POLARIMETRIC CALIBRATION AND ASSESSMENT OF GF-3 IMAGES IN STEPPE

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ABSTRACT:

The GaoFen-3 (GF-3) satellite is the first fully polarimetric synthetic aperture radar (PolSAR) satellite in China. It has three fully polarimetric imaging modes and is available for many applications. The system has been taken on several calibration experiments after the launch in Inner Mongolia by the Institute of Electronics, Chinese Academy of Sciences (IECAS), and the polarimetric calibration (PolCAL) strategy of GF-3 are also improved. Therefore, it is necessary to assess the image quality before any further applications. In this paper, we evaluated the polarimetric residual errors of GF-3 images that acquired in July 2017 in a steppe site. The results shows that the crosstalk of these images varies from -36dB to -46dB, and the channel imbalance varies from -0.43dB to 0.55dB with angle varying from -1.6 to 3.6 degree. We also made a PolCAL experiment to restrain the polarimetric distortion afterwards, and the polarimetric quality of the image got better after the PolCAL processing.

1. INTRODUCTION

The GF-3 satellite is the first fully polarimetric synthetic aperture radar (PolSAR) satellite in China. It has 12 imaging modes, including StripMap mode, ScanSAR mode, Spotlight mode, and ultra-fine strip mode. Furthermore, it has three PolSAR imaging modes, which are full-polarimetric strip Ⅰ, full-polarimetric strip Ⅱ, and wave imaging mode. Therefore, the satellite is available for many research and applications, and its designed applications are marine monitoring, disaster assistance, water monitoring, and meteorological observation. To carry on quantitative research and geophysical parameters inversion, polarimetric calibration (PolCAL) is requisite for PolSAR images. Since the launch of the satellite, the Institute of Electronics, Chinese Academy of Sciences (IECAS) has made several ground verifications in Inner Mongolia, and upgraded the calibration strategy of GF-3. Therefore, it is necessary to assess the image quality before any further researches or applications.

There are dozens of operational microwave types for fully polarimetric mode of GF-3, and the PolCAL situation of each wave type may be different. We can assess the polarimetric quality of some imaging wave types with the images that we acquired in steppes of Inner Mongolia. Although there are several new algorithms lately in many aspects (Shi, 2014, Villa, 2015, Souissi, 2016), the PolCAL methods based on reflection symmetry (Quegan, 1994) and scattering reciprocity (Ainsworth, 2006) are widely used in current PolSAR systems. To assess the polarimetric quality of images, methods based on manmade calibrators (Freeman, 1990, Whitt, 1991) are most accurate. In this study, we assessed the residual errors of GF-3 images by calculating the polarimetric distortion matrices (PDMs) with manmade calibrators and distributed targets. Subsequently, we carried on PolCAL experiment on the GF-3 standard images to restrain the residual errors.

2. METHODS

2.1 The Polarimetric Distortion Model

During the observation, the scattering matrices of ground objects that observed by PolSAR systems are mixed with polarimetric errors. These errors includes the crosstalk, the co-pol channel imbalance, the cross-pol channel imbalance, and the system noise. Generally, the errors are expressed in PDMs by the PolSAR distortion model, which denotes that the real scattering matrices of ground objects are transformed into observed scattering matrices. And the model is (Quegan, 1994) :

$$\begin{pmatrix} O_{hh} & O_{hv} \\ O_{vh} & O_{vv} \end{pmatrix} = A \begin{bmatrix} 1 & w \\ u & 1 \end{bmatrix} \begin{bmatrix} k & 0 \\ 0 & 1 \end{bmatrix} \begin{pmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{pmatrix} * \begin{bmatrix} k & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \alpha & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & z \\ v & 1 \end{bmatrix} + \begin{bmatrix} N_{hh} & N_{hv} \\ N_{vh} & N_{vv} \end{bmatrix} \tag{1}$$

In the model, $S_{hh}, S_{hv}, S_{vh}, S_{vv}$ compose the true scattering matrix of the ground object, with each of them representing a polarization channel. $O_{hh}, O_{hv}, O_{vh}, O_{vv}$ compose the observation matrix. The u, w, v, z parameters are the crosstalk distortions. The k term is the like-pol channel imbalance error, and α is the cross-pol channel imbalance error. Argument A is the absolute calibration factor that will be used in the radiometric calibration. Letters $N_{hh}, N_{hv}, N_{vh}, N_{vv}$ represent the system noise in different channels.

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2.2 Scattering Properties of PolCAL Reference Targets

The landform of experiment site is steppe. The scattering mechanism of sparse grassland obeys the reflection symmetry attribute. This means that the objects are symmetric by the line of sight in radiometric scattering and the coherence of the like-polarization (like-pol) channel and cross-polarization (cross-pol) channel in their average covariance matrix is neglected. Apart from some particular manmade targets, most scattering media conform to the reciprocity property, i.e. $S_{hv}=S_{vh}$, which leads to the following form of covariance matrix (Ainsworth, 2006) :

$$[C]=\begin{bmatrix} C_{hhhh} & 0 & 0 & C_{hhvv} \\ 0 & \beta & \beta' & 0 \\ 0 & \beta' & \beta & 0 \\ C_{vvhh} & 0 & 0 & C_{vvvv} \end{bmatrix} \qquad (2)$$

in which the superscript * is the complex conjugate operator, the values of β and β' are real, and the others are complex. Since reciprocity implies that the two cross-pol channels are identical, for calibrated data, all the four correlation terms of the cross-pol channel must in fact be identical if the system noise is neglected. Based on these particular attributes, Quegan proposed a unified PolCAL method (Quegan, 1994) , which is widely used in the current calibration processing of PolSAR images.

During the image acquisition, there were some polarimetric active radar calibrators (PARC) installed in this test site. There are three kind of PARCS, and the scattering matrices are:

$$S_x=A_x\begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}, \quad S_y=A_y\begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}, \quad S_z=A_z\begin{bmatrix} 1 & 1 \\ e^{i\pi} & e^{i\pi} \end{bmatrix} \qquad (3)$$

The method using PARCs can get more accurate results but is only valid at a small place where the calibrators are placed. Therefore, both of the polarimetric methods that based on scattering symmetry and PARCs are deployed to evaluate the polarimetric errors.

3. EXPERIMENTS

The polarimetric calibration of GF-3 is a cyclical procedure, and the images within the same period and operational wave type are calibrated by the same PDMs. In this PolCAL strategy, the real PDMs of images within the same period should be similar, otherwise the images will still be distorted after PolCAL. Considering this, we assess the PDMs of images to verify the consistency, and the metadata of these images are listed below. The experiment site was in the Inner Mongolia. The terrain of the site is flat and far away from habitation. Meanwhile, the land cover of the site is mostly sparse grassland, making it a perfect field for PolCAL.

3.1 Polarimetric Residual Error in the GF-3 Images

The residual polarimetric errors are calculated with Quegan method, and the results are showed below. The polarimetric errors, i.e., the amplitude of cross-polarization channel imbalance (Alpha Amplitude), phase of cross-polarization channel imbalance (Alpha Phase), and the amplitude of crosstalk (Crosstalk Amplitude) are evaluated.

Acquisition date	Image ID	Central look angle	Wave code
2017-06-24	2441191	43.92	208
	2441190	43.91	208
2017-07-06	2463755	47.45	213
	2463754	47.44	213
2017-07-11	2475549	40.01	203
	2475550	40.01	203
2017-07-16	2491702	30.43	195
	2491701	30.43	195

Table 1. Parameters of the experimental GF-3 images

Currently, the satellite PolSAR systems use Transmit and Receive Modules (TRM) to control the processing microwave (Shimada, 2011) . The images with the same wave code will have alike attributes. From the residual errors showed in **Fig 1** and **Fig 2** we can see that the images with the same wave code have similar polarimetric residual error, and they also have consistency in different image range.

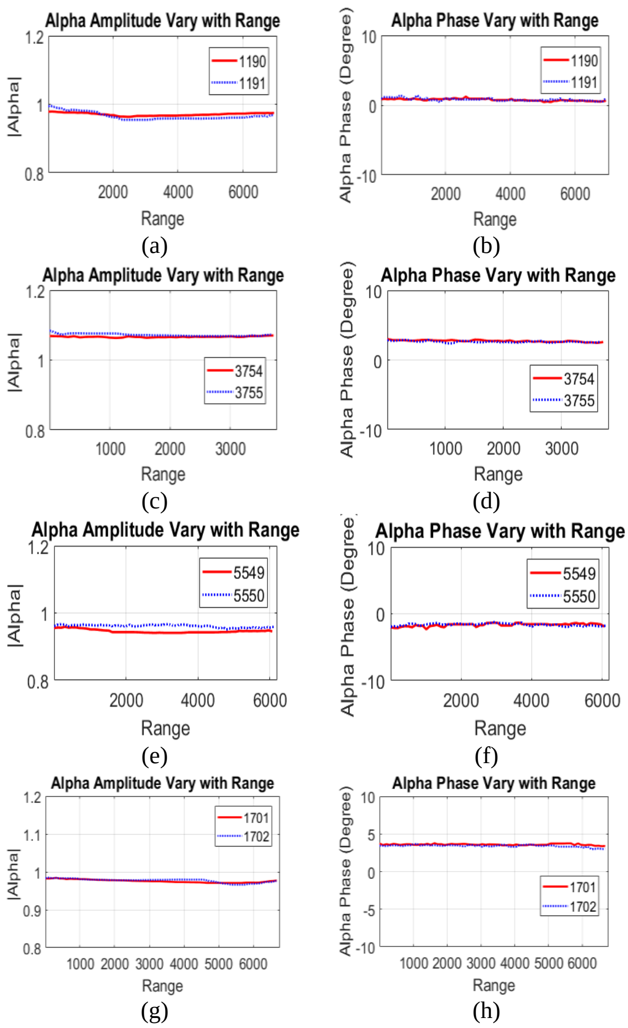

Figure 1. The residual Alpha Amplitude and Alpha Phase error in the image. The legend denotes the image number. Figure (a), (c), (e), (g) show the Alpha Amplitude error; Figure (b), (d), (f), (h) show the Alpha Phase error.

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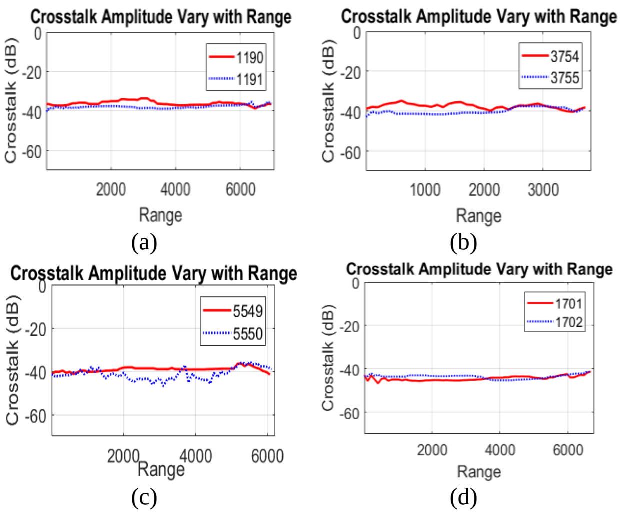

Figure 2. The residual Crosstalk Amplitude error in the image.

Image ID	Crosstalk (dB)	|α| (dB)	Arg(α) (deg.)
2441191	-37 ± 4.0	-0.28 ± 0.15	0.8 ± 0.3
2441190	-36 ± 2.9	-0.22 ± 0.04	0.8 ± 0.2
2463755	-40 ± 3.8	0.55 ± 0.19	2.6 ± 0.1
2463754	-38 ± 2.4	0.48 ± 0.01	2.7 ± 0.1
2475549	-39 ± 4.3	-0.43 ± 0.07	-1.6 ± 0.4
2475550	-41 ± 3.3	-0.30 ± 0.03	-1.6 ± 0.2
2491702	-43 ± 4.1	-0.16 ± 0.06	3.5 ± 0.4
2491701	-46 ± 3.9	-0.18 ± 0.03	3.6 ± 0.1

Table 2. Polarization residual errors after PolCAL

To give a quantitative results, we calculated the average residual errors along the image range, see in Table 2. The results shows that the crosstalk of these images varies from -36dB to -46dB, and the channel imbalance varies from -0.43dB to 0.55dB with angle varying from -1.6 to 3.6 degree.

3.2 PolCAL Refinement Test on the Image

To suppress the residual polarimetric errors in the GF-3 images and refine the image quality, we carried on a PolCAL test. We calibrate the image by Quegan PolCAL method with polarimetric parameters that showed in the previous section. To verify the effect of PolCAL, we compared the polarimetric errors of the images before and after PolCAL. We chose Freeman PolCAL method that based on PARCs to calculate the polarimetric errors, which is more objective.

There are three PARCs that satisfy the formulas in section 2.2 on the image 2441191. So we carried PolCAL test on this image. To compare the polarization error conveniently, the parameters calculated by Freeman PolCAL method were transformed into the format of Quegan PolCAL method. The experiment result is in **Table 3.** The results indicate that the polarization errors calculated by Quegan method and Freeman method are a little different. Nevertheless, the Quegan PolCAL can still improve the polarimetric quality of the image. We can see that the channel imbalance was suppressed to an acceptant level, while the crosstalk changed little, which were already in a fine accuracy before PolCAL.

4. CONCLUSION

In this paper, we presented an experiment on the polarization quality of GF-3 images in a steppe site. Eight images acquired in July 2017 were tested. The results indicates that the images with the same wave code have similar polarimetric residual error and are the errors are consistent in image range. The crosstalk of these images varies from -36dB to -46dB, and the channel imbalance varies from -0.43dB to 0.55dB with angle varying from -1.6 to 3.6 degree. We also showed an image PolCAL experiment in this paper, and the polarimetric residual errors were suppressed to a preferable level after the PolCAL. Generally, the calibration program of GF-3 is still in progress, and the image quality of this satellite may get better over time.

	Crosstalk Amplitude(dB)				Channel Imbalance			
	W	U	V	Z	|α| (dB)	Arg(α) (deg.)	|k| (dB)	Arg(k) (deg.)
Before PolCAL Quegan	-48.2	-39.0	-43.9	-37.8	-0.40	0.82	-0.05	-5.37
Before PolCAL Freeman	-47.8	-40.6	-54.0	-36.1	-0.29	3.71	-0.39	-7.54
After PolCAL Freeman	-38.9	-43.8	-45.9	-44.9	0.07	2.33	-0.30	-1.83

Table 3. Polarization errors before and after PolCAL

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