

SPACE-BASED DATA CENTERS ROADMAP: THE CASE FOR CAUTION

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Findings and Recommendations



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FINDINGS AND RECOMMENDATIONS

A. Findings

1. **In the US, China and other countries, significant activity is underway to deploy space-based data centers in the next few years, including proposals to launch more than one million data centers into low Earth orbit.**
   - Many satellites currently in orbit have small data processing capabilities on board to support their core functions, such as Earth observation or communications.
   - Roughly a dozen satellites have been launched primarily to demonstrate the feasibility of performing artificial intelligence (AI) model training and inference in space.
   - More launches of space-based data centers have been proposed for 2027, with companies hoping to increase deployment significantly in the years that follow.
   - Today there are roughly 19,000 satellites orbiting the Earth. Full implementation of proposed plans for space-based data centers would increase the number of satellites in low Earth orbit by more than 50x.
2. **Operating data centers in space is technically feasible, although operating hundreds of thousands of space-based data centers without collisions would require unproven technologies to be operated at very low failure rates.**
   - No technical barriers preclude the operation of data centers in space.
   - Thermal management is one of the most fundamental determinants of both feasibility and cost. Because a data center in vacuum can shed its waste heat only by radiating it, the size and mass of the radiators—and the temperature at which the chips are allowed to run—largely set how much compute a satellite can carry.
   - Space-based data centers will be much larger than communications satellites, with solar arrays and radiators that greatly increase their cross-sectional area. Preventing collisions among hundreds of thousands of such satellites will require data sharing procedures and maneuver coordination technologies with extremely low failure rates.
   - The weight of individual satellites per unit of compute will be a crucial parameter in determining cost and overall impacts. The weights claimed by leading developers appear to be highly optimistic and beyond currently-proven technology.

3. **High costs are unlikely to be a barrier to initial deployment of space-based data centers.**
   - Despite high costs today, companies may be willing to deploy data centers in space even if costs are significantly higher than for terrestrial data centers, due in part to the value of AI compute and constraints on building new data centers on Earth.
   - Companies may be willing to absorb losses in operating space-based data centers for a sustained period, if those companies believe it will help establish market position or lead to profitable operations in the long run.
   - The pace at which costs will decline depends on technological innovations, the pace of launches and other factors.
4. **Large numbers of rocket launches would be required for small amounts of computing capacity in space.**
   - Based on reasonable assumptions, maintaining a fleet of space-based data centers with 10% of the projected demand for AI data centers in 2030 would require at least 700 launches of Starship-sized rockets per year (2 launches per day) in perpetuity.
   - If the weight of space-based data centers per unit of compute is higher than claims by developers, significantly more launches would be required.
5. **Constellations of hundreds of thousands of space-based data centers would create serious risks. In many cases, mitigating these risks would depend on unproven or undemonstrated technologies. Known risks include the following:**
   - Dramatic alterations of the night sky, so that more satellites than stars would be visible at many times in many places around the world.
   - The creation of debris fields in low-Earth orbit, rendering portions of low Earth orbit unusable for years to come, impacting communications, Earth observation, weather forecasting and many other current satellite services.
   - Property damage and loss of life from disposing of tens of thousands of satellites per year by de-orbiting them into the atmosphere.
   - Increased depletion of the stratospheric ozone layer, driven by rocket fuel emissions during launches and by vaporized satellite components during de-orbiting.
   - Increased global warming, driven by rocket fuel emissions.
   - Significant interference with astronomical observations and research.
6. **Even if all foreseen risks are successfully managed, large constellations of space-based data centers would still have unavoidable impacts.**
   - These impacts include interference with infrared astronomy and very large numbers of rocket launches continuing for as long as the constellations are operational.

7. **There are many "known unknowns" and very likely some "unknown unknowns" with respect to large constellations of space-based data centers.**
   - "Known unknowns" include the technical potential for mitigating the brightness of constellations of space-based data centers, the impacts of de-orbiting large numbers of space-based data centers on the stratospheric ozone layer and the impacts of stratospheric black carbon on the global climate system.
   - "Unknown unknowns" could be very consequential, given the enormous scale of the infrastructure proposed for space-based data centers.
8. **Governance regimes with respect to space-based data centers are fragmented, with large gaps, and are not suited to large constellations of data centers in low Earth orbit.**
   - A patchwork of international and domestic laws covers some topics related to space-based data centers, but many risks are not fully covered by existing laws or regulations.
   - The international space regime was built in a different era, before private companies played central roles in launching and operating satellites and when the number of satellites in orbit was much lower than today. Other areas of international law with relevance mostly do not address operations in space.
   - Current international coordination mechanisms are not adequate to address potential congestion in low Earth orbit from hundreds of thousands of space-based data centers.
   - Nations playing a leading role in the development and deployment of space-based data centers have a wide range of uncoordinated laws on topics including orbital congestion, risks of ground damage and casualties, liability, AI and data governance.
   - Current legal regimes for registering space-based data centers allow for regulatory arbitrage.

B. Recommendations

1. Proceed with caution. Companies should not launch large numbers of space-based data centers until a range of significant risks and impacts are addressed.
    - These risks and impacts include transformation of night skies (so more satellites than stars are visible); collisions in low Earth orbit, creating debris fields that leave parts of low Earth orbit unusable for decades; uncontrolled space debris falling to Earth; significant stratospheric ozone depletion; increased global warming; and serious disruption of astronomical research.
    - In a filing with the US Federal Communications Commission (FCC), SpaceX wrote "Initial operations under this license will be limited to a significantly smaller number of satellites and re-entries than the maximum authorized, providing time to monitor actual effects, validate models with real-world data, and implement any necessary adjustments before scaling."[1] SpaceX and other companies should strictly follow the important principle set forth in this statement.
2. Require phased deployment. National regulators should require phased deployment of space-based data centers to better understand risks.
    - These deployments should proceed slowly, with careful attention to reducing risks. Licenses should be subject to annual renewals granted on the basis of performance in brightness mitigation, deorbit impacts, emissions reduction and other factors.
    - Deployment of other high-potential, high-risk technologies, such as autonomous vehicles, provide precedents for performance-based licensing.
3. Collect and share data. Governments, companies and other stakeholders should establish public-private partnerships to collect, share and analyze data related to space-based data centers.
    - Priority topics include the performance of novel satellite-brightness mitigation technologies, the impacts of satellite demise on stratospheric ozone depletion and the impacts of black carbon in the stratosphere on atmospheric warming.
    - Governments should invest in and expand public sector expertise on relevant satellite design and mega-constellation operations to provide neutral technical analysis of proposed private-sector plans.
    - Companies proposing to launch space-based data centers should provide significant funding for independent scientific research on these and other topics.
4. Learn from past accidents. In evaluating proposals for space-based data centers, policymakers should be mindful of accidents such as Deepwater Horizon and Fukushima.

- History teaches us that deployment of complex technologies can sometimes lead to tragic consequences, even in systems with well-established safety procedures, best practices and regulations. The Deepwater Horizon and Fukushima accidents are examples of such tragic consequences.
- Space-based data centers will employ a wide range of novel technologies that will, at first, lack well-established safety procedures, best practices or regulations. The risks from prematurely scaling space-based data centers are significant.

5. Protect night skies. **Operators should adopt visibility mitigation measures that prevent space-based data centers from being visible from the Earth's surface.**
   - National regulatory agencies should analyze dark-sky impacts as part of their public-interest review for satellite licensing and should not license constellations of space-based data centers that would be visible from the Earth's surface.
6. Protect astronomical research. **In addition to requiring the visibility mitigation measures in #5 above, national regulatory authorities should require operators of space-based data centers to disclose orbital position data and standardized thermal performance to astronomical observatories.**
   - The UN Committee on the Peaceful Uses of Outer Space (COPUOS) should formally adopt comprehensive "Dark and Quiet Skies" protocols that address optical, thermal and radio interference.
7. Manage orbital congestion and collision risks. **Space-faring nations should create an International Space Traffic Management Organization.**[2]
   - Slots in low Earth orbit should be assigned and managed to reduce or prevent overcrowding in key orbit altitudes and inclinations. National regulators should require space-based data centers to be capable of maneuvering either autonomously or manually by personnel available 24/7.
8. Protect life and property on Earth. **National regulators should not allow space-based data centers to be deployed at scale unless re-entry risks to life and property on Earth can be held to acceptable levels at a high level of certainty.**
   - Governments and companies should develop and implement protocols for safe disposal of satellites at end-of-life. Companies should provide financial assurances sufficient to compensate any victims, including through bonding or insurance policies. Parties to the Liability Convention should clarify the standard for fault and liability for service outages, data loss and environmental harms.
9. Do not deplete the ozone layer. **National regulators should delay large-scale deployment of space-based data centers until risks related to stratospheric ozone depletion are better understood through direct measurement of re-entry plumes and dedicated atmospheric modeling.**

- The Parties to the Vienna Convention should establish a standing study program focused specifically on the space sector, including space-based data centers. If further research suggests that space-based data centers and other space activities could present significant threats to the stratospheric ozone layer, the Parties to the Vienna Convention should amend the Montreal Protocol to address these issues.
- The US FCC should end its categorical exclusion for satellite launches under the National Environmental Policy Act (NEPA) and evaluate ozone depletion, climate change and ecosystem impacts before making decisions on constellations of space-based data centers.

10. Do not contribute to global warming. National governments should require life-cycle climate change impact assessments as a condition for authorizing launch and deployment of space-based data center constellations.
    - License applicants should disclose the life-cycle greenhouse gas emissions of space-based data centers and compare these results with terrestrial alternatives using transparent assumptions.
    - The Intergovernmental Panel on Climate Change (IPCC) should clarify that GHG emissions from rocket launches and related operations must be included in national emissions inventory reporting.
11. Protect against attacks. Regulatory agencies in spacefaring nations should designate space-based data centers as critical infrastructure and include cybersecurity requirements into license conditions.
    - Spacefaring nations should work in COPUOS and other international fora to establish protocols for notification of suspected attacks and procedures for de-escalating any conflicts.
12. Promote market competition. Governments should promote competition in markets for compute services in space.
    - National governments should consider (i) requiring dominant providers of launch services and satellite data-transfer capacity to offer access on fair, reasonable and nondiscriminatory terms and (ii) requiring that launch, compute and data-transfer services be provided by unaffiliated firms.
    - In deciding whether to adopt such measures, governments should consider the risk that such requirements could deter socially beneficial investments.
    - Competition authorities should closely scrutinize proposed mergers and exclusive arrangements, as well as self-preferencing by vertically integrated firms. International Telecommunication Union (ITU) Member States should consider whether priority-by-filing-date in the unplanned frequency bands adequately protects future entrants.

C. References

1 LLC) Cecilia Tenge-Rietberg (Space Exploration Holdings. SpaceX-Consolidated Opposition Re Orbital Data Centers (ICFS FIle No. SAT-LOA-20260108-00016) at p. 16; Scribd, Inc., San Francisco, California, https://www.scribd.com/document/1013879641/SpaceX-Consolidated-Opposition-Re-Orbital-Data-Centers-3-16-26 (2026).

2 Bruce McClintock Anca Agachi, Ryan J. Bain, Mélusine Lebret, Thomas Van Bibber, AaSHAE Eberle. Order in Orbit; RAND Corporation, Santa Monica, California, https://www.rand.org/pubs/research_reports/RRA3463-1.html (2025).