The Data Calibration of the AIRSAR PacRim II Mission

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Abstract- In this paper, we present the calibration results of the NASA/JPL Airborne Synthetic Aperture Radar (AIRSAR) for the Pacific Rim II mission. We also demonstrate the key elements of the calibration techniques for both polarimetric SAR (POLSAR) and cross-track interferometric SAR (TOPSAR) processed with the AIRSAR Integrated Processor**.**

I. INTRODUCTION

As part of NASA's Earth Science enterprise, AIRSAR data are currently collected for NASA-funded investigators in the United States as well as sponsors from international organizations. The Pacific Rim II mission took place in July through October 2000. Over 60 hours of AIRSAR data were collected during the mission. The NASA/JPL AIRSAR system is a three-frequency airborne SAR system that was developed as a general test-bed for various advanced SAR techniques.

The AIRSAR Integrated Processor (AIP) is a multi-frequency polarimetric and interferometric SAR processor designed to produce data useful for better understanding of scattering from different type of Earth terrain. The AIP is used to automatically generate co-registered multi-frequency (C-, L-, and P-band) images from both polarimetric and cross-track interferometric data collection modes. The Digital Elevation Map (DEM) can be generated using the C-band and/or L-band interferometric data and polarimetric data channels are projected onto the ground.

II. DATA PROCESSING MODES

The AIRSAR can be operated as TOPSAR , POLSAR , and ATI (Along-Track Interferometric) modes. This paper focus on TOPSAR and POLSAR modes .

In TOPSAR modes, AIRSAR collects cross-track interferometric (denotes as XTI) data using C- and L-band vertically-displaced antenna pairs to produce digital elevation models (DEM's). There are four TOPSAR modes which are XTI2 , XTI1, XTI2P and XTI1P. Each mode can be operated either 40 MHz or 20 MHz bandwidth respectively. The radars which are not being used for interferometry (P-band for XTI2 or P-band and L-band for XTI1) collect quad-pol data co-registered with the C-band DEM. Interferometric data can be collected in "ping-pong" mode (XTI2P and XTI1P), where each of two antenna is used alternately for transmit and the effective baseline is doubled which denotes as a long-baseline modes, an in "common-transmitter" mode where only one antenna is used for transmit which called a short baseline mode. The shot baseline is 2.5 meters for the C-band and 2 meters for the L-band. The XTI2 mode indicates the short-baseline which produce 2 DEMs from C- and L-band, and XTI1 indicates C-band DEM produced only. The PRF of the short-baseline for both XTI2 and XTI1 modes is 840 Hz which is double than the long-baseline modes as 420 Hz . The length of the long-baseline is an effective 5 meters for the C-band and an effective 4 meters long for the L-band. For these four TOPSAR modes, the polarimetric data will be generated in the ground projection along with the DEM, either P-band polarimetric data for XTI2/XTI2P or P- and L-band polarimetric data for XTI1/XTI1P modes.

In the POLSAR mode, the fully polarimetric data are acquired at all three frequencies, quad-polarized mode in the slant range projection . Fully polarimetric means that radar waves are alternatively transmitted in horizontal (H) and vertical (V) polarization, while every pulse is received in both H and V polarizations. The POLSAR can be operated at 40 MHz , 20 MHz and 80 MHz (80 MHz is only for L-band). The PRF is 420 Hz. POLSAR data are sensitive to the geometry (including vegetation) and dielectric properties (water content) of the terrain.

III. POLSAR CALIBRATION

Before performing the calibration functions, the raw echo data, auxiliary data and motion data must be verified and recovered from the anomaly. In the job setup module, the raw echo data is scanned and fixed line by line such as the range samples anomaly extraction and range samples shifting, and Radio Frequency Interference (RFI) contamination. For the PacRim II data, the rate of contaminated pulses was less than 0.1% and most of 80 MHz L-band data had a 2-byte shift which is fixed during data processing. Majority of the P-band data had RFI and some of L-band data as well. About 80% of the RFI can be removed with the current RFI filtering module. An improved version of the RFI filtering module is under evaluation and it will clean the RFI up to 90 %. The Ashtek Differential Global Position System (D-GPS) was incorporated into the AIP during the PacRim II mission along with the H764G **E**mbedded **G**PS Receiver in an **I**nertial Navigation System (INS) (**EGI**). The stability of motion data was increased over previous years.

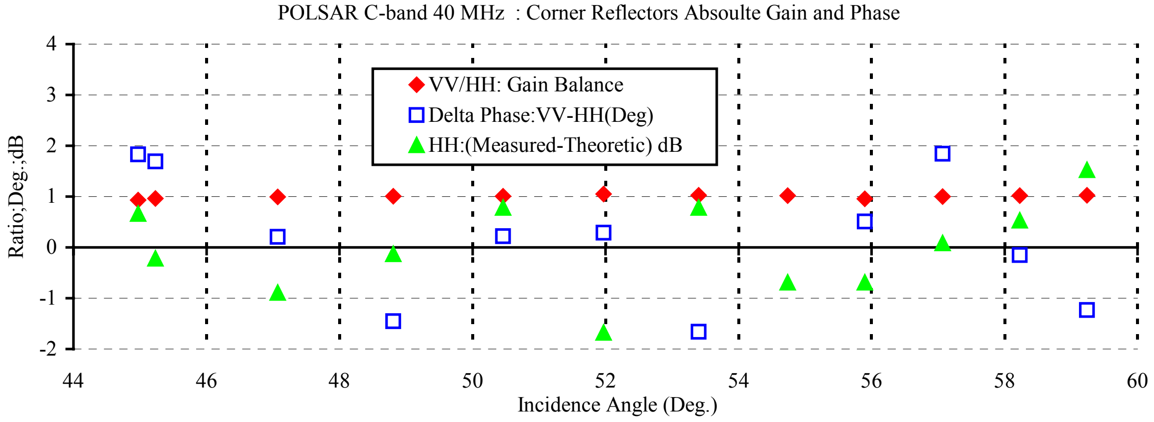
The purpose of the POLSAR calibration is to generate the radar backscatter in Stokes matrix form accurately. External calibration devices (corner reflectors) were used to provide the absolute radiometric calibration[1]. The phase path compensation of the transmitter, receiver, and all antennas is calibrated. Due to the path length differences among the four polarization combinations (HH, HV, VH, and VV) in the radar hardware, a model has been developed [2] to identify the receiver path phase (Φr), transmitter path phase (Φt) and antenna path phase (Φa). Those three path phases measurements can be obtained from the SAR data with co-polarization and cross-polarization phases and the injected caltone phase(Φcal). We had implemented the cross-talk contribution by using eight adjacent pixels in each range line to get one estimate of the cross-talk parameters then averaging over the estimates of all the eight pixel blocks for each range line. What remains is to utilize the backscatter measurements from corner reflectors to correct the residual amplitude offsets in the various polarization channels and to correct for the absolute gain and co-polarized component phase of the radar system.

The calibration site was chosen a very flat dry-lake in Rosamond near by the Edward airforce base, California. We used the trihedral corner reflector as a point-target for performing both POLSAR and TOPSAR calibration works. There are 12 corner reflectors at 170 degrees and 10 corner reflectors at 350 degrees heading in the Dry-lake Rosamond. In calculating the correlator gain, we use the theoretical expression (1) for triangular trihedral corner reflector cross-section[4] .

$$\sigma = \frac{4\pi}{\lambda^2} \cdot l^4 \cdot \left\{ \cos\theta + \sin\theta \cdot (\sin\phi + \cos\phi) - 2 \cdot \left[\cos\theta + \sin\theta \cdot (\sin\phi + \cos\phi)^{-1} \right] \right\}^2 \qquad (1)$$

Where θ is a complement of elevation angle from the broesight and the θ consists of the radar wave incident on this corner reflector at angle θ_{inc} and an angle β which the corner reflector base is elevated , i.e. $\theta = \theta_{inc} + \beta$. The ϕ is defined as an azimuth angle from the boresight. The ϕ consists of an angle α which is difference between the corner reflector azimuth angle and the radar flight direction and an drift angle ϕ_{drift} of the aircraft , i.e. $\phi = 45 - \alpha + \phi_{drift.}$ The short sides of the triangles forming the corner reflector have length and the radar wavelength is λ.

The requirement of the POLSAR image absolute calibration for all 3 bands is within 3 dB and the relatively calibrated between frequencies is 1.5 dB. The plot shown below is the Rosamond's corner reflectors of the PacRim II 40 MHz C-band POLSAR for the ratio of VV/HH gain balance, the phase difference between VV and HH in degrees, and the absolute gain (HH) difference between the measurement and theory in dB.



From the above plot, the x-axis indicates incidence angles and y-axis is the CO-POL gain balance ratio, CO-POL phase difference , and an absolute gain of HH channel. Each red diamond represents the VV/HH gain ratio. The idea value is 1, from this plot we can see that the actual gain ratio is almost 1.0. The blue square denotes CO-POL phase difference. The idea value is zero degree. And the green triangle is as the absolute gain difference between a measured value from the image and a theory value. The idea number should be zero dB. The actual value of the 40 MHz C-band POLSAR are listed: the mean value of the VV/HH ratio is almost 1.0 and the standard deviation (stdev) is less than .04 ; the mean of the Delta phase between VV and HH is less than -.02 degrees and stdev is less than 1.5 ; and the mean of the HH absolute gain offset is less than .005 dB and the stdev is less 0. 9 . These results tell us that the data quality of the 40 MHz C-band POLSAR data is good as we expected.

We summarized all the results of the POLSAR data as the following tables. The upper table displays all 40 MHz POLSAR data for all 3 bands and the lower table shows all 20 MHz POLSAR data, respectively. We can see that the results are pretty much consistent as the previous 40 MHz C-band POLSAR results across all modes, except the 40 MHz P-band which is not as good as the others. This is because of some of corner reflectors contaminated by RFI and it is bout 8% error for CO-POL gain balance ratio and the mean of the CO-POL phase difference is about 1.7 degrees and stdev is about 4.5.

Corner Reflector Measure-ment	POLSAR C-Band 40 MHz			POLSAR L-Band 40 MHz			POLSAR P-Band 40 MHz		
	VV/HH Gain Balance Ratio	**VV-HH** Phase Diff. (Deg.)	**HH** (Meas.- Theo.) (dB)	**VV/HH** Gain Balance Ratio	**VV-HH** Phase Diff. (Deg.)	**HH** (Meas.- Theo.) (dB)	**VV/HH** Gain Balance Ratio	**VV-HH** Phase Diff. (Deg.)	**HH** (Meas.- Theo.) (dB)
Mean	**1.001**	-0.015	**0.004**	**1.001**	**-0.06**	**0.001**	**1.079**	**1.667**	-0.782
STDEV	**0.034**	**1.403**	**0.898**	**0.015**	**1.100**	**0.434**	**0.105**	**4.462**	**1.610**

Corner Reflector Measure-ment	POLSAR C-Band 20 MHz			POLSAR L-Band 20 MHz			POLSAR P-Band 40 MHz		
	VV/HH Gain Balance Ratio	**VV-HH** Phase Diff. (Deg.)	**HH** (Meas.- Theo.) (dB)	**VV/HH** Gain Balance Ratio	**VV-HH** Phase Diff. (Deg.)	**HH** (Meas.- Theo.) (dB)	**VV/HH** Gain Balance Ratio	**VV-HH** Phase Diff. (Deg.)	**HH** (Meas.- Theo.) (dB)
Mean	**0.999**	**0.028**	**-0.004**	**1.009**	**-0.210**	**0.176**	**1.006**	**-0.219**	**0.140**
STDEV	**0.027**	**1.262**	**0.863**	**0.036**	**1.103**	**0.609**	**0.065**	**1.763**	**1.235**

The results of the 80 MHz L-band POLSAR data is as good as the other bands as we predicated. The vv/hh gain ratio is 1.004. The phase difference between vv and hh is less than 0.2 degrees and the absolute gain of the HH channel error is less than 0.2 dB. All three standard deviation(stdev) are looking good : the gain ratio stdev is 0.372, the phase difference stdev is 1.378, and the HH absolute gain stdev is 0.478.

IV. TOPSAR CALIBRATION

In the interferometric SAR data calibration, we determine the following parameters: time delay, the physical baseline length , baseline roll and yaw angles, and the differential phase. In practice, the time delay is divided into two section of determining the differential time delay which between pairs of upper and lower data channels processed interferometrically and determining a common range delay. The baseline between the two antennas and the differential phase are calibrated using corner reflector ground truth position information. The C-band interferometry upper and lower antennas are separated by 2.5 meters with a roll angle of 50 ° and a baseline yaw angle of –0.5°. The L-band antennas are separated by 1.9 meters with a roll angle of 69° and a yaw angle of -2°. The calibration parameters are determined by fitting errors in corner reflector positions using the known sensitivity of the target position to calibration parameter errors[5]. Given the airplane position **P** vector, line of sight **n** and slant range ρ, the position to the corner reflectors (**T**) can be obtained from **T**=**P**+ ρ·**n** . The error in the interferometric measurement (δT) and interferometric phase (δφ) can be written as

$$\delta T = \delta P + \rho \cdot \delta n + \delta \rho \cdot n \qquad (2)$$

$$\delta \varphi = (-4\pi / \lambda)[(\rho 1 - \rho 2) \cdot n] \qquad (3)$$

where ρ1 and ρ2 are slant range from upper and lower antennas , respectively.

From [5], the interferometric phase and DEM height can be expressed as below:

$$\delta \phi = (4\pi / \lambda) \cdot B \cdot \sin(\theta - \alpha) \qquad (4)$$

$$Z(y) = h - \rho \cdot \cos(\theta) \qquad (5)$$

For the interferometric phase, we estimate the baseline vector and differential phase by using the flat portion of the Rosamond lakebed with 663 meter site height in the WGS-84 datum system. When a common flight track is used for processing the interferometric channels, the interferometric phase δϕ can be rewritten as[6].

$$\delta \phi = (-4\pi / \lambda) \cdot (\hat{n}_t - \hat{n}_r) \cdot \overline{B_t} - \frac{4\pi}{\lambda} \hat{n}_r \cdot \overline{b} + \Delta \phi + 2\pi m + \phi_e \qquad (6)$$

where λ=wave length,
n_t = true unit look vector,
n_r = reference unit look vector
B_t = true baseline vector,
b = baseline error vector,
Δϕ = differential phase,
m = absolute phase number, and
ϕ_e = phase due to earth curvature.

When the reference flat height is the same as the true height, the first term of (6) becomes zero. After the earth curvature corrected and the phase ambiguity number (m) are determined, the resulting phase ϕc can be written as

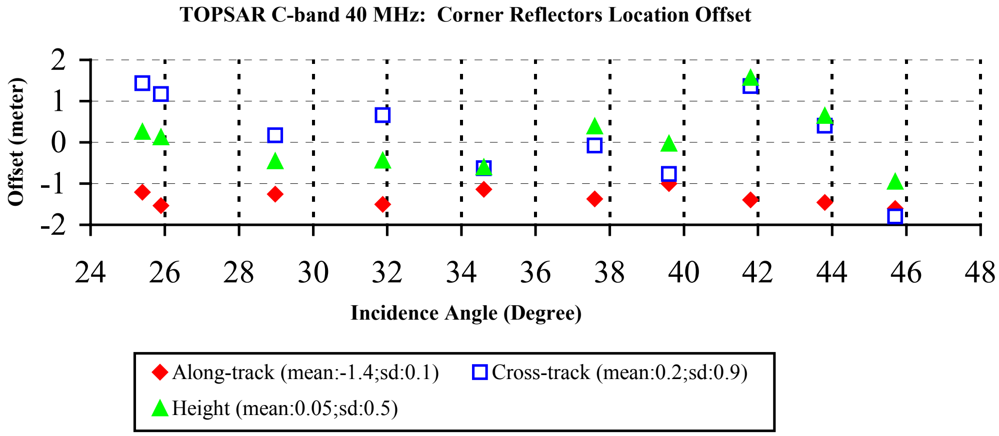
$$\phi_c = \delta \phi - \phi_e = -\frac{4\pi}{\lambda} \hat{n}_r \cdot \overline{b} + \Delta \phi \qquad (7)$$

Using the TOPSAR data, we can determine the baseline error vector (b) and differential phase(Δϕ) with a least square error technique.

For the PacRim II, the relative height accuracy of the TOPSAR data is within 2 to 5 m for C-band and 5 to 10 m for L-band .

The plot shown below is the locations error of the Rosamond corner reflectors for C-band 40 MHz TOPSAR data with heading 350 degrees and
the mean of the location error is around 1.5 meters.

The above plot demonstrates the data quality for the 40 MHz C-band XTI2 DEM**.** The X-axis indicates the incidence angles and the y-axis is the location offset in meters. Here, The red diamond denotes the along-track offset away from the Ground Contorl Point (GCP). The blue square indicates the cross-track offset and the green triangle represents the height offset. For this XTI2 40 MHz C-band data, The mean value of the along-track error is –0.3 meters and stdev 0.3; the cross-track error is –0.2 meters and stdev 1.2 and the height error 0.4 meters and stdev is 0.7. From this result, it demonstrates the average geolocation error is less than about 1.3 meters and stdev is 0.88.



We summarized the location offset of the calibration results for all C-band and L-band data. The upper table lists the 40 MHz data for both C- and L-band and the lower table shows the 20 MHz data for both C- and L-band. From these tables, we can find out the geolocation offset of the C-band DEM is less than 2.5 meters , and the L-band is less than 5.5 meters. The standard deviation of the all modes indicates the TOPSAR is pretty stable. This table also demonstrates the DEM data quality of the C-band for both 40 and 20 Mhz is better than the L-band, as we expected , because the L-band baseline less than C-band and the L-band wavelength is longer than C-band.

Location Offset (meters)	**XTI2P C-Band 40 MHz**	**XTI2 C-Band 40 MHz**	**XTI2P L-Band 40 MHz**	**XTI2 L-Band 40 MHz**
Mean	1.77	1.23	4.82	4.75
STDEV	0.46	0.88	2.92	2.23

Location Offset (meters)	**XTI2P C-Band 20 MHz**	**XTI2 C-Band 20 MHz**	**XTI2P L-Band 20 MHz**	**XTI2 L-Band 20 MHz**
Mean	1.98	2.23	5.21*	4.95
STDEV	0.76	0.68	1.20	1.03

Note: * : Along-track shifted 7 meters due to bad motion data

V. CONCLUSIONS

In this paper, we present the calibration results of AIRSAR POLSAR and TOPSAR modes in detail. All products are calibrated and corrected geometrically (TOPSAR mode), polarimetrically, and radiometrically. A number of precision image data sets will be presented to demonstrate the calibration for the PacRim II data.

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REFERENCES

[1]Van Zyl, J.Jakob. , *Calibration of Polarimetric Radar Images Using Only Image Signatures and Trihedral Corner Reflectors Responses*, IEEE Transactions on Geoscience and Remote Sensing, GE-28, pp.337-348, 1990.

[2]. Zebker,Howard ,Lou, Yunling, *Phase calibration of image radar polarimeter Stokes matrices*, IEEE Trans. Geo. Remote Sensing, Vol. 28 pp.264-252 Mar. 1990.

[3] Van Zyl, J.J.et al., *Image Radar polarimatric Signatures:Theory and Observations*, Radio Science, 22 pp. 529-543, 1987.

[4] Ruck, G.T.,et al.,*Radar Cross Section Handbook*, vol. I, p.593, Plenum, New York, 1970.

[5] Madsen, Soren et al.,*Topographic Mapping Using Radar Interferometry: Processing techniques*, IEEE Trans, Geosci. Remote Sens., GRS-31 pp.246-256, 1993.

[6] Kim , Yunjin and Chu, Anhua "*AIRSAR TOPSAR Calibration* ", JPL Internal Memorandum, June, 1998