Consensus Study Report

MAY 2021

HIGHLIGHTS


# Airborne Platforms to Advance NASA Earth System Science Priorities:
## Assessing the Future Need for a Large Aircraft

Observations have always been essential for humans to understand the Earth system and to thrive. A major focus of NASA's integrated Earth system science research strategy is the ongoing collection of Earth observations through a variety of satellites, suborbital airborne platforms, and surface measurements. Together, data from those observations inform societally relevant decisions ranging from weather prediction to the management of air pollution to the assessment of sea-level rise.

Produced at the request of NASA, this report provides guidance about future needs for airborne platforms to achieve Earth system science research goals. Specifically, the report examines the combination of suborbital airborne platforms that can best contribute to meeting priority science questions identified in a National Academies' decadal survey of Earth science applications from space published in 2017 (referred to as ESAS, see Box 1). Special emphasis was placed on identifying the emerging science and research questions that can be best addressed with large aircraft similar to the Douglas DC-8-72 (hereafter DC-8) in NASA's current fleet, which carries multiple instruments and investigators for their onboard operation.

### AIRBORNE SCIENCE NEEDS FOR ADVANCING ESTABLISHED SCIENCE AND APPLICATIONS PRIORITIES

This report focuses on six of the priority research areas identified in ESAS in which airborne platforms are used to undertake research. For each area, the study considered the role of large and small aircraft, the types of variables to be measured, the contribution of newly available airborne platforms, and the support that airborne platforms provide for satellite calibration and validation, computer model testing, instrument development, and workforce training and development.


**Figure 1.** As shown in this conceptual diagram, the foundation of integrated Earth system science research is the collection of Earth observations via numerous spaceborne observations from satellites and the International Space Station; airborne observations from piloted aircraft, uncrewed airborne systems, and balloons; surface and subsurface observations for land and water as well as remote sensing from the surface.

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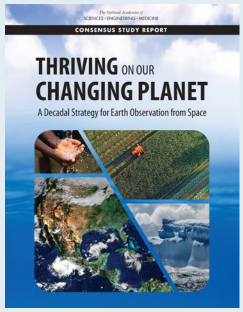
**Box 1. What priority science questions can airborne platforms address?**




Published by the National Academies in 2017, *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space* (referred to as ESAS) provides strategic and programmatic guidance to support the U.S. civil space Earth observation program over the coming decade. Using nearly 300 submitted white papers as well as input from five interdisciplinary panels, the report identified 35 key Earth science and applications questions that should be addressed over the next decade. Many of those priority areas require observations from suborbital airborne platforms.

Key conclusions from this analysis in each of the science areas include:

- **Coupling of the water and energy cycles**: Advancing understanding of the terrestrial water cycle requires observations collected at multiple spatial and temporal scales, which can be conducted on small, agile aircraft that can acquire measurements over a range of altitudes, at different flight speeds, and at multiple times of day. A large aircraft is required for studies of the Earth's coupled water and energy processes.
- **Physics and dynamics for improving weather forecasts**: To obtain comprehensive sets of measurements covering a wide range of temporal and spatial scales needed for advancement in the weather area, a large aircraft is necessary to meet the requirements for the flight duration, altitude range, and large payload capacity to carry lidars, radars, and in situ onboard and deployable instruments.
- **Air quality and atmospheric chemistry—chemistry coupled to dynamics**: Understanding the interplay between future changes in atmospheric composition due to anthropogenic activity and air quality, climate change, and ecosystem dynamics will require a continuation of the airborne science capabilities that the DC-8 has afforded.
- **Ecosystem change—land and ocean**: Future airborne research for ecosystems, including interdisciplinary science, will incorporate multi-instrument, multi-investigator deployments that will require a large aircraft's heavy lift and size capacity, and some missions will likely require long duration.
- **Sea-level rise in a changing climate and coastal impacts**: A long-range aircraft is essential for assessing the contributions of Antarctic and Greenland ice sheet melt to sea level rise and has been invaluable in the past for filling data gaps between satellite missions.
- **Surface dynamics, geological hazards, and disasters**. Small aircraft have been and will continue to be a key platform type in this area. However, the long-range capacity of a large aircraft that could host many sensors (e.g., synthetic aperture radar of several bands and/or lidar and optical instruments) could enhance data collection over a long distance and duration, improving efficiency and temporal sampling for interdisciplinary sciences over a large geographic scale.

The need for a large aircraft for interdisciplinary science to meet societal needs was also considered. Many emerging societal applications require advancing understanding, prediction, and decision making on topics spanning multiple disciplines. A large aircraft can provide the needed capability to allow for integrated and co-located observations of multiple components of the Earth system, using multi-instrument payloads and air-deployable devices. Smaller aircraft and uncrewed airborne systems are also critical, particularly when science questions do not require co-located, simultaneous observations.

## THE VALUE OF A LARGE AIRCRAFT IN EARTH SYSTEM SCIENCE RESEARCH

A large aircraft that has the DC-8–like combination of long duration, heavy lift, multiple ports, and cruising ability at all altitudes from Earth's planetary boundary layer up to about 12.5 km provides unique value to Earth system science research. A large aircraft is needed to:

- Address research needs in the areas of physics and dynamics for improving weather forecasts, air quality and atmospheric chemistry—chemistry coupled to dynamics, and the atmospheric component of the coupling of the water and energy cycles. For example, answering questions requiring simultaneous observation of rapidly changing weather conditions with co-located in situ and remote sensing instrumentation is better accomplished with a large aircraft.
- Provide opportunities for innovative approaches to address some key questions in ecosystem change—land and ocean; surface dynamics, geological hazards, and disasters; and sea-level rise in a chang-

ing climate and coastal impacts, especially those that require multisensor measurements or occur in remote regions.

- Enable increasingly interdisciplinary airborne research, by providing important flexibility to accommodate and enable new approaches and needs for multi-instrument and air-deployable payloads and collect novel combinations of observations simultaneously.
- Support instrument development, particularly for new instruments that will likely be large and heavy, require a greater amount of power, be more conservatively designed, and be operated by people on board; and to allow new instrument prototypes to be operated on the same airborne platform as the legacy instruments they are replacing so that the performance can be compared and evaluated.
- Calibrate and validate space-based remote sensing observations in widespread locations by carrying multiple instrument payloads for measuring many atmospheric constituents or properties, and conducting vertical profiling under satellite overpasses and over surface-based facilities in widespread locations.
- Engage and train the next generation of Earth system scientists, by providing opportunities for students and early-career scientists to participate in airborne missions and serving as an effective facility for attracting, training, and developing a diverse workforce.
- Provide capacity to examine unexpected environmental events that have serious detrimental effects on human health, societies, and economies, by enabling immediate research responses to understand the underlying science and devise sound mitigation strategies.

**Recommendation 1: NASA should acquire, maintain, and operate a large aircraft as part of its aircraft fleet in order to address priority questions developed for the 2017 Earth Science and Applications from Space Decadal Survey and to support satellite calibration and validation, computer model testing, instrument development, and workforce training and development.**

**Recommendation 2: To meet NASA objectives, a new large aircraft must have characteristics comparable to or better than those of the DC-8 in terms of payload capacity, altitude and distance ranges, instrument sampling port versatility, instrument integration, and durability.**

## THE BROADER NASA AIRCRAFT FLEET

A new large aircraft is a necessary member of the NASA fleet, but is only one key contributor to the diverse array of airborne platforms needed to address the variety of Earth system science objectives as prioritized in ESAS. Airborne platforms with diverse specifications of payload, range, altitude, onboard pilot, and operational flexibility form a complementary fleet that can meet a wide range of mission objectives, often in collaboration with airborne platforms in the fleets of other research agencies, private organizations, and other countries.

Smaller airborne platforms in the fleet include piloted aircraft as well as UAS and balloons. As remote sensors continue to get smaller and lighter, the role of UAS in Earth system science research will expand dramatically. Large helium-filled balloons are currently the only way to sample the middle stratosphere in situ. In addition, while there are some promising developments in high altitude, long-duration UAS, and in steerable balloons, these technologies may not advance quickly enough to contribute significantly to Earth system science research within the next decade.

**Recommendation 3: NASA should continue operating a diverse array of airborne platforms in addition to a large aircraft, as part of the broader government, university, and commercial fleet, in order to meet the evolving airborne needs for advancing Earth system science research.**

## PRIORITIZING AND ENABLING INTERDISCIPLINARY EARTH SYSTEM SCIENCE RESEARCH USING A LARGE AIRCRAFT

The inherent complexity of the Earth system, emerging questions resulting from a foundation of disciplinary knowledge, and rapid Earth system changes being observed today highlight the need for growth in interdisciplinary research to meet societal needs.

Large aircraft can carry suites of instruments necessary to make the simultaneous measurements needed to answer wide-ranging interdisciplinary research questions across components of the Earth system. Currently, airborne remote sensing of Earth's surface is accomplished using aircraft smaller than the DC-8 for several reasons: with the miniaturization of remote sensing instruments, a large payload is not needed; incompatible observing requirements for some combinations of remote sensing instruments on a large aircraft have made a combined payload undesirable; the DC-8's high operating costs exceed available budgets; large, multi-investigator projects in some areas such as ecosystems have not needed the DC-8 during the past 15 years; and the perception that the DC-8 would not be available impeded requests.

By proactively seeking proposals involving innovative approaches for using a large aircraft to accomplish interdisciplinary and surface remote sensing research, in addition to new disciplinary research, NASA will increase the impact that a large aircraft can have on achieving its Earth system science research goals.

**Recommendation 4: NASA should continue to solicit large aircraft requests that span the breadth of NASA Earth science, especially encouraging those for interdisciplinary science across the interfaces of Earth system components with integrated multi-instrument payloads and novel strategies for remote sensing and in situ observations.**

## LARGE AIRCRAFT FOR TRAINING, OUTREACH, AND WORKFORCE DEVELOPMENT

Future advancement of NASA Earth system science research depends on the continual emergence of early-career scientists to develop new measurement concepts, make measurements, and eventually take over field study leadership roles currently held by more senior scientists. A large aircraft is an important facility for attracting, training, and developing a diverse workforce and engaging the public because it provides the space to accommodate additional passengers beyond the core scientists and crew needed to carry out the mission.

Creating a more diverse workforce starts with attracting members of underrepresented groups to science, technology, engineering, and mathematics (STEM). General public knowledge events, such as taking reporters on research flights and holding open houses with tours of the aircraft during missions, help to generate public knowledge and spark interest in Earth system science and research opportunities.

**Recommendation 5: NASA is encouraged to build on the training and outreach opportunities it has established using the DC-8 and use a future large aircraft to expand its efforts to attract, develop, and train the next-generation workforce, with particular emphasis on diversity, equity, and inclusion, to foster the capacity to conduct international Earth system science research, and to inform the public.**

**Recommendation 6: NASA is encouraged to continue building on its use of the large aircraft capacity to enable scientists with next-generation measurement concepts, especially early-career scientists, to become active participants in Earth system science research, even beyond airborne science research.**


## COMMITTEE ON FUTURE USE OF NASA AIRBORNE PLATFORMS TO ADVANCE EARTH SCIENCE PRIORITIES

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For More Information . . . This Consensus Study Report Highlights was prepared by the National Academies of Sciences, Engineering, and Medicine based on the Consensus Study Report *Airborne Platforms to Advance NASA Earth System Science Priorities: Assessing the Future Need for a Large Aircraft* (2021). The study was sponsored by The National Aeronautics and Space Administration. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project. Copies of the Consensus Study Report are available from the National Academies Press, (800) 624-6242; http://www.nap.edu or via the Board on Atmospheric Sciences and Climate web page at http://www.nationalacademies.org/basc or the Space Studies Board webpage at https://www.nationalacademies.org/ssb.

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