

EXPLORE EARTH

Development and maturation of HAPS and related technologies for the future NASA Earth System Observatory

Matt Fladeland - NASA Ames Research Center

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

IEEE Geoscience and Remote Sensing Society
Instruments and Future Technologies Webinar
October 3, 2024

Matthew Fladeland



- **Airborne Science Manager** at NASA Ames Research Center
 - Managing Agency-wide engineering support to science and aircraft teams
 - Advanced Planning, Analysis and Reporting
 - New Technology Portfolio
- **Subtopic Manager and COR** for NASA SBIR projects including Xiomas, BlackSwift S2, Swift HAPS, and Electra HAPS

Past projects:

- **Operation Ice Bridge** formulation
- **Principle Investigator** for NASA SIERRA-A UAS
- **Co-Principle Investigator** for NASA Dragon Eye
- **Co-PI** – VEREX (2017), STRATO (2024)
- **COR** for Vanilla SBIR



Outline

- The NASA Earth System Observatory
- Science requirements for HAPS
- Platforms capabilities
- Demonstration projects
- Technology development
- Challenges
- Conclusions



EARTH FLEET

INVEST/CUBESATS

- NACHOS 2022
- CTIM 2022
- NACHOS-2 2022
- MURI-FD 2023
- SNOOPi* 2024
- HYT* 2024
- ARGOS* 2024

JPSS INSTRUMENTS

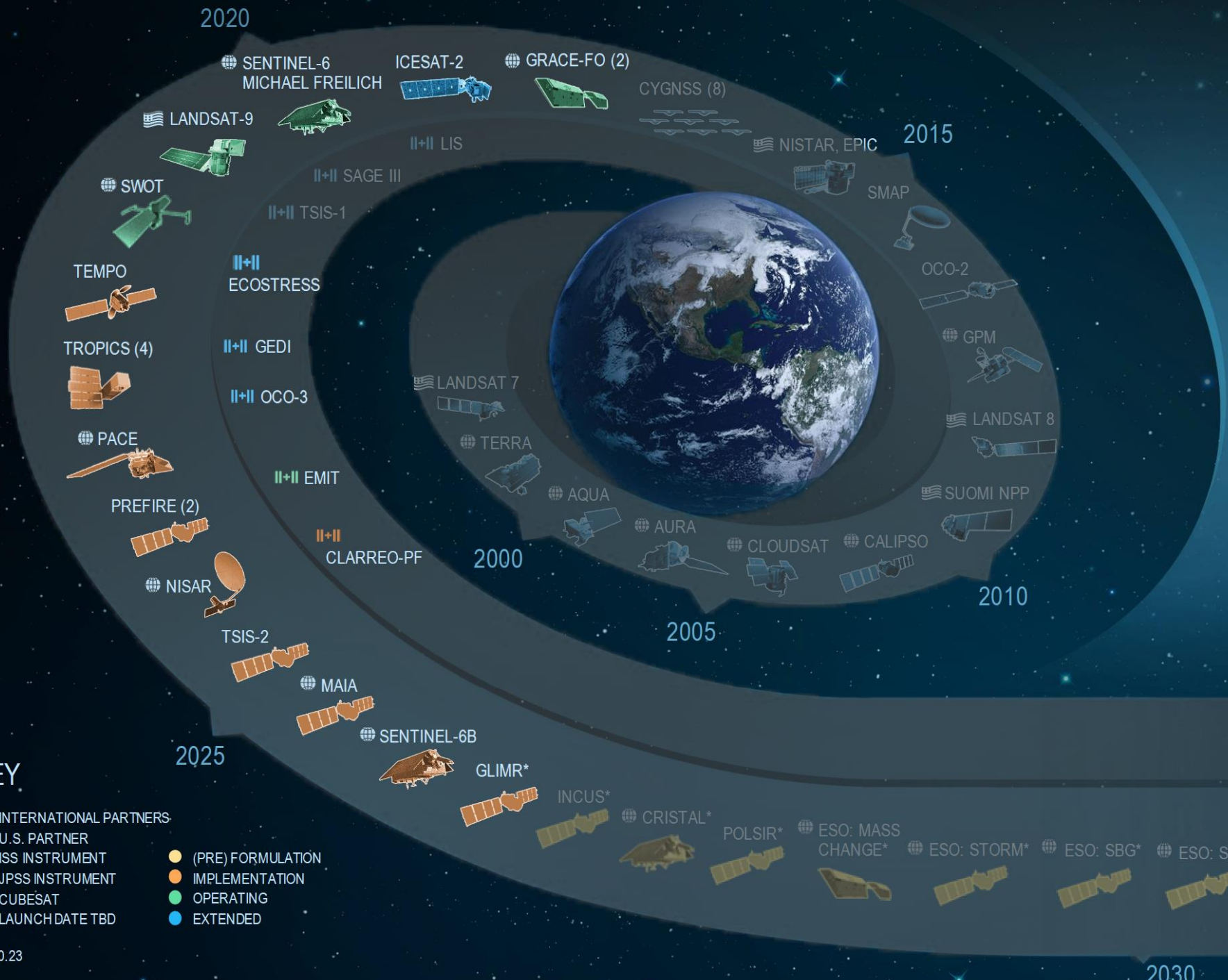
- OMPS-LIMB 2022 +
- LIBERA 2027 +
- OMPS-LIMB 2027 +
- OMPS-LIMB 2032 +

ISS INSTRUMENTS

MISSIONS

KEY

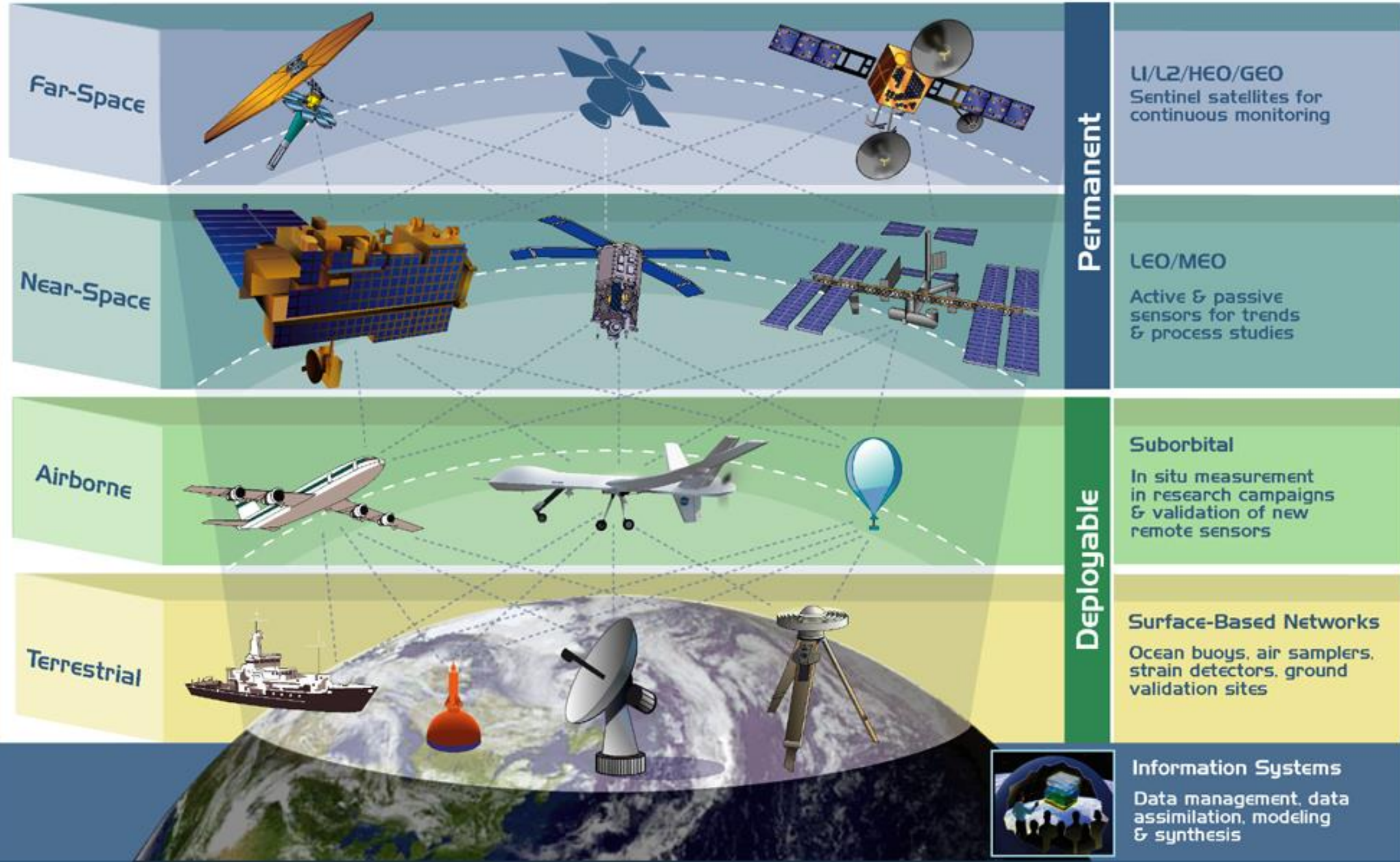
- INTERNATIONAL PARTNERS
- U.S. PARTNER
- ISS INSTRUMENT
- JPSS INSTRUMENT
- CUBESAT
- LAUNCH DATE TBD
- (PRE) FORMULATION
- IMPLEMENTATION
- OPERATING
- EXTENDED



Vantage Points

NASA EOS Vision of a Global System for Earth/Planetary Observation

Capabilities





NASA Earth Science to Action (ES2A)



NASA Directorates and Programs aligned w/ HAPS

- NASA Science Mission Directorate (SMD)
 - Earth Science Technology Office
- NASA Aeronautics Research Mission Directorate (ARMD)
 - Upper E Traffic Management
- NASA Space Technology Mission Directorate (STMD)
 - Flight Opportunities Program
- NASA Small Business Innovative Research (SBIR) Program
 - Phase I, II, -IIE, Climate Sequentials

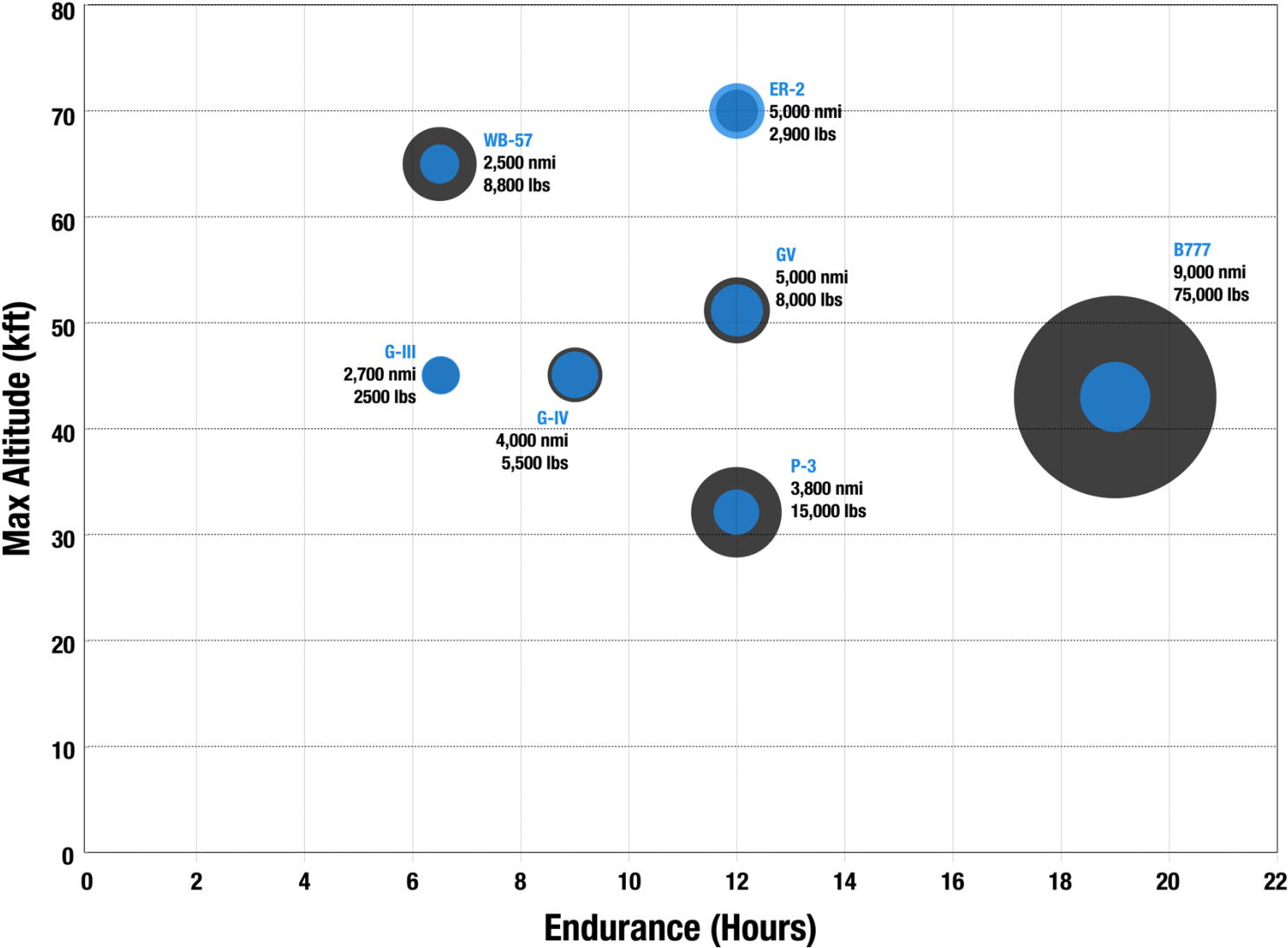


Airborne Science Program
National Aeronautics and Space Administration





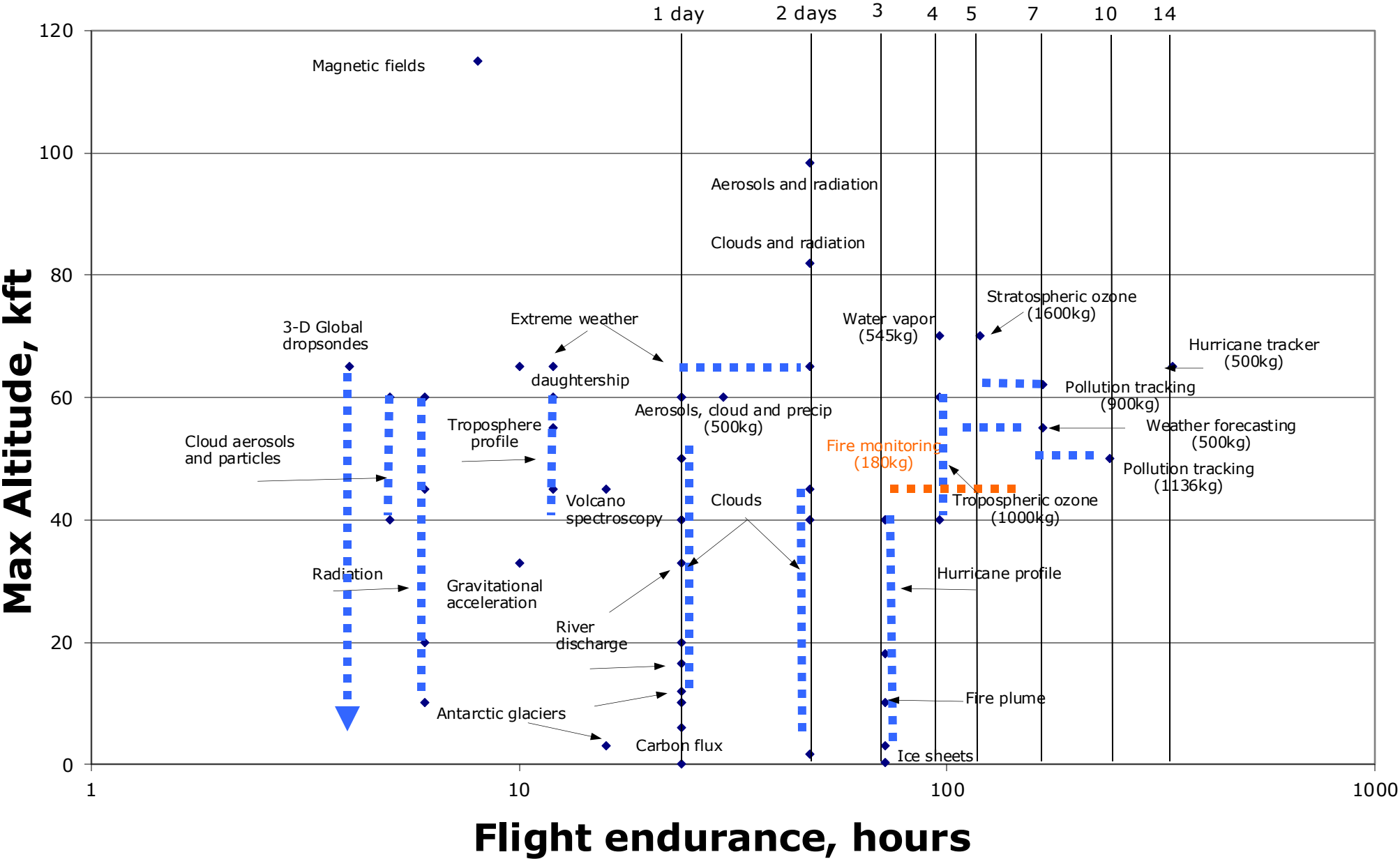
AIRBORNE SCIENCE PROGRAM AIRCRAFT PERFORMANCE

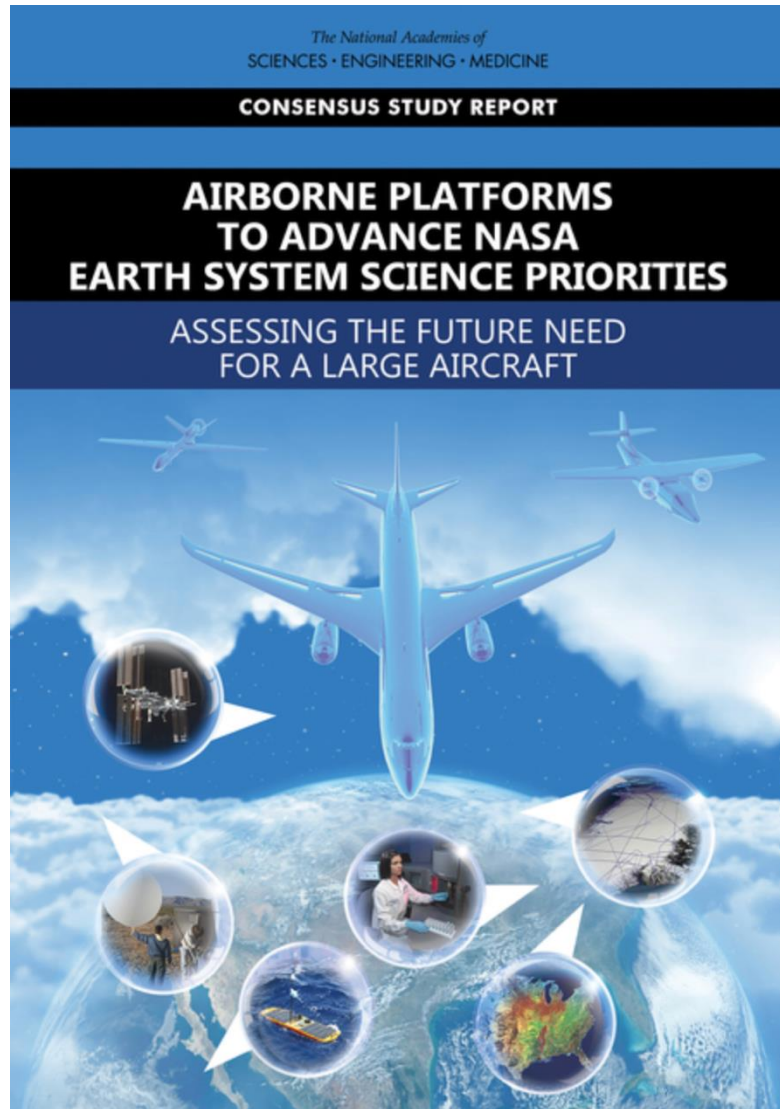


● Represents 1000 nmi Range
● Represents 1000 lbs Useful Payload

Visit the NASA Airborne Science Program website for more information.
<https://airbornescience.nasa.gov>

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





“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]

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>.

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.

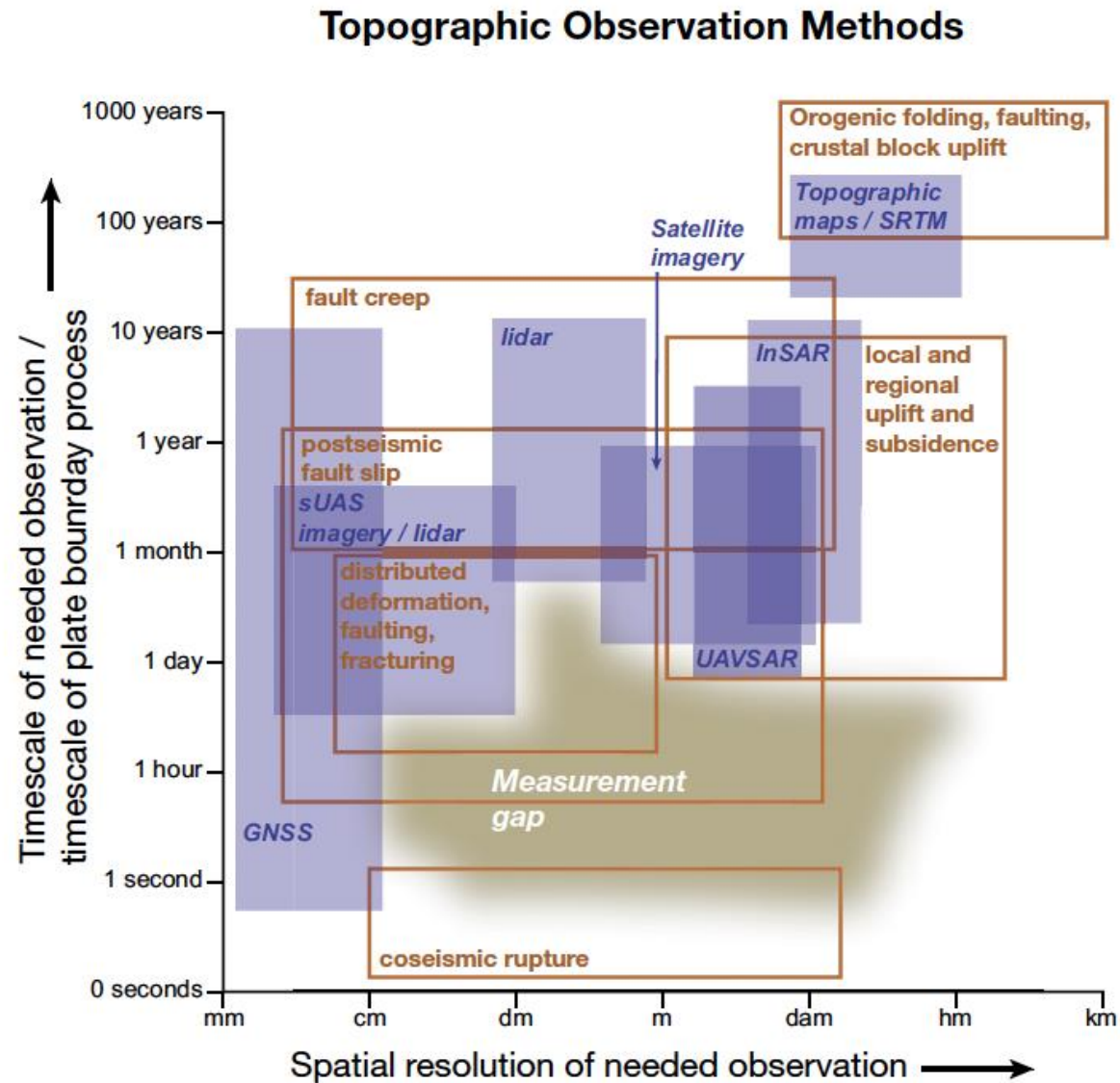
Rapidly capture the transient processes following disasters for improved predictive modeling, as well as response and mitigation through optimal re-tasking and analysis of space data. (DS: S-2a).

“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.”

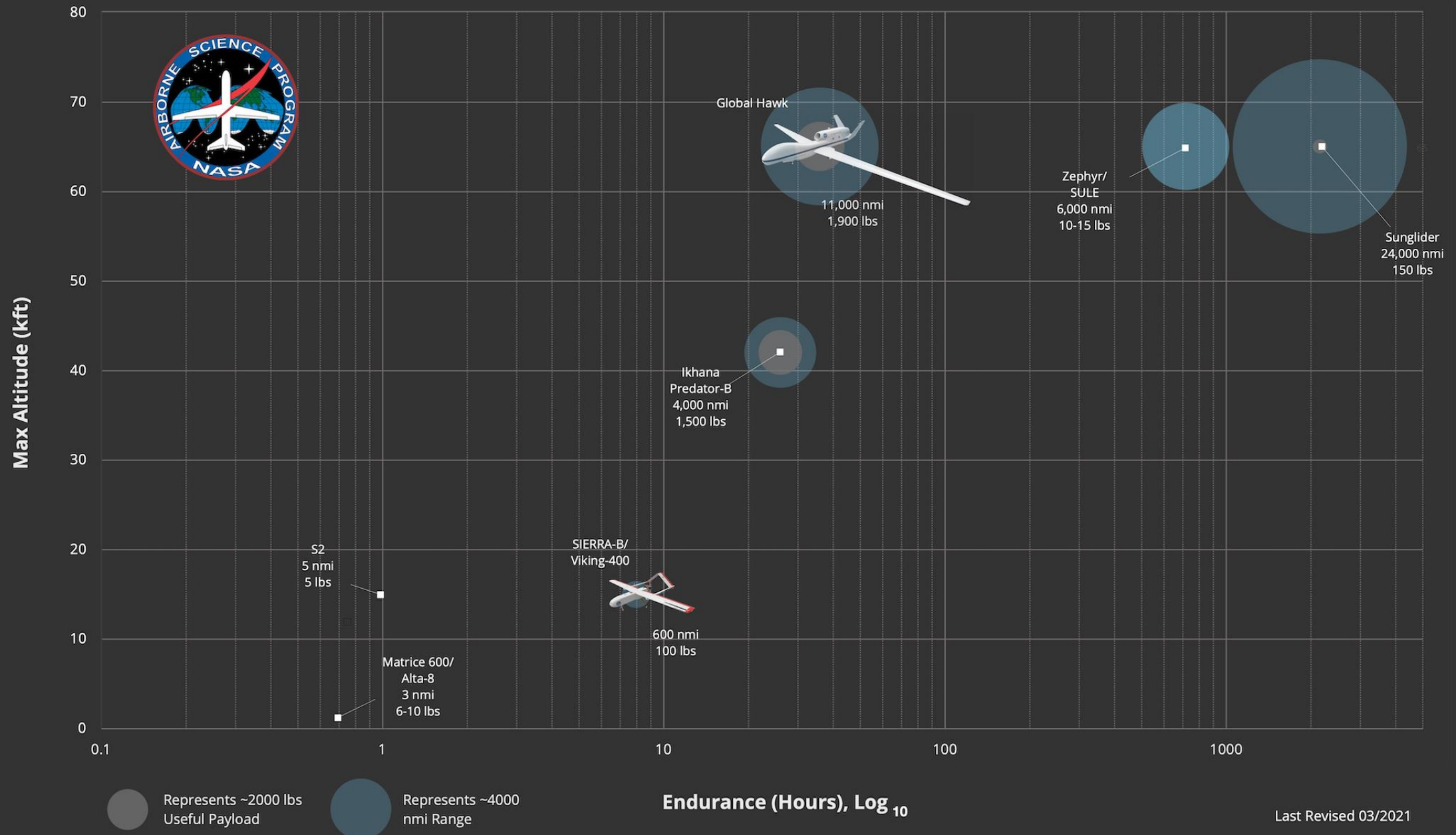
Assess surface deformation, extent of surface change...of volcanic products following a volcanic eruption (hourly to daily temporal sampling). (DS: S-2b)

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.



Comparing UAS Capabilities for NASA Science



Last Revised 03/2021

Courtesy of Aaron Duley



Weight: 175 lbs
Altitude: 50-65k ft
Endurance: 100+ days
Payload capacity: Up to 15 lbs



Swift Engineering Ultra Long Endurance (SULE) aircraft San Clemente, California, USA



- SBIR Phase II-Extended
- Primary payload in the nose compartment
- Currently operating from SpacePort

2024-09-29 13:55:47



2024-09-29 18:06:52



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)

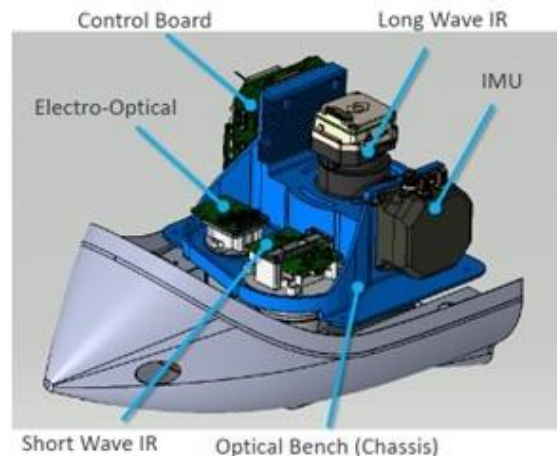
A USFS-NASA partnership to demonstrate infrared observations for weeks to months using next generation solar-electric UAS

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:

- **Stratospheric tests in March 2024**
- **Flight demonstration in Summer 2024**



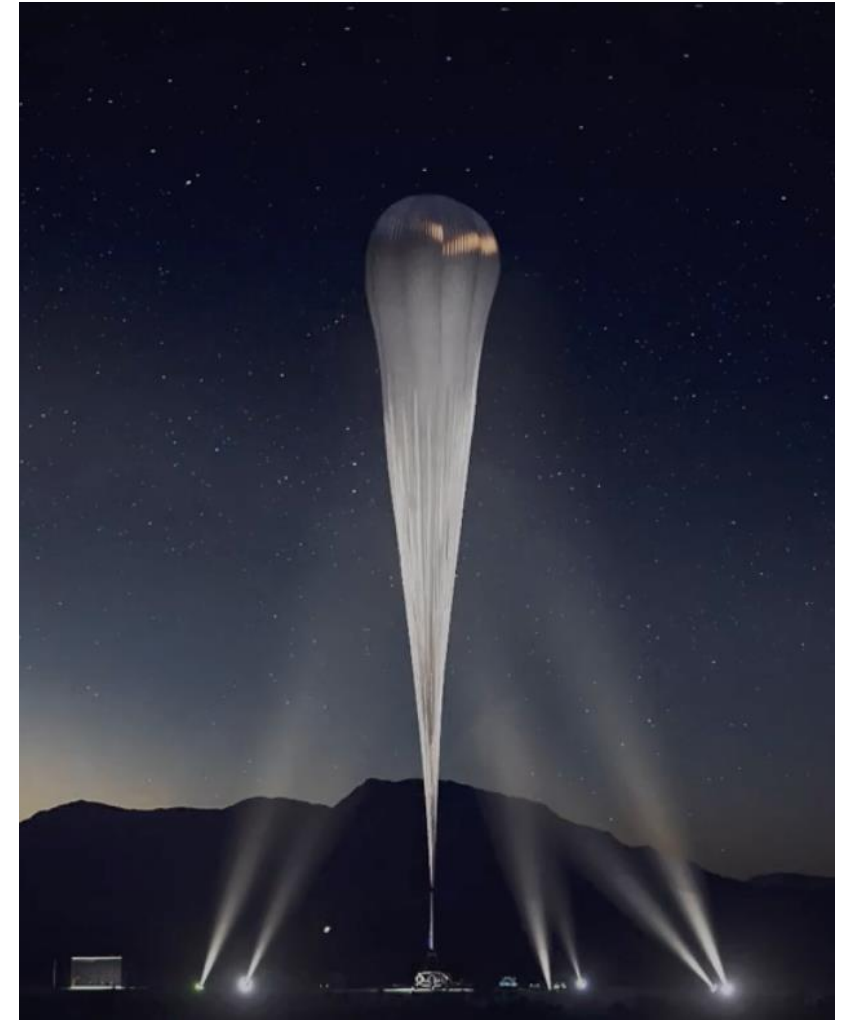
Stratospheric Tactical Radio Tactical Observations (STRATO)



Background



- The USFS requires solutions for last mile connectivity to push data to the incident command center and staff on the fire-line
 - Improve incident response through low latency situational awareness
 - Adapt to quickly changing fires to save life and property
 - FirstNet tethered balloons provide limited coverage, are difficult to deploy and move
- NASA ARMD and SMD are formulating multi-year Programs to use NASA tools and technology for improving observations, models, and response to wildfires.
 - Improved models and observations rely on last mile connectivity to have an impact on management
 - One way to improve fire progression and emission models is to initialize models with data near-real time data from the incident
- This joint effort is intended to baseline the best available technology for providing persistent communications and observations to remote fire management teams
 - Enable NIFC/USDA/USFS to understand the cost and complexity of contracting for this service
 - Identify opportunities to improve the capability for NASA Science and Applications

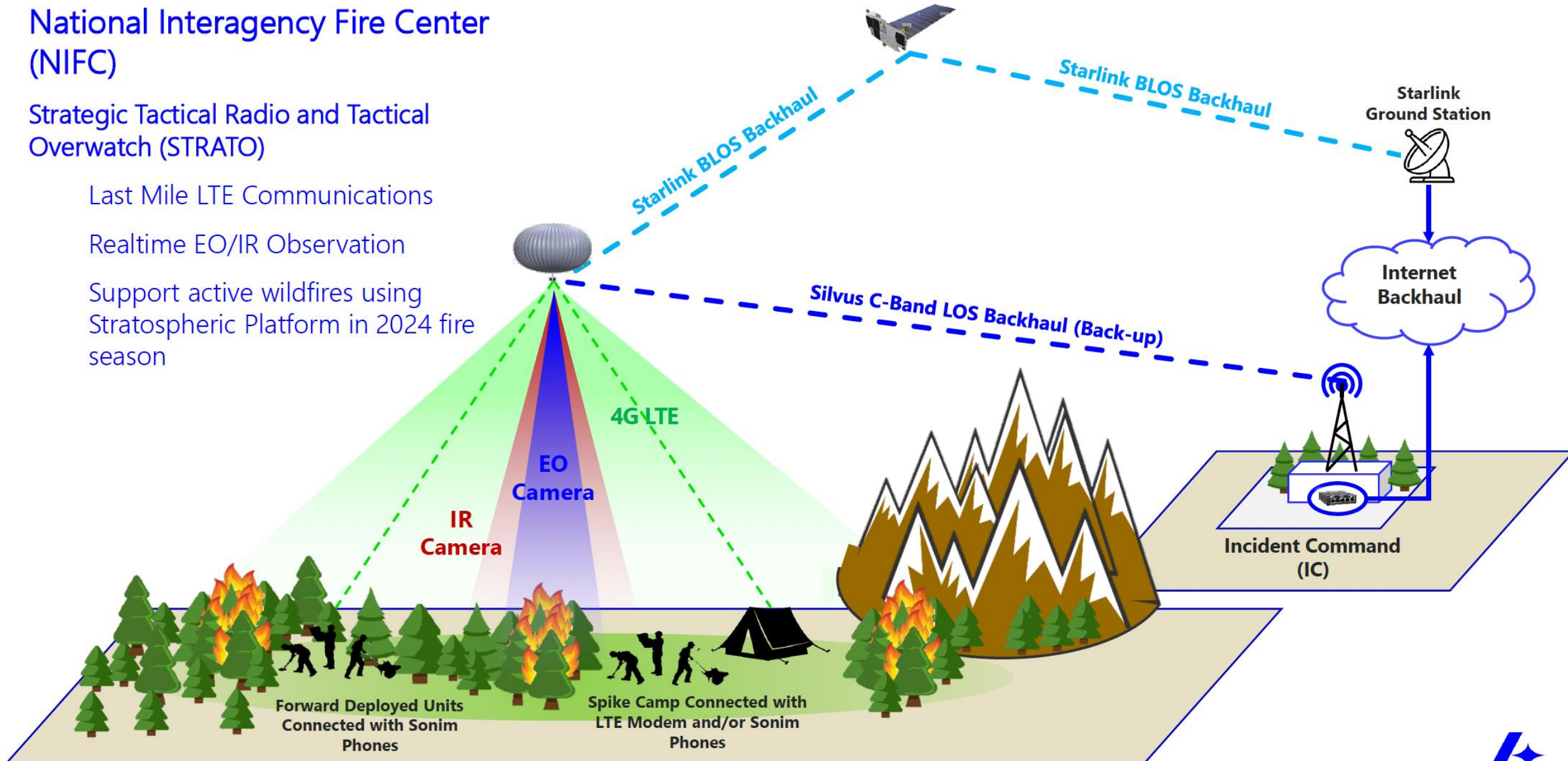


National Interagency Fire Center (NIFC)

Last Mile LTE Communications

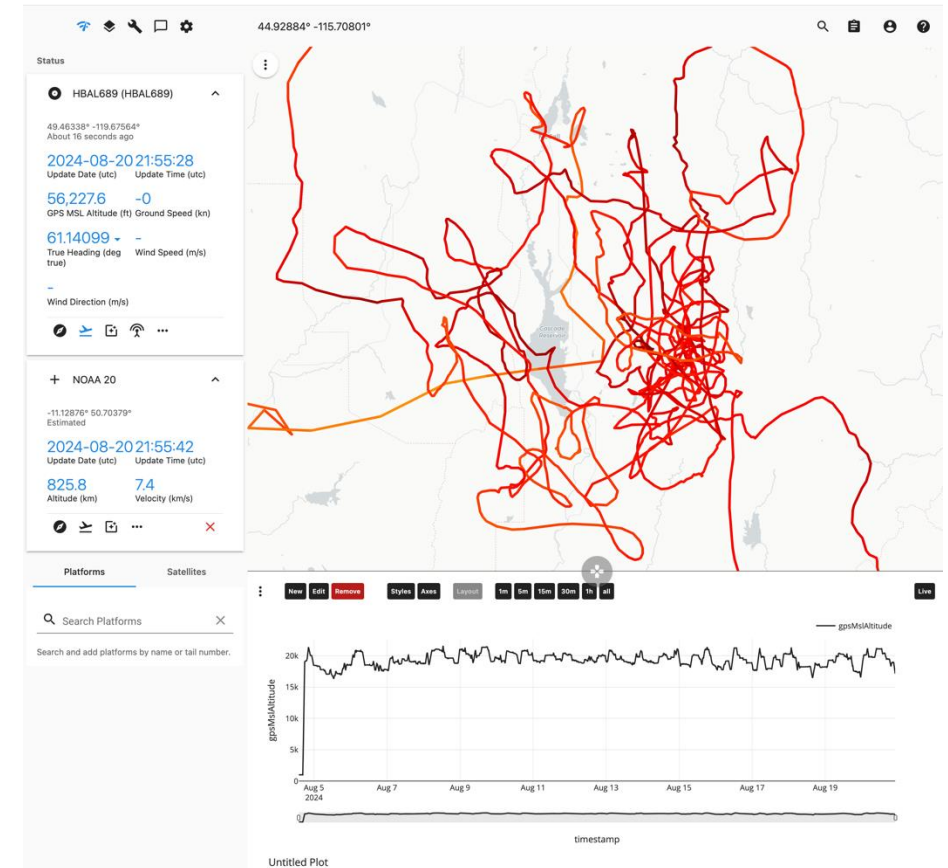
Realtime EO/IR Observation

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 Platforms

NASA 2022 SBIR Phase 1 selections

Guiding development of next generation platforms for science

The NASA SBIR Program recently selected 5 new aircraft for Phase 1 funding. We are working across NASA Centers to support these teams during concept development and

Goals: Enable persistence over a science target with a 10kg payload for 30+ days and

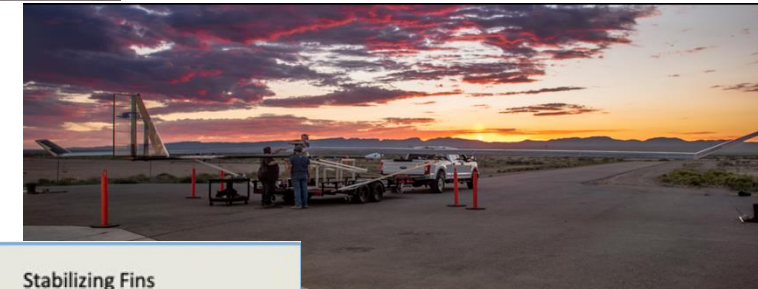
Science interests; Wildfire, hurricane formation and intensification, upper atmospheric chemistry, volcanic processes



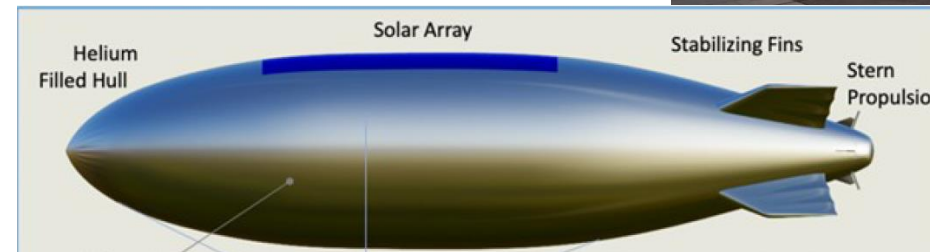
Skydweller



SACOS (Electra)



SULE II (Swift)



S-HALE (Moonprint)



S2-VTOL (BlackSwift)

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

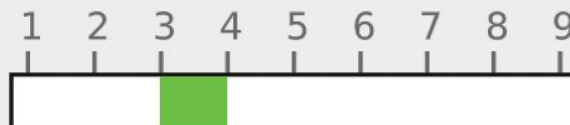


IMAGE TITLE: Electra "SACOS" HALE UAS



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

Ben Marchionna
Electra Aero Inc
EMAIL: marchionna.ben@electra.aero
PHONE: (248) 860-5606

Wingspan = 35m
Endurance = 30+ days
GTOW = 91 kg
Payload = 10 kg

Cruise Speed = 15 KEAS
Cruise Altitude = 20 km MSL
Max Climb Speed = 1 m/s



SACOS – Dawn One
First Flight

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 SWIR Hyperspectral Imaging for Earth Sciences

- Spectral Sciences Inc.
- Platform: SCEYE Airship



SCEYE



Platform

- The lighter-than-air platform is designed for month-long operations in $\pm 40^{\text{th}}$ latitude
- Combines station-keeping with significant payload capacity

LTE, high-resolution and hyperspectral cameras and IoT

- Platform is designed to be capable of lifting 100s of kg

finalizing testing, especially with regards to control dynamics

Payload

- Existing payload includes wide-area

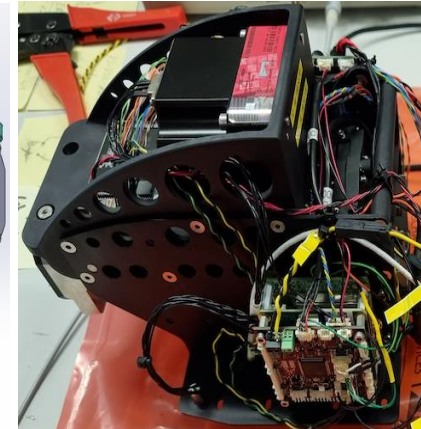
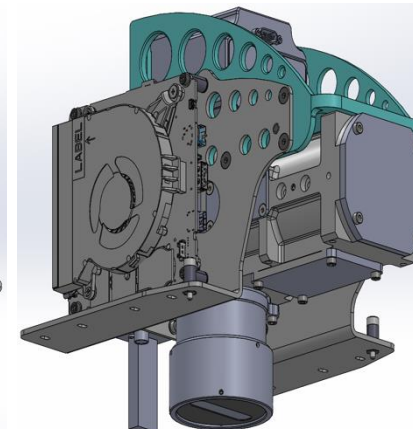
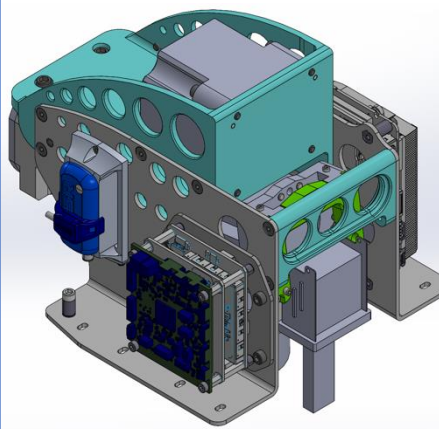
Current Status

- Sceye completed 4-flight ascent dynamics program in 2023
- Flights in 2024 are focussed on

USGS/ARC Mjolnir V-1240 Hyperspectral Instrument

Project

- USGS National Land Imaging Program has interests related to Sustainable Land Imaging Program and mineral mapping while NASA is developing the Surface Biology and Geology Mission.
- This interagency partnership is intended to calibrate and fly the Hypspx Mjolnir as an example of science quality COT instruments for HAPS



CAD Model of the Mjolnir V-1240 Hyperspectral Instrument

Mjolnir V-1240

Milestones

- Fly USGS Mjolnir V-1240 hyperspectral instrument on ER-2 on a non-interference basis during WDTS flight campaign – Fall 2022
- Collect in-flight data to characterize and evaluate the instrument performance including assessing data quality
- Evaluate instrument performance at the NASA Ames Airborne Sensor Facility (ASF) – 2023

Next Steps

- Test payload on SCEYE HAPS airship in Aug 2024
- Flight on Swift Engineering HAPS for SBIR Phase IIE science demonstration Nov-Dec 2024
- Comparative analysis against PICARD and AVIRIS-C/-NG from WDTS flights

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

The overall objective of the SBIR is to develop a high performance, inexpensive, three-band thermal infrared camera system, suitable for deployment in Unmanned Airborne Systems and CubeSats. This imaging system will be capable of mapping thermal features on the surface of the earth with a high revisit rate and high spatial resolution. Xiomias believes the Three Band Infrared Detector (TBIRD) System will see significant demand as a small multiband thermal sensor onboard small to medium sized unmanned airborne vehicles (UAV) and space-based cubesat applications, in both the commercial and military markets.

TECHNICAL OBJECTIVES AND WORK PLAN

The overall objective of the SBIR is to develop a high performance, inexpensive, three-band thermal infrared camera system, suitable for deployment in small manned or Unmanned Airborne Systems (UAS) and CubeSats. This imaging system will be capable of mapping thermal features on the surface of the earth with a wide field of view, a high revisit rate, and high spatial resolution. Xiomias believes the Three Band Infrared Detector (TBIRD) System will see significant demand as a small multiband thermal sensor onboard small manned aircraft, small to medium sized unmanned airborne systems (UAS), and space-based cubesat, in both the civilian and military markets. The system will be useful for a wide variety of environmental research, disaster response, wildfire science, wildfire detection and mapping, oil spill mapping and detection, and thermal anomaly mapping in general.

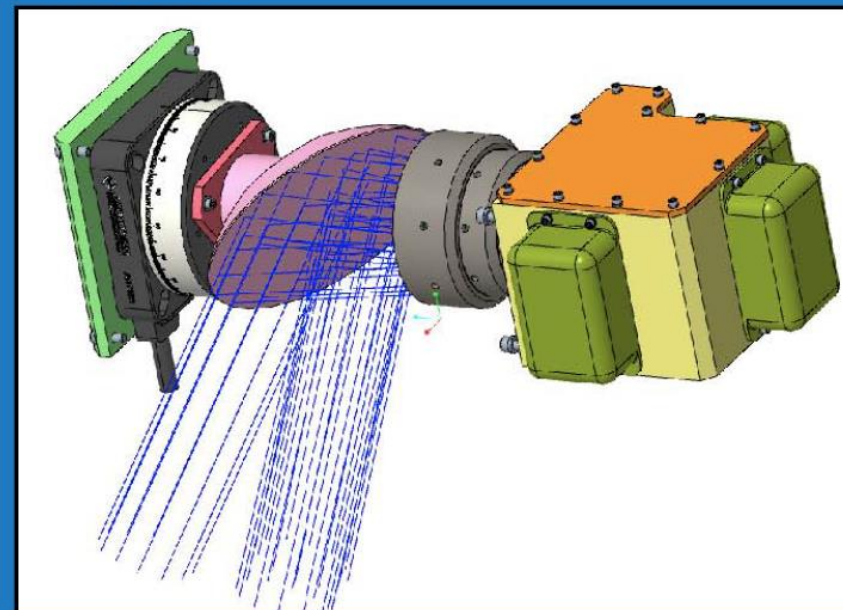
During Phase II a TRL 7 flight ready prototype will be built, characterized, and flight-tested. During Phase II we propose to fly 2 flight tests in manned aircraft or small UAVs.

TRL

Estimated



IMAGE TITLE: TBIRD



NASA APPLICATIONS

The system will be useful for a wide variety of environmental research, disaster response, wildfire science, wildfire detection and mapping, oil spill mapping and detection, and thermal anomaly mapping in general.

NON-NASA APPLICATIONS

Wildfire mapping, ground water mapping, heat loss studies
Military and Intelligence applications

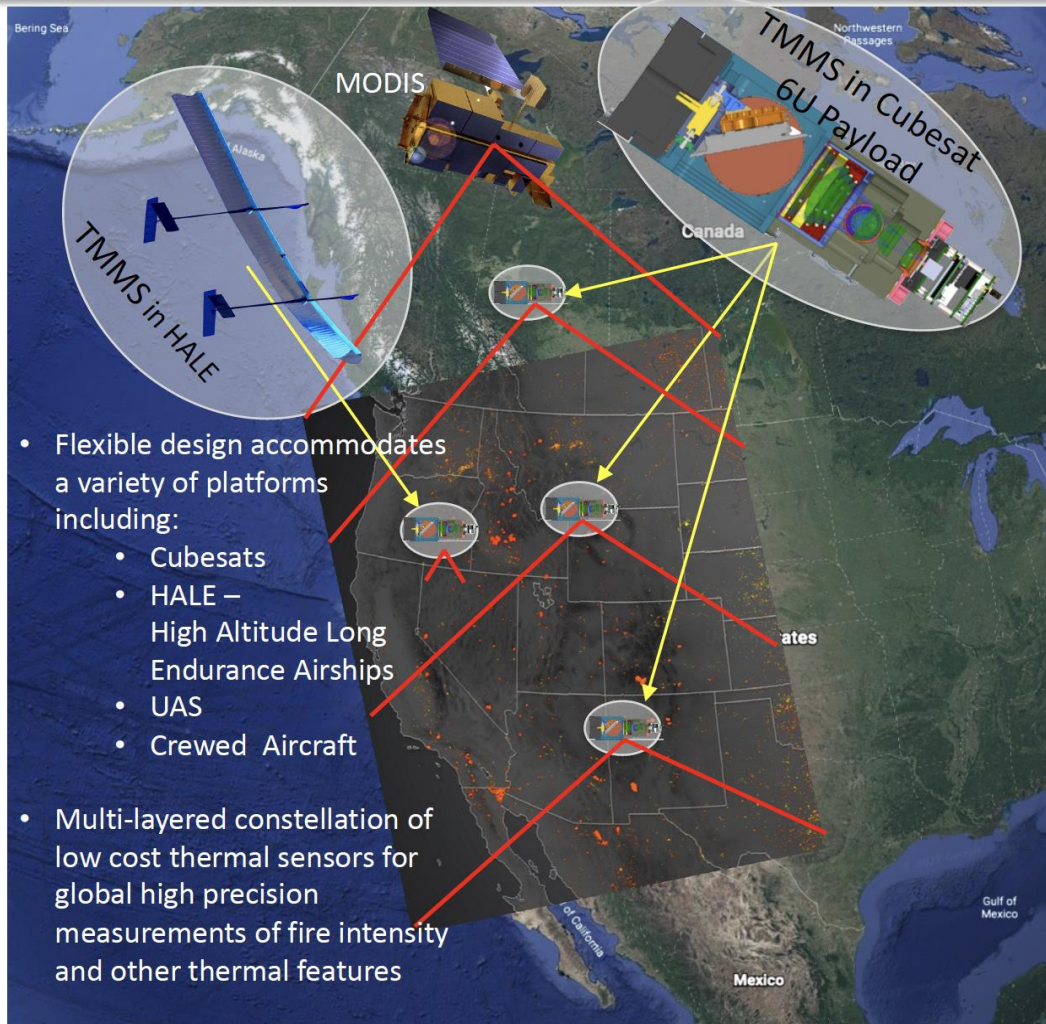
FIRM CONTACTS

John Green
Xiomias Technologies, LLC
EMAIL: johngreen@xiomas.com
PHONE: (734) 646-6535



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 μm

• TMMS Propose Bands:

- 3.96 μm (60nm)
- 9.05 μm (300 nm)
- 10.6 μm (500 nm)

Flexible Design allows multi-layered constellation

- Polar LEO
- Elliptical LEO
- HALE Stratospheric Platforms
- Low Altitude Crewed Acft. and UAS

XIOMAS



Compact Midwave Imaging System (CMIS)

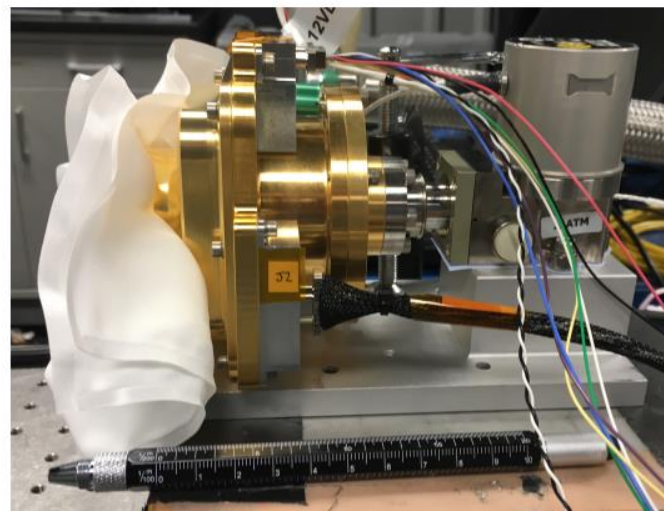
PI: Michael Kelly, Johns Hopkins University/Applied Physics Laboratory

Objective

Develop a midwave imager to provide key observations to meet objectives for the Planetary Boundary Layer (PBL) in the 2017 Earth Science Decadal Survey. The imager must:

- Achieve low weight, low volume and low power to enable accommodation on CubeSats
- Obtain radiometrically calibrated multi-spectral, multi-angular (nadir, fore, aft) imagery for accurate measurements of cloud heights and atmospheric motion vectors (AMVs)
- Provide wide field of view (53°) imagery to enable broad area coverage to complement lidar measurements
- Achieve high sensitivity across large dynamic range to support PBL studies in warm and cold regions (e.g. Arctic/Antarctic)

Conduct airborne flights on the LaRC Gulfstream-III to demonstrate CMIS capabilities that meet science measurement requirements.



CMIS Imager in the laboratory during integration and test phase

Approach

- Design and build imager with small size ($< 2500 \text{ cm}^3$), low weight (3 kg), and low power ($< 7 \text{ W}$)
- Perform laboratory and airborne geometric and radiometric calibration demonstrating NEdT $< 1 \text{ K}$ at 233 K
- Develop and test data processing software, and generate higher level science products (e.g. cloud heights and AMVs)
- Conduct airborne test flights for scientifically relevant scenes to acquire planetary boundary layer (PBL) observations at three spectral bands (2.25, 3.75, 4.05 μm)

Co-Is/ Partners: Dong L Wu, GSFC; Sam Yee, JHU/APL; Andrew Heidinger, NOAA/NESDIS; Carole Anne Clayson, Woods Hole

Key Milestones

• Board functional tests complete	04/19
• Camera structure complete	05/19
• Focal plane module characterized	05/19
• CMIS electronics module integration	06/19
• CMIS Integration and Flight Campaign I	07/20
• Imagery correction in software	08/20
• Update laboratory calibration	10/20
• Flight Campaign II (2 science flights)	01/21
• Final report	03/21
• Publish final Results	03/21

TRL_{In} = 4 TRL_{Current} = 5



A miniaturized payload for stratospheric aerosol composition and radiative properties from HALE aircraft

PI: Frank Keutsch/Harvard University

Target: Evaluate impact of non-sulfate component of stratospheric aerosol on satellite retrievals and atmospheric correction.

Science:

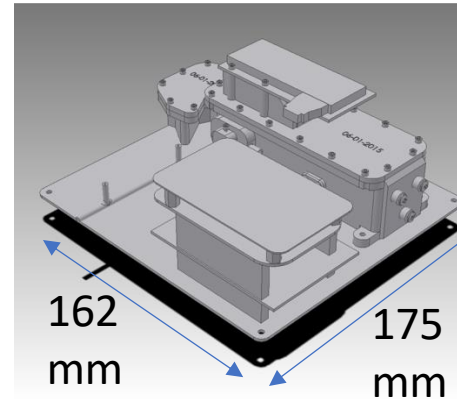
Utilize unique capability of HALE platform to provide critical mechanistic insights into stratospheric aerosol:

- How are the optical properties of stratospheric aerosols transformed over time, due to aging and mixing?
- How do aerosol composition, microphysics, and radiative properties vary for volcanic and wildfire sources?
- What are the sources of organic content in stratospheric aerosol?

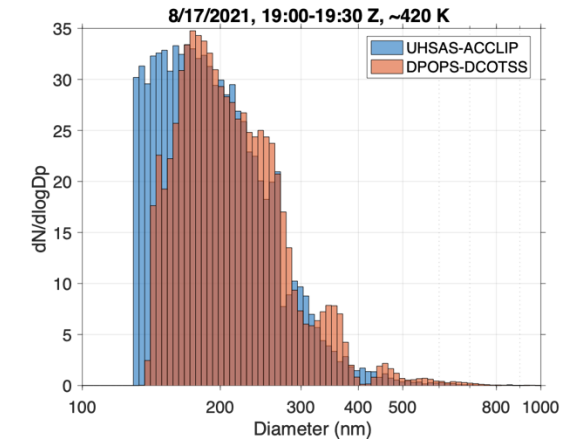
Objectives:

- Integrate customized off-the-shelf POPS (Portable Optical Particle Counter) optical particle counter (OPC) with SULE for a 30-day stratospheric deployment
- Support target selection and flight planning
- Perform scientific analysis of unique Lagrangian observations
- Provide mechanistic insights into spatial distribution and temporal variability of non-sulfate aerosol and their implications for satellite observations

Col: John Dykema/Harvard University



POPS OPC



Validated high-resolution size distribution measurements

Key Milestones:

- (M1) Analyze mechanical, thermal, and air sampling interfaces for HALE integration
- (M3) Fabricate mechanical fixture and sampling inlet and plumbing
- (M4) Assemble system and perform environmental test, calibrate
- (M5) Perform science calibration on laboratory bench
- (M6) Integrate with aircraft and functional test
- (M7) Conduct flight operations
- (M8) Recover instrument, return to laboratory
- (M9) Complete post-flight calibration and produce preliminary data product
- (M10) Science analysis and data finalization
- (M11) Conduct review with aircraft team
- (M12) Submit publication to atmospheric technology journal

TRL 5 to 6

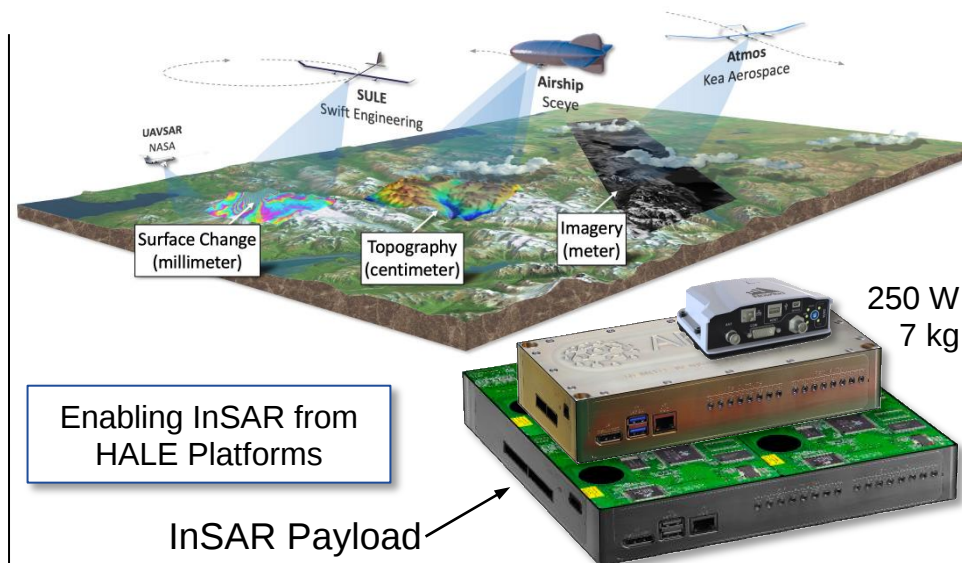


HALE InSAR: Continual and Precise Measurement of Earth's Changing Surface

PI: Lauren C. Wye, Aloft Sensing, Inc.

Objective

- Develop and demonstrate a compact (<7 kg, <250 W) X-band InSAR payload for stratospheric High Altitude Long Endurance (HALE) platforms to capture the high-frequency dynamics of critical geophysical processes in support of Solid Earth science
- HALE-proven low-SWaP InSAR payload will provide mm-level deformation and cm-level topographic measurements
 - Solar-powered HALE aircraft and airships offer affordable persistent regional access
 - Together, HALE-based InSAR enables continual and precise observation of science targets, currently unattainable with existing methods
- Develop and validate algorithms that overcome the challenges of HALE operations, such as low platform velocities and coarse trajectory control



Approach

- Prototype algorithms and verify operation with simulations
- Modify firmware and interfaces on software defined radar (SDRr)
- Design, build, and test active electronically steered array (AESA)
- Redesign Swift Ultra Long Endurance (SULE) nosecone to accommodate HALE-InSAR payload
- Integrate payload and complete first stratospheric flight
- Conduct long duration stratospheric flight
- Assess performance against models

Co-Is/Partners: P. Rennich, B. Pollard, Aloft; K. Sabet, EMAG; J. Carswell, RSS; H. Khalkhali, Swift; M. Fladeland, NASA ARC; . J. Stock, USGS

Key Milestones

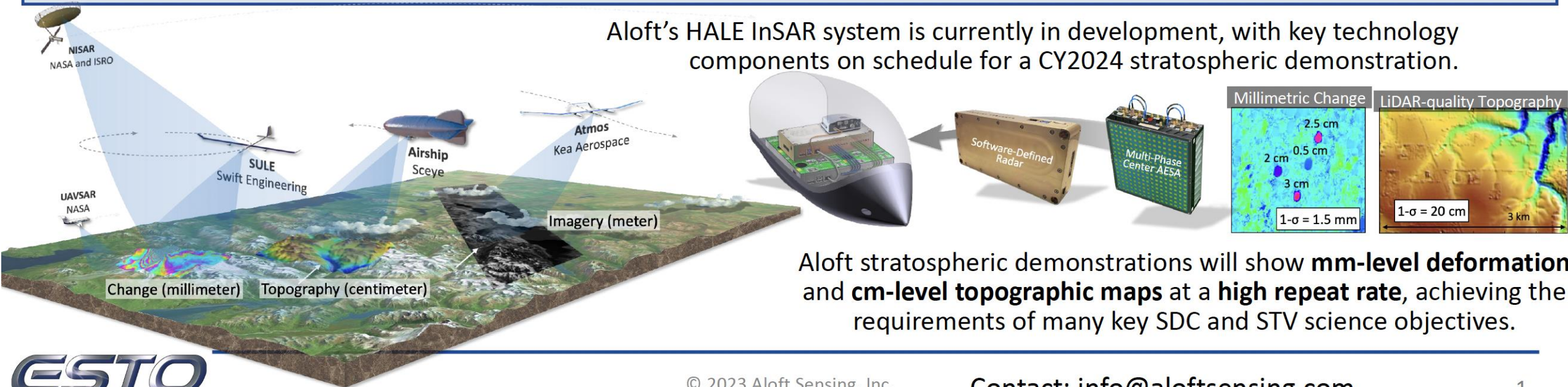
- | | |
|--------------------------------------|-------|
| • AESA Tile verified | 11/22 |
| • HALE algorithm prototypes verified | 12/22 |
| • AESA panel verified | 06/23 |
| • AESA system verified | 08/23 |
| • InSAR payload prototype complete | 09/23 |
| • Stratospheric first flight | 01/24 |
| • Long duration Stratospheric flight | 07/24 |
| • Embedded algorithm prototypes | 10/24 |

TRL_{in} = 2 TRL_{current} = 2



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.



Challenges



- Airspace management
 - Need to expand UTM-like tools for all altitudes for scheduling, tracking and deconfliction
 - Need ADS-B and BVLOS related technologies for improved knowledge of airspace users
 - International cooperation is needed to enable flights between flight regions
 - More flexibility in launch and recovery locations as well as glide and descent trajectories
- Environmental considerations
 - Fixed wing require low winds during ascent and descent phases
 - Icing detection and mitigation/avoidance
- Payload and subsystem mass reduction
 - SUAS and Cubesat engineering are a forcing function towards science-quality HAPS payloads
 - Lower SWAP SATCOM for smaller vehicles to enable BVLOS
 - Lighter and more power dense batteries
- Spectrum deconfliction
 - Need for dedicated aviation frequencies at all altitudes for this class of vehicle for radio line-of-site

Conclusions



- HAPS will play an important role in the NASA Earth System Observatory by complementing satellite measurements with higher spatial and temporal resolution
- The HALE-X and STRATO projects are
- NASA/SMD ESTO is investing in low SWAP payloads and
- NASA/ARMD is furthering the development upper E traffic management systems

Thank you for attending this
IEEE Seminar!



Matt Fladeland
NASA Ames Research Center
Moffett Field, California
Matthew.Fladeland@nasa.gov
650-604-3325