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United States Department of Agriculture
Project Initiation

Project Data for Accession Number 1035329

Project Title

Solar-Powered HALE UAS with L-band Radar for Enhancing Fuel Moisture Inputs towards Wildfire Ignition Risk Probability Mapping and Mitigation

Project Details

Sponsoring Institution National Institute of Food and Agriculture	**Project Status** ACTIVE
Funding Source NIFA Non Formula	**Grant Year** 2026
Grant No. 2026-33530-46974	**Cumulative Award Amt.** $598,822.00
Proposal No. 2025-08089	**Multistate No.** (N/A)
Project Start Date Sep 15, 2026	**Project End Date** Sep 14, 2028
Program Code [8.1] Forests & Related Resources	

Project Director

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Recipient Organization

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Performing Department

(N/A)

Non Technical Summary

Wildfire preparedness is limited by the lack of timely, detailed measurements of how much water is contained in vegetation. Current approaches often depend on weather-based estimates, sparse ground observations, or satellite products that may be too coarse, too infrequent, or degraded by clouds and smoke. This project is based on the premise that a persistent, solar-powered aircraft operating high in the atmosphere can combine an all-weather radar with other environmental measurements to provide more reliable and decision-ready fuel-moisture information while remaining feasible within strict aircraft energy and payload limits.The project will model how radar and optical measurements respond to changing vegetation moisture, determine when combining the two sources improves the result, and quantify the spatial detail, revisit rate, latency, and confidence needed for wildfire applications. The team will also design the instrument's thermal, structural, data-processing, storage, and communications systems and will

use laboratory emulators to test power, timing, data flow, electromagnetic compatibility, and antenna behavior before flight-article use. The expected result is a technically validated path to an uncertainty-quantified fuel-moisture product at approximately 200 m or finer resolution and within 24-48 hours, with guidance and data formats suitable for existing wildfire-risk and spread models. This capability could improve preparedness and risk-based planning for fire agencies, utilities, land managers, insurers, and rural and wildland-urban-interface communities, while also supporting future agricultural and rangeland water-stress monitoring.

Animal Health Component

Animal Health Component: 0%

Research Effort Categories

Basic	0%
Applied	50%
Developmental	50%

Classification

Knowledge Area (KA)	Subject of Investigation (SOI)	Field of Science (FOS)	Percent
122	7210	2020	100%

Knowledge Area

[122] Management and Control of Forest and Range Fires

Subject Of Investigation

[7210] Remote sensing equipment and technology

Field Of Science

[2020] Engineering

Keywords

Solar, Wildfire, HALE, Fuel Moisture, unmanned system

Goals / Objectives

The major goal of this Phase II project is to advance a persistent, all-weather, day/night capability that combines a solar-powered High-Altitude Long-Endurance (HALE) unmanned aircraft, an airborne L-band synthetic aperture radar (SAR), and a multi-sensor data-fusion pipeline to produce timely, spatially detailed, uncertainty-quantified fuel moisture content (FMC) information for wildfire risk assessment and mitigation. The project targets an upstream FMC-200 product with approximately 200 m or finer spatial resolution and no more than 24-48 hours of latency, suitable for ingestion by downstream ignition-risk and fire-spread modeling systems.1. Develop and apply a layered, single-scattering microwave backscatter model to quantify the sensitivity of L-band SAR measurements to changes in FMC across representative wildfire fuel and vegetation structures under nominal and flash-drought conditions, and translate the results into instrument and mission requirements.2. Extend the common vegetation framework to hyperspectral

optical radiative transfer modeling; generate consistent synthetic SAR and optical observations; develop and compare single-sensor and multi-sensor retrieval approaches; and quantify when sensor fusion improves fuel-condition estimation.3. Extend the Phase I information-content framework to assess the effects of spatial resolution, revisit interval, measurement uncertainty, ecoregion, and season; perform spatial and temporal cross-validation and uncertainty propagation; and produce operational guidance and standardized method cards.4. Design, analyze, and validate a lightweight transient thermal architecture and structural integration approach for the SAR instrument, antennas, batteries, maximum power point trackers, avionics, payload-bay air, and structure across hot-day and cold-night operating conditions.5. Develop a low-power, fault-tolerant data and communications architecture that reduces raw SAR data on board, preserves prioritized data, supports time alignment and co-registration, and delivers health, quicklook, and bulk data products through a tiered line-of-sight and satellite communications strategy.6. Verify end-to-end payload readiness through bench-first emulation and combined-effects testing of power, timing, data throughput, storage, fault behavior, electromagnetic compatibility, and antenna/radome performance, and integrate the results into final system-design and operational recommendations.

Project Methods

The project will use an integrated modeling, systems-engineering, and bench-validation approach organized into six coordinated work packages.First, the Harvard team will define representative wildfire fuel and vegetation structures for major at-risk ecosystem types and parameterize crown, understory, litter, and soil layers using literature and available field data. A computationally tractable, layered single-scattering radiative-transfer model will be implemented to predict total L-band SAR backscatter. Simulations will span vegetation types, viewing geometries, moisture states, and nominal versus flash-drought conditions. Sensitivity analysis will quantify changes in SAR observables, establish detectability thresholds under realistic noise and system constraints, and translate the findings into recommended sensor precision, spatial resolution, and revisit requirements.Second, the same vegetation structures and moisture parameters will be extended with optical properties for PROSAIL-based hyperspectral radiative-transfer modeling. This common synthetic framework avoids temporal mismatch and environmental confounding when comparing sensors. Simulated hyperspectral reflectance and canopy-water estimates will be paired with SAR backscatter and FMC estimates. The team will develop and compare single-sensor and multi-sensor retrieval approaches, ranging from straightforward weighted combinations to methods that account for the different physical quantities measured by the sensors. Evaluation will use standard accuracy metrics and information-theory measures to identify the conditions in which fusion provides incremental value.Third, the Phase I Kullback-Leibler-divergence framework will be expanded across the spatial-resolution and revisit-interval ranges relevant to HALE operations. Spatial and temporal block cross-validation will assess generalizability across previously unobserved regions and seasons. Error sources will be propagated from instrument measurements through fusion algorithms to final FMC estimates to produce confidence bounds. Results from the first two work packages will be synthesized into guidance tables and method cards specifying minimum revisit frequency, acceptable latency, expected reliability, algorithms, validation procedures, and performance by ecoregion and season.Fourth, Iris will develop a transient thermal model covering the SAR instrument, antennas and radome, batteries, maximum power point trackers, avionics, payload-bay air, and structure. Time-varying electrical and environmental loads will represent day/night flight and SAR duty cycles. Passive controls will be evaluated first, including optical surface properties, insulation, conductive straps, and radiator areas; targeted heaters, phase-change materials, or active cooling will be considered where needed. The selected configuration will be used to define thermal interfaces, control logic, margins, and structural integration. Heater energy and temperature-dependent battery and power-conversion performance will be fed back into aircraft energy closure.Fifth, Iris will quantify data flow from raw radar measurements through calibrated backscatter and FMC-ready quicklooks. The team will size edge processing, onboard storage, metadata conventions, time discipline, and fault-tolerant behaviors. A tiered communications architecture will use line-of-sight links for planned bulk transfer and low-rate satellite communications for command, health, and prioritized quicklook products, with optional broadband alternatives evaluated subject to size, weight, power, thermal, and energy constraints. Transfer and sensing schedules will be adjusted when energy margins tighten.Sixth, the team will build and use a Mass Thermal Article, Electrical Load Emulator, and Data/Timing Emulator to test payload behavior before use of a flight article. Hardware- and software-in-

the-loop tests will evaluate start-up and shutdown sequences, bus transients, timing determinism, throughput and buffer margins, storage, communications, and injected faults. Electromagnetic interference and compatibility pre-compliance scans will guide harnessing, grounding, and filtering. Vector-network-analyzer and short-range checks will assess antenna match, temperature-related phase stability, pattern, and polarization.Success will be evaluated against the proposal milestones and quantitative indicators. These include completion and acceptance of five contract deliverables at approximately months 1, 6, 12, 18, and 24; quantified SAR moisture sensitivity and detectability thresholds; comparative single-sensor and fusion performance; cross-validated information-content and uncertainty results; guidance tied to ecoregion and season; thermal compliance with component limits and documented hot/cold margins; updated aircraft energy closure; data throughput, buffer, storage, and latency margins; deterministic timing and acceptable bus transients; successful fault responses; electromagnetic compatibility improvements; antenna performance within defined tolerances; and readiness of prioritized data products for delivery within the targeted 24-48 hour latency. Findings will be interpreted jointly by the science and engineering teams and communicated through reports, method cards, reviews, presentations, publications as appropriate, and coordination with prospective operational users and partners.