COLLABORATIVE EFFORTS IN R&D AND APPLICATIONS OF IMAGING WILDFIRES

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ABSTRACT

NASA-Ames and the US Forest Service were recently funded to explore cutting edge technologies in fire imaging, telemetry, data / information integration, and UAV platform demonstrations to facilitate a "technology adaptation" and integration mechanism into the fire management community. The collaborative effort will involve participation from organizations such as RSAC, NIFC, NASA and affiliated universities. The collaborative effort will focus on R&D, test and evaluations, and integration of new technologies into the remote sensing fire imaging community. The over-arching goal of the effort is to allow fire mitigation agencies to be on the forefront of developing technologies, to share expertise and knowledge, and to come to an improved understanding of fire imaging and data / information integration to allow a more rapid decision-making mechanism for the fire mitigation community. This paper will address the collaborative efforts, technology-focus areas, and demonstration concept plans for the program effort.

INTRODUCTION

The Wildfire Research and Applications Partnership (WRAP) project was successfully competed and funded in 2003 under the NASA Office of Earth Science (OES) Cooperative Agreement Notice (CAN) CAN-02-OES-01, entitled “Earth Science REASoN – Research, Education, and Applications Solutions Network, A Distributed Network of Data and Information Providers For Earth Science Enterprise Science, Applications and Education (http://research.hq.nasa.gov/code_y/nra/current/CAN-02-OES-01/winners). The project proposal, originally entitled “NASA Wildfire Response R&D, Applications and Technology Implementation” (REASoN-0109-0172), was shortened to WRAP (http://geo.arc.nasa.gov/sge/WRAP/) to highlight the collaborative partnership of the US Forest Service and NASA in wildfire science and applications. The project is a 5-year funded effort, initiated in July 2003. The objectives of the project are to foster collaborative partnerships between NASA and the US Forest Service to facilitate and demonstrate evolved and evolving technologies for increasing the information content and timeliness of earth resource data collected for wildfires. Both agencies have worked collaboratively on parallel-track developments in fire imaging, but this initiative is the first major effort at formalizing and focusing wildfire science and applications between the agencies. The expected outcomes of this collaborative effort are creation of improved tools for Wildfire Decision Support Systems within the US Forest Service and the other fire mitigation and management agencies.

There are three main focused elements of our collaborative efforts: **1) A research and development element** in remote sensing of wildfires specifically focused on advancing the development of airborne imaging systems, data telemetry, real-time data and information processing and distribution (via the WWW) and development of

Unmanned Aerial Vehicle (UAV) platform technologies (in conjunction with the NASA Research Park – UAV Applications Center). **2) An applications, demonstrations, and validation element** focused on test-bedding and demonstrating the utility of the R&D efforts on both piloted and unmanned (UAV) platforms. **3) A technology transfer / education (workforce development) element.** The R&D effort is focused on development of sensor systems, telemetry, data manipulation strategies, and utilization of innovative remote sensing platforms (UAV).

We propose maturation of these technologies through laboratory and field calibration / validation strategies and piloted and UAV technology demonstration missions. These demonstrations will validate the utility of NASA technologies to our USFS partner. The applications, demonstration and validation element leads directly into a technology transfer and integration phase. The WRAP project provides for a training element, technology integration model and process, and integration success criteria in the technology transfer element. This strategy will lead to a significant improvement in tactical fire imaging, information extraction and fire management and mitigation efforts by the US Forest. Our efforts will reduce the fire information ingestion process from a few hours to within 15 minutes, thereby minimizing the potential loss of resources, personnel and property during a fire event. Our efforts, although focused on wildfire monitoring, modeling, and mitigation, will have crosscutting and synergistic technologies that are applicable to a wide range of disaster-related applications. This project effort ensures that the data, technology, and capabilities developed by the team are exploited to the maximum extent possible for the benefit of society and the monitoring and protection of resources and personnel.

BACKGROUND

NASA-Ames and the Forest Service have been actively involved in airborne fire imaging since the 1960's (Arnold, 1951; Johnson and Thomas, 1951; Hirsch, 1962, 1963, 1964, 1968; Wilson, 1968; Hirsch *et al*., 1971; Dipert and Warren, 1988; George *et al*., 1989; Warren and Celarier, 1991; Warren, 1990, 1992, 1994; Scott, 1991). NASA's involvement increased in the 1970's with the establishment of the High Altitude Aircraft Program, and subsequent sensor development efforts at NASA-Ames (Brass *et al*., 1987). Those early efforts have more recently blossomed into closer aligned activities in the use and development of new systems and platforms. More recent developments by both agencies have occurred along closely aligned parallel tracks, but with little or no shared financial support.

In the late 1990's, cooperative efforts between the USFS and NASA-Ames established new requirements for improving airborne wildfire monitoring. These requirements included: over-the-horizon (OTH) telemetry capability, greater bit-rate throughput telemetry, multiple spectral band data collection and transmission, and improved geo-rectification procedures (Buechel *et al*., 2001). The final requirement was to provide these elements within one hour or less of data collection. With the advent of remotely piloted aerial vehicles, and their attendant large payload capacity, NASA developed demonstrations to exploit the UAV as a remote sensing platform. Those research endeavors led to the successful applications demonstration, FiRE project (Ambrosia *et al*., 2003).

In July 2000, NASA HQ formally established the NASA Wildfire Response Team to oversee coordination of NASA assets related to fire research and applications. NASA-Ames Research Center was selected to lead coordination of the Wildfire Response Team (WRT) with co-coordination provided by NASA-Goddard and the University of Maryland. The goal of the WRT was to provide within-enterprise coordination of wildfire applications development and demonstration activities (WRT website, 2002). In late 2002, the WRT was instrumental in facilitating delivery of NASA satellite (strategic) and aircraft (tactical) imagery to fire management personnel and fire rehabilitation teams. Examples of this successful coordination were delivery of ASTER data to fire managers as well as delivery of AIRDAS data during the Oregon Biscuit fire in August 2002, and the delivery of various satellite asset data and AIRDAS data during the Southern California firestorms of October / November 2003.

GOALS AND OBJECTIVES

The goal of this PROJECT is develop and enhance NASA technology in conjunction with our applications partner (US Forest Service – Remote Sensing Applications Center (RSAC)), to demonstrate the utility of new airborne fire remote sensing imaging capabilities, data telemetry, and data manipulation methods and visualization technologies, and to facilitate the technology transfer, training and integration of those demonstrated technologies into the framework of the Forest Service's fire management and mitigation strategies. Our objective is to develop a unified collaboration with the Forest Service that will provide a simplified mechanism for defining requirements for wildfire thermal real-time imaging, research and development of those required technologies, demonstration testing, system and technology validation, and technology transfer and training (Figure 1). The tools and technology proposed herein will reduce the delivery time of information on wildfire events from hours (generally 4-8 hours) to 15 to 30 minutes (or less), thereby providing social and economic benefit by reducing decision-making time, reducing hazard, and reducing loss of life, structures, and resources. By attaining our objectives, the team will advance the disaster community's ability to rapidly update information about fire and more effectively reduce loss of resources, property, and life.

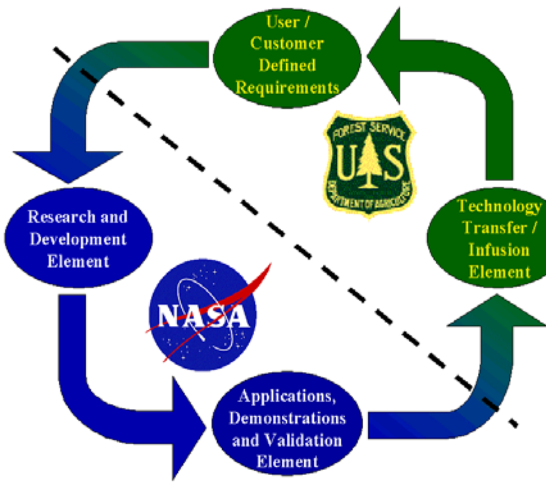

Figure 1. Strategy for full end-to-end implementation of the WRAP project. Our strategy begins with the top element (User-Defined Requirements) which are driven by our USFS Tactical Fire Remote Sensing Committee (TFRSSC) and follows a natural progression through R&D, Applications, Demonstrations, and Validations, through the Technology Transfer / Technology Infusion element, and ultimately feeds back directly to the user who drove the necessity for the effort. Cooperation and interaction between the two major partners (NASA and US Forest Service) will occur, and both partners will partition the effort into primary focus areas where their expertise and capabilities are critical to ensure success.

We propose to develop innovative imaging capabilities, telemetry, image processing, and data handling and distribution systems that will improve the ability of the Forest Service (and like agencies) to manage and mitigate fire-related disasters. The US Forest Service, mandated to protect and manage resources, will be the primary "customer" of this endeavor. NASA, as a Federal agency mandated with providing advanced concept research and development in Earth, airborne, and space sciences will provide research, technology development, and assist in technology transfer, validation and integration of improved "systems" and methodologies for more rapid decision-making during wildfire events. This "teaming" concept, with the Forest Service driving the program "requirements" and NASA driving and facilitating the research, applications and technology transfer will succeed in bringing improved methodologies to, not only the Forest Service, but other disaster management agencies (both State and Federal). The technologies developed and exploited here will provide crosscutting solutions to other agencies seeking real-time remotely sensed information gathering and data exploitation technologies in order to mitigate loss during disaster events.

PROJECT IMPLEMENTATION PLAN

Our strategy for developing improved tactical fire imaging capabilities within the Forest Service involves a systems process approach that provides continuous "checks and balances" for ensuring successful end-to-end implementation. The project team has organized the Tactical Fire Remote Sensing Steering Committee (TFRSSC) to define requirements and technology and demonstration priorities provided by involved fire community members. The requirements will be fed through the TFRSSC to develop a Research and Demonstration Plan for implementation by the NASA-ARC partner. The plan will address primary focus thrusts for development by NASA and the Forest Service. The second phase of this strategy is the R&D and development of the demonstration and validation missions by NASA-ARC. Demonstrations and Validation Reports are provided back through the TFRSSC to facilitate documentation of technology readiness and potential barriers to technology integration. The TFRSSC will then develop a Technology Infusion Plan based on the recommendations developed during the R&D element and the Applications, Demonstrations, and Validation Element. The Technology Infusion Plans will address an integration schedule, milestone development chart, and success metric for this element. Technology infusion will then be initiated by the Forest Service and NASA-ARC through a combined effort for engineering integration, software integration and, most importantly, training. The technology team will develop a Technology Infusion Phase Summary report to the TFRSSC, detailing integration, costs, barriers, acceptance level, and training detail. The TFRSSC will provide documentation to the greater user community on the evaluation of the socio-economic impact that the R&D, applications, and technology transfer and integration elements make to improved wildfire characterization and management / mitigation. This approach will ensure successful project control for the P.I. and the team and will allow a significant positive impact to be made on tactical fire management and mitigation. The management approach for our proposed effort is shown in Figure 2.

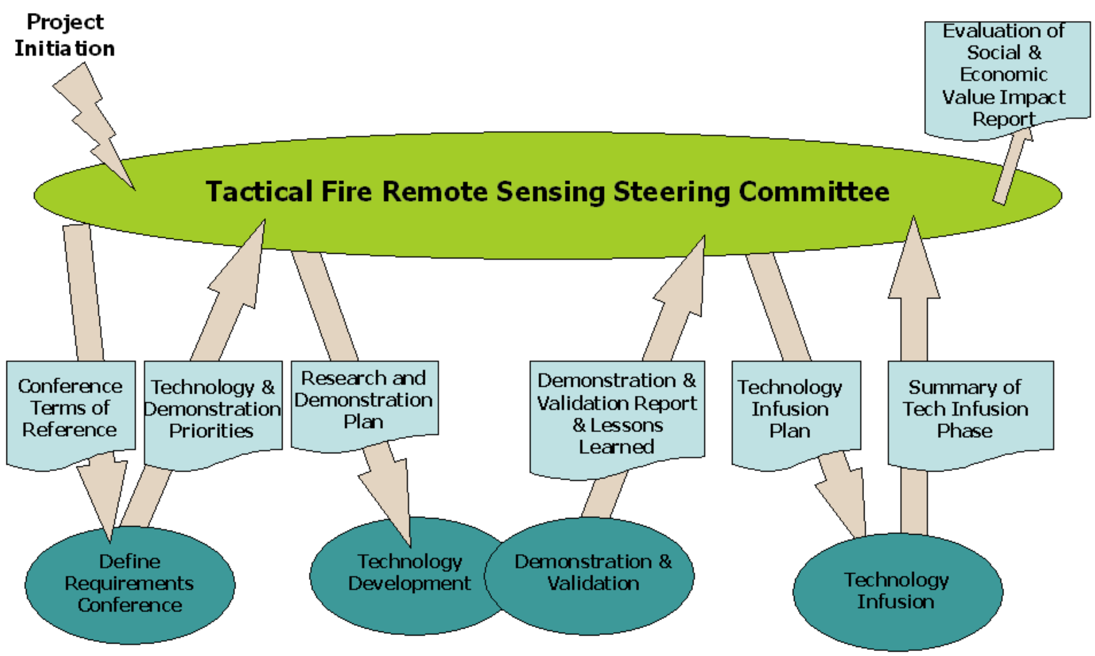

Figure 2. Management and project plan for implementing desirable technologies into the fire community's decision support system mechanism. The thrust of the effort is allowing the fire community to "drive" the requirements, while allowing the NASA team to develop, test, demonstrate and evaluate technologies and feed the information back to the committee. The committee is then tasked to assist in the development of a technology infusion plan to implement changes and enhancements to tactical fire management strategies. The technology infusion then occurs, benefiting the community at large by providing improved information in a cost-effective and time-effective manner, reducing risk and loss of resources.

Major Elements of Implementation Plan

The three elements of the project implementation (R&D element, Applications and Demonstration element, and a Technology Transfer and Integration element) will focus on three components for wildfire DSS enhancements. These three components are areas of critical technology enhancement needs for the fire management community, and include: 1) enhancing sensing and imaging capabilities and systems; 2) enhancing data and information telemetry systems, and; 3) demonstrating innovative platforms for fire imaging, with particular focus towards UAV enhancements and demonstrations. Development and demonstrations of these three technology arenas will showcase the enhanced capabilities available to the fire management community and allow improved decision-making tools to be rapidly ingested and implemented within the community's fire decision support system.

Enhancing sensing and imaging capabilities and systems: Both the USFS and NASA-Ames operate thermal line scanner systems for utilization in fire remote sensing (Ambrosia, 1990). The Forest Service system has been modified over the years to provide two-channel thermal data over fires. Their product is often delivered to the ground as a "black and white" photo sheet (printed aboard the aircraft), depicting a temperature thresholded area (fire) in red. The Forest Service utilizes this system extensively during the fire season (Schrader-Patton and Greenfield, 2000). Due to the mission requirements of their system and operational constraints, research and development of new sensor technology or integration of new components are difficult. The Forest Service has therefore relied on parallel-track development of thermal detection by NASA-Ames Research Center, utilizing the AIRDAS system as a research, test and evaluation "platform" for new components and data collection methodologies. As "concepts", components, and technologies are integrated, tested and proven on AIRDAS, they are evaluated by the Forest Service for integration on their sensing systems (Ambrosia *et al*., 1988). The intent of this element is aligning these two organizations closer to enable a shorter concept-design-test-validate-to-integration process for thermal sensor imaging methodologies.

NASA-Ames will initiate research and development of thermal sensing systems to include the configurations required for operation at higher altitudes, longer-duration missions, and coincident "recording" of other visible spectral and infrared channels on the AIRDAS system. The inclusion of the mid-infrared channel (1.57-1.70μ m) on AIRDAS has proven extremely valuable for differentiating the flaming-front from super-heated smoldering components behind the fire line (Figure 3). This information is key in determining fire movement direction and possible residual high temperature conditions that exist after the flame front passes through an area (Ambrosia and Brass, 1988; Ambrosia *et al*., 1994). The inclusion of this third channel also allows the generation of a three-channel color composite of the fire front and surrounding vegetation condition to be generated. This "color" product has proven to ease interpretation of fire condition, thereby shortening the decision time on deployment of resources to combat specific flaming areas (Ambrosia *et al*., 2003). The inclusion of the "third" channel, also allows discrimination of earth background (vegetation composition, relative stand density, etc) and "cultural" features (homes, roads, infrastructure components, etc.). NASA-Ames will evaluate and demonstrate the concept of this channel (or others), and provide integration capabilities for such on their system to enhance it's utility.

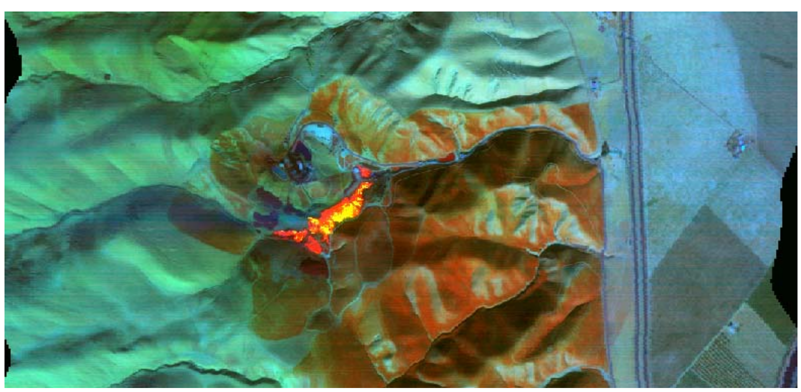

Figure 3. This AIRDAS image data was acquired at 12:11 P.M. (local time) over the Patterson, California tire dump fire on 5 October 1999 from the USFS Piper Navajo twin-engine aircraft operating at 4200 feet AGL. The variations in burn intensity can be seen in this data composed of the non-filtered channel 4 thermal (red), channel 2, mid-IR (green), and channel 1, visible (blue). The hottest portion of the active flame front can be seen in yellow, with bright red representing very hot regions and the other red shades representing previously burned over (and still hot) smoldering regions. The inclusion of the mid-IR channel greatly increases the interpretability of the active fire front and the smoldering background (still hot).

NASA-Ames will also explore the integration of new thermal detector cooling mechanisms to simplify and ease sensor operations during long-duration missions where access to detector coolants (LN2) is limited. Ames has integrated a Sterling detector cooler on the AIRDAS and will provide functional tests on the usability of such systems, and effects on overall system signal response and calibration (Figure 4). This effort will lead to testing, and validation and assistance in integrating similar technologies on the USFS system.

Figure 4. Sterling and TE-cooled detectors. These systems provide improved capabilities over “current” systems that rely on LN2 to “cool” detectors to operating temperature conditions. Improvements include extension of long duration missions without the need to refill dewars with LN2. These considerations are important for long-duration, unattended systems during UAV operations.

NASA will explore the integration of high precision “navigation” systems with thermal scanners. These systems provide much finer platform location and platform / instrument attitudinal information, and therefore allow finer precision mapping or geo-location of fire imagery. With the increased use of GIS mapping systems at major fire complexes, the integration of high-precision geo-located spectral data is a must. Driven by these requirements, NASA-Ames will pursue these technologies along a parallel track R&D and testing integration effort, utilizing the AIRDAS system and both piloted and UAV platforms.

The team will also explore, test, and evaluate improved sensor designs by academia, industry and within-NASA. These potential systems include the NASA-Ames developed AIRDAS system, the USFS /Space Instruments FireMapper system, the Rochester Institute of Technology (RIT) WASP system, the German DLR Airborne BIRD system, the NASA-Ames developed MODIS Airborne Simulator (MAS), the 12-channel Fire scanner in development at NASA-Ames, and the SenSyTech fire imaging system (in development). Other niche instrument will be evaluated when available to the fire imaging community (Figure 5).

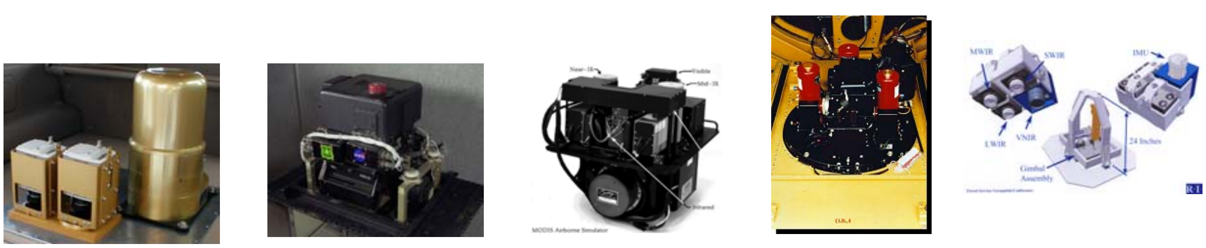

Figure 5. Examples of improved sensor designs for evaluation by the WRAP project team. (L to R): USFS / Space Instruments FireMapper, NASA-Ames AIRDAS, NASA MAS, NASA 12-channel Fire scanner, and RIT WASP imaging system.

The WRAP team will explore the development of image manipulation methodologies for accurately portraying and "visualizing" fire imagery and related information in near real time. The image manipulations methodologies that we propose to explore include the refinement and development of improved platform / sensor model positional information, improved on-board processing, inclusion of on-board "terrain" information for increasing the accuracy of "draped" image data sets, exploration of new data compression techniques, and infusion of new ground-based techniques for portraying fire on GIS-compatible rectified layers (Figure 3). NASA-Ames proposes to continue development of these technologies, leveraging off of current thrusts on other funded endeavors to push these new developments to the system integration level (Figure 6).

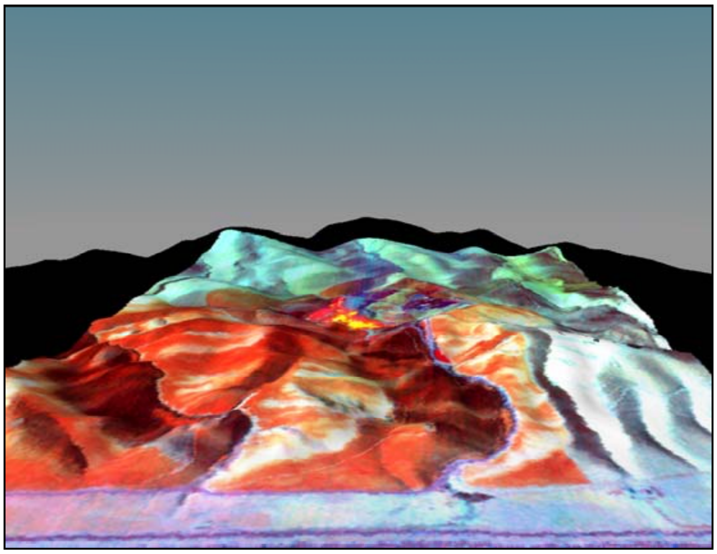

Figure 6. AIRDAS thermal / IR data "draped" over terrain data. This 3D view allows greater visualization of the terrain characteristics and the fire location. This perspective can be generated in near real time (within 10-15 minutes) of data collection from an airborne thermal scanner. This visualization tool allows fire managers to make rapid informed decisions on deployment of personnel and resources to aid in suppression.

Enhanced data and information telemetry systems: The second element of the project implementation plan involves investigating and testing evolving data telemetry systems. Telemetry refers to the "delivery" of aircraft-acquired remote sensing data from the platform to a ground-receiving station, either through direct "line-of-sight" (LOS) communications relays or through an over-the-horizon (OTH) satellite uplink / downlink system (Figure 7). NASA-ARC and the U.S. Forest Service have independently tested and demonstrated real-time data telemetry technology, but the rapid development track of telemetry systems dictates further R&D efforts. NASA-Ames have predominately explored the use of OTH telemetry as a method for data distribution anywhere on the globe. These efforts have leveraged off of development of UAV telemetry systems research at NASA-Ames. The Forest Service parallel-track investigations have explored LOS telemetry schemes. The USFS requires R&D and demonstration / validation experiments before committing to transitioning over to new methodologies. NASA-Ames will facilitate that transition by providing the R&D and applications testing of "new" telemetry systems.

NASA-Ames will develop, demonstrate and validate various telemetry systems on both piloted and UAV platforms. NASA-Ames has well-established test and evaluation procedures for defining component adaptability. The procedures for telemetry operations involve both ground-based operability tests and full-functional airborne evaluations following the ground testing. The extensive evaluation procedures are further detailed in Ambrosia *et al*. (2003). Much of these activities will leverage off of previous, current, and ongoing projects at Ames providing telemetry R&D focus.

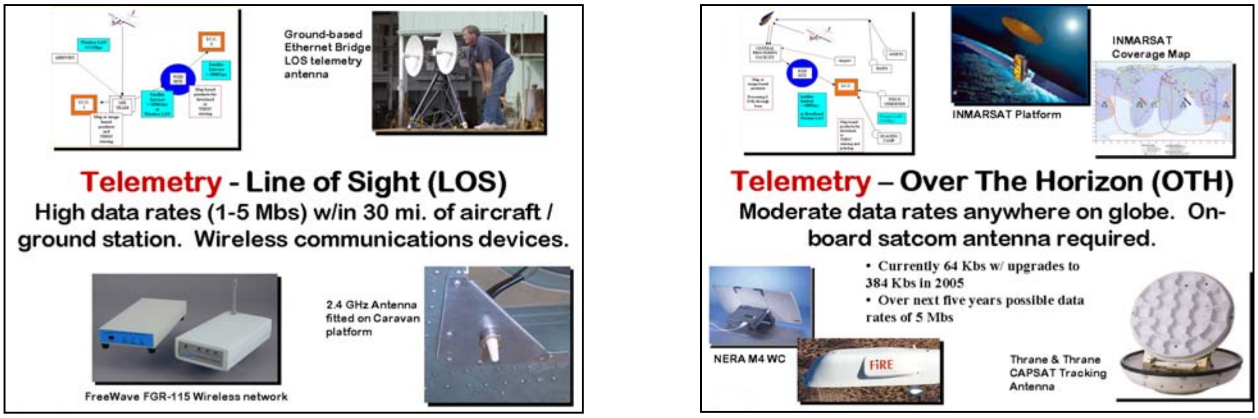

Figure 7. Examples of both Line of Sight (LOS) and Over the Horizon (OTH) telemetry systems and options for distributing data from an aircraft platform to a decision support mechanism on the ground for further data integration and distribution. These example technologies are and will be explored within the WRAP collaborative R&D project elements.

Demonstrating innovative platforms for fire imaging: The USFS has requirements for 24-hour coverage of fire events over large areas (multi-state coverage). UAVs have been shown to be an effective aircraft for filling that required niche (long-duration, high-altitude, tactical fire remote sensing instrument platforms). The successful demonstration of fire imaging capabilities aboard UAVs in September 2001 (Figure 8)(FiRE experiment; Ambrosia *et al*., 2003), has driven the further request for R&D and demonstration opportunities aboard similar platforms, but extending the capabilities of both the imaging instruments and the UAV platform.

Figure 8. The ALTUS II in flight during the FiRE demonstration, September 2001. The payload (AIRDAS scanner) is located in the nose of the aircraft, with telemetry antennas integrated into the forward fuselage fairing. The aircraft is capable of high-altitude, long-range / endurance missions with ample payload capabilities for various sensor configurations.

The WRAP partnership will develop and integrate new technologies and extended mission capabilities for use of UAVs for fire demonstration/ applicability missions. These efforts will be in cooperation with the UAV Applications Center located at the NASA Research Park (co-located at Ames. NASA-Ames will provide R&D

and integration experimentation and testing of the remotely operated AIRDAS on the UAV platforms in coordination with the center to facilitate mission planning, integration, flight readiness, and other managerial and procedural issues. Our close association with the UAV Applications Center allows NASA-Ames to be well positioned to succeed in both the research and development phase of these unique platform integrations and in the demonstration of their capabilities to support missions over wildfires and other disasters.

NASA-Ames R&D will focus on development and modification to payloads to make them capable of remote operations during high altitude and long-duration missions. Development of integration issues will be a focus area for this effort. These integration efforts include compartmentalizing systems and integrating and coupling imaging sensors with telemetry systems onboard UAV platforms.

The WRAP partnership is currently developing the mission design characteristics for a large-scale UAV fire imaging demonstration scheduled for late 2005. This mission will be a "follow-on" to the successful FiRE mission and is currently planned as the Western States Fire Mission. The Western States Fire Mission will leverage development in telemetry enhancements, improved imaging capabilities and improved characteristics of the ALTAIR UAV platform to demonstrate a mission encompassing the entire western US. The objectives of this mission are to demonstrate 24-hour, high-altitude operations of both the payload and the platform. "Stepping-stone" missions are currently planned for late 2004 and early 2205 to ramp-up development and component testing of various sub-systems in preparation for the Western States Fire Mission (Figure 9).

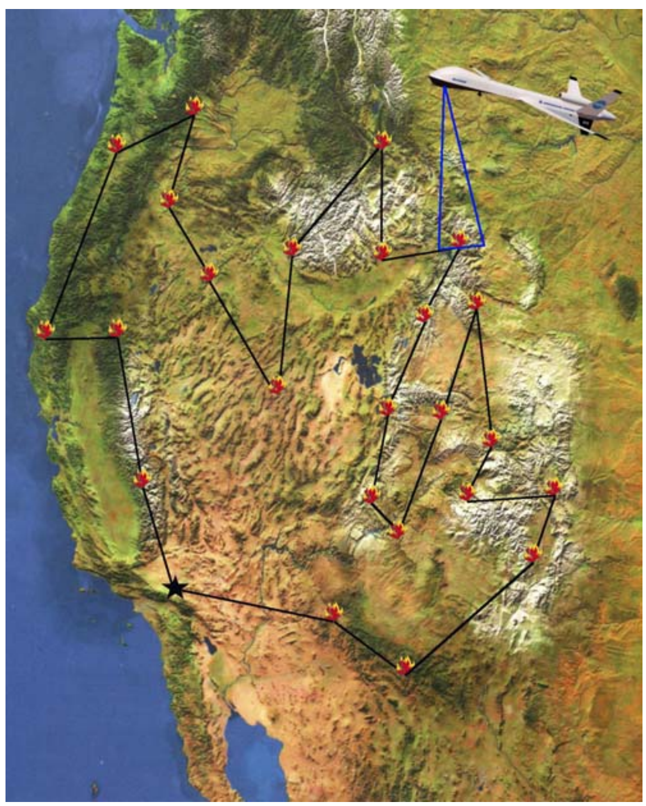

Figure 9. The ALTAIR-Western States Fire Mission will provide 24-hour coverage of fires throughout the Western United States. This +4000 nm long duration mission will allow multiple AIRDAS thermal IR digital data acquisitions over numerous fires spread throughout an area stretching from Mexico to Canada and the Pacific Ocean to Colorado. OTH data telemetry will occur via a large bit-rate data throughput system. All data will be geo-corrected and rectified in near real time for use in any decision making GIS-based system.

CONCLUDING REMARKS

A fully integrated and functional system and methodology for real-time fire remote sensing data collection and distribution will result from this work. The WRAP efforts will significantly improve the data and information delivery time (from 4-8 hours to 15-30 minutes or less) for fire related imagery. A significant improvement will be realized in the accuracy of geo-locating information (to ~1.0 pixels) in near-real-time by integrating innovative sensor / platform positional and navigational data, new geo-rectification software and methodologies, and improved detailed SRTM data to properly "fit" scanner data to a surface "frame." We will demonstrate the development of spatial tools to merge pertinent GIS data layers with derived geo-rectified fire imagery. We will provide a fire imagery database and methodology and help integrate such within the USFS fire decision support system. We will assist the National Interagency Fire Center with creating a structured database of imagery with public access provided through the Internet.

Fire Incident Command managers will have better access to a range of information including the unique remote sensing data for the preparedness, response and recovery phases of a fire event. Fire managers will have an improved view of unfolding incidents in near real time through access to remote sensing data and advanced telemetry technology. Better and faster access to data means that fire managers will have a larger repertoire of information to draw upon. There will be less reliance on estimates, guesses and "learned opinions". Better access also means the fire management staff will need to spend less time collecting and sorting through the data to derive the needed information. Time is the most critical element in disaster management, and quick response usually results in fewer losses of life and property. The remote sensing data and modeling will provide not only a historic and up-to-the- moment view of the disaster setting, but also a prediction of what is going to happen given reliable ancillary data. This capability will give the disaster manager better tools to view the incident, better data to manage the situation, and better information to assess the damage and mitigate impacts. To the extent that property and human losses are minimized, so will the adverse impact on the environment be reduced. This proposed effort would provide data that will help the disaster manager do the job better, more efficiently, and faster, thereby reducing the risk of life and property.

The WRAP partnership project will showcase enhanced NASA capabilities available to the fire management community and allow improved decision-making tools to be rapidly ingested and implemented within the community's fire decision support system. The partnership will address three main focus areas for research and development, technology demonstration and infusion into the US Forest Service fire decision support system. Those three areas are: 1) imaging / sensing systems and information extraction, 2) data and information telemetry technologies, and 3) innovative platform solutions (UAVs) for enhancing airborne infrared operations capabilities. NASA and the USFS will explore innovative solutions to improving the timeliness, content, and methods of gathering tactical information on fire activity. The partners are poised to ensure the delivery of: "*The Right Information to the Right People, at the Right Time.*"

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