NATIONAL SPACE COUNCIL

USERS' ADVISORY GROUP

Enhancing Agricultural Resilience, Enabling Scalable Sustainability, and Ensuring Food Security through Space-based Earth Observations

National Space Council Users' Advisory Group
Climate and Societal Benefits Subcommittee

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Purpose

Space-based Earth Observations (EOs) are an essential public resource and play a critical role in visualization, real-time measurement, and monitoring of the changing planet. However, monitoring these changes is not enough. The U.S. and the global Space Observation community need to move at greater speed and scale to mitigate and adapt to climate change and concomitant biodiversity loss while ensuring our ability to meet the demands of an ever-increasing population. Government operated EO satellite data are released as a 'public good' in an 'open data' format. This is an excellent starting point, but these data are limited in scope, difficult to use without expert knowledge, expert systems, and often inaccessible to some users who might otherwise benefit.

Near-term opportunities exist to further EO applications for scalable solutions that provide societal benefit to address the challenges of climate change in high-impact areas such as agriculture, food security, wildfires, greenhouse gas (GHG) monitoring and reduction, and water resource management.

The paper highlights agriculture as a use case to explore the applications and current challenges surrounding wide-scale utilization EO. While EO holds promise for many applications, including the aforementioned, there are multiple challenges identified by this Users' Advisory Group (UAG) subcommittee that must be addressed to fully realize EO's potential to address these challenges and the impact of climate change. These include data quality, data accessibility, the need for additional information to contextualize EO insights, mission continuity/resilience, and institutional barriers that limit innovation.

Background

Agriculture plays a pivotal role in sustaining global societies and economies by providing essential resources like food, fuel, fiber, and feed. However, this sector faces an unprecedented challenge: the need to fortify itself against geopolitical upheaval, pandemic driven supply chain shock, and the impacts of climate change. It is anticipated that climate change impact will reduce arable land per capita, while evolving consumption patterns of a growing global population will contribute greater stress.[1]

The importance of the agricultural sector has become undeniable in global efforts to reduce GHG emissions to reach climate targets. While atmospheric carbon dioxide (CO_2) levels are often at the forefront of discussions on climate change, the contributions of other GHGs, including methane (CH_4) and nitrous oxide (N_2O), also need to be taken into account considering their global greater warming potential (~28x and ~273x, respectively) than CO_2 over a 100-year timescale.[2] According to the Intergovernmental Panel on Climate Change (IPCC)[3], **22%** of the total

[1]https://www.worldbank.org/en/topic/climate-smart-agriculture
[2]https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf
[3]https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf

anthropogenic emissions derive from Agriculture, Forestry and Other Land Use (AFOLU). If emissions from **pre- and post-production activities** in the global food system are also included, the emissions are estimated to be up to **37%** of total net anthropogenic GHG emissions.[4] Agriculture both contributes to and holds the potential to mitigate global anthropogenic GHGs.[5] Implementing sustainable farming techniques, such as cover cropping, conservation tillage and other climate-smart practices can sequester carbon, enhance soil health, improve water usage, and reduce CO_2, N_2O, CH_4 emissions. [6,7] Balancing the emissions generated by agricultural activities with these mitigation strategies is essential for fostering more sustainable and resilient food production systems.

In the context of global agriculture and the broader agri-food system, EO is a critical enabling technology to provide necessary solutions that consider major challenges (e.g., climate change, pandemic, etc.) faced today by aiding in improving land use, labor efficiency, and increasing agricultural output in a sustaining, regenerative manner. EO can improve supply chain optimization, resiliency, and loss reduction; promote more sustainable resource management and traceability; enable new kinds of farming technologies; and facilitate resilience to climate change via accurate early warning systems and enabling more affordable insurance and credit programs (especially for small holder farmers).[8] EO tools can also help derive better understanding of the complexity and interaction of agriculture and natural resource utilization and impacts (e.g., water resources, biodiversity, and land use change).

While precision agriculture tools are often associated with large farming operations, space-based EO can also benefit-small holder (<10 acre) farmers (SHFs). In this application, EO can offer SHFs (as well as farmer groups, governments, and development organizations like non-governmental organizations [NGOs]) the access to new insights and information that enable more efficient practices, the ability to compare crop production in relation to land/water resources in an unbiased, consistent, and scalable manner and overall system resiliency.[9] While access to digital technology is hampered by cost, lack of infrastructure, and low connectivity & coverage, EO systems and solutions can be utilized by tooling that is tailored for this kind of access and made user friendly for non-technical audiences. A recent example is the Integrated Rice Advisory System (IRAS)--a joint project between NASA and the University of Washington-- that sends SMS messages to SMHs in Bangladesh with guidance on optimizing water usage.[10] More broadly,

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[4] https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf

[5] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf

[6] Syswerda, S. P., Corbin, A. T., Mokma, D. L., Kravchenko, A. N., & Robertson, G. P. (2011). Agricultural management and soil carbon storage in surface vs. deep layers. *Soil Science Society of America Journal*, *75*(1), 92-101.

[7] McNunn, G., Karlen, D. L., Salas, W., Rice, C. W., Mueller, S., Muth Jr, D., & Seale, J. W. (2020). Climate smart agriculture opportunities for mitigating soil greenhouse gas emissions across the US Corn-Belt. *Journal of cleaner production*, *268*, 122240.

[8] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/736211/6.4502_UKSA_SPACEUK_Solutions_for_Agriculture_220818_CMYK_web.pdf

[9] https://blogs.worldbank.org/digital-development/sky-not-limit-satellites-support-smallholder-farming-part-1

[10] https://www.space.com/scientists-texting-water-conservation-advice-bangladesh-farmers-nasa-satellite

SERVIR, a joint initiative with NASA and USAID uses EO data to inform decision making at local, national, and regional scales in five hubs in the Global South.[11] With the slogan of "connecting space to the village," SERVIR focuses on promoting not only food security and resilience but extends the applications of EO to address "critical challenges in climate change, food security, water and related disasters, land use, and air quality."[12]

Precision and Climate-Smart Agriculture

EO enables visualization, monitoring, measurement, analysis, and forecasting of critical environmental factors such as weather patterns, water availability, vegetation cover, and GHG emissions that influence or can be impacted by agricultural systems.[13] Beyond the near- and long-term characterization of environmental influences, EO data provides the foundation for optimized agriculture through the development of precision agriculture tools that allow farmers to monitor the health of their crops in near real-time, allowing for early detection of pests, disease pressures and supporting targeted management strategies, enable the automation and scaling of farm production, and allow farmers to take the best decision possible to insure the best outcome.[14] EO-supported insights provide opportunities for farmers to adopt more site-specific management and activities tailored to specific field conditions, crops, and environments. For instance, EO data can guide precise planting, irrigation scheduling, pesticide application and documentation, minimizing environmental impacts and maximizing yields.[15]

Digital tools for nitrogen (N) scripting currently exist and are based on yield maps or vegetation indices from EO (e.g., normalized difference vegetation index; NDVI) and may allow for in-season monitoring of crop N status and thus more precise applications. However, these tools also have variable levels of uncertainty which affects user uptake in terms of risk tolerance (potential yield loss) and ease of use. Enhancements in EO technology with new satellites, sensors, and computing power (as discussed below) can help mitigate these pain points by enabling the next generation of N-management tools. Given that fertilizer application is a significant source of N_2O emissions in agriculture[16], enhanced digital agriculture tools for N management, combined with other agricultural advancements such as crops with increased nitrogen utilization efficiency, and microbial treatments can work together to enhance farmer adoption of climate-smart N management.

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[11] https://www.nasa.gov/mission_pages/servir/index.html

[12] https://www.nasa.gov/mission_pages/servir/overview.html

[13] https://nasaharvest.org/news/space-farm-how-earth-observation-technologies-are-revolutionizing-global-agri-food-systems

[14] https://nasaharvest.org/news/space-farm-how-earth-observation-technologies-are-revolutionizing-global-agri-food-systems

[15] Sishodia, R. P., Ray, R. L., & Singh, S. K. (2020). Applications of remote sensing in precision agriculture: A review. *Remote Sensing*, *12*(19), 3136.

[16] https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

These types of data-driven insights allow farmers to conserve resources and minimize [food] loss while optimizing their farm and land's productivity in a sustaining manner.[17] Further, EO can support initiatives promoting sustainable land management practices by monitoring changes in land use, including degradation and restoration efforts.[18]

With the proliferation of EO data and technologies, government regulators are now able to pass new rules and legislation to support more sustainable agriculture practices. The recent European Union Deforestation Regulation (EUDR) requires companies trading in six commodities to conduct diligence in their supply chain to ensure the goods do not result from recent deforested land and EO data will be the central source of data for compliance.

The U.S. Congress is currently debating reauthorization of the Farm Bill, an omnibus, multiyear law that governs an array of agricultural and food programs. Among the many issues congress will consider in the Farm Bill is how to incentivize the development and deployment of digital technologies to enable farmers to increase production and improve sustainability.

Several bi-partisan bills have been introduced this year to foster precision agriculture and help fund and deploy digital technologies and broadband. Examples include H.R. 1339, the *Precision Agriculture Satellite Connectivity Act and* S. 734, the *Promoting Precision Agriculture Act* to help facilitate further adoption of precision agriculture technology.

These bills provide models and show pathways on how government can support and improve the access and utilization of technologies to serve a broader group, often empowering the private sector as a key driver to build digital applications.

Earth observation not only can play an innovative role in verifying the adoption of sustainable agriculture practices and emission reduction efforts, but it can be argued is a critical component to scale these activities and benefits. Adoption of practices such as cover crops and conservation tillage at scale require EO to play a role in documentation of practice adoption and quantification of carbon sequestration.[19,20] These practices are the core elements in the creation of agri-centric carbon credits/offsets.[21] Carbon credits (in both voluntary and compliance markets) are certified through registries and 3rd party verification companies which have established standards and

[17] https://www.aem.org/news/the-environmental-benefits-of-precision-agriculture-quantified

[18] Karra, K., Kontgis, C., Statman-Weil, Z., Mazzariello, J. C., Mathis, M., & Brumby, S. P. (2021, July). Global land use/land cover with Sentinel 2 and deep learning. In *2021 IEEE international geoscience and remote sensing symposium IGARSS* (pp. 4704-4707). IEEE.

[19] Thieme, A., Yadav, S., Oddo, P. C., Fitz, J. M., McCartney, S., King, L., ... & Hively, W. D. (2020). Using NASA Earth observations and Google Earth Engine to map winter cover crop conservation performance in the Chesapeake Bay watershed. *Remote Sensing of Environment*, *248*, 111943.

[20] Wang, S., Guan, K., Zhang, C., Zhou, Q., Wang, S., Wu, X., ... & Ma, Z. (2023). Cross-scale sensing of field-level crop residue cover: Integrating field photos, airborne hyperspectral imaging, and satellite data. *Remote Sensing of Environment*, *285*, 113366.

[21] https://verra.org/methodologies/vm0042-methodology-for-improved-agricultural-land-management-v2-0/

protocols for quality and traceability.[22] The methodologies to measure, monitor, report and verify (MMRV) GHG assertions are prescriptive and both labor and cost intensive (e.g., field sampling).[23] The effort to ensure compliance with these requirements is a deterrent for farmers to engage in adopting climate-smart practices and unlocking additional profits that could be realized from 'carbon farming.'[24] The academic community, governments, and private sector technology providers have recognized these hurdles prompting increased research and development of 'alternative' MMRV platforms utilizing EO solutions as these technologies, (when combined with appropriate model and ground-truth data) offer the opportunity for unbiased, cost effective, and relatively accurate assessment and tracking of climate-smart initiatives. The U.S. Government (USG) Greenhouse Gas Monitoring & Measurement Interagency Working Group recently released a draft report outlining a framework for MMRV and removals for the agriculture and forest sectors and identified EO as a research priority "to identify activities (e.g., tillage) and/or estimate environmental variables (e.g., burned areas) critical to GHG estimates. EO data can also measure quantities such as surface soil moisture, which can inform and enhance estimates of GHG fluxes."[25] This low-touch verification process is critical for assessing the adoption and ensuring the effectiveness of such practices at a global scale. Additionally, a globally scalable EO approach can facilitate wider adoption of climate-smart agricultural practices by removing some of the costly barriers to MMRV, allowing farmers to maximize financial incentives for such practices.

Technology Enhancements

To address the challenges posed by climate change and our growing population, it is imperative to advance innovative approaches to enhance agricultural productivity and sustainability. In this context, the utilization of EO technology, coupled with advancements in cloud computing and data fusion techniques, has enabled new forms of digital centric tools and solutions that have utterly transformed agriculture. These solutions have been game-changers enabling the scaling of agriculture through improved efficiency and industrialization while being more sustainable (more with less). EO has become not just a luxury but a necessary utility to enable and allow modern/current farming. Further advancements to improve the frequency of observations and spatial scale, such as satellites in constellations, will be critical to drive the accessibility and scalability of agricultural applications. Novel satellite constellations, such as those from commercial providers like Planet, collect higher-resolution imagery more frequently compared to traditional satellite missions making them particularly beneficial for precision agriculture applications.[26]

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22 https://www.card.iastate.edu/products/publications/pdf/22pb37.pdf

23 https://www.card.iastate.edu/products/publications/pdf/22pb37.pdf

24 https://www.europarl.europa.eu/RegData/etudes/STUD/2021/695482/IPOL_STU(2021)695482_EN.pdf

25 https://www.usda.gov/sites/default/files/documents/Draft-Federal-Ag-and-Forest-MMRV-Strategy.pdf

26 Mulla, D. J. (2021). Satellite remote sensing for precision agriculture. *Sensing Approaches for Precision Agriculture*, 19-57.

While EO data from optical sensors has traditionally been used for agricultural applications, multispectral, hyperspectral (including sun-induced fluorescence) and similar advanced non-optical EO technologies will drive the next generation of agriculture solutions, services, and technologies, including those that are critical to the measurement and implementation of sustainable agriculture practices.[27] More recently, platforms initially developed for non-agriculture uses, such as the Global Ecosystem Dynamics Investigation (GEDI) lasers aboard the International Space Station (ISS), have been used in conjunction with more traditional optical sensors to enhance applicability to agricultural applications.[28] Satellite constellations can be integrated with Internet of Things (IoT) devices and networks on the ground to create a more comprehensive data ecosystem for agriculture. This integrated approach offers a holistic view of agricultural systems, enabling farmers to make data-driven decisions and automate various farm operations.

Accessibility

While the private sector continues to develop and bring to market new innovations, such as EO for carbon MMRV, limitations still exist due to the prohibitive cost. Three of the most significant advancements in agriculture over the past three decades have been the provision of free/near-free access to public satellite imagery, Global Positioning System (GPS), and Soil Survey Geographic Database (SSURGO) data, leading to innovations like precision agriculture tools.[29,30] Providing higher resolution publicly available EO data will be invaluable for the accessibility and development of cost-effective carbon MMRV and more refined digital agriculture tools.

To realize the societal benefits of EO applications more fully in high-impact areas such as agriculture, and to drive broader and more equitable access of EO data, governments and space agencies can adopt open data policies, supporting EO data as a public utility. By promoting open access, innovators, researchers, and farmers can better utilize EO data to develop fresh solutions for agriculture. Establishing common standards and formats can ensure interoperability, allowing user communities to access and integrate data from diverse sources. Likewise, user-friendly interfaces, visualization tools, and application programming interfaces (APIs) can enable non-expert users to effectively access and interact with the data and develop innovative solutions tailored to the needs of farmers at local and regional scales.

Encouraging collaboration between space agencies, technology companies, research institutions, and agricultural stakeholders can also promote the development of innovative solutions. Public-private partnerships can drive the integration of EO data with other datasets, such as weather

[27]Mulla, D. J. (2021). Satellite remote sensing for precision agriculture. *Sensing Approaches for Precision Agriculture*, 19-57.
[28]Stefania Di Tommaso *et al* 2021 *Environ. Res. Lett.* **16** 125002
[29]https://www.gps.gov/applications/agriculture/#:~:text=The%20accuracy%20of%20GPS%20allows,samples%20or%20monitor%20crop%20conditions
[30]https://ohioline.osu.edu/factsheet/fabe-55204

information or ground-based sensor data, to provide trusted standards to power novel digital applications for agriculture.

Climate change, the drive to reduce GHG emissions, biodiversity loss, fragile supply chains, and a growing population have placed new pressures on our agricultural systems. Considering these headwinds, the development of innovative technologies, applications, and approaches that can contribute to sustainable farming practices, increased productivity, and improved resource management are critical. Making space based EO data more accessible and usable and the concurrent advancements like increased frequency, resolution, and sensors (e.g., hyperspectral) will drive the next generation of ag solutions at a global scale. Capitalizing on new/evolving technologies like Artificial Intelligence (AI), Machine Learning, improved computing, and cheap storage capable of ingesting more data will allow users to leverage EO from a variety of sources (e.g., NASA missions, ESA missions, private constellations). The combination will provide not only new insights but ensure that EO-based insights are used to their fullest potential.

Specific Challenges and Considerations

While EO holds promise for agricultural applications, there are challenges identified by this subcommittee that must be addressed to fully realize its potential to address the challenges of climate change. These include data quality/ accessibility, the need for additional information to contextualize EO insights, and institutional barriers that limit innovation.

Findings and Recommendations of the Subcommittee:

1. The **EO is vital:** Space-based Earth observations (EO) play a critical role in real-time measurement and monitoring of the changing planet.

2. **Monitoring is not enough:** The US and the global community need to move at greater speed and scale to mitigate and adapt to climate change to improve our resiliency.

3. **We can do more:** Near-term opportunities exist to further EO application for societal benefits in high-impact areas such as agriculture, wildfires, greenhouse gas monitoring and reduction, and water resources.

Considering the critical need for agriculture to perform under the challenges of climate change and the potential the EO must enable insights and tools for more sustainable and resilient agricultural systems, the recommendations in the following four pages should be adopted to address Climate and Societal Benefits:

Recommendation 1: Earth Information and Action Lead (EIAL)

Finding:

- The demand for Earth-related information products has increased significantly demonstrating the vital role that space-based EO play in the Nation's ability to understand, respond, and prepare for climate-related and other societal challenges.

Recommendation:

- To establish an over-arching leadership role within the National Security Council to assess, prioritize, and guide the Nation's multi-agency EO effort along with consideration of private sector capabilities for the purpose of accelerating and improving environmental information and action promoting greater resiliency.

Rationale for Recommendation:

- The urgency and complexity of climate change and its importance to our national interests demands new thinking and approaches. USG EO efforts are spread across several agencies and guided by different missions, priorities, subject areas, science versus operations frameworks, budget structures, planning processes, private sector engagement mechanisms, and end users. For the U.S. to strengthen this critical capability, maximize its multi-billion-dollar annual investment, and capitalize on rapidly-emerging private sector offerings, an over-arching leadership position is needed to guide and advance this national effort.

Consequences of No Action on the Recommendation:

- The U.S. will fail to meet the information needs of government organizations, businesses, and citizens who require the best, most timely, thorough, trusted environmental insights to guide decision making and ensure our national resiliency to adverse events (e.g., climate change, pandemics, etc.).

Recommendation 2: Engagement with the private sector

Finding:

- Applications enable accessibility, and the private sector excels at connecting Americans to EO data. However, there are barriers to USG engagement with private and nonprofit users on space-based data.

Recommendation:

- The USG should work to streamline applications of EO for societal benefit.
- The Earth Information and Action Lead should leverage existing authorities and appropriations to create partnerships that enable public, nonprofit, and commercial applications of EO for climate action and societal benefit.

Rationale for Recommendation:

- Mitigation action is not moving with the speed and scale necessary to prevent dangerous climate change.
- The weather enterprise is a model for a partnership that leverages freely available USG data, allows private business to add value through interfaces, and provides wider societal benefits.
- Other public-private-nonprofit partnerships have emerged to communicate risk and shape choices in a changing climate.
- New opportunities exist for the private sector to engage with EO data to drive innovations in existing sectors such as agriculture and nascent industries such as carbon management.

Consequences of No Action on the Recommendation:

- The U.S. fails to respond to climate change at the speed and scale required, nascent industries will not receive crucial support, and existing industries will not benefit from public and private investments in space data.

Recommendation 3: Modernize data systems

Finding:

- Outdated systems inhibit data discovery and use.

Recommendation:

- The Administration should work across government agencies and missions (NASA, NOAA, USGS, DoD, IC) to standardize and require better data architectures, standards and interoperability for broader use and more equitable access within the USG, industry, and user communities. This process should also identify areas where EO applications can digitize workflows and incorporate advanced AI or machine learning methods.

Rationale for Recommendation:

- It is necessary but not sufficient for data to be “open”; it must also be standardized, discoverable, interpretable, and useful. Right now, it is not.
- Small companies and start-ups have limited access to and time with experts and often insufficient resources to do much more than surface the data.
- Advanced technologies such as AI and machine learning are under leveraged in the public sector, while insufficient, unreliable, or inaccessible data hamper the private sector’s ability to apply these tools.

Consequences of No Action on the Recommendation:

- Inequities will be perpetuated: communities and groups who might benefit from data will be unable to access and use it.
- Government and private sector resources that could be put to better use will be wasted on accessing and downloading data.

Recommendation 4: Space data ethics

Finding:

- New capabilities raise new ethics considerations.

Recommendation:

- The National Academies should convene a group to develop a framework for space data ethics, as distinct from existing data ethics.

Rationale for Recommendation:

- Existing data ethics frameworks appear ill-equipped to evaluate responsible use of space data given different and more diverse data subjects, purposes, interests, risks, etc. Given its unusually broad diversity, space data may draw from or inform related fields, such the ethics of data, AI, surveillance, intelligence, research, open data, citizen science, and more. Because space data may be combined with other data, the synthesis of the two also should be examined for new ethics considerations, e.g., if new or special risks can arise.

Consequences of No Action on the Recommendation:

- Without identifying a responsible path forward, we risk both oversharing data that can be abused and under sharing data that could benefit us and the world. This can affect our national security, economy, and other domestic interests, as well as global interests, such as climate change.