Exploring the potential of Sentinel-3 fully-focused SAR altimeter range data for enhanced detection of coastal currents on the Northwestern Atlantic Shelf

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I. Introduction

Fully-focused Synthetic Aperture Radar (FFSAR) is a novel SAR altimetry data processing technique that makes it possible to focus the complex echoes along the aperture (Egido and Smith, 2017). This study seeks to exploit this potential by using FFSAR to improve range measurement precision and detection of nearshore currents in the NW Atlantic shelf, including 1) the Nova Scotian Shelf (NSS), 2) the semi-closed sea Gulf of Maine (GoM), and 3) the Mid-Atlantic Bight (MAB) (**Fig 1**).

In this highly dynamic coastal system, the well-defined coastally trapped Nova Scotia current (NSC) resides 10-60 km from the coast and advects along the coastal shelf downstream to the GoM and MAB coastal shelves. However, conventional altimetry fails to adequately capture expected sea level slopes tied to these coastal currents.

Sentinel-3A (S3A) FFSAR data (~80Hz) including sea surface height, significant wave height (SWH) and backscattering coeff. Sigma as well as SSH-derived cross-track (nearly alongshore) geostrophic currents (V_g) will be assessed. The reference baseline is unfocused S3A SAR (UFSAR) and the pseudo-low resolution mode (PLRM) data (1Hz and 20Hz) (**Table 1**). Specific **objectives** are to evaluate if the following improvements occur:

1) reduced noise for SSH, SWH, Sigma0 and then SSH-based V_g at scales inside of 50 km from the coastlines

2) increased data recovery nearer to the coast

3) identification of fine-scale signals like small gyres and internal waves in the FFSAR data, in comparison with other processing approaches (e.g. UFSAR)

II. Data and Methods

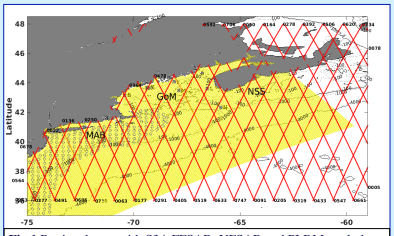


Fig.1 Regional map with S3A FFSAR, UFSAR and PLRM track data availability for year 2018 (cycles 27-39) on the NW Atlantic shelf. The isobaths of 100m-, 200m, etc are also shown. The yellow shaded region is the domain over which a ROMS circulation model (DOPPIO) is run by Rutgers University.

FFSAR (NOAA) (~80Hz) FFSAR : Fully Focused SAR	UFSAR (EUMETSAT) (~20Hz) UFSAR : Un-focused SAR	UFSAR/PLRM (RADS) (~1Hz) PLRM: Pseudo Low Resolution Mode
SSH[a], SSHA[b], SWH, Sigma0, MSS,Geoid, Orbit, GeosCorrs[c] goodness of fit	SSH[a] , SSHA[b], SWH, Sigma0, MSS,Geoid, Orbit, GeosCorrs[c]	SSH[a], SSHA[b],SWH , Sigma0, MSS, Geoid, Orbit, GeosCorrs[c] rms[d] in SSH/SWH/Sigma.,

SSH[a] (Sea Surface Height) =Orbit-Range(instrument correction applied)
SSHA[a] (Sea Surface Height anomaly) =SSH-(Range+GeosCorrs)-MSS
GeosCorrs[c] includes tides ,dry/wet troposphere, iono, SSB, etc .
rms[d] based on respective valid 20hz rate measurements

Table 1. S3A altimeter data availability for 2018 (cycles 27-39)

Performance of FFSAR, UFSAR and PLRM altimeter data

1) Measurement noise level in 20Hz rate data is estimated as the absolute difference between consecutive along-track values of SSH or SSHA (Cipollini et al. 2017)
- Calculate 20Hz FFSAR SSH by bin-averaging 80Hz SSH at a ¼ second(~20Hz) rate,
- Compare noise levels of FFSAR and UFSAR are the same 20Hz rate data (**Fig. 2**)

2) Noise (rms) in 1Hz rate data is estimated,
- For 1Hz UFSAR/PLRM data in RADS, a set of rms parameters estimated from 20Hz measurements are available, i.e "range_rms_ku", "swh_rms_ku", and "sig0_rms_ku",
- To objectively compare noise levels of FFSAR parameters with those from UFSAR/PLRM in 1Hz rate, we estimate 1Hz FFSAR parameters from 80Hz FFSAR as follows,
  - FFSAR:80Hz data is smoothed by a ¼ second(~20Hz) running-mean
  - mean and rms are estimated over 1 second intervals.

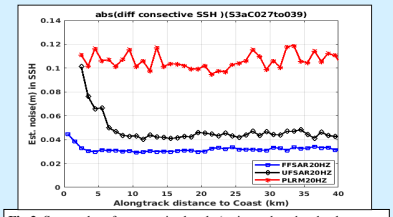


Fig.2 Scatterplot of range noise levels (estimated as the absolute value difference between consecutive 20Hz SSH measurements) against along-track distance from the coast. Median statistic estimated in 1-km wide bins. Encouragingly, FFSAR shows excellent performance - having the lowest noise, nearly 1cm lower than un-focused SAR(UFSAR). [FFSAR QC flag = goodness of fit < 0.05]

III. 1Hz bulk noise statistics of FFSAR, UFSAR & PLRM: SSH, SWH, Sigma0

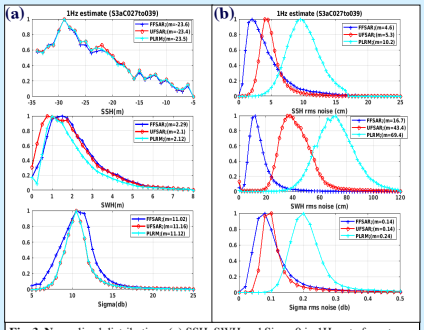


Fig. 3. Normalized distributions (**a**) SSH, SWH and Sigma0 in 1Hz rate from top to bottom for FFSAR, UFSAR and PLRM and (**b**) their corresponding noises.
(**a**) Nearly no bias seen among SSHs; Slight biases exist between FFSAR and UFSAR /PLRM in SWH (<0.2m) and in Sigma0(~0.2dB, respectively);
(**b**) Noise reduction of the FFSAR data (BLUE) is extremely obvious in the three parameters over ones in UFSAR /PLRM, particularly FFSAR noise levels reveal lower than un-focused SAR(RED).

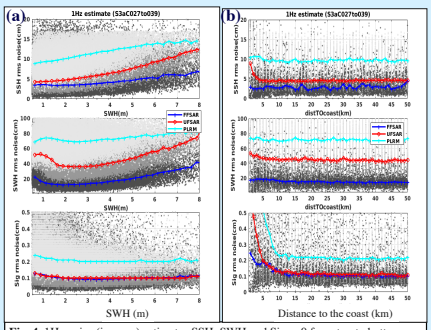


Fig. 4. 1Hz noise (i.e rms) estimates SSH, SWH and Sigma0 from top to bottom as a function of (**a**) SWH and (**b**) distance from the coast, respectively.
1) data show significantly improved FFSAR precision wrt UFSAR and PLRM - a factor of 2 vs. UFSAR in both SSH and SWH .
2) The dependency of FFSAR SSH rms on SWH is clearly reduced (**see a**)
3) FFSAR SSH & SWH rms do not degrade near to the coast as seen in(**b**)

IV. FFSAR vs. UFSAR & PLRM Geostrophic Currents

- **Estimated cross-track geostrophic current Vg**

$$Vg = \frac{g}{f}\frac{\partial(ADT)}{\partial(s)} = \frac{g}{f}\frac{ADT(j+N) - ADT(j-N)}{\Delta(s)}, N > 0$$
$$= \frac{g}{f}\frac{ADT(j) - ADT(j-1)}{\Delta(s)}, N = 0$$

where ADT is the Absolute Dynamic Topography, FFSAR, UFSAR or PLRM; f is Coriolis parameter; s is along-track position; N is the half-span for data points along the track. There are two ways to calculate ADT:
(1) ADT= SSHA +MDT; (2) ADT= SSH –Geoid

- **Assessment of the estimated Vg is based on the following semi-independent current products**
  - GlobCurrent : Total absolute current components: Geostrophic velocity+depth (0m,15m) Ekman velocity at 1/4 deg and daily time step (highly correlated with AVISO gridded SSHA fields)
  - ROMS/DOPPIO 4VAR assimilation model outputs: Total surface 50m mean velocity components in daily res. Current components are interpolated to the track positions, and projected onto the altimeter Vg vector.
- **Vg analyses focus on the shelf with water depth less than 500 m**

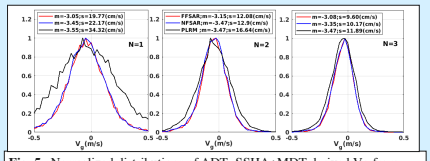


Fig. 5. Normalized distributions of ADT=SSHA+MDT derived Vg from 1Hz FFSAR, UFSAR, and PLRM, a)/b)/c) for half span N=1,2,3 representing 2*N length scale ~15km,~20km and ~40km (1Hz), respectively. Mean (m) and standard deviation (s) are given. Note 1) the mean magnitude of Vg in [-4, -3] cm/s is as expected ; 2) Vg noise in FFSAR/UFSAR is lower than PLRM. (See **Fig 6**)

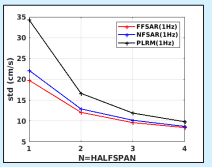


Fig. 6. Vg noise against half span N. Apparently, Vg FFSAR noise is significantly lower than PLRM

V. Two along-track geostrophic current examples

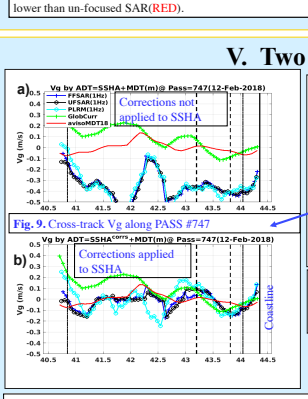


Fig. 9. Cross-track Vg along PASS #747

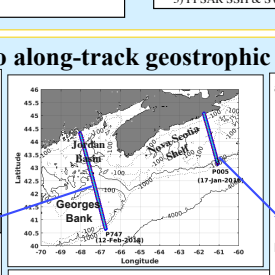


Fig 8. Map with two S3A passes
- Pass#747 across the Georges Band and Jordan Basin in the GoM; calculation,
- Pass#005 across the Nova Scotia Shelf

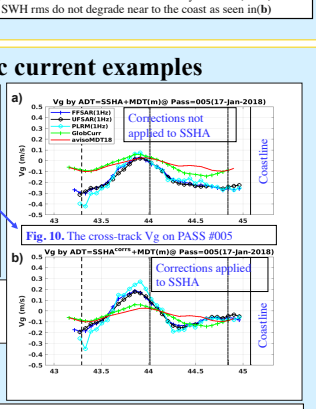


Fig. 10. The cross-track Vg on PASS #005

Fig. 9 and 10 . The cross-track Vg (negatives indicate downstream southwest-ward current) on PASS #747 and #005 (half span N=3 , representing scale of 2*N = ~40km) estimated by ADT = SSHA+MDT, (a) SSHA and (b) SSHA^{corrs} indicates without and with Geophysical (Tide, Atmos, SSB, etc.) corrections, using 1Hz FFSAR, UFSAR, and PLRM data. Simultaneous GlobCurrent (=Geostrophic plus Ekman) and the mean current from AVISO MDT2019 are given as references. What can be summarized 1) SSHA should be geophysically corrected. Corrected data are less biased against GlobCurrent; 2) FFSAR and UFSAR Vg show lower noise than PLRM; (3) Small-scale features such as gyre in Jordan Basin and coastal current on 747 may come into better focus.

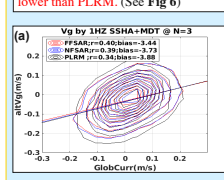
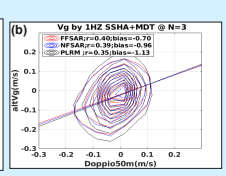


Fig. 7. Scatter plot Vg (1Hz) for half span N=3 case vs. (**a**) Globcurrent and **b**) ROMS DOPPIO model. (Contours are normalized 2D data population distributions). Both comparisons with moderate correlations (~0.4) and with high bias. This is not surprising because both Globcurrent and ROMS estimates used here are suboptimal ground "truth" for validation.



VI. Conclusions

Details of along-track noise observed for SSH, SWH, and Sigma0 data
- Nearly no bias seen among SSHs; Slight SWH and Sigma0 biases observed between FFSAR and UFSAR and PLRM (SWH <0.1m and Sigma0~0.2dB, respectively) (**see Fig.3a**)
- Noise reduction (improved precision) is apparent in FFSAR and UFSAR vs. PLRM for all SSH/SWH and Sigma0, and also FFSAR noise falls below UFSAR for SSH and SWH (**Figs 2, 3b**),
- SWH-dependence of FFSAR SSH noise is apparently reduced vs. the others (**Top Fig4a**)
- FFSAR SSH noise does not increase near to the coast (**Top/mid Fig4b**)

Assessments of ADT-derived cross-track geostrophic current Vg indicate:
- Use of ADT= SSHA +MDT is better than ADT= SSH –Geoid, particularly inside the Gulf of Maine (not shown)
- Geophysical corrections (tides, atm, etc.) should be applied to SSH for regional Vg calculations (**Figs 9,10**)
- Vg estimate noise for FFSAR and UFSAR is significantly lower than for PLRM (**Fig.6**), and FFSAR is slightly lower than UFSAR.
- Moderate correlations (~0.4) are found when comparing along-travk Vg to GlobCurrent and ROMS products.

Future steps in terms of this regional analysis of FFSAR SSH data
- Detect and examine small-scale signals that may represent internal tides/waves, narrow currents, shelf break fronts, and coastally-trapped currents. Use improved SSHA to better isolate known gyres.

References
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