TECHNICAL SPECIFICATION

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Geographic information — Calibration and validation of remote sensing imagery sensors and data —

Part 3: **SAR/InSAR**

Information géographique — Calibration et validation de capteurs de télédétection —

Partie 3: SAR/InSAR

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 211, *Geographic information/Geomatics*.

A list of all parts in the ISO 19159 series can be found on the ISO website.

Introduction

Imaging sensors are one of the major data sources for geographic information.

The image data captures spatial and spectral measurements and has numerous applications ranging from road/town planning to geological mapping. Typical spatial outcomes of the production process are vector maps, digital elevation models, and 3-dimensional city models.

In each case the quality of the end products fully depends on the quality of the measuring instruments that have originally sensed the data. The quality of measuring instruments is determined and documented by calibration.

Calibration is often a costly and time consuming process. Therefore, a number of different strategies are in place that combine longer time intervals between subsequent calibrations with simplified intermediate calibration procedures that bridge the time gap and still guarantee a traceable level of quality.

This document standardizes the calibration of remote sensing imagery sensors and the validation of the calibration information and procedures. It does not address the validation of the data and the derived products.

Many types of imagery sensors exist for remote sensing tasks. Apart from the different technologies the need for a standardization of the various sensor types has a different priority. In order to meet those requirements ISO/TS 19159 has been split into several parts. ISO/TS 19159-1 addresses the optical sensors. ISO/TS 19159-2 addresses the airborne lidar (light detection and ranging) sensors. ISO/TS 19159-3 (this document) covers synthetic aperture radar (SAR) and interferometric SAR (InSAR).

Geographic information — Calibration and validation of remote sensing imagery sensors and data —

Part 3: SAR/InSAR

1 Scope

This document defines the calibration of SAR/InSAR sensors and validation of SAR/InSAR calibration information.

This document addresses earth based remote sensing. The specified sensors include airborne and spaceborne SAR/InSAR sensors.

This document also addresses the metadata related to calibration and validation.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19103, *Geographic information — Conceptual schema language*

ISO/TS 19130:2010, *Geographic information — Imagery sensor models for geopositioning*

ISO/TS 19130-2:2014, *Geographic information — Imagery sensor models for geopositioning — Part 2: SAR, InSAR, lidar and sonar*

ISO 19157, *Geographic information — Data quality*

ISO/TS 19159-1:2014, *Geographic information — Calibration and validation of remote sensing imagery sensors and data — Part 1: Optical sensors*

ISO/TS 19159-2, *Geographic information — Calibration and validation of remote sensing imagery sensors — Part 2: Lidar*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
accuracy
closeness of agreement between a test result or measurement result and the true value

Note 1 to entry: In this document, the true value can be a reference value that is accepted as true.

[SOURCE: ISO 3534-2:2006, 3.3.1, modified — NOTES 1, 2 and 3 have been deleted. New Note 1 to entry has been added.]

3.2
antenna pattern
ratio of the electronic-field strength radiated in the direction θ to that radiated in the beam-maximum direction

3.3
aperture reference point
ARP
3D location of the centre of the synthetic aperture

Note 1 to entry: It is usually expressed in ECEF coordinates in metres.

[SOURCE: ISO/TS 19130:2010, 4.4]

3.4
attitude
orientation of a body, described by the angles between the axes of that body's coordinate system and the axes of an external coordinate system

[SOURCE: ISO 19116:2004 4.2]

3.5
azimuth resolution
<SAR> resolution in the cross-range direction

Note 1 to entry: This is usually measured in terms of the impulse response of the SAR sensor and processing system. It is a function of the size of the synthetic aperture, or alternatively the dwell time (e.g. larger aperture → longer dwell time → better resolution).

Note 2 to entry: 3 dB width of the impulse response is the normal value of measurements.

Note 3 to entry: Cross-range direction is also the same as along-track direction.

[SOURCE: ISO/TS 19130:2010, 4.7, modified — Notes 2 and 3 to entry have been added.]

3.6
backscattering coefficient
average radar cross section per unit area

Note 1 to entry: If the radar return from the illuminated area is contributed by a number of independent scattering elements, it is described by the backscattering coefficient instead of radar cross section used for the point target. It is calculated as:

$$\sigma^0 = \frac{\sigma}{A}$$

where

σ is the total radar cross section of an area A;

σ^0 is a dimensionless parameter and is usually expressed in decibels (dB) as follows:

$$\sigma^0_{\text{dB}} = 10 \log_{10} \sigma^0$$

Note 2 to entry: "Backscattering coefficient" is sometimes called "normalized radar cross section".

3.7
calibration
process of quantitatively defining a system's responses to known, controlled signal inputs

[SOURCE: ISO/TS 19101-2: 2008, 4.2]

3.8
calibration coefficient
ratio of SAR image pixel power to radar cross section without considering additive noise, after the processor gain is normalized to one, and elevation antenna pattern, range and atmospheric attenuation are all corrected

3.9
correction
compensation for an estimated systematic effect

Note 1 to entry: See ISO/IEC Guide 98-3:2008, 3.2.3, for an explanation of "systematic effect".

Note 2 to entry: The compensation can take different forms, such as an addend or a factor, or can be deduced from a table.

[SOURCE: ISO/IEC Guide 99:2007, 2.53]

3.10
cross-talk
any signal or circuit unintentionally affecting another signal or circuit

Note 1 to entry: For PolSAR sensor, if the transmitting channel is horizontally (H) polarized, the cross-talk on transmitting defines the ratio of V polarization transmitting power to H polarization transmitting power, expressed in decibels (dB). The cross-talk on receiving is similar to that on transmitting.

3.11
digital elevation model
DEM
dataset of elevation values that are assigned algorithmically to 2-dimensional coordinates

[SOURCE: ISO/TS 19101-2:2008, 4.5]

3.12
height
h, *H*
distance of a point from a chosen reference surface measured upward along a line perpendicular to that surface

Note 1 to entry: A height below the reference surface will have a negative value.

Note 2 to entry: The terms elevation and height are synonyms.

[SOURCE: ISO 19111:2007, 4.29 — modified: Note 2 to entry has been added.]

3.13
incident angle
vertical angle between the line from the detected element to the sensor and the local surface normal (tangent plane normal)

[SOURCE: ISO/TS 19130:2010, 4.57]

3.14
interferometric baseline
distance between the two antenna phase centre vectors at the time when a given scatterer is imaged

3.15
integrated side lobe ratio
ISLR
ratio between the side lobe power and the main lobe power of the impulse response of point targets in the radar imaging scene

Note 1 to entry: The integrated side lobe ratio (ISLR) can be obtained by integrating the power of the impulse response over suitable regions. The ISLR is expressed as

$$\text{ISLR} = 10\log_{10}\left\{\frac{P_{\text{total}} - P_{\text{main}}}{P_{\text{main}}}\right\}$$

where

P_{total} is the total power;

P_{main} is the main lobe power.

Note 2 to entry: The main lobe width can be taken as α times the impulse response width (IRW), centred around the peak, where α is a predefined constant, usually between 2 and 2,5.

3.16
interferometric synthetic aperture radar
InSAR
technique exploiting two or more SAR images to generate maps of surface deformation or digital elevation through the differences in the phase of the waves returning to the radar

3.17
look angle
vertical angle from the platform down direction to the slant range direction, usually measured at the aperture reference point (ARP)

Note 1 to entry: “Off-nadir angle” has the same definition as “look angle”.

[SOURCE: ISO/TS 19130-2:2014, 4.42, modified — new Note 1 to entry has replaced the original Note 1 to entry.]

3.18
metadata
information about a resource

[SOURCE: ISO 19115-1:2014, 4.10]

3.19
peak side lobe ratio
PSLR
ratio between the peak power of the largest side lobe and the peak power of the main lobe of the impulse response of point targets in the SAR image

Note 1 to entry: The peak side lobe ratio is usually expressed in decibels (dB) and computed as follows:

$$\text{PSLR} = 10\log_{10}\left\{\frac{P_{\text{sidepeak}}}{P_{\text{mainpeak}}}\right\}$$

where

P_{mainpeak} is the peak power of the main lobe;

P_{sidepeak} is the peak power of the largest side lobe

3.20
polarimetric synthetic aperture radar
SAR sensor enhanced by transmitting and receiving in different combinations of polarization

Note 1 to entry: By combining multiple polarization modes, it is possible to characterize the target more clearly. Quad-Pol SAR system both transmits and receives orthogonal (e.g. horizontal and vertical) polarizations, which creates four polarizations of a single imaging scene. The calibration of Quad-Pol SAR is addressed in this document.

3.21
polarization channel imbalance
bias in the estimation of the scattering matrix element ratio between coincident pixels from two coherent data channels

Note 1 to entry: Polarization channel imbalance includes the amplitude imbalance and phase imbalance.

3.22
pulse repetition frequency
number of times the system (e.g. LIDAR) emits pulses over a given time period, usually stated in kilohertz (kHz)

[SOURCE: ISO/TS 19130-2:2014, 4.53]

3.23
radar cross section
measure of the capability of the object to scatter the transmitted radar power

Note 1 to entry: Radar cross section is calculated as

$$\sigma = \lim_{R \to \infty} 4\pi R^2 \frac{|E_s|^2}{|E_i|^2}$$

where

σ is the radar cross section;

E_i is the electric-field strength of the incident wave;

E_s is the electric-field strength of the scattered wave at the radar with a distance R away from the target.

Note 2 to entry: Radar cross section has the dimensions of area, with the unit of square metres. Usually, it is expressed in the form of a logarithm with the unit of dBsm as follows:

$$\sigma_{dBsm} = 10 \log_{10} \sigma$$

3.24
range
<SAR> distance between the antenna and a distant object, synonymous with slant range

[SOURCE: ISO/TS 19130-2:2014, 4.54]

3.25
range bin
<SAR> group of radar returns that all have the same range

[SOURCE: ISO/TS 19130:2010, 4.69]

3.26
range direction
slant range direction
<SAR> direction of the *range vector*

[SOURCE: ISO/TS 19130:2010, 4.70]

3.27
range resolution
spatial *resolution* in the range *direction*

Note 1 to entry: For a SAR *sensor*, it is usually measured in terms of the impulse response of the sensor and processing system. It is a function of the bandwidth of the pulse.

Note 2 to entry: 3 dB width of the impulse response is the normal value of measurements.

[SOURCE: ISO/TS 19130:2010, 4.71 — modified: Added Note 2 to entry.]

3.28
remote sensing
collection and interpretation of information about an object without being in physical contact with the object

[SOURCE: ISO/TS 19101-2:2008, 4.33]

3.29
resolution (of imagery)
smallest distance between two uniformly illuminated objects that can be separately resolved in an image

Note 1 to entry: This definition refers to the spatial resolution.

Note 2 to entry: In the general case, the resolution determines the possibility to distinguish between neighbouring features (objects).

Note 3 to entry: Resolution can also refer to the spectral and the temporal resolution.

[SOURCE: ISO/TS 19130-2:2014, 4.61 — modified: Added Notes 1, 2 and 3 to entry.]

3.30
scattering matrix
matrix characterizing the scattering process at the target of interest for polarimetric SAR

Note 1 to entry: Scattering matrix is defined by

$$\begin{pmatrix} E_H^s \\ E_V^s \end{pmatrix} = \frac{e^{jkR}}{R} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} E_H^i \\ E_V^i \end{pmatrix}$$

where

$\begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix}$ is the scattering matrix;

$\begin{pmatrix} E_H^i \\ E_V^i \end{pmatrix}$ is the electronic field vector of the wave incident on the scatterer;

$\begin{pmatrix} E_H^s \\ E_V^s \end{pmatrix}$ is the electronic field vector of the scattered wave;

k is the wavenumber of the illuminating wave;

R is the distance between the target and the radar antenna.

3.31
sensor
element of a measuring system that is directly affected by a phenomenon, body, or substance carrying a *quantity* to be measured

Note 1 to entry: Active or passive sensors exist. Often two or more sensors are combined to a measuring system.

[SOURCE: ISO/IEC Guide 99:2007, 3.8 — modified: The EXAMPLE and NOTE were replaced by Note 1 to entry.]

3.32
uncertainty
parameter, associated with the result of measurement, that characterizes the dispersion of values that could reasonably be attributed to the measurand

Note 1 to entry: The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.

Note 2 to entry: Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information.

Note 3 to entry: It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

Note 4 to entry: When the quality of accuracy or precision of measured values, such as coordinates, is to be characterized quantitatively, the quality parameter is an estimate of the uncertainty of the measurement results. Because accuracy is a qualitative concept, one should not use it quantitatively, that is associate numbers with it; numbers should be associated with measures of uncertainty instead.

Note 5 to entry: Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

Note 6 to entry: The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

Note 7 to entry: Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

Note 8 to entry: In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quality value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

[SOURCE: ISO 19116:2004, 4.26 modified: Added Notes 1, 2, 3, 5, 6, 7 and 8 to entry.]

3.33
validation
process of assessing, by independent means, the quality of the data products derived from the system outputs

Note 1 to entry: In this document, the term validation is used in a limited sense and only relates to the validation of calibration data in order to control their change over time.

[SOURCE: ISO/TS 19101-2:2008, 4.41]

4 Symbols, abbreviated terms and conventions

In this document, conceptual schemas are presented in the Unified Modelling Language (UML). ISO 19103 conceptual schema language presents the specific profile of UML used here.

4.1 Symbols

A	area of the ground resolution cell
B	length of the interferometric baseline vector
f_d	doppler centroid frequency
f_s	sampling frequency
f_1	amplitude and phase imbalance between the H and V channels on receive
f_2	amplitude and phase imbalance between the H and V channels on transmit
G_p	imaging processor gain
G_r	gain in the radar receiver
G_t^A	transmit antenna gain in the maximum-gain direction
G_r^A	receive antenna gain in the maximum-gain direction
$g_r^A(\theta)$	receive antenna elevation pattern which is normalized to unit gain in the maximum-gain direction
$g_t^A(\theta)$	transmit antenna elevation pattern which is normalized to unit gain in the maximum-gain direction
H	height of the antenna relative to the reference plane
h	height of the target relative to the reference plane
K_c	calibration coefficient
K_s	overall radar system gain
L_a	atmospheric propagation attenuation loss
L_s	system loss

$\boldsymbol{N}$	matrix characterizes the additive noise term of PolSAR sensor
P_{I}	image pixel power
P_{n}	additive noise power
P_{t}	peak transmitted power
PRF	pulse repetition frequency
p	InSAR collection mode sign, $p = 1$ for standard mode and $p = 2$ for ping-pong mode
R	range from the antenna phase centre to the target
$\boldsymbol{R}$	matrix characterizes the radar receive system of PolSAR sensor
R_{e}	radius of earth at the equator
R_{p}	polar radius of earth
$\boldsymbol{S}$	ideal scattering matrix
$\boldsymbol{T}$	matrix characterizes the radar transmit system of PolSAR sensor
t_{i}	azimuth imaging time
t_0	azimuth imaging start time
$\boldsymbol{Y}$	measured scattering matrix
α	angle the interferometric baseline makes with respect to a reference horizontal plane
δ_1	cross-talk from H channel to V channel on receive
δ_2	cross-talk from V channel to H channel on receive
δ_3	cross-talk from H channel to V channel on transmit
δ_4	cross-talk from V channel to H channel on transmit
θ	look angle
λ	radar wavelength
σ	radar cross section
σ^0	scattering coefficient
τ_0	time delay from radar to the first range sample
φ	interferometric phase
$\vec{S}$	antenna phase centre position vector
$\vec{T}$	target position vector
$\vec{V}$	antenna phase centre velocity vector

4.2 Abbreviated terms

ARC Active Radar Calibrator

CRS Coordinate Reference System

DEM Digital Elevation Model

DInSAR Differential Interferometric SAR

GCP Ground Control Point

GNSS Global Navigation Satellite System

IMU Inertial Measurement Unit

InSAR Interferometric Synthetic Aperture Radar

ISLR Integrated Side Lobe Ratio

NESZ Noise Equivalent Sigma Zero

Radar RAdio Detection And Ranging

PolSAR Polarimetric Synthetic Aperture Radar

PRF Pulse Repetition Frequency

PSLR Peak Side Lobe Ratio

RCS Radar Cross Section

SAR Synthetic Aperture Radar

UML Unified Modelling Language

4.3 Conventions

ISO 19103 requires that names of UML classes, with the exception of basic data type classes, include a two-letter prefix that identifies the standard and the UML package in which the class is defined. Table 1 lists the prefixes used in this document, the International Standard in which each is defined and the package each identifies. UML classes defined in this document belong to a package named Calibration Validation and have the same two letter prefixes as ISO/TS 19159-1 and ISO/TS 19159-2 CA.

Table 1 — UML class prefixes

Prefix	International Standard	Package
CA	ISO/TS 19159-1, ISO/TS 19159-2 and ISO/TS 19159-3 (this document)	Calibration Validation
MD	ISO 19115-1	Metadata
SD	ISO/TS 19130	Sensor Data
SE	ISO/TS 19130-2	Sensor Data Extensions
SC	ISO 19111	Spatial Coordinates
DQ	ISO 19157	Data quality
TM	ISO 19108	Temporal Schema

5 Conformance

This document specifies three conformance classes. Details of the conformance classes are given in the abstract test suite in Annex A. Any set of calibration and validation information of SAR sensors, InSAR sensors or Polarimetric SAR (PolSAR) sensors, claiming conformance to this document shall satisfy the requirements described in the abstract test suite A.1, A.2 or A.3, respectively.

6 General SAR sensor calibration model

6.1 Introduction

This document addresses the calibration of SAR/InSAR sensors and validation of SAR/InSAR calibration information. It includes the detailed description of SAR performance and parameters related to SAR geometric and radiometric calibration, which can be used for refined SAR image processing.

Figure 1 depicts a package diagram that shows all parts of the ISO/TS 19159 series as of the time this document was developed.

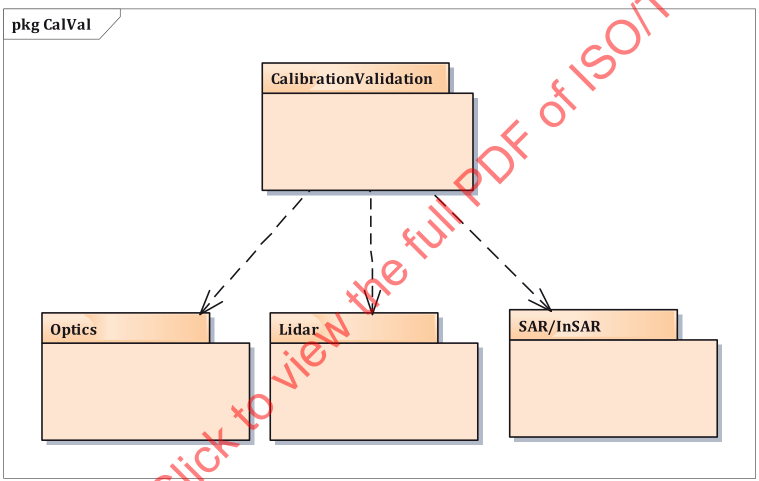

Figure 1 — Package diagram of the package CalibrationValidation

SAR is a kind of imaging radar. As an active system, SAR provides its own illumination and it is not dependent on light from the sun. Furthermore, depending on the frequency microwaves can penetrate through cloud, fog and rain. Consequently, SAR has the ability to observe the earth in both day and night, and for almost all weather conditions.

SAR transmits successive radar pulses to illuminate the target scene and receives echo pulses from a side-looking antenna mounted on a moving platform to create an image. Different from real aperture radar, SAR is a coherent system in which both phase and amplitude of the echo pulses are preserved. As a result, SAR creates a large virtual antenna known as synthetic aperture, by moving the real sensor antenna along the flight direction and synthesizing the information of a series of received pulses within the synthetic antenna length. This method improves the azimuth resolution considerably without increasing the physical antenna size.

In the range direction, the pulse compression technique is used by SAR to achieve both high resolution and high signal-to-noise ratio. SAR system usually employs a chirp pulse, which is linearly modulated in frequency for the duration of time. The received pulse is then processed with a matched filter which compresses the long pulse to very short pulse duration.

Interferometric SAR (InSAR) combines complex SAR images recorded by antennas at different locations or at different times. The range differences for corresponding points of the image pair can be determined by the interferograms on the sub-wavelength scale. It can be used as an alternative to conventional stereo photographic techniques for topographic map generation. InSAR can also be used for velocity mapping and surface deformation detection.

Radar polarimetry is concerned with the full vector nature of polarized radar waves. It can be used for extraction of target properties from the behaviour of scattered waves from a target. Polarimetric SAR (PolSAR), the incorporation of coherent polarimetric phase and amplitude into SAR signal, brings about further improvements in monitoring capabilities such as land-use classification, forest mapping, biomass estimation, target identification, emergency response and damage assessment.

Polarimetric SAR interferometry (PolInSAR) is a technique which combines the advantages of InSAR and PolSAR. It provides combined sensitivity to the vertical distribution of scattering mechanisms and has the capacity to optimize the quality of height estimation. It is very useful in the field of physical parameter inversion and hidden surface/target imaging.

Calibration is the process of quantitatively defining a system's response to controlled signal inputs. SAR calibration contains two aspects, geometry and radiometry.

For many applications, such as geologic mapping and land surveys, the geometric fidelity of the data product is very important. For the sake of high geometric accuracy, geometric calibration is essential to measure various error sources.

The purpose of SAR radiometric calibration is characterizing the performance of the end-to-end SAR system so that the real radiometric parameters of ground targets, i.e. RCS or backscattering coefficients, can be derived from the SAR image.

However, calibration is often a costly and time consuming process. Therefore, simplified intermediate calibration procedures are carried out to bridge the time gap between subsequent calibrations and ensure a long-term confidence in the quality.

For specific SAR acquisition modes, such as InSAR and PolSAR, additional parameters should be calibrated to improve the product quality besides ordinary geometric and radiometric calibration.

This clause describes the general model of SAR sensor calibration and validation of calibration information. InSAR and PolSAR sensors are described in Clauses 7 and 8, respectively. Calibration and validation of PolInSAR is not addressed in this document.

6.2 Top-level model

Figure 2 depicts the top-level class diagram of this document. The classes shown in Figure 2, their attributes and their associations shall be used as described in the data dictionary of B.2, B.12.1 and in ISO/TS 19130-2.

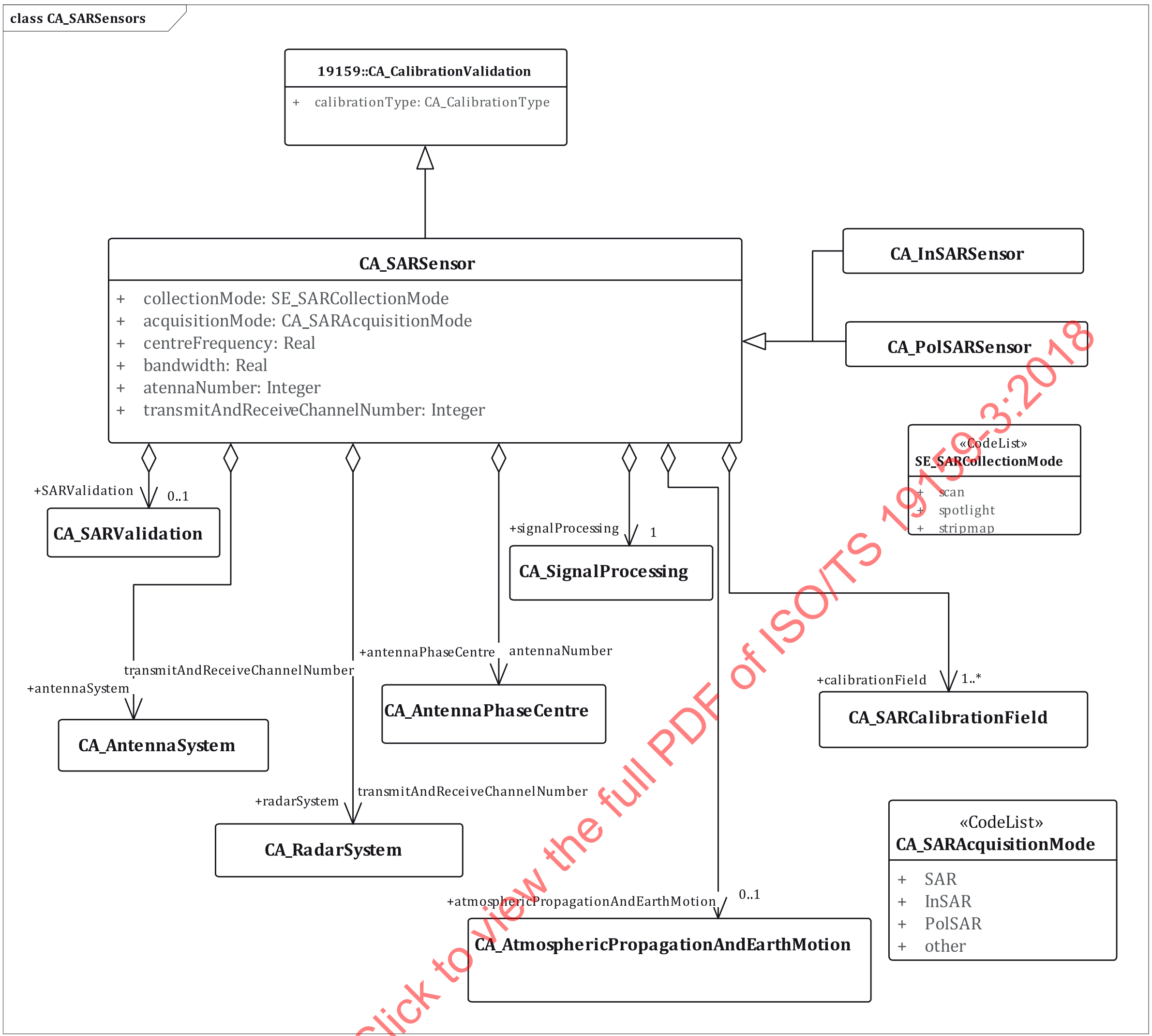

Figure 2 — Top-level class diagram of ISO/TS 19159-3

The class CA_SARSensor is a top level class for all information of calibration and validation of SAR sensors. It aggregates seven classes named CA_Radar-System, CA_AntennaSystem, CA_AntennaPhaseCentre, CA_SignalProcessing, CA_Atmospheric-PropagationAndEarthMotion, CA_SARCalibrationField and CA_SARValidation. Details of the radar system are shown in Figure 3, of the antenna system are shown in Figure 4, of the antenna phase centre are shown in Figure 5, of the signal processing are shown in Figure 6, of the atmospheric propagation and earth motion are shown in Figure 7, of the calibration field are shown in Figure 8, of SAR validation are shown in Figure 9.

It has two subclasses named CA_InSARSensor and CA_PolSARSensor which are shown in Figure 11 and Figure 12, respectively.

The attribute collectionMode defines the method used by SAR system to collect data.

The attribute acquisitionMode defines the acquisition mode of SAR system according to the code list set in the class CA_SARAcquisitionMode.

The attribute centreFrequency defines the centre frequency of the SAR sensor.

The attribute bandwidth defines the bandwidth of transmitted signal.

The attribute antennaNumber defines the number of antennas of SAR system.

The attribute transmitAndReceiveChannelNumber defines the channel number of SAR system. One channel refers to one transmitting and receiving channel. General SAR has one channel. Dual antenna InSAR has two channels even if it operates in the standard mode that one antenna transmits and both antennas receive echoes. Full polarimetric SAR has four channels whose polarimetric modes are HH, HV, VH and VV respectively.

6.3 Radar system

The radar generates pulses by the transmitter and radiates them into space by the antenna. A fraction of the radar signal is returned from the reflecting targets in the direction of the radar. The returned echo is collected by the antenna and amplified by the receiver. SAR is a kind of imaging radar. This clause describes radar system parameters related to SAR calibration except antenna parameters, which is described in Clause 6.4.

Figure 3 depicts the class diagram of radar system. The classes shown in Figure 3, their attributes and their associations shall be used as described in the data dictionary of B.3.

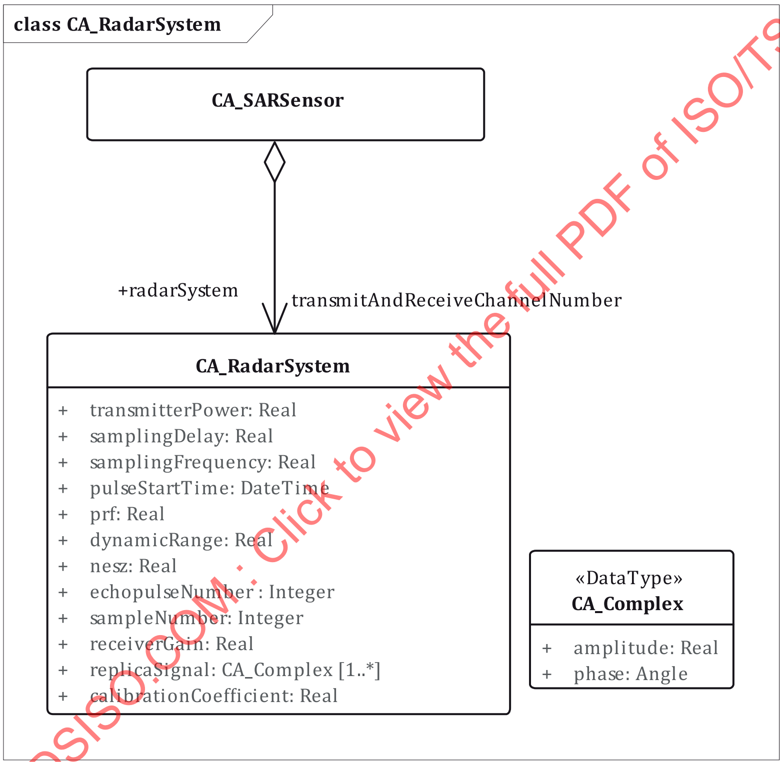

Figure 3 — CA_RadarSystem

The class CA_RadarSystem contains all information about the radar system of SAR sensor.

The attribute transmitPower defines peak transmitted power of radar system.

The attribute samplingDelay defines the echo reception time delay of the first range sample with respect to the pulse transmitted time.

The attribute samplingFrequency defines the range sampling frequency.

The attribute pulseStartTime defines the azimuth time of the first pulse.

The attribute prf defines the radar pulse repetition frequency. This document only addresses calibration of general SAR/InSAR system working on a fixed PRF. Systems with complex working modes, calibration will be closely related with basic SAR system data acquisition. It may be discussed in a future part of ISO TS 19159.

The attribute dynamicRange defines the range of input signal strength over which the receiver can amplify the input signal linearly.

The attribute nesz defines noise equivalent sigma zero of the radar system. It is a measure of the sensitivity of the system to areas of low radar backscatter and is given by the value of the backscattering coefficient corresponding to a signal-to-noise ratio of unity.

The attribute echopulseNumber defines the number of received pulses.

The attribute sampleNumber defines the number of samples of one pulse.

The attribute receiverGain defines the gain of radar receiver.

The attribute replicaSignal defines a replica of the transmitted pulse injected into the data stream during the quiet periods between pulse transmission and echo reception, which is used to determine the exact range compression function in the signal processor.

The calibrationCoefficient defines the ratio of SAR image pixel power to RCS without considering additive noise, after the processor gain is normalized to one, elevation antenna pattern, range and atmospheric attenuation are all corrected.

The class CA_Complex is a datatype that defines a complex number.

The attribute amplitude defines the amplitude of a complex number.

The attribute phase defines the phase of a complex number.

6.4 Antenna system

The basic role of the antenna is to provide a tranducer to transmit or receive electromagnetic waves. A single antenna can be used for both transmitting and receiving. This holds true for most SAR systems. However, there are exceptions such as bistatic SAR which must have separated transmit and receive antennas. The key parameters affecting the SAR performance include the antenna gain and its beam pattern. This clause describes useful information of SAR antenna system used for SAR radiometric calibration. This document only addresses calibration of general SAR/InSAR systems with a simple antenna system. Systems with advanced antennas may be discussed in a future part of ISO TS 19159.

Figure 4 depicts the class diagram of antenna system. The classes shown in Figure 4, their attributes and their associations shall be used as described in the data dictionary of B.4, B.12.2 and in ISO/TS 19130.

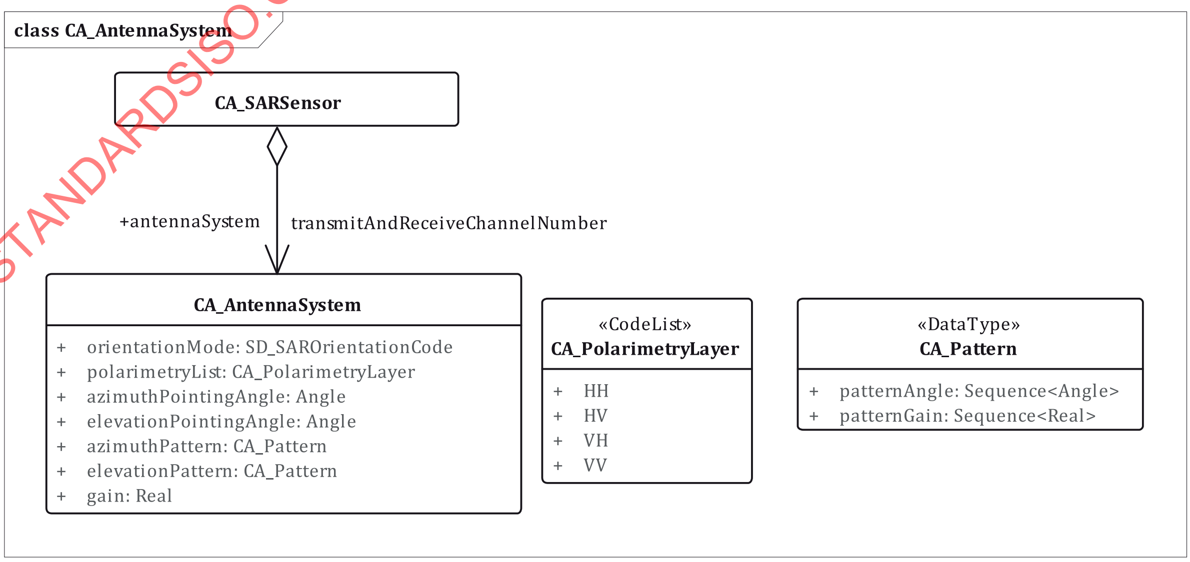

Figure 4 — CA_AntennaSystem

The class CA_AntennaSystem contains all information about the antenna of SAR sensor.

The attribute orientationMode defines the antenna orientation.

The attribute polarimetryList defines the antenna polarimetric mode.

The attribute gain defines the antenna power gain.

The attribute azimuthPointingAngle defines the pointing angle of azimuth antenna beam.

The attribute elevationPointingAngle defines the pointing angle of elevation antenna beam.

The attribute elevationPattern defines the elevation antenna pattern.

The attribute azimuthPattern defines the azimuth antenna pattern.

The class CA_Pattern is a datatype that defines one dimensional antenna pattern.

The attribute patternAngle defines the elevation or azimuth angle relative to the peak of beam.

The attribute patternGain defines the relative gain normalized by the peak gain in the angle that patternAngle defines.

6.5 Antenna phase centre

The position, attitude and velocity of antenna phase centre of SAR sensors are needed in the process of SAR raw data focusing. Therefore, the antenna phase centre is a critical element in determining the system calibration accuracy and image quality. Uncertainty of the position and velocity affects the target geolocation accuracy. The attitude variables are key parameters to determine the echo data doppler parameters and the image quality. This clause describes the related parameters of antenna phase centre which can be used for raw data focusing, geometric correction and radiometric correction.

Figure 5 depicts the class diagram of antenna phase centre. The classes shown in Figure 5, their attributes and their associations shall be used as described in the data dictionary of B.5.

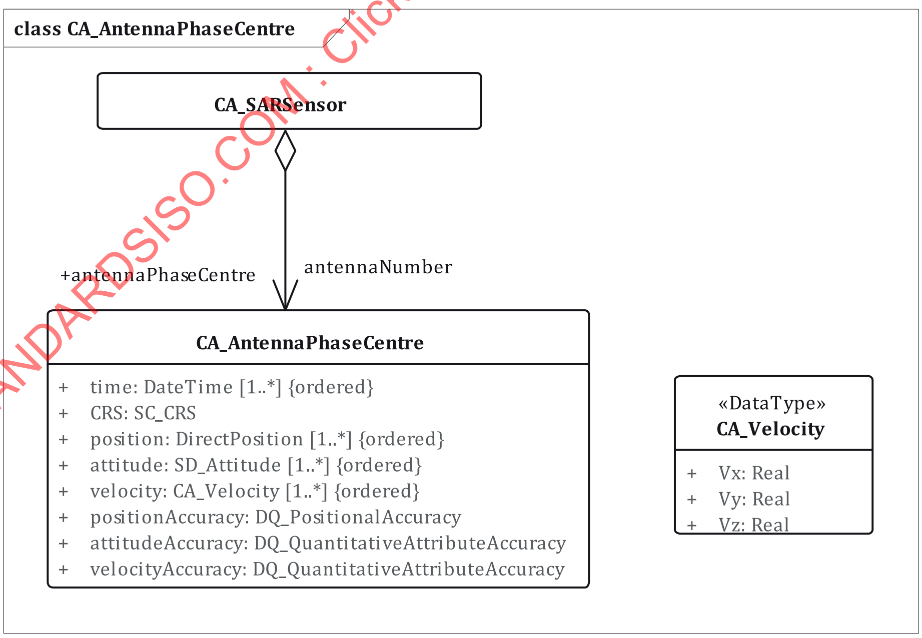

Figure 5 — CA_AntennaPhaseCentre

The class CA_AntennaPhaseCentre contains the parameters about the antenna phase centre of SAR sensor.

The attribute time defines the trigger time of each transmitting pulse.

The attribute CRS defines the coordinate reference system in which the values for the velocity and position of antenna phase centre are measured.

The attribute position defines the position of the antenna phase centre at each pulse transmitting time.

The attribute attitude defines the orientation of the antenna relative to the platform coordinate reference system at each pulse transmitting time.

The attribute velocity defines the velocity of the antenna phase centre at each pulse transmitting time.

The above attributes position, attitude and velocity are the processing output of onboard GNSS, IMU or other navigation measurement data, processed by special filter and time interpolation.

The attributes positionAccuracy, attitudeAccuracy and velocityAccuracy define the accuracy of above attributes position, attitude and velocity, respectively.

6.6 SAR signal processing

SAR sensors collect echo pulses reflected by each target. However, we cannot obtain useful information about the ground scene from the raw data. In order to derive the best representation of the original 2-D reflectivity function, SAR signal processing is necessary to invert the raw data into well focused images. Many algorithms have been developed for SAR raw data imaging processing. This clause describes related information of SAR signal processing which are useful for SAR calibration and validation.

Figure 6 depicts the class diagram of SAR signal processing. The classes shown in Figure 6, their attributes and their associations shall be used as described in the data dictionary of B.6, B.12.3 and B.12.4.

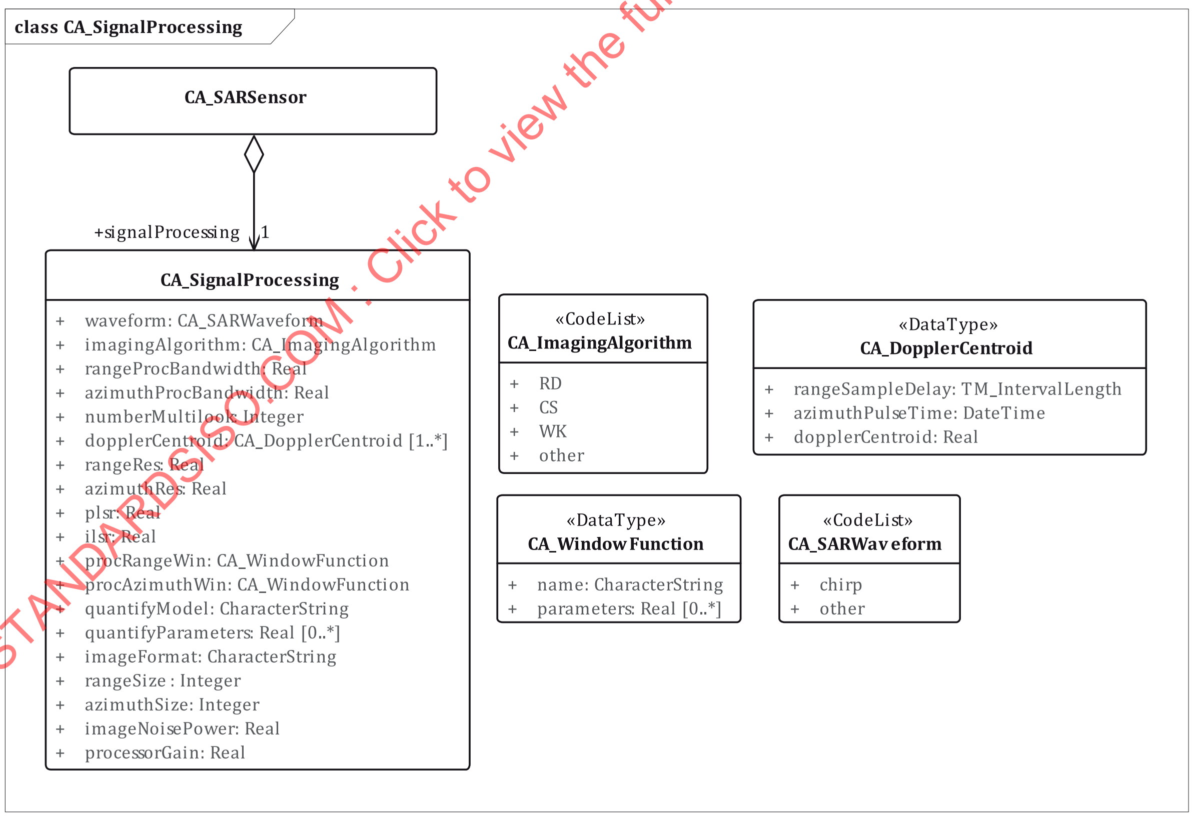

Figure 6 — CA_SignalProcessing

The class CA_SignalProcessing contains the information related to SAR imaging processing of the raw echo signal.

The attribute waveform defines the waveform of the transmitted signal.

The attribute imagingAlgorithm defines the imaging algorithm used to process the raw echo signal to form the SAR image.

The attribute rangeProcBandwidth defines the processing bandwidth in the range direction.

The attribute azimuthProcBandwidth defines the processing bandwidth in the azimuth direction.

The attribute numberMultilook defines the multilook number in the processing procedure.

The attribute dopplerCentroid defines a set of doppler centroid frequencies at different azimuth time and range time.

The attribute rangeRes defines the image resolution in the range direction.

The attribute azimuthRes defines the image resolution in the azimuth direction.

The attribute pslr defines the PSLR of a point target.

The attribute islr defines the ISLR of a point target.

The attribute procRangeWin defines the window function used in the range direction for imaging processing.

The attribute procAzimuthWin defines the window function used in the azimuth direction for imaging processing.

The attribute quantifyMode allows for a description of the quantification mode which transfers the power image to digital numbers.

The attribute quantifyParameter defines the parameters of the quantification mode.

The attribute imageFormat defines the data format of the SAR image according to which users can read the image.

The attribute rangeSize defines the pixel number along the range direction of the SAR image.

The attribute azimuthSize defines the pixel number along the azimuth direction of the SAR image.

The attribute imageNoisePower defines the noise power of the SAR image.

The attribute processorGain defines the gain of the SAR imaging processor.

The class CA_WindowFunction is a datatype that defines the window function used in the process of SAR imaging.

The attribute name defines the name of window function.

The attribute parameters define the parameters of this type of window function.

The class CA_DopplerCentroid is a datatype that defines the doppler centroid frequency at a certain azimuth time and range time.

The attribute rangeSampleDelay defines the echo reception time delay of the current range sample with respect to the pulse transmitted time.

The attribute azimuthPulseTime defines the azimuth time of the current pulse.

The attribute dopplerCentroid defines the doppler centroid frequency at current azimuth time and range time.

6.7 Atmospheric propagation and earth motion

The propagation of transmitted and reflected electromagnetic waves through the atmosphere can result in significant modification of the wave parameters. The main effects include signal attenuation, propagation delay and rotation of the polarized wave, which affects SAR performance in radiometry, geometry and polarimetry, respectively. For high accurate calibration requirements, these effects should be considered and corrected using a proper model. The deformation of the earth also has an effect on the ranging accuracy of SAR sensors, such as solid earth tide, tidal ocean loading, polar tides and continental drift. These factors should be taken into account for the centimetre-level range accuracy. This clause describes the related parameters of atmospheric propagation and earth motion used for SAR calibration.

Figure 7 depicts the class diagram of atmospheric propagation and earth motion effects. The classes shown in Figure 7, their attributes and their associations shall be used as described in the data dictionary of B.7.

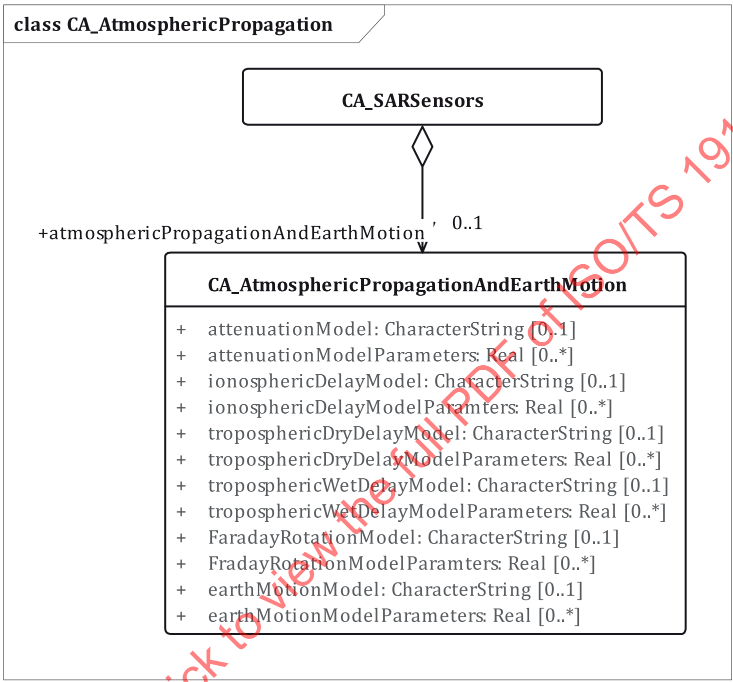

Figure 7 — CA_AtmosphericPropagationAndEarthMotion

The class CA_AtmosphericPropagationAndEarthMotion contains information about the effect of atmospheric propagation and earth motion on the calibration.

The attribute attenuationModel allows for a description of the atmospheric attenuation model that is applied for SAR radiometric calibration.

The attribute attenuationModelParameters defines the parameters of the atmospheric attenuation model.

The attribute ionosphericDelayModel allows for a description of the ionospheric delay model that is applied for SAR geometric calibration.

The attribute ionosphericDelayModelParameters defines the parameters of the ionospheric delay model.

The attribute troposphericDryDelayModel allows for a description of the tropospheric dry delay model that is applied for SAR geometric calibration.

The attribute troposphericDryDelayModelParameters defines the parameters of the tropospheric dry delaly model.

The attribute troposphericWetDelayModel allows for a description of the tropospheric wet delay model that is applied for SAR geometric calibration.

The attribute troposphericWetDelayModelParameters defines the parameters of the tropospheric wet delay model.

The attribute FaradayRotationModel allows for a description of the atmospheric perturbation model that is applied for PolSAR calibration.

The attribute FaradayRotationModel parameters defines the parameters of the atmospheric perturbation model.

The attribute earthMotionModel allows for a description of the earth motion model that is applied to geometric calibration.

The attribute earthMotionModelParameters defines the parameters of the earth motion model.

6.8 SAR calibration field

6.8.1 Introduction

Calibration field is a place to carry out external calibration. Two types of calibration field are usually used for SAR external calibration, namely natural calibration field and manmade calibration field.

Natural calibration field usually refers to natural distributed targets of large areas with homogeneous backscattering properties, such as the Amazon rain forest. On the assumption that the scattering properties of such areas are stable or the variation is well characterized, it can be used for measuring antenna elevation patterns.

In the manmade calibration field, groups of calibration equipment are deployed in along-track and cross-track configurations. They are used to measure the geometric calibration and radiometric calibration parameters, and the quality index of SAR images such as resolution, PSLR and ISLR. Calibration equipment includes active radar calibrators and passive radar calibrators. The most frequently used passive devices for SAR calibration are corner reflectors. Active radar calibrators usually include transponders and receivers.

This clause describes the related parameters of SAR calibration field and calibration equipment.

Figure 8 depicts the class diagram of SAR calibration field. The classes shown in Figure 8, their attributes and their associations shall be used as described in the data dictionary of B.8, B.12.5, B.12.6 and B.12.7.

The class CA_SARCalibrationField specifies SAR calibration field. It has two subclasses. The subclass CA_SARCalibrationNaturalField specifies natural calibration field while the subclass CA_SARCalibrationManmadeField specifies manmade calibration field.

The subclass CA_SARCalibrationManmadeField aggregates the class CA_SARCalibration-Equipment describing information of calibration equipment deployed in the manmade calibration field.

The class CA_SARCalibrationEquipment has two subclasses CA_CornerReflectorAnd-Transponder and CA_GroundReceiver which specify different types of calibration equipments.

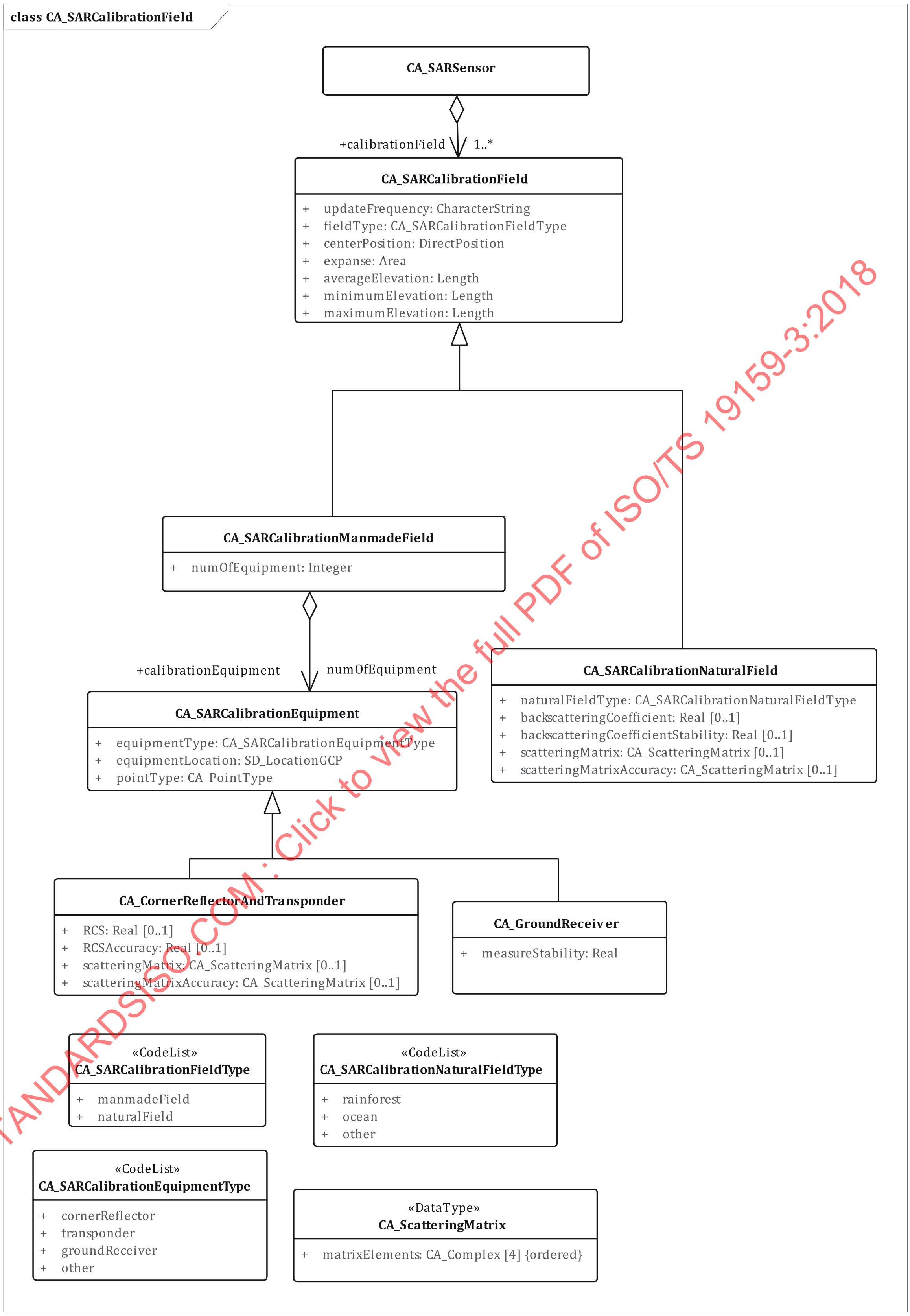

Figure 8 — CA_SARCalibrationField

6.8.2 CA_SARCalibrationField

The class CA_SARCalibrationField contains all information related to the calibration field.

The attribute updataFrequency describes the frequency of the calibration procedure.

The attribute fieldType defines the characteristic of the calibration field according to the code list set in the class CA_SARCalibrationFieldType.

The attribute centrePosition defines the geographic position of the centre of calibration field.

The attribute expanse defines the 2-dimensional size of the calibration field.

The attribute minimumElevation, maximumElevation and averageElevation define the lowest, the highest, and the average elevation of the calibration field respectively.

6.8.3 CA_SARCalibrationNaturalField

The class CA_SARCalibrationNaturalField contains useful information about the natural calibration field.

The attribute naturalFieldType defines the characteristic of the natural calibration field according to the code list set in the class CA_SARCalibrationNaturalFieldType.

The attribute backscatteringCoefficient defines the average backscattering coefficient of the natural calibration field.

The attribute backscatteringCoefficientStability defines the backscattering coefficient stability of the natural calibration field.

The attribute scatteringMatrix defines the average polarimetric scattering matrix of the natural calibration field.

The attribute scatteringMatrixAccuracy defines the polarimetric scattering matrix accuracy of the natural calibration field.

6.8.4 CA_SARCalibrationManmadeField

The class CA_SARCalibrationManmadeField contains useful information about the manmade calibration field. It aggregates the class CA_SARCalibrationEquipment.

The attribute numOfEquipment defines the number of the calibration equipment units deployed in the field.

6.8.5 CA_SARCalibrationEquipment

The class CA_SARCalibrationEquipment contains all information about the calibration equipment deployed in the calibration field.

The attribute equipmentType defines the characteristic of the calibration equipment according to the code list set in the class CA_SARCalibrationEquipmentType.

The attribute equipmentLocation defines the location of the equipment including the geographic coordinates and grid coordinates in the image.

The attribute pointType defines the characterization of the point coded with the code list CA_PointType, which is defined in ISO/TS 19159-1:2014.

6.8.6 CA_CornerReflectorAndTransponder

The class CA_CornerReflectorAndTransponder contains information about corner reflectors or transponders used in the external calibration.

The attribute RCS defines the ideal RCS of the corner reflector or transponder.

The attribute RCSAccuracy defines the RCS accuracy of the corner reflector or transponder.

The attribute scatteringMatrix defines the ideal polarimetric scattering matrix of the corner reflector or transponder.

The attribute scatteringMatrixAccuracy defines the polarimetric scattering matrix accuracy of the corner reflector or transponder.

6.8.7 CA_GroundReceiver

The class CA_GroundReceiver contains information about ground receivers which are usually used to measure antenna patterns.

The attribute measureStability defines the measure stability of the ground receiver.

6.8.8 CA_ScatteringMatrix

The class CA_ScatteringMatrix is a datatype that defines a scattering matrix.

The attribute matrixElements defines the four elements in the scattering matrix.

6.9 SAR validation

This clause describes information necessary to perform validation of SAR/InSAR calibration information. Figure 9 depicts the class diagram of validation. The classes shown in Figure 9, their attributes and their associations shall be used as described in the data dictionary of B.9.

The class CA_SARValidation contains the information about validation of SAR/InSAR calibration information. The attribute validationTime defines the time of validation. Validation of calibration information is the process to evaluate the quality of the calibration information. Therefore, the class CA_SARValidation aggregates the class DQ_Confidence which specifies the trustworthiness of a data quality result as defined in ISO 19157. It generalizes the attribute of the class DQ_Element. The evaluation method and procedure are described in the class DQ_EvaluationMethod. The reference to the measure used is defined in the class DQ_MeasureReference. The output of the evaluation is defined in the class DQ_Result.

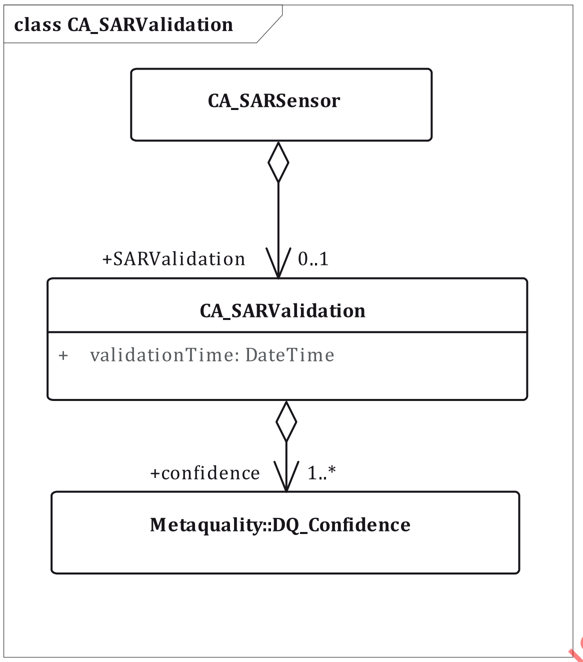

Figure 9 — CA_SARValidation

6.10 SAR Requirement

For the calibration description of the imagery from SAR sensor, all of the mandatory classes and mandatory attributes described in Clause 6 shall be provided.

7 InSAR sensor calibration model

7.1 General

Interferometric SAR (InSAR) exploits two or more SAR complex images acquired from different orbit positions or at different times to get the phase difference information, which can be used to generate digital elevation models (DEM) or detect surface deformations.

According to the methods of data acquisition, InSAR can be divided into different types. Single pass interferometry uses two SAR images from two antennas on a single platform, while repeat pass interferometry uses two or more SAR images taken from two or more repeat passes of a sensor over the same target area. Tandem interferometry is the interferometry of two sensors on two platforms flying in close orbit formation.

The baseline of InSAR, defined as the vector separating the two antenna phase centres, is a very important parameter for InSAR. For dual-antenna single pass InSAR, two typical baseline configurations are perpendicular to the flight track, called cross-track InSAR, and parallel to the fight track, called along-track InSAR. Cross-track InSAR can be used for topographic mapping. Along-track InSAR can be used for detecting surface/scatter motion in the direction of the radar line of sight. For repeat pass InSAR, the baseline vector is determined by the platform positions. It can be configured to cross-track or along-track geometry. In most cases of repeat pass observations, the orbit does not repeat itself exactly, so the baseline vector has both cross-track and along-track components, and the interferometric measurement consists of topography and surface displacement. Differential interferometric SAR (DInSAR) technique can be used to remove topography and detect minor surface deformation.

This document only addresses calibration of dual-antenna cross-track InSAR.

Airborne InSAR, for example, in Figure 10 shows cross-track InSAR geometry. The two antennas are located at A_1 and A_2 separated by the baseline vector. B is the length of the baseline vector. α is the angle the baseline makes with respect to a reference horizontal plane. θ is the look angle of the antenna A_1. H is the height of the antenna A_1 relative to the reference plane. h is the height of the target relative to the reference plane.

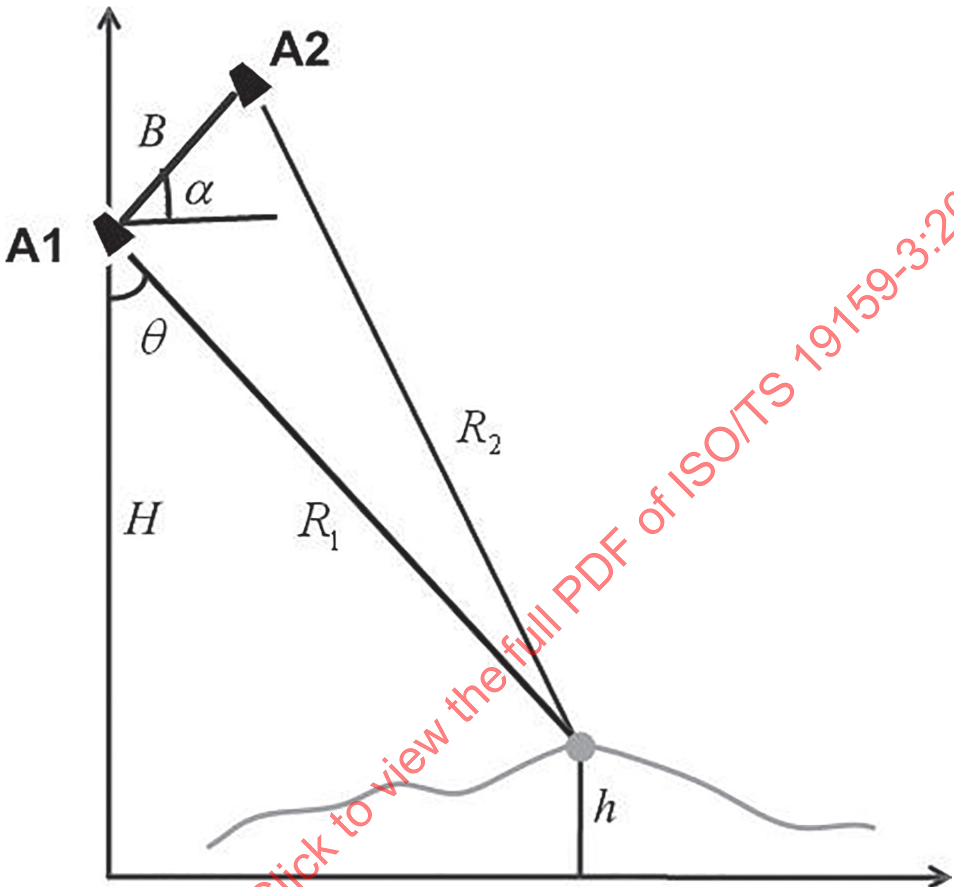

Figure 10 — Geometry of airborne cross-track InSAR

The interferometric phase difference between the SAR images from the two antennas can be formed by conjugated multiplication for each image pixel. In essence, this phase difference is related to the geometric path length difference, which depends on the topography. According to the InSAR geometry, the phase difference can be converted to the height of each image pixel. Therefore, cross-track InSAR provides a third dimensional measurement, in addition to the along-track and cross-track location of the target.

Therefore, to derive an accurate DEM, InSAR requires not only ordinary geometric calibration, but also calibration of the baseline and the interferometric phase. More details about InSAR calibration are discussed in Annex C.

7.2 CA_InSARSensor

Figure 11 depicts the class diagram of InSAR sensor. The classes shown in Figure 11, their attributes and their associations shall be used as described in the data dictionary of B.10.

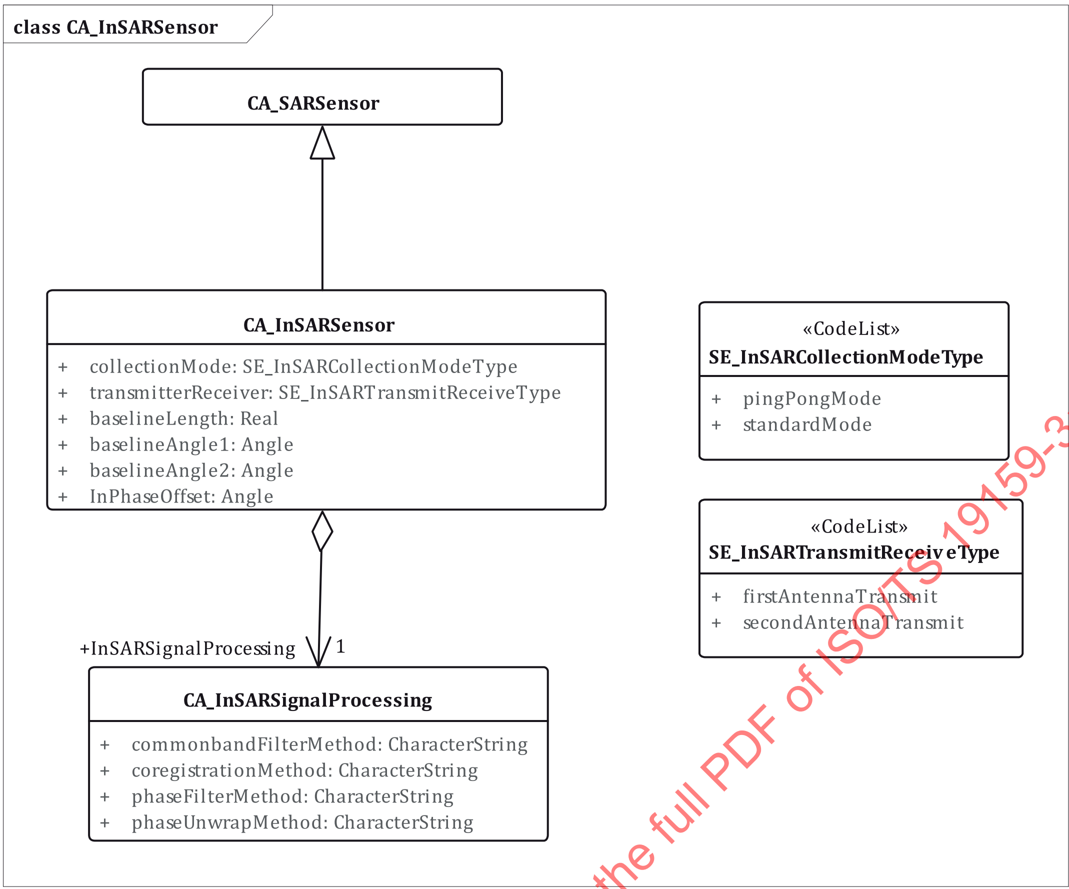

Figure 11 — CA_InSARSensor

The class CA_InSARSensor defines special information for InSAR sensor.

The attribute collectionMode defines the InSAR data collection mode according to the code list set in the class SE_InSARCollectionModeType.

The attribute transmitterReceiver defines the InSAR antenna transmitting and receiving arrangement according to the code list set in the class SE_InSARTransmitReceiveType.

The attribute baselineLength defines length of the interferometric baseline vector.

The attribute baselineAngle1 defines the angle that the interferometric baseline vector makes with respect to its cross-track component.

The attribute baselineAngle2 defines the angle that the cross-track component of interferometric baseline vector makes with respect to a reference horizontal plane.

The attribute InPhaseOffset defines the constant interferometric phase offset present in the unwrapped interferograms.

The class CA_InSARSignalProcessing contains the information related to InSAR interferoemtric processing of the InSAR complex image pair.

The attribute commonbandFilterMethod defines the filter method used to extract the common frequency band of the InSAR complex image pair.

The attribute coregistrationMethod defines the method used for coregistration of InSAR complex image pair.

The attribute phaseFilterMethod defines the method used to filter the interferometric phase.

The attribute phaseUnwrapMethod defines the method used to unwrap the interferometric phase.

7.3 InSAR Requirement

For the calibration description of the imagery from InSAR sensor, all of the mandatory classes and mandatory attributes described in Clauses 6 and 7 shall be provided.

8 PolSAR sensor calibration model

8.1 General

The fully Polarimetric SAR (PolSAR) system is capable of acquiring four simultaneous channels, two like and two cross orthogonal polarizations. It is a powerful tool in many applications such as land-use classification, forest mapping, biomass estimation and target identification.

The scattering process at the target of interest for PolSAR is characterized by the scattering matrix. For a linear, horizontally (H) and vertically (V) polarized system, it can be characterized as follows:

$$\begin{pmatrix} E_H^s \\ E_V^s \end{pmatrix} = \frac{e^{jkR}}{R} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} E_H^i \\ E_V^i \end{pmatrix} \quad (1)$$

where

$\begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix}$ is the scattering matrix;

S_{ij} is a complex number;

i and j represents the receive and transmit polarization respectively;

$\begin{pmatrix} E_H^i \\ E_V^i \end{pmatrix}$ is the electronic field vector of the wave incident on the scatterer;

$\begin{pmatrix} E_H^s \\ E_V^s \end{pmatrix}$ is the electronic field vector of the scattered wave;

k is the wavenumber of the illuminating wave;

R is the distance between the target and the radar antenna.

As has been shown in Clause 3.23, radar cross section can be calculated by:

$$\sigma = \lim_{R \to \infty} 4\pi R^2 \frac{|E_s|^2}{|E_i|^2} \qquad (2)$$

where

σ is the radar cross section;

E_i is the electric-field strength of the incident wave;

E_s is the electric-field strength of the scattered wave at the radar with a distance R away from the target. E_i and E_s depend on the polarization of the incident field and scattered field. Hence, for the receiving polarization p and transmitting polarization q, the radar cross section at a given target is expressed as:

$$\sigma_{pq} = \lim_{R \to \infty} 4\pi R^2 \frac{|E_{s_p}|^2}{|E_{i_q}|^2} = 4\pi |S_{pq}|^2 \qquad (3)$$

It can be seen that the real radiometric parameters of ground targets for PolSAR sensors are reflected by the scattering matrix, which is critical for PolSAR application. However, the measurements by PolSAR sensors cannot reflect the real scattering characterization due to the cross-talk and the channel imbalance between the H and V polarization channels on receive and transmit. Hence, to derive accurate scattering matrix, PolSAR requires not only general radiometric calibration, but also calibration of the cross-talk terms and channel imbalance terms. More details about PolSAR calibration are discussed in Annex D.

8.2 CA_PolSARSensor

Figure 12 depicts the class diagram of PolSAR sensor. The classes shown in Figure 12, their attributes and their associations shall be used as described in the data dictionary of B.11.

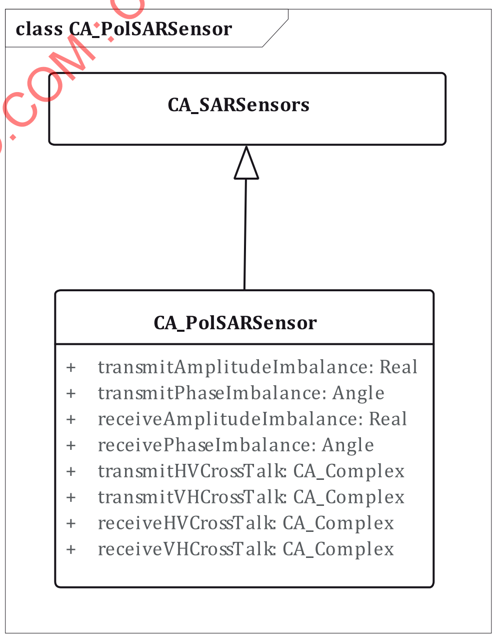

Figure 12 — CA_PolSARSensor

The class CA_PolSARSensor defines special parameters which need to be calibrated for PolSAR sensor.

The attribute transmitHVCrossTalk defines the cross-talk from V channel to H channel on transmit.

The attribute transmitVHCrossTalk defines the cross-talk from H channel to V channel on transmit.

The attribute receiveHVCrossTalk defines the cross-talk from V channel to H channel on receive.

The attribute receiveVHCrossTalk defines the cross-talk from H channel to V channel on receive.

The attribute transmitPhaseImbalance defines the phase imbalance between the H and V channels on transmit.

The attribute transmitAmplitudeImbalance defines the amplitude imbalance between the H and V channels on transmit.

The attribute receivePhaseImbalance defines the phase imbalance between the H and V channels on receive.

The attribute receiveAmplitudeImbalance defines the amplitude imbalance between the H and V channels on receive.

8.3 PolSAR requirement

For the calibration description of the imagery from PolSAR sensor, all of the mandatory classes and mandatory attributes described in Clauses 6 and 8 shall be provided.

Annex A
(normative)

Abstract test suite

A.1 SAR sensor

a) Test purpose: Verify that the metadata provided with the image data instantiates CA_SARSensors with its attributes and associated classes.

b) Test method: Inspect the content of the metadata intended to support SAR calibration.

c) Reference: Clause 6.10.

A.2 InSAR sensor

a) Test purpose: Verify that, when the SAR acquisition mode is InSAR, metadata provided with the image data properly instantiates CA_InSARSensor and its attributes.

b) Test method: Inspect the content of the metadata intended to support InSAR calibration.

c) Reference: Clause 7.3.

A.3 PolSAR sensor

a) Test purpose: Verify that, when the SAR acquisition mode is PolSAR, metadata provided with the image data properly instantiates CA_PolSARSensor and its attributes.

b) Test method: Inspect the content of the metadata intended to support PolSAR calibration.

c) Reference: Clause 8.3.

Annex B
(normative)

Data dictionary

B.1 General

This annex provides a detailed description of each of the classes and each class attribute in the models presented in this document in the form of a tabular data dictionary.

B.2 Overview of SAR sensors (Figure 2)

	Name/Role name	Definition	Obligation/Condition	Max occurrence	Data type/Class	Domain
1.	CA_CalibrationValidation	Root entity that defines information about calibration	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (MD_Coverage Description)	Line 2
2.	calibrationType	Characterization of the calibration coded with the data type CA_CalibrationType	M	1	CA_CalibrationType	
3.	CA_SARSensor	Top level class for all calibration information of SAR sensors	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_CalibrationValidation)	Line 4 to 16
4.	collectionMode	Method used by SAR system to collect data	M	1	SE_SARCollectionMode	ISO/TS 19130-2
5.	acquisitionMode	Acquisition mode of SAR system	M	1	CA_SARAcquisitionMode	
6.	centreFrequency	Centre frequency of the SAR sensor	M	1	Real	>0, the unit is Hz
7.	bandwidth	Bandwidth of transmitted signal	M	1	Real	>0, the unit is Hz
8.	antennaNumber	Number of antennas of SAR system	M	1	Integer	> = 1
9.	transmitAndReceive ChannelNumber	Channel number of SAR system	M	1	Integer	> = 1
10.	*Role name:* antennaSystem	Antenna system of SAR sensors	M	N	CA_AntennaSystem	
11.	*Role name:* radarSystem	Radar system of SAR sensors	M	N	CA_RadarSystem	
12.	*Role name:* antennaPhaseCentre	Antenna phase centre of SAR sensors	M	N	CA_AntennaPhaseCentre	

	Name/Role name	Definition	Obliga-tion/ Condition	Max occurrence	Data type/Class	Domain
13.	*Role name:* signalProcessing	SAR imaging processing of the raw echo signal	M	1	CA_SignalProcessing	
14.	*Role name:* atmosphericPropagation	Atmospheric effect on the calibration	O	1	CA_AtmosphericPropagation	
15.	*Role name:* calibrationField	Calibration field	M	N	CA_SARCalibrationField	
16.	*Role name:* validation	Validation	O	1	CA_SARValidation	

B.3 Radar system (Figure 3)

	Name/Role name	Definition	Obliga-tion/ Condi-tion	Max occurrence	Data type/Class	Domain
17.	CA_RadarSystem	Information about the radar system of SAR sensors	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_SARSensors)	Line 18 to 29
18.	transmitPower	Peak transmitted power of radar system	M	1	Real	>0, the unit is dB
19.	samplingDelay	Echo reception time delay of the first range sample with respect to the pulse transmitted time	M	1	TM_IntervalLength	ISO 19108
20.	samplingFrequency	Range sampling frequency	M	1	Real	>0, the unit is Hz
21.	pulseStartTime	Azimuth time of the first pulse	M	1	DateTime	ISO 19103 Unrestricted
22.	prf	Radar pulse repetition frequency	M	1	Real	>0, the unit is Hz
23.	dynamicRange	Range of input signal strength over which the receiver can amplify the input signal linearly	M	1	Real	>0, the unit is dB
24.	nesz	Noise equivalent sigma zero of the radar system	M	1	Real	The unit is dB
25.	echopulseNumber	Number of received pulses	M	1	Integer	> = 1
26.	sampleNumber	Number of samples of one pulse	M	1	Integer	> = 1
27.	receiverGain	Gain of radar receiver	M	1	Real	> 0,the unit is dB
28.	replicaSignal	Replica of the transmitted pulse injected into the data stream during the quiet periods between pulse transmission and echo reception used to determine the exact range compression function in the signal processor	M	1	Sequence<CA_Complex>	

	Name/Role name	Definition	Obligation/ Condition	Max occurrence	Data type/ Class	Domain
29.	calibrationCoefficient	Ratio of SAR image pixel power to RCS without considering additive noise, after the processor gain is normalized to one, elevation antenna pattern, range and atmospheric attenuation are all corrected	M	1	Real	Unrestricted
30.	CA_Complex	Datatype that defines a complex number	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class < <DataType> >	Line 31 to 32
31.	amplitude	Amplitude of a complex number	M	1	Real	Unrestricted
32.	phase	Phase of a complex number	M	1	Angle	ISO 19103 Unrestricted

B.4 Antenna system (Figure 4)

	Name/Role name	Definition	Obligation/ Condition	Max occurrence	Data type/ Class	Domain
33.	CA_AntennaSystem	Information about the antenna system of SAR sensors	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_SARSensors)	Line 34 to 40
34.	orientationMode	Antenna orientation	M	1	SD_SAROrientationCode	ISO/TS 19130
35.	polarimetryList	Antenna polarimetric mode	M	1	CA_PolarimetryLayer	
36.	gain	Antenna power gain	M	1	Real	> = 0, the unit is dB
37.	azimuthPointingAngle	Pointing angle of azimuth antenna beam	M	1	Angle	−90 < azimuthPointingAngle- > Value < 90
38.	elevationPointingAngle	Pointing angle of elevation antenna beam	M	1	Angle	0 < rangePointingAngle- > Value < 90
39.	azimuthPattern	Elevation antenna pattern	M	1	CA_Pattern	
40.	elevationPattern	Azimuth antenna pattern	M	1	CA_Pattern	

	Name/Role name	Definition	Obligation/ Condition	Max occurrence	Data type/ Class	Domain
41.	CA_Pattern	Datatype that defines one dimensional antenna pattern	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class < <DataType> >	Line 42–43
42.	patternAngle	Elevation or azimuth angle relative to the peak of beam	M	1	Sequence<Angle>	
43.	patternGain	Relative gain normalized by the peak gain in the angle that the attribute patternAngle defines	M	1	Sequence<Real>	

B.5 Antenna phase centre (Figure 5)

	Name/Role name	Definition	Obligation/ Condition	Max occurrence	Data type/ Class	Domain
44.	CA_AntennaPhaseCentre	Parameters about the antenna phase centre of SAR sensors measured by the onboard GNSS and IMU	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_SARSensors)	Line 45 to 52
45.	time	Time when the values for platform velocity and position are provided by GNSS	M	N	DateTime {ordered}	ISO 19103
46.	CRS	Coordinate reference system in which the values for the velocity and position of antenna phase centre are measured	M	1	SC_CRS	ISO 19111
47.	position	Position of the antenna phase centre measured by the GNSS	M	N	DirectPosition {ordered}	ISO 19107
48.	attitude	Orientation of the antenna phase centre measured by the IMU	M	N	SD_Attitude {ordered}	ISO/TS 19130
49.	velocity	Velocity of the antenna phase centre measured by the GNSS	M	N	CA_Velocity {ordered}	ISO 19103
50.	positionAccuracy	Accuracy of position	M	1	DQ_PositionalAccuracy	ISO 19157
51.	attitudeAccuracy	Accuracy of attitude	M	1	DQ_QuantitativeAttributeAccuracy	ISO 19157
52.	velocityAccuracy	Accuracy of velocity	M	1	DQ_QuantitativeAttributeAccuracy	ISO 19157

	Name/Role name	Definition	Obligation/ Condition	Max occurrence	Data type/ Class	Domain
53.	CA_Velocity	Datatype which defines the velocity in the three dimensional coordinates	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class < <DataType> >	Line 54 to 56
54.	Vx	Velocity in the x coordinate	M	1	Real	Unrestricted
55.	Vy	Velocity in the y coordinate	M	1	Real	Unrestricted
56.	Vz	Velocity in the z coordinate	M	1	Real	Unrestricted

B.6 Signal processing (Figure 6)

	Name/Role name	Definition	Obligation/ Condition	Max occurrence	Data type/ Class	Domain
57.	CA_SignalProcessing	Information related to SAR imaging processing of the raw echo signal	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_SARSensors)	Line 58 to 76
58.	waveform	Waveform of the transmitted signal	M	1	CA_SARWaveform	
59.	imagingAlgorithm	Imaging algorithm used to process the raw echo signal to form the SAR image	M	1	CA_ImagingAlgorithm	
60.	rangeProcBandwidth	Processing bandwidth in the range direction	M	1	Real	>0, the unit is Hz
61.	azimuthProcBandwidth	Processing bandwidth in the azimuth direction	M	1	Real	>0, the unit is Hz
62.	numberMultilook	Multilook number in the processing procedure	M	1	Integer	> = 1
63.	dopplerCentroid	A set of doppler centroid frequencies at different azimuth time and range time	M	N	CA_DopplerCentroid	
64.	rangeRes	Image resolution in the range direction	M	1	Real	>0, the unit is meter
65.	azimuthRes	Image resolution in the azimuth direction	M	1	Real	>0, the unit is meter
66.	pslr	PSLR of a point target	M	1	Real	<0, the unit is dB
67.	islr	ISLR of a point target	M	1	Real	<0, the unit is dB
68.	procRangeWin	Window function used in the range direction for imaging processing	M	1	CA_WindowFunction	
69.	procAzimuthWin	Window function used in the azimuth direction for imaging processing	M	1	CA_WindowFunction	

	Name/Role name	Definition	Obligation/ Condition	Max occurrence	Data type/ Class	Domain
70.	quantifyMode	Description of the quantification mode which transfers the power image to digital numbers	M	1	CharcterString	Unrestricted
71.	quantifyParameter	Parameters of the quantification mode	M	N	Real	Unrestricted
72.	imageFormat	Data format of the SAR image according to which users can read the image	M	1	CharcterString	Unrestricted
73.	rangeSize	Pixel number along the range direction of the SAR image	M	1	Integer	> = 1
74.	azimuthSize	Pixel number along the azimuth direction of the SAR image	M	1	Integer	> = 1
75.	imageNoisePower	Noise power of the SAR image	M	1	Real	The unit is dB
76.	processorGain	Gain of the SAR imaging processor.	M	1	Real	Unrestricted
77.	CA_WindowFunction	Datatype that defines the window function used in the process of SAR imaging	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class < <DataType> >	Line 78 to 79
78.	name	Name of window function	M	1	CharacterString	Unrestricted
79.	parameters	Parameters of window function	M	N	Real	Unrestricted
80.	CA_DopplerCentroid	Datatype that defines the doppler centroid frequency at a certain azimuth time and range time	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class < <DataType> >	Line 81 to 83
81.	rangeSampleDelay	Echo reception time delay of the current range sample with respect to the pulse transmitted time	M	1	TM_IntervalLength	ISO 19108
82.	azimuthPulseTime	Azimuth time of the current pulse	M	1	DateTime	ISO 19103
83.	dopplerCentroid	Doppler centroid frequency at current azimuth time and range time	M	1	Real	The unit is Hz

B.7 Atmospheric propagation and earth motion (Figure 7)

	Name/Role name	Definition	Obligation/ Condition	Max occurrence	Data type/ Class	Domain
84.	CA_AtmosphericPropagation	Information about the effect of atmospheric propagation and earth motion on the calibration	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_SARSensors)	Line 85 to 96
85.	attenuationModel	Description of the atmospheric attenuation model that is applied for SAR radiometric calibration	O	1	CharcterString	Unrestricted
86.	attenuationModelParameters	Parameters of the atmospheric attenuation model	O	N	Real	Unrestricted
87.	ionosphericDelayModel	Description of the ionospheric delay model that is applied for SAR geometric calibration	O	1	CharcterString	Unrestricted
88.	ionosphericDelayModelParameters	Parameters of the ionospheric delay model	O	N	Real	Unrestricted
89.	tropospher-icDryDelayModel	Description of the tropospheric dry delay model that is applied for SAR geometric calibration	O	1	CharcterString	Unrestricted
90.	tropospher-icDryDelayModel Parameters	Parameters of the tropospheric dry delay model	O	N	Real	Unrestricted
91.	troposphericWetDelayModel	Description of the tropospheric wet delay model that is applied for SAR geometric calibration	O	1	CharcterString	Unrestricted
92.	tropospher-icWetDelayModel Parameters	Parameters of the tropospheric wet delay model	O	N	Real	Unrestricted
93.	FaradayRotationModel	Description of the Faraday rotation model that is applied for polsar calibration	O	1	CharcterString	Unrestricted
94.	FaradayRotationModel Parameters	Parameters of the Faraday rotation model	O	N	Real	Unrestricted
95.	earthMotionModel	Description of the earth motion model that is applied to geometric calibration	O	1	CharcterString	Unrestricted
96.	earthMotionModelParameters	Parameters of the earth motion model	O	N	Real	Unrestricted

B.8 SAR calibration field (Figure 8)

	Name/Role name	Definition	Obligation/Condition	Max occurrence	Data type/Class	Domain
97.	CA_SARCalibrationField	Information related to the calibration field	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_SARSensors)	Line 98 to 104
98.	updateFrequency	Frequency of the calibration procedure	M	1	CharacterString	Unrestricted
99.	fieldtype	Characteristic of the calibration field	M	1	CA_SARCalibrationFieldType	
100.	centrePosition	Geographic position of the centre of calibration field	M	1	DirectPosition	Unrestricted
101.	expanse	2-dimensional size of the calibration field	M	1	Area	Unrestricted
102.	minimumElevation	Lowest elevation of the calibration field	M	1	Length	Unrestricted
103.	maximumElevation	Highest elevation of the calibration field	M	1	Length	Unrestricted
104.	averageElevation	Average elevation of the calibration field	M	1	Length	Unrestricted
105.	CA_SARCalibrationManmadeField	Information of the manmade calibration field	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_SARCalibrationField)	Line 106 to 107
106.	numOfEquipment	Number of the calibration equipments deployed in the field	M	1	Integer	> = 1

	Name/Role name	Definition	Obligation/Condition	Max occurrence	Data type/Class	Domain
107.	Role name: calibrationEquipment	Calibration equipments deployed in the calibration field	M	N	CA_SARCalibrationEquipment	
108.	CA_SARCalibrationEquipment	Information about the calibration equipments deployed in the calibration field	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_SARCalibrationManmadeField)	Line 109 to 111
109.	equipmentType	Characteristic of the calibration equipment	M	1	CA_SARCalibrationEquipmentType	
110.	equipmentLocation	Location of the equipment including the geographic coordinates and grid coordinates in the image	M	1	SD_LocationGCP	ISO/TS 19130
111.	pointType	Characterization of the point coded with the code list CA_pointtype	M	1	CA_PointType	ISO/TS 19159-1
112.	CA_CornerReflectorAndTransponder	Information of corner reflectors or transponders used in the external calibration	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_SARCalibrationEquipment)	Line 113 to 116
113.	RCS	Ideal RCS of the corner reflector or transponder	O	1	Real	The unit is dBsm
114.	RCSAccuracy	RCS accuracy of the corner reflector or transponder	O	1	Real	The unit is dBsm

	Name/Role name	Definition	Obligation/Condition	Max occurrence	Data type/Class	Domain
115.	scatteringMatrix	Ideal polarimetric scattering matrix of the corner reflector or transponder	O	1	CA_ScatteringMatrix	
116.	scatteringMatrixAccuracy	Polarimetric scattering matrix accuracy of the corner reflector or transponder	O	1	CA_ScatteringMatrix	
117.	CA_GroundReceiver	Information of ground receivers which are usually used to measure antenna pattern	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_SARCalibrationEquipment)	Line 118
118.	measureStability	Measure stability of the ground receiver	M	1	Real	The unit is dB
119.	CA_SARCalibrationNaturalField	Information of the natural calibration field	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_SARCalibrationField)	Line 120 to 124
120.	naturalFieldType	Characteristic of the natural calibration field	M	1	CA_SARCalibrationNaturalFieldType	
121.	backscatteringCoefficient	Average backscattering coefficient of the natural calibration field	O	1	Real	The unit is dB

	Name/Role name	Definition	Obligation/Condition	Max occurrence	Data type/Class	Domain
122.	backscatteringCoefficientStability	Backscattering coefficient stability of the natural calibration field	O	1	Real	The unit is dB
123.	scatteringMatrix	Average polarimetric scattering matrix of the natural calibration field	O	1	CA_ScatteringMatrix	
124.	scatteringMatrixAccuracy	Polarimetric scattering matrix accuracy of the natural calibration field	O	1	CA_ScatteringMatrix	
125.	CA_ScatteringMatrix	Datatype that defines a scatter matrix	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Class < <DataType> >	Line 126
126.	matrixElements	Four elements in the scattering matrix	M	4	CA_Complex {ordered}	

B.9 SAR validation (Figure 9)

	Name/Role name	Definition	Obligation/Condition	Max occurrence	Data type/Class	Domain
127.	CA_SARValidation	Information necessary to perform SAR validation	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_SARSensors)	Line 128 to 129
128.	validationTime	Time of validation	M	1	DateTime	ISO 19103 Unrestricted
129.	Role name: confidence	Trustworthiness of the calibration information quality result	M	N	DQ_Confidence	ISO 19157

B.10 InSAR sensor (Figure 11)

	Name/Role name	Definition	Obligation/Condition	Max occurrence	Data type/Class	Domain
130.	CA_InSARSensor	Special information for insar sensor	Use obligation/condition from referencing object	Use maximum occurrence from referencing object		Specified Class (CA_SARSensors) Line 131–137
131.	collectionMode	Insar data collection mode	M	1	SE_InSARCollectionModeType	ISO/TS 19130-2
132.	transmitterReceiver	Insar antenna transmitting and receiving arrangement	M	1	SE_InSARTransmitReceiveType	ISO/TS 19130-2
133.	baselineLength	Length of the interferometric baseline vector	M	1	Real	>0
134.	baselineAngle1	Angle the interferometric baseline makes with respect to makes with respect to its cross-track component	M	1	Angle	−180 < baselineAngle- > Value < = 180
135.	baselineAngle2	Angle that the cross-track component of interferometric baseline vector makes with respect to a reference horizontal plane	M	1	Angle	−180 < baselineAngle- > Value < = 180
136.	InPhaseOffset	Constant interferometric phase offset present in the unwrapped interferograms	M	1	Angle	Unrestricted
137.	Role name: InSARSignalProcessing		M	1	CA_InSARSignalProcessing	

	Name/Role name	Definition	Obligation/Condition	Max occurrence	Data type/Class	Domain
138.	CA_InSARSignalProcessing	Information related to insar interferoemtric processing of the insar complex image pair	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_InSARSensor)	Line 139 to 142
139.	commonbandFilterMethod	Filter method used to extract the common frequency band of the insar complex image pair	M	1	CharcterString	Unrestricted
140.	coregistrationMethod	Method used for coregistration of insar complex image pair	M	1	CharcterString	Unrestricted
141.	phaseFilterMethod	Method used to filter the interferometric phase	M	1	CharcterString	Unrestricted
142.	phaseUnwrapMethod	Method used to unwrap the interferometric phase	M	1	CharcterString	Unrestricted

B.11 PolSAR Sensors (Figure 12)

	Name/Role name	Definition	Obligation/Condition	Max occurrence	Data type/Class	Domain
143.	CA_PolSARSensor	Special parameters which need to be calibrated for polsar sensor	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	Specified Class (CA_SARSensors)	Line 144 to 151
144.	transmitAmplitudeImbalance	Amplitude imbalance between the H and V channels on transmit	M	1	Real	Unrestricted
145.	transmitPhaseImbalance	Phase imbalance between the H and V channels on transmit	M	1	Angle	Unrestricted