PALSAR CALVAL Summary (JAXA-PI193)

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Abstract This paper summarizes the geometric and radiometric calibration results of the PALSAR achieved during the ALOS initial calibration phase, which covers five months between May 16 2006 and October 23, 2006, and the half-year of the operational phase. All the PALSAR modes, FBS (fine beam single), FBD (Fine beam dual), SCANSAR, DSN (band limited SAR), and POL (Full polarimetry) were calibrated and validated using in-total 500 calibration points collected world widely and distributed target data from the Amazon. Through the characterization of the PALSAR, antenna pattern determination, and polarimetric calibration, we performed the adjustments of the PALSAR radiometric and geometric model installed on the SAR processor (SIGMA-SAR). Using the reference points, we finally confirmed that the geometric accuracy of the FBS, FBD, DSN, and POL modes is 9.3m, that of SCANSAR is 70m, and radiometric accuracy is 0.64 dB. Polarimetric calibration was successful that amplitude balance of VV/HH is 0.025dB and the phase balance is 0.32 degrees.

I. INTRODUCTION

Since the Advanced Land Observing Satellite, ALOS, was launched to the 691.5 km height-sun-synchronous orbit on January 24 2006, the commissioning phase when the functionalities of the satellite bus system and the sensor systems were evaluated has started. After the first activation of the Phased Array type L-band Synthetic Aperture Radar, PALSAR, on February 15 2006, the PALSAR calibration was initiated. This paper summarizes the PALSAR calibrations, which consists of the raw data evaluation and the image quality.

Keywords PALSAR, ALOS, Calibration and validation

II CALVAL

1) Stability of the chirp data

PALSAR has only three chirp rates although it has six modes, i.e., FBS, FBD, DSN, SCAN-WB1, SCAN-WB2, and polarimetry. The temporal variation of these chirp rates were measured and plotted in Fig.1. It shows that all the chirp rates have very good stabilities (normalized standard deviation, standard deviation divided by an average) of less than 1.0e-4 during the one years monitoring after the ALOS launch. This variation gives only 1.0 degree at maximum of disagreement at the pulse end and does not cause any compression error in the range compression step.

$$2\pi \frac{\Delta k}{2}\left(\frac{\tau}{2}\right)^2 \le \frac{\pi}{180} \qquad (1)$$

where, Δk is the deviation in the chirp rate, τ is the pulse width. Δk that makes phase disagreements of 1 degree at the pulse end are 3.0e7 for FBS, 3.0e7 for FBD, and 8.7e7 for polarimetry. The measurements always lower than this value. This means that the chirp rate can be fixed to the constant.

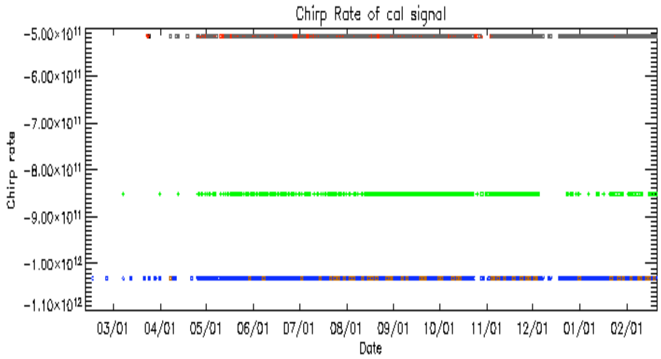


Fig. 1 Temporal stabilities of the three chirp rates observed from the PALSAR calibration data. Here, black shows the chirp rate of FBS, SCAN-WB2, that of green is for FBD, DSN, and SCAN-WB1, and the green for polarimetry.

2) Raw data summary

Table 1 summarizes the raw data characterization obtained from all the PALSAR data. This result at the end of the CAL/VAL phase is improved slightly. SNR of the natural target is improved for FBD. This is because that the FBD of 34.3 is included and in total worse SNR of only 4.15 was improved. Saturation rate was measured in general less than 3%. This is much improvement than the previous report [1][4]. This is because that the attenuator for all the modes were optimized on Aug. 7 2006 and the additional update for the SCANSAR made for SCAN 2 to 5. Interference is not changed so much. In total, PALSAR shows the good characteristic of the raw data than JERS-1 SAR.

3) Stabilities of the azimuth antenna pattern (AAP)

In [1], we reported that the PALSAR AAP is almost as same as the pre-launch AAP (exactly the same in the main lobe and only the slight difference at the side lobe). The temporal change was evaluated by drawing all the AAP in the same plane (Fig. 2). The AAP can be obtained by converting the azimuth time to the angle between the satellite and the target, and the orbital deviation (height, shift from the nominal orbit) needs the exact conversion of the coordinate system. For the simplicity, we evaluate the time variation of the AAP's main lobe only. This figures shows that the main lobe does not change over six flights. The other AAPs at the diffrent off nadir angles and the different modes, in total 7 cases, also do not show any differences. AAP is time invariant.

Table 1 Summary of the PALSAR raw data characteristics

	FBS	FBD	PLR	WB1	WB2
I	16.049	16.188	16.254	16.245	16.041
Q	15.850	15.973	16.078	15.950	15.835
Gain rati I/Q	1.007	1.010	1.001	1.015	1.008
Phase diff. o I/Q (deg)	1.598	1.579	1.577	1.581	1.597
SNR (dB)	8.6698	6.9575	8.5104	9.4869	8.3310
Chirp rat (Hz/s)	-1.03158 x E12	-0.515923 x E12	-0.85097 x E12	- 0.515903 x E12	-1.03159 x E12
Chirp rate Std	2.5e7	2.2e7	4.0e7	1.2e7	5.1e7
Saturation	Saturation rate dropped down to 3% after Augus 7 2006.				
Interference	In general, the interference is less than JERS-SAR (because of 4 time bigger transmissio power). except for seldom wider bandwidth noise				

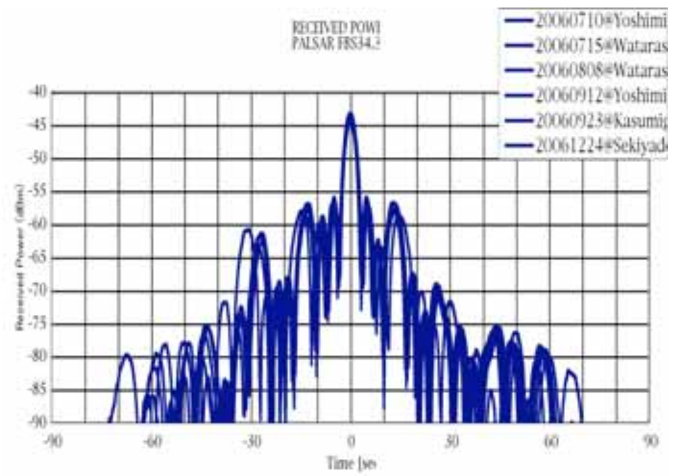


Fig. 2 Measured azimuth antenna pattern (in HH pol). Red curve and Blue curve are real measurement and the ground measurement.

3) Elevation Antenna Pattern (EAP)

EAP were measured using the Amazon data and showed that at less than 40 degrees of off nadir angles, the EAPs were almost the same as the on-ground measurements, at above of that EAPs were degraded due to the range ambiguities (see Fig. 3, and the small circles at 41.5 of FBS and FBD shows that EAP deviates due to the azimuth ambiguity). Thus, the 34.3 and 21.5 degrees of off nadir angles are being used as the standard operation.

4) Image quality and summary.

4-1) Resolution: After the calibration of the PALSAR data, we measured the image quality of the PALSAR data using the all the corner reflectors responses. The summary was given in Table 2. The representative IRF (Impulse response function) was shown in Fig. 4 for two cases.

4-2) Geometric accuracy: Geometric accuracy was achieved as 9.2 meter as RMS (Fig. 5).

4-3) Radiometric accuracy: see Fig. 6 for the distribution of the calibration factor using all the CRs.

4-4) Disturbances of VV/HH in phase and amplitude: Fig. 7 shows these two parameters measured from the CRs.

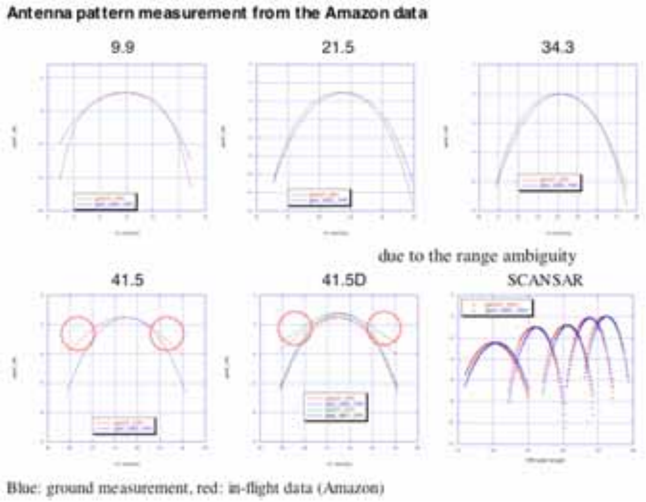


Fig.3 EAP were compared between the before and the after the launch. Small circles posed on the both shoulders of the 41.5 case shows the range ambiguities.

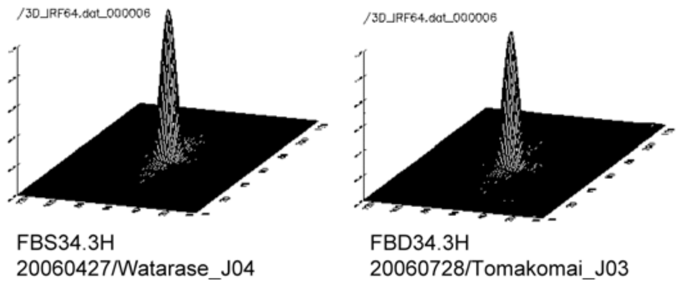


Fig.4 3D responses (Left: FBS and Right: FBD)

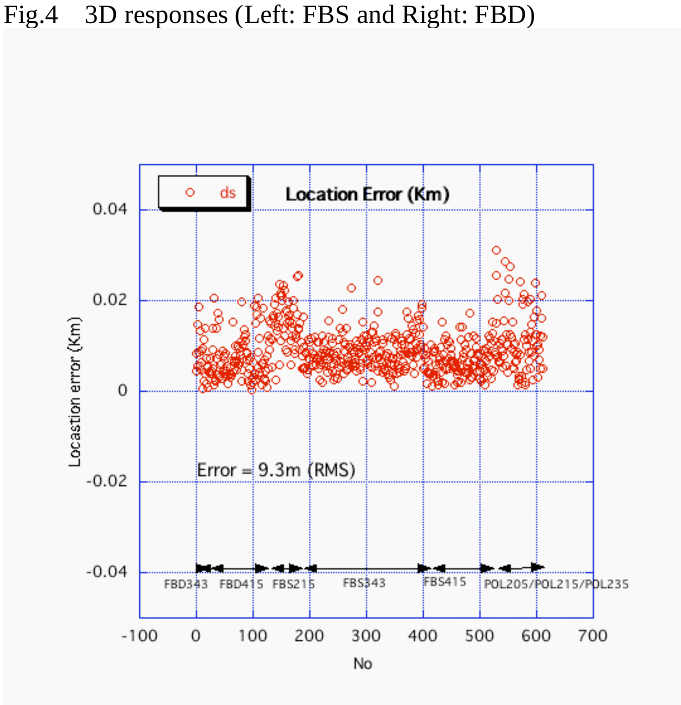


Fig. 5 Geometric error distribution

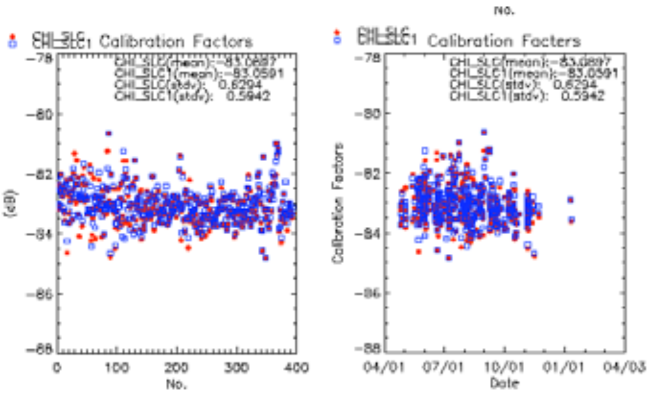


Fig. 6 Distribution of the calibration factors. Left shows for all the modes, and the right is ordered in time.

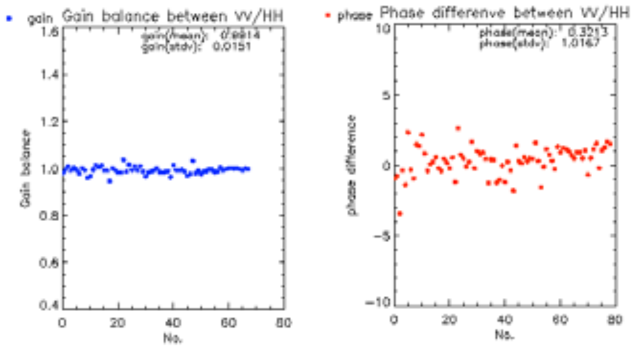
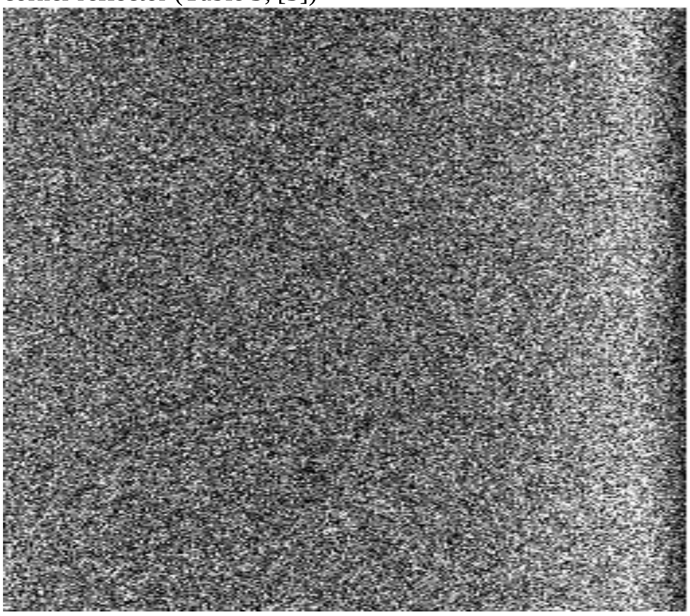


Fig.7 Amplitude a phase disturbance of the Pol-Caled PALSAR data (left: Gain difference, right: phase difference). Here, the distortion matrix were calculated using the Amazon corner reflector (Table 3, [3])



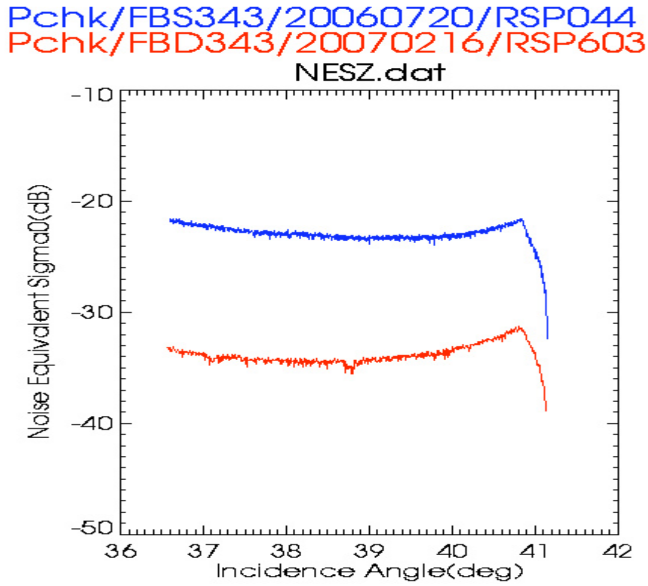


Fig.8 Noise equivalent sigma-naught vs. the incidence angle. Above curve is the Greenland by FBSHH and bottom is from the Hawaii by FBD-HV, which is shown in the above picture.

4-5) Noise equivalent sigma-naught: The noise equivalent sigma-naught is a parameter showing how dark target can be observed. The value finding is to search the minimum from the browse strip data which is generated for cataloging all the PALSAR images at the EORC. Browse processing is made available by combing the range compression and the azimuth SPECAN. The minimum value is searched in azimuth direction at every range bin. Fig. 8 shows the two cases, a) from the FBS over the Greenland ices, and b) from HV polarization of the image path over the Hawaii islands. Both curves look like the inverse of the range antenna pattern and seemed to the right values were obtained. It can be said that the noise equivalent sigma-zero is -34 dB and 10 dB better than the other spaceborne sensors, and 13 dB better than JERS-1 SAR.

4-6) Stability evaluation of the gamma-zero using the Amazon rain forest: Amazon is the uniform and reference target for relative (range and azimuth antenna pattern determination) and absolute calibration target. The statistical analysis [2] shows that the seasonal variation is only 0.25 dB. Thus, the Amazon can be usable for the calibration. For the multiple beam type SAR, like PALSAR, has many modes for calibration. The limited condition for the deployment of the corner reflector requires the inclusion of the Amazon based calibration both for relative and absolute calibration. At the beginning of the PALSAR Calval, we sued the among for determining the gain offset among the beams, which is so that the gamma naught could be constant over the incidence angle, i.e.,

$$\gamma^0 = \sigma^0 / \cos\theta = constant. \quad (2)$$

where, θ is the incidence angle. Here, we confirmed the validity of this assumption using the 10 Amazon data for the strip mode and two data for the SCNSAR. Fig. 9 shows the stability of the PALSAR Amazon data. From this, it cannot say that the

Amazon data is stable seasonally and spatially. The difference is between 0.5 dB to 1.0 dB. We need further investigation on this variation. It can say that the Amazon forest can be used only for the relative calibration but not for the absolute calibration. Independently, the calibration sites, which include the corner reflectors, were established world widely and more than 600 match up data sets were collected. The calibration, where I mean the determination of the calibration factor, should rely on the CRs. However, in general, the gamma-naught is measured as -6.5 dB with the standard deviation of 0.5 dB.

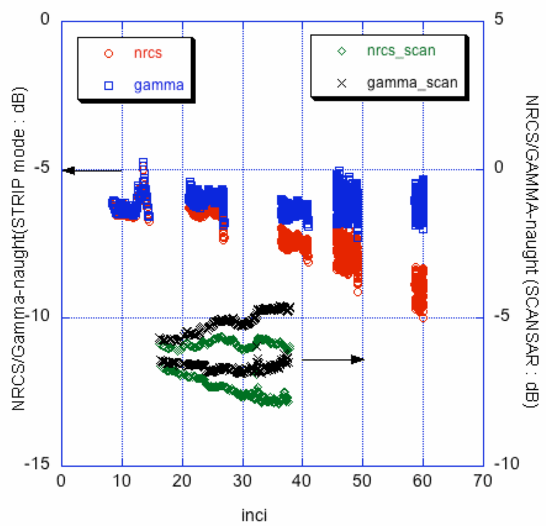


Fig. 9 Measured gamma-naught vs. incidence angle. a) the strip modes, b) the ScanSAR case.

5) Conversion formula

Conversion of standard products (Level 1.1 or 1.5) that JAXA produces to normalized radar cross-section can be expressed by

$$\sigma^0{}_{sigma-sar,Q16} = 10 \cdot \log_{10}\left\langle DN^2 \right\rangle + CF_1 \qquad (3\text{-}1)$$

$$\sigma^0{}_{sigma-sar,slc} = 10 \cdot \log_{10}\left\langle I^2 + Q^2 \right\rangle + CF_1 - A \qquad (3\text{-}2)$$

where, I, Q is the real and imaginary part of SLC（Single Look Complex, process level is 1.1) and DN is the digital number of amplitude image (1.5). Conversion factor, CF1 is -83.0 and its standard deviation is 0.64 dB. Additional factor (A) of 32.0 exists when the SLC is considered. The standard deviation of 0.64 is obtained by using all the CRs deployed in the world. The CRs are the trihedral corner reflectors and their responses might be deviaited since their characteristics and test site condition on the over flights differ. When we limited the CRs from the Swedish ones, which is the biggest CR of 5m-leaf size, standard deviation is minimized to 0.17 dB. It can be estimated that the PALSAR radiometric performance can be told as 0.17 dB.

Table 2 PALSAR calibration accuracy (summary)

Items	Measured values		Data	Spec.
Geometric accuracy	9.3m(RMS): Strip mode		615	100m
	70m(RMS): SCANSAR			
Radiometric accuracy	0.64 dB (1 sigma)		478	1.5 dB
	0.17 dB (1sigma: Sweden)		16	1.5 dB
	-34dB(Noise equivalent NRCS)			-23 dB
Polarimetric calibration	VV/HH ratio	0.02 dB (0.04)	79	0.2 dB
	VV/HH phase diff	0.32deg(1.01)		5 deg.
	Crosstalk	31~40 dB		30 dB
Resolution	Azimuth	4.49 m (0.1	478	4.5m
	Range (14M)	9.6m(0.1m)		10.7m
	Range (28M)	4.7m(0.1m)		5.4m
Side lobe	PSLR (azimuth)	-16dB	478	-10dB
	PSLR (range)	-12.5 dB		-10dB
	ISLR	-8.6 dB		-8dB
Ambiguity	Azimuth	not appeared		16dB
	Range	23 dB		16dB

Table 3 Polarimetric distortion matrices

Item	Values(real, imaginary)
Transmission distortion matrix	(1.000000e+00, 0.000000e+00) (8.747163e-03, 1.435490e-02) (-1.438816e-02, -8.398601e-03) (9.636059e-01, 4.023897e-01)
Reception distortion matrix	(1.000000e+00 0.000000e+00) (-7.426688e-04, 4.024918e-03) (-9.462905e-03, 7.531153e-03) (7.235826e-01, -9.659156e-03)

IV Conclusion

We finally confirmed that the geometric accuracy of the FBS, FBD, DSN, and POL modes is 9.3m, that of SCANSAR is 70m, and radiometric accuracy is 0.64 dB. Polarimetric calibration was successful that amplitude balance of VV/HH is 0.025dB and the phase balance is 0.32 degrees.

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