Response to Reviewer 2

We thank the Reviewer 2 for valuable suggestions to improve our manuscript. In this revised version, we try out best to clarify the problems and make our manuscript better. The following are the corresponding comments and responses.

►**Comments 1-3: The aim of this study, assesing priority of reflection symmetry properties of volume dominated targets used to calibrate copol channel imbalance phase in CQP SAR data synthesised from linear quad-polarization data of ALOS, GF-3, and RADARSAT-2. I think the topic original or relevant in the field of remote sensing. According to this paper notes that the reflection symmetry used to estimate the phase of k has poor applicability in volume-dominated target regions, which reduces the estimation accuracy of the k phase.**

►**Response**: Thank Reviewer 2 for those comments. We are very grateful to Reviewer 2 for your careful reading and comments. In un-calibrated CQP SAR systems, the common method for estimating the co-polarization (co-pol) channel imbalance k phase is directly based on part of reflection symmetry assumptions, namely equations (9)-(11) in the revised version. However, the reflection symmetry assumptions of CQP SAR systems used in literature have low applicability in volumed-dominated targets, leading to the large error in estimating the k phase. In this paper, we first evaluate the reflection symmetry priority of the volume-dominated targets in the CQP SAR image, then propose an algorithm to estimate the phase of k based on the high priority reflection symmetry (termed semireflection symmetry in paper) assumptions of volume-dominated targets, and finally provide a channel imbalance calibration scheme based on the proposed algorithm.

►**Comment 4-1: What is SAR system parameters? please mention it at introduction sectin.**

►**Response**: We would like to thank Reviewer 2 for pointing out this question. In this paper, the CQP SAR system parameters involved mainly consist of cross-polarization (x-pol) channel imbalance, co-polarization (co-pol) channel imbalance, and crosstalk. These system parameters cause the observed measurement to differ from the undistorted one, which can be expressed by equations (1)-(3) in the revised vision. It should be noted that crosstalk is caused by poor antenna isolation. For decades, the electronic workmanship can make the polarimetric antennas have high isolation (better than -32dB) [1]-[3], so this paper mainly concentrates on estimating the channel imbalances.

[1] Touzi R , Hawkins R K , Cote S . High-Precision Assessment and Calibration of Polarimetric RADARSAT-2 SAR Using Transponder Measurements[J]. IEEE Transactions on Geoscience and Remote Sensing, 2013, 51(1):487-503.

[2] Azcueta M , D'Alessandro M M , Zajc T , et al. ALOS-2 preliminary calibration assessment[C]// IGARSS 2015 - 2015 IEEE International Geoscience and Remote Sensing Symposium. IEEE, 2015.

[3] Shangguan S , Qiu X , Fu K , et al. GF-3 Polarimetric Data Quality Assessment Based on Automatic Extraction of Distributed Targets[J]. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2020, 13:1-1.

We apologize for the confusion caused by our lack of clarity regarding the SAR system parameters mentioned in our paper, which resulted in the reviewer's difficulty in understanding. In the **Introduction** section, we have explained these CQP SAR system parameters: channel imbalance and crosstalk, which have been marked by blue in the following and the revised version (Page2 Line36 - Page2 Line42):

" Due to its high sensitivity to clutter backscatter, quad- polarization SAR provides high-quality data for a wide range of remote applications [3–7]. However, hardware system distortions can lead to unfaithful representations of clutter 36 backscatter. It is very important to calibrate the observation matrix to the undistorted measurement, which is known as polarimetric calibration (PolCAL) [8–10]. The polarimetric distortion, **which are SAR system parameters,** mainly includes crosstalk, co-polarization (co-pol) channel imbalance, and cross-polarization (x-pol) channel imbalance [11–15]. For decades, SAR antennas have been highly isolated (better than 32dB [16–18]) with crosstalk that is stable at different incidence angles. Therefore, x-pol and co-pol channel imbalances in PolCAL merit further study. Although CQP SAR systems have been extensively studied in the imaging radar"

We will take your feedback into account and strive to improve the clarity and effectiveness of our writing in future publications. Thank you for bringing this to our attention.

►**Comment 4-2: What is distortion? what are distortion parameters. please explain.**

►**Response**: We would like to thank Reviewer 2 for pointing out this question. Distortion is the changing of something into something that is not true. In this paper, distortion in CQP SAR systems refers to the fact that due to environmental changes and hardware losses, the backscatter coefficient of ground targets received by SAR systems is inconsistent with the design specifications. According to the transceiver characteristics of CQP SAR system, distortion parameters ,namely crosstalk and channel imbalances, are proposed to quantify the above inconsistencies, namely equations (1)-(3) in the revised vision. The x-pol channel imbalance mainly affects the RL and LR images of CQP SAR; the co-pol channel imbalance mainly affects the LL and RR images of CQP SAR; crosstalk acts on LL, LR, RL, and RR images of CQP SAR.

►**Comment 4-3: According to paper the filtering operations can be divided into three steps: how did you calibrate the covariance matrices and why do you need.**

►**Response**: We would like to thank Reviewer 2 for answering this question. In this paper, we preliminarily estimate cross-polarization (x-pol) channel imbalance alpha and co-polarization (co-pol) channel imbalance k from the selected targets based on equations (6)-(7) and (21)-(28), respectively. After initial estimations, the filtering operations on alpha and k are used to eliminate the errors caused by the selection of improper scattering areas to a large extent to obtain robust results, although we have used the robust strategy of extracting areas (equation (17)).

First, we will explain **the filtering operations on the initial estimations of alpha** and the reasons for these steps and *covariance matrices calibration by the filtered alpha*:

Filtering Operations on the Initial Estimations of Alpha and the Reasons

(1) We first obtain the initial estimated amplitude and phase results of alpha from the extracted

surface-dominated areas in the uncalibrated CQP SAR images. The purpose of this step is to obtain the preliminary estimated alpha results extracted in the area with high signal-to-noise ratio in the x-pol channel to improve the estimation accuracy.

(2) First-order polynomial fitting is performed on the azimuths along each range direction to determine amplitude and phase of the alpha values, which are then averaged for each range direction. In section 3.1.2, we assume consistent polarimetric distortion parameters along the azimuth direction due to the short flight time of a SAR image. First-order polynomial fitting and averaging operations eliminate errors caused by improperly selected data along the azimuth direction.

(3) The bin index-phase/amplitude of the alpha coordinate system is rotated to determine the main gradient direction. Histogram statistics are used to select 70% of the points near the highest value, which are then subjected to first-order polynomial fitting to derive the continuous phases and amplitudes of alpha for the entire CQP SAR image. The main purpose of this step is to eliminate the range fitting error caused by improper selection and get robust solution results. The reason for rotation is that the amplitude and phase of alpha change linearly along the distance. After rotation to the amplitude and phase of the main gradient, the histogram peak value can be directly used to perform subsequent filtering. Histogram statistics cannot be performed without rotation to the main gradient.

Covariance Matrix Calibration by the Filtered Alpha

The filtered alpha will be used on equation (18) to eliminate the distortion effect of x-pol channel imbalance on the CQP SAR systems as much as possible:

$$\left[M_{4LR}{}'\right] = \left(\left[Q\right]\right)^{-1}\left[M_{4LR}\right]\left(\left[Q\right]^{\dagger}\right)^{-1} = \left[K_4\right]\left[C_{4LR}\right]\left[K_4\right]^{\dagger} \tag{18}$$

where $\left[Q\right]$ is the filtered alpha matrix; $\left[M_{4LR}\right]$ and $\left[M_{4LR}{}'\right]$ are the original observed covariance matrix and filtered alpha-calibrated covariance matrix, respectively; the superscript † indicates the conjugate transpose operator. When the effect from low and reciprocal crosstalk unknowns is neglected, the undistorted covariance matrix $\left[C_{4LR}\right]$ is directly related to $\left[M_{4LR}{}'\right]$ by the co-pol channel imbalance matrix $\left[K_4\right]$.

Second, we will explain **the filtering operations on the initial estimations of k** and the reasons for these steps and *covariance matrices calibration by the filtered k*:

Filtering Operations on the Initial Estimations of K and the Reasons

(1) We first obtain the initial estimated phase and amplitude results of k from the extracted volume-dominated areas in the uncalibrated CQP SAR images. The purpose of this step is the same as that of the first step of the alpha filtering operation, that is to obtain the initial co-pol channel imbalance estimated results from the area with high signal-noise ratio of the co-pol channel (volume-dominated area) to reduce the determined k errors caused by additive noise.

(2) The first-order polynomial fitting is carried out along the azimuth bins to average the fitted

amplitude and phase values so as to obtain more robust results in a distance direction. First-order polynomial fitting and averaging operations eliminate errors caused by improperly selected data along the azimuth direction because of the azimuth no-drifting property.

(3) In this step, the amplitude filtering operation of k is the same as the third step of alpha amplitude filtering, in order to make the amplitude results of k more robust along the range direction. However, the phase filtering operation of k is different from that of alpha, mainly because there exist $\pm\pi$ ambiguity in the solution results of k, according to equation (22). The phase filtering operation of k can be separated into the following several steps:

1) The histogram statistics of the rotated coordinates are divided into several parts due to a phase shift of $\pm\pi$.
2) 80% of the points near the peak in each part are selected for first-order polynomial fitting.
3) The fitting results of phases (three results in total: the true one and $\pm\pi$ ambiguity) and amplitudes are used to calibrate k. Digital elevation model (DEM) can be used to sperate the true one from the total fitting results [1]. If the DEM cannot be obtained, the angle fitted by the data in the middle part of the histogram is selected as the final solution.

Covariance matrices calibration by the filtered k:

In the 3) step, the formula for calibrating k can be written by

$$[C_{4LR}] = \left([K_4]\right)^{-1}\left[M_{4LR}{}'\right]\left([K_4]^{\dagger}\right)^{-1}$$

To enhance the readability of the paper, we have refrained from restating the above formula in the revised vision as it solely serves as the inverse of equation (18).

[1] L. Shi, J. Yang, and P. Li, Co-polarization channel imbalance determination by the use of bare soil[J], ISPRS J. Photogramm., vol. 95, no. 1, pp. 53-67, 2014.

►Comment 5: Please read this paper for introduction :Duysak, H. & Yiğit, E. (2022). Investigation of the performance of different wavelet-based fusions of SAR and optical images using Sentinel-1 and Sentinel-2 datasets . International Journal of Engineering and Geosciences , 7 (1) , 81-90 . DOI: 10.26833/ijeg.882589.

►**Response**: We would like to thank Reviewer 2 for improving the quality of the article. We have read this paper carefully and think it is very relevant to our article, especially in the description of SAR. In the revised version, we have already mentioned this paper as citation [3].

►Comment 7: Please include any additional comments on the tables and figures. Fig. 5 is not clear please enlarge it.

►**Response**: We would like to express our gratitude to Reviewer 2 for improving the readability of this article. We have enlarge the figure in the revised vision.

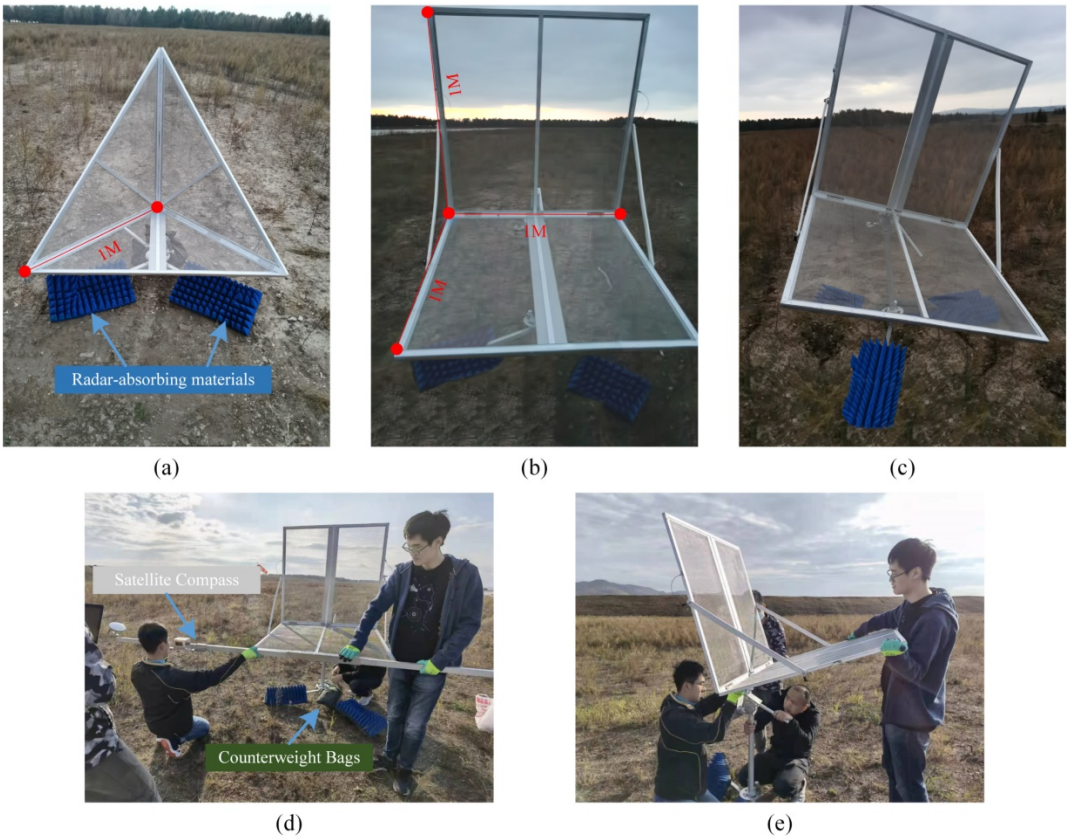


Fig.5 Ground-deployed CRs at Yudaokou Airport in September 2021. (a)-(c) Trihedral CR, dihedral CR, and 22.5° rotated dihedral CR, respectively. (d)-(e) Placement process and measuring equipment.