INSPIRE: From Teaching Tools to Sun and Earth Observation Satellites

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1 – Abstract

The International Satellite Program in Research and Education (INSPIRE) is a global consortium of space Universities formed to advance space science and engineering. Each INSPIRE small satellite typically proceeds from concept to flight in three years, providing the opportunity for undergraduate and graduate student involvement in small satellite design, implementation, testing, and operations. INSPIRE brings science, engineering, and management to campuses across the globe. The INSPIRE program aims to provide a constellation of Earth and space weather observing satellites. To date, 8 satellites are part of this program. The main objective of this poster is to present the various space missions, emphasizing those tasked with monitoring the Earth and the Sun, particularly focusing on the observation of Essential Climate Variables (ECVs) – Hansen et al., 2011.

2 – Introduction

The INSPIRE program is a collaborative effort involving several institutions worldwide, including the **University of Colorado at Boulder** (USA), the **Indian Institute of Space Science and Technology, Nanyang Technological University** (Singapore), the **National Central University** (Academy of Sciences in Taipei), and the **University of Versailles Saint-Quentin-en-Yvelines** (France). It also includes the **University of Alberta** (Canada), **Sultan Qaboos University** at Muscat (Oman), **Kyushu Institute of Technology** (Japan), and the **Research Centre Jülich and Wuppertal University** (Germany). Within the INSPIRE program, each small satellite, as shown in Figure 1, is designed to tackle crucial challenges that contribute to our knowledge of ionosphere dynamics and plasma transport (Inspire-Sat 1, Inspire-Sat 2, Inspire-Sat 4, Inspire-Sat 6), investigate auroral magnetic fields and thermospheric gravity waves (Inspire-Sat 3), and monitor ECVs (**Inspire-Sat 5 primarily known as Uvsq-Sat, Inspire-Sat 7, Inspire-Sat X primarily known as Uvsq-Sat NG**). The aim of this poster is to highlight the three satellites operating under the French flag (Figure 2), dedicated to measuring the components of the Earth's radiation budget (ERB) and observing greenhouse gases (GHGs). Table 1 provides the scientific requirements for the different missions (Uvsq-Sat, Inspire-Sat 7, Uvsq-Sat NG, Terra-F constellation) developed by LATMOS.

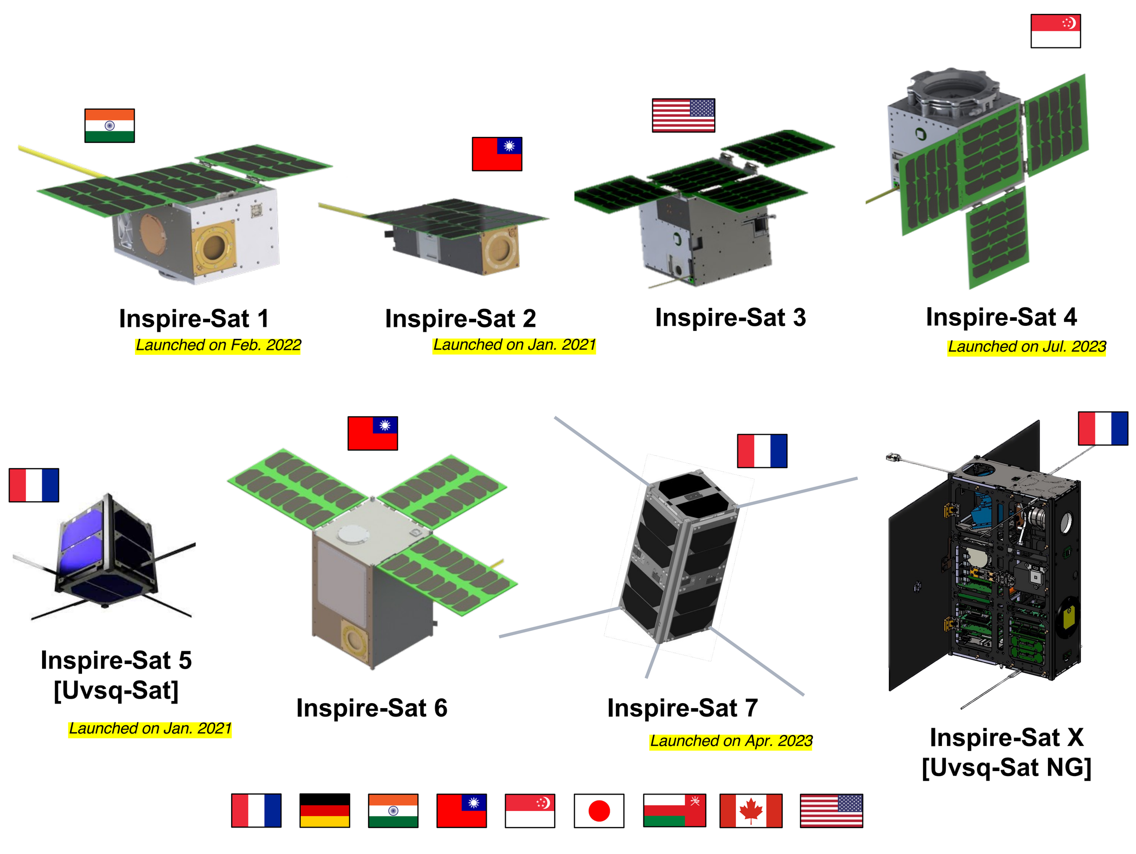

Figure 1. The 8 satellites of the international INSPIRE constellation.

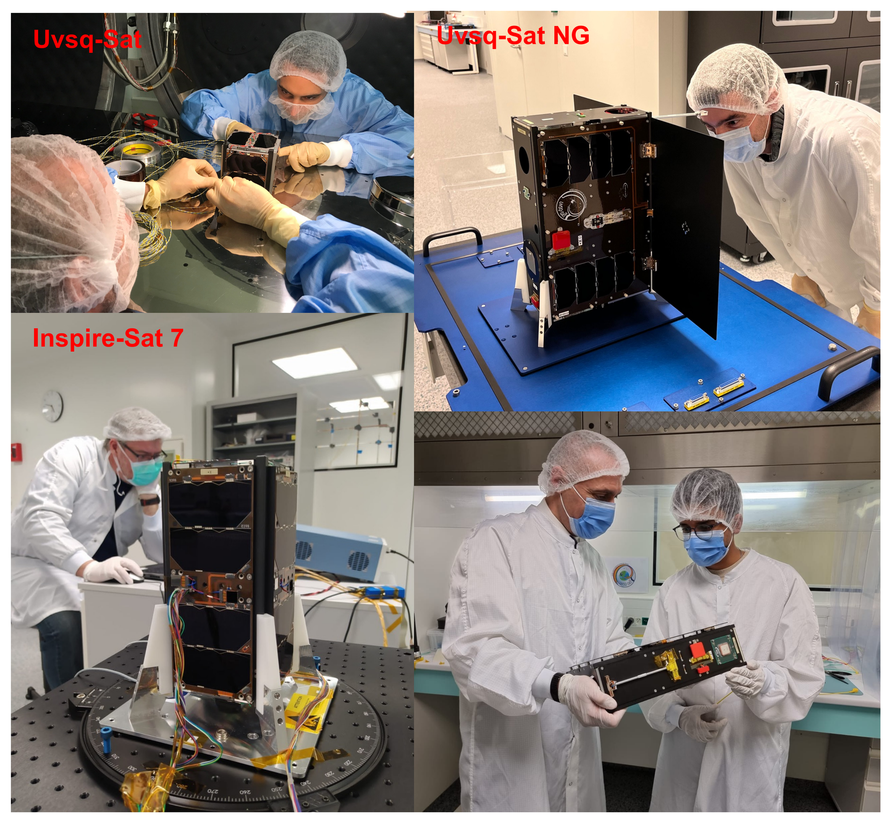

Figure 2. Presentation of the 3 LATMOS satellites during AIT phases.

Requirements for Uvsq-Sat—Launched on 24 January 2021 from Cape Canaveral, Florida, USA				
ECV	Absolute accuracy	Stability per year	Spatial resolution	Temporal resolution (global map)
OSR	±10.00 Wm^{-2}	±5.00 Wm^{-2}	2500 km per element	30 days with one CubeSat
OLR	±10.00 Wm^{-2}	±1.00 Wm^{-2}	2500 km per element	30 days with one CubeSat
Requirements for Inspire-Sat 7—Launched on 15 April 2023 from Vandenberg, California, USA				
ECV	Absolute accuracy	Stability per year	Spatial resolution	Temporal resolution (global map)
OSR	±5.00 Wm^{-2}	±1.00 Wm^{-2}	2500 km per element	10 days with two CubeSats
OLR	±5.00 Wm^{-2}	±1.00 Wm^{-2}	2500 km per element	10 days with two CubeSats
Requirements for Uvsq-Sat NG—Launch Date in 2025 or in 2026				
ECV	Absolute accuracy	Stability per year	Spatial resolution	Temporal resolution (global map)
OSR	±3.00 Wm^{-2}	±1.00 Wm^{-2}	2500 km per element	5 days with three CubeSats
OLR	±3.00 Wm^{-2}	±1.00 Wm^{-2}	2500 km per element	5 days with three CubeSats
CO_2	±4.0 ppm	±1.0 ppm	2–10 km per pixel	>30 days
CH_4	±25.0 ppb	±10.0 ppb	2–10 km per pixel	>30 days
Requirements for a Hypothetical Satellite Constellation Named Terra-F—Horizon 2035				
ECV	Absolute accuracy	Stability per decade	Spatial resolution	Revisit time
TSI	±0.54 Wm^{-2}	±0.14 Wm^{-2}	–	24 h
OSR	±1.00 Wm^{-2}	±0.10 Wm^{-2}	10–100 km per pixel	3 h
OLR	±1.00 Wm^{-2}	±0.10 Wm^{-2}	10–100 km per pixel	3 h
EEI	±1.00 Wm^{-2}	±0.10 Wm^{-2}	–	24 h
CO_2	±1.0 ppm	±1.5 ppm	1–5 km per pixel	3 h
CH_4	±10.0 ppb	±7.0 ppb	1–5 km per pixel	3 h

Table 1. Scientific requirements.

3 – Inspire-Sat's observations in orbit

Launched into orbit in January 2021 (at an altitude of 534 km with a Local Time of Ascending Node (LTAN) of 21H34), Uvsq-Sat (a CubeSat weighing around 2 kg) has been operational since February 2021. It conducts various observations (Figure 3), including Total Solar Irradiance (TSI), Incident Solar Irradiance (ISR) and Outgoing Shortwave Radiation (OSR) as well as Outgoing Longwave Radiation (OLR), all aimed at determining the Earth's Energy Imbalance (EEI). In April 2023, Inspire-Sat 7 (Meftah et al., 2022) joined Uvsq-Sat (Meftah et al., 2020) in orbit (Figure 4) at an altitude of 510 km and a LTAN of 10H44, together establishing the inaugural CubeSat constellation focused on monitoring ECVs. Figures 5, 6, 7, and 8 show results obtained from observations of these two satellites. It seems that OSR decreases during the three years of observations. Some factors that might contribute to a reduction in OSR are increased absorption by atmospheric gases, decreased surface albedo, changes in cloud cover and type, and land use changes.

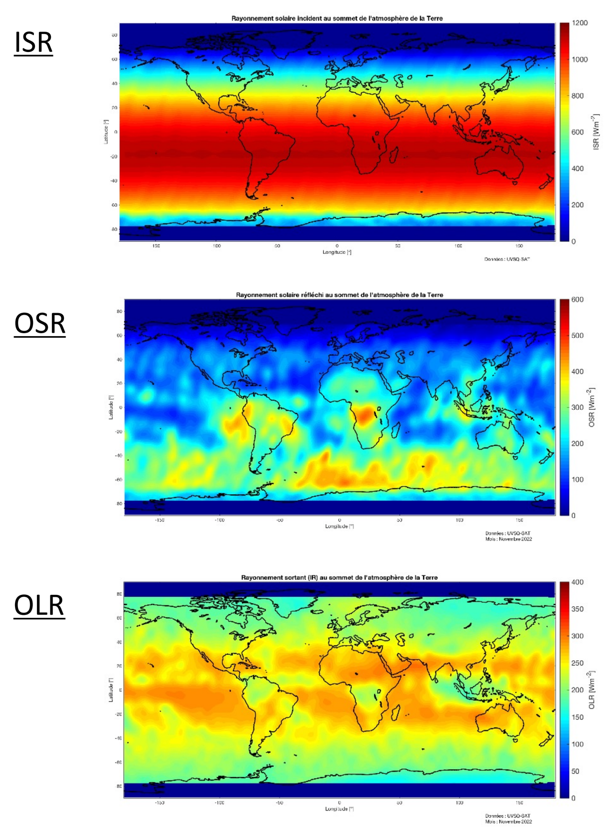

Figure 3. Uvsq-Sat observations in 2022.

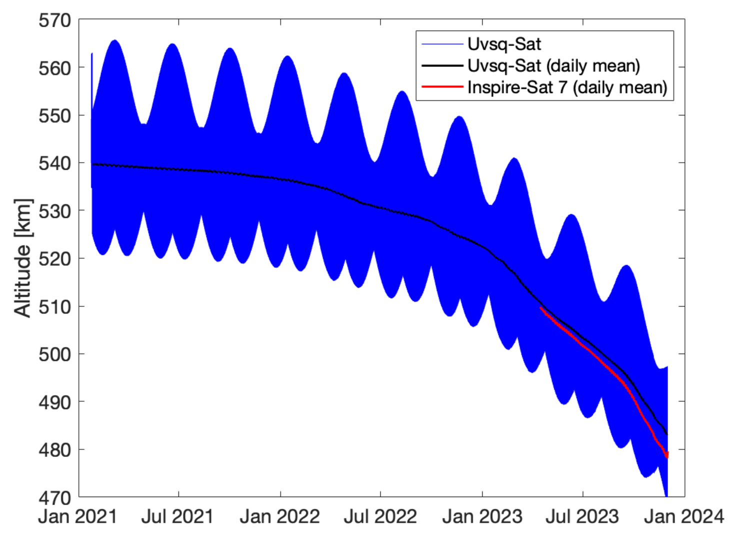

Figure 4. Altitude of the satellites since their launch into orbit.

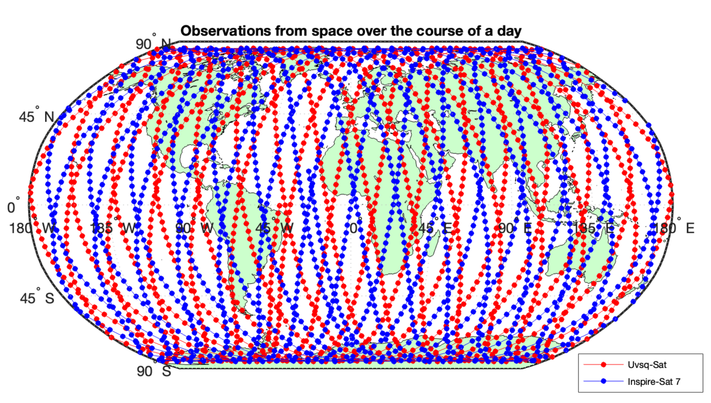

Figure 5. Location of the observations made by the two satellites at the top of the atmosphere.

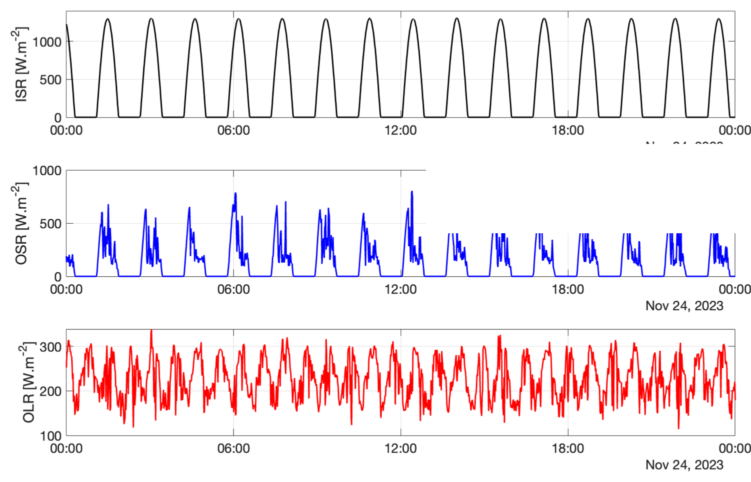

Figure 6. Time series of observations made by Inspire-Sat 7 in November 2023.

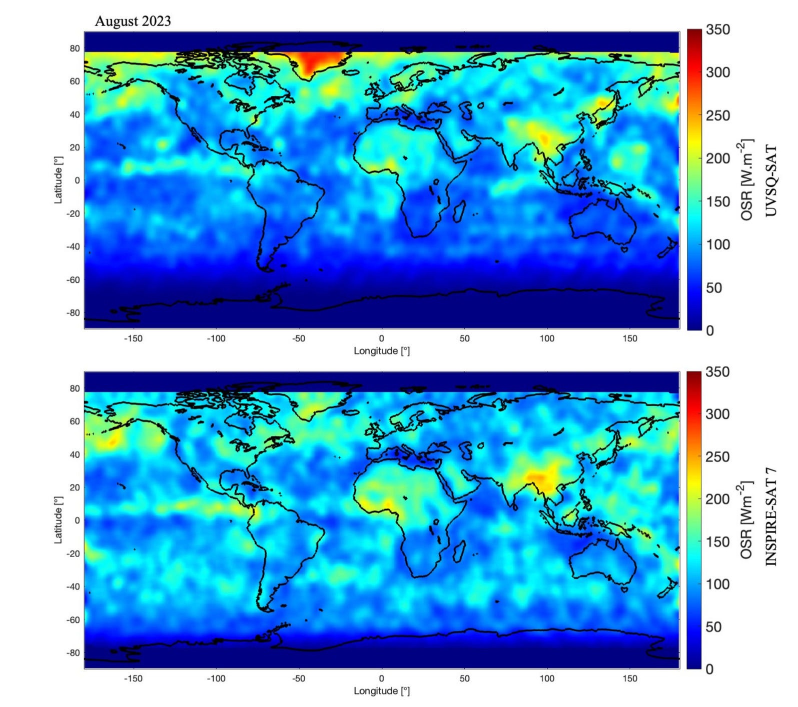

Figure 7. OSR observations in August 2023.

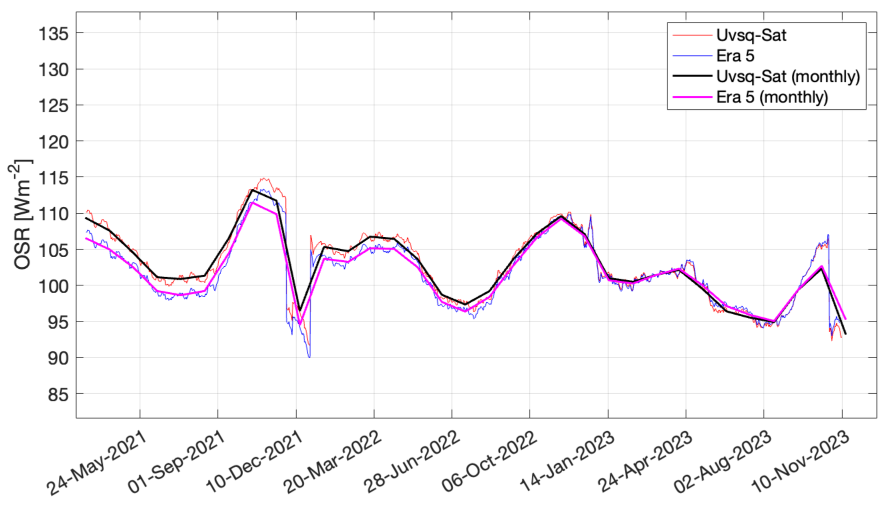

Figure 8. Monthly time series of the TOA outgoing shortwave radiation of ERA5 model with UVSQ-SAT data time acquisition, and UVSQ-SAT (data in orbit) since 2021.

4 – Uvsq-Sat NG development

Uvsq-Sat NG (Figures 2 and 9), also known as Inspire-Sat X (Meftah et al., 2023), aims to ensure the seamless continuation of ERB measurements, building upon the groundwork laid by the Uvsq-Sat and Inspire-Sat 7 satellites. One of its primary objectives is to conduct broadband ERB measurements, leveraging state-of-the-art yet user-friendly technologies. Furthermore, the Uvsq-Sat NG mission seeks to conduct precise and comprehensive monitoring of global atmospheric gas concentrations (Figure 10) with its miniaturized spectrometer, focusing on CO_2 and CH_4, and examining their correlation with Earth's OLR.

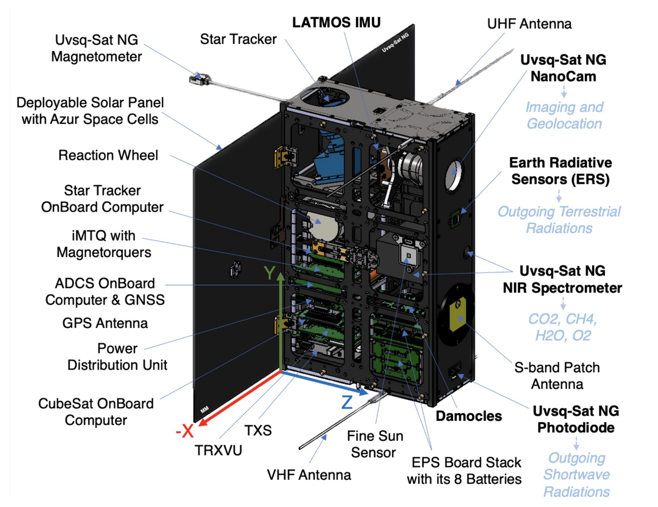

Figure 9. Computer-aided design of the Uvsq-Sat NG CubeSat.

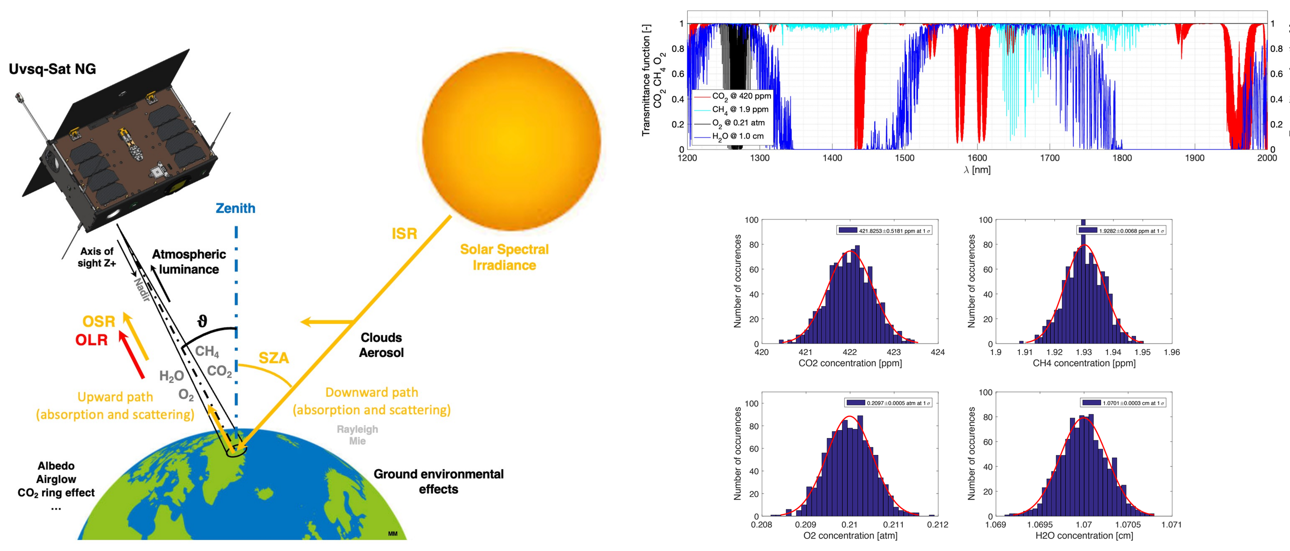

Figure 10. Observation approach of the Uvsq-Sat NG satellite.

5 – Conclusions

Uvsq-Sat, the first French CubeSat to measure key ECVs such as Outgoing Shortwave Radiation and Outgoing Longwave Radiation, was successfully launched in 2021. Since February 2021, it has been consistently conducting Earth Radiation Budget measurements. In 2023, it was joined in orbit by Inspire-Sat 7, which observes these variables at a different local time. In 2025, Uvsq-Sat NG aims to ensure the seamless continuation of ERB measurements, building upon the groundwork laid by the Uvsq-Sat and Inspire-Sat satellites. The use of a constellation of small satellites is gaining traction for observing climate change, offering broader and more continuous spatial and temporal coverage of the Earth compared to a single large satellite. This approach enables real-time observations, revisiting each point on the globe hourly, and provides coverage for remote areas, like the polar regions, which are difficult to monitor from the ground. This enhanced observation capability is vital for more effective monitoring of climate variations.

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