S3-43
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N94-20598

Earth Observing System
Calibration Advisory Panel

Definitions in use by the Visible and Near-Infrared, and Thermal Working Groups

Carol J. Bruegge, Ed Miller, Bob Martin
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California 91109

Hugh H. Kieffer
United States Department of the Interior
Flagstaff, Arizona 86001

James M. Palmer
University of Arizona, Optical Sciences Center
Tucson, Arizona 85721

November 13, 1991

Introduction

The Calibration Advisory Panel (CAP) is composed of calibration experts from each of the Earth Observing System (EOS) instruments, science investigation, and cross-calibration teams. These members come from a variety of institutions and backgrounds. In order to facilitate an exchange of ideas, and assure a common bases for communication, it was desirable to assemble this list of definitions. These definitions were developed for use by the visible and near-infrared working group, and the thermal infrared working group. Where necessary or appropriate, deviations from these for specific instruments or other sensor types are given in the individual calibration plans.

The definitions contained in this document are derived, wherever possible, from definitions accepted by international and national metrological commissions including the United States National Institute of Standards and Technology (NIST), the International Bureau of Weights and Measures (BIPM), the International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO), and the International Organization of Legal Metrology (OIML).

Often, the way specific terms are defined can impact procedures, delineate personnel or programmatic responsibilities, and define the time frame in which a given measurement is to be made. It may be sufficient, for example, during *verification* testing, to perform a quick check-out procedure using less accurate sources or testing equipment than that required during a *calibration* test. The *calibration* of an instrument may be conducted by different personnel than the *validation* of an instrument's data products. Thus, the terms used here are updated from those in the literature as needed to reflect the usage of this particular remote sensing community.

In reviewing this document, it is noted that subtle differences often exist between terms. For example, care is used to distinguish between *accuracy*, *precision*, *error*, and *uncertainty*. If a measurement system is used to repeatedly measure a constant known source, with some defined variation of environmental conditions, such as the ambient temperature, the population of the measured (reported) values would have the following characteristics:

- one minus the relative standard deviation (standard deviation to mean ratio) of this population is the *precision*,
- the standard deviation plus known systematic error terms compose the *uncertainty*,
- one minus the relative uncertainty is the *accuracy*,
- the difference between any particular measurement and the true value is an *error*.

Where appropriate, therefore, cross-reference is made within the definitions to clarify subtle differences in terms.

Definitions

accuracy. An estimate characterizing the closeness of a measurement to the true measurand. It can be given as one minus the absolute value of relative uncertainty (negative values are set to 0), or as a percentage after multiplication by 100. Note that while *accuracy* assumes reference to a standard or knowledge of error sources, *precision* is a relative measure of the agreement amongst a set of measurements. Also, with *accuracy* higher numbers are better, and with *uncertainty* lower numbers are preferred.

calibration. The set of operations which establish, under specified conditions, the relationship between values indicated by a measuring instrument and the corresponding known values of a standard. For EOS sensors this typically implies the radiometric, spectral, or geometric characterization of an instrument as needed to understand the impact of the instrument performance on the data or the derived data products.

> **absolute calibration.** The determination of calibration factors by comparison with a standard whose output is known in accepted physical (SI) units.
>
> **ground calibration.** The radiometric calibration of an in-orbit sensor through an *intensive field-campaign*. This calibration is established via a
>
> > 1) reflectance-based ground calibration in which atmospheric and surface reflectance characteristics are measured and used to compute exo-atmospheric radiances, or
> >
> > 2) radiance-based ground calibration in which helicopter or aircraft sensors are used to map radiances and extrapolate to the required exo-atmospheric radiances.
>
> **in-flight calibration.** The calibration of an aircraft or satellite-based sensor while in flight. This may be through ground calibration exercises, or through use of an on board calibration system.
>
> **preflight calibration.** The calibration of a sensor prior to launch.
>
> **relative calibration.** The determination of the correction by comparison with a standard whose output is not necessarily known in physical units, but which is established in ratio or as a fraction of the value of the standard.
>
> **self-calibrating.** A *standard* of calibration based upon known physics. These may include
>
> > 1) self-calibrating photodiodes, also known as quantum efficient detectors, or silicon photodiodes of known or negligible reflectance and known internal quantum efficiency,
> >
> > 2) blackbody radiation simulators operating at a well defined temperature and emittance, and
> >
> > 3) electrical substitution radiometers in which a measured amount of electrical power used to heat a given material is compared to the optical heating of the same material.

calibration curve. The result of a calibration; a term or set of terms by which the instrument values are related to the corresponding known standard values. It may be expressed with calibration coefficients, or with use of a curve. Also referred to as the radiometric transfer curve.

characterization. The measurement of the typical behavior of instrument properties which may affect the accuracy or quality of its response or derived data products. The results of a characterization may or may not be directly used in the calibration of the instrument response, but may be used to determine its performance (the characterized properties may inherently affect the calibration of the instrument.)

confidence interval. An interval about the result of a measurement or computation within which the true value is expected to lie, as determined from an uncertainty analysis with a specified probability.

cross-calibration. The process of assessing the relative accuracy and precision of response of two or more instruments. A cross-calibration would provide the calibration and/ or correction factors necessary to intercompare data from different instruments looking at the same target. Ideally this would be done by simultaneous viewing of the same working standards or target. Any variations in environmental conditions, calibration procedures, or data correction algorithms between the instruments must be accounted for in the assessment.

data product. The final processed data sets associated with the various measured and derived geophysical parameters which are the object of a specified investigation and referred to as a higher level product than the measurement provided by the instrument.

data product validation. The process of assessing, by independent means, the uncertainty of observables or geophysical parameters derived from sensor output. Accurate calibration, data transmission, and processing algorithms are prerequisite to data validation. Data product validation can further be divided into correlative measurements or data product verifications.

correlative measurements. Spatially and temporally coincident measurement of the parameters deduced from a given sensor, made with independent surface, aircraft, or separate in-orbit instrumentation. These activities require coordination with other ground stations, EOS validation teams, concurrent intensive field campaigns, or long-term monitoring stations.

data product verification. Perform product validation analyses by simulation, checks with physical bounds, or self-consistency analyses. Comparisons with routine data products from other in-orbit sensors, or utilization of existing data bases for trend analyses are included.

drift. The slow variation with time of a metrological characteristic of an instrument.

engineering units. A set of defined units commonly used by an engineer in a specific field to express a measurand.

environmental variables. Variable physical properties in the environment of the instrument or target (such as temperature, particulate and electromagnetic radiation, vacuum, and vibration) which may effect the result of a measurement. Note the sensor does not measure an environmental variable; it measures an *observable.*

error. The difference between a reported value and its true value.

relative error. The absolute error of measurement divided by the true value of the measurand.

random error. A component of the error of measurement which, in the course of a number of measurements of the same measurand, varies in an unpredictable way. It is not possible to correct for random error, but its magnitude may be determined by the application of statistical procedures.

systematic error. A component of the error of measurement which, in the course of a number of measurements of the same measurand, remains constant or varies in a systematic predictable way. Systematic errors and their causes may be known or unknown. This error is also referred to as "bias error".

functional test. A test that demonstrates a go/ no go condition with respect to a functional requirement.

geometric calibration. The characterization of the correlation between the actual geometric properties of the observed target and the output of the measuring instrument. Includes such parameters as fields-of-view, registration, and pointing knowledge.

geophysical parameters. Those variables of the Earth's environment, including aspects of the land and water surfaces, atmosphere and space, which are used to describe the environment and geophysical processes. Geophysical parameters may be directly observable or deduced from sensor output as a higher level product.

hysteresis. The property of an instrument whereby its response to a given stimulus depends on the sequence of preceding stimuli. In photodetectors, hysteresis refers to the retention of signal in detectors that have already been read in an amount proportional to the input.

integrator verification tests. *Verification tests* conducted at the integrator facility.

comprehensive test. The full complement of *verification tests* performed at the instrumentor facility at the conclusion of the environmental test phase.

bench acceptance test. A subset of the *comprehensive tests*, performed before and after shipment of instrument to the integrator.

functional test. A subset of the *comprehensive tests*, performed before, during, and after environmental exposure tests to verify that the payload has not degraded. Externally mounted sources and simple targets will be utilized.

operability test. A subset of the *functional tests* used to provide traceability of the instrument performance through PMP (Payload Mounting Plate) integration, observatory integration, and shipment to the launch site. No externally mounted targets will be used.

aliveness test. A subset of the *operability tests* used to monitor the housekeeping command and telemetry data. No science or engineering data are acquired. The test is done before and after shipment to the launch site.

intensive field campaign. A limited period of time in which in-situ measurements are made in support of a remote sensing program. These measurements may be used to provide a sensor calibration, or validate observables or derived data products. An *intensive field campaign* differs from a *long-term monitoring program* in that the latter provides an on-going activity in which instrumentation and personnel are dedicated to the in-situ measurements task. See *ground calibration.*

long-term monitoring program. An on-going in-situ measurements program which is typically at a fixed site using dedicated personnel. These measurements may be used to provide a sensor calibration, or validate observables or derived data products. This contrasts to an *intensive field campaign* in which equipment and personnel are brought to a test site where they remain until the experiment objectives have been accomplished, or until allotted funds or time are depleted.

measurement assurance program (MAP). A program applying specified (quality) principles to a measurement process. A MAP establishes and maintains a system of procedures intended to yield calibrations and measurements with verified limits of uncertainty based on feedback of achieved calibration of measurement results. Achieved results are observed systematically and used to eliminate sources of unacceptable uncertainty.

model.

mathematical model. A mathematical description of a (sensor) system relating inputs to outputs. For EOS, may be implemented in a variety of ways but must be of sufficient detail to provide inputs to system analysis studies such as performance prediction, uncertainty (or error) modeling, and isolation of failure or degradation mechanisms, or environmental limitations.

error model. A mathematical model of the measurement chain in which all potential error sources are identified, quantified, and combined such that a meaningful estimate of measurement uncertainty can be determined.

model validity. Our expectation of the accuracy of assumptions used to develop a mathematical model for a given system.

observables. The fundamental physical quantity or quantities that a sensor can measure, such as temperature which through a process of calibration can be related to a Geophysical parameter. Observables can usually be measured by processes traceable to physical standards.

pointing.

absolute pointing knowledge. The total angle between the actual pointing direction and the reconstructed pointing direction. The reconstructed pointing direction is obtained after the fact by processing "best fit" ephemeris and attitude determination data, sensor data, and instrument image data.

bore-sight angle. The deviation in total angle between the actual pointing direction of an instrument and some reference.

pointing control (absolute placement). The total angle between the actual pointing direction and the desired pointing direction

pointing stability. The variation of the total angle between the actual pointing direction and the desired pointing direction over some time interval.

precision. The consistency of measurements made with the same sensor, as determined through a statistical study. The confidence with which a measurement can be repeated with a given sensor under controlled conditions, or the confidence that two different sensors or techniques can yield a result.

absolute precision. Magnitude of the uncertainty in the result in the same units as the result.

relative precision. Magnitude of the uncertainty in terms of a fraction of the value of the result.

registration. The accurate geometric matching or superposition of two or more measurements of the same object.

repeatability. The ability of an instrument to give under specific conditions of use, closely similar responses for repeated applications of the same stimulus. Measurements are carried out over changing conditions such as:

The method of measurement,	The observer,
The measuring instrument,	The location,
The condition of us,	The time.

Examples are measurements made over long time periods, or where excursions of ambient conditions have occurred. This contrasts to precision where a comparison of measurements is made under constant conditions.

resolution. A quantitative expression of the ability of an instrument to distinguish meaningfully between the smallest detectable values of the input quantity measured. Generally defined by the Rayleigh Criterion in optical systems for angular response. For radiometric observables, this may be set by the digitization size (1 DN).

response time. The time interval in which a sensor increases from 10% to 90% of its final output value, in response to a stimulus which has undergone a specified abrupt change.

rise time. The interval in which a sensor increases to 1-1/e, or 63%, of its final output value.

fall time. The interval in which a sensor decreases to 1/e, or 37%, of its initial output value.

settling time. The time interval it takes an instrument to reach and remain within specified limits of its final value.

responsivity. The change in the response of a measuring instrument divided by the corresponding change in the stimulus. Sometimes referred to as sensitivity.

sampling interval. The size of the samples used to measure something; i.e. in imaging, sampling refers to pixel size. In spectroscopy, sampling refers to the spectral separation between the centers of adjacent samples.

sensor. A device that responds to either the absolute value or change in a physical stimulus (heat, light, sound, magnetism, pressure, or particular motion) and produces a corresponding signal. A sensor can be an entire instrument or the part of it that measures a phenomenon.

spectral calibration.

band-to-band calibration. The determination of variation in radiometric response from one spectral channel relative to another spectral channel.

center wavelength. The wavelength that represents the bandpass of a sensor or sensor channel. It can be defined as the wavelength at the centroid of the instrument's response, the midvalue of the spectral bandpass, or peak value.

spectral sampling interval. The distance in wavelength or wavenumber between the center wavelength/ wavenumber of adjacent spectral channels.

spectral bandwidth. The range of spectral input to which a channel of a sensor produces output at acceptable levels of sensitivity. Can be calculated as the full width at half maximum response for a channel, or by alternative descriptions such as those based on moments analyses.

stability. The ability of an instrument to maintain constant metrological characteristics. Generally a measure of variation in response to a known, stable standard.

short-term stability. Stability as measured over a short time interval. This may be over a period of a shorter than a seconds to one orbital revolution, or may be over a single instrument measurement cycle (single image frame, line time, etc.)

intermediate stability. Stability as measured over an intermediate time interval. This may be on the order of several revolutions to an orbital repeat period (few weeks).

long-term stability. Stability as measured over a long time interval. This may be, for example, from several orbital repeat periods, to the lifetime of an instrument (nominally 5 years).

standard deviation. For a series of n measurements of the same measurand, the parameter σ characterizing the dispersion of the results and given by the formula:

$$\sigma = \sqrt{\frac{\sum_{n=1}^{N} (x_n - \bar{x})^2}{n-1}}$$

standards (physical). An accepted material, instrument, procedure, or system to be used as a reference for establishing a unit for the measurement of a physical quantity.

primary standard. A standard which has the highest metrological qualities in a specified field. It may be realized from first principles, or established by international agreement.

secondary standard. A standard whose value is fixed by comparison with a primary standard

international standard. A standard recognized by an international agreement to serve internationally as the basis for fixing the value of all other standards of the quantity concerned.

national standard. A standard recognized by an official national decision as the basis for fixing the value, in a country, of all other standards of the quantity concerned. The national standard in a country is usually a primary standard. In the United States, National Standards are set by the National Institute of Standards and Technology (NIST). As a working group we recognize that NIST is not the exclusive supplier of standards.

reference standard. A standard, generally of the highest metrological quality available at a given location, from which measurements made at that location are derived.

working standard. A standard which usually calibrated against a reference standard, is used routinely to calibrate or check material measures or measuring instruments.

transfer standard. A standard used as an intermediary to compare standards, material measures or measuring instruments.

travelling standard. A standard, sometimes of special construction, intended for transport between different locations.

traceability. The property of a result of a measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of comparisons.

uncertainty. An estimate characterizing the range of values within which the true value of a measurand lies. (As compared to *accuracy*, here smaller numbers are better). Uncertainty comprises, in general, many components. Some of these may be estimated on the basis of the statistical distribution of the results of measurements made under constant and controlled conditions (e.g. the standard deviation). Estimates of other components can only be based on experience or other information. It can also be based upon a set of absolute measurements (made with reference to some standard). Included with uncertainty should be some stated confidence level (3σ, or a 99% confidence level is recommended).

relative uncertainty. Magnitude of the uncertainty in terms of a fraction of the value of the result.

units.

standard (SI) units. The coherent system of units adopted and recommended by the General conference on Weights and Measures (CGPM). The SI is based on the following seven base units:

Entity	Term	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	sec
Electric Current	ampere	A
Thermodynamic Temperature	kelvin	K
Amount of Substance	mole	mol
Luminous Intensity	candela	cd

derived (SI) units. A unit of measurement of a quantity derived from the SI system of base units. Some derived units have special names and symbols:

Entity	Term	Symbol
Capacitance	farad	F
Inductance	henry	H
Electric Charge	coulomb	C
Voltage (emf)	volt	V
Electric Field Strength	volt/meter	E
Resistance	ohm	Ω
Frequency	hertz	Hz
Energy(work,heat)	joule	J
Power	watt	W
Magnetic flux	weber	Wb
Magnetic flux density	tesla	T
Force	newton	N
Pressure	newton per square meter or pascal	$N\ m^{-2}$ or Pa

derived radiometric units. (Mathematical Symbol in parenthesis)

Entity	Term	Symbol
Radiant Energy (Q)	joule	J
Radiant Flux (Φ)	watt	W
Radiant Flux Density at a surface Radiant Exitance (M) Irradiance (E)	watt per square meter	$W\ m^{-2}$
Radiant Intensity (I)	watt per steradian	$W\ sr^{-1}$

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Entity	Term	Symbol
Radiance (L)	watt per steradian and square meter	$W\ sr^{-1}\ m^{-2}$
Reflectance = Φ_r/Φ_i = (ρ)	unitless	
Emissivity= $M/M_{blackbody}$ = (ε)	unitless	
Absorptance = Φ_a/Φ_i=(α)	unitless	
Transmittance =Φ_t/Φ_i=(τ)	unitless	

where $\Phi_i,\Phi_r,\Phi_t,\Phi_a$ = incident, reflected, transmitted, and absorbed flux respectively.

SI prefixes. Used as prefixes in combination with the terms and symbols of SI units to form decimal multiples an submultiples of those units.

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{18}	exa	E	10^{-1}	deci	d
10^{15}	peta	P	10^{-2}	centi	c
10^{12}	tera	T	10^{-3}	milli	m
10^{9}	giga	G	10^{-6}	micro	µ
10^{6}	mega	M	10^{-9}	nano	n
10^{3}	kilo	k	10^{-12}	pico	p
10^{2}	hecto	h	10^{-15}	femto	f
10^{1}	deca	da	10^{-18}	atto	a

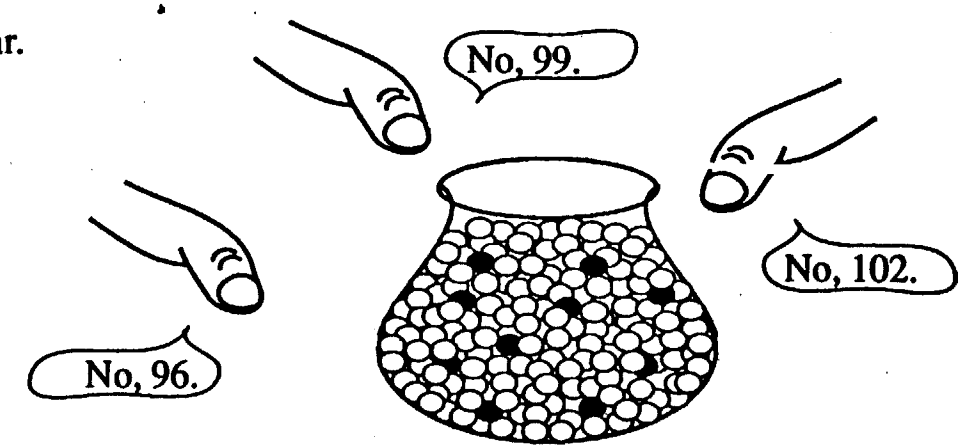
verification. Tests and analyses to be performed during the design, development, assembly, and integration phases of an instrument to assure all instrument functional requirements have been met. Includes all sub-system and system tests done at the functional level. See *integrator verification tests*.

References

Cohen, E. Richard, and Pierre Giacomo (1987). *Symbols, Units, Nomenclature, and Fundamental Constants in Physics*. International Union of Pure and Applied Physics, Document IUPAP-25 (SUNAMCO87-1).

International Organization for Standardization (1982). *Units of Measurement, ISO Standards Handbook 2*. Geneva, Switzerland.

Definitions Example



Problem

Estimate the number of marbles in the jar.

Assumptions

Jar is filled.

Model

Marble diameter, shape; jar volume, computation algorithm.

Systematic error evaluation

- Marbles may be limited to those viewed from outside (other internal material).
- Marble, jar dimensions of estimated uncertainty.
- Algorithm validity

Accuracy specification

Measurement uncertainty: <7% @ 3σ @ full jar
One count relative to another: ±2% @ 3σ @ full jar

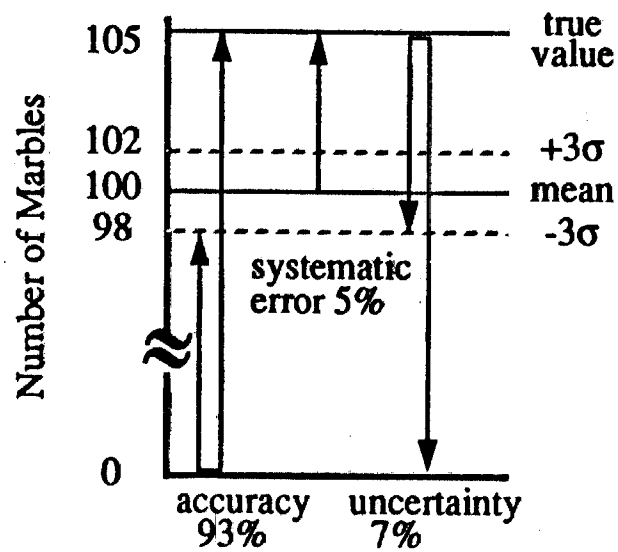
confidence level (→ 3σ)

measurement conditions (different specification if only one marble) (→ full jar)

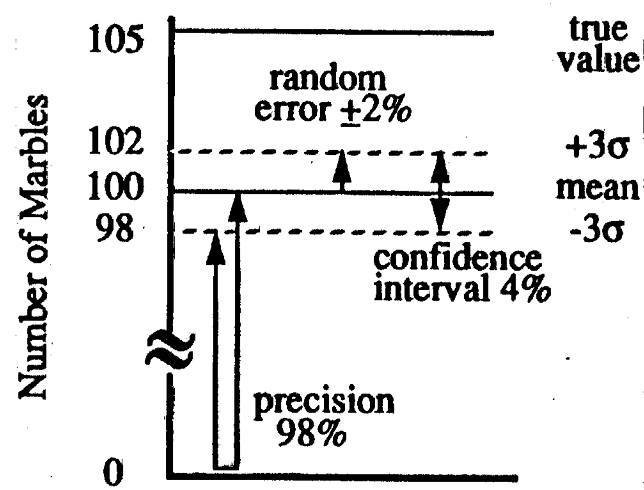
Use proper terminology, NOT THIS:
Accuracy: 7%(is uncertainty meant?)
Relative count: 2% (from mean, or full range?)

Definitions Example, cont.

Error analyses



Error parameters computed through model validation and statistics



Error parameters computed through statistical evaluation only