National Aeronautics and
Space Administration

EXPLORE EARTH

NASA support for HAPS development and testing

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** Prepared with inputs from numerous colleagues from NASA HQ, centers, and research community*

Why is NASA engaged here?

- HAPS interests across NASA Directorates:
  - Space Technology Mission Directorate (STMD)
    - Smallsat Payload and component testing
  - Science Mission Directorate
    - Earth and Space science observations
  - Aeronautics
    - Enabling access to airspace and exploiting HAPS for improving aviation safety
- Stratospheric observations help simulate measurements through 98% of the atmosphere.
- HAPS provide a unique vantage point for mission critical measurements requiring high spatial and high temporal resolution.

Why NASA?

- Land Remote Sensing Policy Act of 1992 P.L. 102-555 (51 U.S.C. 601 Title III Sec. 301(a)(2) whereby NASA is authorized and encouraged to continue and enhance programs of remote sensing tech development, R&D, including applications demonstration programs and basic research at universities, cooperative R&D with interagency, public, and private entities, and foreign governments and international organizations.
- Commercial Space Act of 1998, P. L. 105-303 SEC. 107. SOURCES OF EARTH SCIENCE DATA by seeking a commercial provider for services related to remote sensing, including acquisition "The Administrator shall, to the extent possible and while satisfying the scientific or educational requirements of the National Aeronautics and Space Administration, and where appropriate, of other Federal agencies and scientific researchers, acquire, where cost-effective, space-based and airborne Earth remote sensing data, services, distribution, and applications from a commercial provider".
- P.L. 116-9 (2019) John D. Dingell Jr. Conservation, Management, and Recreation Act Sec. 1114 Wildfire Technology Modernization
- The NASA SBIR/STTR Program is statutorily required in 15 USC 638 to make awards to small-business concerns to enable them to undertake and to obtain the benefits of research and development in order to maintain and strengthen the competitive free enterprise system and the national economy.

3 decades flying UAS for NASA Earth Science

- 1989 – First Community Workshop on using UAVs for Earth Science
- 1993 – DOE/ARM UAV Program: first demonstration flight of a science payload on a UAV
- 1994 – Perseus UAV selected for participation in ASHOE/MAESA
- **1994 - 2003 – NASA Environmental Research Aircraft and Sensor Technology (ERAST) program**
- 1997 – Pathfinder+ and DAISY: first NASA science payload flown on solar powered UAV
- 1999 – NASA ERAST and DOE ARM UAV Hawaii Experiment
- **2000-2002 – NASA UAV Science Demonstration Program (UAVSDP)**
- 2001 – First Response Experiment (FiRE) successfully combines Altus, remotely operated sensors and advanced information technologies to provide geo-registered imaging to Internet
- 2001 – Pathfinder+ demonstrates high resolution imaging during flights over Kauai coffee plantation
- 2002 – Altus UAV used with manned aircraft in CAMEX-4 (**Altus Cumulus Electrification Study**)
- 2003 – Formation of UAV Application Center at NASA Research Park
- 2004 – First use of SAVDS radar and short range tracking for detect-and-avoid
- 2005 - First Altair remote sensing missions
- 2005 - 2 SIERRA UAV acquired from NRL
- 2006 – Interagency SUAS fire demo at Fort Hunter Liggett
- 2006 – Maldives stacked UAVs Campaign (NSF/NOAA/NASA)
- 2007 – NOAA / NASA flight of Aerosonde into Hurricane Noel

Brief NASA science history with UAS (continued): 2007-present

- 2007 - Western States Fire missions on the Ikhana (Predator-B)
- 2008 - SensorNet for crewed aircraft based on Ikhana architecture
- 2009 - SIERRA team Svalbard in support of Sea Ice experiment CASIE
- 2009 – NASA AFRC receives 2 Global Hawk UAS from the Air Force, ACTD 1 & 6
- 2011 - Aura Validation Experiment GloPac - first Global Hawk science mission
- 2011-2013: **UAS Enabled Earth Science:**
  - 2012 - Surprise Valley Magnetometer survey with USGS on SIERRA
  - 2012 - Florida Keys Hyperspectral survey on SIERRA
  - 2012 – SIERRA MIZOPEX mission to Alaska
- 2012 – GRIP mission on Global Hawk with NOAA
- 2012-2015 – EVS-1 HS3 on Global Hawk
- 2013-2014 – EVS-1 ATTREX on Global Hawk
- 2013 - ASTER SO2 validation over Turrialba using Dragon Eye
- 2017 – SO2 sampling flights over Kiluea using DragonEye UAS
- 2018 – SIERRA-B Operational at Ames
- 2019-2021 – Fluid Lensing demonstrations on multi-rotor SUAS
- 2019 – ESTO IIP SAR testing on SIERRA
- 2020-2022 –Ice Radar mission on Vanilla/Platform
- 2021 – USGS/NASA flights of S2 over Makushin volcano
- 2021 – ES&I UAS workshop - https://meeting-info.org/uas-workshop-2021/
- 2023 – NOAA/NASA flights of SIERRA-B in Aleutians for Marine Mammal Surveys
- 2024 – FireSense SUAS meterology testbed
- 2024 – **STRATO Thunderhead communications and IR imaging experiment with USFS**

How is NASA engaged in HAPS?

- Contracted Aviation Services (CAS) for instrument testing:
  - Eg. STMD Flight Opportunities Program TechFlights Program
- NASA Earth Venture Suborbital Program
  - Has funded ER-2, WB-57, and Global Hawk flights, demonstrating high value of HAPS for hurricane research and upper atmospheric process studies.
- NASA Small Business Innovative Research Program
- NASA Earth Science Technology Office
  - Advanced Component Techology Program
  - Instrument Incubator Program
- NASA Upper E Traffic Management (ETM)

National Academies of Sciences, Engineering, and Medicine. 2021. Airborne Platforms to Advance NASA Earth System Science Priorities: Assessing the Future Need for a Large Aircraft. Washington, DC: The National Academies Press. https://doi.org/10.17226/26079.

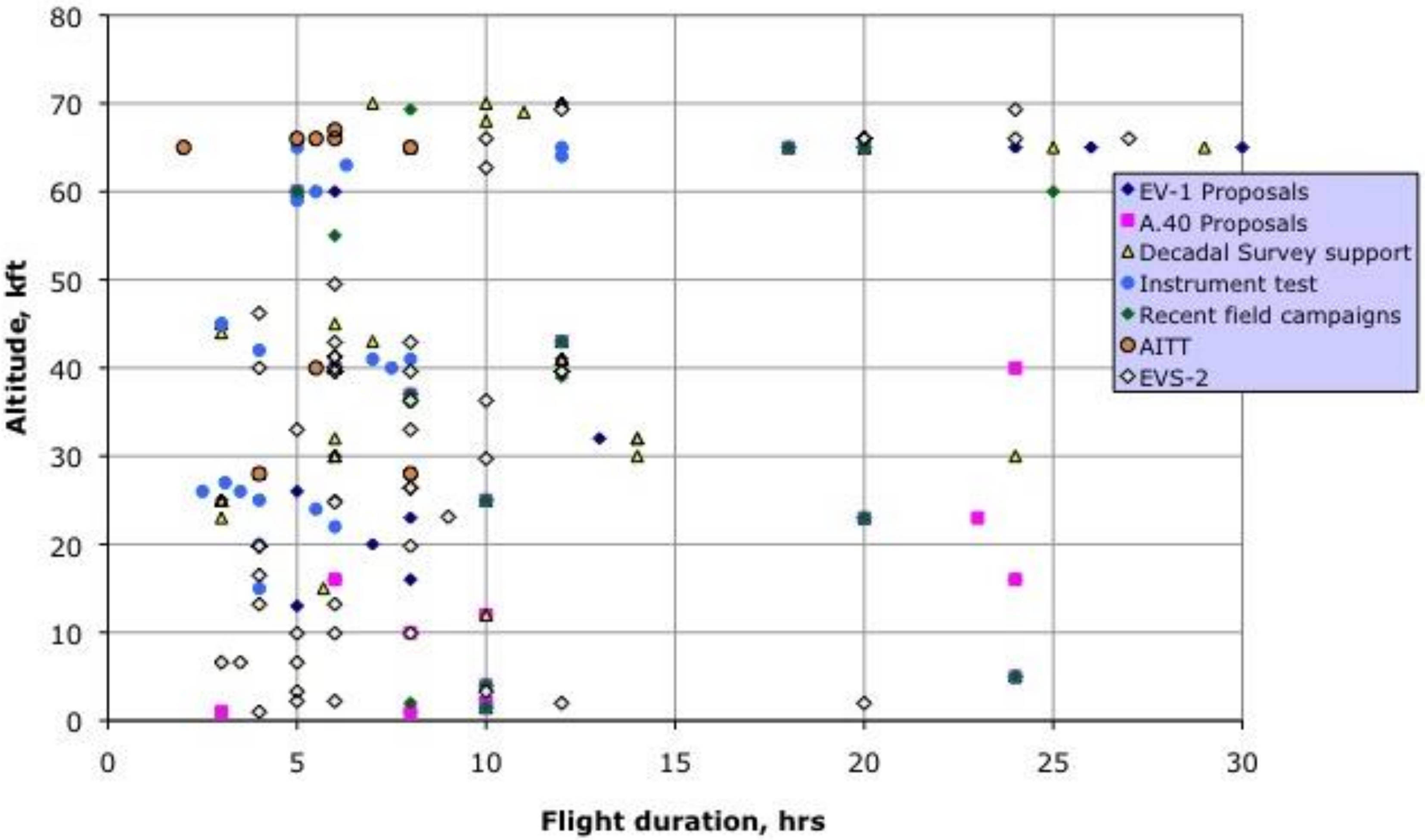
Excerpts re: UAS

"Measurements from long-duration UAS or stratospheric balloons could now have the capability of tracking the evolution of weather phenomena that have long lifetimes, such as the evolution of tropical cyclones, where it is important to observe the process of rapid intensification; the complete life cycle of cyclones as they traverse the United States; and collection of routine statistics on various meteorological phenomena." Pg. 75

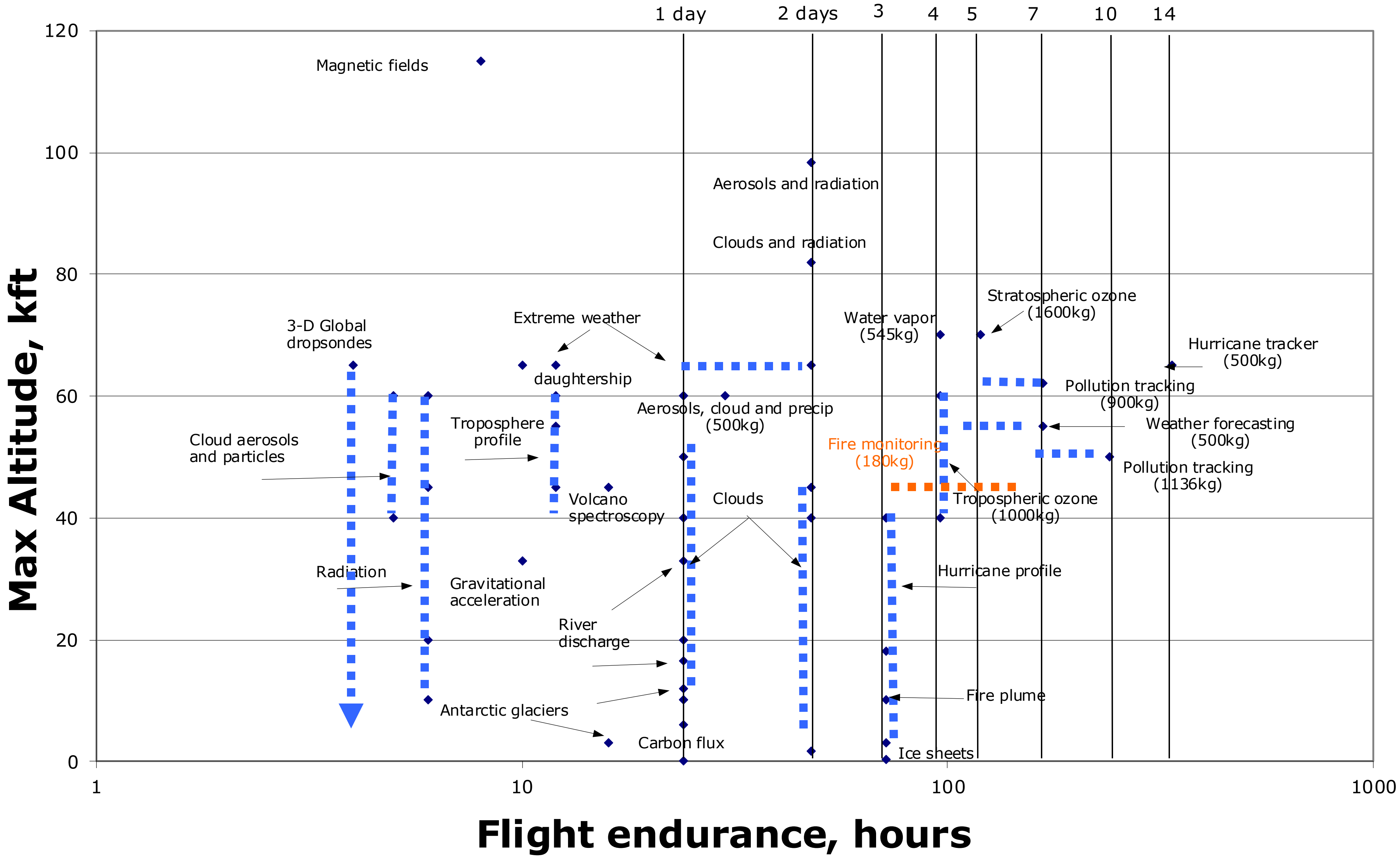
"Finally, because rapid deployment and high temporal sampling are key requirements for disaster response, UAS measurements can be essential for capturing transient processes associated with geological disasters on timescales of hours and days, filling the data gap left by satellite observations." Pp. 115

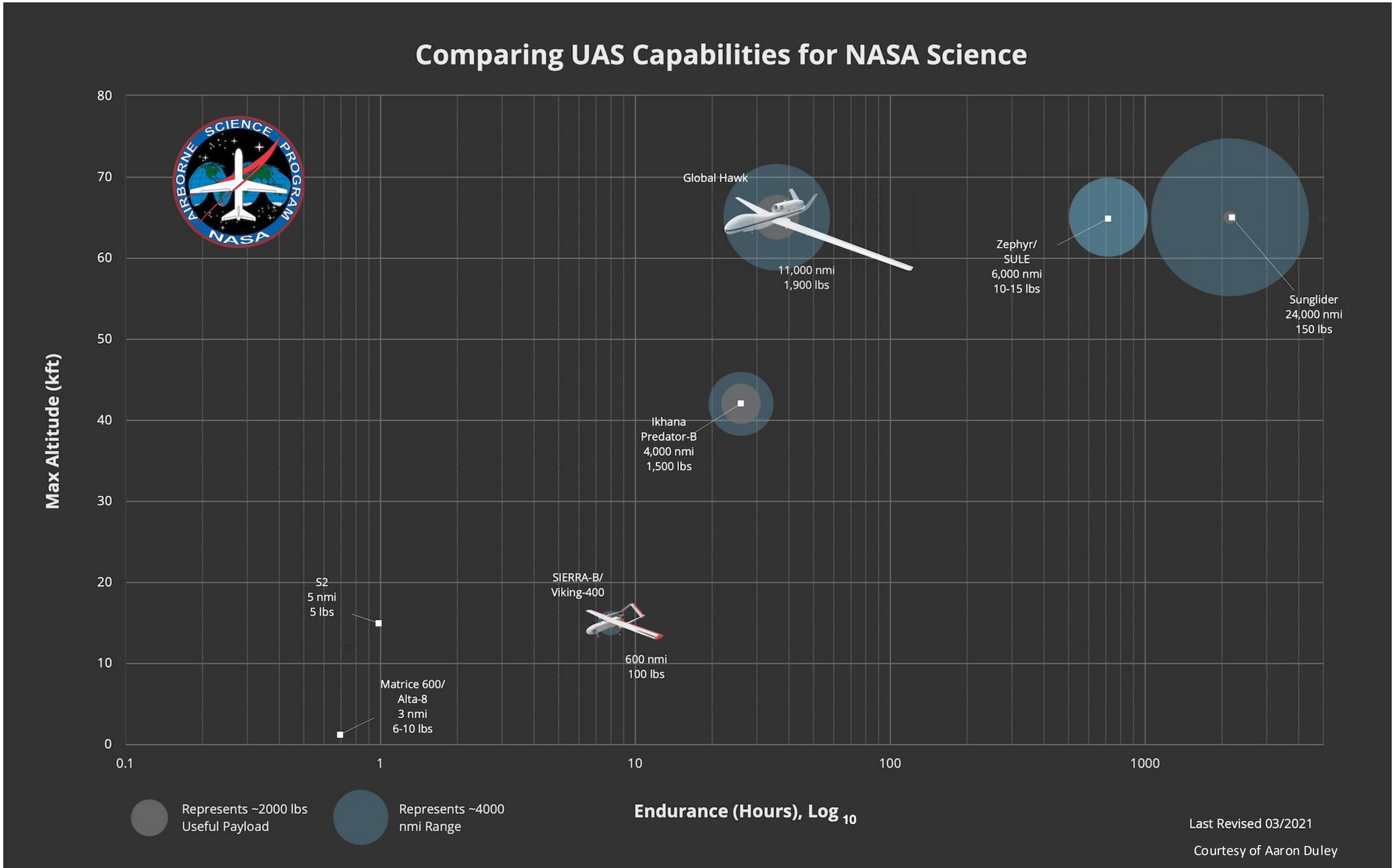
However, while there are some promising developments in high-altitude, long-duration UAS and in steerable balloons, these technologies may not advance quickly enough to contribute significantly to Earth system science research within the next decade. PP 142 [emphasis added]

NASA Science Community Requirements for Airborne Measurements



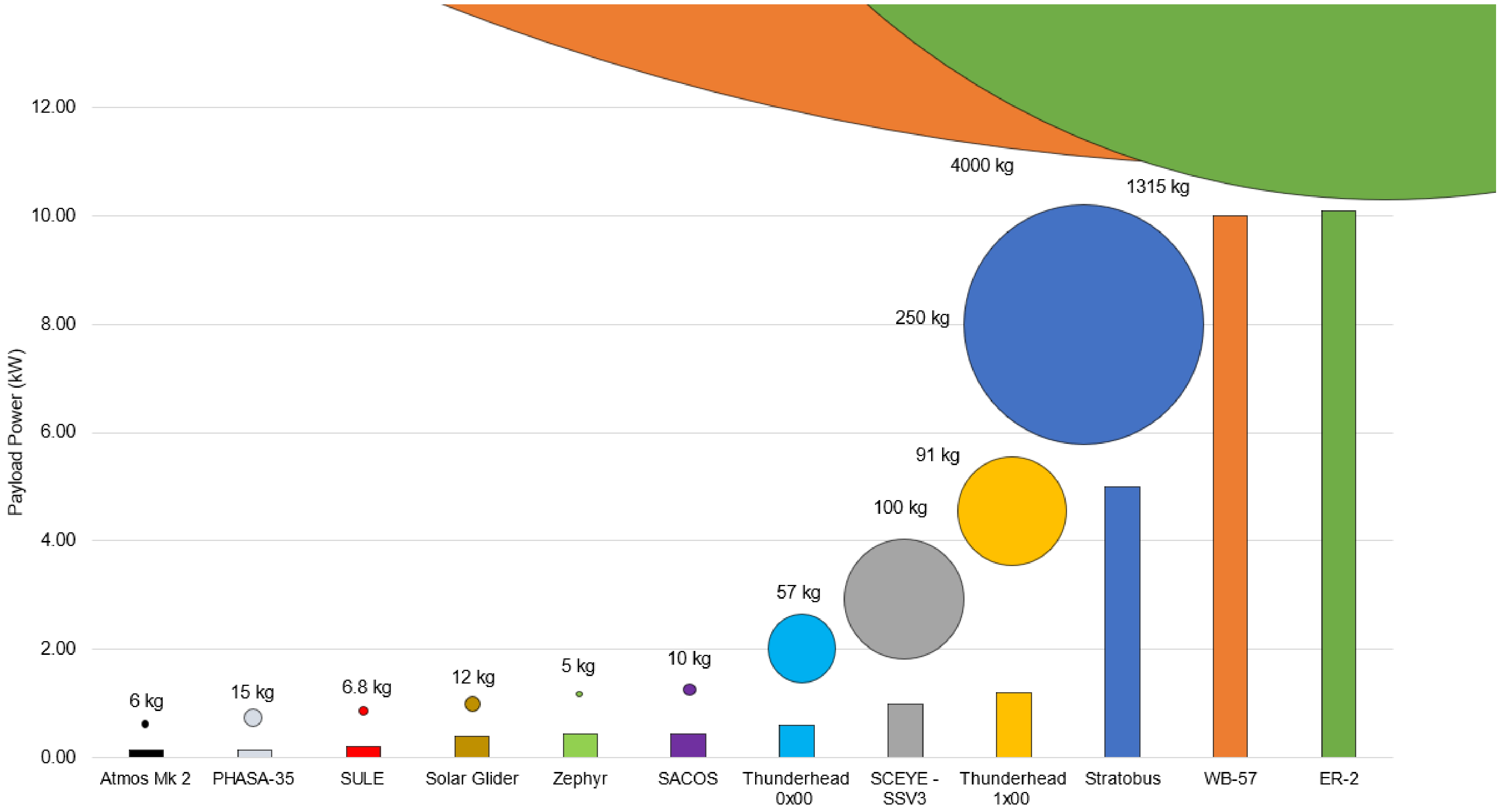
NASA Suborbital Science Missions of the Future (2004) : Science needs for HAPS





Comparing UAS Capabilities for NASA Science
Max Altitude (kft)
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
Endurance (Hours), Log 10
AIRBORNE SCIENCE PROGRAM
NASA
Global Hawk
11,000 nmi
1,900 lbs
Zephyr/
SULE
6,000 nmi
10-15 lbs
Sunglider
24,000 nmi
150 lbs
Ikhana
Predator-B
4,000 nmi
1,500 lbs
S2
5 nmi
5 lbs
SIERRA-B/
Viking-400
600 nmi
100 lbs
Matrice 600/
Alta-8
3 nmi
6-10 lbs
Represents ~2000 lbs
Useful Payload
Represents ~4000
nmi Range
Last Revised 03/2021
Courtesy of Aaron Duley

Comparing payload mass and power available from current stratospheric platforms



Science Needs – Surface Topography & Vegetation

Landslides generate significant time-varying topography. Given sufficiently fine spatial resolution, topography time-series are used to measure surface motion and detect changes from nearby background rates.

Following catastrophic landslides, differential topography can be used to infer large-scale displacements and landslide volumes, which can then be used to constrain physical models.

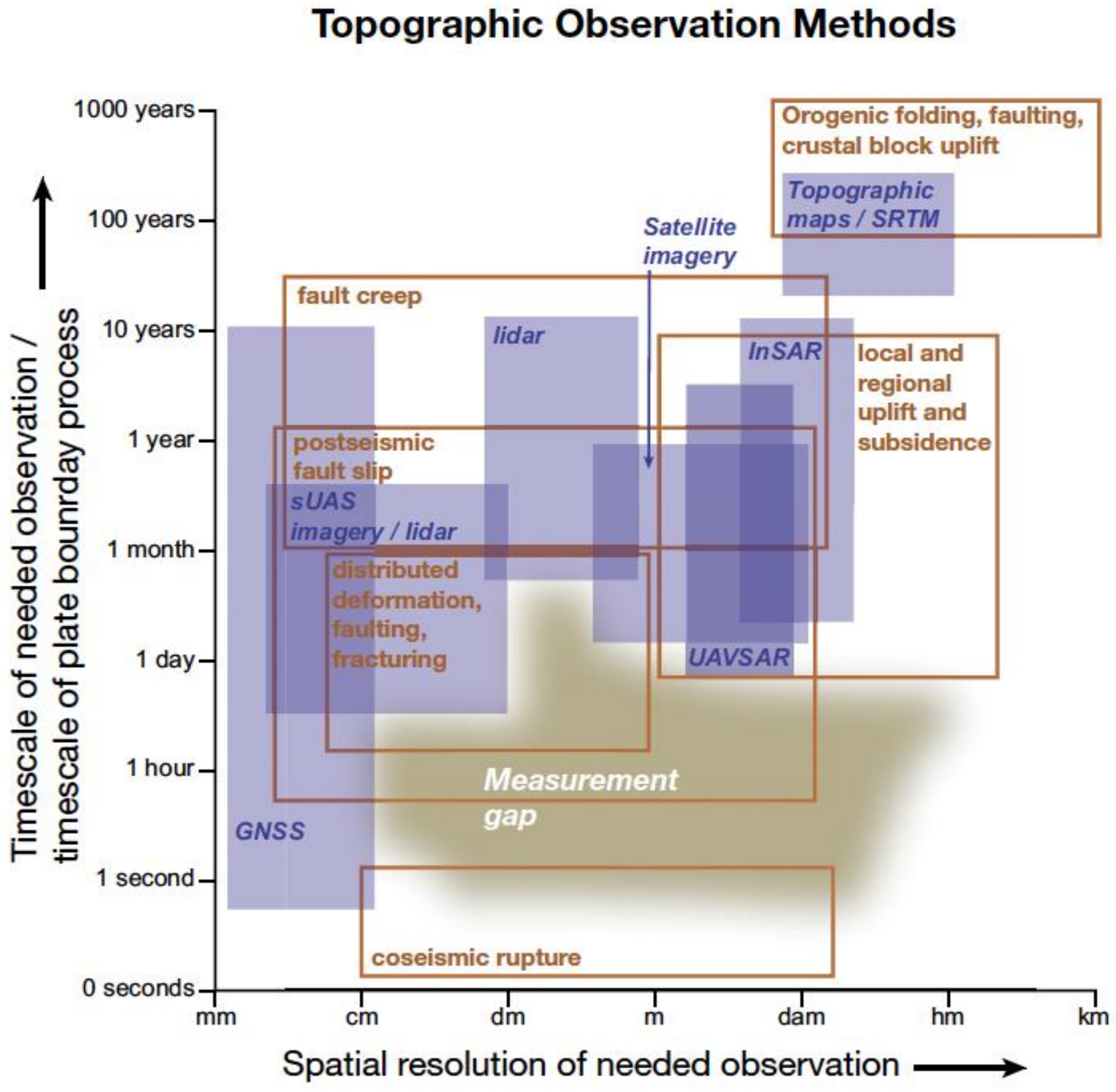
Rapidly capture the transient processes following disasters for improved predictive modeling, as well as response and mitigation through optimal re-tasking and analysis of space data. (DS: S-2a).

“High-resolution topography enables quantified assessments of landscape change due to erosion, deposition, and vegetation disturbance. An important objective for all of these data is the rapid dissemination of higher-level products to local emergency responders and the global scientific community.”

Assess surface deformation, extent of surface change…of volcanic products following a volcanic eruption (hourly to daily temporal sampling). (DS: S-2b)

This focuses on volcano disaster response and builds on S-2a. Relevant topography data would include short repeat interval topography at low latency to measure loss and depositional changes to the landscape that would affect

FIGURE 3-3. Summary of current estimates of the spatial resolution and the timescale of needed observations. Relevant timescale of the solid earth process of interest. Measurement gap emphasizes need for high-frequency observations over a range of spatial scales and resolutions.

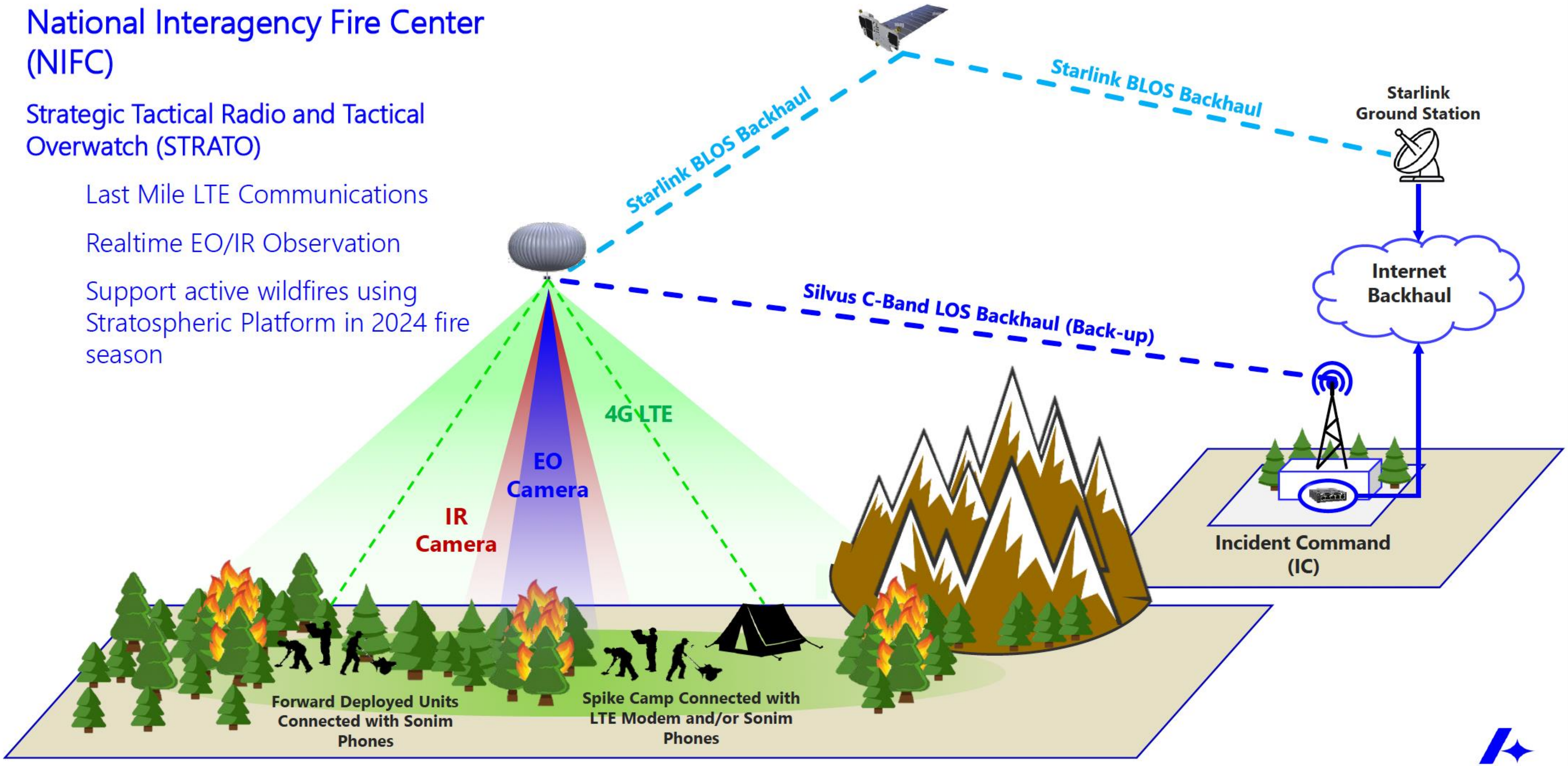


NASA STRATO PROJECT OVERVIEW

National Interagency Fire Center (NIFC)

Strategic Tactical Radio and Tactical Overwatch (STRATO)

- Last Mile LTE Communications
- Realtime EO/IR Observation
- Support active wildfires using Stratospheric Platform in 2024 fire season



NASA SMD ESD STRATO Objectives:

- Evaluate the capabilities of the Thunderhead platform.
- Assess integration engineering and payload SWAP characteristics
- Demonstrate capability to send and receive data from a remote fire incident for science and applications
- Track and display information in an open source framework for near realtime data sharing
- Provide visualization tools for ground teams testing signal coverage and strength.
- Understand cost structure for conducting future missions.

NASA Mission Tools Suite flight track summary with altitude strip chart

High-Altitude Long-Endurance Experiment (HALE-X)
Persistent IR imaging of wildfires

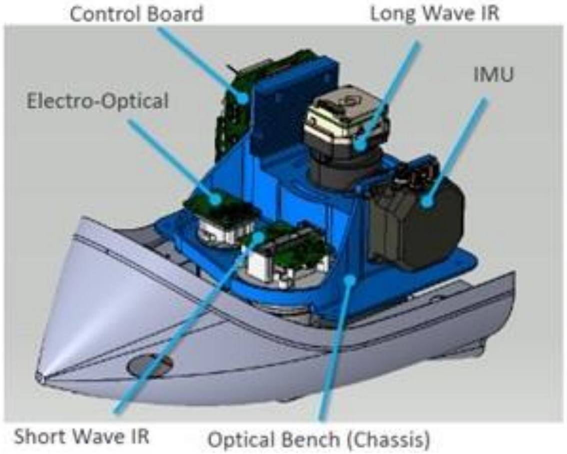
Sean Triplett (USFS), Matt Fladeland (NASA), Erik Rodin (USFS), Chris Bolz (USFS), Sam Markson (USFS)

A USFS-NASA partnership to demonstrate infrared observations for weeks to months using next generation solar-electric UAS

Goals:

- Provide **continuous realtime L2 data products on fire location and perimeter** for wildfire science and management.
- Demonstrate technical and procedural feasibility of airspace integration, logistics, and cost of operations for fixed-wing HALE UAS.
- Identify barriers to introducing this capability across the Nation for disaster response.

Swift Ultra Long Endurance UAS releasing from launch vehicle during first flight in July 2020 in New Mexico The vehicle was designed to stay aloft for 30 days at 20km with a 5kg payload.



HALE-X payload built by Swift with Sensor Labs and Lucent

NASA SBIR funded platform; NASA Ames is supporting Airworthiness/Safety and Airspace Integration with NASA ASP Project management

USDA/USFS/NIFC funded the payload development, integration and flight demonstration from New Mexico SpacePort

Next milestones:

- **Flight demonstration in May/June 2025**

USDA · Forest Service UAS · Swift Engineering · NASA · Airborne Science Program

SBIR·STTR America's Seed Fund™ POWERED BY NASA

S16.04-1968 - Integrated Flight Validation of HALE UAP Avionics & Propulsion Systems for Science Missions

PI: James Stewart , Electra Aero Inc - Falls Church, VA

NASA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

The Stratospheric Airborne Climate Observing System (SACOS) is a solar powered, high altitude, long endurance (HALE) UAS that will be capable of remaining aloft up to a year at altitudes up to 85,000 feet to host active and passive payloads for climate science. The goal of the vehicle is to be a platform for instruments that have been under development at Harvard University for decades to collect in-situ and remotely sensed data that is crucial to strengthen the critical links between theory and global climate models. These small scale, yet highly sensitive instruments will help further our understanding of the physics that is so critical to ultimately developing science-based national and international economic policies to combat global climate change and address risks.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

Objective 1 – Objective Aircraft Development. Complete the evaluation of the science sensor payloads and define the mechanical, electrical, and software interface into the SACOS concept to minimize weight (similar to the modular experiment interface panel). Refine the Objective Aircraft sizing point and complete the conceptual design (airframe, avionics, propulsion, etc.) for that vehicle. Present a Concept Design Review (CoDR) on the results.

Objective 2 – Propulsion and Avionics Development.
Procure and ground test an integrated battery pack (4 modules) including Avionics-BMS systems and interface to allow for integrated testing on the Dawn One demonstrator aircraft. Test charge/discharge/SOC management across packs in charge/discharge representing diurnal cycles. Procure and test the avionics architecture and integrate onto the copper bird for testing. Build and test objective aircraft HILSIM (including vehicle model) and test interface with copper bird.

Objective 3 – System Integration and Flight Testing.
Integrate avionics package into subscale surrogate aircraft to test "up and away" avionics package and reduce test risk on the objective aircraft. Integrate new avionics package and propulsion into Dawn One aircraft and complete ground test. Conduct low-altitude flight test of the new technologies on the aircraft. Document lessons and findings during testing.

TRL

Estimated

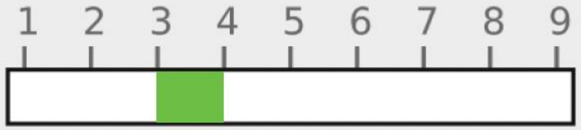


IMAGE TITLE: Electra "SACOS" HALE UAS

NASA APPLICATIONS

Numerous climate science related missions identified by stakeholder engagements with the NASA Airborne Science Program (Matt Fladeland), Cryospheric Science Program (Thorsten Markus), and NASA Goddard (Dave Harding).

NON-NASA APPLICATIONS

Science Missions: High Latitude Ice Observations (Antarctic Ice Shelf Collapse Forecasting, Greenland Glacier Flow Prediction), Direct Stratospheric Sampling (Sampling of Stratospheric Aerosols, In-situ Measurement of Storm Driven Stratospheric Chemistry), Drought, Wildfire, and Flood Monitoring (Coastal Flood Monitoring, Drought and Wildfire Prediction), Oceanic Surface and Cyclone Monitoring.

FIRM CONTACTS

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Electra Aero Inc
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High Altitude Long Endurance Platforms

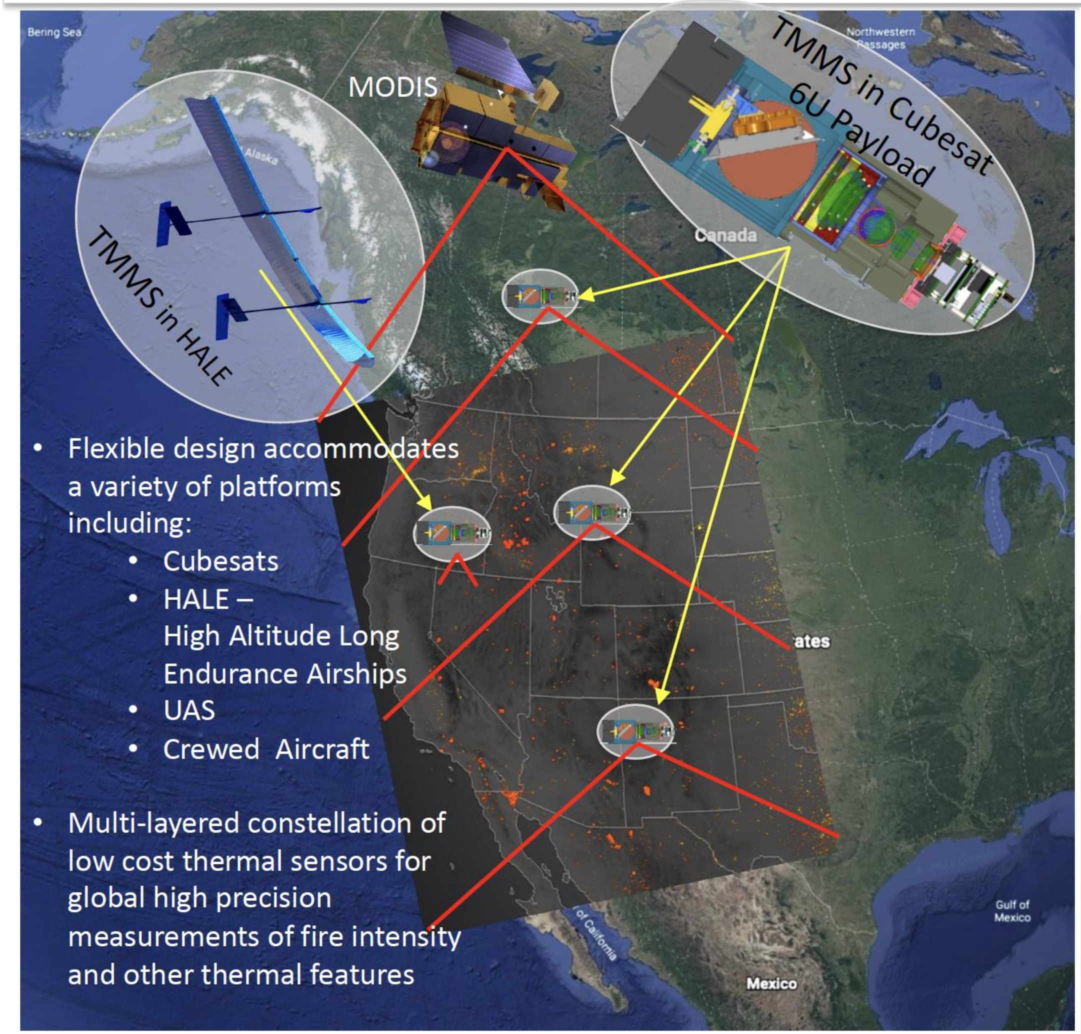
NASA 2024 SBIR Phase 1 selections

HAPS Day Night Hyperspectral Imaging Demonstrator
- Innovative Imaging & Research Corp.
- Platform: Aerostar Thunderhead

Swift Ultra Long Endurance (SULE) High-Altitude Platform Systems (HAPS) Capability Demonstration
- Swift Engineering
- Platform: SULE

High-Altitude, Long-Endurance, Visible Through Extended SWIRHyperspectral Imaging for Earth Sciences
- Spectral Sciences Inc.
- Platform: SCEYE Airship

TMAS Sequential SBIR – NASA Contract 80NSSC23CA038
Thermal Mapping and Measurement System (TMMS)



- Flexible design accommodates a variety of platforms including:
  - Cubesats
  - HALE – High Altitude Long Endurance Airships
  - UAS
  - Crewed Aircraft
- Multi-layered constellation of low cost thermal sensors for global high precision measurements of fire intensity and other thermal features

	MODIS (LWIR)	24 TMMS in LEO	TMMS in HALE
Orbit	Polar 705 km AGL	Polar 705 km AGL	20 km AGL
Resolution	1,000 m	106 m	3 m
Swath	2300 km	2300 km	57 km diameter
Revisit	1 to 2 days	1 to 2 hours	Persistent 5 to 10 mins.

Flexible design allows any 3 bands between 3 and 12 um

- TMMS Propose Bands:
  - 3.96 um (60nm)
  - 9.05 um (300 nm)
  - 10.6 um (500 nm)

Flexible Design allows multi-layered constellation
  - Polar LEO
  - Elliptical LEO
  - HALE Stratospheric Platforms
  - Low Altitude Crewed Acft. and UAS

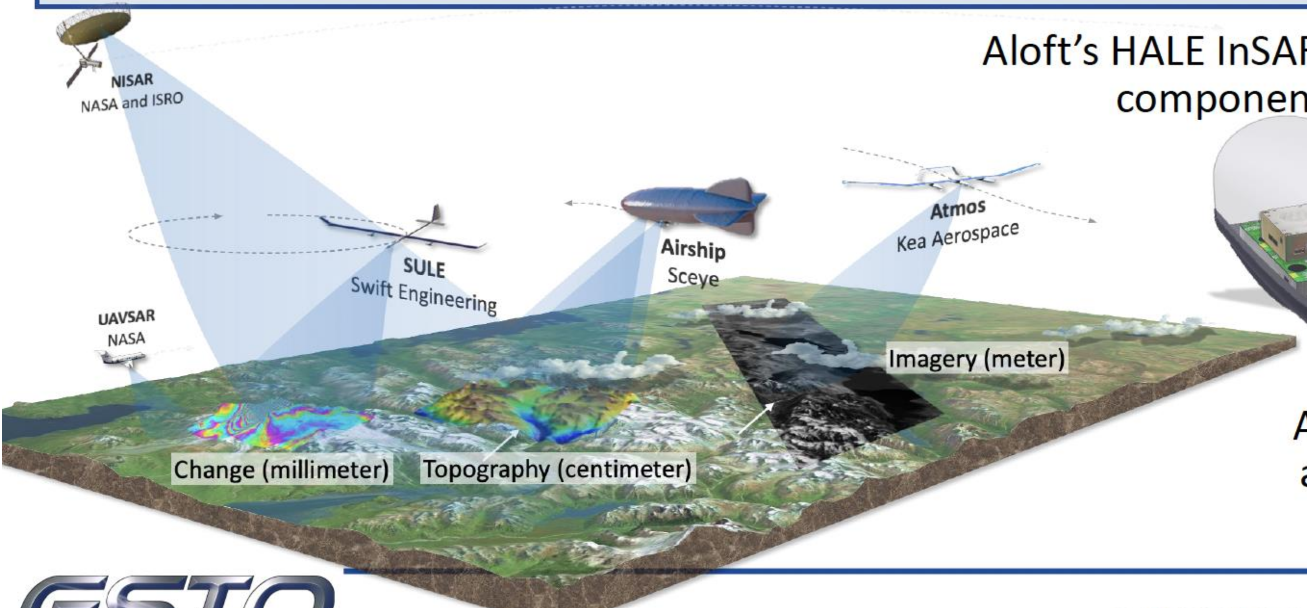
XIOMAS

Xiomas Technologies, L.L.C. https://xiomas.com johngreen@xiomas.com 734-646-6535

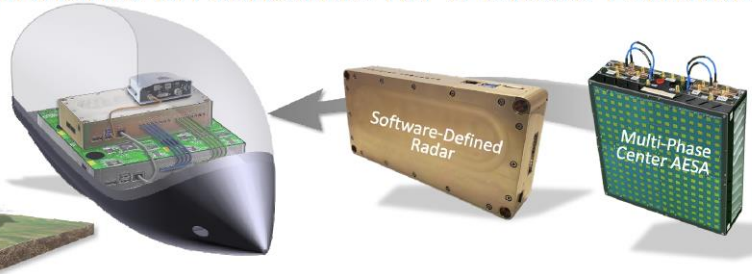
Aloft IIP Project Summary

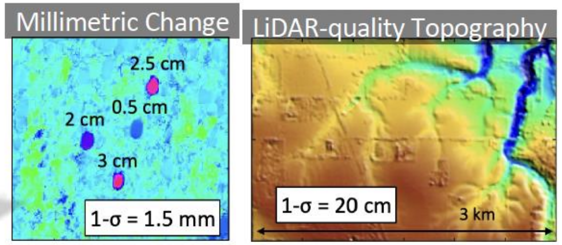
High Altitude, Long Endurance (HALE) InSAR for Continual and Precise Measurement of Earth's Changing Surface

- Solar-powered HALE aircraft and airships offer **affordable persistent regional access**.
  - Potential to capture the high-frequency dynamics of critical geophysical processes
- Aloft is applying novel algorithms & state-of-the-art electronics to **reduce the SWaP of InSAR** instrumentation and enable integration onto smaller and more affordable HALE platforms.
- Aloft is refining these algorithms to **overcome the challenges** associated with HALE operations: relatively slow velocities, often irregular trajectories, and coarse navigation control.
  - Aloft positioning and timing techniques ("AloftPNT") maintain sensor coherence over long collection times and wide spatial baselines
- Aloft's HALE InSAR has the potential to **improve revisit times** from weekly to sub-hourly (a 100x benefit), while also providing **ultra-precise sensitivity over broad-areas,** for a new level of regional presence and data accessibility.



Aloft's HALE InSAR system is currently in development, with key technology components on schedule for a CY2024 stratospheric demonstration.





Aloft stratospheric demonstrations will show **mm-level deformation** and **cm-level topographic maps** at a **high repeat rate**, achieving the requirements of many key SDC and STV science objectives.

Intelligent Long Endurance Observing System

PI: M. Chandarana (NASA Ames Research Center)

Objective

Intelligent Long Endurance Observing System (ILEOS):

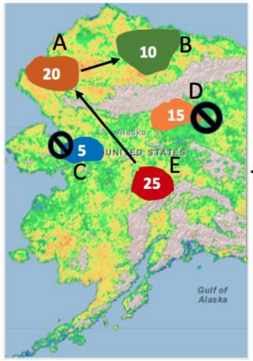
A *Science activity planning* system to enable NOS consisting of satellites and *HALE UAS-mounted instruments.*

Optimize *fine-grained spatio-temporal resolution data collection of GHG-relevant gases* using HALE UAS.

Incorporates *coarse-grained satellite GHG-data* and near real-time environmental (wind, weather, airspace constraints) data to generate high-value fine-grained resolution data collection plans.

Designed for human operators; *plan explanation and data provenance features* will ensure science mission planners understand all key choices made while generating targets and plans.

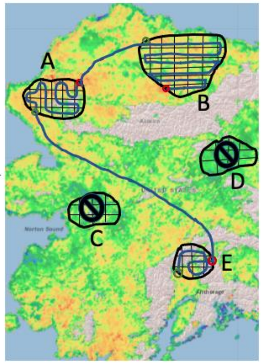
IMPACT: Reduced cost for GHG observations in environments ranging from arctic to urban to offshore (some previously inaccessible), continuous observations not possible for current field/in-situ campaigns, improved science and health outcomes



Scene Sequencing: E ➡ A ➡ B

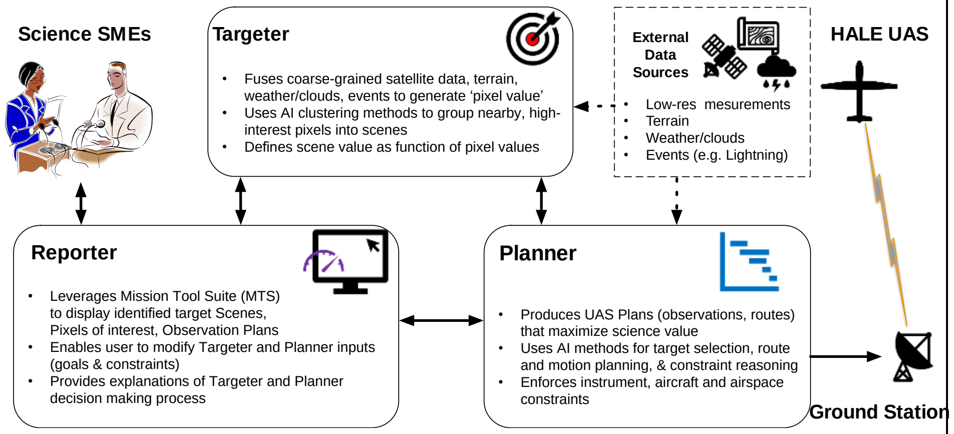
Route + Motion Planning Output (UAS plan)

Plan Step	Start time	Duration
Travel from Start Location to **D** entry point	1	30 mins
Scan **D**: Lawnmower pattern	2	2 hours
Travel from **D** exit point to **A** entry point ETM: Avoid trajectory <x,y,z,t>	4	1 hour
Scan **A**: Spiral pattern	5	1 hour
Travel from **A** exit pt. to **B** entry pt.	6	30 mins
Scan **B**: Loiter over a single position	7	1 hour



Generated Flight Path

Approach



Key Milestones

- Complete ILEOS requirements / design — Q4/22
- Prototype ILEOS for NO2 science use case — Q4/23
- Prototype ILEOS for CH4 science use case — Q1/24
- 3d year proposal to AIST program — Q4/23
- User testing and evaluation of ILEOS — Q2/24
- Airborne Science Program integration reqts/design — Q3/24
- Infusion into Airborne Sciences Program — Q2/25
- Final Report / Project Closeout — Q2/25

$TRL_{in} = 3$
$TRL_{out} = 5$

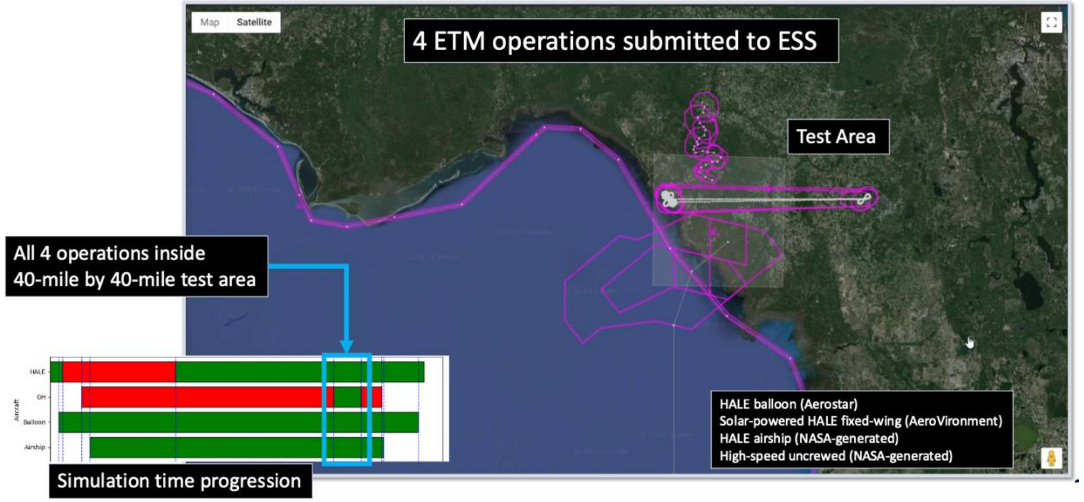
Co-Is/Partners: NASA GSFC, USGS, JHU

Earth Science Technology Office

NASA-FAA Upper E Traffic Management (ETM)

- Community-based, cooperative approach to airspace integration and management
- Provide data-exchange and service-oriented information architecture for shared situational awareness
- Accommodate a diverse set of vehicles with a wide range of performance characteristics
- Goal: unsegregated airspace to support collaborative operations
- Goal: regulatory certainty to operate under consistent fair set of cooperative operational practices
- Goal: Scalability to provide intent sharing and situational awareness for cooperative separation

- Collaborative Evaluation #1 (CE-1) was completed in June 2024 – partners were invited to evaluate the Common Operative Picture (COP) and connect to a prototype NASA research ETM System



Airspace Operations Laboratory

Challenges and Opportunities for applying HAPS to NASA missions

- Need to continue to miniaturize payloads for limited HAPS SWAP.
- Defining V&V for automonous operations and flight approvals
- More flexibility needed in launch and recovery trajectories and locations
- Developing business models that enable government and industry to buy data or flight services on demand
- Multi-mission payloads can improve return on flight hours but introduces need for deconflicting observing system requirements

Thanks for supporting UND SOARS 2025!