NASA'S TECHNOLOGY DEVELOPMENT PROGRAM FOR WILDFIRE SCIENCE, MANAGEMENT, AND DISASTER MITIGATION

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ABSTRACT

NASA's Earth Science Technology Office (ESTO) has established a new program called Technology Development for support of Wildfire Science, Management, and Disaster Mitigation (FireSense Technology), to develop innovative new technologies and capabilities to better predict, monitor and manage wildfires and their impacts. ESTO's FireSense Technology program works in collaboration with NASA's Applied Sciences Wildland Fire Program, the Aeronautics Research Mission Directorate (ARMD), the Space Technology Mission Directorate (STMD), and the Small Business Innovative Research (SBIR) program. The program will also work closely with interagency partners such as the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Agriculture Forest Service, the California Department of Forestry and Fire Protection, the National Interagency Fire Center, and others. In this paper we will discuss the program objectives and provide an update on the technological developments to date.
Index Terms— Wildfires, NASA, Earth Science, Remote Sensing.

1. INTRODUCTION

A recent report by the President's Council of Advisors on Science and Technology (PCAST) on Wildfires estimated that "more than 100 million Americans now live in areas threatened by wildfires" [1]. A separate report from the US Environmental Protection Agency (EPA) has estimated that the average monthly burned area in the United States has increased from 88,000 hectares to 209,000 hectares between 1984- 2001 and 2002-2020 [2]. Over the past few decades, the United States has routinely spent more than $1 billion per year to fight wildfires, including $2.3 billion in 2020.
In Greece, in 2023, several wildfires in Rhodes, Evia, the Evros region, and other locations, resulted in dozens of deaths and injuries, devasted forests, and destroyed multiple structures. The fire in Evros, near Alexandroupolis, was the largest wildfire ever recorded in the European Union [3]. NASA remote sensing satellites such as the Visible Infrared Imaging Radiometer Suite (VIIRS) on the NOAA-NASA Suomi NPP satellite recorded the extent of the destruction.
A combination of factors, such as higher global temperatures, increased fuel loads, urbanization, land and forest management practices, are contributing to the increased frequency and severity of wildfires.

In order to better monitor the pre-fire, active-fire, and post-fire environment and mitigate the impact of wildfires NASA's FireSense Technology program is developing new observation and information system technologies to enhance capabilities of existing and new science instruments; reduce their mass and power for accommodation by next-generation small spacecraft and aerial platforms; enable measurements from model-directed, coordinated observations using autonomous tasking; address computational challenges for modeling and for data acquisition, fusion, and processing in a real-time environment; facilitate machine learning and artificial intelligence to create new data products needed for wildland fire management; enhance the exchange of information between spaceborne, airborne, and in situ assets and first responders.

2. FIRESENSE TECHNOLOGY PROGRAM

The FireSense Technology program plans to deliver relevant technology and improved capabilities to operational stakeholders such as federal, state, or local agencies that are engaged in fire management. These capabilities include updated characterization of fuels; better forecasts for risk assessment; faster and improved fire behavior models; increased detection and tracking of active fire dynamics and smoke plumes with improved spatial and temporal resolution; improved mapping of burn severity; reduced uncertainty for post-fire hazards to air, land, and watersheds.

The program includes an airborne component where it will test existing and new instruments and evaluate new aerial platforms, such High-Altitude Long Endurance (HALE) fixed-wing aircraft and Unmanned Aircraft System (UAS), to demonstrate the utility of the new technologies. Annual airborne campaigns are currently planned culminating in a capstone campaign in 2027-28. The final objective would be to deliver the new technologies and capabilities to operational agencies and enable a seamless and efficient exchange of relevant information between spaceborne, airborne, and in situ assets while reducing latency and information overload.

In order to achieve these objectives, the program is currently funding several projects that will develop new tools for monitoring fire events and forecasting wildfire spread.

The projects span a variety of observation and information technologies including thermal, multispectral, or hyperspectral imagers to determine fuel types, fuel loading, and fuel moisture, improved fire-spread and plume dispersion models, digital twins, and coordinated measurements, assisted by artificial intelligence (AI), from multiple platforms. The current projects include:

A Wildfire Digital Twin (WDT) project to implement and evaluate a regional digital twin model for the simulation of fire, its spread, and smoke impacts on air quality, regional deforestation, and human health in local and distant communities. WDT will utilize machine learning to provide wildfire forecasts in real time and implement a satellite data assimilation scheme to conduct impact scenarios on wildfires and wildfire smoke.

A Technology Development project to Integrate Innovative Observation Capabilities into Coupled Wildfire Models for Improved Active Fire Forecasting. The project will synthesize innovative observation capabilities, including mobile Doppler RADAR observations, the northern California Doppler wind LIDAR network, high-resolution hyperspectral wind fields, and low latency satellite fire detections to develop the technology needed for utilizing these observations in coupled atmosphere-fire forecasting.

A UAS thermal infrared spectroscopy project to improve real time evaluation of hazards and environmental impacts of wildfires. The project will advance the spatiotemporal resolution and latency of novel multispectral thermal infrared (TIR) data acquired from a small UAS, increasing the accuracy of the detection and characterization of burn stages and derive the 3-dimensional temperature and emissivity of both the solid and gas phases and improve knowledge of maximum burn temperatures and gas flux rates.

An AI-enabled Drone Swarms for Fire Detection, Mapping, and Modeling project to develop a hierarchical platform of multiple UASs to provide long-term coverage of fires and develop low-computation real-time collaborative learning methods for fire detection and mapping onboard the drones and transmit the final fire map to stakeholders. The project will develop an AI-based onboard fire spread modeling using deep learning methods, a Digital Twin Environment for fire management activities so that fire management teams can interactively assess risks across active wildland fires.

An airborne Compact Fire Imager (CFI) project to develop a push broom instrument with six spectral bands between the shortwave infrared (SWIR) and thermal infrared (TIR), including two channels in the mid-wave infrared (MWIR) specifically designed to detect and characterize flaming and smoldering fires. The CFI will deliver unsaturated multi-spectral measurements at high spatial resolution in a form factor that is compatible with the size, weight, and power (SWaP) constraints for NASA's next-generation airborne platforms. CFI builds on the design and performance of the dual-band Compact Thermal Imager (CTI) that collected more than 15 million images from the International Space Station (ISS) in 2019, including thousands of fires.

A Distributed Spacecraft with Heuristic Intelligence project to monitor Wildfire Spread for Responsive Control project to develop and verify a space-based distributed observing system that will enhance the Weather Research and Forecasting Fire Spread Model (WRF-SFIRE) and other existing fire danger products. The project plans to use Global Navigation Satellite Systems- reflectometry (GNSS-R) data from currently operational Cyclone Global Navigation Satellite System (CYGNSS) and Spire Global satellites to make improved soil moisture measurements and to generate Burnt Area Maps (BAMs). These data products will significantly augment current fire predictions and provide new frameworks for wildfire observation and management.

A Pyro-Atmosphere Infrared Sounder (PIRS) project to provide 3-dimensional information about the state of the atmosphere during the pre- and active-fire stages of wildland fires. The instrument would measure temperature and humidity with high spatial resolution, providing insights into how fires start and spread as well informing fire management response.

A Wildfire Thermal Detection Instrument Development project, a concept study to develop and demonstrate low-cost and scalable infrared sensing and other technologies for wildfire management. The project will conduct a study to mature a low-cost mass-producible, space-based fire detection thermal Earth observation imager. The study will mature a space-based fire detection instrument as part of the active fire stage of the wildfire lifecycle. The study focuses on validating the approach of leveraging SWIR and/or MWIR thermal cameras to perform real-time fire detection from space. By validating the instrument and sensing concept of operations, the study will investigate the case for a low-cost proliferated low-earth-orbit (LEO) constellation approach to wildfire detection, capable of providing a 15-minute detection cadence across the continental US.

A summary of the current ESTO FireSense Technology projects, with the principal investigator, their affiliations, and the titles is shown in Table I below and the abstracts are available on the ESTO website [4].

Table 1 Current FireSense Technology Projects

Principal Investigator	Affiliation	Title
Milt Halem	University of Maryland, Baltimore County	Towards a NU-WRF based Mega Wildfire Digital Twin: Smoke Transport Impact Scenarios on Air Quality, Cardiopulmonary Disease and Regional Deforestation
Sreeja Nag	Bay Area Environmental Research Institute	Distributed Spacecraft with Heuristic Intelligence to monitor Wildfire Spread for Responsive Control
Sun Wong	Jet Propulsion Laboratory	Pyro-Atmosphere Infrared Sounder: Monitoring Fire Weather Conditions with a Sub-Kilometer Spatial-Resolution Hyperspectral Infrared Sounder
Doug Morton	NASA Goddard Space Flight Center	The airborne Compact Fire Imager (CFI) for measurements across the entire fire lifecycle
Kyle Hilburn	Colorado State University	Technology Development to Integrate Innovative Observation Capabilities into Coupled Wildfire Models for Improved Active Fire Forecasting
James Thompson	University of Texas at Austin	UAS thermal infrared spectroscopy will improve real time evaluation of hazards and environmental impacts of wildfires
Fatemeh Afghah	Clemson University	AI-enabled Drone Swarms for Fire Detection, Mapping, and Modeling
Simon Hook	Jet Propulsion Laboratory	Wildfire Thermal Detection Instrument Development

3. AIRBORNE CAMPAIGNS

Over the next five years, in collaboration with other agencies, the FireSense Program plans a series of airborne field campaigns culminating with a capstone mission in 2027-2028 to demonstrate the technologies and evaluate their contribution in wildland fire management. The campaigns will include both prescribed fires and active fires as well pre-fire soil moisture and vegetation measurements and collect both remote sensing and in situ data (where available) to help improve fire models and wildfire management.

In 2023, the first airborne campaign utilizing existing instrumentation was conducted at multiple sites in collaboration with the Fire and Smoke Model Evaluation Experiment (FASMEE) effort and partners engaged in active research on sites in private and public lands across the western United States [5, 6]. During the 2023 campaign, four aircraft were deployed with active and passive remote sensing instruments from NASA centers and academic institutions to sample vegetation and soil moisture at sites across the western United States and monitor targeted prescribed and wildland fires. The instruments included visible and infrared imaging, a scanning spectrometer, a synthetic aperture radar, and a scanning L-band radar and passive microwave radiometer.

Future airborne campaigns will include and evaluate instrumentation and information technology being developed under the FireSense Technology Program.

4. SUMMARY

Over the last two decades wildfires have become more frequent and intense in many parts of the world. Their economic and ecological impact has also significantly increased. In the summer of 2023, Canadian wildfires released large amounts of smoke and particulate matter into the atmosphere resulting in poor air quality and posing significant health risks in Canada and the United States. Wildfires also have a substantial impact on climate change especially in Arctic regions, which have experienced rapid warming. Boreal forests store large amounts of carbon, and wildfires release stored carbon into the atmosphere [7].

Addressing the wildfire problem requires improved understanding of a variety of factors including soil moisture, increasing fuel loads, climate change and rising temperatures, precipitation patterns, improved land and forest management, and sustainable urban development, among others. In order to mitigate the impact of wildfires and better understand the pre, active, and post-fire environment, improved models and technologies are needed. The NASA FireSense technology program is part of a larger NASA wide Wildland Fire initiative involving the Science Mission Directorate (SMD), the Aeronautics Research Mission Directorate (ARMD), and the Space Technology Mission Directorate (STMD) and is committed to advancing our understanding of wildfires and delivering new capabilities to operational agencies and stakeholders engaged in fire management. The program, which includes an airborne component, is currently funding several projects that will develop new tools for monitoring fire events and forecasting wildfire spread. The projects span a variety of technologies including passive and active multispectral, or hyperspectral imagers and spectrometers to determine fuel types, fuel loading, and fuel moisture, improved fire-spread and plume dispersion models and coordinated measurements from airborne and space platforms. These new capabilities would include better characterization of fuels, updated fire risk assessment, improved fire and smoke spread models, faster detection and tracking of active fire dynamics with improved spatial and temporal resolution and better assessment of post-fire hazards to air, land, and watersheds.

5. REFERENCES

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