Traceability of Radiometric Measurements as an Important Element of Data Quality Assurance within the GEOSS Program

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Working Group on Calibration and Validation
(CEOS WGCV-26, Chiang Mai, Thailand, 31 Oct-2 Nov 2006)

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NIST
National Institute of Standards and Technology
VEGA
VEGA INTERNATIONAL INC.

DA-06-02: GEOSS Quality Assurance Strategy

This work is being done within the task DA-06-02 ADC GEO:

Develop a GEO data quality assurance strategy, beginning with space-based observations and evaluating expansion to in situ observations, taking into account existing work in this area.

Russia's Potential Contribution (in co-operation with USA)

The All-Russian Institute for Opto-Physical Measurements (VNIIOFI), in cooperation with the National Institute of Standards and Technology, the Space Dynamics Laboratory, and Vega International, Inc. (both from Logan, Utah) will participate in the development of a strategy to assure high-quality radiometric data provided by the Global Earth Observation System of Systems

OUTLINE

- Terms and definitions
- Ensuring traceable and stable instrument radiometric scales
- Summary

Starting points

- We discuss only the radiometric aspect of quality of data belonging to the optical spectral region.
- Data format and geolocation issues lie outside of our scope.
- We deal only with data of Levels 0 and 1A.
- **The goal is to ensure the compatibility of data acquired by different national Earth observation systems.**
- Creating a proper standards calibration base requires us to follow the most rigorous requirements for the accuracy of measurements.
- **We discuss the metrological support only for future systems.**

Terms and Definitions - I

We need a properly recognized list of terms and definitions

Ensuring high quality of data at an international level is not possible without mutually recognized and officially approved documents on terms and definitions.

For several years, experts from VNIIOFI and the S.I. Vavilov State Optical Institute (GOI) from Russia, **NIST, SDL, and Vega International, Inc. from the U.S. have been developing a thesaurus on radiometric calibration of optoelectronic instruments. The results were eventually published as a NIST Internal Report.**

Title page

NISTIR 7203

Spaceborne Optoelectronic Sensors and their Radiometric Calibration. Terms and Definitions.

Part 1. Calibration Techniques

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Terms and Definitions - II

Contents:

1. Basic concepts – Основные положения
2. Symbols, and Units – Величины, символы и единицы измерения
3. Optical phenomena – Оптические явления
4. Optical characteristics of surfaces and media – Оптические характеристики поверхностей и сред
5. Components of Radiometric Systems – Компоненты радиометрических систем
6. Characteristics of radiometric system components – Характеристики компонентов радиометрических систем

*) The document can be found at the WGCV web site http://wgcv.ceos.org/documentation/WGCV26_registration_letter.htm

Example

1.3.22. Traceability of measurements – Привязка к эталонам

Term
Traceability of measurements

Definition
Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.

Synonyms

Comments
1. The concept is often expressed by the adjective traceable.
2. The unbroken chain of comparisons is called a traceability chain.

Термин
Привязка к эталонам

Определение
Свойство результата измерений или значения эталона, заключающееся в возможности установления его связи с соответствующими эталонами, обычно международными или национальными, посредством непрерывной цепи сличений, имеющих установленные погрешности.

Синонимы
Прослеживаемость измерений

Примечания
1. Данное понятие часто выражается с применением прилагательного "прослеживаемый".
2. Непрерывная цепь сличений называется цепью привязки к эталонам (цепью передачи размера единицы от эталона).

Terms and Definitions - III

A draft version of Part 2, *Metrological Aspects* has also been developed.

Suggestions:

- Publish Part 1 of the thesaurus as an official GEO document.
- Finish Part 2 (*requires financial support*)

Ensuring traceable and stable instrument radiometric scales

- **In what follows, we will be discussing the absolute radiometric data that must be traceable to SI**

- **What we need to develop:**

1. A full list of specific properties of radiometric data quality with their definitions
2. Requirements for the properties (in cooperation with other GEO committees).
3. Develop proper methodological support (*not discussed here*)
4. Develop suggestions for a proper radiometric standards base

Some properties of absolute radiometric data quality

Property	Comments
Accuracy	Described with the measurement uncertainty
Stability	Characterizes the stability of instrument's responsivity; we also regard stability as a data quality criterion that would allow one to decide the feasibility of using the data over different time intervals

GEOSS Application Areas in accordance with the internationally approved 10-year Implementation Plan

- Reducing loss of life and property from natural and human-induced disasters.
- Understanding environmental factors affecting human health and well-being.
- Improving management of energy resources.
- Understanding, assessing, predicting, mitigating, and adapting to climate variability and change.
- Improving water resource management through better understanding of the water cycle.
- Improving weather information, forecasting, and warning.
- Improving the management and protection of terrestrial, coastal, and marine ecosystems.
- Supporting sustainable agriculture and combating desertification.
- Understanding, monitoring, and conserving biodiversity.

For a number of applications such as climatology, meteorology, and environmental monitoring, assuring the traceability of radiometric measurements obtained by all national systems and at an unusually high accuracy and stability levels is of extreme importance.

Maximum accuracy requirements for observation of object parameters and required accuracy and stability of satellite instruments [1, 2]

Parameter	Required accuracy	Required radiometric accuracy	Required radiometric stability (per decade)
Cloud base height	**0.5 km**	**1 K**	**0.2 K**
Cloud top height	**0.15 km**	**1 K**	**0.2 K**
Cloud top pressure	**15 hPa**	**1 K**	**0,2 K**
Cloud top temperature	**0.5 K**	**0.5 K**	**0.2 K**
Cloud optical thickness	**10 %**	**5 %**	**1 %**
Spectrally resolved thermal radiance	**0.1 K**	**0.1 K**	**0.04 K**
Atmosphere temperature	**0.5 K**	**0.5 K**	**0.04 K**
Water vapor	**5 %**	**1 K**	**0.03 K**
Ozone profile	**3 %**	**1 %**	**0.1 %**
Surface albedo	**0.01**	**5 %**	**1 %**
Normalized differential vegetation index	**1 %**	**≤ 0.5 %**	**0.8 %**
Land surface temperature	**0.3 K**	**0,3 K**	**-**
Snow cover	**2 %**	**5 %**	**10 %**
Sea ice area	**2 %**	**5 %**	**10 %**
Sea surface temperature	**0.1 K**	**0.1 K**	**0.01 K**

In columns 3 and 4:

[%] – requirements for radiance measurements within the spectral bandwidth from 0.2 μ to 3.0 μ
[K] – requirements for radiance temperature measurements within the spectral bandwidth from 3 μ to 25 μ
[1] – WMO requirements
[2] – Satellite Instrument Calibration for Measuring Global Climate Change. NISTIR 7047.

Maximum Requirements

Spectral region, μm	Accuracy	Stability (per decade)
0.2 – 3.0	0.5 %	0.1 %
3.0 - 25	0.1 K	0.01 K

What needs to be done - I

- **The necessary conditions for the implementation of these requirements and for the assurance of traceability of measurements include**
  - High-quality methodological basis (***not discussed here***), and
  - High-quality systems for both ground and in-flight radiometric calibration of the measuring devices.
- **The methodological basis includes such components as**
  - Full definitions of measurands and respective measurement units,
  - Methods and techniques of calibration including transfer of measurement units, and
  - Techniques to estimate the accuracy of measurement results during the calibration process.
- **With regard to the ground calibration systems, we need**
  - To improve our calibration standards as well as methods and devices used to transfer the dimensions of radiometric quantities from standards to the instrument that is being calibrated
  - To have high-quality calibration installations and conduct international comparisons of calibration standards throughout the program.

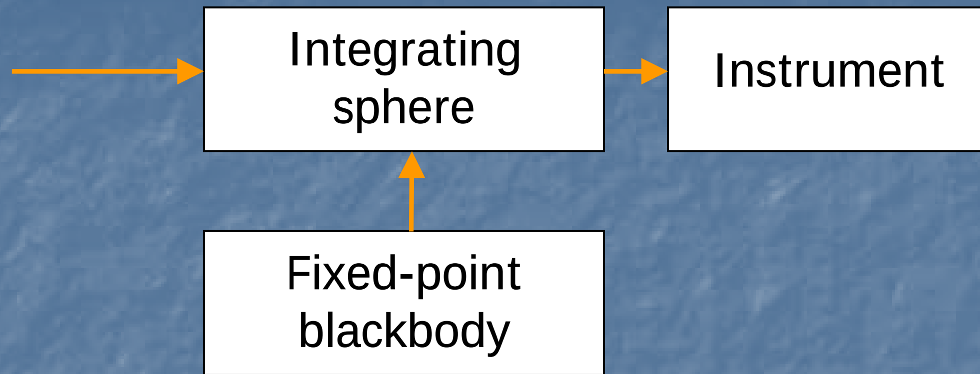
What needs to be done - II

- These efforts should result in traceable, stable and accurate scales of radiometric quantities (requires a mandatory participation of respective national metrological institutions).
- The current level of radiometric standards is good enough for meeting the above-formulated accuracy requirements.
- Yet, it will not be a simple matter to implement this potential for *all* GEOSS national systems so that discrepancies between different radiometric scales in excess of the values given here are quite possible unless proper measures are taken.

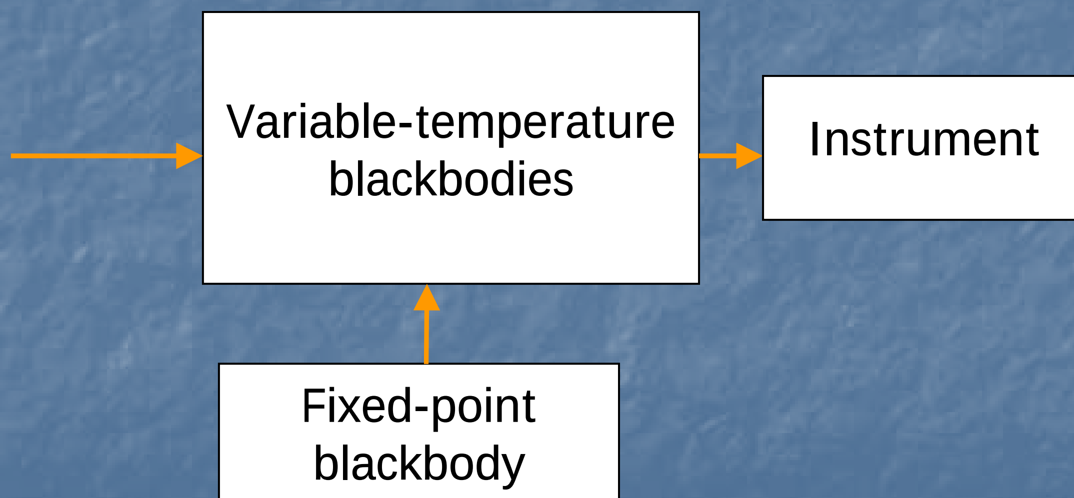
Suggested Solution

- GEOSS calibration installations should include fixed-temperature blackbodies (BB) based upon the phenomenon of phase transition of eutectic alloys or pure metals; such BBs assure a very high reproducibility
  - Within the UV, Vis, and NIR spectral regions, we would need high-temperature BBs built on the basis of eutectic alloys with melting temperatures of 2500K to 3500K
  - Calibration within the thermal IR spectral band will require BBs that use the phenomenon of phase transition of eutectic alloys or pure metals with melting temperatures between 280K and 430K

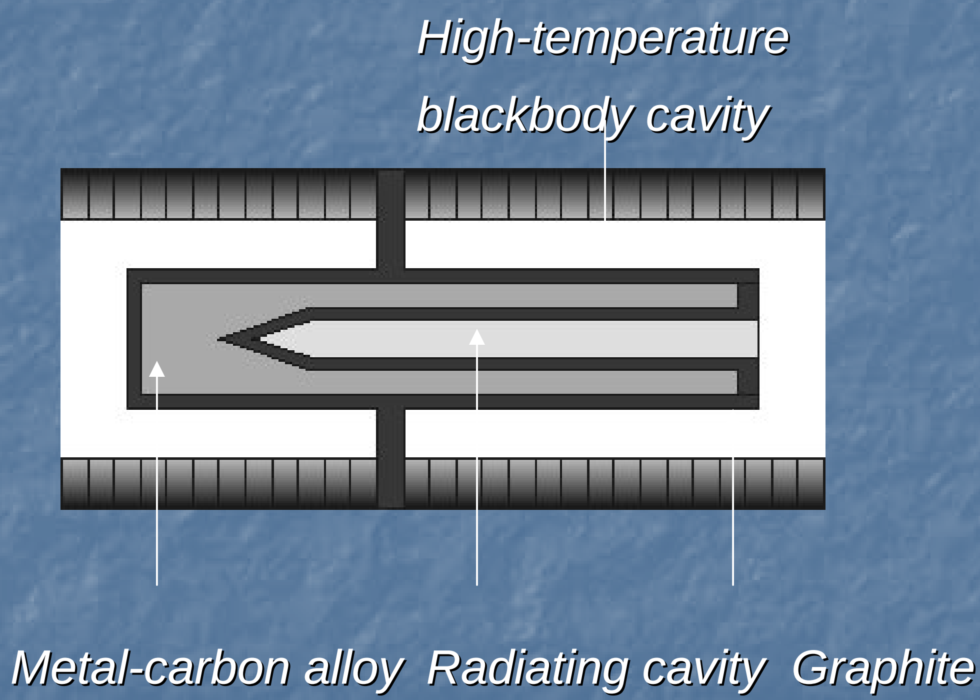
Solution for the 0.2 μm – 3 μm region



Solution for the 3 μm – 25 μm region



Eutectic-alloy phase transition blackbody schematic



Eutectic alloys and pure metals to be used and their phase transition temperatures

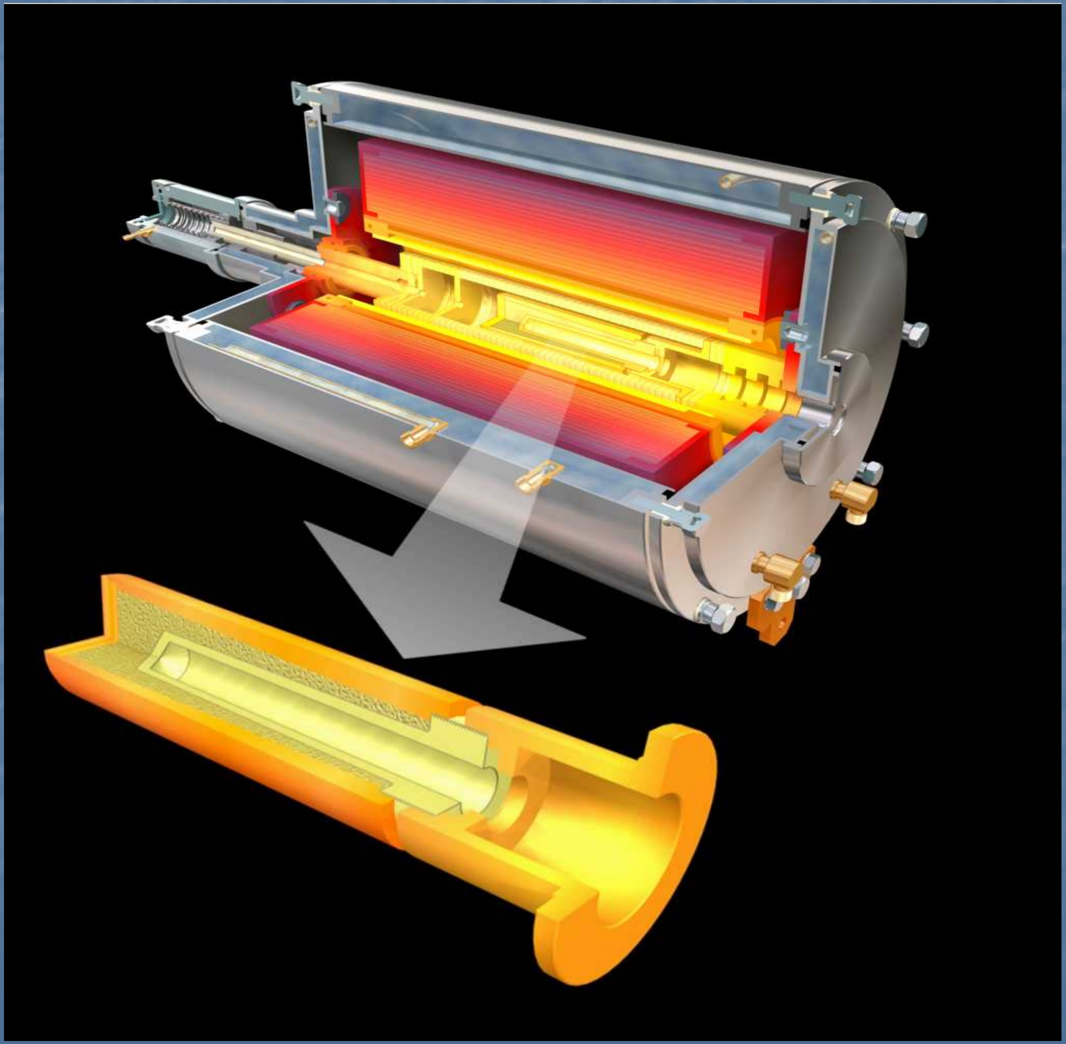
High-temperature		Medium-temperature		Low-temperature	
Substance	Temperature, K	Substance	Temperature, K	Substance	Temperature, K
HfC-C*	3458	Cu	1357.8	In**	429.7485
ZrC-C*	3154	Au	1337.3	Ga**	302.9146
TiC-C*	3034	Ag	1234.9	GaZn***	298.5
Re-C*	2748			GaSn***	293.5
Ir-C*	2563			GaIn***	288.5
WC-C***	3022				

* Available as VNIIOFI's blackbody BB3500

** Available as VNIIOFI's blackbodies BB29gl and BB156in

* * * Under development.

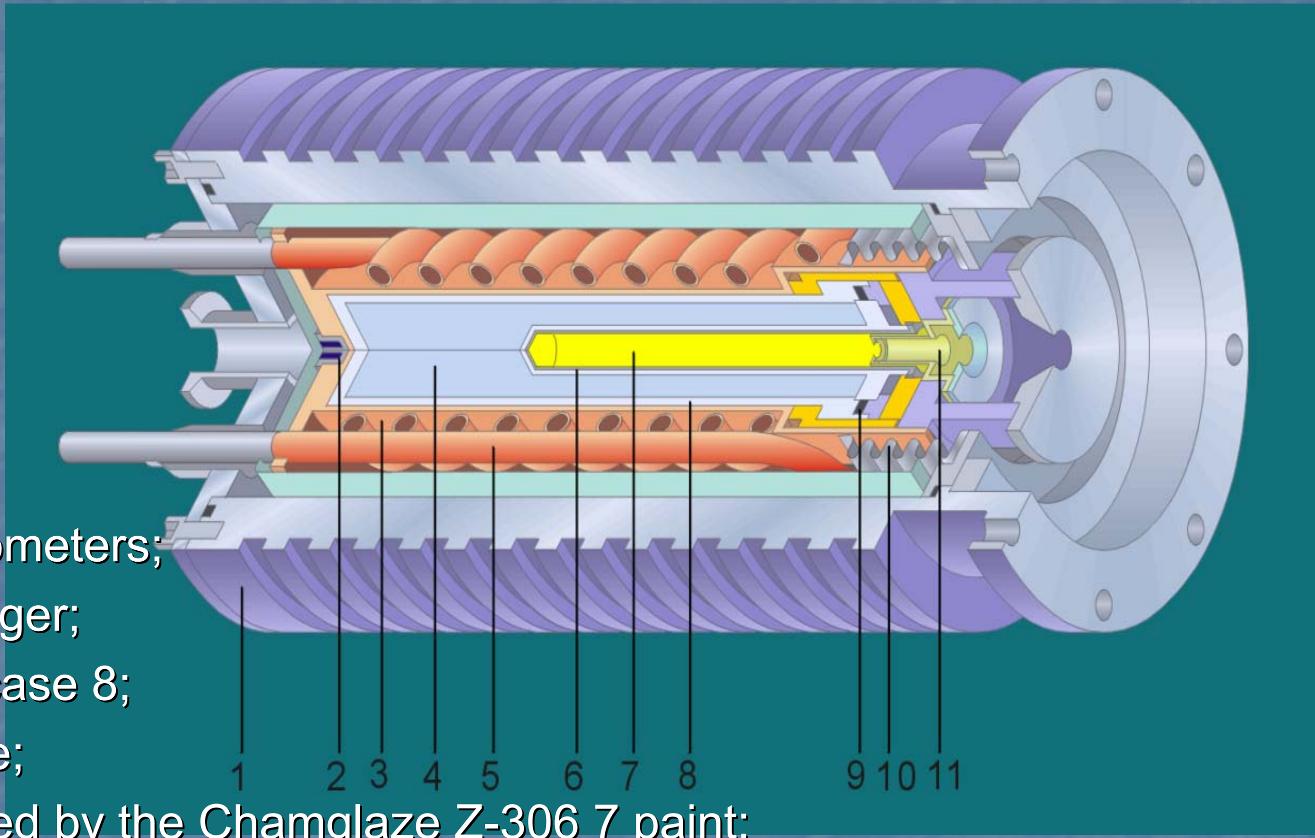
Multi-Purpose High Temperature Blackbody BB3500MP



Summary of measurements of the melting / freezing temperatures of eutectics (VNIIOFI data)

	Metal Purity	Repeatability, σ	
		T, K	Radiance, % 650 nm
Re-C	0.99995	0.04 – 0.09	0.01 – 0.022
TiC-C	0.9998	0.05	0.012
ZrC-C	0.9994	0.09	0.02
HfC-C	0.999	0.30	0.06

Ga fixed-point blackbody BB29gl



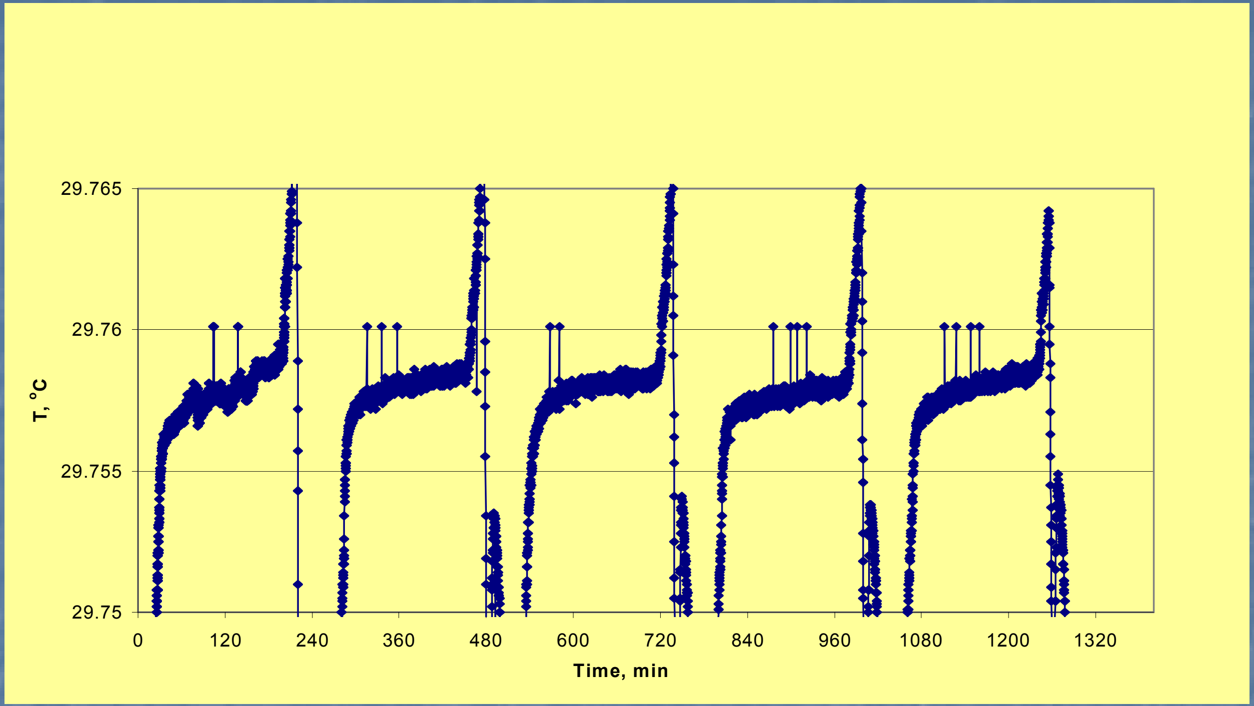
1 - Body;
2 - Pt resistance thermometers;
3 - Copper heat-exchanger;
4 - Gallium in a Teflon case 8;
5 - Heat-exchanger tube;
6 - Copper cavity covered by the Chamglaze Z-306 7 paint;
9 - "O" ring;
10 - Sylphon;
11 - Aperture.

Achieved reproducibility: 0.2 mK

Examples

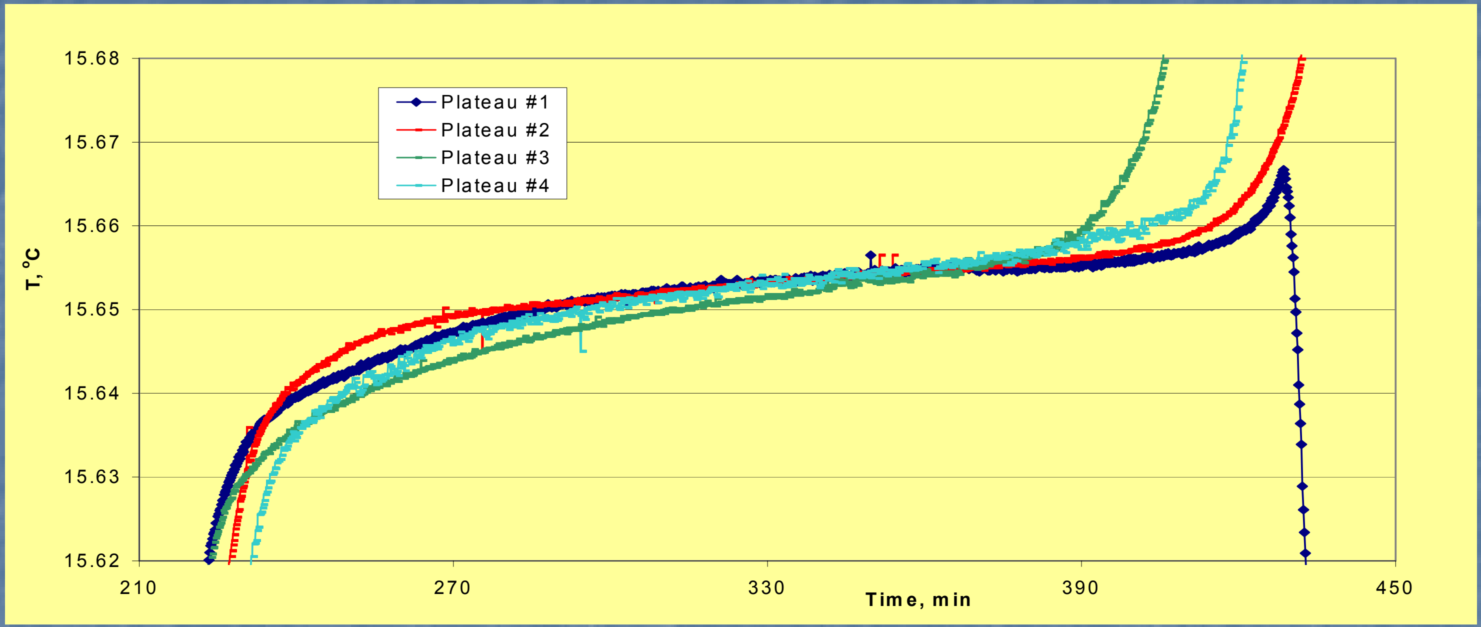
The following examples are based upon results of a study of prospective low-temperature fiducial melting points of pure gallium and its eutectic alloys GaIn, GaSn, and GaZn. The study was conducted in 2006 by VNIIOFI, Vega International and SDL.

A series of Ga melting plateaus



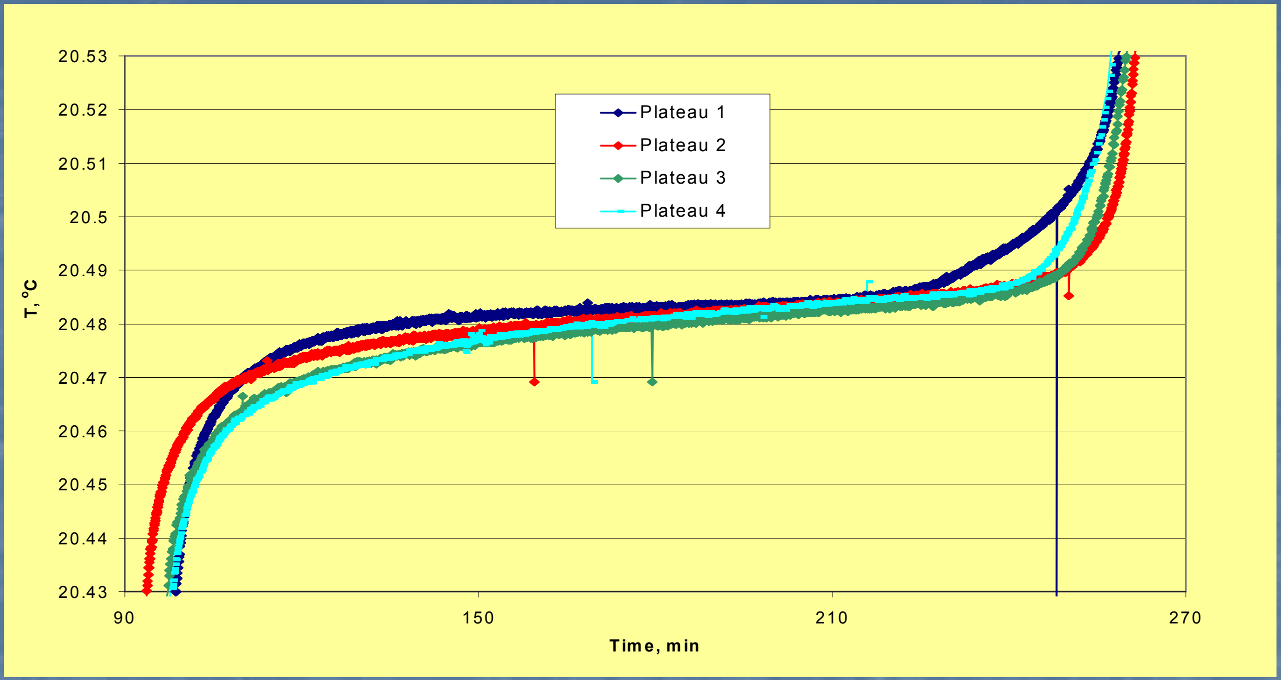
Cell	Repeatability (σ) within individual series	Net repeatability (σ)
Ga	0.5-1 mK	2.6 mK

A series of GaIn-2 melting plateaus (24.4 mass% In)



Cell	Repeatability (σ) in individual series	Net repeatability (σ)
GaIn-1 (~18 mass% In)	1-1.5 mK	2.2 mK
GaIn-2 (24.4 mass% In)	1-2 mK	3.0 mK

A series of GaSn-1 (13.8 mass% Sn) melting plateaus



Cell	Repeatability (σ) in individual series	Net repeatability (σ)
GaSn-1 (13.8 mass% Sn)	0.8-1 mK	2.7 mK
GaSn-2 (20.0 mass% Sn)	1-1.5 mK	2.4 mK

Recommendation

The results of these experiments lead us to believe that assuring traceable radiometric instrument scales within GEOSS is possible through the use of fixed-point blackbodies.

If such blackbodies are included into the GEOSS calibration installations on a regular basis, we will have to expand efforts designed to develop these sources that possess very high repeatability. Their application by all GEOSS participants will allow us to ensure the traceability of radiometric scales within the entire program.

In-flight monitoring

Spectral region 0.2 – 3.0 µm

- Stability - 0.1 %/decade
- **Achievable** through using the moon as a test source (Kiefer et al., 2005)

- **Spectral region 3 – 25 µm**
  - Stability - 0.01 K/decade

Traditional in-flight monitoring techniques cannot track the stability of instruments within the required limits.

Approaches to problem solution

1. Develop and use onboard sources based upon phase transition of substances.

   Studies are required to
   - select suitable substances,
   - determine their properties under the space environment,
   - design onboard sources.

2. Develop a space-borne radiometric calibration facility

Summary - I

The way to achieve the goal of combining individual observation systems into a single Global Earth Observation System of Systems is to solve the above-stated problems through joint efforts of all participants of the program, with a mandatory participation of respective national metrological institutions.

Summary-II

Current status:

- We have a thesaurus on the physical basis of radiometric calibration of optoelectronic instruments
- Metrologically most important properties of radiometric data quality are discussed
- Maximum requirements to the properties are formulated; these requirements can serve as a guideline for determining the profile of the radiometric standard base to be used for calibrations of our instruments

Summary-III

- It is recommended that fixed-point blackbodies based upon the phenomenon of phase transition of eutectic alloys and pure metals be actively studied as a potential solution to the problem of traceability of radiometric data within GEOSS.

Thank you

2007-2009 Work Plan – Outline v2

Five Strategic Elements of GEOSS Implementation

1. Establish the basic arrangements and policies to build the system of systems.

Task No.	Title
AR-07-P1	Interoperability arrangements for GEOSS
AR-07-P2	Interface Implementation for GEOSS
AR-07-P3	Virtual Constellation
AR-06-11	Radio Frequency Protection
DA-06-01	GEOSS Data Sharing Principles
DA-06-02	GEOSS Quality Assurance Strategy

GEO

- **2006 and 2007-2009 WORK PLANS**
  - Architecture and Data Committee
  - Data Management Task
- **DA-06-02: GEOSS Quality Assurance Strategy**
  - **Develop a GEO data quality assurance strategy, beginning with space-based observations and evaluating expansion to in situ observations, taking into account existing work in this area.**
  - **In our case, we are discusasing radiometric data only.**
  - Lead Organizations: CEOS, IEEE
  - Point of Contact – Stephen G. Ungar
  - Expected participants: representatives of 8 nations and 9 international bodies

Major References

1. Global Earth Observation System of Systems GEOSS. 10-Year Implementation Plan. GEO 1000.
2. Global Earth Observation System of Systems GEOSS. 10-Year Implementation Plan Reference Document. GEO 1000R. Implementation Plan Reference Document
3. CIPM Mutual Recognition Arrangement.
4. The International System of Units (SI).
5. On the Importance of SI Traceable Measurements to Monitor Climate Change, CCPR Recommendation.
6. Guide to the Expression of Uncertainty in Measurement, ISO.
7. General requirements for the competence of testing and calibration laboratories, ISO/17025-2000 .
8. Spaceborne Optoelectronic Sensors and their Radiometric Calibration. Terms and Definitions. Part 1. Calibration Techniques. NISTIR 7203.
9. Satellite Instrument Calibration for Measuring Global Climate Change. NISTIR 7047.

Some properties of absolute radiometric data quality

Property	Comments
Accuracy*)	Described with measurement uncertainty
Stability*)	Characterizes the stability of the instrument's responsivity; we also regard stability as a data quality indicator that would allow one to decide the feasibility of using the data over different time intervals

*) most important with respect to the metrological support for the quality of radiometric data