IMPROVED LLM METHODS USING LINEAR REGRESSION

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ABSTRACT

This paper is focused on investigations of the improved correction of the effect of variation in incidence angle on ScanSAR data. Conventional correction methods (such as LLM, locally linear mapping) typically assume that each target class has a similarity distribution in the middle of the image. The objectives of this study are to extend the correction algorithm to full swath width without any assumptions. For a target class only distributed on one or both sides of the image, interpolation or extrapolation of the confidence interval is realized using the linear regression technique based on the exponential model. The position of the reference band is then determined and the correction is performed. Experiments were performed on ENVISAT ASAR and RADARSAT-2 ScanSAR data. The results show the effectiveness of the proposed method.

Index Terms—ScanSAR, sea ice, incidence angle correction, linear regression

1. INTRODUCTION

Sea ice monitoring is very important for climate research, shipping traffic and marine resource development. Synthetic Aperture Radar is an important tool for sea ice monitoring with its unique day and night imaging capability. Among its various modes of operation, ScanSAR mode is widely used as the main means of large-scale observation. However, there is a significant incidence angle effect in Wide Swath Mode, that is, the radar returns will be stronger in the close range and decrease progressively towards the far range. This effect will affect the interpretation of ScanSAR data.

Several methods of efficiently compensating for variations of the incidence angle have been proposed, including cosine-based corrections [1] and other empirically based approaches [2], [3]. The look up table (LUT) technique can be applied to adjust recorded backscatter intensities to a nominal incidence angle [4]. Class-based normalization was first introduced in [5]. A normalization approach called HIST, which is based on a class histogram matching procedure, was proposed by [6] to adjust multi-incidence Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) data to a fixed angle of incidence. Additionally, the class-based locally linear mapping (LLM) technique is remarkable, and each class in ScanSAR data can be normalized to a nominal incidence angle in the middle of the image [7]. However, the assumption that sea ice types have similarity distributions in the middle of the image may often be invalid. This work extends the correction algorithm of [7] to the whole incident angle range of the image without any assumptions.

The paper is organized as follows: Section 2 details the procedure of the proposed method. Experimental results are given in Section 3 and conclusion in Section 4.

2. METHOD

First of all, a binary mask for each class in the original image is constructed. For the convenience of discussion, the masks in this paper are currently performed manually based on the ice chart and expert knowledge. Similar to the steps described in the LLM algorithm, the analysis unit for radar backscattering is the azimuth band of incidence angle. Each band in the image represents 1° of the incidence angle's observation, and the backscatter coefficients ($\sigma°$ values) for a particular target class in each band are numerically sorted. The sorted values are then divided into N subsets and the mean of each subset is calculated. The selection of *N* depends on the numerical range of the σ^0 values and should be consistent across all azimuth bands.

When N is large enough, the $\sigma°$ values within each subset are considered to be locally linear, so that these values in an actual azimuth band can be mapped into the corresponding subset in the reference band. In the actual azimuthal band, the difference between the $\sigma°$ value of a pixel and the *N* mean values are calculated, and the mean value closest to the pixel value is what we need to map.

The distance between classes is determined by the selection of the reference band. In general, a reference band is selected approximately half of an image. But if the reference band of all ice classes is placed at the center of the image or a fixed angle, it is difficult to achieve the maximal difference between the σ° values of different target classes. Therefore, for each target class with a range of incidence angles from θ_{near} to θ_{far}, it is assumed by LLM that more than one azimuth band occurs within the interval $[(3\theta_{near}+\theta_{far})/4, (\theta_{near}+3\theta_{far})/4]$, which has a similar distribution of the target class. However, the above assumption may often be invalid, for example, when a target class is only distributed in the upper and lower 1/4 interval, or only within one of the intervals. Consequently, the proposed method will interpolate or extrapolate the interval $[(3\theta_{near}+\theta_{far})/4, (\theta_{near}+3\theta_{far})/4]$ using the linear regression technique and determine the reference band position corresponding to such distribution.

The exponential model is based on extensive measurements at the University of Kansas [8]. Through experiments, it is found that the average change of the scattering coefficient of the North American terrain in summer has such an exponential relationship. Ulaby also reported a similar relationship, and pointed out that the exponential form is suitable for snow-covered areas and sea ice observations [9]. It seems that exponential model is the best one of the many experimental models. The model is defined as follow [8]:

$$I=I_0 e^{-\theta_i/\theta_0} \qquad (1)$$

where I is the surface intensity observed, I_0 is the intensity (brightness) of an ideal reflector at the observation wavelength, θ_i is the wave incident angle and θ_0 is the constant associated with a target class.

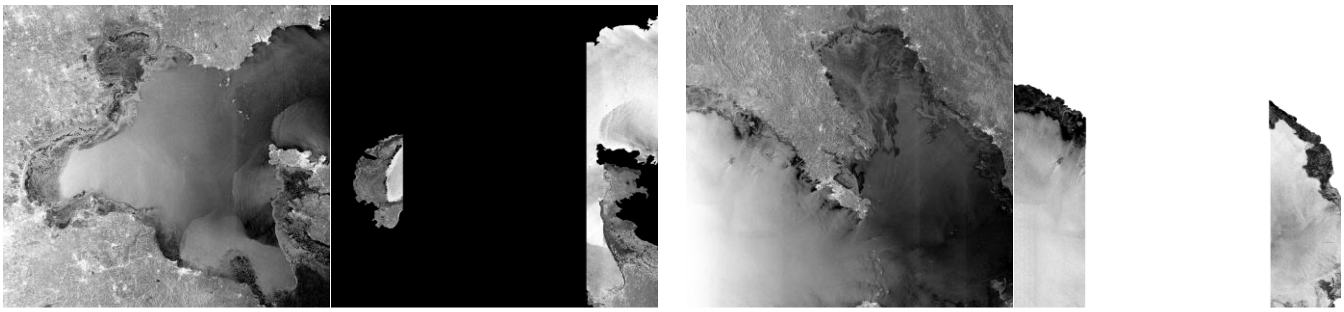
A better estimation of θ_0 was sought as it will produce the best fitting curve along the range. For this purpose, the coefficients of a linear regression model were calculated with the following regression equation:

$$y=mx+n \qquad (2)$$

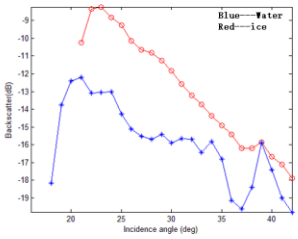
where $y=10\log_{10} I=\sigma^0$, $x=\theta_i$, $m=\left(-\frac{10}{\theta_0}\right)\log_{10} e$, $n=10\log_{10} I_0$. The coefficients m and n can be estimated using least squares.

3. RESULT AND ANALYSIS

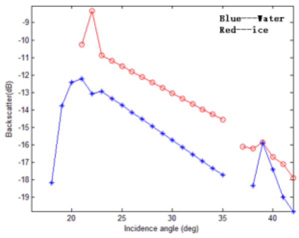
The experimental data used in this paper are provided by the ASAR instrument on ENVISAT satellites and the RADARSAT-2. Two Bohai Bay images were collected by ENVISAT ASAR ScanSAR with a swath width of 400 km and a spatial resolution of 150 m. One was acquired on January 31, 2010, with a descending right-looking orbit for which the range increases from east to west; another image was acquired over the same area on January 14, 2010, during which the range distance increased towards the east. To facilitate the interpolation, the pixels within the interval $[(3\theta_{near}+\theta_{far})/4, (\theta_{near}+3\theta_{far})/4]$ are filled with white color. The RADARSAT-2 data was acquired over the Gulf of Saint Lawrence on February 27, 2009(centered at 48°47' N, 60°58' W), and it has a wide incidence angle ranging from 23° to 46°. In the image, open water is distributed only in the interval $((\theta_{near}+3\theta_{far})/4, \theta_{far}]$. The result of experiments of average backscattering σ° using linear regression technique are shown in Fig.1-3 and table1:



(a) Original image (b) After correction (c) Original image (d) After correction

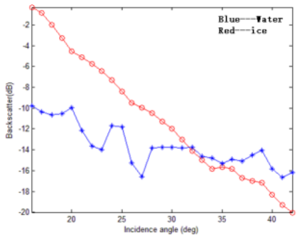


(c) Original backscatter

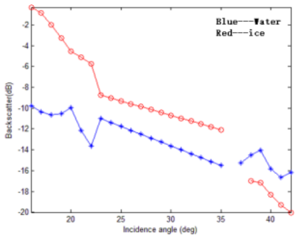


(d) Backscatter after correction

Fig1. Bohai Bay data (201400114)



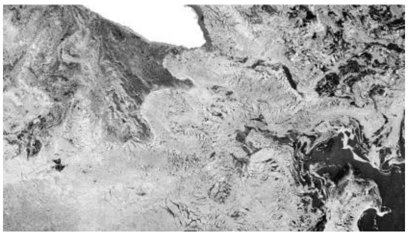
(c) Original backscatter



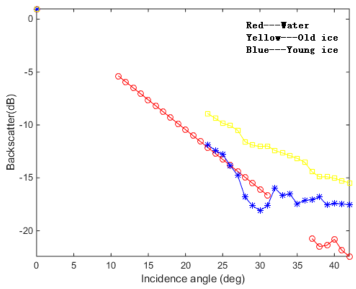
(d) Backscatter after correction

Fig2. Bohai Bay data (20100131)

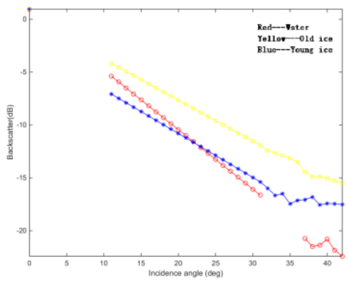
(a) Original image



(b) After correction



(c) Original backscatter



(d) Backscatter after correction

Fig3. The gulf of Saint Lawrence before correction and after correction

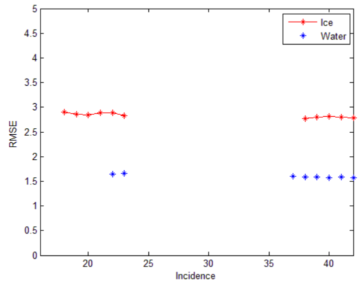
Table1. Corrected results using linear regression

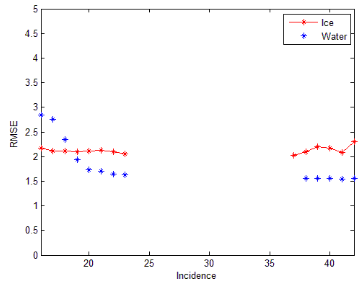
Date/class		m	n	θ_0	Ref_{angle}	Ref_{ori}
Bohai Bay(20100114)	Water	-0.43613	0.63348	2.2929	23°	23°
	Ice	-0.20663	-9.6842	4.8397	35°	36°
Bohai Bay(20100131)	Water	-0.73147	10.8224	1.3671	23°	23°
	Ice	-0.21228	-7.2052	4.7107	35°	27°
The gulf of Saint Lawrence	Water	-0.5631	-2.6750	1.7760	25°	11°
	Young ICE	-0.4152	-2.5051	-2.5051	19°	23°
	Old Ice	-0.3878	0.1032	2.5786	19°	23°

Quantitative analysis is necessary in order to evaluate the efficiency of this method, we introduce the RMSE (root mean square error), which is defined as follows:

$$RMSE = \sqrt{\overline{\left[(\sigma^{\circ}_{norm} - \sigma^{\circ}_{act})^2\right]}} \qquad (3)$$

Where σ°_{act} and σ°_{norm} are radar backscatter values before correction and after correction and expressed in dB; "—" represents mean value. The RMSE values for each experiment are shown in Fig.4-6:





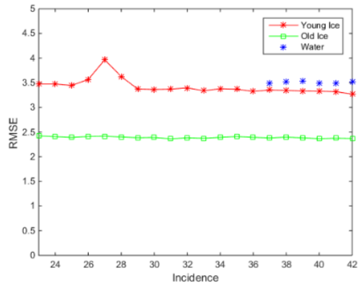


Fig.4 The Bohai Bay(20100114) RMSE **Fig.5** The Bohai Bay(20100131) RMSE **Fig.6** The gulf of Saint Lawrence RMSE

Through the RMSE analysis of three images, it is not difficult to see that the correction effect of SAR sea ice image is valid by combining linear regression and LLM method.

4. CONCLUSION

In this paper, we have improved the LLM method through the linear regression technique. From the experimental results, we can see that for the image that is distributed outside $[(3\theta_{near}+\theta_{far})/4, (\theta_{near}+3\theta_{far})/4]$ in the image, the improvement is obvious and effective, but for the junction parts between $[(3\theta_{near}+\theta_{far})/4, (\theta_{near}+3\theta_{far})/4]$ internal and external,the results is still not smooth enough, This will be studied in future work.

5. ACKNOWLEDGEMENTS

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