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# LEVERAGING SPACE INFORMATION-SHARING ECOSYSTEMS FOR MARKETPLACE-LIKE CLIMATE ACTION AND SUSTAINABLE DEVELOPMENT

## Abstract

This paper proposes space information-sharing ecosystems as a "Marketplace" for climate action and sustainable development. It underscores the critical role of international collaboration in harnessing space-based data for climate change characterization. It emphasizes the necessity of a united global effort, underpinned by integrated space architecture and space policy frameworks, to generate precise and actionable climate data.

The discourse highlights the policy dimensions of data sharing, illustrated by the decision-making processes behind the NASA Landsat and Copernicus programs' open data policies. These examples underscore the debates and controversies accompanying such policy decisions yet demonstrate the substantial need and benefits of making space-derived climate data broadly accessible. By facilitating the amalgamation of data from diverse space assets, these policies have significantly enhanced our ability to address climate change's multifaceted challenges.

The presentation explores the symbiotic relationship between climate action, space safety, accessibility, and sustainability. It presents space diplomacy and policy interaction as essential to advancing space sustainability and pivotal for expanding space-based climate initiatives. The narrative extends to how national defense, civil space, and commercial sectors' perspectives on space utilization converge in the context of climate policy, particularly through earth observation systems that monitor environmental trends and policy efficacy in reducing harmful emissions.

The work of The MITRE Corporation, in support of the U.S. Department of Commerce's (DOC) Office of Space Commerce (OSC), is the foundation for this analysis, showcasing space systems' unique capabilities in providing global space sensor insights and how space innovation can be retooled for socio-economic climate impact. The paper proposes proactive engagement in fostering information-sharing ecosystems. Such ecosystems are vital for ensuring transparency, building trust, and promoting spaceflight safety, ultimately facilitating environmental security and climate resilience. It advocates for the interdisciplinary integration of earth observation systems, highlighting the need for increased funding, attention, and utility to ensure effective design and development. This approach enriches the dialogue on climate change and paves the way for innovative satellite constellations to support sustainable development goals, embodying the session's focus on societal and economic applications, challenges, and benefits of Earth Observation data.

We propose leveraging community-accepted Space Situational Awareness (SSA) principles and OSC's Traffic Coordination System for Space (TraCSS) technological foundation as a starting point. The paper suggests creating a marketplace for climate change monitoring by enabling optimized satellite constellations dedicated to monitoring climate change indicators. This paper also discusses the socio-economic benefits of such a marketplace, including developing value-added services for climate resilience and promoting economic growth and innovation in selected climate technologies.

# 1. Foundation of Knowledge

## 1.1 Introduction

This paper elucidates the critical role of space-based data in the global effort to combat climate change and proposes the establishment of a marketplace for climate monitoring sensors. This marketplace concept posits that a centralized and dynamic platform for exchanging and integrating space-based climate data will catalyze the space economy and significantly enhance the efficacy of climate change initiatives worldwide. Space-based data, with its unparalleled ability to provide comprehensive and precise environmental insights, is indispensable for understanding and addressing the multifaceted challenges posed by climate change. By fostering a collaborative environment where data from diverse international sources can be seamlessly integrated, we can amplify the impact of our collective efforts and drive more effective climate action.

## 1.2 Background

Historically, space-based climate data initiatives have played a pivotal role in advancing our understanding of the Earth's climate systems. Programs such as Landsat and Copernicus have set precedents in the open data policy domain, providing valuable resources for researchers, policymakers, and the public. Since its inception, NASA's Landsat has offered continuous, long-term observational data that is instrumental in monitoring environmental changes. Similarly, the Copernicus program (European Union Space Programme), with its comprehensive suite of satellites, has significantly contributed to the accessibility of high-quality climate data through its open data policy. These initiatives have demonstrated the profound benefits of open and collaborative approaches to data sharing, setting a foundation upon which a more integrated and market-driven framework can be built.

## 1.3 Integrated Space Architecture and Policy Frameworks

Developing an integrated space architecture can maximize the utility of space-based climate data. Architecture integration ensures that data from various satellite missions, both existing and future, are harmonized and made accessible through a unified platform. This comprehensive data integration can enhance accurate climate modeling, forecasting, and policymaking. Supporting such an architecture requires a well-crafted policy framework that promotes data sharing, collaboration, and innovation. Policies encouraging data fusion from national, commercial, and international sources will create a more resilient and responsive climate monitoring system. This fusion can drive the evolution of the space economy, enabling the development of new technologies and services that address climate change more effectively.

## 1.4 Importance of International Collaboration

International collaboration is paramount in harnessing the full potential of space-based data for climate action. Climate change's complexity and global nature necessitate a coordinated effort among nations. Successful collaborations, such as those seen in the partnerships between NOAA and international satellite programs, exemplify the benefits of shared knowledge and resources. These partnerships have facilitated the development of sophisticated climate monitoring systems and have set standards for data exchange and utilization. By building upon these collaborative models, we can create a marketplace that fosters innovation and ensures that climate data is accessible and actionable for all stakeholders. This marketplace will catalyze the space economy, driving sustainable development and enhancing the global capacity to mitigate and adapt to climate change.

Establishing a marketplace for space-based climate sensors represents a transformative approach to climate action. Integrating data from diverse sources and promoting international collaboration can significantly enhance the efficacy of climate monitoring and policymaking. This integrated and collaborative effort will advance our understanding of climate dynamics, uncover gaps and opportunities, and foster a thriving space economy contributing to global sustainability.

# 2. International Space Relations and Space Policy

## 2.1 Space Diplomacy and Policy Interaction

Space diplomacy is crucial in advancing space sustainability and fostering international cooperation. Establishing a Space Information Sharing Ecosystem (SISE) [1] can significantly enhance the transparency and effectiveness of space activities. As a platform-agnostic framework, SISE promotes interoperability and fosters constructive engagement across national boundaries.[2] It encourages sharing information, best practices, and innovations essential for addressing the complex challenges associated with space exploration and utilization. In this context, space diplomacy facilitates the peaceful use of outer space and aligns the interests of various stakeholders, including national defense, civil space, and commercial sectors. This alignment is critical to ensure space policies support climate action and other global priorities.

## 2.2 Policy Dimensions of Data Sharing

The decision-making processes behind open data policies are pivotal in shaping the future of space activities. Establishing a SISE can streamline these processes by providing a common data exchange and collaboration platform. Open data policies foster an environment where information is freely available, enabling stakeholders to make informed decisions and develop innovative solutions. However, these policies are often debated and controversial, particularly regarding national security and commercial interests. Balancing these concerns requires a nuanced approach that considers the benefits of transparency and the need for confidentiality. A well-structured SISE can address these challenges by establishing clear guidelines for data sharing, ensuring that sensitive information is protected while promoting the free flow of non-sensitive data.

## 2.3 Enhancing Space-Based Climate Initiatives

Space policy is instrumental in expanding climate initiatives and leveraging space-based data for environmental monitoring and climate action. A climate-oriented marketplace within the broader SISE framework can significantly enhance the efficacy of these initiatives. This marketplace can provide comprehensive and accurate climate information by integrating data from various international sources, facilitating better decision-making and policy development. Examples of successful policy implementations highlight the importance of international cooperation and data sharing in achieving climate goals. For instance, partnerships between agencies like NOAA and international space programs have demonstrated the benefits of collaborative efforts in space-based climate monitoring. These initiatives underscore the value of a SISE in promoting innovation, improving data accuracy, and enhancing overall climate action impacts.

### 2.4 THE VALUE OF A SPACE INFORMATION-SHARING ECOSYSTEM (SISE)

The Space Information Sharing Ecosystem (SISE) concept extends beyond climate initiatives, encompassing various sectors that can benefit from enhanced international discourse and information transparency. SISE provides a structured and collaborative environment where stakeholders can share knowledge, develop best practices, and coordinate efforts to address common challenges. This ecosystem fosters a culture of transparency and mutual trust, which is essential for the sustainable development of space activities. Establishing a climate-oriented marketplace within SISE exemplifies how this framework can be leveraged to address specific global challenges while contributing to the broader goals of space sustainability and international cooperation. Moreover, SISE serves as a model for other sectors, demonstrating the potential of collaborative frameworks in driving innovation and achieving shared objectives.

Establishing a SISE represents a transformative approach to space policy and international cooperation. It promotes the transparent exchange of information, fosters collaboration, and enhances the effectiveness of space-based initiatives across various sectors. The integration of a climate-oriented marketplace within SISE underscores the value of this ecosystem in addressing global challenges and advancing the sustainable use of outer space. Fostering a culture of transparency and mutual trust, SISE can significantly contribute to developing a stable and inclusive space economy, benefiting all stakeholders and ensuring long-term space program sustainability.

## 3. PROLIFERATED LEO ACTIVITY AND THE OFFICE OF SPACE COMMERCE (OSC)

### 3.1 IMPACT OF LEO GROWTH ON CLIMATE SATELLITES

In our current decade, space commerce (not government) has led the way to impressive mega-constellations with thousands of new satellites to accomplish a variety of communications and Earth-sensing missions. The global space economy in 2022 was $546 Billion (U.S.), almost $600 Billion in 2023, and expected to total more than $1 Trillion (U.S.) by 2030.[3] More space objects have been launched in the last 10 years (2014-2024) than in the previous 56 years combined (1957-2013).[4] As of this writing (August 2024), the U.S. Space Force (USSF) is currently tracking 29,006 objects in orbit, which is double that of 2009 objects[5], a doubling rate of every 15 years. 2023 was the busiest year of the *Space Age,* with a record 212 successful global space launches, placing 2,891 satellites into various earth orbit regimes (23% more than the previous year), of which 2,734 were deployed into LEO (95%).[6] Operators from 52 nations deployed satellites in 2023; this is 30% higher than in 2022 and 58% more than in 2021.[7] Most of this space growth has been in Proliferated Low Earth Orbit (P-LEO), and 2024 will no doubt also be a record year in all these categories.

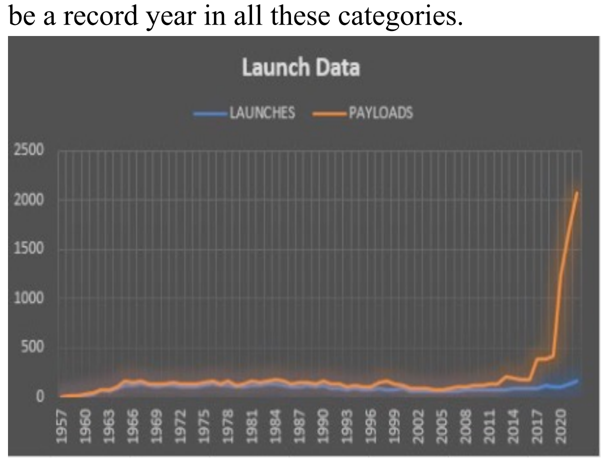


Figure 1. Space Deployment Rate (18th SDS)[8]

This space growth trend continues as space systems support every critical infrastructure component on our planet (Figure 2). Thousands of additional satellites in P-LEO constellations are planned for orbit by 2030 from numerous civil, commercial, and international stakeholders, including SpaceX (Starlink), Amazon (Kuiper), and China. As of December 2023, the Federal Communications Commission has issued licenses for 20,736 new satellites that await launch, most of which are intended for P-LEO.[9] Many of these are 'new space' concepts. *Small Satellites* are loosely defined as satellites less than 500 kg and smaller than house appliances (as opposed to large satellites greater than 500kg, which are sized on the order of cars, trucks, and buses). Over the last decade, the successful miniaturization of satellite components (sensors, payloads, batteries, etc.) created the emergence of small, lightweight, but highly effective Cube Satellites (CubeSats). The standard size CubeSat is based on a 10cm cube (1U), which can be easily stacked and integrated into modular platforms of 3U, 6U, 12U, 27U, etc. The advent of small satellites opened the door to cost-effective access to space for many non-traditional space users, such as academia and small businesses. Combining small satellites with low-cost space launches (e.g., Falcon 9) results in P-LEO constellations for commercial and civil space missions that provide important products and services to the global space economy.


Figure 2. Space Economic Impacts[10]

To complicate space traffic challenges, human spaceflight is at an all-time high with ongoing ISS activities in LEO and independent Chinese Space Station *taikonaut* missions in LEO. NASA and ESA are partners in cislunar-crewed Artemis missions to the moon, with the Space Launch System, Orion, and Lunar Gateway Space Station. Space tourism is now a legitimate space activity with suborbital human tourist space launches from Blue Origin and Virgin Galactic and orbital human space tourism with SpaceX Dragon missions. There have been at least 112 space tourists, most occurring in the last 3 years.

The natural consequences on the space environment from surging space commerce, P-LEO mega-constellations, small satellites, and space tourism are threefold: 1) intensified space congestion; 2) significantly increased risks of space collisions (conjunctions); and 3) disruptive electromagnetic interference (EMI) on and between satellites. Increased space traffic, particularly with small satellites, which are harder to detect and track, and P-LEO congestion puts commercial, civil, and national security missions at risk and elevates space environment debris and collision concerns. On-orbit collision risks are significantly increasing, evidenced by a dramatic increase of 1,486 reportable conjunctions in 2022 with the International Space Station (ISS), a 233% increase from the previous year.[11]

Most space-based climate and earth monitoring systems are in LEO orbits. To ensure they can function and survive in a congested space environment, mitigation strategies must be implemented to protect climate observation systems and sensors. First and foremost, improved Space Situational Awareness (SSA) is needed for accurate and timely space object tracking. SSA is critical for Conjunction Assessment (CA), Conjunction Data Messages (CDMs) to alert and warn satellite Owners and Operators (O/O's), and space user deconfliction measures. Additionally, satellites increasingly need collision avoidance measures (onboard SSA sensors and propulsion) to maneuver with short notice from space traffic. Finally, with the exponential growth and sheer numbers of objects in PLEO, space systems require more artificial intelligence (AI) and Machine Learning (ML) for automated onboard real-time evasive measures. '*Smart Satellites*' equipped with SSA sensors, AI, and ML can self-maneuver for station keeping, orbit optimization, and collision avoidance. A good example is the SpaceX Starlink constellation, which has over 6,000 smart satellites able to self-maneuver independent of ground segments without Human-in-the-Loop (HIL) intervention.

## 3.2 Role of the Office of Space Commerce (OSC)

Given the flourishing growth of space missions and recognizing there is an urgent need for more effective SSA, in 2018, the U.S. President issued Space Policy Directive 3 (SPD-3), [12] which identifies the need for better Space Traffic Coordination (STC) among all space users. SPD-3 directs the migration of SSA services for commercial and civil space system Owners and Operators (O/O's) from the U.S. Department of Defense (DoD) to the Department of Commerce (DOC), specifically NOAA's Office of Space Commerce (OSC). As a civil U.S. agency, the OSC is now responsible for commercial and civil STC, while the DoD will continue its national security Space Domain Awareness (SDA) mission to accomplish the Protect and Defend mission. The STC construct is similar to U.S. Air Traffic Control (ATC), which is also led by a U.S. civil agency, the Federal Aviation Administration (FAA). The transition of the STC mission to DOC relieves the DoD of SSA responsibilities with the burgeoning global commercial space industry and allows the DoD to concentrate its resources on national security space missions. OSC's vision for the future is for a globally coordinated system of SSA providers yielding SSA data for spacecraft O/O's.

OSC is developing improved SSA capability that blends government and commercial data to provide more accurate and timelier SSA data with the Traffic Coordination System for Space (TraCSS). [13] TraCSS provides free Basic SSA Services to promote safer space operations, predicts collisions (using CA), and transmits collision alert warnings (with CDMs) to civil and commercial O/Os. TraCSS establishes and maintains a resident space object data repository (catalog) from which all the basic SSA services are derived and used for commercial, civil, and international coordination purposes. OSC is leveraging U.S. commercial SSA providers and integrating their data into TraCSS basic services to provide complete SSA sensor coverage. Using these TraCSS basic SSA services, O/Os are informed to enable evasive actions to protect their space systems from potential on-orbit incidents.

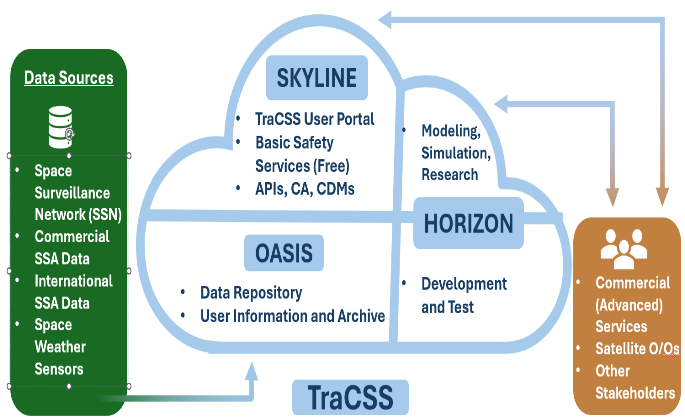

Figure 3. TraCSS Architecture

To promote global SSA standards and best practices, the TraCSS implementation is driven by OSC's focus on spaceflight safety, space sustainability, and international coordination. The TraCSS architecture consists of three primary elements: [14] 1) an SSA data repository (OASIS); 2) SSA application services (SKYLINE); and 3) HORIZON, which provides research and development, modeling and simulation to advance SSA science and technology in a development and test environment. OSC is developing and fielding TraCSS using an Agile process with phased implementation and incremental functional blocks of capabilities. The initial TraCSS Phase 1 capabilities start in Fall 2024 with a limited set of Beta Users.[15] Ultimately, TraCSS will be the collaborative STC centerpiece for global commercial, civil, and international space safety of flight.

## 3.3 Converse Relationship: Space Systems and Climate Impact

Space systems are highly effective data contributors for understanding climate change, earth monitoring, and enabling environmental sustainability. Conversely, space systems are affected by the space environment itself. Both aspects shape space contributions, which can be maximized by leveraging innovative retooling for socio-economic climate impact. Let's take a deeper dive into both sides of this relationship.

The space environment is harsh on space systems, with extreme temperature ranges, radiation, and natural space debris (e.g., meteorites) as primary detrimental threats. Most importantly for satellites, the Sun produces powerful and potentially damaging electromagnetic radiation from solar flares, prominences, sunspot activity, coronal mass ejections, and geomagnetic solar storms. These charged particles reach Earth in the solar wind within minutes to hours and are destructive to unprotected (unhardened) space systems. While most of the Sun's electromagnetic energy is deflected by the Earth's magnetosphere, some of it penetrates through its polar magnetic field to regions of Earth's orbits and upper atmosphere. Solar radiation is accentuated during the Sun's Solar Maximum, the peak activity level of the Sun's 11-year cycle.[16] Solar Maximum has two major impacts on space systems. First, solar radiation levels cause single event upsets (SEUs) on satellite electronic components, ranging from minor to serious impacts on satellite payloads and subsystems, regardless of orbit type. Satellites require radiation hardening and subsystem redundancy to ensure operations during major solar events. Second, solar activity heats the Earth's upper atmosphere, causing it to expand into LEO with increased atmospheric drag. This causes satellites to decay in orbit quicker and particularly affects LEO satellites at an altitude less than 500 km, with more frequency and impact during peak solar maximum.

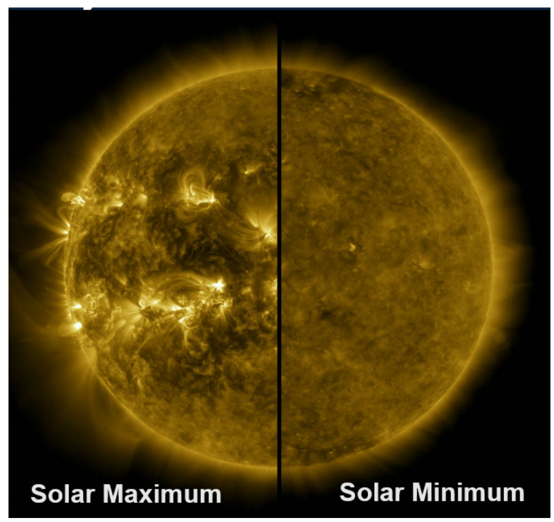

Figure 4. 11-Year Solar Cycle Activity[17]

Leading up to the next Solar Maximum in 2025, two recent examples of severe geomagnetic solar activity have occurred in the last two years. In February 2022, NOAA's Space Weather Prediction Center (SWPC) issued a geomagnetic storm watch for solar coronal mass ejection activity. Unfortunately, this G2-level event impacted the Earth as newly launched SpaceX Starlink satellites were still in LEO parking orbit (about 200km altitude). The increased atmospheric drag caused 38 of 49 Starlink satellites to decay from orbit.[18] Another recent example is the G5-extreme level geomagnetic storm on May 7-11, 2024, resulting from eight x-class solar flares (the most powerful on the solar flare scale). This was the most severe space weather event since 2003, leading to the strongest

Aurora Borealis (Northern Lights) in over 20 years.[19]

Space Weather events will be amplified during Solar Cycle 25 maximum peak (in 2025), impacting environmental monitoring satellites in LEO with increased drag, deorbit uncertainty, and SEUs. This potentially damages satellite environmental climate data necessary for global climate change detection and monitoring. Climate data from space systems includes including terrestrial temperatures, wind speeds, ocean currents, cloud coverage, weather patterns, precipitation monitoring, drought data, wildfires, natural disasters, greenhouse gases (CH4 and CO2), and remote sensing imagery for agriculture, deforestation, natural resources, mapping, and pollution (land, sea, air). This environmental data comes from highly sophisticated space systems that use a variety of technologies such as change-detection from detailed Very Near and Short-Wave Infrared (VNIR, SWIR) satellite imagery, multispectral and hyperspectral sensors (MSI / HIS), Artificial Intelligence (AI), Machine Learning (ML) algorithms, and Computer Vision (CV) management systems.[20] An ESA-JAXA joint effort recently orbited the Earth Cloud, Aerosol, & Radiation Explorer (EarthCare) with various environmental sensors to support climate change analysis.[21] Figure 5 illustrates some current space systems that are key to climate sustainability.

| System | Description | Orbit |
|---|---|---|
| GOES | Geostationary Ops Environmental Sat | Geostationary |
| JPSS | Joint Polar Sat Sys | LEO / Polar |
| Landsat | Earth Observation | LEO / Polar |
| Planet Dove | Earth Imaging | LEO / Polar |
| Copernicus | Earth Observation | LEO / Polar |
| Radarsat | Synthetic Aperture Radar | LEO / Polar |
| EarthCARE | Earth Science; MSI, LIDar, Radar, xband | LEO / Polar |
| Sentinel 1-6 | Copernicus missions | LEO / Polar |

Table 1. Space Climate Systems

# 4. NOAA, Space Weather, and Climatology

## 4.1 Overview of NOAA's Role

The U.S. National Oceanic and Atmospheric Administration's broad mission includes understanding and predicting changes in space weather and the Earth's climate.[22] NOAA's National Environmental Satellite, Data, and Information Service (NEDSIS) operates a fleet of environmental satellites in various orbit regimes that provide secure and timely terrestrial and space environmental data.[23]

Additional NOAA roles and responsibilities are delineated in the December 2020 National Space Policy of the United States of America. These responsibilities include requirements to establish international partnerships and to purchase commercial weather and climate data from the private sector when appropriate[24]

## 4.2 Integration of Earth Observation Systems

The international weather and climate enterprise recognized the need to fully integrate all aspects of global earth observations dating back to 1950 when the United Nations established the World Meteorological Organization (WMO).[25] Through the WMO Integrated Global Observing System (WIGOS), the WMO coordinates individual member nations' operational and research and development (R&D) environmental satellite programs and promotes the use of satellite data for weather forecasting, climate monitoring, and related fields. Two important international organizations implementing the WIGOS plans are the Coordination Group on Meteorological Satellites (CGMS)[26] and the Committee on Earth Observing Satellites (CEOS).[27] CGMS consists of 22 member and observer international space and meteorology agencies today. CGMS provides a forum for exchanging technical information on geostationary and polar-orbiting meteorological satellite systems and research & development missions. Recently, CGMS added Space Weather Coordination and Climate Working Groups. CEOS was formed in 1984 under the auspices of the G7 Economic Summit. Like CGMS, its role has dramatically expanded over the past decades as satellites have become more complex and the user community has become more diverse.

Because earth-observing satellites have been in orbit collecting weather forecasting information since the 1960s, the countries who have launched and operated these satellites have archived 60+ years of meteorological data.

The WMO has defined Essential Climate Variables (ECVs) as those ideally monitored by remote-sensing spacecraft in low earth orbit. ECVs result in long-term observations essential for observing long-term trends in observations such as the Earth's radiation budget, sea surface temperature, coral reef bleaching, ocean color, atmospheric composition, ice cap melting, drought monitoring, atmospheric aerosols caused by pollution, break-up of reentering spacecraft and natural events such as volcanic eruptions.

Of particular interest to orbital flight safety is total solar irradiance (TSI), which is a measure of the Sun's thermal energy reflected off the atmosphere and projected back into space. This thermal pressure can affect the orbits of large LEO constellations. While space weather effects can lower spacecraft orbits, increased TSI has the opposite effect. TSI pressure can raise orbits. A study from University College London showed that TSI is one of six environmental forces affecting satellite orbits.[ [28] The DOC TraCSS system must be able to incorporate current and projected TSI data into its orbit determination software and algorithms in one of its block updates.

Mission authorization and licensing agencies of the U.S. and other governments must consider TSI and space weather in their licensing. For example, effects on orbits from TSI and space weather add uncertainty in calculations for 25-year and 5-year deorbit guidelines. Based on the 11-year solar cycle, a spacecraft in a 25-year orbit could experience two or even three solar cycles.

## 4.3 Funding and Development of Satellite Constellations

Civil space agencies cannot respond quickly enough to climate change observation requirements. Although NOAA, ESA, JAXA and others recognize the need for climate sensors on orbit, these sensors are often secondary instruments on weather satellites.

The 2018 National Academies Earth Science decadal survey, *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space (2018),* identified and established weather and climate focus areas.[29] The focus areas include aerosols and their impact on climate and air quality, the role of clouds, convection, and precipitation in the global hydrological cycle, and mass change, particularly the distribution and movement of mass among oceans, ice sheets, groundwater, and the atmosphere. Additionally, it encompasses surface biology and geology to monitor ground and water temperature, snow reflectivity, active geological processes, vegetation, and algal biomass, as well as surface deformation and change to observe Earth's surface dynamics, including earthquakes, landslides, ice sheets, and permafrost.

The National Academies further identified focus areas for collecting data from lower-cost sensors. These include greenhouse gases, ice elevation, ocean surface winds and currents, ozone and trace gases, snow depth, terrestrial ecosystem structures such as forest canopy, and atmospheric winds. While we cannot expect any government or group of like-minded governments to fund all the identified ten-year climate observation needs fully, the commercial space sector can respond more quickly. Some of these instruments, once developed, could be carried as hosted payloads on commercial space missions. Depending upon the urgency level among climate scientists, some could fly as stand-alone climate missions with the data sold to government scientific agencies.

Certainly, as noted earlier, continuity of total solar irradiance (TSI) observations is critical for both climate research and space situational awareness operations.

# 5. Creating a Marketplace for Climate Change Monitoring

## 5.1 Concept of a Marketplace for Climate Action

Establishing a marketplace for climate change monitoring represents a transformative approach to leveraging space-based data for environmental sustainability. This marketplace concept is predicated on the hypothesis that a centralized platform for exchanging and integrating climate data will catalyze the space economy in sustainable and meaningful ways. Such a marketplace would provide a dynamic and centralized hub where data from various international sources can be integrated, thereby enhancing the precision and comprehensiveness of climate monitoring. Integrating diverse data sources is critical for effective climate action, as it enables a more nuanced understanding of environmental changes and fosters the development of innovative solutions. The marketplace concept extends beyond mere data exchange; it envisions a collaborative environment where stakeholders from different sectors, including governmental, commercial, and international entities, can engage constructively. This engagement is essential for driving the collective efforts required to address the multifaceted challenges of climate change.

In addition to broad observational requirements and needs documented in the earth science decadal survey cited in Section 4.3, the WMO Observing Systems Capability Analysis and Review Tool (OSCAR) provides a comprehensive source of WMO-validated observational requirements.[30] Combined with the National Academies lower-cost observational needs list noted in Section 4.3, commercial satellite manufacturers can select from dozens of observational requirements needed for climate research. Another benefit for the commercial satellite industry is that most of these sensors do not require precision spacecraft attitude control or positional knowledge for sensors contributing data to real-time weather prediction models. Hence, commercial spacecraft with modest capabilities in this area can readily fly climate sensors without significant cost impacts. While total solar irradiance measurements are needed to enhance the accuracy of TraCSS SSA products, many other observations are needed for terrestrial climate research.

## 5.2 Leveraging SSA Principles and TraCCS Technology

The marketplace for climate action can greatly benefit from Space Situational Awareness (SSA) principles and the deployment of advanced climate technologies like TraCCS (Tracking and Characterization of Climate Sensors). SSA principles are integral to maintaining the safety and sustainability of space operations through Space Traffic Coordination (STC), ensuring that satellites and other space-based assets can operate without interference. Applying these principles to climate monitoring involves meticulously tracking and managing climate sensors, enhancing their reliability and effectiveness.

TraCCS climate technology plays a pivotal role in this context by optimizing the performance and coordination of satellite constellations dedicated to climate monitoring. This technology enables real-time tracking and data assimilation, which is crucial for accurate climate modeling and forecasting. Integrating SSA principles and TraCCS environmental technology within the climate marketplace framework ensures that data collection is robust, reliable, and responsive to the dynamic needs of climate science and policy.

Integrating terrestrial and space environments is important for increasing the accuracy of SSA observations in TraCSS. As the Sun heads toward it next Solar Maximum in late 2024 or early 2025, there have already been documented adverse space weather effects on satellites and the sensors that track them. In February 2022, increased atmospheric drag resulting from a geomagnetic storm caused 38 49 Starlink satellites to reenter shortly after launch.[31] During the four-day May 2024 geomagnetic storm, satellites, and debris objects descended at up to 180 meters per day. Thousands of active satellites began maneuvering to regain the lost altitude. The current government and commercial SSA systems couldn't keep up with all of the simultaneous maneuvers to issue close approach warnings.[32]

While space weather events decrease satellite altitude, the climate effects of TSI cause satellites to increase in altitude as reflected solar irradiance increases pressure.[28] While not as dramatic as altitude loss during space weather events, solar irradiance effects will increase over time as the atmosphere absorbs increasing amounts of greenhouse gases.

The SSA enterprise should strategically plan and adequately fund research to develop more accurate orbit determination tools that can account for environmental effects such as space weather and TSI.

## 5.3 Socio-Economic Benefits and Value-Added Services

Creating a climate-oriented marketplace within the Space Information Sharing Ecosystem (SISE) promises significant socio-economic benefits. This marketplace can drive economic growth by fostering innovation in climate technologies and generating new business opportunities. Developing value-added services for climate resilience, such as advanced weather forecasting, disaster response coordination, and environmental impact assessments, can impact society. These services enhance our ability to respond to climate-related challenges and create new markets and job opportunities. Furthermore, the marketplace can stimulate international collaboration, enabling countries to effectively pool resources and expertise to tackle climate change. The economic benefits extend beyond direct financial gains; they encompass the broader societal advantages of improved climate resilience and sustainability. As the marketplace evolves, it can catalyze broader space economy development, driving technological advancements and fostering a culture of innovation and cooperation.

Establishing a marketplace for climate change monitoring within the SISE framework represents a visionary approach to climate action. This marketplace can significantly enhance the efficacy of climate monitoring and policymaking by integrating diverse data sources and fostering international collaboration. Leveraging SSA principles and TraCCS climate technology ensures that the marketplace is based on successes and is thus more reliable and precise. The socio-economic benefits of this marketplace are profound, driving economic growth, fostering innovation, and enhancing climate resilience. Creating a centralized platform for climate data exchange can amplify the impact of collective efforts to combat climate change and pave the way for a sustainable and prosperous future.

# 6. CONCLUSION

## 6.1 SUMMARY OF KEY POINTS

This paper proposes space information-sharing ecosystems as a "Marketplace" for climate action and sustainable development. The paper underscores the critical role of international collaboration in harnessing space-based data for climate change characterization. It emphasizes the necessity of a united global effort, underpinned by an integrated space architecture and space policy frameworks, to generate precise and actionable climate data.

The discourse highlights the policy dimensions of data sharing, illustrated by the decision-making processes behind the NASA Landsat and Copernicus programs' open data policies. These examples underscore the debates and controversies accompanying such policy decisions yet demonstrate the substantial need and benefits of making space-derived climate data broadly accessible. By facilitating the amalgamation of data from diverse space assets, these policies have significantly enhanced our ability to address climate change's multifaceted challenges.

The presentation explores the symbiotic relationship between climate action, space safety, accessibility, and sustainability. It presents space diplomacy and policy interaction as essential to advancing space sustainability and pivotal for expanding space-based climate initiatives. The narrative extends to how national defense, civil space, and commercial sectors' perspectives on space utilization converge in the context of climate policy, particularly through earth observation systems that monitor environmental trends and policy efficacy in reducing harmful emissions.

The work of The MITRE Corporation, in support of the U.S. Department of Commerce's (DOC) Office of Space Commerce (OSC), is the foundation for this analysis, showcasing space systems' unique capabilities in providing global space sensor insights and how space innovation can be retooled for socio-economic climate impact. The paper proposes proactive engagement in fostering information-sharing ecosystems. Such ecosystems are vital for ensuring transparency, building trust, and promoting spaceflight safety, ultimately facilitating environmental security and climate resilience. It advocates for the interdisciplinary integration of earth observation systems, highlighting the need for increased funding, attention, and utility to ensure effective design and development. This approach enriches the dialogue on climate change and paves the way for innovative satellite constellations to support sustainable development goals, embodying the session's focus on societal and economic applications, challenges, and benefits of Earth Observation data.

We propose leveraging community-accepted Space Situational Awareness (SSA) principles and OSC's Traffic Coordination System for Space (TraCSS) technological foundation as a starting point. The paper suggests creating a marketplace for climate change monitoring by enabling optimized satellite constellations dedicated to monitoring climate change indicators. This paper also discusses the socio-economic benefits of such a marketplace, including developing value-added services for climate resilience and promoting economic growth and innovation in selected climate technologies.

## 6.2 FUTURE DIRECTIONS

The future of climate monitoring and sustainable development through space-based technologies hinges on the continued evolution of data-sharing frameworks and international collaboration. Several key areas merit further research and policy development:

1. **Advancement of TraCSS-Related Technologies**: The Traffic Coordination System for Space (TraCSS) ensures safe and efficient space operations. Future research could focus on enhancing TraCSS capabilities by integrating advanced space weather monitoring and predictive modeling tools. This inclusion involves developing more accurate algorithms for tracking and predicting the effects of space weather events and total solar irradiance (TSI) on satellite orbits. Ensuring that these tools are reliable and precise will be critical in maintaining the safety and functionality of space-based climate monitoring systems.
2. **International Standards for Space Data**: There is a need for internationally recognized standards for space data collection, sharing, and utilization. These standards should be developed through a consensus-driven approach involving key stakeholders from government, academia, and the private sector. Establishing common protocols for data verification, security, and integration will enhance the reliability and usefulness of space-based climate data globally.
3. **Incentivizing Commercial Participation**: Governments and international organizations should incentivize commercial entities to host climate-monitoring payloads on their satellites. The private sector can be encouraged to contribute more actively to global climate monitoring efforts by offering financial support, tax incentives, or guaranteed data purchase agreements. This approach would expand the availability of critical climate data and foster innovation within the commercial space industry.
4. **Expanded Research into Environmental Impacts on Space Operations**: Research into the environmental effects of space operations on both the space environment and Earth's climate could be expanded. This research may include studying the long-term impacts of satellite mega-constellations on space congestion and debris management and the potential effects of increased solar activity on satellite reliability. Understanding these impacts will be crucial for developing sustainable space policies that balance technological advancement with environmental stewardship.
5. **Collaboration Between Space and Climate Communities**: Strengthening the ties between the space and climate science communities will be essential for leveraging the full potential of space-based data in climate action. Interdisciplinary collaborations should be fostered through joint research initiatives, conferences, and shared funding opportunities. This collaboration will ensure that climate data from space is accurate, comprehensive, and actionable for policymakers and climate scientists.

### 6.3 FINAL THOUGHTS

The convergence of space technology and climate action represents one of the most promising avenues for addressing the global challenges of climate change and sustainable development. The interdisciplinary integration of earth observation systems, underpinned by international collaboration, is imperative for the success of these efforts. The proposed marketplace for climate change monitoring, facilitated by a Space Information Sharing Ecosystem (SISE), embodies a forward-looking approach that combines the strengths of space-based data with the collective will of the global community.

The effectiveness of this marketplace will depend on our ability to harness cutting-edge technologies while fostering a culture of transparency, trust, and cooperation across national boundaries. Prioritizing the development of standardized, accessible, and actionable data ensures that space-based climate monitoring systems are pivotal in guiding global climate policy and resilience efforts.

The vision of a climate-oriented marketplace within the SISE framework offers a transformative path that aligns economic growth with environmental sustainability. The socio-economic benefits of such an approach are vast, ranging from enhanced climate resilience to the creation of new markets and technologies. As we look to the future, the collaborative and interdisciplinary spirit that underpins this vision will be key to its realization, paving the way for a sustainable and prosperous future for all.

# APPENDIX A: SUMMARY TABLE OF KEY POINTS

## TABLE 1: KEY POINTS

| Section | Key Points |
|---|---|
| **Space Diplomacy and Policy Interaction** | • Space diplomacy is essential for advancing space sustainability and international cooperation.<br>• Establishing a Space Information Sharing Ecosystem (SISE) enhances transparency and effectiveness in space activities.<br>• SISE promotes interoperability and constructive engagement across national boundaries.<br>• Space diplomacy facilitates the peaceful use of outer space and aligns interests of national defense, civil space, and commercial sectors. |
| **Policy Dimensions of Data Sharing** | • Decision-making behind open data policies shapes future space activities.<br>• SISE streamlines data exchange and collaboration processes.<br>• Open data policies foster informed decisions and innovative solutions.<br>• Balancing transparency and confidentiality is crucial.<br>• SISE establishes guidelines for data sharing protecting sensitive information while promoting non-sensitive data flow. |
| **Enhancing Space-Based Climate Initiatives** | • Space policy expands climate initiatives using space-based data for environmental monitoring and action.<br>• A climate-oriented marketplace within SISE enhances the efficacy of these initiatives.<br>• Integrating data from international sources improves climate information accuracy.<br>• Successful policy implementations show the importance of international cooperation in achieving climate goals.<br>• SISE promotes innovation, data accuracy, and effective climate action programs. |
| **The Value of a Space Information Sharing Ecosystem** | • SISE benefits multiple sectors through enhanced international discourse and information transparency.<br>• It provides a collaborative environment for knowledge sharing and addressing common challenges.<br>• SISE fosters a culture of transparency and mutual trust for sustainable space activities.<br>• Establishing a climate-oriented marketplace within SISE addresses global challenges and contributes to space sustainability.<br>• SISE serves as a model for collaborative frameworks, driving innovation and achieving shared objectives. |
| **Concept of a Marketplace for Climate Action** | • A marketplace for climate change monitoring leverages space-based data for sustainability.<br>• A centralized platform for exchanging and integrating climate data catalyzes the space economy.<br>• Integrating diverse data sources enhances climate monitoring precision and comprehensiveness.<br>• The marketplace fosters collaborative engagement among governmental, commercial, and international stakeholders. |
| **Leveraging SSA Principles and TraCSS Technology** | • Space Situational Awareness (SSA) principles ensure the safety and sustainability of space operations.<br>• TraCSS technology can serve as a model to optimize the performance and coordination of satellite constellations for climate monitoring.<br>• Real-time tracking and data assimilation improve climate modeling and forecasting. |
| **Socio-Economic Benefits and Value-Added Services** | • A climate-oriented marketplace within SISE drives economic growth and innovation in climate technologies.<br>• Development of value-added services for climate resilience, such as advanced weather forecasting and disaster response.<br>• The marketplace stimulates international collaboration, pooling resources and expertise.<br>• Economic benefits include direct financial gains and broader societal advantages of improved climate resilience.<br>• The marketplace catalyzes broader space economy development, fostering a culture of innovation and cooperation. |

# APPENDIX B: SUMMARY TABLE OF FUTURE DIRECTIONS

| Future Direction | Key Points |
|---|---|
| **Advancement of TraCSS-Related Technologies** | • Focus on leveraging TraCSS-like concepts for advanced space weather monitoring and predictive modeling tools.<br>• Develop accurate algorithms for tracking and predicting the effects of space weather events and total solar irradiance (TSI) on satellite orbits. |
| **International Standards for Space Data** | • Develop internationally recognized standards for space data collection, sharing, and utilization.<br>• Establish common protocols for data verification, security, and integration to enhance the reliability and usefulness of global space-based climate data. |
| **Incentivizing Commercial Participation** | • Create financial incentives for commercial entities to host climate-monitoring payloads on their satellites.<br>• Offer tax incentives, financial support, or guaranteed data purchase agreements to encourage private sector participation in global climate monitoring efforts. |
| **Expanded Research into Environmental Impacts** | • Expand research into the environmental impacts of space operations, including the long-term effects of satellite mega-constellations on space congestion and debris management.<br>• Study the potential effects of increased solar activity on satellite reliability and sustainability. |
| **Collaboration Between Space and Climate Communities** | • Strengthen interdisciplinary collaboration between the space and climate science communities through joint research initiatives and shared funding opportunities.<br>• Foster ties between these communities to ensure that space-based climate data is accurate, comprehensive, and actionable. |

# Appendix B: Acronyms

### Table 2: Acronyms

| Acronym | Full Term |
|---|---|
| | Artificial Intelligence |
| **ATC** | Air Traffic Control |
| **CA** | Conjunction Assessment |
| **CDM** | Conjunction Data Messages |
| **CEOS** | Committee on Earth Observing Satellites |
| **CGMS** | Coordination Group on Meteorological Satellites |
| **CV** | Computer Vision |
| **DOC** | Department of Commerce |
| **DoD** | Department of Defense |
| **ECV** | Essential Climate Variables |
| **EMI** | Electromagnetic Interference |
| **FAA** | Federal Aviation Administration |
| **FCC** | Federal Communications Commission |
| **GOES** | Geostationary Operational Environmental Satellite |
| **HIL** | Human-in-the-Loop |
| **IAF** | International Astronautical Federation |
| **ISS** | International Space Station |
| **JPSS** | Joint Polar Satellite System |
| **LEO** | Low Earth Orbit |
| **MEDEA** | Measurements of Earth Data for Environmental Analysis |
| **ML** | Machine Learning |
| **NEDSIS** | National Environmental Satellite, Data, and Information Service |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **O/O** | Owners and Operators |
| **OSC** | Office of Space Commerce |
| **OSCAR** | Observing Systems Capability Analysis and Review Tool |
| **P-LEO** | Proliferated Low Earth Orbit |
| **SDA** | Space Domain Awareness |
| **SEU** | Single Event Upset |
| **SISE** | Space Information Sharing Ecosystem |
| **SPD-3** | Space Policy Directive 3 |
| **SSA** | Space Situational Awareness |
| **SEU** | Single Event Upset |
| **STC** | Space Traffic Coordination |
| **SWIR** | Short-Wave Infrared |
| **SWPC** | Space Weather Prediction Center |
| **TASA** | Taiwan Space Agency |
| **TraCCS** | Tracking and Characterization of Climate Sensors |
| **TraCSS** | Traffic Coordination System for Space |
| **TSI** | Total Solar Irradiance |
| **USSF** | United States Space Force |
| **VNIR** | Very Near Infrared |
| **WIGOS** | WMO Integrated Global Observing System |
| **WMO** | World Meteorological Organization |
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