TECHNICAL SPECIFICATION

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

Part 4: **Space-borne passive microwave radiometers**

Information géographique — Calibration et validation de capteurs de télédétection —

Partie 4: Radiomètres spatiaux à micro-onde passive

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Foreword

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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).

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For an explanation of 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 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.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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. In addition to the different technologies, the need for standardization of the various sensor types takes into account different priorities. In order to meet such needs, the ISO 19159 series 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 addresses synthetic aperture radar (SAR) and interferometric SAR (InSAR). ISO/TS 19159-4 (this document) covers space-borne passive microwave radiometers.

In accordance with the ISO/IEC Directives, Part 2, 2018, *Rules for the structure and drafting of International Standards*, in International Standards the decimal sign is a comma on the line. However, the General Conference on Weights and Measures (Conférence Générale des Poids et Mesures) at its meeting in 2003 passed unanimously the following resolution:

"The decimal marker shall be either a point on the line or a comma on the line."

In practice, the choice between these alternatives depends on customary use in the language concerned. In the technical areas of geodesy and geographic information it is customary for the decimal point always to be used, for all languages. That practice is used throughout this document.

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

Part 4:
Space-borne passive microwave radiometers

1 Scope

This document defines the calibration of space-borne passive microwave radiometers and the validation of the calibrated information.

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 19159-1, *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 and data — Part 2: Lidar*

ISO/TS 19159-3, *Geographic information — Calibration and validation of remote sensing imagery sensors and data — Part 3: SAR/InSAR*

3 Terms and definitions

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

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

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

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

3.1
antenna beam width
half-power full width
half-power beam width
full angle at which the antenna's pattern (in power units) is at half its maximum value

Note 1 to entry: In engineering convention, this is also known as the "3 dB beam width."

3.2
antenna main-beam efficiency
η_M
fraction of the total radiant energy that is received from the *main beam* (3.29), which is defined as the ratio of the power received within the "main lobe" to that of the total power received by the antenna

Note 1 to entry: η_M is calculated using the following formula:

$$\eta_M = \frac{\iint_Y F_n(\theta,\phi)d\Omega}{\iint_{4\pi} F_n(\theta,\phi)d\Omega}$$

where

F_n is the antenna pattern;

θ is the elevation angle;

ϕ is the azimuth angle;

$d\Omega$ is the differential solid angle;

Y is the main lobe value.

Note 2 to entry: *Main beam* (3.29) is also referred as main lobe.

3.3
antenna output temperature
$T_{A,out}$
physical temperature of correctional impedance that delivers to the receiver the same noise power as the antenna collects

Note 1 to entry: This includes two terms: the noise coming from the environment attenuated by the antenna Ohmic efficiency and the thermal noise added by the antenna Ohmic losses. In the Rayleigh-Jeans approximation, the following formula applies:

$$T_{A,out}(\Omega_0) = \eta_\Omega T_A(\Omega_0) + (1-\eta_\Omega)T_p$$

where

T_A is the antenna aperture temperature;

T_p is the physical temperature of the antenna;

Ω_0 is the Ohmic loss;

η_Ω is the Ohmic efficiency of the antenna.

Note 2 to entry: The antenna output temperature ($T_{A,out}$) is related to the input noise temperature of the receiver as shown in the following formula:

$$T_{rec,in} = \frac{h\nu}{e^{h\nu/kT_{A,out}} - 1}$$

where

$T_{rec,in}$ is the input noise temperature of the receiver;

h is the Plank's constant ($6.626\,07\times10^{-34}$ J·s);

ν is the frequency in Hz;

k is the Boltzmann's constant ($1.380\,648\,52\times10^{-23}$ J/K);

e is the base of natural logarithm.

3.4
antenna pattern
ratio of the electronic-field strength radiated in the direction θ to that radiated in the beam-maximum direction

Note 1 to entry: In microwave radiometry, this is the spatial distribution of a quantity (usually proportional to or equal to power flux density or radiation intensity) that characterizes the electromagnetic field generated by an antenna.

[SOURCE: ISO/TS 19159-3:2018, 3.2, modified — Note 1 to entry added.]

3.5
antenna radiation efficiency
η_l
ratio of the total radiated power divided by the total power accepted by the antenna

Note 1 to entry: This is also equivalent to the ratio of the antenna radiation resistance (R_{rad}) divided by the sum of the antenna radiation resistance and the antenna Ohmic resistance (R_{Ω}), as described in the following formula:

$$\eta_l = \frac{P_{rad}}{P_{in}} = \frac{R_{rad}}{R_{rad} + R_{\Omega}}$$

where

P_{rad} is the total radiated power;

P_{in} is the total power accepted by the antenna;

R_{rad} is the antenna radiation resistance;

R_{Ω} is the antenna Ohmic resistance.

Note 2 to entry: Antenna radiation efficiency (η_l) is also called as Ohmic efficiency (η_{Ω}).

3.6
antenna sidelobe
antenna radiation pattern away from its *main beam* (3.29), or defined as part of an antenna response pattern which is not contained in the main beam

3.7
antenna temperature
T_A
temperature (K) equivalent of the power received with an antenna, or physical temperature (K) of the 'antenna radiation resistance' that delivers to a matched receiver the same noise power as the antenna collects

3.8
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 19116:2019, 3.3, modified — Note 1 to entry removed.]

3.9
blackbody load
microwave load with characteristics very close to those of a *perfect blackbody* (3.30) within a certain frequency range

3.10
blackbody radiance
$I_{bb,v}$
physical radiance of an absorber determined by applying Planck's function (either in wavelength space or in terms of frequencies) to absorber temperature, T_w, as shown in the following formula (in frequency space):

$$I_{bb,v} = \frac{2hv^3}{c^2} \frac{1}{e^{\frac{hv}{kT_w}} - 1}$$

where

T_w is the temperature of the absorber;

h is the Plank's constant ($6.626\ 07 \times 10^{-34}$ J·s);

v is the frequency in Hz;

c is the velocity of light ($2.997\ 925 \times 10^{8}$ m/s);

k is the Boltzmann's constant ($1.380\ 648\ 52 \times 10^{-23}$ J/K);

e is the base of natural logarithm.

Note 1 to entry: The constants are defined in terms of a *perfect blackbody* (3.30).

3.11
boresight
calibration of a lidar sensor system, equipped with an inertial measurement unit (IMU) and a global navigation satellite system (GNSS), to accurately determine or establish its position and orientation

Note 1 to entry: In microwave radiometry, the boresight is usually used to characterize the beam-maximum direction of a highly directive antenna.

[SOURCE: ISO/TS 19159-2:2016, 4.4, modified — Original note 1 to entry deleted and replaced with new note 1 to entry.]

3.12
brightness temperature
T_B
descriptive measure of radiation in terms of the temperature (K) of a hypothetical blackbody emitting an identical amount of radiation at the same wavelength, which can be derived from the Planck's radiation law

Note 1 to entry: In the Rayleigh-Jeans limit, the microwave power per unit bandwidth received by a *radiometer*, *P*, (3.33) is:

Note 2 to entry: $P = k \cdot T_B$

Note 3 to entry: where k is the Boltzmann's constant ($k = 1.380\ 648\ 52 \times 10^{-23}$ J/K).

Note 4 to entry: For the frequency range of microwave, Planck's radiation law can be well approximated by the Rayleigh-Jeans formula. Usually the microwave radiometers use the Rayleigh–Jeans equivalent brightness temperature, which is defined as:

$$T_{b,v}^{(RJE)} = \frac{c^2}{2v^2 k} I_v$$

where

$T_{b,v}^{(RJE)}$ is the Rayleigh–Jeans equivalent brightness temperature;

v is the frequency in Hz;

c is the velocity of light (2.997 925×10^{8}m/s);

k is the Boltzmann's constant (1.380 648 52×10^{-23} J/K);

I_v is the radiance.

3.13
brightness temperature sensitivity
minimum detectable change of the *brightness temperature* (3.12) incident at the antenna-collecting aperture

Note 1 to entry: For the purpose of this document, the noise equivalent delta temperature (NEDT) values shall be defined as the standard deviation of the *radiometer* (3.33) output in K when the antenna is viewing a 300 K uniform and stable target. For microwave radiometer, this is also called *radiometric resolution* (3.34).

Note 2 to entry: The formula relative to sensitivity is shown in D.2.

3.14
calibration
process of quantitatively defining a system's response to known, controlled signal inputs

[SOURCE: ISO/TS 19101-2:2018, 3.2]

3.15
calibration equation
equation relating the primary measure and that of the *radiometer* (3.33), for example the *brightness temperature* (3.12), to subsidiary measurands, such as powers, and to calibration quantities, such as standard values

3.16
co-polarization
fraction of total power within the *main beam* (3.29) that is detected in the main *polarization* (3.31)

3.17
cosmic microwave background
CMB
isotropic radiation in the microwave region that is observed almost completely uniformly in all directions

Note 1 to entry: This radiation is understood to be the radiation emitted by the universe at an early period of its history.

Note 2 to entry: In order to use CMB for calibrating a microwave radiometer operating at microwave to sub-millimetre band, it should be converted into *brightness temperature* (3.12), T_B, according to the following formula:

$$T_B = \frac{hv\left(e^{\frac{hv}{kT_c}}+1\right)}{2k\left(e^{\frac{hv}{kT_c}}-1\right)}$$

where

h is the Planck's constant (6.626 07×10^{-34} J·s);

v is the frequency in Hz;

k is the Boltzmann's constant (1.380 648 52×10^{-23} J/K);

T_c is the cosmic background temperature (2.736 ± 0.017 K);

e is the base of natural logarithm.

3.18
cross-calibration
process of relating the measurements of one instrument to another instrument which is usually well-calibrated, serving as a reference

Note 1 to entry: Cross-calibration of instruments operating during the same period requires careful collocation wherein instrument outputs are compared when the instruments are viewing the same Earth scenes, at the same times, from the same viewing angles.

3.19
cross-polarization
fraction of total power within the main beam that is detected in the orthogonal polarization

3.20
effective blackbody brightness temperature
physical temperature of a perfect absorber that would produce the same spectral brightness density or spectral radiance density as that under consideration

3.21
emissivity
ratio of the energy radiated by an emissive surface relative to that of an ideal blackbody source at the same temperature

3.22
end-to-end calibration
<of microwave radiometer> calibration of the entire *radiometer* (3.33) system as a unit, achieved by observing the values of output quantities (e.g. voltage, power) for known values of incident radiance at the antenna aperture

3.23
experimental standard deviation
for a series of n measurements of the same measurand, the quantity, $s(q_k)$, characterizing the dispersion of the results and given by the formula

$$s(q_k) = \sqrt{\frac{\sum_{j=1}^{n}(q_j - \bar{q})^2}{n-1}}$$

where

q_k is the result of the kth measurement;

$\bar{q}$ is the arithmetic mean of the n results considered;

n is the number of the measurements.

Note 1 to entry: Considering the series of n values as a sample of a distribution, $\bar{q}$ is an unbiased estimate of the mean μ, and s^2 is an unbiased estimate of the variance σ^2 of that distribution. The expression $s/\sqrt{n}$ is an estimate of the standard deviation of the distribution of $\bar{q}$ and is called the experimental standard deviation of the mean.

[SOURCE: ISO/IEC Guide 98-3:2008 B.2.17, modified — Notes 3 and 4 to entry have been removed.]

3.24
external calibration
calibration method that applies reference signals from targets that lie outside the *radiometer* (3.33)

Note 1 to entry: If these targets illuminate the antenna of the radiometer, an *end-to-end calibration* (3.22) is obtained.

3.25
half-power bandwidth
frequency range at which the power response is half the maximum value

3.26
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 19130-1:2018, 3.13]

3.27
instantaneous field of view
IFOV
instantaneous region seen by a single detector element, measured in angular space

[SOURCE: ISO/TS 19130-2:2014, 4.36, modified — Admitted term added.]

3.28
linearity
property of a mathematical relationship or function which means that it can be graphically represented as a straight line

Note 1 to entry: The formula relative to the linearity is shown in D.1.

3.29
main beam
main lobe
major part of the radiated field where maximum radiated energy exists (region around the direction of maximum radiation)

Note 1 to entry: The main beam is also defined as 2.5 times 3 dB beamwidth for mathematical computation of antenna main beam efficiency.

Note 2 to entry: The width of main beam (which is commonly called "null to null beamwidth") is defined as the angular span between the first pattern nulls (the magnitude of the radiation pattern decreases to zero, negative infinity dB) adjacent to the main lobes.

3.30
perfect blackbody
perfect absorber (and therefore the best possible emitter) of thermal electromagnetic radiation, whose spectral radiance density (or spectral brightness density, L_f) is given by the Planck formula

$$L_f = \frac{2 \mathrm{h} v^3}{\mathrm{c}^2 \left(\mathrm{e}^{\mathrm{h}v/\mathrm{k}T} - 1 \right)}$$

where

v is the frequency in Hz;

h is Planck’s constant ($6.626\ 07 \times 10^{-34}$ J·s);

k is Boltzmann’s constant ($1.380\ 648\ 52 \times 10^{-23}$ J/K);

T is physical temperature of the blackbody in K;

c is velocity of light ($2.997\,925 \times 10^8$ m/s).

e is the base of natural logarithm.

3.31
polarization
restricting radiation, especially light, vibrations to a single plane

Note 1 to entry: In microwave radiometry, the direction of the polarization is defined by the direction of the electric field (E, in most cases) or magnetic field (H) in a propagating electromagnetic wave.

Note 2 to entry: A general, elliptically polarized electromagnetic plane wave propagating in the $\hat{r}$ direction can have its electric field expressed in phasor form as:

$$\vec{E} = \left(\hat{p}E_{\mathrm{p}} + \hat{q}E_{\mathrm{q}}\right)\mathrm{e}^{-jw_{\mathrm{n}}r}$$

where

$\hat{p}$ and $\hat{q}$ are unit vectors oriented perpendicular to $\hat{r}$ and satisfying $\hat{p} \times \hat{q} = \hat{r} = \bar{r} / \left|\bar{r}\right|$;

E_{p} and E_{q} are the complex amplitudes of the electric field in the $\hat{p}$ and $\hat{q}$ directions, respectively;

w_{n} is the wavenumber of the propagating wave, and $r = \left|\bar{r}\right|$.

Note 3 to entry: Vertical polarization and horizontal polarization are specific cases of elliptical polarization.

[SOURCE: ISO 19115-2:2019, 3.24, modified — Notes to entry added.]

3.32
radiance
I_{v}
point on a surface and in a given direction, the radiant intensity of an element of the surface, divided by the area of the orthogonal projection of this element on a plane perpendicular to the given direction

Note 1 to entry: In microwave radiometry, radiance can be expressed as the radiated power per unit solid angle per unit area normal to the direction defined by the solid angle Ω:

$$I_{\mathrm{v}} = \frac{dP}{d\Omega dA_{\perp}}$$

where

dP is the differential radiation power;

$d\Omega$ is the differential solid angle;

$dA_{\perp} = \cos\theta' dA$ in which θ' is the angle between the direction defined by the solid angle and the normal to the area element dA.

3.33
radiometer
very sensitive receiver, typically with an antenna input, used to measure radiated electromagnetic power

3.34
radiometric resolution
smallest change in input *brightness temperature* (3.12) or *radiance* (3.32) that can be detected in the system output

Note 1 to entry: This is often estimated by using the ideal equation for a total-power *radiometer* (3.33), as shown in the following formula.

$$\Delta T_{min} = \frac{T_{sys}}{\sqrt{B\tau}}$$

where

ΔT_{min}	is the radiometric resolution;
T_{sys}	is the radiometer system temperature;
B	is the bandwidth of the radiometer system;
τ	is the integral time.

Radiometric resolution can be also estimated from the variant of this equation that is appropriate for the particular *radiometer* (3.33) in question.

3.35
spatial resolution
length of the major and/or minor axes diameters of the 3 dB contour of the *antenna pattern* (3.4) projected onto the Earth's surface

Note 1 to entry: The diameter of the two axes may differ.

Note 2 to entry: See also IFOV (3.27).

3.36
spectral response function
SRF
relative sensitivity of the sensor to monochromatic radiation of different wavelengths

Note 1 to entry: For microwave *radiometer* (3.33), SRF refers to the receiver's band-pass, $B(v)$, which can be determined by performing two measurements per frequency at different input power levels, as shown in the following formula:

$$B(v) = \frac{\Delta V_{out}(v)}{\Delta P_{in}(v)}$$

where

ΔV_{out}	is the output voltage difference;
ΔP_{in}	is the input power difference;
v	is the frequency in Hz.

3.37
spillover
condition where radiation from the feed antenna falls outside the edge of the dish and does not contribute to the *main beam* (3.29)

Note 1 to entry: Spillover factor is written as $1-\Lambda_P$ and can be measured in the field, where Λ_P is the ratio of *antenna pattern* (3.4) within the Earth to all space of 4π.

$$\Lambda_{\mathrm{P}} = \int_{\mathrm{Z}} d\Omega \left(F_{n,\mathrm{PP}} + F_{n,\mathrm{PQ}} \right)$$

where

$F_{n,\mathrm{PP}}$ is the co-polarization antenna pattern;

$F_{n,\mathrm{PQ}}$ is the cross-polarization antenna pattern;

$d\Omega$ is the differential solid angle;

Z is the Earth.

3.38
stability
ability of a measuring instrument or measuring system to maintain its metrological characteristics constant with time

3.39
Stokes parameters
set of four real quantities, which completely describe the *polarization* (3.31) state of monochromatic or quasi-monochromatic radiation

Note 1 to entry: The parameters are, collectively, known as the Stokes Real {ordered}, a 4 × 1 Real {ordered}.

Note 2 to entry: The Stokes parameters were introduced as a mathematically convenient alternative by Sir George Stokes.[14,17] These four parameters are related to the horizontally and vertically polarized components of electric field by:

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \frac{1}{\eta} \begin{bmatrix} \left\langle |E_{\mathrm{v}}|^2 \right\rangle + \left\langle |E_{\mathrm{h}}|^2 \right\rangle \\ \left\langle |E_{\mathrm{v}}|^2 \right\rangle - \left\langle |E_{\mathrm{h}}|^2 \right\rangle \\ 2\mathrm{Re}\left\langle E_{\mathrm{v}} E_{\mathrm{h}}^* \right\rangle \\ 2\mathrm{Im}\left\langle E_{\mathrm{v}} E_{\mathrm{h}}^* \right\rangle \end{bmatrix}$$

where

E_{v} is the vertically polarized component of electric field;

E_{h} is the horizontally polarized component of electric field.

The units of the Stokes parameters are $\mathrm{W/m^2}$. The first Stokes parameter (I) gives the total radiation power density, and the second Stokes parameter (Q) represents the power density difference between the two linearly polarized components. The third and fourth Stokes parameters (U and V) describe the correlation between these two components.

Note 3 to entry: For microwave remote sensing, modified Stokes parameters are often used. Under the Rayleigh-Jeans approximation, the modified Stokes parameters in *brightness temperature* (3.12) are given by the following formula:[19], [37]

$$\begin{bmatrix} T_{\mathrm{v}} \\ T_{\mathrm{h}} \\ T_3 \\ T_4 \end{bmatrix} = \frac{\lambda^2}{\mathrm{k}\eta B} \begin{bmatrix} \left\langle |E_{\mathrm{v}}|^2 \right\rangle \\ \left\langle |E_{\mathrm{h}}|^2 \right\rangle \\ 2\mathrm{Re}\left\langle E_{\mathrm{v}} E_{\mathrm{h}}^* \right\rangle \\ 2\mathrm{Im}\left\langle E_{\mathrm{v}} E_{\mathrm{h}}^* \right\rangle \end{bmatrix}$$

where T_v, T_h, T_3 and T_4 are, respectively, the vertically and horizontally polarized and the third and fourth Stokes parameters, and B is the radiometer system bandwidth.

[SOURCE: ISO 12005:2003, 3.11, modified — Original notes to entry have been removed and replaced.]

3.40
traceability chain
sequence of measurement standards and *calibrations* (3.14) that is used to relate a measurement result to a reference

[SOURCE: ISO/IEC Guide 99:2007, 2.42, modified — Notes to entry have been removed.]

3.41
true value
value consistent with the definition of a given quantity

Note 1 to entry: This is a value that would be obtained by perfect measurement. However, this value is in principle and in practice unknowable.

[SOURCE: ISO 17123-1:2014, 3.1.3]

3.42
two-point calibration
adjustment of the relationship between the input signal and the output response of a *radiometer* (3.33) using two distinct input stimuli

Note 1 to entry: Assuming a linear receiver, all possible input signal levels can now be retrieved from the radiometer output responses.

Note 2 to entry: In the case of an external *end-to-end calibration* (3.22), the input signal equals the *antenna temperature* (3.7) of the radiometer.

3.43
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: 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.

[SOURCE: ISO 19116:2019, 3.28]

3.44
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 19101-2:2018, 3.41, modified — Note 1 to entry added.]

3.45
viewing angle
angle between the line-of-sight and the line orthogonal to the surface of the display at the point where the line-of-sight intersects the image surface of the display

[SOURCE: ISO 9241-5:1998, 3.1]

3.46
vicarious calibration
post-launch calibration of sensors that make use of natural or artificial sites on the surface of the Earth

[SOURCE: ISO/TS 19159-1:2014, 4.41]

4 Symbols, abbreviated terms and conventions

4.1 Abbreviated terms

AMSR-E	advanced microwave scanning radiometer for the Earth observing system
APC	antenna pattern calibration
CMB	cosmic microwave background
DSB	double side band
GNSS	global navigation satellite system
HPBW	half-power beam width
HPFW	half-power full width
IFOV	instantaneous field of view
LSB	lower side band
MR	microwave radiometer
NEDT	noise equivalent delta temperature
OMB	observation field minus background field
SCF	sensor constant file
SRF	spectral response function
SSB	single side band
SSM/I	special sensor microwave/imager
TA	antenna temperature
TB	brightness temperature
UML	unified modeling language
USB	upper side band
XML	extensible markup language

4.2 Symbols

B	radiometer system bandwidth
$B(v)$	spectral response function (receiver's band-pass)
$C_{\mathrm{H}}(i,j)$	hot target count of the ith scan, jth hot target

$\bar{C}_{\mathrm{H}}(i)$	mean hot target counts of the ith scan
dA	area element
$dA_{\perp}$	area element normal to the direction defined by the solid angle
dP	differential radiation power
$d\Omega$	differential solid angle
E_{h}	horizontally polarized component of electric field
E_{p}	amplitude of the electric field in the $\hat{p}$ direction
E_{q}	amplitude of the electric field in the $\hat{q}$ direction
E_{v}	vertically polarized component of electric field
F_n	antenna pattern
$F_{n,\mathrm{PP}}$	co-polarization antenna pattern
$F_{n,\mathrm{PQ}}$	cross-polarization antenna pattern
$\bar{G}(i)$	mean antenna gain of the *i*th scan
h	Plank's constant (6.626 07×10^{-34} J·s)
I	total radiation power density (first Stokes parameter)
$I_{\mathrm{bb,v}}$	blackbody radiance
I_{v}	radiance
j	imagery unit
k	Boltzmann's constant (1.380 648 52×10^{-23} J/K)
L_{f}	spectral radiance density of a perfect blackbody
M	number of hot targets viewed during each scan
N	number of scans
n	number of the measurements
P	power per unit bandwidth received by a radiometer
P_{in}	total power accepted by the antenna
P_{rad}	total radiated power
$\hat{p}$	unit vector oriented perpendicular to $\hat{q}$ and satisfying $\hat{p}\times\hat{q}=\hat{r}$
q_k	result of the *k*th measurement
$\bar{q}$	arithmetic mean of the n results considered
$\hat{q}$	unit vector oriented perpendicular to $\hat{p}$ and satisfying $\hat{p}\times\hat{q}=\hat{r}$
R_{rad}	antenna radiation resistance

R_{Ω} antenna Ohmic resistance

$\hat{r}$ unit vector oriented in the wave propagating direction

s experimental standard deviation

T_3 third modified Stokes parameters in brightness temperature

T_4 forth modified Stokes parameters in brightness temperature

T_{A} antenna temperature

$T_{\mathrm{A,out}}$ antenna output temperature

$T_{\mathrm{B,v}}^{(\mathrm{RJE})}$ Rayleigh–Jeans equivalent brightness temperature

T_{C} physical temperature of the cold blackbody

T_{c} cosmic background temperature

T_{CC} effective blackbody brightness temperature of the cold target

T_{H} physical temperature of the hot blackbody

T_{h} second modified Stokes parameters in brightness temperature

T_{HC} effective blackbody brightness temperature of the hot target

T_{NED} noise equivalent delta temperature

T_{p} physical temperature

$T_{\mathrm{rec,in}}$ effective input noise temperature

T_{sys} radiometer system temperature

T_{v} first modified Stokes parameters in brightness temperature

T_{w} temperature of the absorber

U real part of the correlation between these two components (third Stokes parameter)

u nonlinearity coefficient

V imagery part of the correlation between these two components (forth Stokes parameter)

v frequency in Hz

V_{A} output voltage viewing the scene

V_{C} output voltage viewing the cold target

V_{H} output voltage viewing the hot target

w_n wavenumber of the propagating wave

Y main lobe value

Z Earth

ΔP_{in} input power difference

ΔT_{BAC} nonlinear term of antenna temperature

ΔT_C correction to the contribution of emissivity and the surroundings of the cold target

ΔT_H correction to the contribution of emissivity and the surroundings of the hot target

ΔT_{min} radiometric resolution

ΔV_{out} output voltage difference

η wave impedance

η_l antenna radiation efficiency

η_M antenna main-beam efficiency

η_Ω Ohmic efficiency

θ elevation angle

θ' angle between the direction defined by the solid angle and the normal to the area element dA

λ electromagnetic wavelength

$1\text{-}\Lambda_P$ spillover

τ integral time

φ azimuth angle

Ω_0 Ohmic loss

4.3 Conventions

In accordance with ISO 19103, the names of UML classes, with the exception of basic data type classes, shall 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 document in which each is defined and the package each identifies. UML classes defined in this document belong to a package named "Calibration Validation" and shall have the same two letter prefix as in ISO/TS 19159-1, ISO/TS 19159-2 and ISO/TS 19159-3: CA (see Table 1). The XML schema for the UML model defined in this document is described in Annex C.

Table 1 — UML class prefixes prefix standard package

Prefix	Document	Package
CA	ISO/TS 19159-1, ISO/TS 19159-2, ISO/TS 19159-3 and ISO/TS 19159-4 (this document)	Calibration Validation

5 Conformance

This document defines one conformance class:

— “Microwave Radiometer Sensors Calibration/Validation” (specification target: Microwave Radiometer Sensors).

A specification, standard, test suite or test tool claiming conformance to this document shall implement the conformance class relevant to that specification target.

Conformance with this document shall be assessed using all the relevant conformance test cases specified in Annex A.

6 Notation

6.1 UML notation

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

6.2 Identifiers

The complete document is identified by the following URI:

https://standards.isotc211.org/iso19159/-4/1

The normative provisions in this document are denoted by the following URI:

https://standards.isotc211.org/iso19159/-4/1

All requirements and abstract test cases that appear in this document are denoted by partial URIs which are relative to this base.

The name and contact information of the maintenance agency for this document can be found at www.iso.org/maintenance_agencies.

7 General microwave radiometer sensor and data calibration and validation model

7.1 Introduction

This document addresses the calibration of space-borne microwave radiometers and validation of space-borne microwave radiometers calibration information [brightness temperature (TB) or radiance]. It includes the detailed description of space-borne microwave radiometers performance and parameters related to space-borne microwave radiometers calibration, which can be used for refined space-borne microwave radiometers information processing.

Figure 1 depicts a package diagram that shows all parts of the ISO 19159 series at the time of this document's publication. The calibration and validation of Optics, LIDAR and SAR/InSAR sensors and data have been standardized in ISO/TS 19159-1, ISO/TS 19159-2 and ISO/TS 19159-3 respectively.

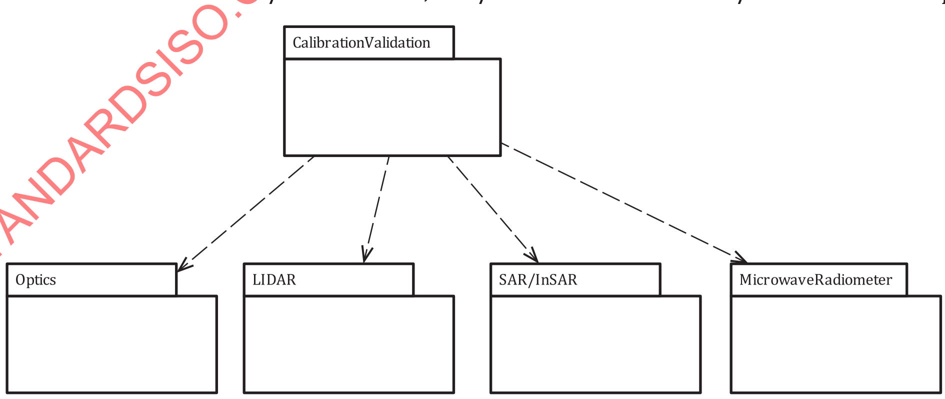

Figure 1 — Package diagram of the package Calibration/Validation

Radiometer calibration (which is used as the abbreviation of "space-borne microwave radiometers calibration" in this document) is the process of quantitatively defining a microwave receiver's outputs, whether in voltages or their counts, to controlled or known TB inputs. The purpose of microwave radiometer calibration is to characterize the performance of the end-to-end microwave radiometer system so that the real radiometric parameters can be derived from the measurement of the microwave radiometer.

Although on-board calibration is usually carried out on the microwave radiometer system, its post-launch calibration/validation, usually called external calibration, can ensure the differences between the measurements and the TB or radiance from simulations by microwave transfer models, and can bridge the time gap between calibrations of the radiometer, as well as radiometers from other platforms, and ensure a long-term confidence in the quality.

This subclause describes the general model of microwave radiometer sensor calibration and validation. A flow chart for microwave radiometer calibration is shown in Figure 2.

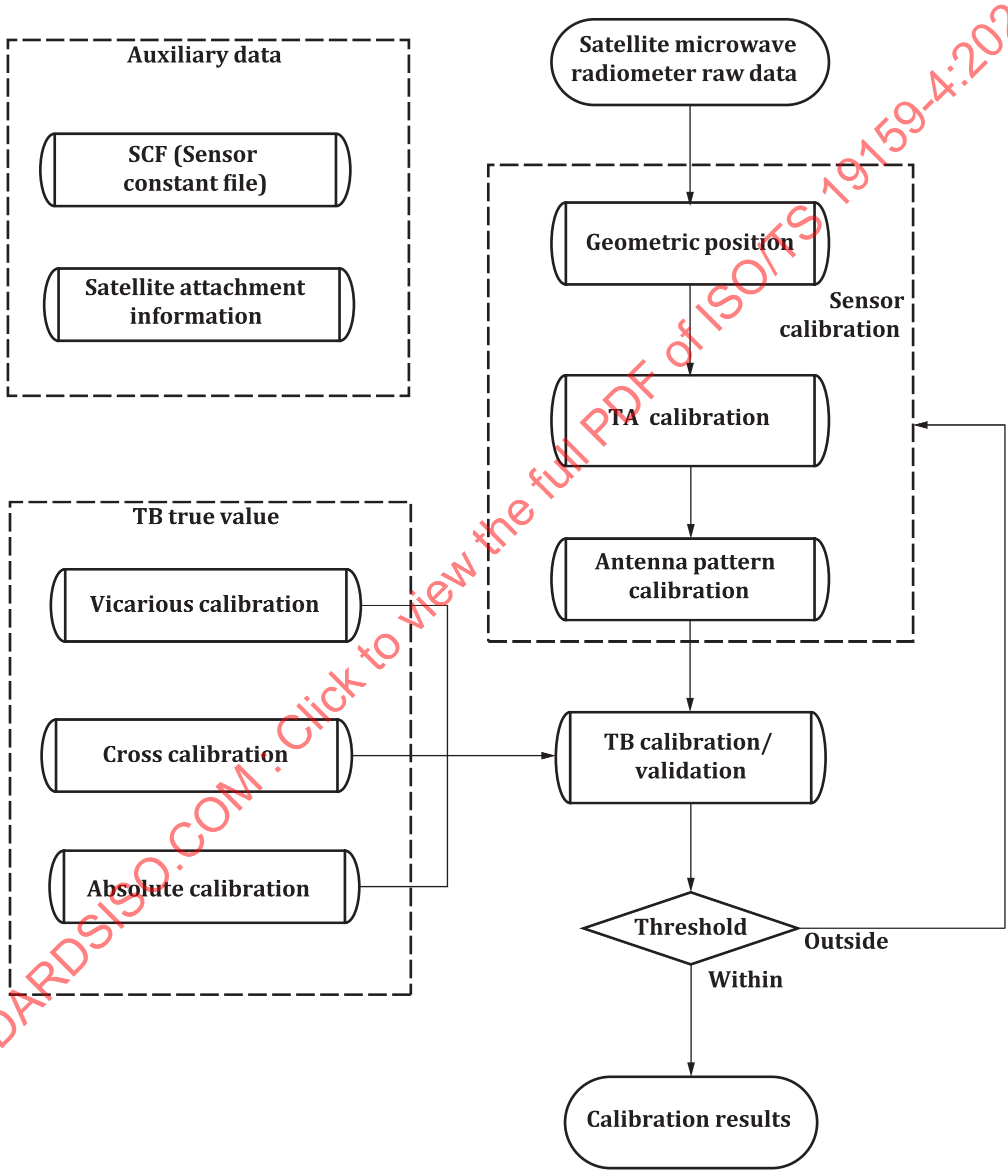

Figure 2 — Flow chart for microwave radiometer calibration

Calibration of a radiometer begins with “sensor calibration” using “satellite microwave radiometer raw data”, which usually include data and parameters for producing a two-point calibration equation. The process of sensor calibration generally includes three stages named as “Geometric position”, “TA calibration” of the receiver, and “Antenna pattern calibration” of the antenna. Sensor calibration is a routine in the space-borne microwave radiometer operational system, which is used for producing the data products of level 1. It is also necessary in “TB calibration/validation” after the differences outside the given “Threshold”, to find the roots of mismatch.

In Figure 2, “TB True Value” serves as input for the module “TB calibration/validation” (defined in the class “CA_TBCalibrationValidation” in 7.5.1) to calibrate “TB to be calibrated”, and the results will be assessed. If the assessments are within the “Threshold”, the calibrated TB will be outputted as “recalibrated TB". Otherwise, three main processes in the “Sensor calibration” will follow for correcting the errors by “Geometric position” (defined in the class “CA_GeometricPosition” in 7.3.1), “TA calibration” module (defined in the class “CA_TACalibration” in 7.3.2), and “Antenna pattern calibration” (defined in the class “CA_AntennaPatternCalibration” in 7.3.3). The re-calibrated TB as output from “Sensor calibration” will be as new input for “TB Calibration/Validation” module, until the final “recalibrated TB” is generated. The “Calibration results”, including the statistics of calibration errors, such as bias of each band, standard deviation, and uncertainty, etc., should also be provided.

7.2 Top-level model

Figure 3 depicts the top-level class diagram of this document.

Requirement 1/req/specification/Top-levelClass:

The classes shown in Figure 3, their attributes and their associations shall be used as described in the data dictionary of Tables B.1, B.8, B.14 and B.17.

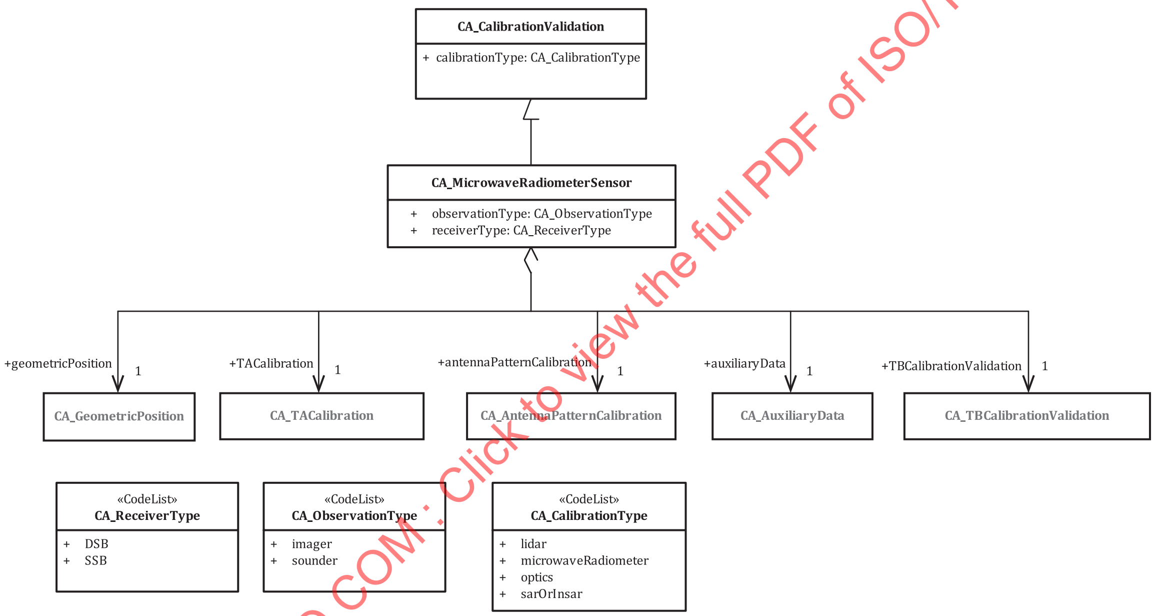

Figure 3 — Class diagram of ISO/TS 19159-4 (this document)

The class CA_MicrowaveRadiometerSensor is a top-level class for all information of calibration and validation of microwave radiometer sensors. It aggregates five classes named: CA_GeometricPosition, CA_TACalibration, CA_AntennaPatternCalibration, CA_AuxiliaryData and CA_TBCalibrationValidation. The first three classes describe the procedure of the sensor calibration. Details of the geometric position are shown in Figure 4, details of the antenna temperature calibration are shown in Figure 5, and details of the antenna pattern calibration are shown in Figure 6. CA_AuxiliaryData is needed in the calibration and validation activities, and the details are shown in Figure 7. Details of the brightness temperature (TB) calibration/validation are shown in Figure 8. The details of the classes are shown in Annex B.

The attribute receiverType defines the type of the microwave receiver according to the code list set in the class CA_ReceiverType. In the calibration view, radiometer receivers can be categorized into two types: double side band (DSB) ones and single side band (SSB) ones.

The attribute observationType defines the observation type of the microwave radiometer according to the code list set in the class CA_ObservationType. There are two types of observation: sounders, which are usually used for sounding the atmosphere profiles, and imagers, which are usually used for sensing the Earth surface.

7.3 Sensor calibration

7.3.1 General description

The primary objective of the space-borne satellite radiometer sensor on-board calibration is to find the relationship between the radiometer's output (usually voltage) and the input brightness temperature (TB), by means of well-known internal or external targets at different temperatures. The process should count antenna pattern into it for correcting antenna sidelobes, cross-polarization, incidence angle of the boresight and spillover for the reflector-feed system of the antenna.

Usually, sensor calibration is first conducted by the ground system of the satellite mission for producing level-1 product of TB, which is used as input of calibration/validation in Figure 2. According to the positions of the calibrators, on-board calibration involves antenna pattern correction or calibration when the antenna is not within the path between the two calibrators, for example, in cases of calibration at the feeds of the receivers using the hot blackbody load and the cold space for sensors like AMSR-E, SSM/I, etc. Even if the antenna is within the same path with the calibrators, antenna sidelobes and cross-polarization should be corrected in order to derive more accurate TB of the scene.

The purpose of this document is to address calibration/validation of the original TB by finding the error through comparing them with those true values and removing them at large from the original TB. This is achieved by correcting the bias or uncertainties in geometry computation, TA calibration and antenna pattern calibration.

7.3.2 Geometric position

Geometric positioning is an important part in the process of space-borne microwave radiometer calibration. Figure 4 depicts the class diagram of geometric position.

Requirement 2 /req/specification/GeometricPosition:
The classes shown in Figure 4, their attributes and their associations shall be used as described in the data dictionary of Table B.2.

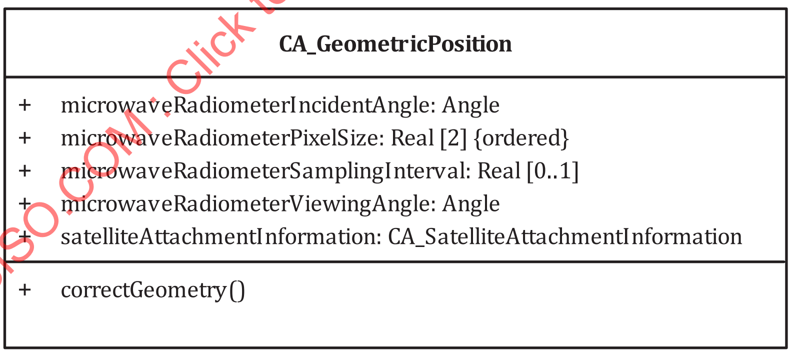

Figure 4 — CA_GeometricPosition class diagram

The class CA_GeometricPosition contains all information about the geometric positioning.

The attribute satelliteAttachmentInformation defines the satellite attachment information. The definition of the class CA_SatelliteAttachmentInformation can be found in Figure 7.

The attribute microwaveRadiometerViewingAngle defines the microwave radiometer viewing angle (expressed in the nadir angle and azimuth angle of the radiometer boresight).

The attribute microwaveRadiometerIncidentAngle defines the microwave radiometer incident angle (expressed in the nadir angle and azimuth angle of the incident microwave) at the Earth surface.

The attribute microwaveRadiometerPixelSize defines the microwave radiometer pixel size (including two elements: the first is the elevation resolution expressed in km, and the second is the azimuth resolution expressed in km).

The attribute microwaveRadiometerSamplingInterval defines the microwave radiometer sampling interval (expressed in ms).

The operation correctGeometry defines the function for realizing the geometric position, the output being latitude, longitude, elevation angle and azimuth angle of the pixel.

7.3.3 TA calibration

Microwave radiometer TA calibration is needed in the process of space-borne microwave radiometer correction.

Figure 5 depicts the class diagram of CA_TACalibration.

Requirement 3 /req/specification/TACalibration:
The classes shown in Figure 5, their attributes and their associations shall be used as described in the data dictionary of Tables B.3, B.10 and B.12.

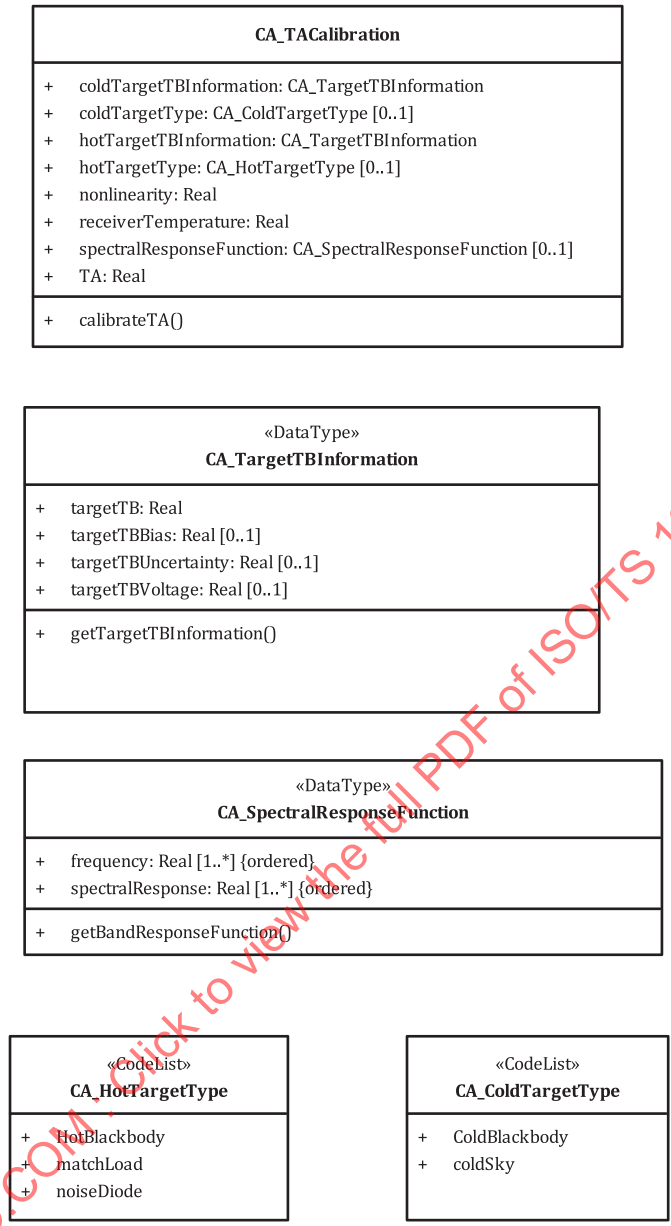

Figure 5 — CA_TACalibration class diagram

The class CA_TACalibration contains all information about the microwave radiometer TA calibration.

The attribute hotTargetTBInformation defines the hot target TB information.

The attribute coldTargetTBInformation defines the cold target TB information.

The attribute receiverTemperature defines the receiver temperature (usually detector's temperature of the radiometer, or instrument temperature) of the microwave radiometer system.

The attribute hotTargetType defines the type of the hot target according to the code list set in the class CA_hotTargetType. The most common hot-end reference is the hot blackbody.

The attribute coldTargetType defines the type of the cold target according to the code list set in the class CA_ColdTargetType. The most common cold-end reference is the cold sky (CMB).

The attribute spectralResponseFunction defines the spectral response function.

The class CA_SpectralResponseFunction is a data type that defines the spectral response function with respect to the frequency expressed in Hz.

The attribute nonlinearity defines the nonlinear term (often expressed in TB) at different instrument temperatures.

The (output) attribute TA defines the antenna temperature.

The operation calibrateTA defines the function to calibrate the antenna temperature.

7.3.4 Antenna pattern calibration

Antenna pattern calibration (APC) is needed in the process of space-borne microwave radiometer calibration. Figure 6 depicts the class diagram of antenna pattern calibration.

Requirement 4 /req/specification/AntennaPatternCalibration:
The classes shown in Figure 6, their attributes and their associations shall be used as described in the data dictionary of Table B.4.

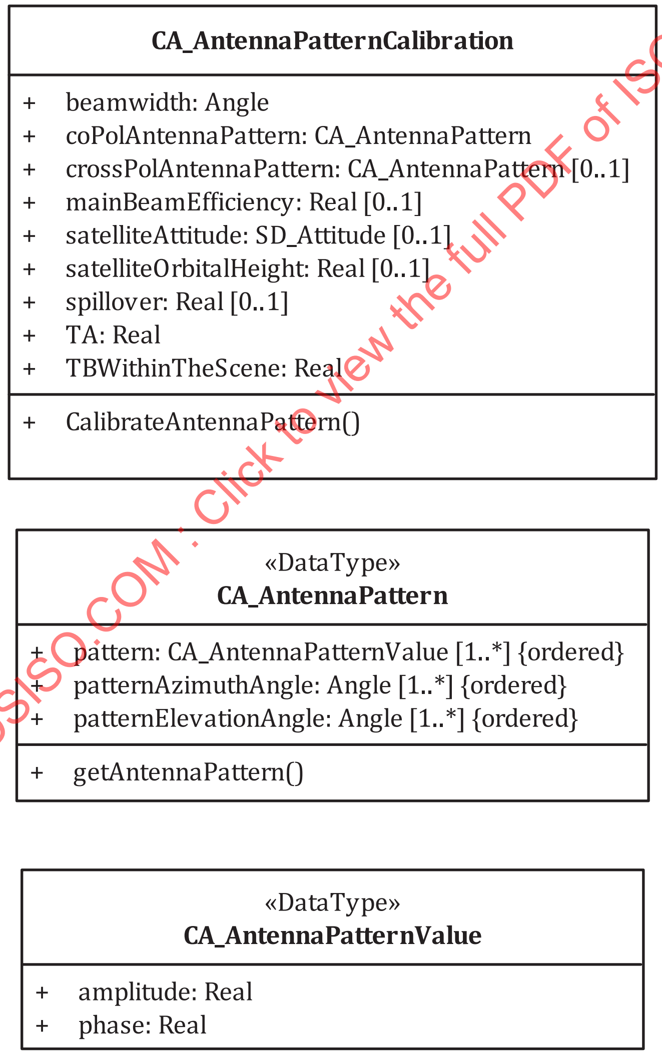

Figure 6 — CA_AntennaPatternCalibration class diagram

The class CA_AntennaPatternCalibration contains all information about the APC.

The attribute TA defines the antenna temperature inputted from CA_TACalibration.

The attribute spillover defines the spillover factors of the band.

The attribute satelliteAttitude defines the satellite attitude (expressed in the combination of the omega, phi and kappa components).

The attribute satelliteOrbitalHeight defined the orbital height (expressed in km).

The attribute beamwidth defines the antenna beamwidth (expressed in degrees).

The attribute mainBeamEfficiency defines the antenna main beam efficiency.

The attribute coPolAntennaPattern defines the co-polarization antenna pattern at least in E- and H-cuts.

The attribute crossPolAntennaPattern antenna pattern defines the cross-polarization antenna pattern at least in E- and H-cuts.

The class CA_AnttenaPattern is a data type that defines an antenna pattern in two dimensions (with respect to the elevation angle expressed in degrees and the azimuth angle expressed in degrees).

The (output) attribute TBWithinTheScene defines the TB within the observed scene.

The operation calibrateAntennaPattern defines the function to calibrate the antenna pattern and the coefficients for correcting TA to TB.

7.4 Auxiliary data

The class CA_AuxiliaryData is needed in the process of space-borne microwave radiometer calibration. Figure 7 depicts the class diagram of auxiliary data.

Requirement 5 /req/specification/AuxiliaryData:
The classes shown in Figure 7, their attributes and their associations shall be used as described in the data dictionary of Tables B.5 and B.16.

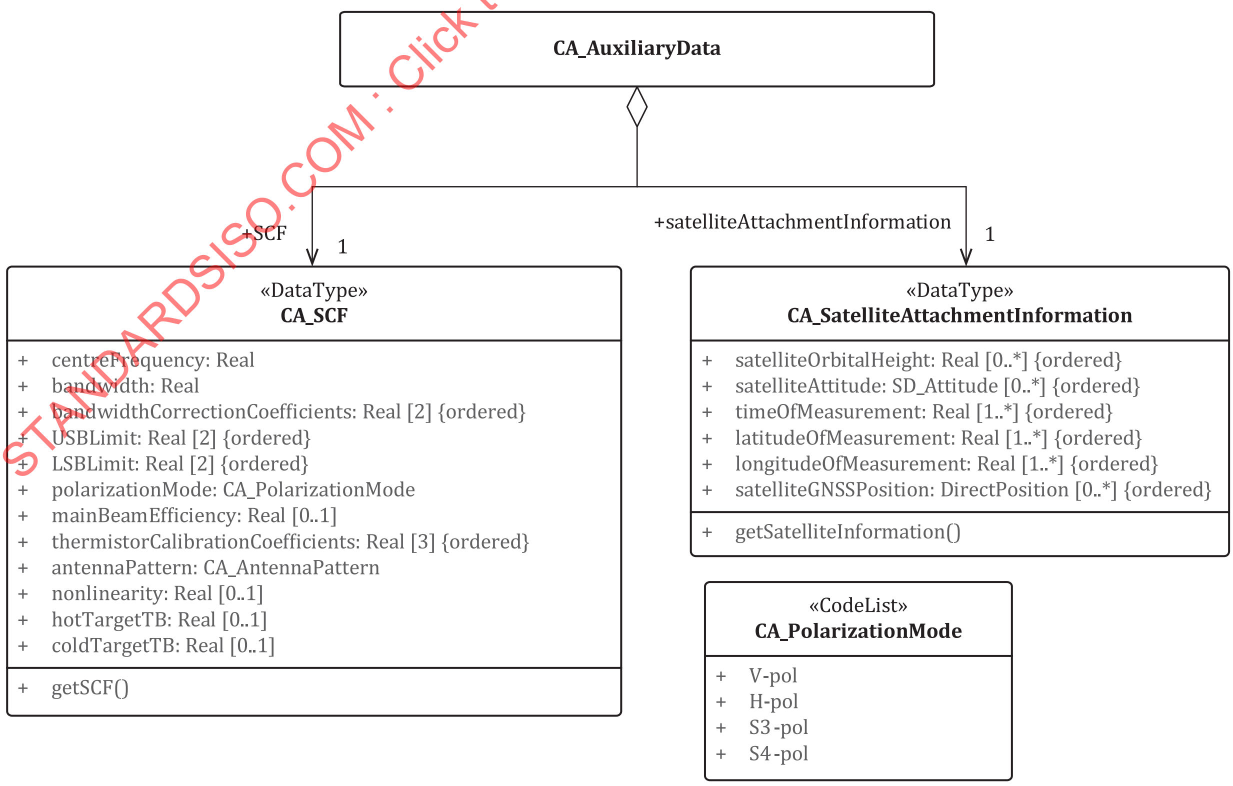

Figure 7 — CA_AuxiliaryData class diagram

The class CA_AuxiliaryData includes two subclasses: CA_SCF and CA_SatelliteAttachmentInformation. The former contains the sensor constants needed in the calibration procedure, and the latter provides the information of the platform (satellite) for geometric position.

The class CA_SCF is a data type that defines the sensor constants file (SCF) derived from the prelaunch calibration, which includes centreFrequency (expressed in Hz), bandwidth (usually referring to half-power bandwidth of the receiver, expressed in Hz), bandwidthCorrectionCoefficients, USBLimit (Upper Side Band limit expressed in Hz), LSBLimit (lower side band limit expressed in Hz,) polarizationMode [identifying the polarization mode corresponding to the TB measurement to be calibrated, including four possibilities: vertical (V-pol), horizontal (H-pol), third (S3-pol) and fourth (S4-pol) Stokes parameters], mainBeamEfficiency, thermistorCalibrationCoefficients, antennaPattern, nonlinearity, hotTargetBias and coldTargetBias.

The class CA_ SatelliteAttachmentInformation is a data type that defines the satellite attachment information, which includes satellite orbital height (expressed in km), satellite attitude (expressed in the combination of the omega, phi and kappa components), time of measurement (with the data type "DateTime"), latitude of measurement (expressed in degrees), longitude of measurement (expressed in degrees), satellite GNSS position ([X, Y, Z] coordinates, expressed in m), etc.

7.5 TB calibration/validation

7.5.1 TB calibration/validation class diagram

TB calibration/validation is needed before it is used for deriving geophysical parameters or any other applications. The fundamental function of the TB calibration / validation is to calibrate and validate the TB products (not of the higher-level geophysical products for further uses) to compute the bias and standard deviation of the TB relative to an equivalent TB true value, and to record the results of calibration/validation to keep the traceability chain complete.

Figure 8 depicts the class diagram of TB calibration / validation.

Requirement 6 /req/specification/TBCalibrationValidation:

The classes shown in Figure 8, their attributes and their associations shall be used as described in the data dictionary of Tables B.6 and B.15.

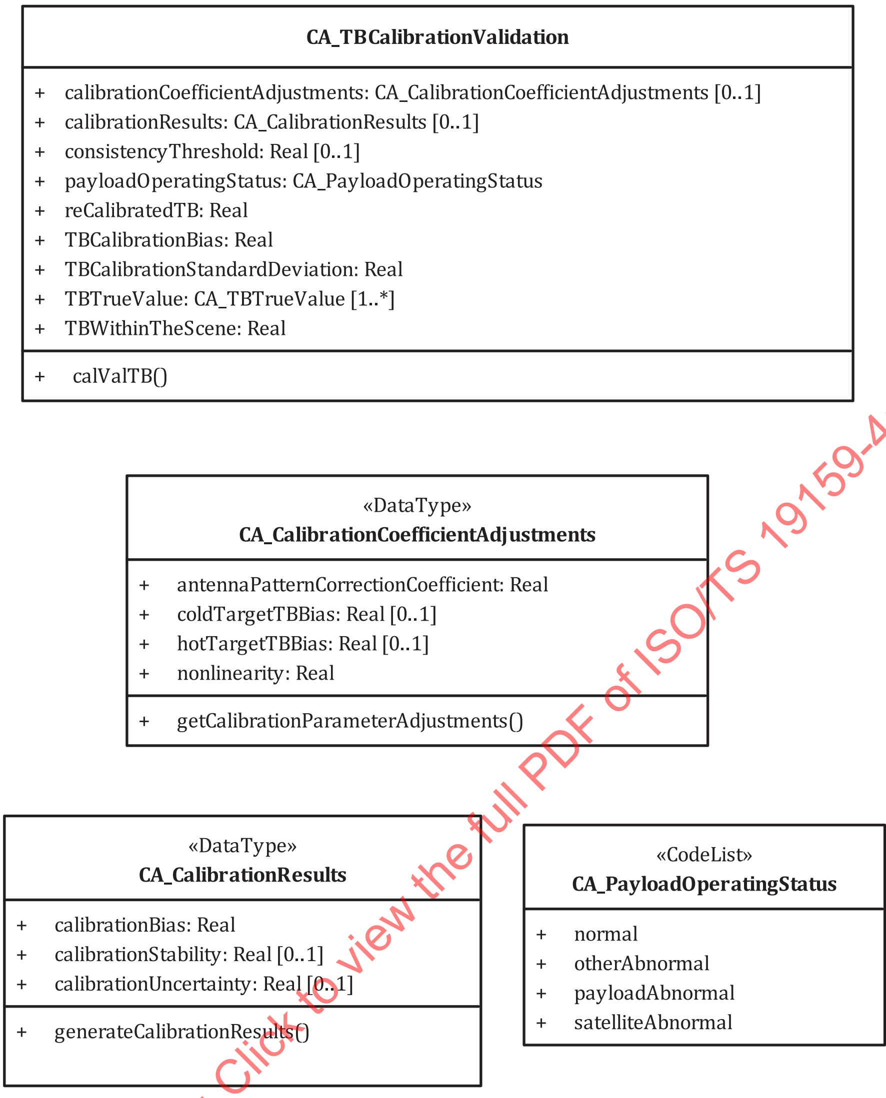

Figure 8 — CA_TBCalibrationValidation class diagram

The class CA_TBCalibrationValidation contains all information about the TB calibration/validation.

The attribute TBWithinTheScene defines the TB of the scene.

The attribute payloadOperatingStatus defines the microwave radiometer payload operating status according to the code list set in the class CA_PayloadOperatingStatus. The status can be normal or abnormal (due to satellite, payload or other factors).

The attribute CA_TBTrueValue defines the equivalent TB true value, which is shown in detail in Figure 9.

The attribute consistencyThreshold defines the consistency threshold.

The (output) attribute TBCalibrationBias defines the TB calibration bias.

The (output) attribute TBCalibrationStandardDeviation defines the TB calibration standard deviation (defined in 3.24).

The (output) attribute calibrationCoefficientAdjustments defines the calibration/validation report, which includes the hot target TB bias, cold target TB bias, nonlinearity, antenna pattern correction, etc.

The (output) attribute reCalibratedTB defines the re-calibrated TB.

The (output) attribute calibrationResults defines statistics of the calibration results, which includes the calibration bias, calibration uncertainty, calibration stability, etc.

The operation calValTB defines the function to realize the TB calibration/validation.

7.5.2 TB calibration/validation methods

7.5.2.1 General description

According to the source of TB true value, there are three categories of TB calibration/validation methods, named vicarious calibration, cross calibration and absolute calibration, which can be used to produce “true value” for validating TB. This document does not include pre-launch calibration in thermal vacuum chamber aiming at deriving nonlinearity coefficients of each band of microwave radiometer, and does not include the process on how to generate the coefficients for on-board calibration.

7.5.2.2 Vicarious calibration

Vicarious calibration, the validation using well-characterized, stable Earth targets, is a fall-back option when a satellite instrument cannot be directly traceable to an agreed reference standard, for example due to the absence of a reliable on-board calibration device. Data records from past instruments can be “re-calibrated” retrospectively if additional information on the state of these instruments becomes available, for example through comparison with reprocessed, well-known historical time series.

The vicarious calibration technique consists of three principle steps. First, calibration algorithms are coded up for each sensor. These algorithms convert raw (level 0) radiometer digital counts into level 1 radiometric antenna temperatures by correcting for on board calibration and other instrumental effects, then into level 2 main beam averaged brightness temperatures by correcting for antenna pattern and spacecraft attitude effects. The vicarious calibration data allows for the identification of errors in sensor calibration. The third step involves characterization of the calibration errors, typically by appropriate sorting and binning of the results of step 2, followed by an iterative refinement of the level 1 and level 2 algorithms to remove the errors. Adequate characterization of the errors is critical to determine which part(s) of the algorithms should be adjusted.

a) **Cold-end vicarious calibration**

The coldest possible brightness temperatures observed by a downward-looking microwave radiometer from space are often produced by calm oceans under cloud free skies and very low humidity. This set of conditions tends to occur with sufficient regularity that a space-borne radiometer will accumulate a useful number of observations within a period of a few days to weeks.

b) **Hot-end vicarious calibration**

An ideal hot-end target would be a large isothermal blackbody extending over the main beam of the Earth pointing antenna, such as the rainforest.

7.5.2.3 Cross-calibration by simultaneous observations

Cross-calibration of satellite instruments involves relating the measurements of one instrument to those of a high-quality, well-calibrated instrument serving as a reference.

Cross-calibration of instruments operated during the same period requires careful collocation wherein instrument outputs are compared when the instruments are viewing the same Earth scenes, at the same times, from the same viewing angles.

An alternative approach for instrument cross-calibration, which is less demanding in computation and applicable posteriori to long data series, is to simply compare the statistical distribution of overlapping time series of two satellite instrument data records without imposing individual matches of individual scenes.

7.5.2.4 Absolute calibration

Based on radiative transfer model, a radiometer observation simulation can be constructed, which includes the effects of ocean or land surface and atmosphere parameters. A background TB field can be established from the absolute calibration (also called the OMB method) which is used for deriving the difference between simulated and measured TB (from the radiometer to be calibrated) to determine the bias and standard deviation of the radiometer TB measurements.

Generally, absolute calibration usually uses the ocean surface at clear sky for TB simulations, but the land surface of desert, tropical rainforest and the Antarctic ice sheet are also used for hot TB calibrations.

7.5.3 TB true value class diagram

7.5.3.1 General description

Figure 9 depicts the class diagram of TB true value which plays an essential role in the TB calibration/ validation and provides data for validating the TB.

Requirement 7 /req/specification/TBTrueValue:
The classes shown in Figure 9, their attributes and their associations shall be used as described in the data dictionary of Tables B.7, B.9, B.11 and B.13.

The class CA_TBTrueValue contains all information about the TB true value. CA_TBTrueValue is the parent class of the following three subclasses: CA_VicariousCalibrationTrueValue, CA_CrossCalibrationTrueValue and CA_AbsoluteCalibrationTrueValue. Each subclass corresponds to a certain calibration/validation method described in 7.5.2. The attributes TBTrueValue and uncertainty in any subclass can be assigned to the class CA_TBTrueValue as required.

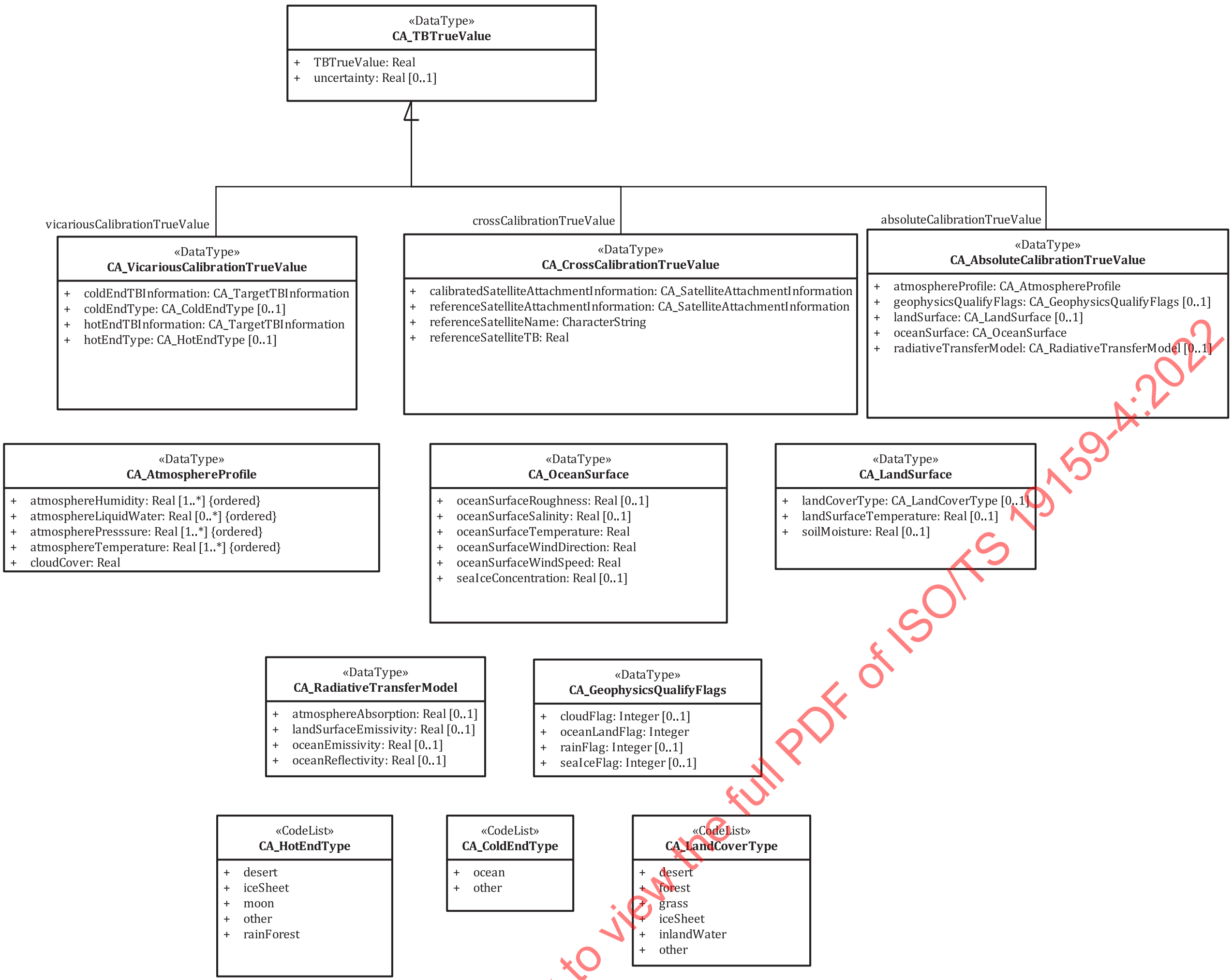

Figure 9 — CA_TBTrueValue class diagram

7.5.3.2 Vicarious calibration true value class diagram

The class CA_VicariousCalibrationTrueValue contains all information about the vicarious calibration TB true values.

The attribute hotEndTBInformation defines the TB information (including at least the TB, the TB bias and the TB uncertainty) of the hot end.

The attribute coldEndTBInformation defines the TB information (including at least the TB, the TB bias and the TB uncertainty) of the cold end.

The class CA_TargetTBInformation is a data type that is defined in Figure 5.

The attribute hotEndType defines the type of the hot end according to the code list set in the class CA_HotEndType. The hot-end reference can be rain forest, desert, moon, ice sheet and others.

The attribute coldEndType defines the type of the cold end according to the code list set in the class CA_ColdEndType. The most common cold-end reference is the ocean surface.

7.5.3.3 Cross calibration true value class diagram

The class CA_CrossCalibrationTrueValue contains all information about the cross calibration TB true values. There are two types of satellite in this class: the "reference" satellite provides the high-quality

TB which can be regarded as a true value, and the "calibrated" satellite produces the TB measurement which needs to be calibrated.

The attribute referenceSatelliteName defines the name of the reference satellite.

The attribute calibratedSatelliteAttachmentInformation defines the calibrated satellite attachment information.

The attribute referenceSatelliteAttachmentInformation defines the reference satellite attachment information.

The attribute referenceSatelliteTBdefines the name TB of the reference satellite.

The attribute referenceSatelliteTBMatchCorretion defines the TB match (with the calibrated satellite) correction term (deviations expressed in K or equation coefficients of the fitting) to that of the reference satellite.

7.5.3.4 Absolute calibration true value class diagram

The class CA_AbsoluteCalibrationTrueValue contains all information about the TB true values from the absolute calibration method. The absolute calibration true value is determined from simulation based on the radiative transfer model. Auxiliary information of the atmosphere, the ocean surface and the land surface are required in the simulation.

The attribute atmosphereProfile defines the clear sky atmosphere profile, which includes the atmosphere temperature, the atmosphere moisture, the atmosphere pressure, etc.

The attribute oceanSurface defines the ocean surface information, which includes the ocean surface temperature, the ocean surface salinity, the ocean wind speed, the ocean wind direction, etc., which are used for computing the ocean surface emissivity and the reflectivity, as well as other parameters related to the scattering of the ocean surface.

The attribute landSurface defines the land surface information, which includes the soil moisture, the land surface temperature, the land cover type, etc., which are used for computing the land surface emissivity and reflectivity, as well as other parameters related to the scattering of the land surface.

The attribute landCoverType in the data type of CA_LandSurface defines the type of the land cover according to the code list set in the class CA_LandCoverType. The land cover type can be forest, grass, desert, inland water, ice sheet and others.

The attribute radiativeTransferModel defines the radiative transfer model parameters, which includes the atmosphere absorption, the surface emissivity and reflectivity models, etc.

The attribute geophysicsQualifyFlags defines a set of geophysics flags such as oceanLandFlag, cloudFlag, rainFlag and seaIceFlag. For all these flags, the data should be rejected as low-qualify data in the calibration process if the flag value equals 1.

7.6 Satellite microwave radiometer

Requirement 8 /req/specification/CalibrationDescription:
For the calibration description of the imagery from the satellite microwave radiometer sensor, all the mandatory classes and mandatory attributes described in Clause 7 shall be provided.

Annex A
(normative)

Abstract test suite

A.1 Introduction

This annex specifies an abstract test suite which shall be passed by any implementation claiming conformance with this document, under the specifications of ISO 19105.

Requirements identifiers below are relative to <http://standards.isotc211.org/iso19159/-4>

A.2 Conformance test class: Microwave radiometer sensors calibration/validation

A.2.1 Overview

The URI identifier of this conformance class is: https://standards.isotc211.org/19159/-4/conf/MicrowaveRadiometerSensorsCalibrationValidation

The URI identifier of this requirements class is: https://standards.isotc211.org/19159/-4/req/MicrowaveRadiometerSensorsCalibrationValidation

Tests identifiers in the following subclauses are relative to http://standards.isotc211.org/iso19159/-4

A.2.2 Metadata validates

a) Test ID: /conf/MicrowaveRadiometerSensorsCalibrationValidation/Top-levelClass

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

c) Test method: Inspect the content of the metadata intended to support satellite microwave radiometer sensors calibration. Test passes if constraint evaluates to be 'true'. An XML schemaDefinition file has been developed for the test.

d) Reference: /req/MicrowaveRadiometerSensorsCalibrationValidation/Top-levelClass

A.2.3 Geometric positioning description validates

a) Test ID: /conf/MicrowaveRadiometerSensorsCalibrationValidation/GeometricPosition

b) Test purpose: Verify that the geometric position description provided with the image data instantiates CA_MicrowaveRadiometerSensor with its attributes and associated classes.

c) Test method: Inspect the content of the metadata intended to support satellite microwave radiometer sensors calibration. Test passes if constraint evaluates to be 'true'. An XML schemaDefinition file has been developed for the test.

d) Reference: /req/MicrowaveRadiometerSensorsCalibrationValidation/GeometricPosition

A.2.4 TA Calibration description validates

a) Test id: /conf/MicrowaveRadiometerSensorsCalibrationValidation/TACalibration

b) Test purpose: Verify that the TA Calibration description provided with the image data instantiates CA_MicrowaveRadiometerSensor with its attributes and associated classes.

c) Test method: Inspect the content of the metadata intended to support Satellite microwave radiometer sensors calibration. Test passes if constraint evaluates to be 'true'. An XML schemaDefinition file has been developed for the test.

d) Reference: /req/MicrowaveRadiometerSensorsCalibrationValidation/TACalibration

A.2.5 Antenna pattern calibration description validates

a) Test ID: /conf/MicrowaveRadiometerSensorsCalibrationValidation/AntennaPatternCalibration

b) Test purpose: Verify that the antenna pattern calibration description provided with the image data instantiates CA_MicrowaveRadiometerSensor with its attributes and associated classes.

c) Test method: Inspect the content of the metadata intended to support Satellite microwave radiometer sensors calibration. Test passes if constraint evaluates to be 'true'. An xml schemaDefinition file has been developed for the test.

d) Reference: /req/MicrowaveRadiometerSensorsCalibrationValidation/AntennaPatternCalibration

A.2.6 Auxiliary data description validates

a) Test ID: /conf/MicrowaveRadiometerSensorsCalibrationValidation/AuxiliaryData

b) Test purpose: Verify that the auxiliary data provided with the image data instantiates CA_MicrowaveRadiometerSensor with its attributes and associated classes.

c) Test method: Inspect the content of the metadata intended to support Satellite microwave radiometer sensors calibration. Test passes if constraint evaluates to be 'true'. An XML schemaDefinition file has been developed for the test.

d) Reference: /req/MicrowaveRadiometerSensorsCalibrationValidation/AuxiliaryData

A.2.7 TB calibration/validation description validates

a) Test ID: /conf/MicrowaveRadiometerSensorsCalibrationValidation/TBCalibrationValidation

b) Test purpose: Verify that the TB calibration/validation description provided with the image data instantiates CA_MicrowaveRadiometerSensor with its attributes and associated classes.

c) Test method: Inspect the content of the metadata intended to support Satellite microwave radiometer sensors calibration. Test passes if constraint evaluates to be 'true'. An XML schemaDefinition file has been developed for the test.

d) Reference: /req/MicrowaveRadiometerSensorsCalibrationValidation/TBCalibrationValidation

A.2.8 TB true value description validates

a) Test ID: /conf/MicrowaveRadiometerSensorsCalibrationValidation/TBTrueValue

b) Test purpose: Verify that the TB true value description provided with the image data instantiates CA_MicrowaveRadiometerSensor with its attributes and associated classes.

c) Test method: Inspect the content of the metadata intended to support Satellite microwave radiometer sensors calibration. Test passes if constraint evaluates to be 'true'. An XML schemaDefinition file has been developed for the test.

d) Reference: /req/MicrowaveRadiometerSensorsCalibrationValidation/TBTrueValue

A.2.9 Calibration description description validates

a) Test ID: /conf/MicrowaveRadiometerSensorsCalibrationValidation/CalibrationDescription

b) Test purpose: Verify that the calibration description provided with the image data instantiates CA_MicrowaveRadiometerSensor with its attributes and associated classes.

c) Test method: Inspect the content of the metadata intended to support satellite microwave radiometer sensors calibration. Test passes if constraint evaluates to be ‘true’. An XML schemaDefinition file has been developed for the test.

d) Reference: /req/MicrowaveRadiometerSensorsCalibrationValidation/CalibrationDescription

Annex B
(normative)

Data dictionary

B.1 General

This annex provides a detailed description of the classes and each class attribute in the models presented in this document in the form of a tabular data dictionary. The letters “M” and “O” in the "Obligation/Condition" column in the tables of this Annex denote “Mandatory” and “Optional” respectively.

B.2 Overview of microwave radiometer sensors

The data dictionary of the top-level model is tabulated in Table B.1 (corresponding to Figure 3). The rows shaded dark grey in Table B.1 (and the subsequent tables in Annex B) are the beginnings of the definition of self-defined classes in this document.

Table B.1 — Data dictionary of the top-level model

Line number	Name/ Rolename	Definition or description	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	AggregatedClass (MD_CoverageDescription)	Line 2
2.	calibrationType	Characterization of the calibration coded with the data type CA_CalibrationType	M	1	CA_CalibrationType	
3.	CA_MicrowaveRadiometerSensor	Top-level class for all calibration information of microwave radiometer sensors	Use obligation/condition from referencing object	Use maximum occurrence from referencing object	SpecifiedClass (CA_CalibrationValidation)	Lines 4 to 10
4.	observationType	Observation type of the microwave radiometer sensor	M	1	CA_observationType	Imager or sounder
5.	receiverType	Type of the microwave radiometer receiver	M	1	CA_ReceiverType	SSB or DSB
6.	*Rolename:* TACalibration	Antenna temperature calibration, the antenna temperature is acquired after the calibration on the receiver.	M	1	CA_TACalibration,	Calibration to the receiver of a microwave radiometer
7.	*Rolename:* antennaPatternCalibration	Antenna pattern calibration in which antenna pattern sidelobe and cross-polarization should be corrected for deriving a more accurate TB of the scene	M	1	CA_AntennaPatternCalibration	Antenna pattern correction

Table B.1 *(continued)*

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/Class	Domain
8.	*Rolename:* geometricPosition	Geometric positioning which can account for the bias or uncertainties in geometry computation	M	1	CA_GeometricPosition	Latitude and longitude of the pixel
9.	*Rolename:* auxiliaryData	Auxiliary data including SCF and satellite attachment information	M	1	CA_AuxiliaryData	
10.	*Rolename:* TBCalibrationValidation	Calibration and validation of the brightness temperature product	M	1	CA_TBCalibrationValidation	

The data dictionary of the geometric position model is tabulated in Table B.2 (corresponding to Figure 4).

Table B.2 — Data dictionary of the geometric position model

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
11.	CA_GeometricPosition	Information related to the geometric correction of the microwave radiometer system	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_MicrowaveRadiometerSensor)	Lines 12 to 16
12.	satelliteAttachmentInformation	Satellite attachment information	M	1	CA_satelliteAttachmentInformation	
13.	microwaveRadiometerViewingAngle	Microwave radiometer viewing angle with respect to the platform	M	1	Angle	≥0, ISO 19103
14.	microwaveRadiometerIncidentAngle	Microwave radiometer incident angle with respect to the earth surface	M	1	Angle	≥0, ISO 19103
15.	microwaveRadiometerPixelSize	Microwave radiometer pixel size (expressed with the elevation spatial resolution multiplying the azimuth spatial resolution)	M	1	Real[2]	>0, the unit is km·km
16.	microwaveRadiometerSamplingInterval	Microwave radiometer sampling interval between the successive samples in a scan	O	1	Real	>0, the unit is ms

The data dictionary of the TA calibration model is tabulated in Table B.3 (corresponding to Figure 5).

Table B.3 — Data dictionary of the TA calibration model

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
17.	CA_TACalibration	Information related to the antenna temperature calibration of the microwave radiometer system	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_MicrowaveRadiometerSensor)	Lines 18 to 25
18.	hotTargetTBInformation	Hot target TB information	M	1	CA_TargetTBInformation	
19.	coldTargetTBInformation	Cold target TB information	M	1	CA_TargetTBInformation	
20.	receiverTemperature	Operation temperature of the microwave radiometer receiver	M	1	Real	240 ≤ receiverTemperature -> Value ≤ 350, the unit is K
21.	hotTargetType	Hot target type	O	1	CA_HotTargetType	
22.	coldTargetType	Cold target type	O	1	CA_coldTargetType	
23.	spectralResponseFunction	Spectral response function	O	1	CA_SpectralResponseFunction	
24.	nonlinearity	Nonlinear term of the antenna temperature for the receiver temperature	M	1	Real	Unrestricted, the unit is K
25.	TA	Antenna temperature (output attribute)	M	1	Real	0 ≤ TA - > Value ≤ 350, the unit is Kelvin
26.	CA_SpectralResponseFunction	Data type that defines the spectral response function of the microwave radiometer sensor	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class <<Data type>>	Lines 27 to 28
27.	frequency	Frequency	M	1	Real {ordered}	>0, the unit is GHz
28.	spectralResponse	Response weights or radio at the frequencies within the bandwidth of the receiver	M	1	Real {ordered}	Usually in normalized weights in dB, −100 ≤ spectralResponse ->Value ≤ 0
29.	CA_TargetTBInformation	Data type that defines the target (either hot or cold) TB information	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class <<Data type>>	Lines 30 to 33
30.	targetTB	TB from the measured target, usually form varied-temperature blackbody	M	1	Real	0 ≤ targetTB - > Value ≤ 350, the unit is K
31.	targetTBBias	Bias in TB of the target	O	1	Real	the unit is K

Table B.3 *(continued)*

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
32.	targetTBUncertainty	Uncertainty in TB of the target	O	1	Real	>0, the unit is K
33.	targetTBVoltage	Microwave radiometer output in voltage or count	O	1	Real	the unit is Volt or count

The data dictionary of the antenna pattern calibration model is tabulated in Table B.4 (corresponding to Figure 6).

Table B.4 — Data dictionary of the antenna pattern calibration model

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
34.	CA_AntennaPatternCalibration	Information related to the antenna pattern calibration of the microwave radiometer system	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_MicrowaveRadiometerSensors)	Lines 35 to 43
35.	TA	Antenna temperature	M	1	Real	0 ≤ TA - > Value ≤ 350, the unit is K
36.	spillover	Spillover	O	1	Real	0 ≤ spillover- > Value ≤ 1
37.	satelliteAttitude	Satellite attitude expressed in the combination of the omega, phi and kappa components	O	1	SD_Attitude	ISO/TS 19130-1
38.	satelliteOrbitalHeight	Satellite orbital height	O	1	Real	>0, the unit is km
39.	beamwidth	Antenna beamwidth	M	1	Angle	>0
40.	mainBeamEfficiency	Antenna main beam efficiency	O	1	Real	0<meanBeamEfficiency - > Value < 1
41.	coPolAntennaPattern	Co-polarization antenna pattern	M	1	CA_AntennaPattern	Data for antenna pattern at the co-polarization
42.	crossPolAntennaPattern	Cross-polarization antenna pattern	O	1	CA_AntennaPattern	Data for antenna pattern at the cross-polarization
43.	TBWithinTheScene	TB of the scene within its spatial resolution (output attribute)	M	1	Real	0< TBWithinTheScene - > Value ≤ 350, the unit is Kelvin
44.	CA_AntennaPattern	Data type that defines the antenna pattern in the elevation and azimuth dimensions	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class <<Data type>>	Lines 45 to 47

Table B.4 *(continued)*

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
45.	patternElevationAngle	Elevation angle	M	1	Angle {ordered}	−90 ≤ patternElevationAngle - > Value ≤ 90
46.	patternAzimuthAngle	Azimuth angle	M	1	Angle {ordered}	−180 ≤ patternAzimuthAngle - > Value ≤ 180
47.	pattern	Complex pattern including the amplitude and phase at different elevation angles and azimuth angles, at least given in E- and H-cuts of the ports of the antenna	M	1	CA_ AntennaPatternValue {ordered}	
48.	CA_AntennaPatternValue	Data type that defines the antenna pattern value	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class <<Data type>>	Lines 49 to 50
49	amplitude	Amplitude of the antenna pattern	M	1	Real	<0, the unit is dB
50	phase	Phase of the antenna pattern	M	1	Real	0 ≤ phase - > Value ≤ 360

The data dictionary of the auxiliary data model is tabulated in Table B.5 (corresponding to Figure 7).

Table B.5 — Data dictionary of the auxiliary data model

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
51.	CA_AuxiliaryData	Information related to the auxiliary data that are needed in the microwave radiometer calibration procedure	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CA_MicrowaveRadiometerSensor)	Lines 52 to 71
52.	CA_SatelliteAttachmentInformation	Data type that defines the satellite attachment information	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class(CA_AuxiliaryData)	Lines 50 to 55
53.	satelliteOrbitalHeight	Satellite orbital height with respect to the reference ellipsoid	O	1	Real {ordered}	>0, the unit is km
54.	satelliteAttitude	Satellite attitude expressed in the combination of the omega, phi and kappa components	O	1	SD_Attitude{ordered}	ISO/TS 19130-1
55.	timeOfMeasurement	Time of measurement	M	1	DateTime{ordered}	ISO 19103 Unrestricted

Table B.5 *(continued)*

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
56.	latitudeOf-Measurement	Latitude of measurement	M	1	Real {ordered}	−90 ≤ latitudeOfMeasurement ->Value ≤ 90, the unit is degree
57.	longitudeOf-Measurement	Longitude of measurement	M	1	Real{ordered}	−180 ≤ longitudeOf-Measurement ->Value ≤ 180, the unit is degree
58.	satelliteGNSSPosition	Satellite GNSS position ([X, Y, Z] coordinates, expressed in m),	O	1	DirectPosition{ordered}	ISO 19107
59.	CA_SCF	Sensor constant file used for calibration			Aggregated Class(CA_AuxiliaryData)	Lines 57 to 68
60.	centreFrequency	Centre frequency of the microwave radiometer sensor	M	1	Real	0.1≤ centre-Frequency - > Value ≤ 3 000, the unit is GHz
61.	bandwidth	Bandwidth of the microwave radiometer receiver	M	1	Real	>0, the unit is GHz
62.	bandwidth-Correction-Coefficients	Bandwidth correction coefficients including 2 items of the first-order correction	M	1	Real[2]	Including 2 items: the 1st item is non-dimensional, the unit of the 2nd is K
63.	USBLimit	Frequency range of the Upper Side Band	M	1	Real {ordered}	>0, the unit is GHz
64.	LSBLimit	Frequency range of the Lower Side Band	M	1	Real {ordered}	>0, the unit is GHz
65.	polarization-Mode	Polarization mode of the radiometer TB measurement, usually referring to vertical or horizontal polarization, which corresponding to the first two modified Stokes parameters, most generally referring to one of the four Stokes parameters	M	1	CA_PolarizationMode	vertical-polarization, horizontal polarization, the third Stokes parameter, the fourth Stokes parameter
66.	main-BeamEfficiency	Antenna main beam efficiency	O	1	Real	0<main-BeamEfficiency - > Value ≤ 1

Table B.5 *(continued)*

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
67.	thermistorCalibrationCoefficients	Thermistor calibration coefficients	M	1	Real[3]	Including 3 items: the unit of the 1st is K/V^2, of the 2nd is K/V, of the 3rd is K
68.	antennaPattern	Antenna pattern at a given frequency within a range of elevation angles and azimuth angles	M	1	CA_AntennaPattern	Data for antenna pattern at co-polarization and cross-polarization
69.	nonlinearity	Nonlinear term at different operation temperatures of the radiometer	O	1	Real	Unrestricted, the unit is K
70.	hotTargetBias	Bias in TB of the hot target blackbody	O	1	Real	Unrestricted, the unit is K
71.	coldTargetBias	Bias in TB of the cold target	O	1	Real	Unrestricted, the unit is K

The data dictionary of the TB calibration validation model is tabulated in Table B.6 (corresponding to Figure 8).

Table B.6 — Data dictionary of the TB calibration validation model

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
72.	CA_TBCalibrationValidation	Calibration/validation of the TB	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Aggregated Class (CAMicrowaveRadiometerSensors)	Lines 73 to 81
73.	TBWithinTheScene	TB of the scene within the spatial resolution of the microwave radiometer	M	1	Real	0< TBWithinTheScene - > Value ≤ 350 the unit is K
74.	payloadOperatingStatus	Payload operating status	M	1	CA_PayloadOperatingStatus	
75.	TBTrueValue	The equivalent TB true value	M	1	CA_TBTrueValue	0< TBTrueValue > Value ≤ 350, the unit is K
76.	consistencyThreshold	Consistency threshold	O	1	Real	Unrestricted, the unit is K
77.	TBCalibrationBias	TB calibration bias (output attribute)	M	1	Real	Unrestricted, the unit is K
78.	TBCalibrationStandardDeviation	TB calibration standard deviation (output attribute)	M	1	Real	≥0, the unit is K
79.	calibrationCoefficientAdjustments	Calibration adjustment coefficients (output attribute)	O	1	CA_CalibrationCoefficientAdjustments	

Table B.6 *(continued)*

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
80.	reCalibratedTB	Re-calibrated TB (output attribute)	M	1	Real	>0, the unit is K
81.	calibrationResults	Parameters in the calibration/validation report (output attribute)	O	1	CA_CalibrationResults	
82.	CA_CalibrationCoefficient Adjustments	Data type that defines the calibration adjustment coefficients	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class <<Data type>>	Lines 83 to 86
83.	hotTargetTBBias	Hot target TB bias	O	1	Real	Unrestricted, the unit is K
84.	coldTargetTBBias	Cold target TB bias	O	1	Real	Unrestricted, the unit is K
85.	nonlinearity	Nonlinearity correction	M	1	Real	Unrestricted, the unit is K
86.	antennaPatternCorrectionCoefficient	Antenna pattern correction coefficient	M	1	Real {ordered}	0 ≤ antennaPatternCorrectionCoefficient ->Values≤ 1
87.	CA_CalibrationResults	Data type that defines the calibration/ validation results	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Class <<Data type>>	Lines 88 to 90
88.	calibrationBias	Calibration bias	M	1	Real	Unrestricted, the unit is K
89.	calibrationUncertainty	Calibration uncertainty	O	1	Real	Unrestricted, the unit is K
90.	calibrationStability	Calibration stability	O	1	Real	the unit is K/y

The data dictionary of the TB true value model is tabulated in Table B.7 (corresponding to Figure 9).

Table B.7 — Data dictionary of the TB true value model

Line number	Name/ Rolename	Definition or description	Obligation/ Condition	Max. occurrence	Data type/ Class	Domain
91.	CA_TB-TrueValue	TB true value	Use obligation/ condition from referencing object	Use maximum occurrence from referencing object	Generalized Class	Lines 92 to 93
92.	TBTrueValue	TB true value	M	1	CA_TB-TrueValue	0< TBTrueValue-> Value ≤ 350, the unit is K
93.	uncertainty	Uncertainty of the true value	O	1	Real[0..1]	