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Report No.: AS97-5001

Extraction of Beta Nought and Sigma Nought from RADARSAT CDPF Products

Rev. 4 – 28 April 2000

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28 April 2000

Contract No.: 9F005-6-0025/001/SN

Document Revision History

First issued as Technical Note 4.2 - CDPF Output Data Calibration 20 January 1997

Re-issued as Report No. AS97-5001 Extraction of Beta Nought and Sigma Nought from RADARSAT CDPF Products , ALTRIX Systems, 21 February 1997.

Appendix A converted from Mathcad 4.0 document to WP 6.1 for integration with body of document.

Appendix B - History of Payload Parameter File Changes added.

AS 97-5001, Revision 1 - 30 September 1997.

Appendix A, part 1: first equation changed to clarify the $\tan^2$ function. Units of *eph_orb_data* changed to metres to conform with CEOS record values.

Appendix A, part 3: correction of bracket position in arccos argument.

Appendix B: updated Payload Parameter file change history.

AS97-5001, Revision 2 - 22 May 1998.

Update reference to RADARSAT Product Specification Rev.5/1 (was 4/3)

Where occurring - replace calibration by data extraction or similar phrase (purpose of document is to enable users to extract data).

Expanded description of interpolation procedure relating LUT samples to pixel indexes. Correct formulae for interpolation and extrapolation for near range first images and far range first images.

In the description of conversion to Sigma Nought, change the method for calculating incidence angle and slant range from LUT sample increments to image pixel increments. Add note to the effect that this method involves some approximations.

Include a description of the extraction of beam elevation angle from incidence angle, for use in interpretation of CSA provided beta nought correction data.

Appendix B: updated Payload Parameter file change history.

AS97-5001, Revision 3 – 24 August 1999

Section numbers added to aid in review/comment.

References to “Detailed Processing Parameters Record” changed to “Processing Parameter Record” to comply with record heading in CEOS product.

Modification of procedure for incidence angle calculation for ScanSAR products, in Section 7.1, titled “Special Considerations for ScanSAR Products”.

Correction of an error in the units for eph_orb_data(1) in Appendix ‘A’. Example value for α was in km.; changed to m. Factor of 10^3 removed in equation for *h*.

AS97-5001, Revision 4 – 28 April 2000

Added Table of Contents
Appendix B: updated Payload Parameter file change history.

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1. Introduction

This Technical Note provides a guide for users who wish to perform radiometric scaling of the processed image data contained in the CEOS Processed Data Records produced by the RADARSAT Canadian Data Processing Facility (CDPF). The procedures described here cover the radiometric calibration of SGF, SGX, SGC, SCN, SCW and SLC products.

It is assumed that the reader is familiar with the CEOS SAR Data Format, and has access to the RADARSAT CDPF Product Specification, MDA doc. no. RZ-SP-50-5313 Rev. 5/1.

Note that the descriptions in this document are specific to products generated by the CDPF and do not necessarily apply in cases where raw RADARSAT sensor data is processed by another facility.

Extraction of calibrated data from the pixel data in the image requires reversal of an output scaling operation, which was performed on the data during processing. Each pixel in the output data is represented by one (or two) digital numbers (DN) which represent the magnitude of the detected pixel data (or the value of each I and Q component for SLC data). The scaling which was applied to the product during processing is described in the CEOS Radiometric Data Record. The following describes how the pixel DN s can be converted to beta nought ($ß^o$) or radar brightness values by extraction and application of the scaling information. Conversion of DN s to radar backscatter coefficient (sigma nought), s^o, additionally requires knowledge of the incidence angles over the image swath. The conversion from beta nought to sigma nought as a function of pixel incidence angle is described.

Appendix ‘A’ describes how the required incidence angles are calculated using auxiliary parameters provided in the CEOS record. Also included in Appendix ‘A’ is a method for deriving the beam elevation angles corresponding to the calculated incidence angles.

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2. The Radiometric Data Record

Fields 12 to 531 of the CEOS Radiometric Data Record provide information on the range dependent scaling gain and fixed offset terms applied during product generation. The Radiometric Data Record is a component of the SAR Leader File for single beam products and of the SAR Trailer File for ScanSAR products. Principal field attributes are:

Field	Mnemonic	Bytes	Format	Description
12	table_des	37-60	A24	Designator OUTPUT$SCALING$$..
13	n_samp	61-68	I8	Number of look up table samples, generally = 512
14	samp_type	69-84	A16	Designator GAIN$$$$$$$..
15	samp_inc	85-88	I4	Increment between table entries in range pixels
16-527	lookup_tab	89-8265	512E16.7	Output scaling LUT values A_i - linear values
529	noise_scale	8285-8300	F16.7	Thermal noise reference level (dB)
531	offset	8317-8332	E16.7	Scaling offset A3 - linear, set to 0 for SLC products

The first sample in field 16 (bytes 89 to 104) gives the scaling look up table (LUT) value, A_0, for the nearest range pixel. The next sample in bytes 105 to 120 gives the scaling LUT value, A_1, for the pixel at the next sample increment in range. This sample point is positioned at N pixels from the near range pixel, where N = samp_inc as given by the integer value in field 15. The third table value gives the scaling at 2*N pixels from the nearest range pixel and so on.

The number of scaling table values is fixed at 512. The table pixel spacing, samp_inc, is selected to the nearest integer value which allows the samples to span the maximum possible range in the processed image.

3. Beta Nought Extraction for Detected Products

The following procedures are used to extract the value of the radar brightness for pixels in the processed image for detected products (SGF, SGX, SGC, SCN, SCW).

If DN_j is the digital number which represents the magnitude of the j th. pixel from the start of a range line in the detected image data, then the corresponding value of radar brightness, $ß^o{}_j$, for the pixel is given by:

$$ß^o{}_j = 10*\log_{10}[(DN_j{}^2 + A3)/A2_j] \text{ dB} \qquad 1$$

where $A2_j$ is the scaling gain value for the j th. pixel, and A3 is the fixed offset. A3 is obtained directly from field 531 (offset) in the Radiometric Data Record. $A2_j$ is obtained by linear interpolation of the gain values (lookup_tab) given in fields 16-527 of the Radiometric Data Record, as described below:

4. Interpolation of LUT Values to find $A2_j$

With the present CDPF configuration LUT data are always provided in ascending range order, deviating from the CDPF Product Specification section 5.1.5, which requires LUT s to be output in ascending pixel order. *This deviation may be removed as part of continuing CDPF upgrades, and users will be notified appropriately of changes*. For single beam products, the range lines are always output in West - East order. Consequently, for ascending pass right looking and descending pass left looking products, the image range pixel indexes and LUT indexes both increment in order of increasing range. The first LUT entry corresponds to the scaling gain for the first, nearest range, image pixel. ScanSAR products also follow this convention regardless of left or right looking data acquisition mode since ScanSAR products are always generated in natural - or ascending range - order.

For descending pass right looking, and ascending pass left looking, single beam products, the image range line pixels are arranged far range first. The first LUT entry therefore corresponds to the scaling gain for the last pixel in the range line.

In the following the LUT table values are denoted by A_i , where i has the range 0 to (n_samp - 1). For all current CDPF products n_samp is set to 512, hence i = 0..511. The image pixel index is denoted by j where j represents the j th. pixel from the start of the range line. The range of j is 0 to (n_data_pixel - 1), where n_data_pixel is the number of data pixels in the range line as given in field 10 of the CEOS Processed Data Record. The scaling gain, $A2_j$, for an image pixel is found by linear interpolation between the two values for LUT scaling gain, A_i , which bracket the range of the image pixel. In some instances pixels near to the maximum range of a range line will lie at ranges beyond the range covered by the LUT. In such cases, $A2_j$ is found by linear extrapolation from the last two LUT values, A_{510} and A_{511}.

4.1 Near Range First

For products generated with near range pixels first, including all ScanSAR products, find the LUT sample indices, i_L and i_U, (lower and upper) corresponding to the j th. image pixel from:

$$i_L = floor(j/samp\_inc)$$
$$i_U = ceil(j/samp\_inc)$$

where samp_inc is the increment between LUT table entries, obtained from field 15 of the CEOS Radiometric Data Record. From the LUT extract the gain values Ai_L and Ai_U corresponding to these indices. The required interpolated value of $A2_j$ is then given by:

$$A2_j = Ai_L + [(Ai_U - Ai_L) * ((j/samp\_inc) - i_L)] \quad 2$$

Equation 2 is valid for all pixel indexes up to and including j = samp_inc*(n_samp-1).

To find $A2_j$ for pixels for which j > samp_inc*(n_samp-1), it is necessary to extrapolate the LUT values based on the last available LUT values, namely A_{510} and A_{511} . The extrapolated value of $A2_j$ for these pixels is given by:

$$A2_j = A_{511} + [(A_{511} - A_{510}) * ((j/samp\_inc) - 511)] \quad 3$$

4.2 Far Range First

For products in which the j=0 pixel is the farthest range pixel in the range line, the lower and upper LUT sample indices for the j th. image pixel are given by:

$$i_L = floor[(n\_data\_pixel - j - 1)/samp\_inc]$$
$$i_U = ceil[(n\_data\_pixel - j - 1)/samp\_inc]$$

where samp_inc is the increment between LUT table entries, obtained from field 15 of the CEOS Radiometric Data Record.

From the LUT extract the gain values Ai_L and Ai_U corresponding to these indices. The required value of $A2_j$ is then given by:

$$A2_j = Ai_L + [(Ai_U - Ai_L) * \{((n\_data\_pixel - 1 - j)/samp\_inc) - i_L\}] \quad 4$$

Equation 4 is valid for all pixel indexes down to and including:

$$j = n\_data\_pixel - samp\_inc*(n\_samp - 1) - 1$$

To find $A2_j$ for pixels for which $j < n\_data\_pixel - samp\_inc*(n\_samp - 1) - 1$, it is necessary to extrapolate the LUT values based on the last available LUT values, namely A_{510} and A_{511} . The extrapolated vale for $A2_j$ for these pixels is given by:

$$A2_j = A_{511} + [(A_{511} - A_{510}) * (((n\_data\_pixel - 1 - j)/samp\_inc) - 511)] \qquad 5$$

5. Beta Nought Extraction for SLC Products

For complex (SLC) single beam products, the pixel number, j, is related to the LUT index, i, using the same procedure as for detected products. The radar brightness for the j th. range pixel is then given by:

$$ß^o_j = 10*\log_{10}[(DNI_j/A2_j)^2 + (DNQ_j/A2_j)^2] \text{ dB} \qquad 6$$

or:

$$ß^o_j = 20*\log_{10}(DN_j/A2_j) \text{ dB} \qquad 7$$

where DNI_j and DNQ_j are the digital values of the I and Q components of the j th. pixel from the start of the range line, $A2_j$ is the corresponding range dependent gain and $DN_j^2 = DNI_j^2 + DNQ_j^2$. The offset is not used in SLC product generation.

6. System Beta Nought Calibration Updates

RADARSAT System calibration is maintained by regular maintenance operations, which may result in re-assessment of the system gains and required antenna beam shape corrections which are embodied in the payload parameter files. In some cases, products may have been generated by the CDPF before the relevant beam profiles were completely established, and such data may benefit from calibration if radiometric fidelity is critical to the application.

Calibration of the product requires that the raw data be re-processed at the CDPF using the correctly calibrated payload parameter file. The user may estimate the magnitude of the radiometric error in the original product by reference to beta nought correction data published by CSA. These data are provided for each beam in terms of the beta nought correction in dB over the range of beam elevation angles. Appendix A includes a description of a method of calculating the incidence angles for the image pixels. The corresponding beam elevation angles are then derived from the incidence angles, as described in part 4 of Appendix ‘A’.

7. Conversion to Sigma Nought

The relationship between radar brightness ($ß^o$) and radar backscatter coefficient (σ^o) is:

$$\sigma^o_j = ß^o_j + 10*\log_{10}(\sin I_j) \text{ dB} \quad (8)$$

where I_j is the incidence angle at the j th. range pixel. This formula assumes that the earth is a smooth ellipsoid at sea level.

Data required for calculating the incidence angle for any given pixel in the image range line are available in the CEOS record. Given these data, a relatively straightforward approximation to the incidence angle can be performed. For scene products the resulting error in conversion from beta nought to sigma nought resulting from the approximation should be less than 0.4 dB.

The detailed calculation of the incidence angle I_j is provided in Appendix A .

Before starting the calculation, the following data are required from the CEOS record:

From the Dataset Summary Record:

Field	Mnemonic	Bytes	Format	Description
17	ellip_major	181-196	F16.7	Ellipsoid semi-major axis (km)
18	ellip_minor	197-212	F16.7	Ellipsoid semi-minor axis (km
36	plat_lat	453-460	F8.3	Platform geodetic latitude (deg.)
122	pix_spacing	1703-1718	F16.7	Pixel spacing (m)

From the Processing Parameter Record

Field	Mnemonic	Bytes	Format	Description
411	eph_orb_data	4649-4664	E16.7	First element of equinoctial orbit elements = orbit semi-major axis (km)
426-431	srgr_coef	4908-5003	6 x E16.7	Set of six slant to ground range coefficients repeated up to 19 times for swath products.

From the Processed Data Record

Field	Mnemonic	Bytes	Format	Description
10	n_data_pixel	25-28	B4	Data pixel count

Note: The same information may be derived from l_dataset, (SAR Data Record Length (bytes)), field 30, bytes 1687-192, in the Image Options File Descriptor Record. For ScanSAR products subtract 192 from l_dataset to give the data pixel count. For single beam products subtract 192 and divide by two. For SLC products subtract 192 and divide by four.

Using the procedures described in Appendix A , find the following:

- Earth radius, r, and the orbit altitude, h, for the image.
- Ground range increment, dRg = pix_spacing, between pixels.
- Slant range, RS_j, for each pixel.
- Incidence angle, I_j, for each pixel.

Notes:

1) The pixel index, j , assumes a range of 0..n_data_pixel-1.

2) For scene products the platform latitude and SRGR coefficients used in the calculation described in Appendix A apply to the scene centre. Some numerical values are included from a typical beam S1 SGF scene product at mid latitude.

3) For SLC products the procedure is similar, however, the conversion from ground to slant range is not required and the slant range RS_j for each pixel is calculated directly from the pixel spacing (see Appendix A).

7.1 Special Considerations for ScanSAR Products

In the case of ScanSAR products, SRGR coefficients are calculated and updated at intervals throughout the swath. The SRGR update intervals are the same as those applied to the estimation of the doppler centroid, therefore the SRGR update interval, in seconds, can be found from field 287, bytes 2689-2704 (dopcen_inc) of the Processing Parameter Record. The number of SRGR coefficient sets applicable to the image is given by field 288, bytes 2705-2708 (n_dopcen). The total number of SRGR coefficient sets reported in field 424, bytes 4883-4886 (n_srgr) may exceed n_dopcen, and this merely means that some additional SRGR coefficient sets, applicable to regions past the imaged swath, were calculated and written to the CEOS record.

For relatively short ScanSAR images, where the product of dopcen_inc and n_dopcen is less than 2 minutes (120 seconds), the first set of SRGR coefficients will provide sufficiently accurate estimates of incidence angle for any region within the image. Likewise the platform geodetic latitude at the start of the image swath (plat_lat), and given in field 36, bytes 453-460, of the

Dataset Summary Record, can be considered as being valid over the image. The same applies to image regions known to be within 2 minutes of the start of acquisition, but within longer duration ScanSAR images. For short ScanSAR images, or regions near to the start of the image, the calculation of incidence angle is therefore essentially as for single beam image scenes.

For longer ScanSAR images, and image regions acquired more than 2 minutes after start of acquisition, improved incidence angle estimation may be achieved by selection of a more appropriate set of SRGR coefficients. The platform geodetic latitude applicable to the portion of the image under consideration may also be estimated.

To find the appropriate set of SRGR coefficients proceed as follows:

a) Select a range line in the region of interest, and from the Processed Data Record find the acquisition time from fields 13, 14 and 15, bytes 37-48, (acq_year, acq_day, acq_msec).

b) From the Processing Parameter Record, field 14, bytes 150-170, (act_ing_start), find the acquisition start time.

c) Subtract the result of (b) above from (a) to find the time from the start of the image (seconds) – note that the time formats in these fields are different.

d) Find the update rate of the SRGR coefficient sets (seconds) from field 287, bytes 2689-2704, (dopcen_inc) of the Processing Parameter Record.

e) Divide the result of (c) above by (d) to find the nearest integer, n.

Use the n th. set of SRGR coefficients.

To find an approximation for the platform latitude, proceed as follows:

f) From the Dataset Summary Record field 36, bytes 453-460, find the platform geodetic latitude at the start of the image swath (plat_lat).

g) From the Dataset Summary Record field 12, bytes 101-106, (asc_des), establish whether the pass is ascending or descending.

h) The change of spacecraft latitude is approximately 0.06 degrees per second, therefore the platform latitude difference from the start of the image to the region of interest is given by (result from step c above)*0.06 degrees.

For ascending passes calculate a new value for platform latitude by changing the original value of plat_lat by (h above) degrees North. For descending passes modify plat_lat by (h) degrees South.

Appendix A - Incidence and Elevation Angle Calculation

1) **Calculate earth radius - r, and satellite altitude- h**

From the CEOS Data Set Summary Record

ellipsoid semi-major axis:	ellip_maj = 6378.14	km
ellipsoid semi-minor axis:	ellip_min = 6356.755	km
platform geodetic latitude:	plat_lat = 45.901	deg

From the CEOS Processing Parameter Record

eph_orb_data(1)	$\alpha = 7.167055 \, . \, 10^6$	m

$$r = ellipmin.\frac{\sqrt{1+\tan^2(platlat.\frac{p}{180})}}{\sqrt{\frac{ellipmin^2}{ellipmaj^2}+\tan^2(platlat.\frac{p}{180})}}.10^3$$

Calculate earth radius, r, at image centre position (start of image for swath products):

i.e. $r = 6.367.10^6$ m

$$h = a - r$$

Calculate orbit altitude, h:

i.e. $h = 8 \, . \, 10^5$ m

2) **Calculate the slant range for each ground range increment of the output scaling LUT:**

From the Processing Parameter Record: 6 values of SRGR coefficients [srgr_coef(1-6)]

1^{st} SRGR coeff = a	$a = 8.4087600 \, . \, 10^5$
2^{nd} SRGR coeff = b	$b = 3.3333325 \, . \, 10^{-1}$
3^{rd} SRGR coeff = c	$c = 6.0235465 \, . \, 10^{-7}$
4^{th} SRGR coeff = d	$d = -2.4054597 \, . \, 10^{-13}$
5^{th} SRGR coeff = e	$e = -1.1672899 \, . \, 10^{-19}$
6^{th} SRGR coeff = f	$f = 1.9135056 \, . \, 10^{-25}$

From the CEOS Data Set Summary Record:

pixel spacing:- pix_spacing = 12.5 m

For detected products, let dRg = pix_spacing = 12.5 m in this example.

For SLC products, the slant range pixel spacing, dRs = pix_spacing.

For all products, let the pixels be denoted by j, where j is counted from the start of the range line and has a range: < j = 0 .. (n_data_pixel -1)>.

For detected products arranged near range pixels first, find the slant range for the j th. pixel from:

$$RS_j = a + j.dRg.b + (j.dRg)^2 .c + (j.dRg)^3 .d + (j.dRg)^4 .e + (j.dRg)^5 .f$$

For SLC products arranged near range first: $RS_j = a + dRs.j$

For detected products having far range pixels first, calculate the slant range for the j th. pixel from:

$$RS_j = a + k.dRg.b + (k.dRg)^2 .c + (k.dRg)^3 .d + (k.dRg)^4 .e + (k.dRg)^5 .f$$

For SLC products arranged far range first: $RS_j = a + dRs.k$

where k = n_data_pixel - j

3) **Calculate the incidence angle at each pixel:**

The incidence angle for the j th. pixel is given by:

$$I_j = \arccos \left[\frac{(h^2 - (RS_j)^2 + 2.r.h)}{2.RS_j.r} \right]$$

4) **Calculate the corresponding beam elevation angles:**

The elevation angle, q_j, for the j th. pixel is given by:

$$q_j = \arcsin \left[\sin(I_j) \cdot \frac{r}{r+h} \right]$$

where I_j is the incidence angle calculated in part 3 above, *r* is the earth radius, and *h* is the orbit altitude. q_j is the beam elevation angle measured w.r.t to the nadir direction.

The conversion from incidence angle to elevation is required in order to estimate the differences in beta nought values between calibrated and uncalibrated products. CSA publishes separately a document containing tables and plots which show the beta nought differences as a function of beam elevation angle. For this purpose it is sufficiently accurate to take *r* as a mean earth radius of 6367 km., and *h* as the mean orbit altitude of 800 km.

APPENDIX B - RADARSAT PAYLOAD PARAMETERS FILES

FILE #	Submitted	Valid Start Time	Valid End Time	Comments
P0000005.ppr	28-Nov-95	1995-12-28 23:24:28	1996-02-28 21:03:41	
P0000006.ppr	28-Feb-96	1996-02-28 21:03:41	1996-05-21 21:36:00	Revised replica_phase_coeff
P0000007.ppr	21-May-96	1996-05-21 21:36:00	1996-06-14 15:34:53	New beam table load
P0000008.ppr	14-Jun-96	1996-06-14 15:34:53	1996-07-23 20:06:25	New beam patterns for S1-7, W1-3, F1-5
P0000009.ppr	23-Jul-96	1996-07-23 20:06:25	1996-09-25 21:13:05	Refinement of elevation beam patterns and GCF
P0000010.ppr	25-Sep-96	1996-09-25 21:13:05	1996-11-27 19:39:39	Beam slot changes for extended high beams
P0000011.ppr	27-Nov-96	1996-11-27 19:39:39	1997-01-21 14:35:58	Calibration of beams S1, S2, S3, S4 of CDPF products
P0000012.ppr	21-Jan-97	1997-01-21 14:35:58	1997-02-14 17:12:08	EL1 Beam replacing EH1 beam
P0000013.ppr	14-Feb-97	1997-02-14 17:12:08	1997-06-02 16:39:46	S5-S7, W1-W3 calibrated, S1, S2, S4 and GCFs upgraded
P0000014.ppr	02-Jun-97	1997-06-02 16:39:46	1997-08-12 15:35:51	F1-F5 calibrated, GCFs and TRNLs updated, Relative beam gains adjusted
P0000015.ppr	12-Aug-97	1997-08-12 15:35:51	1997-09-08 07:00:00	Calibration upgrade to Beam EL1
P0000016.ppr	08-Sep-97	1997-09-08 07:00:00	1997-09-09 07:00:00	Beam EL1 calibrated
P0000017.ppr	8-May-98	1997-09-09 07:00:00	1997-10-20 19:00:00	Beam S4 Calibrated for Left-Looking Mode (Antarctic Mapping Mission)
P0000018.ppr	8-May-98	1997-10-20 19:00:00	1998-04-21 21:12:32	Copy of Payload 16 with an update of TNRL
P0000019.ppr	23-Dec-98	1998-04-21 21:12:32	1998-10-13 20:57:17	Beams F4 and W1 re-calibrated
P0000020.ppr	21-Apr-99	1998-10-13 20:57:17	1998-12-10 20:57:17	Beams S3 and S6 re-calibrated
P0000021.ppr	17-Jun-99	1998-12-10 20:57:17	1999-10-25 22:00:00	Beams S1 re-calibrated and TNRL updated
P0000022.ppr	15-Feb-00	1999-10-25 22:00:00	2014-07-23 00:0:00	Beam EXTL1 re-calibrated ***(Current Payload File)***
P0000023.ppr	*TBS*	*1999-11-25 10:00:12*	*2014-07-23 00:0:00*	*Beam S71 re-calibrated (NOT YET SUBMITTED)*