  TALES : coastal sub-waveform retracker

  STAR : coastal sub-waveform retracker

  auxiliary data:

  GPD+, TPXO ocean model, BSH ocean model

GPOD options

GPODO/SAM2 vrs GPODC/SAM+

20Hz
Hamming in coastal only
Exact beam forming approximated
FFT Zero-Padding

GPODO/SAM2	Common	GPODC/SAM+
128 range bins (radar receiving windows)		**256 range bins**
	NO antenna path correction	
	LUT	
SAMOSA2 (SAM2) retracker		**SAMOSA+ (SAM+)* retr.**

*Selection of First-Guess epoch → position of the correlation peak between 20 consecutive wf
*Treatment of land contaminated wf (SWH=0, Mean Square Surface Slope(mss) free parameter)

The best correction: **GPD+ wet tropo**
TPX08 ocean model

PLRM Processing

- FBR -> L1b : Incoherent average of echoes (20 Hz data 64 individual echoes x 4)

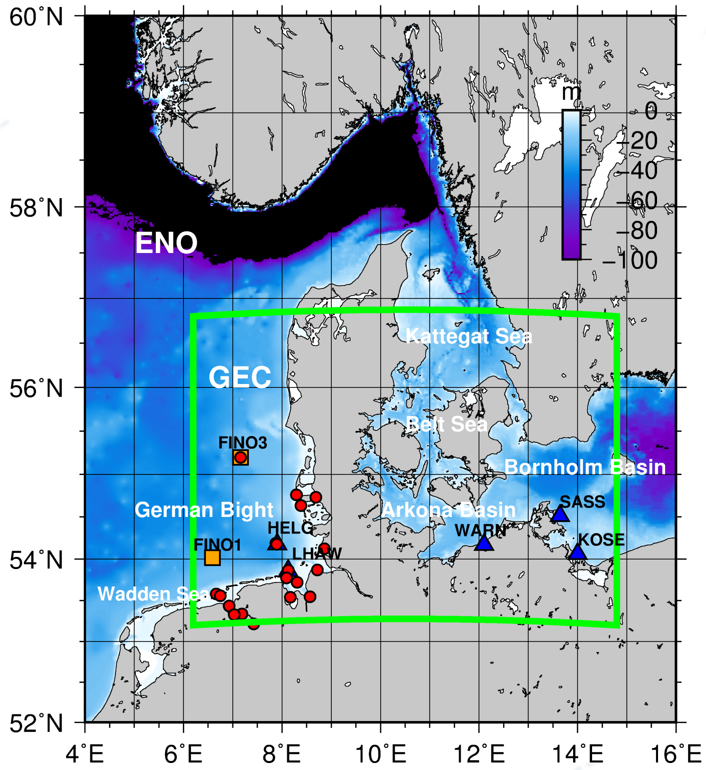
- L1b -> L2 :
  - TALES : Sub-waveform ALES dapted for Cryosat-2 PLRM using SINC2 instead of MLE3 (Buchhaupt et al., submitted)
  - STAR : Sub-waveform detection by conditional random field (Ubbing et al., submitted); (1) derive partitioning of the wf using successive wf; (2) retrack; (3) points cloud of SSH; (4) find best path using Dijstra algorithm

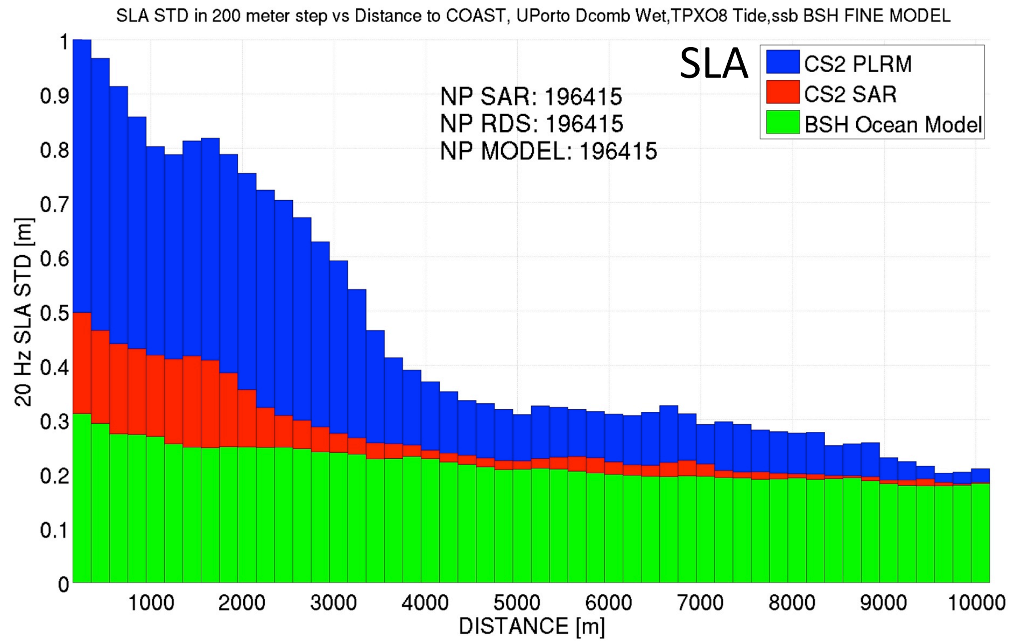
SLA in coastal zone (< 10 km)

• GEC (German Coast) & GPODC

2010-2016 coastal zone Dinardo et al., submitted;

PLRM SINC2, Buchhaupt et al., submitted,



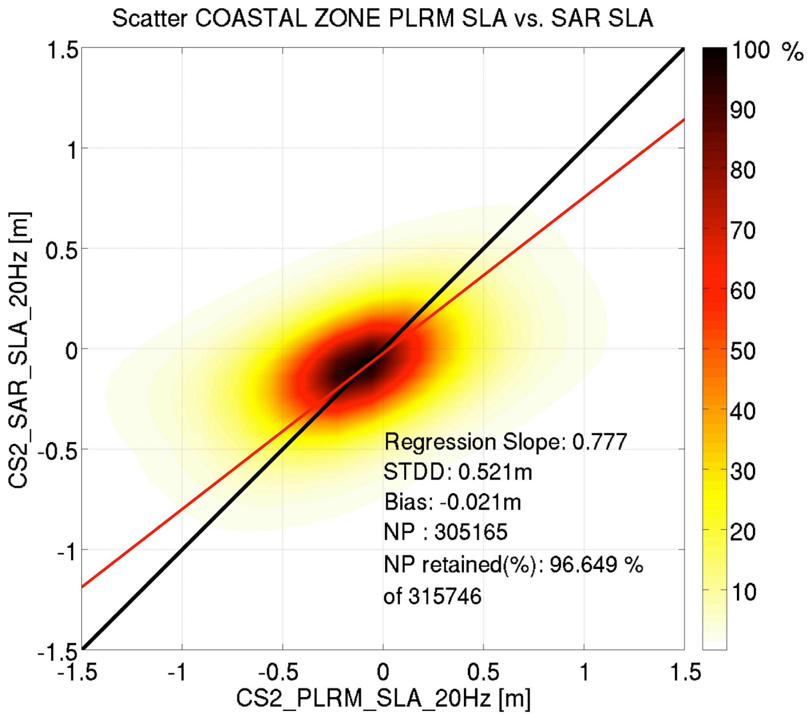


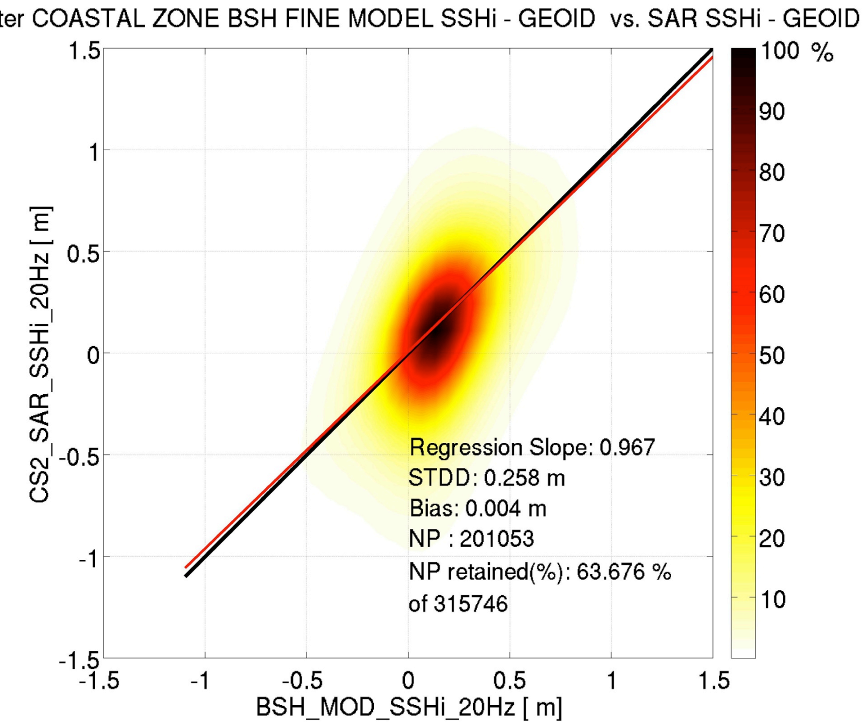
ENO Eastern North Sea and Western Baltic Sea

GEC German Coast (BSH coastal model, 0.9 x 0.9 km)

ENO: SLA in Eastern North Sea and Western Baltic

❑ GPODC





ENO: SAM+ against PLRM, SLA
all corrections applied

GEC: SAM+ against BSHfine, DOTi
no IB & oc.tide

SLA PLRM/TALES worse than GPODC by a factor 2 (and respect to mod

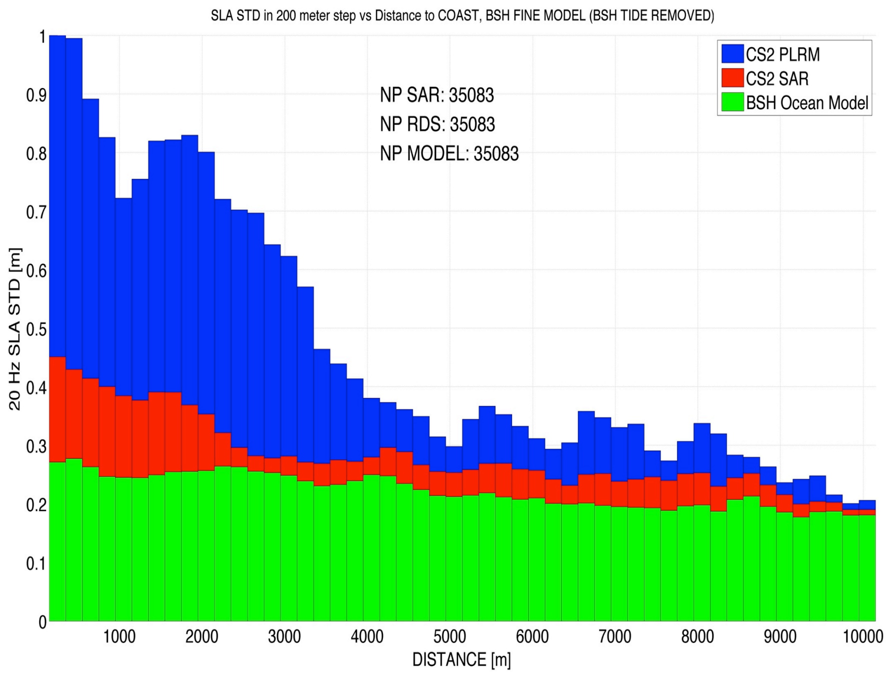
Results in open ocean 1Hz *(Fenoglio et al., AdSR 2015)*
are: no bias, 2.6 cm, 0.98; multiply by factor 4 to have values at 20 Hz (√20)

Coastal zone 1Hz/20 Hz SSH *(Dinardo et al., submitted)*

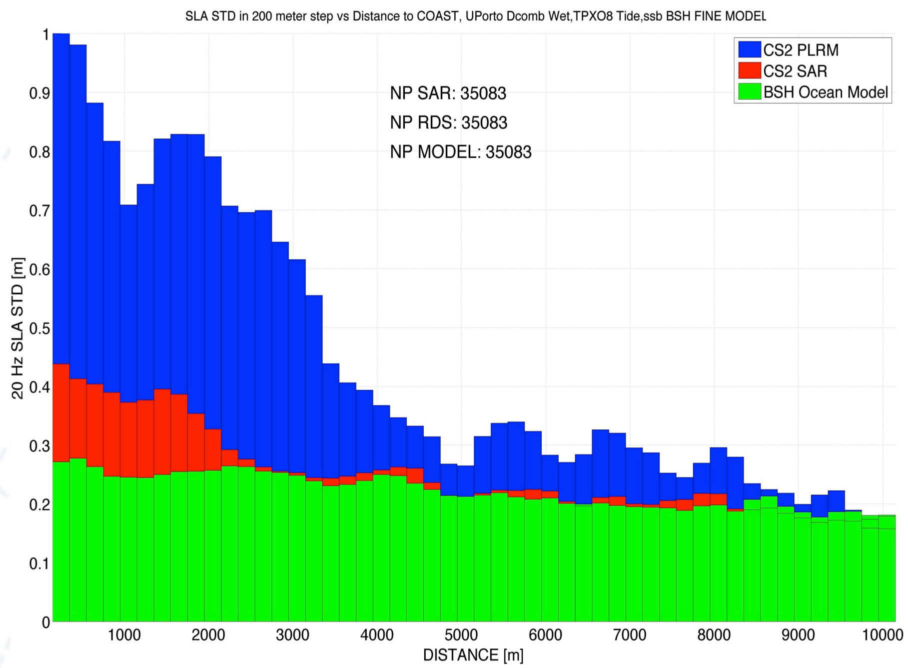
- SLA
  - SAR as in open ocean
  - PLRM worse by a factor 2 vrs SAR (and respect to model)
  - SLA SAR vrs PLRM : no bias, 26 cm, 0.80 (bias, STDD, slope)
- SWH bias between SAR and PLRM (and model)

Effect of Ocean Tide model selected (GEC, 2012)

FES2004

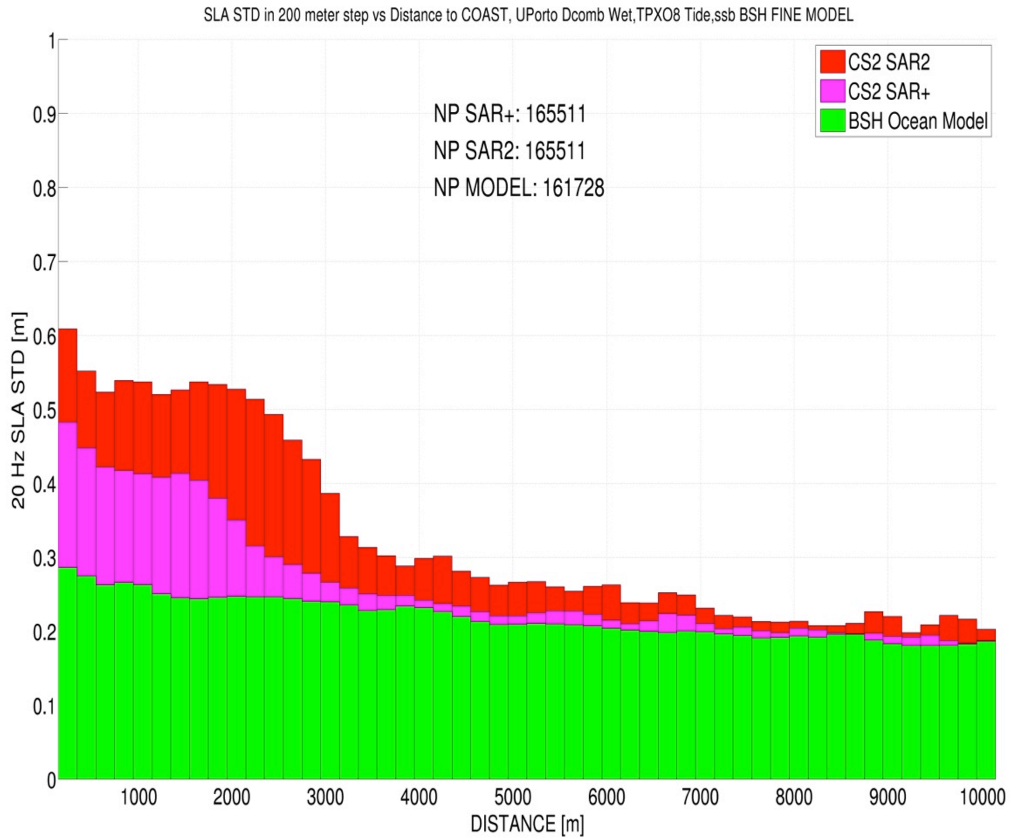


TPXO



Small improvement by using TPX ocean model

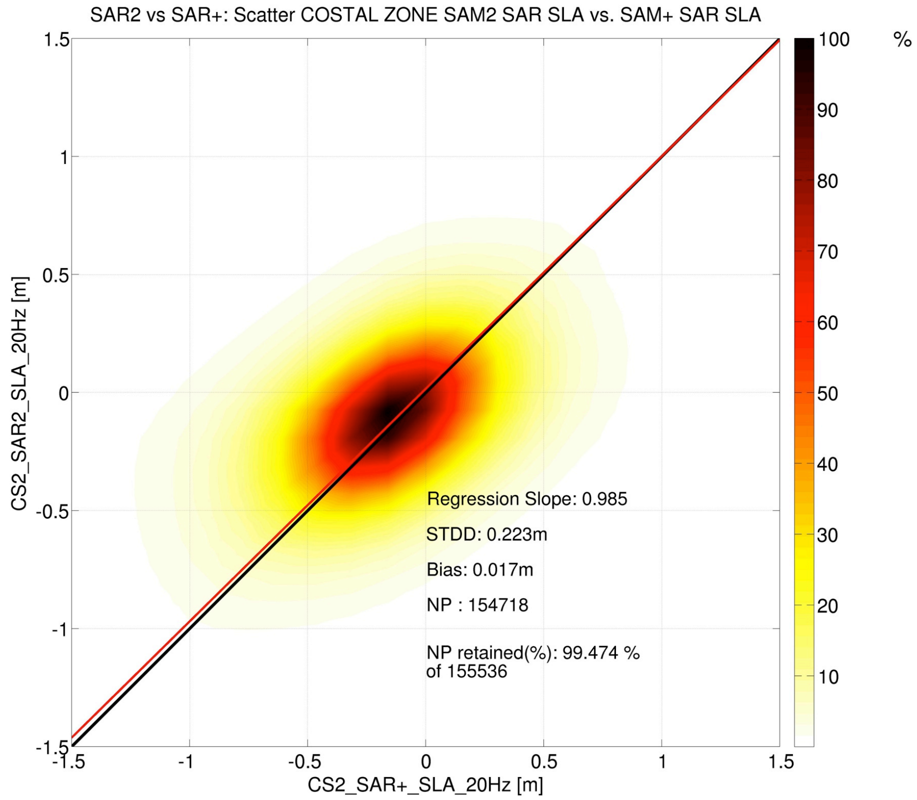
GEC 2011-2015: GPODO against GPODC (BSHku model as reference)



Large improvement by using GPODC (violet) unstead of GPODO (red)

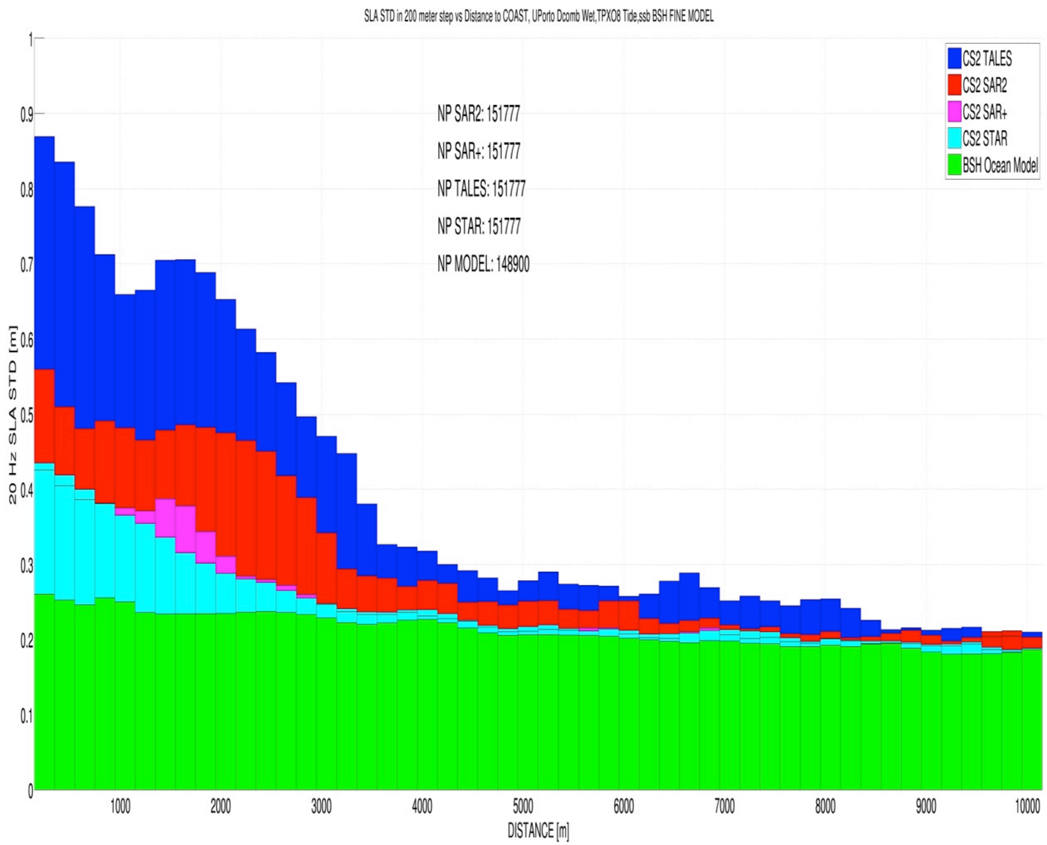
Results

GEC 2011-2015: SLA Crossvalidation of GPODO vrs GPODC



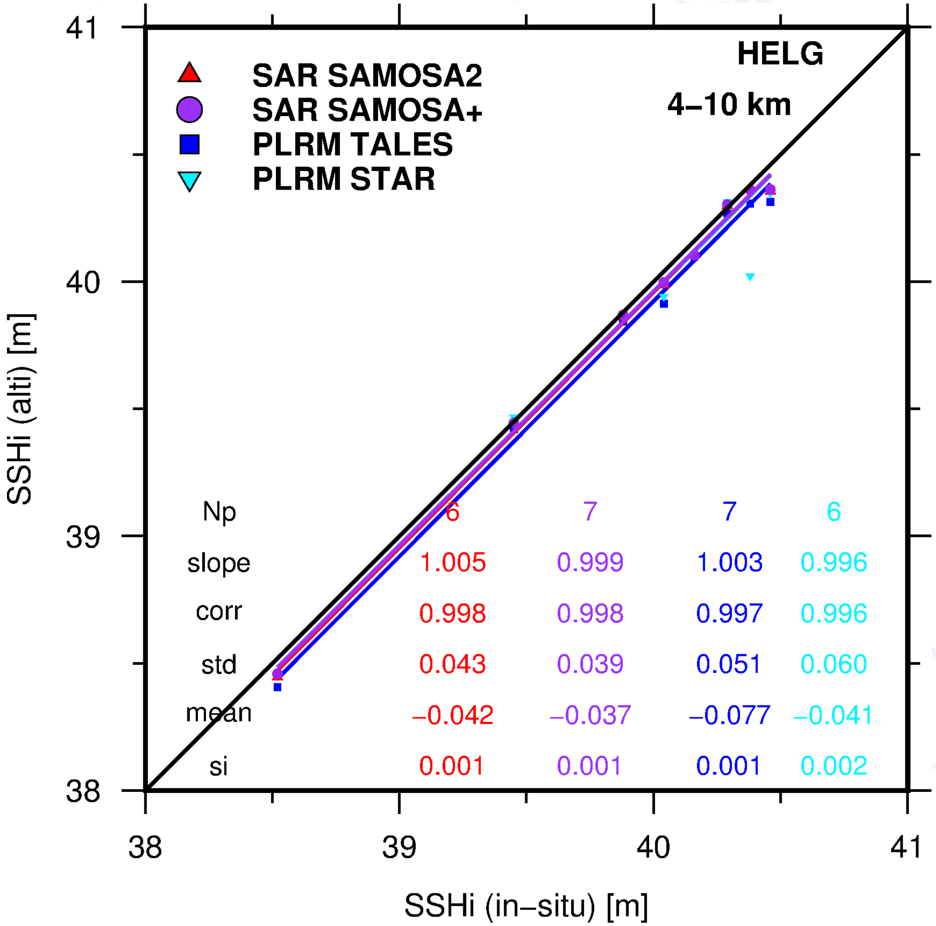
Coastal Zone (stdd=22 cm)

GEC 2011-2015: GPODO against GPODC, PLRM TALES and STAR (BSHku model as reference)



GEC 2012: Helgoland in-situ validation

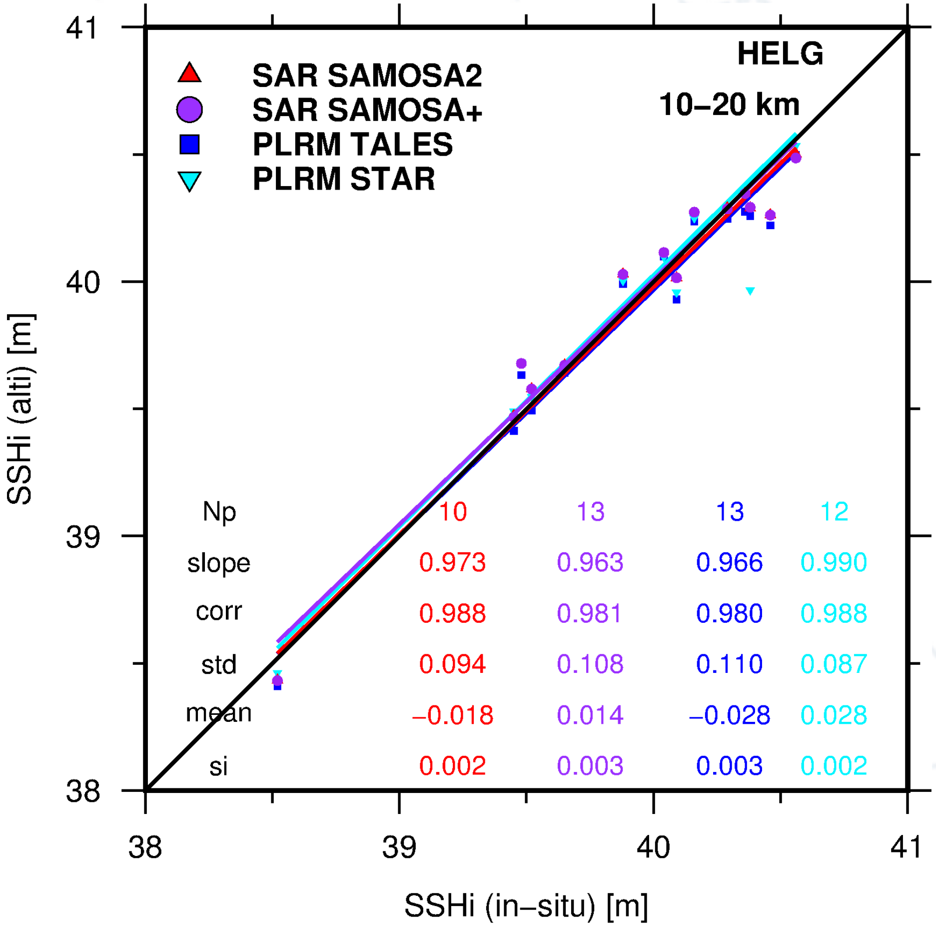
GPODO against GPODC, PLRM TALES and STAR



Best accuracy with GPODC
STDD = 3.9 cm

GEC 2012: Helgoland in-situ validation

GPODO against GPODC, PLRM TALES and STAR



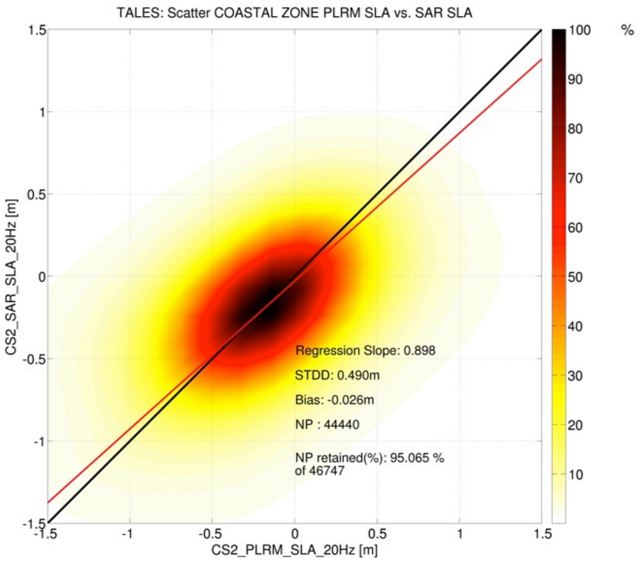
Absolute
best accuracy with STAR
STDD = 8.7 cm

Best accuracy in SAR
With GPODO
STDD = 9.4 cm

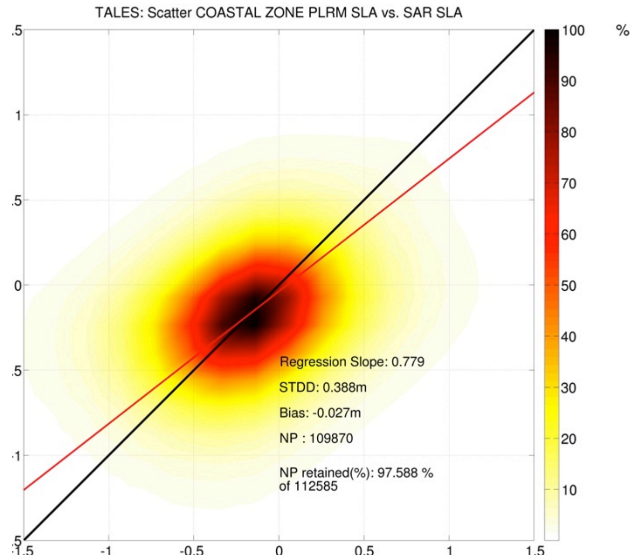
Analysis over more TGs and more Years is necessary!

TALES GPODO

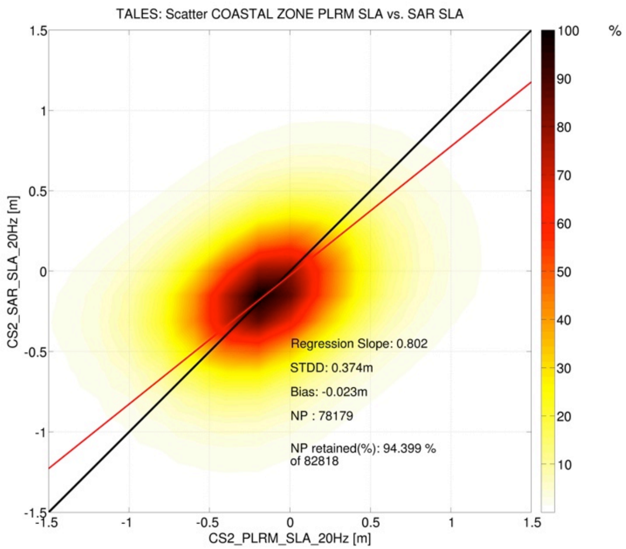
BEN



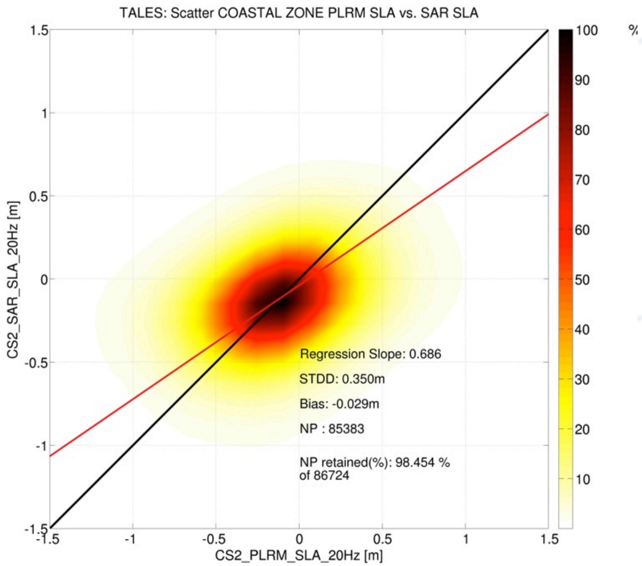
FRA



UKS

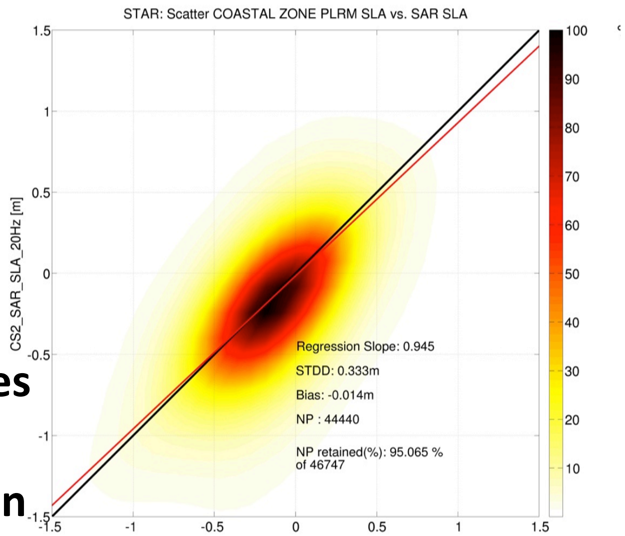


WIB

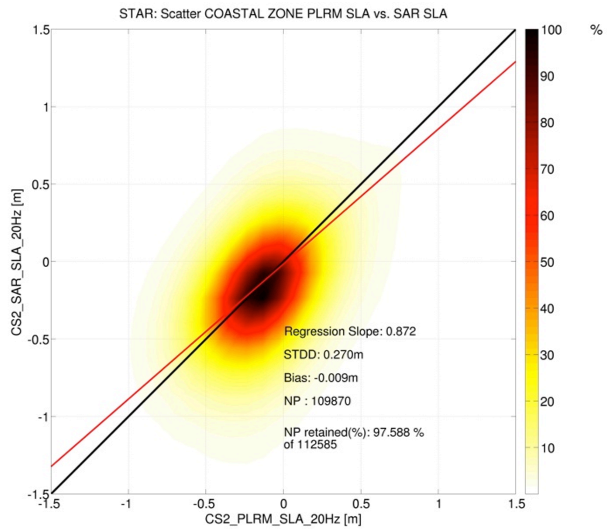


STAR GPODO

BEN



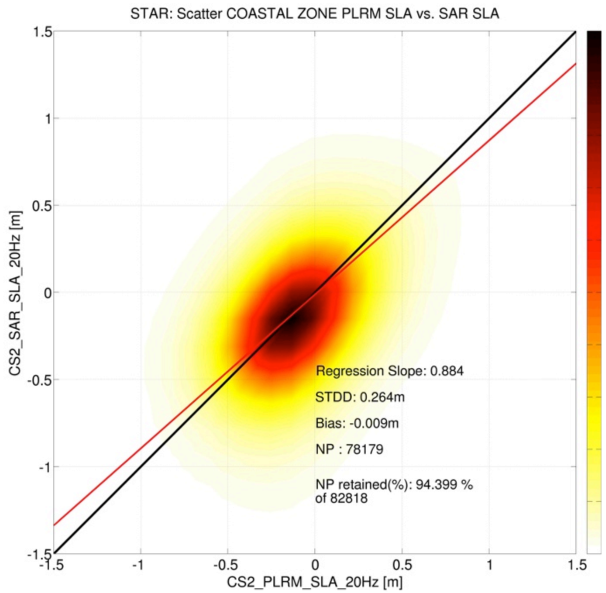
FRA



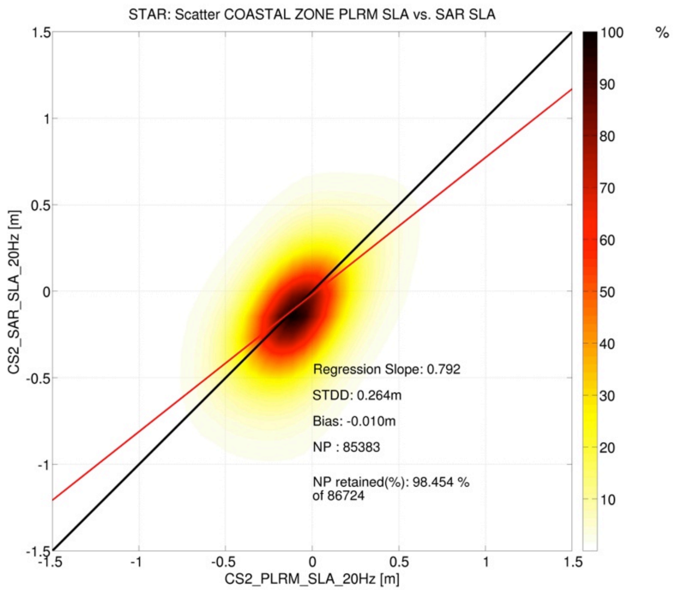
SPREAD decreases

Higher correlation

UKS

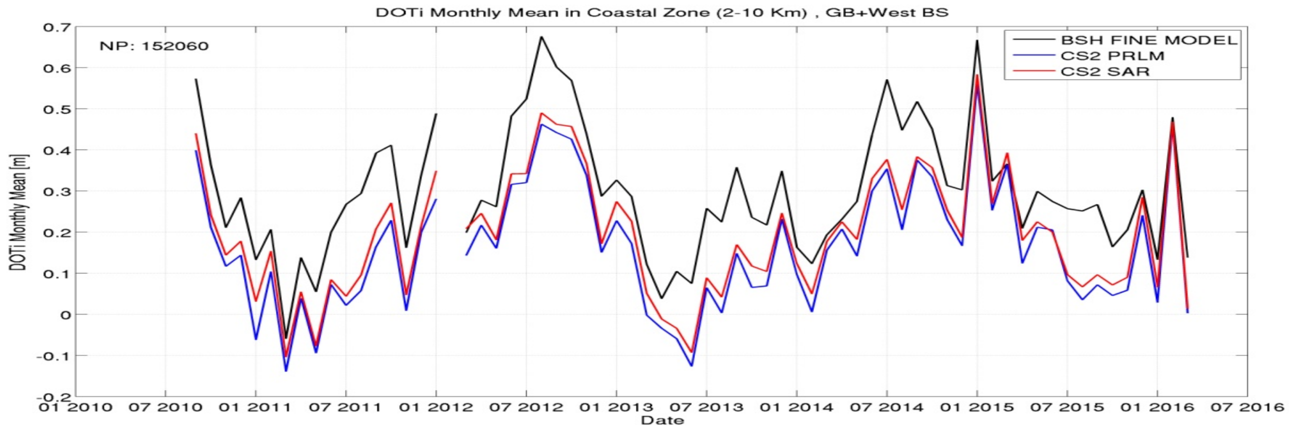


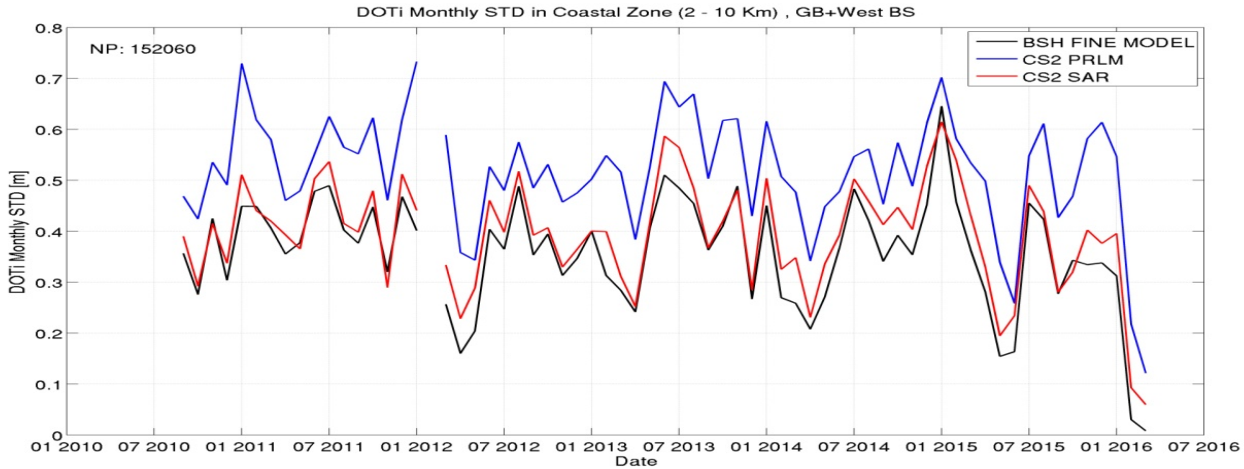
WIB



Mothly sea level

GEC





Conclusions

- In coastal zone SAR altimetry is more accurate than TALES/ PLRM
- SAR leads to significantly smaller errors in SLA
- STAR/PLRM is less noisy than TALES
- SAR processing options have to be selected with care: GPODC is more accurate that GPODO near coast, the two are very similar in open ocean
- New limit of SAR altimetry near coast is 2-3 km from land
- SAR monthly cycle is more accurate than PLRM

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