Big Fish and Lost Lakes Fires
White River National Forest

Meeker, CO
August 19-25, 2002

Review of Airborne Thermal Infrared Imaging For Incident Support of Wildland Fire Use

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INTRODUCTION

In August, 2002 a collection of federal, private, and state scientists and private data contractors was assembled to participate in a project aimed at exploring the use of a contracted thermal infrared (TIR) imaging system in support of a Wildland Fire Use Management Team (Wayne Cook, IC) on the Big Fish fire near Meeker, Colorado (White River National Forest). The purpose of this document is to provide feedback to the National Infrared Coordinator as to the dispensation of this TIR project.

Attached to this review are several documents that were compiled by the Infrared working team during the project; including contact list, statement of objectives, orders of the day, and examples of graphic products. Full-size copies of all image maps delivered to the Incident Management Teams (IMT) are on the enclosed compact disk.

Further distribution of this review is to be made only through or with the approval of the authors or the National IR Coordinator.

BACKGROUND

In the summer of 2000, scientists from the Missoula Fire Sciences Lab and the University of Montana Remote Sensing Program contracted with a private firm, Airborne Data Systems (ADS), to conduct thermal imaging experiments on wildland and wildland use fires burning in western Montana. While this TIR working group was deployed through the MAC group in Missoula, task-based imaging was conducted for incident support on a variety of fires. Primary among those Incident Management Team activities was reconnaissance work conducted for Wayne Cook's Wildland Fire Use Management Team (on the Wilderness Complex, Bitterroot National Forest, Montana).

As a result of those activities as well as subsequent fire-related work by ADS, the opportunity to further examine the potential of contracted TIR capability arose when Cook's IMT was assigned to the Big Fish Fire in Colorado. Based on a conversation with the National IR Coordinator the evening of August 19, we agreed to compile these comments for his review. Note that the authors of this document have wildland fire experience; including GIS for incident support, fire behavior modeling (Farsite, Behave, Rerap and FireFamily+), Queen is carrying an IRIN task book, and both have doctoral experience in TIR remote sensing including ground, platform, aircraft and satellite platforms. Both have also worked (as AD's) for Cook's IMT on previous incidents.

INITIAL INCIDENT SUPPORT OBJECTIVES (20 August, 2002):

1. Support the mission and objectives of the Incident Management Team.
2. Develop an efficient processing stream to derive a variety of thermal image-map products.
3. Compile data to support science-based objectives including heat flux estimation, radiometric control, time-series imaging, and calibration.
4. Document the practices and procedures developed to manage the deployment of the Airborne Data System or other like technologies.
5. Develop a review document of this assignment for the National Infrared Coordinator.
6. Explore the fusion of ground, airborne, and satellite thermal data; including twice-daily MODIS images.

The TIR Group was assigned as follows: The three ADS staff consisted of a pilot, an IR technician, and a ground support/data preprocessing specialist. The UM staff functioned as image analysts and GIS specialists. Fire Lab staff served as group leader and ADS liaison (Hardy), and the other two as field calibration specialists. ADS relocated to the Meeker Airport on August 19 and secured motel rooms. Fire lab and UM staff also traveled on the 19th and secured motel accommodations at the same place as the ADS staff. One UM individual came to Meeker from the Biscuit Fire in Oregon and arrived earlier than the other staff. He was thus able to begin to make logistical arrangements as well as contact with the Big Fish IMT.

NARRATIVE

08/19/02
Travel Day

08/20/02
A “war room” was established at a motel in Meeker, CO for purposes of processing the digital imagery. The GIST assigned to the incident was set up in the Rio Blanco district office in Meeker, and we were able to make use of the large-format plotter in that office as well as being able to interact with the GIST as needed. As this document will show, in order to generate useful “intelligence” products some post collection processing is required. Details on this will follow in the comments section of this document.

A log sheet (form) was created to track flight line requests, flight metadata, and information regarding the post processing. The form was modeled after the IRIN interpreter log (a copy is attached). This form served to log all flight requests, was copied and given to the aircrew for flight planning, was used to debrief the mission, and was the basis for determining costs.

A visit was made to the Rio Blanco Forest Service District office, and a brief discussion was held with the District Ranger and other staff to inform them of the activities that the group would be engaged in.

Although the original “tasking” was through the Big Fish IMT, there was significant interest in sharing the resource with all fires and IMT’s in the area. This liaison function was performed by the IC (Cook) at Big Fish; and occurred within the context of the regular phone calls between IMT’s.

One the team/group was established in Meeker, two flight requests were received. The first was a linked series of flight lines over the Big Fish fire; the second was a set of three points of interest to the IMT on the Green Creek fire. The Big Fish coordinates were translated into flight line sets by ADS, and the mission began at 1200. Low clouds allowed only two lines to be flown; even these were mostly obscured and of little utility. No products were delivered to the IMT’s.

Coordinate data for the Green Creek fire were provided as single coordinate pairs. ADS then developed a set of both N/S and E/W flight lines that completely covered the area of interest. Once over the area they could then choose a set of lines to fly. Coordinates provided (by the IMT) were insufficient and there simply were no additional geographic references that could be used to develop a flight plan. Thus it became a priority to communicate directly with the IMT’s to define specific coverage boxes.

A vicinity map and briefing map (no control lines shown—only perimeter) were provided to the IR team by the GIST on Big Fish. These will prove very useful in subsequent mission planning exercises; but will need to be kept up-to-date.

Base maps that could be used to generate image maps (as base layers for the IR data) were very difficult to come by. The contractor did not bring with them nor did they participate in producing base layers. The IT team also processed and provided a DEM to ADS for use in terrain-correcting the TIR data. Note that there was a substantial investment in people and technology that were working with ADS (not for ADS) in order to generate useful intelligence…

A significant amount of energy was spent dealing with the “contract” status of ADS. The issue revolved around whether costs could be charged to the fire; or whether research dollars from either Forest Service Research or the University of Montana could be used to cover costs. Although we know little of the specifics of the processes/practices involved, it is clear that ADS is not “carded,” that the Part 137 10-day test waiver is in-place; that no inspection of the aircraft or its crew had as yet been completed; and that there are outstanding issues regarding what remains to complete the process. Dave Fuhr did have a phone conversation with the Region 2 aviation staff (Bill Snyder?) and the conclusion was reached that it

would not be possible to complete this process within the timeframe of this deployment. As of 2200 it was still not clear how/who to pay for the deployment.

08/21/02

Flight logs were developed for three missions; one for the Hinman fire, one for the Green Creek fire, and a series of flights over the calibration site. Based on phone conversations with the SITL, there were concerns over spotting and fire spread on both fires and a lat/lon box was derived for these flights (circa 1245 hrs). Flight planning was initiated; but a convective sigmet was issued and the missions over the fires were stood down. Six flights over the thermal calibration targets were arranged; three elevations with two range settings at each height for the TIR camera.

At 1316 a fourth flight request was received from the SITL for the Burn Ridge fire. Requested flight boxes were identified and flight plans made; the sigmet prevented acquisition.

A reference grid was developed using ArcMap to facilitate flight requests. As described elsewhere, IMT requests took many forms—"this Division," "this coordinate," "this line," "these waypoints." In order to standardize the process and to make IMT requests easier and more efficient, a 0.8 nautical mile grid was overlain on the vicinity map and grid squares were referenced by a letter and a number. Copies of this map will be sent to each IMT. Subsequent requests for TIR flights then could be made by simply referencing the appropriate grid square box; e.g., "I need a flight over grid reference A2." The IR team could then immediately transfer that request into a flight plan using ArcMap and the flight planning software used by ADS. Postscript—this did not work! In talking to the Teams it was clear that they wanted to provide either snap-line or box coordinates.

There are costs associated with having a contract ship on call/site. Given the poor to non-existent flying conditions that we have experienced the past two days; we are incurring costs for the ADS team (as well as the real but not explicit) costs of the IR working team. Depending on how the contractor is detailed or assigned; this may also make it difficult to deploy the ship to other fires/locations… at least it would need to be clear who determines uses of the aircraft/scanner. If it is assigned to a given fire; does the IC determine the asset's availability to other fires in the region? How are the costs incurred in flying a fire that the ship is not "assigned to" covered? It was less expensive to stand ADS down for a day than to release them and call them back once the weather cleared (see attached cost sheet for details of relocation and stand-down costs).

08/22/02
Clearing weather allowed us to task ADS to three morning missions on the 22nd: Hinman, Green Creek, Burn Ridge, and calibration site. This afternoon we will fly the NW side of the Big Fish fire.

In a conference call at 1000 with Wayne Cook (IC) and Rich Lakso (PSC) at the Big Fish fire, they agreed to place a resource order for the ADS plane and the data they produce. While the Big Fish Fire Use Team is placing the order; costs are to be shared amongst the fires to which the aircraft is tasked. In a MAC conference call on the 21st, it came up that it may be possible to "assign" the ship to the MAC group; it could then be tasked to specific fires/IMT's who would then cover costs. Copies of the ERA and ADS Cost sheets need to be provided to the IMT. Notes from that meeting are attached.

Generation of image map products from the data acquired is detailed elsewhere in this document.

08/23/02
Most of the comments to be made for this working day are spread throughout the rest of this document. Given the poor weather the ADS crew was stood down. The remainder of the team spent time compiling base GIS data, surveying the calibration site, making layout maps (in ERDAS Imagine, ArcView and ArcMap) that would make it faster to generate products once data were in-hand, making contact with the planning staff on the incidents, and compiling and organizing documentation.

08/24/02
New perimeters were received for all five fires (Hinman, Burn Ridge, Green Creek, Big Fish, and Lost Lakes) and flight plans were built. In the morning Big Fish and Lost Lakes were flown and data delivered to the processing team in Meeker. In the afternoon the other fires were flown. Weather was mostly clear with scattered high clouds (cirrus)—so flying conditions were the best since we arrived in Colorado.

Note that the data collected today was to be used for two purposes. One was, of course, to map heat on all of the fires. The other was a request by both Forest Supervisors through Wayne Cook (IC) to acquire wall-to-wall high resolution imagery that could be used to support severity mapping and rehabilitation efforts. A benefit of the ADS system is the ability to make one flight and meet both objectives.

Image data were delivered by ADS over all five fires, and our processing began. The total data volume to be processed was approximately five gigabytes; given the replication of those data in processing we had to manage approximately 20 gigabytes of data. Once the data were georeferenced and mosaiced it was determined that on two of the five fires the data did not cover the entire extent of

the known perimeter. On one fire (Big Fish) the flight, which began in the SE corner and ran to the west), the flight lines/data stopped about 2.5 miles too far to the east; thus leaving a data gap for the west edge of the fire. On the Hinman flight the data stopped about half-way up the fire. In talking to ADS it became clear that their flight planning software had "crashed" in the morning, and lines had to be rebuilt for Big Fish while they were airborne. This resulted in the coverage gap. On Hinman it was clearly operator error; when the flight lines were built the planner built lines N/S of the southern edge of the fire rather than the center line of the fire. This resulted in data for the south half of the fire and an equivalent amount of coverage to the south of the requested flight box.

On the 25th ADS was to be tasked to re-fly complete coverage of both fires. Before they left the airport we imported the flight plans into ArcMap to verify that the flight plan did cover the area of interest.

A complete work log for the TIR group was completed in the afternoon and is attached for reference.

08/25/02
Flight plans were recompiled and verified; ADS went wheels-up at approximately 0930 to re-fly the two fires. A visit by the PSC from Big Fish was made at 1100 and the general process was discussed.

Considerable time was spent developing the files and metadata that were to be delivered at the "close" of the mapping effort. Heat maps for all five fires would be posted to the shared ftp site as shapefiles. Two sets of image composites were compiled; RGB natural color composites and NIR false color composites. These are to be used by the Forests in the rehabilitation effort. Finally, the band data were archived to CD. It is unlikely that a GIST could process the band data; but it would be available if any analyst wanted to recompile or re-plot composite alternatives. We also will provide hard-copy maps of the composites.

In order to ensure wall-to-wall data with minimal gaps the flight plan assumed a mean elevation of 10,000'. Given the local relief in this area this meant considerable overlap and endlap in the resulting image data. Generally this would be 40% and 60% respectively. In actuality this ranged up to 100% in areas that were at lower elevations. Thus the compositing process took considerable time, and resulted in issues regarding how to mosaic pixels in the common area. In the case of the thermal data a "maximum value composite" routine was used in order to retain all of the warmest pixels. For the optical data composites, however, maximum value compositing resulted in ghosting. A "feathering" or "averaging" routine caused blurring in the overlap areas and was deemed unacceptable. In sum, the method chosen was a maximum value composite. The thermal data were then clipped and used to map heat and the optical data (RGB, NIR) was normalized and histogram matched to minimize seam lines in the mosaic. None-the-less, artifacts in the form of seam lines and

illumination differences remained in the mosaics. Further image processing could be performed to minimize these further, but this level of processing was well beyond the scope of this effort.

Flights on the 25th were successful and generated the coverage needed without data gaps in the requested areas. Post-collection processing was very streamlined; and shapefiles of heat were posted to the ftp site within five hours of the flight. When good data are available and a process is in-place to generate the outputs the overall efficiency and timeliness were notable.

Lastly, the five color composites for all five fires that were requested were compiled and burned to CD for delivery to the National Forests.

At 1800 ADS was released from the incident.

COMMENTS

It is clear that coordination, pre-planning, and considered review are necessary before this type of asset can be more readily available and useful to the fire community. A significant amount of this need revolves around management/organizational issues as opposed to technical capacity. The contrast that might be made is that between the well-integrated current National IR program and the (contrasting) distances between contractors and the fire community. ADS is unfamiliar with fire management, IMT's, and the intelligence needs/planning cycles that are in place. Their technical capability is strong; perhaps even more that needed for "heat mapping." That capacity may prove useful in other applications (BAER Teams?).

Our experience in Colorado was that a liaison is needed between the contractor (ADS) and the customer (IMT's). This person needs to be familiar with both sides of the issues that are being worked through (remote sensing and IMT/ICS).

The data generated by ADS is non-conventional in comparison to the standard IR products. It is digital (does not need to be digitized), and is geolocated. Georegistration and conflation are still under examination; but appear to be acceptable and provide improvement over non-corrected imagery.

The log sheet was created not only to track each mission; but also because the contractor did not provide systematic metadata about each mission/flight line. The missions/lines tended to be variable in terms of HAGL, range settings, etc so these logs are crucial.

ADS gets tasked to flight "boxes" or lines, creates a flight plan, acquires the data; then preprocesses the data via band-to-band registration, performs geolocation using a DEM and the on-board GPS/IMU/INS, and generates a file that can be processed in ERDAS Imagine (.img file). The rest of the process to generate the products specified in the ERA was developed by UM and Fire Lab staff working in the war room. After the first set of flights, delivery of digital data files, and a site visit to discuss the new image maps with the IMT, procedures and processes to ensure an efficient and correct process came together. Copies of notes from that meeting are attached to this document.

The TIR data were processed using Imagine; and were thresholded by temperature range through use of calibration coefficients derived from calibration flights over our hot and cold references. Note that ADS does not use calibration references in processing their data.

Flight planning evolved throughout the week; with the addition of more dialog with the IMT's, sending jpeg images of the current perimeter overlain on the flight box area, and follow-up phone calls to verify the box. We also were able to

secure current perimeter data that we could use to check the boxes; previously the only perimeters we had were on paper maps that were 2-4 days old.

Beginning on the 24th we generated gray-scale (B/W) 8.5x11" maps that showed the most current perimeter and the flight box overlain on a hill shade. This map was then faxed to each fire to re-confirm the coverage area. This should close the loop in terms of coverage. Step one is to get coordinates from the fire. Step two is to plot the coordinates and confirm them over the phone. Step three is to fax the coverage to the fire and receive phone, fax, or email confirmation.

Copies of the ERA were shared with the cost unit leader and the IMT; and a spreadsheet showing costs was developed through visits with the ADS lead. Quantifying costs was essential as both forests in the area (White River and Medbow/Routt) requested that ADS be tasked to fly wall-to-wall optical data over the burned areas so that a mosaic could be built in support of rehabilitation efforts. This flight (tasked for the 24th) also would collect full thermal infrared coverage for the fires.

IMAGE PROCESSING SEQUENCE

TIR image maps were exported from the ADS system as ERDAS Imagine (.img) files. These were delivered to the team on CD's; as terrain-corrected, geolocated files. ADS typically uses mean terrain elevation to integrate their INS/IMU data into the output files. We provided them a 25-meter digital elevation model (DEM) that was used in preprocessing. We imported the .img files into Imagine, mosaiced the flight lines, and re-projected to the base map parameters being used by the GIST's on the fires (UTM, Zone 13, Clarke's 1866 spheroid, NAD27).

We then subset the thermal band out of the five-band mosaic (bandpasses are blue green, red, near infrared, and thermal infrared) so that we could map heat. The objective was to map heat; but to also explore the ability to map levels of heat ("temperature"). In order to get at actual temperature values, we set up a calibration site at the Meeker Fairgrounds (see attached map). This site contained a 1-meter square hot plate, a 36-square foot fold-a-tank (600 gallons), and instrumentation. The hot plate is a 5/8" $1m^2$ thick aluminum deck with high-emissivity paint on the surface. Under the plate are a thermal mass and two propane burners. The entire assembly is surrounded by a 6' welding screen to prevent wind from over-cooling the surface. Propane is delivered through a metering system that can be used to determine thermal use as a function of weight of gas consumed. The plate is heated to a temperature of around 200° centigrade—depending on ambient site conditions. The plate surface has 24 thermocouples embedded in the surface that enable us to continuously monitor temperature.

The water tank has six thermocouples on a stand within the tank, as well as mixers that prevent any thermal skin from developing on the water surface.

These thermocouples are also continuously monitored. A hand-held infrared radiometer and a contact based quantum detector probe are used to periodically monitor the site and the ground cover so that a total heat budget for the site can be derived. The ground around the site is kept wet to maximize thermal contrast when viewed from above. Wind speed and direction are monitored, and a tripod-mounted infrared radiometer is used to monitor the plate surface as well as to look horizontally across the table so that both the vertical and the horizontal components of the heat flux can be partitioned and quantified. This heat budget allows us to derive a site heat budget, kinetic temperatures, radiant temperatures, emissivity, thermal blooming (adjacency effect) into surrounding image/scene pixels, and calibration parameters for remotely sensed digital thermal data. Ideally the calibration site is flown before and after each mission; and every other day is re-flown at three different elevations and two range settings. A copy of "general" notes regarding the calibration work is attached; further details would be available once we have time to fully analyze the data. Note that ADS can set the range on the thermal camera, and that we employed two ranges (2 and 3) in our calibration work.

The cool, wet weather resulted in two days of no flights; and on the third flight day the fires were very cool overall. Thus the total dynamic range of TIR data collected was less than the dynamic range of the calibration parameters. This meant that the fires were so cool that we could not derive the higher ranges of heat (there were no pixels hot enough on the ground) with a high degree of confidence.

As a consequence, the reprojected and mosaiced TIR data was level-sliced into heat ranges. Then we overlaid the heat sources on the visible and NIR imagery to determine whether the source was within or adjacent to a burned area, was an isolated heat source outside of the known perimeter; or another type of ground cover that was not likely to be "fire" (e.g., rock outcrops, roads, or bare areas within meadows or on gravel bars). A text box was added to the image maps that explained the heat that was mapped on the images. A copy of that text is attached.

Once a pixel was matched to those criteria a final image map was created showing all heat sources. This map was compressed into a MrSid file and emailed to the GIST and/or SITL on each fire. MrSid files were chosen due to their small size (150K to 950K) and compatibility with a variety of GIS packages (most GIST's were using ArcView 3.2a). The heat image mosaics in raw form were big; ranging from 1.o to 65 megabytes in size—too large to email or ftp given the internet bandwidth available.

The enclosed CD's contain the MrSid files derived for the fires; names are mnemonic and the base map parameters are as described above. On the evening of the 23rd we gained access to an ftp site (ftp2@fs.fed.us) with a directory structure where we could post data. Some GIST's were unfamiliar with

MrSid files so we posted heat maps as shape files—a simpler format for users; made feasible by the ftp site.

SUMMARY

- Management of this kind of resource is critical. How the resource is ordered and assigned needs to be made clear to all involved.
- If the resource is shared with other incidents, it is also critical to make sure that task assignments are clear, that lines of communication and authority are defined, and that contact between the TIR group and the Situation Unit on the fire has been made.
- Given the lack of fire experience on the part of this particular contractor, a liaison between contractor and IMT/ICP should be in-place. This person can gather intelligence requests, confirm arrangements with the team(s), maintain logs and other documentation, and task the contractor appropriately. These functions would be very difficult (at best) for the contractor to perform.
- In order to convert the "standard" ADS imagery into "heat maps" there is a need for intermediate digital image processing and GIS. Functionally this is similar to the function of an IRIN who converts thermal "data" into "information," but is substantially different in process given that the data are in digital format.
- There is a need to define what the exact products are that will be/can be created from this type of system. The thermal camera collects 8 bits (ranges from 0 to 255) of digital counts for a given ground resolution element (nominally 1 meter square). There are no temperature threshold that yield an image where all of the "heat" is mapped to a single color or byte scale value. Thus, in this type of interpretation, the image analyst must make a determination as to what the range of count values is that constitutes meaningful heat sources in the imagery. In the case of this past week, the fires were sufficiently cool and the weather was cool, cloudy, and wet—so the thermal images did not have a very dynamic range. If temperatures can be derived from calibration efforts and if temperature thresholds can be specified by users this process would be very straightforward. Frankly, this is unlikely in the near term. If temperatures are not reported then exactly what "heat" means must be made clear.
- Coverage areas for each mission must be verified; and the coverage box requested and the actual box flown should be indicated.
- On all products gaps in coverage must be noted and clearly communicated.
- Internet/email/ftp access is needed in order to distribute products in a timely fashion—especially if the resource is operating from a remote location.
- The cost schedules should be re-examined if the "incident" provides significant data processing (as happened here)
- With this kind of effort we are asking the fire community to learn about something that is new. Care must be taken during an incident to communicate clearly what is taking place and how—while remaining

cognizant of the pressure and workload already being placed on IMT personnel.

- As may be the case with any heat mapping effort, it is necessary to communicate to the users that the objective of TIR flights is to map heat not fire perimeter, burned area, or fire scars.
- Some of the confusion regarding heat/temperature thresholds was exacerbated by the daytime flights. In the morning solar heating was insufficient to cause systemic confusion; but late afternoon/evening flights had many warm pixels that were undoubtedly not associated with “fire.”
- In the future it is recommended that the ADS system be deployed for night-time flights.

LIST OF ATTACHMENTS AND ENCLOSURES

- Statement of project Objectives
- Copy of “Orders of the Day”
- Contact List for project participants
- Notes from 08/23 meeting with Cook’s IMT
- Map of the calibration site at Meeker, CO fairgrounds ball field
- Copy of calibration site notes (not a full set pending further analysis)
- Explanatory Text put on first image map outputs
- Copy of cost schedules as of 08/23/02
- Work Log for the TIR Group
- CD_ROM of image map files