Development of the Chinese Space-Based Radiometric Benchmark(CSRB) Mission LIBRA

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Abstract

Abstract: Climate observations and their applications require measurements with high stability and low uncertainty in order to detect and assess climate variability and trends. The difficulty with space-based observations is that it is generally not possible to trace them to standard calibration references when in orbit. In order to overcome this problem, it has been proposed to deploy space-based radiometric reference systems which intercalibrate measurements from multiple satellite platforms. Such reference systems have been strongly recommended by international expert teams. This paper describes the Chinese Space-based Radiometric Benchmark (CSRB) project which has been under development since 2014. The goal of CSRB is to launch a reference-type satellite named LIBRA in around 2025. We present the roadmap for CSRB as well as requirements and specifications for LIBRA. Key technologies of the system include miniature phase-change cells providing fixed-temperature points, a cryogenic absolute radiometer, and a spontaneous parametric down-conversion detector. LIBRA will offer measurements with SI traceability for the outgoing radiation from the Earth and the incoming radiation from the Sun with high spectral resolution. The system will be realized with four payloads, i.e., the Infrared Spectrometer (IRS), the Earth-Moon Imaging Spectrometer (EMIS), the Total Solar Irradiance (TSI), and the Solar spectral Irradiance Traceable to Quantum benchmark (SITQ). An on-orbit mode for radiometric calibration traceability and a balloon-based demonstration system for LIBRA are introduced as well in the last part of this paper. As a complementary project to the Climate Absolute Radiance and Refractivity Observatory (CLARREO) and the Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS), LIBRA is expected to join the Earth observation satellite constellation and intends to contribute to space-based climate studies via publicly available data.

1. Introduction

Without accurate, high quality observations on relevant time and space scales, climate science applications and services will be limited. To anchor satellite-based climate observation, several reference-type missions against an absolute standard are being considered by several space agencies. The Traceable Radiometry Underpinning Terrestrial- and Helio-Studies (TRUTHS) has been accepted by the ESA (European Space Agency) as a climate mission with an unprecedented SI-traceable accuracy. The Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission has been underway by the National Aeronautics and Space Administration (NASA) since the mid-2000s.

In the recent Vision 2040 document of the WMO Integrated Observing System (WIGOS), it is presumed that operational meteorological satellite systems will remain the key elements of a space-based climate observing system capable of unambiguously monitoring indicators of changes in the Earth's climate. Satellite agencies are therefore encouraged to develop new satellite instruments with climate applications in mind. The proposed reference systems would go a long way in that direction. This will also enable the production of much improved Essential Climate Variables (ECVs) in accordance with established key requirements for climate monitoring

Realizing the importance of reference-type missions for improving climate science and for harmonizing global satellite observations, an expert team on Earth observation and navigation of Ministry of Science and Technology of China (MOST) proposed the concept of the Chinese Space-based Radiometric Benchmark (CSRB) in 2006. The CSRB project was approved and initially funded by MOST in 2014. To date, Phase A of the CSRB project, completed in 2018, resolved the fundament problems of building the SI-traceable calibrator for the thermal infrared band and reflected solar band. The ultimate goal of the CSRB project is to build a flight model of the Chinese radiometric benchmark satellite, named 'LIBRA', for launch during 2022–2025.

2.CSRB Project Roadamap in China

CSRB concept was proposed by an expert team on Earth observation and navigation of the Ministry of Science and Technology in 2006. The project has three phases: Phase A, extended from 2014 to 2018, with the goal to develop the SI-traceable calibrator for the thermal infrared band (IR) and the reflective solar band (RSB). Phase B, from 2018 to 2022, has the objective to develop an engineering model of the reference instruments. During Phase C, from 2022 to 2025, a flight model ready for launch will be developed. The roadmap of the CSRB project is shown in Figure 1.

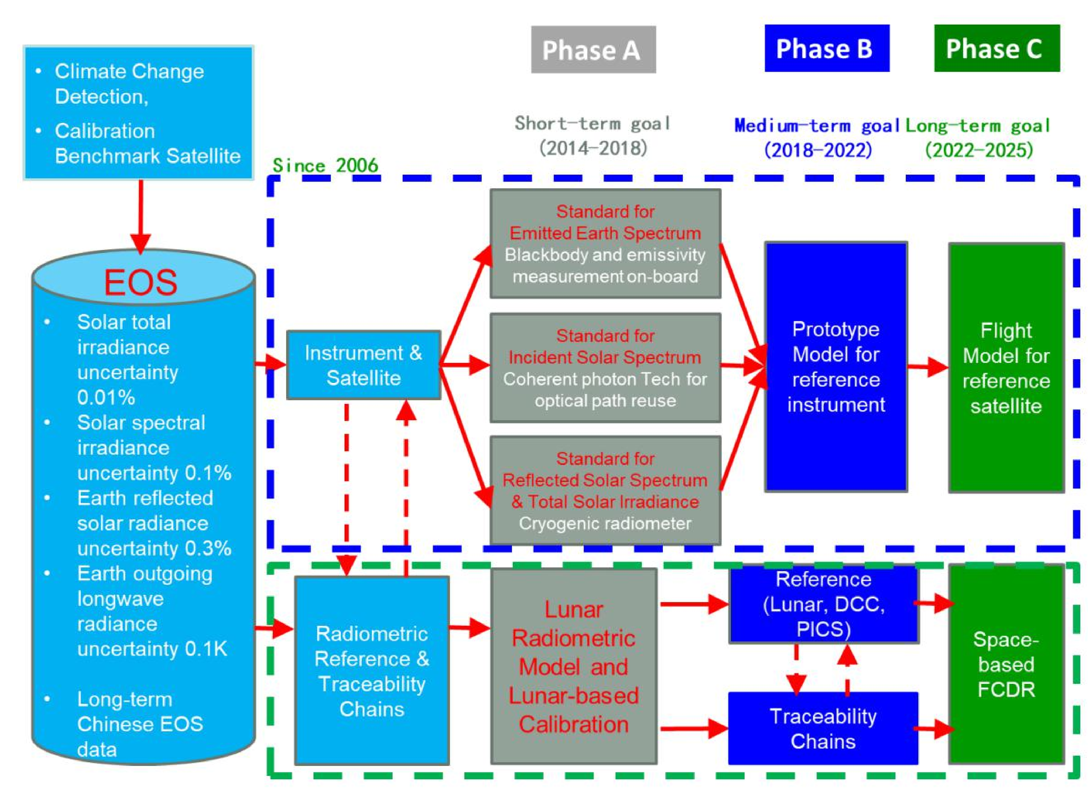

Figure1. The roadmap of the Chinese Space-based Radiometric Benchmark (CSRB) project. EOS is the acronym for Earth Observation System, DCC for Deep Convective Cloud, PICS for Pseudo Invariant Calibration Sites, and FCDR for Fundamental Climate Data Record.

3. Prototype Model of LIBRA

The LIBRA mission consists of one satellite carrying four payloads: an Infrared Spectrometer (IRS) with hyperspectral resolution, an Earth-Moon Imaging Spectrometer (EMIS) measuring in reflected solar radiation, a Total Solar Irradiance (TSI) instrument, and a Solar spectral Irradiance monitoring instrument Traceable to Quantum benchmark (SITQ). A GPS/Beidou Globle Navigation Satellite System Radio Occultation (GPS/BD GNSS RO) will be an optional instrument depending on the spacecraft bus capability. The detailed payload specifications of the LIBRA prototype model and the key technologies used are listed in Table 1.

As space-based climate and calibration observatories, the proposed CLARREO and TRUTHS missions have important potential contributions to make both directly through well-calibrated measurements and indirectly through facilitating intercalibration of the data from other platforms. By using advanced technologies, such as phase-change points, a cryogenic absolute radiometer, and spontaneous parametric down-conversion (SPDC), LIBRA will provide measurements with SI traceability for both the IR and the reflected solar components. The main characteristics of LIBRA, CLARREO, and TRUTHS are summarized in Table 2.

Table 1. Detailed payloads specifications of the LIBRA prototype model.

Instrument Name	Payload Requirements	Key Technology
IRS	Spectral range: 600–2700 cm^{-1} Spectral resolution: 0.5 cm^{-1} IFOV: 24 mrad Sensitivity: 0.1 K@270 K Emissivity of BB:≤0.999 Measurement uncertainty: 0.15 K (k = 2)	Miniature fixed-temperature phase-change cells
EMIS	Spectral range: 380–2350 nm, Spectral resolution: 10 nm, Spectral precision: 0.5 nm, Spatial resolution: 100 m, Coverage: 50 km, Measurement uncertainty: 1% (k = 2)	Space Cryogenic Absolute Radiometer
TSI	Spectral range: 0.2–35 um, Measurement uncertainty: 0.05% (k = 2) Long-term stability:0.005%	Space Cryogenic Absolute Radiometer
SITQ	Spectral range: 380–2500 nm, Spectral resolution: 3 nm (380–1000 nm), 8 nm (1000–2500 nm) Spectral precision: 0.1–0.3 nm, Self-calibration uncertainty: 0.2%, Measurement uncertainty: 0.35% (k = 2)	Spontaneous Parametric Down-Conversion

Table 2. Comparison among radiometric benchmark satellite.

Satellite	Libra				Clarreo		Truths		
Instrument Type *	IR	RS	TS	SS	IR	RS	RS	TS	SS
Spectral Coverage	600–2700 cm^{-1}	380–2350 nm	0.2–35 um	380–2500 nm	200–2000 cm^{-1}	320–2300 nm	380–2300 nm	0.2–35 um	320–2450 nm
Spectral Resolution	0.5 cm^{-1}	10 nm	–	3~8 nm	0.5 cm^{-1}	8 nm	5~10 nm	–	1~10 nm
Measurement Uncertainty	0.15 K (k = 2)	1% (k = 2)	0.05% (k = 2)	0.35% (k = 2)	0.065 K (k = 2)	0.3% (k = 2)	0.1% (k = 2)	0.02% (k = 2)	0.2% (k = 2)
SI-traceability	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* In the line 'Instrument type', IR represents the instrument to measure the spectrally resolved infrared radiance, RS represents the instrument to measure the spectrally resolved reflectance of solar radiation, TS represents the instrument to measure the total solar irradiance, and SS represents the instrument to measure the spectrally resolved solar irradiance.

4. Instrument Design and Key Technologies

The LIBRA will provide a calibrated reflected solar spectrum and total solar irradiance based on the Space Cryogenic Absolute Radiometer (SCAR), instead of a solar diffuser, standard lamps, vicarious calibration methods, and ground-based calibration techniques.

The TSI calibration on the satellite is designed to improve the long-term stability of TSI measurements, as shown in Figure 2. The SCAR is also the benchmark of TSI calibration onboard the satellite.

The SCAR is also the benchmark of TSI calibration onboard the satellite. The SCAR and TSI are installed on the precision Sun tracker. Traceability chain of the IRS is shown in Figure 3. Three on-orbit absolute radiance IR calibrators realize on-orbit self-calibration of the cavity blackbody. An on-orbit temperature scale from 270 to 350 K is established using ITS-90 miniature phase-change cells traceable to ITS-90 with an uncertainty of better than 10 mK (k = 2).

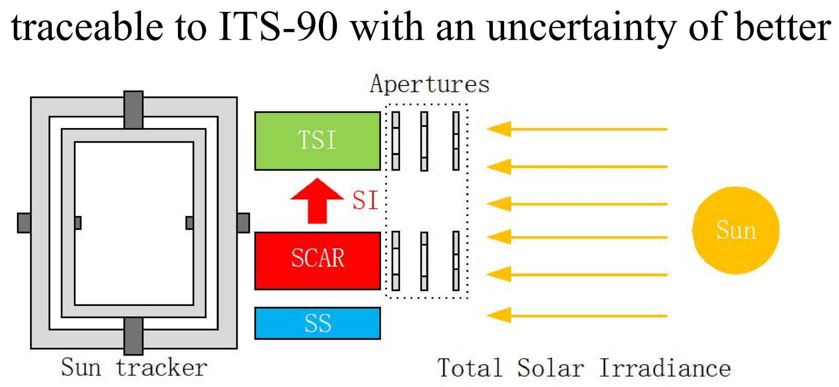

Figure 2. Schematic diagram of Total Solar Irradiance (TSI) calibration on satellite

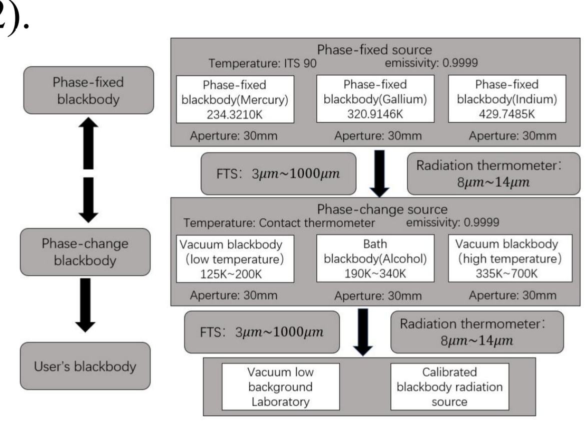

Figure 3. Traceability chain of the Infrared Spectrometer (IRS)

5. Conclusions

As a complementary project to CLARREO and TRUTHS, LIBRA is expected to join an Earth observing satellite constellation and intends to contribute to space-based climate studies via publicly available data. Intercalibration of data from space-based observations falls under the auspices of the international CEOS Working Group on Calibration and Validation (WGCV) and GSICS. Therefore, intensive cooperation with the WGCV and GSICS is highly recommended during instrument development and data utilization of the LIBRA project.