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Space-borne passive microwave radiometers

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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).

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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:

$$\eta_{\mathrm{M}} = \frac{\iint_{Y} F_n(\theta,\phi)\, d\Omega}{\iint_{4\pi} F_n(\theta,\phi)\, d\Omega}$$

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
$T_{\mathrm{A,out}}$
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:

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

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 ($T_{\mathrm{A,out}}$) is related to the input noise temperature of the receiver as shown in the following formula:

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

where

$T_{\mathrm{rec,in}}$	is the input noise temperature of the receiver;
h	is the Plank’s constant (6.626 07×10^{-34} J·s);
ν	is the frequency in Hz;
k	is the Boltzmann’s constant (1.380 648 52×10^{-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
$I_{\mathrm{bb,v}}$
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):

$$I_{\mathrm{bb,v}} = \frac{2\mathrm{h}v^3}{\mathrm{c}^2} \frac{1}{\mathrm{e}^{\frac{\mathrm{h}v}{\mathrm{k}T_{\mathrm{w}}}} - 1}$$

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: $P = \mathrm{k} \cdot T_B$

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:

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

where

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

v is the frequency in Hz;

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

k is the Boltzmann's constant ($1.380\ 648\ 52 \times 10^{-23}$ 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 ($6.626\ 07 \times 10^{-34}$ J·s);

ν is the frequency in Hz;

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

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

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.

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

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:

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

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 $1-\Lambda_{\mathrm{P}}$ 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.