Development and Long-term Maintenance of Consistent Radiometric Scales

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Working Group on Calibration and Validation
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Maximum accuracy requirements for observation of Earth object's parameters and corresponding radiometric 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 0.3 μm to 3.0 μm
[K] – requirements for radiance temperature measurements within the spectral bandwidth from 3 μm to 25 μm
[1] – WMO requirements
[2] – Satellite Instrument Calibration for Measuring Global Climate Change. NISTIR 7047.

Ensuring consistent and stable instrument radiometric scales I

- Metrological support for Earth observation is to be directed at highest requirements to satellite instruments
- The absolutely highest requirements are imposed in Thermal IR range – e. g. measuring SST with accuracy 0.1 K during decades for the purpose of monitoring long-term temperature trends
- To meet such a demand consistency of instrument radiometric scales, once established on Earth, must be periodically verified on orbit
- Proceeding from accuracy 0.1 K - the long-term stability of instrument radiometric scales on orbit must be at the level of the order of 0.01 K/decade in IR range

Ensuring consistent and stable instrument radiometric scales II

Accuracy and stability of satellite instruments in spectral range 0.3 – 25 μm required for precision monitoring global climate change

Spectral range, μm	Accuracy	Stability (per decade)
0.3 – 3.0	0.5 %	0.1 %
3.0 - 25	0.1 K	0.01 K

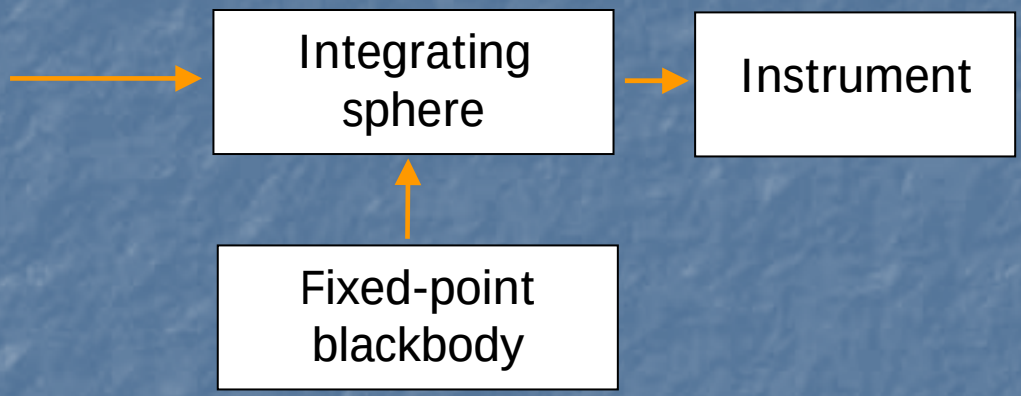
Satellite Instrument Calibration for Measuring Global Climate Change. NISTIR 7047.

To succeed, calibration of radiometric instruments based upon the phase transition of eutectic alloys and pure metals is suggested:

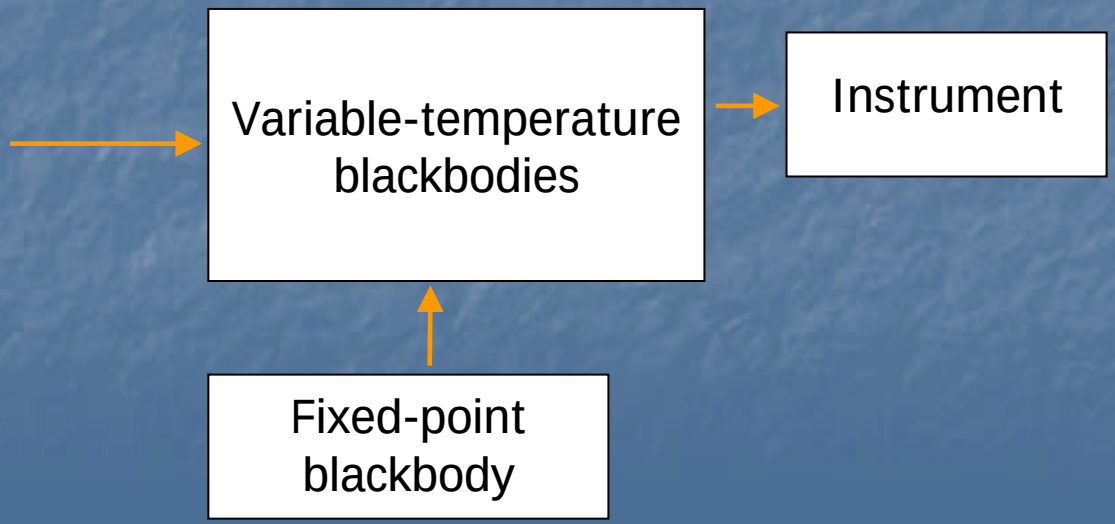
- within spectral range 0.3 – 3.0 μm in ground calibration ONLY
- within spectral range 3.0 – 25 μm in BOTH ground calibration and in-flight radiometric testing systems

Ground calibration

Solution for the 0.3 μm – 3 μm range



Solution for the 3 μm – 25 μm range



In-flight testing I

- **Spectral range 0.3 – 3.0 μm**
  - Required stability - 0.1 %/decade

  Most probable solution:
  - Durectly using the moon as a test source
- **Spectral range 3 - 25 μm**
  - Required stability - 0.01 K/decade

  Most probable solution is to be realized in three steps:
  - Developing spacecraft fixed-point CELLS and controlling devices for testing thermal sensors on orbit
  - Developing standard spacecraft RADIATION SOURCES based on phase-transition fixed points
  - Developing spacecraft radiometric TESTING SYSTEMS based on standard fixed-point radiation sources

In-flight testing II

Small-size fixed points for developing standard spacecraft radiation sources in the Thermal IR wavelength range has been selected and studied.

Results of the studies are published in

***Metrologia* 45 (2008) pp. 75 – 82**

Melting Points of Gallium and of Binary Eutectics with Gallium Realized in Small Cells

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In-flight testing III

A paper reporting results of more detailed studying gallium based eutectics is prepared for publication in

Journal of Thermophysics
(Proceedings of Tempmeko 2007)

Development of Gallium and Gallium-based Small-Size Eutectic Melting Fixed Points for Calibration Procedures on Autonomous Platforms

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In-flight testing IV

Already investigated Ga-based eutectics and pure Ga (In small-size cells)

and additionally proposed eutectics for future studies

Substances	Melting temperature (approximate), K	Repeatability (1δ), K
Ga-In-Sn	283.7	
Ga-In	288.81	~ 0.0025
Ga-Sn	293.63	~ 0.0025
Ga-Zn	298.34	~ 0.008
Ga	302.92	~ 0.0020
In-Bi	345.5	

- Ga-based and (or) two or three eutectic-based fixed points are to be finally selected to develop calibration scale for thermal sensors in the range ~280-350 K
- Temperature interval between these fixed points should preferably be as wide as possible

In-flight testing V

Russian Space Agency included the space experiment «Studying the effects of micro-gravity upon the melting/freezing phase transitions of eutectic alloys»

into the long-term scientific program on board ISS (Russian segment, 2009 - 2011)

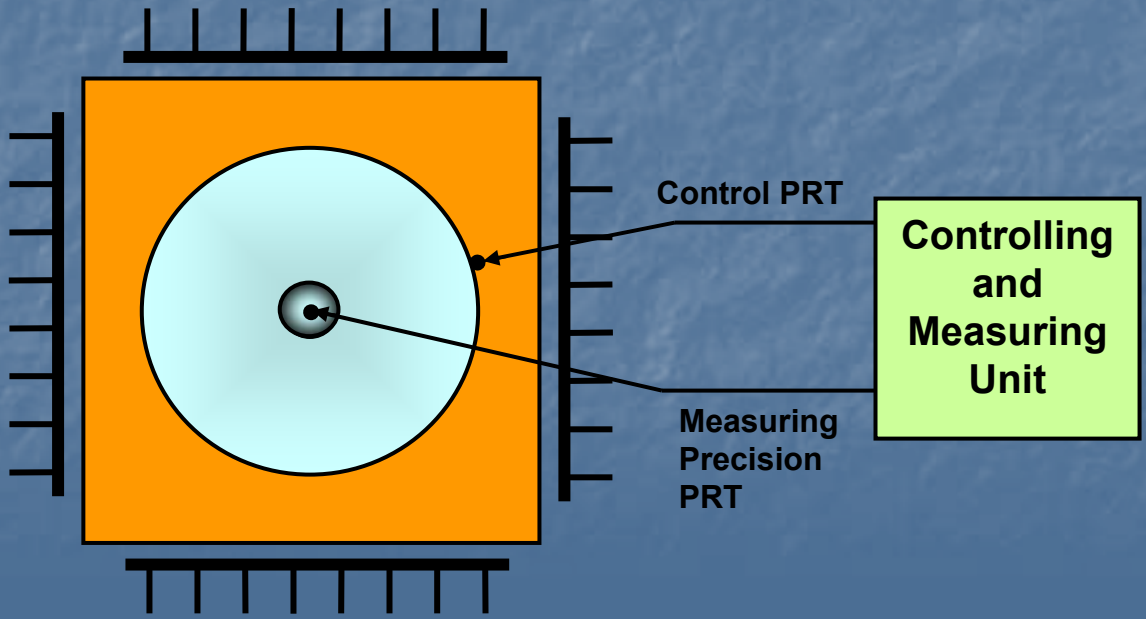
- **Immediate goal of the space experiment – developing fixed-point cells and procedures for testing thermal sensors on orbit**
- **Final goal – developing spacecraft radiometric testing systems based on standard fixed-point radiation sources for the purpose of monitoring long-term climatic trends**

Principal participants:
VNIIOFI – Russian Agency on Technical Regulation
TSNIIMASH, RKK «ENERGIYA» - Russian Space Agency

Device for the space experiment (schematic design)

Evolution from ground to on-orbit conditions:

- Transfer from fluid thermostat to dry calibration device with thermo-electric heating/cooling elements
- Transfer from serial high-precision measuring instruments to home-grown (VNIIOFI) equipment meeting tough requirements for the spacecraft apparatus



Conclusion

- Developing standard radiation sources referenced to phase-transition fixed points for calibration of Earth observation IR sensors started as international project.
The final goal of the project – ensuring metrological support for long-term monitoring thermal radiation data trends to draw reliable deductions on global climate change.
- For the purpose a number of eutectic fixed points in the temperature range ~ 280 - 310K was selected and studied under ground conditions.
- At the moment space experiment directed at studying phase transition in selected (Ga-based) eutectics under microgravity conditions onboard ISS is on the way.

- We think it is the right time to again join efforts of international institutions.