Use of Long Endurance Uncrewed Aerial Vehicles to Complement the Space-Based Earth Observing System

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1. What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?

Creating a comprehensive integrated observing system in an environment of stagnant budgets is a key challenge for Earth System Science operations. An integrated observing system would complement existing space-based assets by providing airborne and ground measurements to advance NASA's and the broader Earth Science research community's science goals. Specifically, coordinated, cross-Agency investments in an integrated observing strategy could enable more rapid progress toward answering a broad array of key science needs such as gaining a better understanding of and improving predictive capability for changes in climate forcing and air quality associated with changes in atmospheric composition.

For example, understanding of *how the sources of methane are changing over time* requires a coordinated approach. Satellite observations provide important data locations of persistent atmospheric “hot” spots of high methane concentrations (like the U.S. 'Four Corners' region). But, the relative infrequency and inadequate spatial/vertical detail of satellite observations does not enable the community to understand why these hot spots exist. Airborne measurements can provide the finer resolution that are required to identify sources (e.g., coal bed methane extraction, active coal mines, natural gas seeps, thawing permafrost) and processes that lead to enhanced methane emission for state/local decision makers. Airborne and ground measurements can also provide important data for validating and constraining top-down emission estimates from the satellite data.

The need for synergistic measurements (with higher spatial and temporal resolution) involving multiple instruments (e.g., radar, radiometer, and lidar observations), and different platforms (e.g., geosynchronous, low-Earth orbit, and airborne) is well-recognized throughout the community but the available budgetary resources are limited. In order to close this gap and answer the key science questions, new types of platforms (e.g., small satellites, cube sats, and long-endurance (LE) uncrewed aerial vehicles) are needed. This NOI describes how one of these alternative platforms, LE UAVs, can fulfill an important part of the observing system and complement space-based measurements.

2. Why are these challenges/questions timely to address now especially with respect to readiness?

Space-based instruments have provided critical observations of the Earth's atmosphere and surface over the last 50+ years. These observations have enabled the Earth Science community to gain an almost infinite improvement in their understanding of the weather and climate system. It is clear that a space-based Earth observing system will continue to be critical over the coming decades to monitor weather and climate change. Despite the vast array of benefits provided by space-based platforms, it has also become clear to the community that space-based platforms have key limitations that inhibit our understanding of processes that occur at fine temporal and spatial scales. In addition, development of new satellite programs requires a significant financial commitment over a number of years, a hurdle that can inhibit innovation and limit progress toward addressing critical science questions.

It is imperative that the community continues to develop alternative Earth observation instruments and platforms that can fill gaps in our existing observational network and knowledge at an affordable cost. Airborne field campaigns have been conducted in recent years to study a variety of processes and phenomena at fine detail, validate satellite-based observations and derived products, and demonstrate new instrument technology that could later be flown in space. These campaigns are invaluable to the Earth Science community and can be conducted a relatively low cost (10s of millions vs. 100s-1000s of millions for a satellite program). But these campaigns are typically focused over limited geographic domains and cannot be sustained for long time periods (i.e. continuous flight for one-week) due to the limited endurance of "traditional" crewed aircraft (see Figure 1) and strain on aircraft crew and campaign science teams.

Airborne assets such as LE UAVs could fly autonomously and continuously for multi-day time periods, offer unique capabilities that cannot be provided by other observing platforms. LE UAVs could collect detailed observations at fine spatial and temporal scales over broad geographic regions, representing a bridge between previous short-term and geographically limited crewed aircraft campaigns and long-term but coarse space-based observations. Recently, NASA and NOAA have begun to demonstrate the value of LE UAV observations to the Earth System Science community with the NASA Global Hawk. The Global Hawk provides up to 30 hours endurance, can fly at a 65,000 foot altitude, and can be outfitted with a variety sensors that weigh up to ~2000 lbs. The Global Hawk was able to fly above and around the tropical cyclones and hazardous thunderstorms within the NASA Hurricane and Severe Storm Sentinel (HS3) and the NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT) programs, collecting innovative and sustained observations of storm internal structure and the surrounding environment. These observations have helped scientists to better understand dynamical processes occurring within storms and the wind flow that dictates their path. Cyclone intensity and track predictions improve when these observations, in concert with satellite-based and other conventional datasets, are assimilated into numerical weather prediction models. The Global Hawk has also been used to provide a comprehensive set of water vapor, cloud, and air chemistry observations within the tropical tropopause and lower stratosphere through the NASA Airborne Tropical TRopopause EXperiment (ATTREX). The Global Hawk was used to profile the atmosphere at high altitudes over remote oceanic regions that would otherwise be inaccessible to existing crewed research aircraft.

Over the coming decade, a new set of LE UAVs will be emerging with support primarily from the defense and information technology industries (Google, Facebook, and many others). LE UAVs currently being tested and/or developed will offer 5-7 day endurance or greater with maximum altitudes above of 60,000 feet, capabilities that far exceed those of the Global Hawk and other crewed aircraft (see Figure 1). These vehicles would be outfitted with state of the art autonomy and sense and avoid technologies that will enable flight above populated regions, assuming the continued development of Federal Aviation Administration regulations governing safe operation of UAVs in the National Airspace System. Most significantly, these vehicles are being designed to overcome the key challenges faced by today's UAV platforms, namely operational cost and large logistical ground footprints, proprietary systems and interfaces that limit payload modularity and flexibility, and extensive and time consuming mission planning requirements. The net result is a potential "satellite-like" atmospheric monitoring capability at greatly reduced cost.

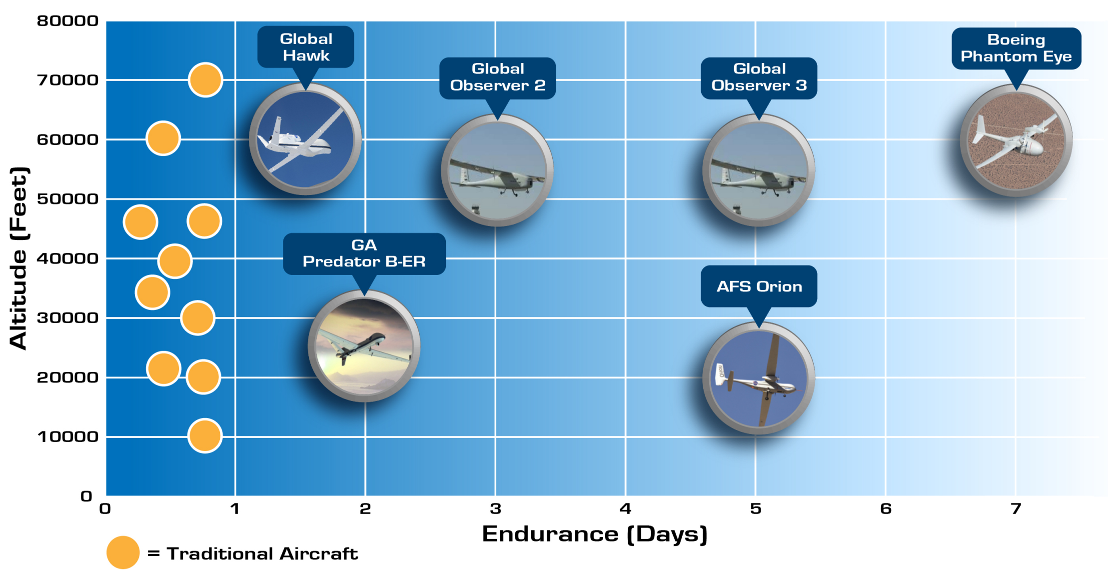

Figure 1: The relationship between endurance and maximum cruise altitude of "traditional" crewed NASA research aircraft (e.g. ER-2, WB-57, DC-8, and King Air) relative to current and proposed next-generation LE UAVs.

3. Why are observations from alternative observational platforms fundamental to addressing these challenges/questions?

The capabilities of LE UAVs enable a wealth of new science that can greatly complement and enhance the space-based observing system over the coming decades. A constellation of LE UAVs could be operated continuously over land and ocean, downlinking data to the ground for immediate visualization by forecasters or assimilation into numerical weather prediction (NWP) models. A LE UAV could perform targeted observations in regions where there is the most uncertainty in the NWP model analysis, thereby improving forecasts of high impact weather events. LE UAVs could loiter over a given region for long time periods, providing valuable insight into the evolution of processes such as transport and diurnal variability of pollution from urban areas. LE UAVs can also follow features such as smoke, volcanic ash, or pollution plumes with time to study their characteristics and evolution throughout their lifetime, in addition to identifying potential hazards for commercial aviation flying 20,000+ feet below. The endurance of LE UAVs enables them to reach regions typically inaccessible to crewed research aircraft such as the Southern Pacific Ocean or the Poles. Long range also enables collection of a comprehensive database of cloud, chemistry, and aerosol properties over broad geographic regions, a process that would be very costly or, in some cases, impossible to do. LE UAVs can also help to perform rigorous validation of satellite-derived products and collect necessary training datasets to enable development of more accurate products. The much lower altitude of the UAV relative to a satellite permits detailed vertical profiling of the planetary boundary layer, a capability not provided by most satellite-based instruments. Another valuable aspect of a UAV is that, if an instrument were to fail in some way, the UAV can land and the instrument could potentially be replaced or repaired in a short period of time which would not currently be possible with a satellite.

The capabilities of next-generation LE UAVs will cause a paradigm shift in how the community collects Earth Science observations. Instead of operating UAVs like aircraft which require a large support team on the ground, a satellite-like operational concept can be applied where a fleet manager oversees the autonomous operation of multiple airborne assets with very little required hands-on interaction. This new paradigm will enable a “satellite-like” monitoring capability at a fraction of the cost of a large satellite mission with the inherent flexibility of aircraft-based operations. LE UAVs represent an emerging Earth Science and Applications support capability, offering opportunities to leverage existing interagency activities to augment space-based Earth observations and improve overall resiliency. An upcoming Decadal Survey White Paper will provide greater detail on our vision of how LE UAVs will complement space-based observations and serve as a critical component within an integrated Earth observing system.