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ON THE DE-RAMPING OF SLC-IW TOPS SAR DATA AND OCEAN CIRCULATION PARAMETERS ESTIMATION

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ABSTRACT

The spectral characteristics of single-look complex - interferometric wide (SLC-IW) swath, terrain observation by progressive scan (TOPS), are significantly different from those of strip-map (SM). Due to the burst mode and series of sub-swaths, the target area is scanned for a short period of time. Therefore, swath width comes at the expense of azimuth resolution. To eliminate quadratic phase drift and achieve SLC baseband, significant processing is required. De-ramping is a necessary step to compute ocean circulation parameters. In this work, we extract ocean parameters from the complex echo signal based on data driven Doppler centroid (f_{DC}) regardless of the OCN product information and geophysical f_{DC} image. The radial surface velocity (RSV) is retrieved from Doppler history, and the significant wave height (SWH) is estimated with an empirical relationship of RSV. The results of ocean circulation parameters are promising when compared with benchmark and in-situ data. This work demonstrates the efficacy and necessity of de-ramping the TOPS data for subsequent use in a variety of ocean remote sensing applications.

Index Terms— IW-TOPS, De-ramping, f_{DC}, RSV, SWH

1. INTRODUCTION

Sentinel-1 is a well-known new generation of ESA C-band SAR that is an open source and provides data in real time. SAR plays an important role in ocean remote sensing. It offers a very good complement for mapping and monitoring small-scale circulation in coastal areas, such as surface velocity/current, wave height, and directional swell [1]. The wide-swath coverage is achieved by the novel TOPS acquisition mode, which is an enhanced version of ScanSAR [2]. The IW TOPS mode operates for the systematic monitoring of large land and coastal areas. Due to burst-mode, SLC-IW TOPS differs from SM in terms of scanning, and the system observes in the form of sub-swaths periodically. As a result, the target region is scanned only for a fraction of the burst duration, and thereby the illumination is reduced, and the wide swath comes at the cost of azimuth resolution [3].

The IW TOPS data preserves quadratic phase term in the azimuth direction which leads to phase ramps, and hinders DC, thus this term needs to be eliminated for the subsequent applications. De-ramping is required to eliminate the phase term and achieve spectral centering, which can be done, either to make use of time information (η, τ) relative to each burst to design a chirp function or utilizing SNAP toolbox to de-ramp the SLC data [4, 5]. Due to the azimuth null spacing between every burst, it generally requires careful analysis.

The azimuth scanning in TOPS at different positions and squint angles within the burst dominates the f_{DC}, which compromises other parameters associated with f_{DC}. In fact, in order to precisely observe parameters of interest, it is necessary to center the spectrum around zero Doppler and perform f_{DC} estimation.

In the literature, the ocean circulation parameters for IW data are estimated based on the information provided in the OCN level-2 product, or geophysical interpretation are calculated from satellite orbit parameters [6, 7]. The geophysical prediction of f_{DC} from the orbit parameters velocity V, and incident angle θ in practical is usually with low resolution of f_{DC} which hardly fulfills the need of SAR imaging. We use doppler shift to estimate the f_{DC} with a high resolution from complex echo data.

In this article, we discuss the de-ramping of SLC-IW TOPS data using chirp signal and also design a state of the art de-ramping method in the SNAP tool. The ocean parameters are estimated using SAR Doppler frequency shift. To better understand, comparisons are made with benchmark data.

2. THE PRINCIPLE OF DE-RAMPING

The presence of phase term hinders the components related to azimuth time, i.e. f_{DC}. To remove this term, we developed chirp signal for de-ramping given in [4], and discuss the efficient use of SNAP tool to achieve de-ramping [5].

2.1. Chirp signal formation for de-ramping

To remove the quadratic drift, it is essential to move spectral component of SLC-IW to baseband. The phase term needs to be multiplied in time domain with SLC signal S_{SLC}. The phase term for de-ramping is defined as:

$$\phi(\eta,\tau) = \exp\{(-\mathrm{j}\pi \mathrm{k_t}(\tau))(\eta - \eta_{\mathrm{ref}}(\tau))^2\} \qquad (1)$$

whereas, reference time $\eta_{ref}(\tau)$, and Doppler centroid rate $k_t(\tau)$ are function of range samples, while η is zero-Doppler azimuth time. Finally, after evaluation of necessary parameters, de-ramping to cancel quadratic drift can be achieved by simply multiplying phase term with SLC signal.

$$S_d(\eta, \tau) = S_{SLC} \times \phi(\eta, \tau) \tag{2}$$

2.2. De-ramping by using SNAP tool

Alternatively, de-ramping can be achieved in SNAP tool using Sentinel-1 TOPS operator. The methodology is given in Fig. 1. As TOPS consists of multiple swaths, at first split the required swath, and apply "deramp-demod" operator. Here, $\phi(\eta, \tau)$ is the phase information obtained during de-ramping process while i and q are real and imaginary parts respectively. To compensate the azimuth null spacing (to avoid residual ramps) between each burst, the operator "deburst" greatly helps in achieving a refined scene and removing stripes that impede feature extraction. Since we are interested in ocean parameters only, the SNAP tool helps to mask out land area, thus to get better estimates. The land-ocean mask is applied to avoid Doppler effect caused by dynamic objects present on the land.

3. OCEAN CIRCULATION PARAMETERS ESTIMATION

The ocean circulation parameters in this paper are extracted from complex SAR data that are data-driven, whereas the parameters in the benchmark/reference are predicted from ocean product (OCN) information and based on the polynomials given in the metadata [7].

On that account, Doppler centroid f_{DC} is the essence of this topic. In the literature, the geophysical f_{DC} estimation algorithm is applied to obtain f_{DC} image, which requires the correction for miss-pointing DC. In this paper, to estimate f_{DC} we use correlation doppler estimation (CDE) which takes an advantage of azimuth shift and the use of PRF [8]. To achieve doppler, the de-ramped signal $S_d(\eta, \tau)$ correlates with its shifted version in azimuth direction:

$$C(\eta, \tau) = \sum_{\eta} S_d(\eta, \tau) S_d^*(\eta + \Delta\eta, \tau) \tag{3}$$

The phase correlation ϕ_{acc} estimated by the mean value of the correlation coefficient in the range direction with a sum mean kernel.

$$\phi_{acc}(\eta, \tau) = arg(\sum_{k=1}^{N} C(\eta, \tau_k)) \tag{4}$$

where N is the average number of cross correlation coefficients. The Doppler centroid 'f_{DC}' based on the PRF and phase correlation function is calculated as:

$$f_{DC}(\eta, \tau) = -\frac{PRF}{2\pi} \phi_{acc}(\eta, \tau) \tag{5}$$

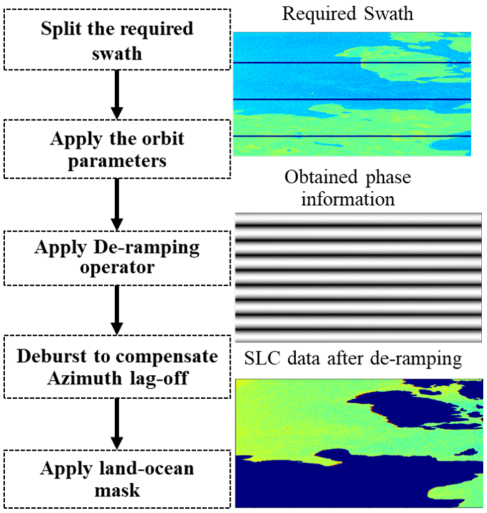

Fig. 1. De-ramping by using SNAP tool. Required swath paves burst of data, after de-ramping, final data is in baseband.

Table 1. Essential acquisition parameters of SAR data.

Parameters	Values
Acquisition date	June 07, 2020
Time	17:47:01
PRF	1717.1289 Hz
Data type	S1B IW SLC
Incident Angle	43.46 [deg]
Polarization	VH and VV
Latitude	58.45 to 58.95 [deg] N-S
Longitude	-3.0 to -3.7 [deg] E-W

The radial surface velocity (RSV) is derived from f_{DC}, incident angle θ, and wave number k_r, as given below [9]:

$$V_D = -\frac{\pi f_{DC}(\eta, \tau)}{k_r \sin\theta} \tag{6}$$

while calculated value of k_r is 113.28 m^{-1} for Sentinel-1. Thus, V_D is used to retrieve SWH in time domain based on empirical relationship given as [10]:

$$H_s = 4\sqrt{(\frac{1}{K}\sum_{i=1}^{K}(V_{D_i}))^2} \tag{7}$$

H_s is an important parameter for seashore engineering. The SWH is the average wave height in a given period of time K, which is the azimuth time span of data under observation.

4. RESULTS AND DISCUSSION

The SAR scene in this paper was taken from the reference location given in [7]. The essential acquisition parameters

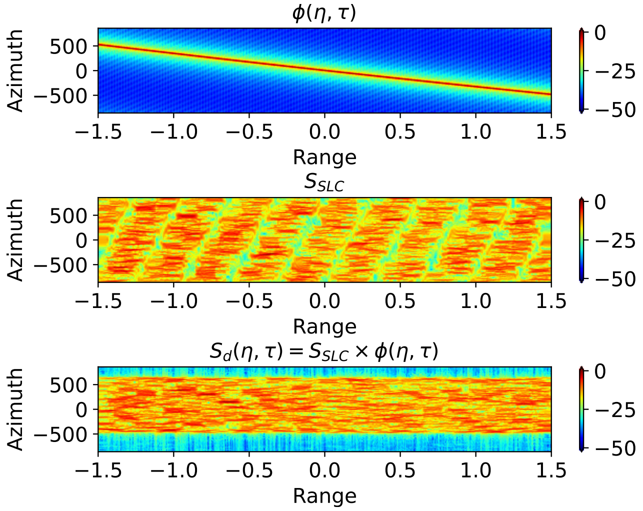

Fig. 2. $\phi(\eta,\tau)$ is the de-ramping function, while S_{SLC} represents the bursts mode data SLC-IW TOPS before de-ramping, and $S_d(\eta,\tau)$ is baseband data after de-ramping.

of data are given in Table.1. Regardless of the OCN product and gridded-based low resolution, we estimate ocean circulation parameters with high resolution based on SAR Doppler frequency shift. Beforehand, for TOPS data, de-ramping is required to avoid phase ramps preserved in the data. The de-ramping is done so far to eliminate quadratic drift of phase term by chirp signal or using SNAP tool. When phase term $\phi(\eta,\tau)$ is multiplied with original SLC signal S_{SLC} the data moves to baseband domain, as shown at the bottom of Fig. 2, though proper f_{DC} estimation is required because the data is not centered.

The ocean circulation parameters include RSV, SWH and directional swell. We evaluate the RSV using f_{DC} estimated by the CDE method, which perfectly matches the benchmark data shown in Fig. 3. The RSV is in a good match and reaching up to 2.5 m/s in the core of the stream. The surface velocity on the ground is zero as land is masked and paving zero doppler. As compared to benchmark data, we achieve the same signature of RSV. Despite the difference, we used data driven parameters for ocean circulation parameter estimation rather than OCN product information. Nevertheless, spatial resolution agrees and clear stream can be observed.

RSV is an associated parameter for retrieving significant wave height, which is shown in Fig. 4. The wave height varies by a few meters; we use dual polarization VH, which provides a better estimate of H_s than single polarization. The numerical merit of the comparison are made for V_D and H_s between two polarizations (VH and VV). Both calibrated with good spatial correlation of 0.945, and observing the same circulation pattern with minimum RMSE of 0.225 m/s, while mean absolute error (MAE) is negligible around 0.0522 m. However, we find that VH polarization estimates are more reliable than VV polarization estimates because co-polarization is sensitive to angle of incidence and exhibits scalloping.

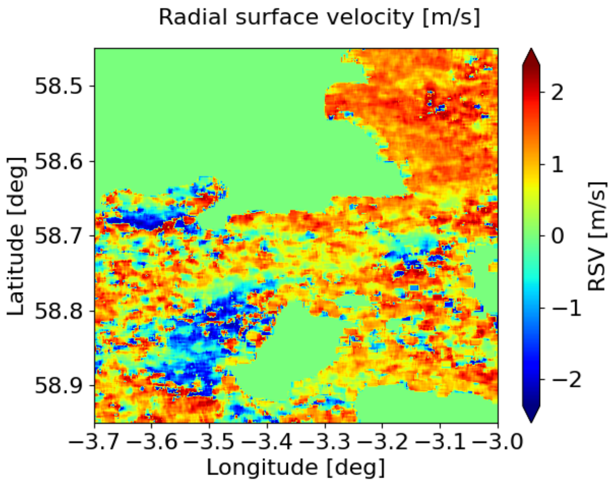

Fig. 3. RSV (m/s) derived from SLC-IW TOPS data based on data-driven Doppler centroid (f_{DC}).

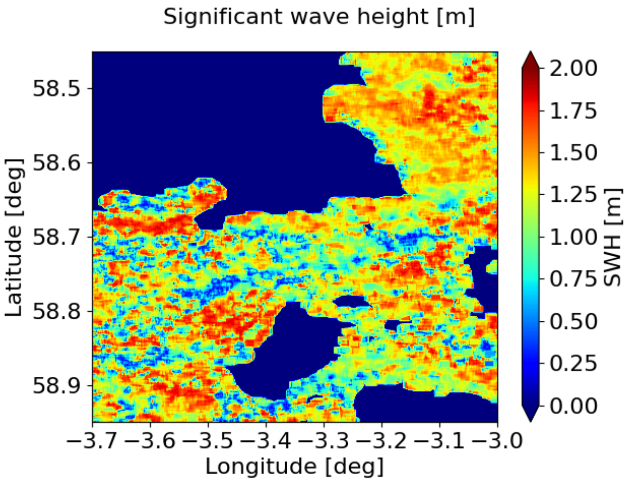

Fig. 4. SWH (m) derived from RSV and averaged over the given period of azimuth time samples.

The synergistic data of ocean parameters is provided by the *OceanDataLab* given at https://www.oceandatalab.com/syntool. The Syntool solution aiming to provide in-situ data for ocean remote sensing and seashore engineering. On that account, the direction vectors retrieved from in-situ data shown in Fig. 5, represents a distinct and strong tidal stream directing from east to west at the core. Whereas, Fig. 6, represents benchmark result. Despite the difference in absolute value and with a high resolution of imagery, both the retrieved and benchmark data show the same directional swell, particularly the spatial variation and numerical values.

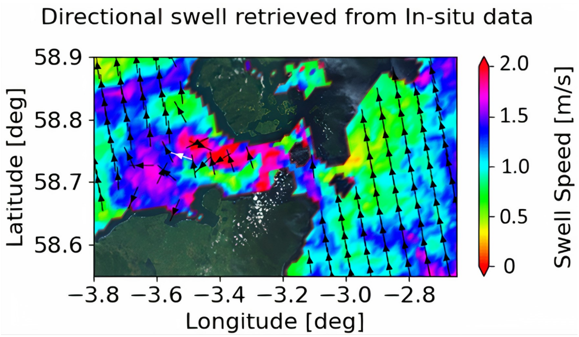

Fig. 5. Directional swell with absolute values extracted from in-situ data, color-map presents current.

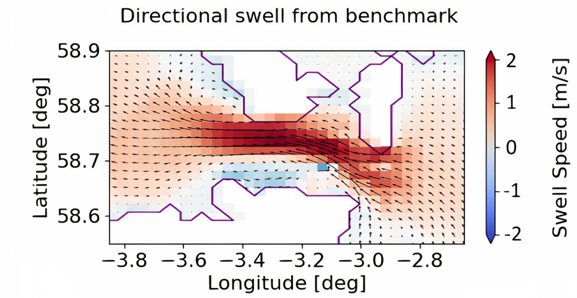

Fig. 6. Directional swell provided by the benchmark data [7], and vectors represents the direction.

5. CONCLUSION

In this paper, we proposed de-ramping of TOPS data and retrieval of ocean circulation parameters from echo signals with high resolution of visual interpretation. The method developed in SNAP tool de-ramps TOPS data and data set achieved after calibration fulfills the need of ocean remote sensing. The retrieved ocean circulation parameters based on estimated f_{DC}, and their numerical values are compared with benchmark data (where f_{DC} image obtained from geophysical parameters) and observed with similar characteristics and, however, with high-resolution. The numerical merit of comparisons among VH, and VV polarization are in a good spatial correlation with minimum RMSE and negligible MAE. The reasonable parameter estimates demonstrating the efficacy and necessity of de-ramping for the SLC-IW TOPS data. The error estimation lacks in this paper, and some physical process remain to be investigated regarding ocean current field, which will be carried out in future work.

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