Report on the Pembroke NVD-Aided Aerial Forest Fire Detection Trials held April 22-25, 2010

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Executive Summary

Early detection of forest fires, while still in their emergent stages, could greatly improve suppression effectiveness and reduce overall costs. When used for aerial detection patrols, night vision devices (NVD) have potential to improve response times to potential starts and to improve sensitivity. The flight trials described in this report were designed to explore the potential for NVD aided detection in a real operational context but with experimental control and 'ground truth' knowledge of the fire source.

A series of flight trials were run April 22 to 25, 2010 in the vicinity of the city of Pembroke in the Ottawa Valley region of Eastern Ontario. Small test fires were set at known locations within the Ontario Ministry of Natural Resources (OMNR) infrared (IR) test grid and continuously monitored by remote data loggers. NVD flight detection patrols for an EC130 helicopter were planned in the region of the IR grid. The observers were the only members of the flight crew responsible for detecting fires and had no knowledge of the fire configuration or location. Each observer flew two detection patrols on separate nights with different configurations of sources.

The average detection distance for a fire across all nights was 3,584m (95%CI: 2,697m to 4,471m). The average discrimination distance, where a source could be confidently determined to be a fire or distracter, was 1,193m (95%CI: 944m to 1,442m). The hit rate was 68% over the course of the flight trials, higher than expectations based on the small fire sources and novice observers. The hit rate showed improvement over time, likely as observers became familiar with the task and terrain. There was only a single false alarm, when an observer falsely identified a non-fire target as a fire. Correct rejections were quite common (30 events), likely due to the relatively large number of environmental lights in the test area.

The results demonstrate that small fires can be detected and reliably discriminated using NVDs at night from distances compatible with typical daytime aerial detection patrols. The trials provide guidance on altitude and spacing requirements for detection patrols and for cues to discriminate environmental light sources from fires. Analysis of detection performance in ongoing field experiments will help to evaluate the utility of and determine best practices for NVD-aided detection of wildland fires.

Summary

Wildland fires are a continual threat to people, communities and natural resources across Canada. Early detection of forest fires, while still in their emergent stages, could greatly improve suppression effectiveness and reduce overall costs. In Ontario, approximately half of all fires are ignited by lightning strikes (Wotton and Martell, 2005). An extensive lightning locator sensor system combined with modern predictive modelling can indicate areas with a high probability of new starts. Early detection also relies on the ability to fly detection patrols sooner to detect fires while they are small.

NVDs are head-mounted electro-optical devices that amplify available light in the scene, greatly improving visibility. When used for aerial detection patrols, NVDs have the potential to improve response times to nascent fires and to improve sensitivity. The ability to fly safely at night increases operational windows and allows for IR detection of hot spots and fires in darker, cooler conditions when contrast of the fire to the background is improved. We envision that it would be advantageous to fly fire-intelligence guided night-time detection patrols following thunderstorm activity thereby identifying fires early and permitting suppression with minimal delay. The flight trials described in this report were designed to explore the potential for NVD aided detection in a real operational context but with experimental control and `ground truth' knowledge of the fire source.

A series of flight trials were run April 22 to 25, 2010 in the vicinity of the city of Pembroke in the Ottawa Valley region of Eastern Ontario. The aircraft and experimenters were based out of the local airport and test fires were set in the nearby IR detection test grid maintained by the OMNR. This IR grid consists of 109 surveyed locations for precisely located test fires. Small test fires were set at known locations within the IR grid in fireproof containers with charcoal briquettes, artificial fireplace logs or torches as sources. In some instances, multiple sources were combined in a single plot to simulate a larger fire. The sources used were very small by typical aerial detection patrol standards, essentially point sources. Ground crews monitored the fires and fire temperature was continually logged by means of remote data loggers and thermocouple sensors. Flight detection patrols for the EC130 helicopter were planned by an experienced Aircraft Management Officer. All crew wore Generation III, ANVIS 4949 binocular NVDs mounted to their flight helmets. The pilots had NVD certification and extensive detection experience. They were the only members of the flight crew aware of the IR grid location. However, they were not aware of fire locations and profiles. The observers were the only members of the flight crew responsible for detecting fires. During the flight the following events and associated geographical locations were logged by the experimenter using custom software: the detection of a suspected fire, the discrimination of a detected event as a true fire or not, as well as the actual location of the fire. If the target was confirmed as a fire it was approached so that its exact location and characteristics, such as intensity, size and fuel source, could be recorded.

Isolated light sources could be seen at distances of many kilometres but observers needed to be nearer to identify a light as a potential source worthy of further investigation (detection). The average detection distance across all nights was 3,584m (95%CI: 2,697m to 4,471m). Of all the detection events 44% were actual fires. The average discrimination distance, where a source could be confidently determined to be a fire or distracter, was 1,193m (95%CI: 944m to 1,442m). Events were classified as hits, correct rejections, misses or false alarms. Misses occurred when the observer failed to detect or discriminate a fire. The average percentage hit rate (number of fires found divided by number of actual fires) was 68% over the course of the flight trials, higher than expected based on the small fire sources

and novice observers. The hit rate showed improvement over time, likely due to observers becoming familiar with the task and terrain. It is important to note that the pilots were able to detect every fire during each sortie. Had the task of detection been given to the pilots, the hit rate would have been 100 per cent and the number of distractions would have decreased. Experience seems to play an important role as the pilots had the most aerial detection experience.

One novice observer detected two actual fires on her first detection patrol but could not confirm them as actual fires; another observer missed targets due to a change in flight path to investigate an environmental light source. Correct rejections were defined as any target that was pursued and correctly identified as something other than a fire. Correct rejections were quite common (30 events out of 59), likely due to the relatively large number of environmental lights in the test area and the novice observers. Flickering lights from vehicles and houses behind the canopy were most likely to be detected and subsequently correctly discriminated from fires. Correct rejections also declined with time, perhaps as observers became more discriminating in which targets they chose to investigate. There was only a single false alarm, when one observer falsely identified a non-fire target as a fire.

The FireHawk system showed great promise. However it is designed as a day-time system and modifications would be required for effective use in an NVD-aided detection scenario. These include NVD compatible filtering, reduced display brightness, and a high contrast colour scheme for improved interface usability. Once these modifications are implemented, the FireHawk system should aid observers in detection and discrimination tasks, and help maintain spatial awareness and orientation.

The FireHawk system we utilized during the Pembroke trials was not complete; it was lacking the eastern fire region’s map information. This essentially made evaluation of the map portion of the software impossible. However, we were able to use and evaluate the fire report portion of the system to record fire event characteristics.

Rationale

Forest fires are a continual threat to people, communities and natural resources across Canada. Although forest fires are a natural ecological process, unwanted fires can threaten valuable timber resources or the limited old-growth forest remaining. Furthermore, with concerns about global warming and carbon emissions, there is incentive to prevent, control and extinguish fires that do not threaten commercial or natural heritage forests. This study aims to evaluate NVDs in the aerial detection of forest fires. If forest fires are detected while still in their emergent stages it would greatly improve suppression success and reduce overall costs.

Background

An obvious first step in the suppression of a wildland fire is the detection and characterization of a fire event. Existing detection techniques from elevated vantage points include human spotting of daytime smoke from fixed-wing aircraft (or towers), aircraft based infrared thermal imaging (Thomas and Nixon, 1993), automated and human scanning of satellite imagery (e.g., Abuelgasim and Fraser, 2002; Briess et al, 2003; Giglio, 1999; Li, 2000; Lynham et al, 2002; Martín-Rico et al, 2001), and automated or human infrared/visible detection from towers (e.g., Arrue et al, 2000; Vescoukis et al, 2001) with emerging technologies like unmanned aerial vehicles (UAV) (e.g. Casbeer et al, 2005) poised to take over some of these roles. Automated tower-based sensing techniques are promising and are being investigated by the OMNR but are necessarily limited to operation in the vicinity of the tower, UAVs are currently limited by technology and regulatory constraints (e.g.,line of sight requirements), and satellite imagery is limited in the detection of small fires due to resolution, temporal sampling and sensitivity limitations. Thus, aerial detection patrols on conventional aircraft are a key technology in the effective and timely detection of wildland fires.

NVDs are head-mounted electro-optical devices that amplify available light in the scene, greatly improving visibility. When used for aerial detection patrols, NVDs have the potential to improve response times to nascent fires and to improve sensitivity. The ability to fly safely at night increases operational windows and allows for IR detection of hot spots and fires in darker, cooler conditions when contrast of the fire to the background is improved. We envision that it would be advantageous to fly fire-intelligence guided night-time detection patrols following thunderstorm activity thereby identifying fires early and permitting suppression with minimal delay. Jennings et al (1997) described preliminary investigations of the utility of NVD-aided forest fire suppression operations in the OMNR operating context. Their conclusions were that NVDs “have potential to improve the safety and efficiency of airborne forest fire suppression, including forest fire perimeter mapping and take-off and landing in the vicinity of open fires. [Night vision device] operations at some distance from the fire pose minimal risk to flight, and provide an enhanced capability to identify areas of combustion at greater distances and accuracy.” Besides the OMNR other services are using NVDs for suppression or detection activities, notably the San Diego fire department[1]

The success of airborne sensing inevitably depends on looking in the right locations. The OMNR currently has NVD equipped and certified rotary-wing platforms with no near term plans for fixed wing certification. Aerial detection from helicopters has many advantages but searches must be as efficient as possible to maximize these advantages while controlling costs and respecting operational limitations (their slower speed and range and higher cost). Thus, detection patrols need to be guided to regions where there is a high probability of a new start. Planning of fire detection patrols is a complex task that relies on timely and accurate data and experienced interpreters and planners. The OMNR approach to aerial detection of fires is outlined in “How Aircraft Find Wildfires” (McFayden et al, 2008) and is guided by real time weather, smoke, fuel and other data interpreted in the light of analyst experience, historical trends and state-of-the-art models. In terms of night-time fire prediction and planning, the model of Wotton and Martell (2005) is under continuing development and refinement and can be used to predict the incidence of lightning strike ignited wildfires based on fuel moisture levels, rainfall, lightning strike location and other parameters. Ideally, such planning will put the night-time aerial detection patrol in an area where efficient detection can occur.

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[1] For example see http://www.fdnntv.com/news.asp_Q_articleid_E_3038_A_title_E_San_Diego_Fire-Rescue_Allowed_to_Do_Aerial_Water_Drops_at_Night_in_Cal_Fire_Territory

NVDs have the potential to improve the ability for early detection by permitting aerial detection patrols rapidly following lightning strike events. This is likely particularly important during extreme fire conditions. We envision that it would be advantageous to fly fire-intelligence guided night-time detection patrols following thunderstorm activity thereby identifying fires early and permitting suppression with minimal delay. NVDs improve the ability to fly safely at night which increases operational windows and allows for IR detection of hot spots and fires in darker, cooler conditions when contrast of the fire to the background is improved.

Beyond facilitating IR detection patrols, NVDs can also be directly beneficial in detection, as the visibility of fires at night with NVDs is high. Note that OMNR does not fly detection patrols with IR (but does fly IR mapping of known fire perimeters) so NVDs provide a night detection capability to their operations. Compared with typical IR scanning operations, NVD detection at night is similar in many respects to ocular detection scans in daylight. Specifically, the observer's natural search abilities and spatial abilities are optimised by the 'egocentric' nature of the helmet-mounted device, which moves naturally with the observers gaze. This potentially allows for many of the benefits of IR detection combined with the efficiency and coverage of ocular detection. The flight trials described in this report were designed to explore the potential for NVD aided detection in a real operational context but with experimental control and `ground truth' knowledge of the fire source.

Finally timely response to a fire requires that information be fed back efficiently and accurately to decision makers in the fire management headquarters and eventually to front-line suppression teams. As part of the trials we also explored the potential of the FireHawk GIS based fire reporting system (Ontario Ministry of Natural Resources, 2009) with the goal of evaluating its usefulness in NVD use and to develop recommendations for development of a similar system for night-time NVD-aided detection patrols.

Objectives

This experiment seeks to examine the efficacy of NVDs in the aerial detection of forest fires. As a preliminary step to collecting data in a real operational scenario this study took place in the controlled setting of the IR grid in Pembroke Ontario; providing an opportunity to test out experimental protocols and gain experience in forest fire detection at night.

Specific objectives included:

1. Determine suitable flight parameters (altitude and flight path) for NVD detection patrols
2. Determine the feasibility of detecting small (point source) fires at night from typical detection patrol altitudes and distances
3. Shakedown and evaluate the Pembroke IR test grid for IR detection testing. Develop model fire sources for NVD detection testing
4. Determine the feasibility of detecting and discriminating wildland fires from other sources under conditions of varying canopy and fuel source

5. Evaluate protocols and procedures for data collection and analysis in order to optimize for summer fire detection experiments

6. Provide an opportunity to evaluate and develop software for night vision aided detection. A tablet computer running a prototype of the OMNR developed FireHawk reporting software was tested

Methods

From April 22 to 25, 2010 a series of flight trials were run in Pembroke Ontario. Each night, one to six small test fires were set in the nearby IR grid area. Test fires were lit in fireproof containers (12 inches by 16 inches) at known locations within the IR grid. Ground crews monitored these fires throughout the night, and in some instances refuelling was required. The sources used were very small (point source) by typical aerial detection patrol standards. The OMNR would not expect daytime patrols to find fires this small.

On the first night there was a safety briefing regarding the EC130 and a briefing about experimental goals and procedures. Every night before take off the York University staff and OMNR personnel assembled for a pre-flight briefing and equipment check. Prior to take off, each member of the flight crew calibrated their NVDs and setup the experimental equipment. In addition, the observer filled out a brief questionnaire to indicate the number of hours they had slept and their current level of fatigue. Sorties typically began at 21:30 each night and continued until approximately 02:00. Materials, tasks, data recorded, IR grid description and fire descriptions are described below.

Materials

Generation III ANVIS 4949 binocular night vision goggles were used while mounted to flight helmets. Data recording was done using a custom form in Microsoft OneNote 2007 on a Toshiba Portégé tablet computer. A custom Korry Nightshield NSX General Purpose IR Absorbing Film (PN 38421-001) was placed over the display screen of the tablet in order to minimize the amount of light that could wash out the NVDs.. A Canon FS200 was used to record video. Audio from the cockpit was fed directly into the camera. A custom mount was fabricated in order to set the NVD ocular in front of the camera lens.

A Garmin GPS 96C was used to mark the aircraft location in flight in real time. This unit reported aircraft position every 15 seconds with an accuracy of less than 15 meters 95% of the time. When using the Wide Area Augmentation System the position accuracy is less than three meters 95% of the time. In addition, automated flight following data from the aircraft was also obtained. This system reported aircraft position every minute. The FireHawk system consisted of custom software on a Panasonic U1 Toughbook (OMNR, 2009). All flights took place in an EC130 aircraft. A FLIR ThermaCAM P25 camera was used to take IR still shots during one sortie. Fuels for the planned IR fires were placed in 12 inch by 16 inch aluminum fire proof containers. Fuel sources were charcoal briquettes, artificial fireplace logs and alcohol gel torches (see Figure 1). The temperature for one fire per plot was recorded using remote

HOBO U12 K Thermocouple (U12-014) data loggers with temperature sensors. These sensors measure temperature at a range of 0 to 1250 °C with an accuracy of ± 4 °C and a resolution of 0.32 °C at 625 °C.

Controlled experiments relating the temperature of a fire to NVD visibility will be conducted separately. Protocol for this experimenter is reported in Appendix A.

Figure 1: A) Photographs of fire logs during setup and while burning; B) briquettes during setup, while burning and post burn; C) torches during setup and burning

Flight Crew Roles

Flight crew consisted of five or six people; two *pilots*, one *observer*, one *experimenter*, one *audio/video technician* and occasionally one *FireHawk technician*. The *pilots* were the only members of the flight crew aware of the IR grid location. However, they were not aware of fire locations and profiles. Only the *observers* were responsible for detecting fires; the pilots did not provide any information to them. All data about pursued targets were recorded by the observer using the tablet computer[2]. This same information was recorded by the *experimenter* on a paper form identical to the one on the tablet computer providing a separate record. This was a redundancy in the event the tablet computer stopped working or the observer became cognitively overloaded. In addition, the *experimenter* operated the Garmin GPS, which they used to mark waypoints and the time. An *audio/video technician* continually recorded audio and video during most flights. A *FireHawk technician* recorded fire location and characteristics on the Toughbook.

Ground Tasks

The ground crew consisted of a small group of OMNR staff responsible for setting up, lighting and maintaining the fires within the IR grid. There were a total of six fires on the 22nd, four fires on both the 23rd and 24th as well as one fire on the 25th. Before dusk the ground crew setup the specified fires within fireproof containers to reduce the possibility of spreading (description of fire set ups and profiles below). In many instances, multiple sources were combined in a single plot to simulate a larger fire. Ground crews monitored the fires throughout the night. Fire temperature was recorded at one minute intervals by means of remote data loggers and thermocouple sensors. The thermocouple was a standard type K, calibrated for readings in degrees Celsius. The sensors were placed several inches above the source in the hottest part of the flame. An internal temperature sensor in the data logger measured ambient temperature. Each night at approximately 21:30 the fires were lit. The fires extinguished at varying times throughout the morning, but continued to burn during all sorties except one (described later).

Air Tasks

On the 22nd there were three sorties, on both the 23rd and 24th there were five sorties and there were two sorties on the 25th. Each night the Fire Duty Officer planned a detection route which brought the aircraft near the IR grid. Detection patrols typically flew at an altitude between 3,000 feet (ft) to 4,000ft above ground level (AGL) and at a speed between 60 and 90 knots. In flight, the observer scanned their visible area for potential fires. Observers were always seated in the front right seat of the aircraft. This means they were unable to see the areas behind and to the rear-left of their position.

Once the observer spotted a target of interest they notified the pilots and experimenter. The experimenter provided the observer with a waypoint and time, which would mark the aircraft location for target detection. Then the pilots deviated from the flight path towards the target. Upon closer inspection the observer either confirmed or rejected the target as a fire. Once again, a waypoint and time was recorded in order to mark the aircraft location for target discrimination. If the target was confirmed as a fire, it was circled so that fire characteristics, such as intensity, size and fuel source, could

[2] Data collection forms are shown in Appendix B

be recorded. A final waypoint and time was recorded to mark the approximate fire location. Once all the required data was recorded the pilots returned to the flight path. If a target was identified as something other than a fire, the observer attempted to identify the target and then the pilots returned to the flight path.

Plot Profiles

Figure 2 is a map of the IR grid with plot labels[3]. The IR grid consists of 109 surveyed locations for precisely located test fires. The grid is 100 hectares with each plot point spaced at $100m^2$ intervals. The plots that were used during this experiment are highlighted in Figure 2. A daytime photograph of the IR grid is shown in Figure 3. Canopy density and type of tree coverage varied with each plot. Elevation was fairly consistent between plots and stayed between 215m and 295m above sea level (ASL). Plot 57 is located on the North West side of the IR grid. It has a dense canopy consisting of predominately coniferous trees. Plot 46 is located on the South East side of the IR grid. It is covered in dense canopy and contains coniferous and some deciduous trees. Also on the South East side of the IR grid is plot number 99. It has a semi-dense canopy consisting of coniferous and some deciduous trees. Plot number 103 is on the South East side and contains a semi-dense canopy of mostly deciduous trees. Figure 4 shows ground view photographs of the canopy for each fire plot used from the 23rd to the 25th. Although it was still springtime, the canopy for the deciduous stands was beginning to fill in, likely due to the mild weather.

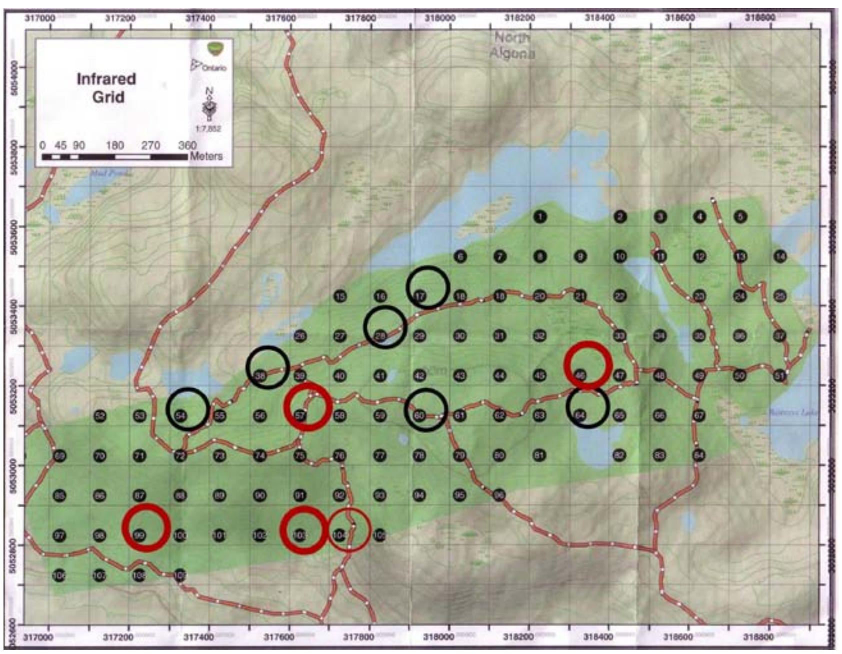

Figure 2: Map of the IR grid with plot labels (22nd = black; 23rd to 25th = red)

[3] A topographical map of the IR grid is shown in Appendix E along with Google Earth images of each flight path

Figure 3: Photograph of IR grid during the day. The large body of water in the top right corner (south of the IR grid) is Golden Lake.

Figure 4: Ground view photographs of canopy cover variation at the time of the trials. The upper half of the figure shows dense canopy plots 57 and 46 and the lower two photographs show semi-dense canopy plots 99 and 103.

Conditions/flights

The amount of light reflected by the moon has a significant effect on NVD use, such that two little or too much light can reduce image quality. Fortunately, during data collection there was a first quarter moon (half moon), which provided a near ideal amount of light. All observers reported NVD visibility as good and atmospheric conditions were favourable. Below is a brief description of the weather. Any special circumstances are also noted here. Unless otherwise stated, calm winds and clear skies prevailed most evenings, with a visibility of nine statute miles; temperature and dew point rose slightly between the 22nd and 24th.

Edited video footage and images can be found at http://www.cse.yorku.ca/percept/NVG/Pembroke%20Report/

April 22nd

The three sorties on April 22nd were used to determine ideal altitude, flight patterns and patrol distances for the subsequent nights. Because this night was a test run for the following nights the data collected here is not used in the statistical analysis. The first sortie flew in a spiral path with the IR grid at its center. The sortie began at 1,000ft AGL. At this altitude they flew at radii of five, three and one mile from the IR grid. The observer found visibility was reduced at this altitude (this was confirmed by the rest of the crew). The next sweep of the area occurred at 4,000ft AGL; radii of five, three and one miles were used again. At 1,000ft AGL with radii of five and three miles the observer was unable to accurately detect the fires. It was not until they flew a radius of one mile that the observer was able to detect the fires. At all radii at 4,000ft AGL the observer was able to detect the fires. Both the observer and the pilots reported that 4,000ft AGL allowed for greater visibility. In addition, the observer continually reported feeling disoriented, probably due to constant circling in the same direction for a long period of time as well as due to inexperience in aerial navigation.

The second sortie approached the IR grid from each of the cardinal directions at an altitude of either 4,000ft AGL or 2,500ft AGL. The observer reported that 4,000ft AGL enabled greater detection range due to the increased scanning distance. In addition, they reported being able to maintain adequate spatial orientation throughout the flight because of their experience in aerial navigation. Similarly, sortie three approached the IR grid from each of the cardinal directions. This observer reported no problems in spatial orientation either.

From these flights it was determined that an effective night-time fire detection altitude over terrain such as the IR grid is between 3,000ft and 4,000ft AGL. Lower altitudes were necessary when attempting to discriminate fire characteristics. All observers reported feeling as though their detection abilities increased during the sortie. Observers also reported that the patrol length, approximately one and a half to two hours, was adequate, but that they could have been slightly longer. Observers found no issues with the speed of the aircraft, which was approximately 90 knots. Occasionally, for discrimination purposes the speed was reduced to 60 knots. The most common problem reported during sorties was too much light given off by the tablet computer, which reflected off the observer side window. This problem was remedied for the subsequent nights by decreasing the display brightness and configuring the software so that only the tablet pen (and not other touch inputs) could be used as an input device, so that observers could cover the screen if necessary.

April 23rd [4]

The air temperature varied between 1–8 °C with a dew point of -4 °C. There were four targets in total at plots 46, 57, 99 and 103.

Plot 57 contained three separate fires, each fuelled by two artificial fireplace logs. These containers were separated by 15ft. An example of a thermal profile for log fires can be seen at Figure 5. Log fires tend to rise rapidly in temperature shortly after being lit, then gradually decline in temperature throughout the evening. They usually smoulder much longer then other fires, lasting into the late morning.

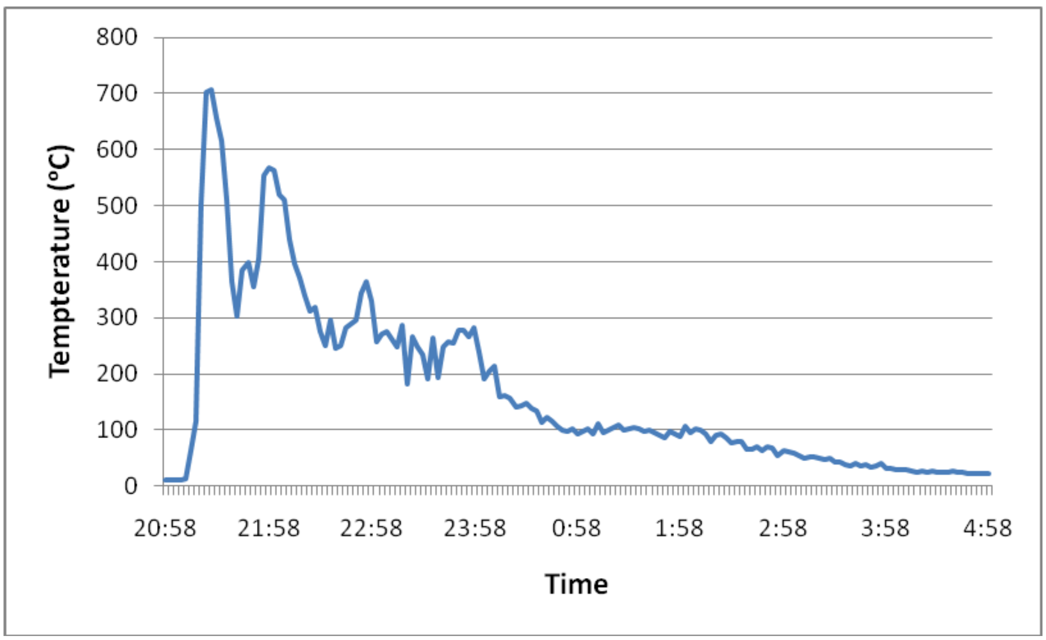

Figure 5: Data logger thermal profile for the log fire at plot 46 on April 24th. Note that there is some variability in thermocouple placement so that absolute temperature readings are not necessarily comparable across fire sources.

[4] Each set of sorties is identified by the night that the phase of the experiment began although it continued into the following morning. For example, April 23rd refers to sorties on the night of April 23rd and the morning of April 24th.

The fire scenario on plot 46 was a mixture of fuel sources; one charcoal briquette, one log fire that consisted of three logs and one torch fire. The data logger profile recorded temperatures for the briquette fire only. An example of a briquette fire thermal profile is shown in Figure 6. Briquette fires typically burned hottest after lighting, presumably due to the open flame and effects of the starter before starting a phase of approximately exponential decay in temperature.

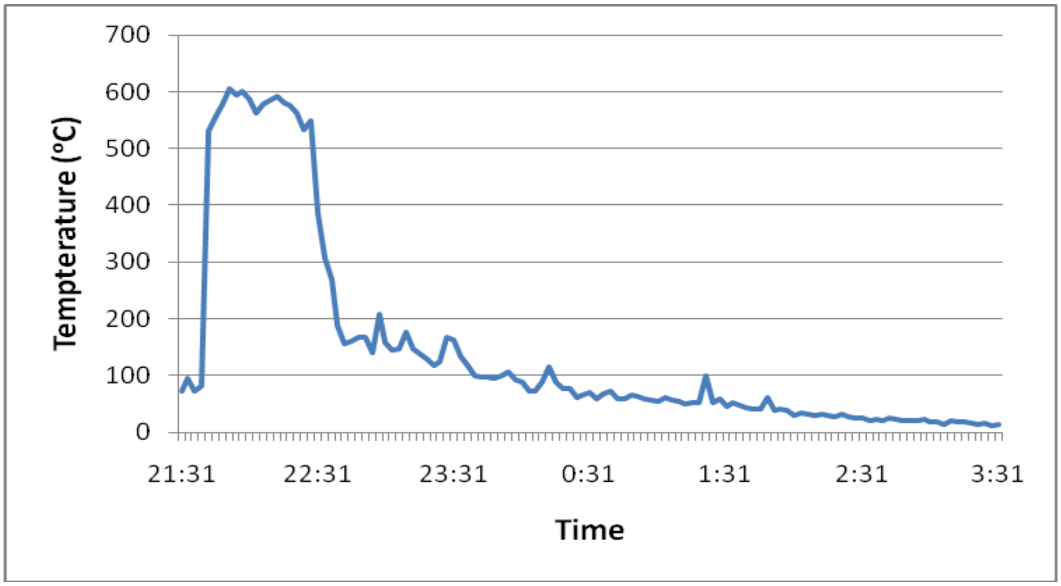

Figure 6: Data logger thermal profile for the briquette fire at plot 103 on April 23rd.

The fire on plot 99 contained three torches configured 15ft apart. Figure 7 displays the thermal profile for this torch fire. The temperature of torch fires typically increases rapidly then burns fairly uniformly (with spiking and oscillatory fluctuations likely due to wind gusts and variations) before decreasing rapidly. As a result they are a well-controlled target until they begin to extinguish. The rapid extinction essentially makes these sources both present and stable (on the scale of minutes although flickering on a shorter time scale), or essentially 'out'. Across all nights torch fires were relit a second time in order for the fire to remain visible throughout the night. Between 23:30 and 23:56 this fire was not visible from the air due to this drop in temperature. It was extinguished by 01:51.

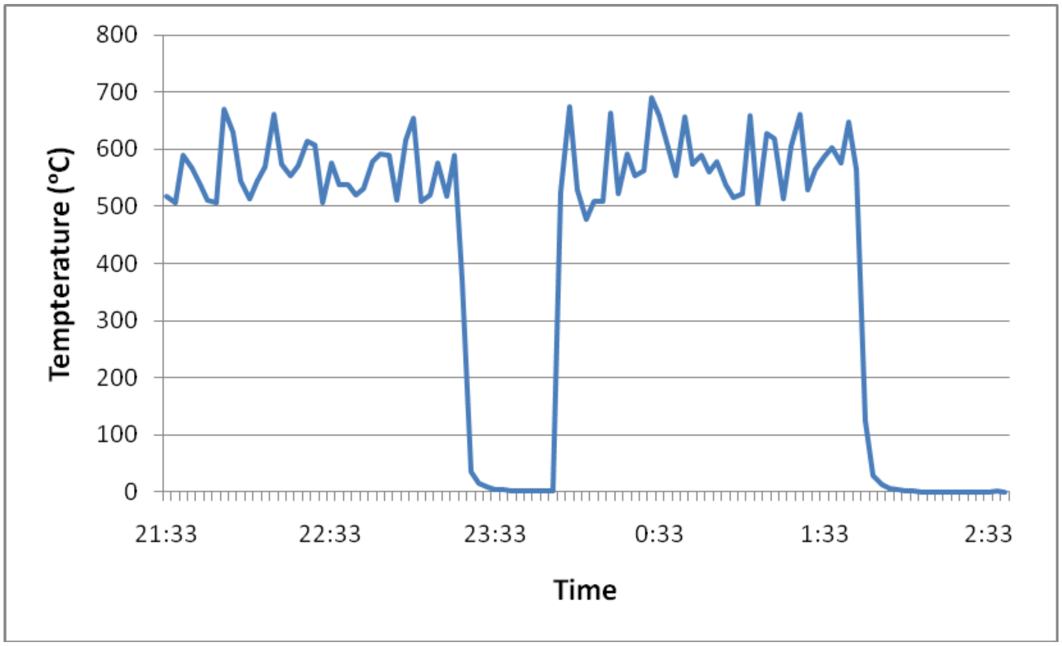

Figure 7: Data logger thermal profile for the torch fire at plot 99 on April 23rd. Fire was re-lit shortly before midnight.

The final fire was lit on plot 103 and consisted of two briquette fires placed ten feet apart. Figure 6 shows the fire thermal profile for this briquette fire.

The flight path taken during each sortie on this night approached the IR grid from the North, West or North West, so that observers could perceive the IR grid from their position in the aircraft. Unless otherwise noted all subsequent flights followed a similar pattern. The fires at plot 57 and 46 were simultaneously the first fires to be detected by three of the four observers. Video footage confirms that these two fires were the largest and brightest of the targets (Figure 8). Two observers failed to detect the fires at plot 99 and 103 despite the fact that they were still burning. From a review of the video footage, the fires were faint, but still visible from the air. During sortie three the observer spotted two of the four fires and then confirmed them as such. After closer inspection, however, they retracted their previous confirmation. These were recorded as misses. One campfire was detected and confirmed during sortie four. During sortie five the torch fires at plot 99 went out; therefore, the observer had three targets to identify instead of four.

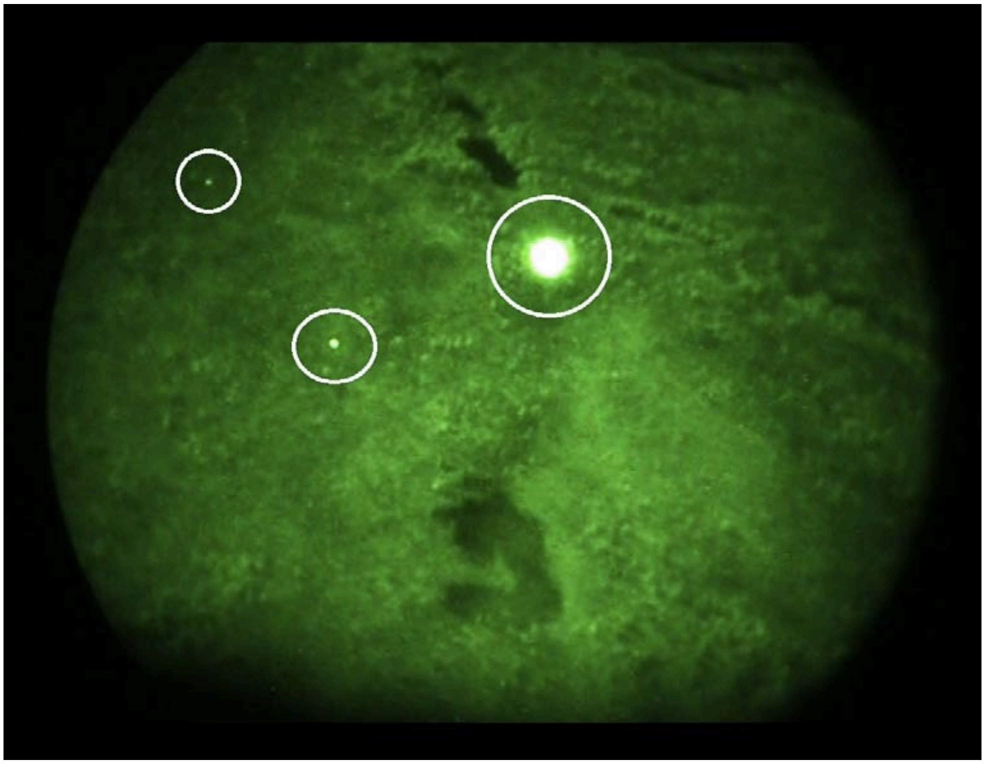

Figure 8: NVD image of one of the brightest fires (far right) at plot 57, the fire at plot 103 (bottom) and the faintest fire at plot 99 (top left corner). The second brightest fire at plot 46 is not visible in this image.

April 24th

Wind speeds were as high as six knots, with gusts of up to 21 knots. By early morning the wind speed reduced to three knots with no gusts. Temperature ranged from 10–16 °C with a dew point of 1 °C.

There were four fires in total at plots 57, 46, 103 and 104. The fire at plot 104 was unplanned and consisted of one torch lit in an area just outside of the plot where the ground crew was stationed for the night. Therefore, there is no data logger information or pictures for this fire. The fire at plot 57 consisted of one torch. This torch fire did not burn as hot as the other torch fires. Figure 9 displays the thermal profile. This fire consistently burned at a much lower temperature than previous torch fires, which had a peak temperature between 500 °C and 750 °C. This torch fire, however, peaked at 105 °C. The lower temperature observed in the data logger record may have been caused by a shifted or poorly mounted temperature sensor. This is likely since the torch was visible from the air and was confirmed as lit by the ground crew.

Plot 46 contained one fire with two fire logs. This fire followed the typical log fire thermal profile quite closely (Figure 5). Two torch fires were lit on plot 103. This fire also followed closely to the typical torch thermal profile (see Figure 7 for an example from the previous night)[5].

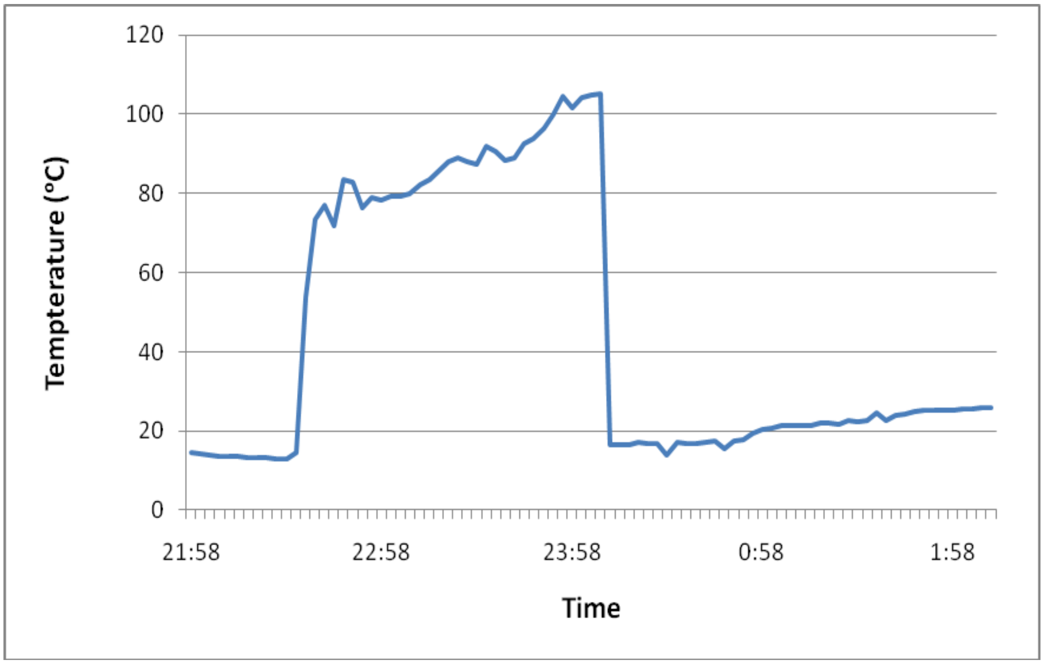

Figure 9: Data logger thermal profile for the torch fire at plot 57 on April 24th. The torch fire at plot 57 has an abnormal thermal profile likely due to a misplaced thermocouple.

There was one bright fire (plot 46), which seemed to draw observers close (Figure 10). Once they were circling the area to record fire characteristics they were able to detect the surrounding dimmer fires. The flight paths for sortie 1 and 5 placed the IR grid on the left side of the aircraft, making it more difficult for the observers to detect fires. During sortie 1 the observer did not detect any fires. The observer during sortie 5 found no planned fires because all of them were extinguished by that time (confirmed by data logger readings). However, this observer found two campfires. During sortie 2 there was an unknown light source in the IR grid around plot 103 (Figure 11). During this flight the observer detected the false alarm and confirmed it (erroneously) as a fire. In the middle of this same sortie, the unknown target disappeared. Since this light source was not recorded by the OMNR staff, it was considered to be a false alarm. From review of the video footage, it is believed to have been a lantern or flashlight.

[5] The specific thermal profile for each fire is shown in Appendix C

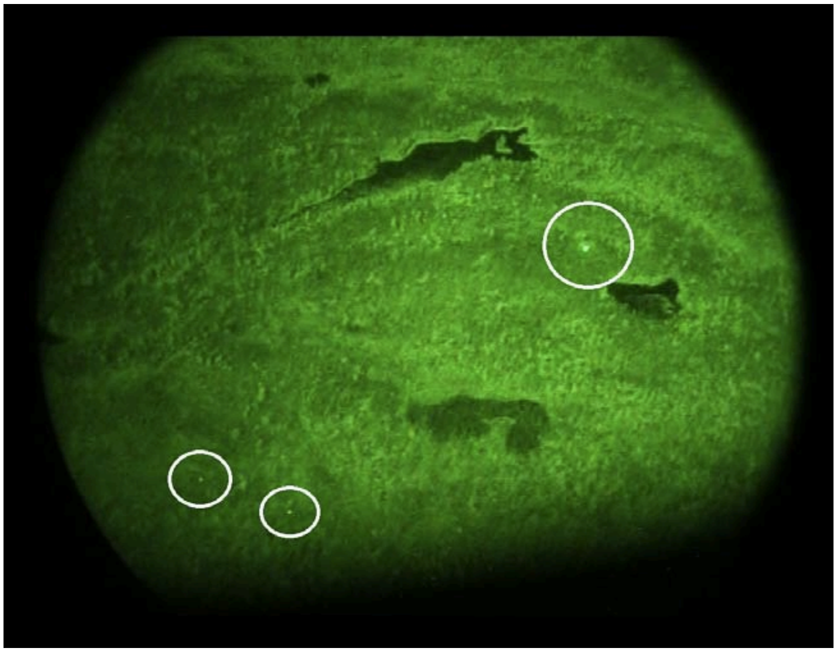

Figure 10: NVD image of the brightest fire (between two lakes in top right) on plot 46 and the two fainter fires (on the bottom left) at plot 104 (to the right) and 103 (to the left).

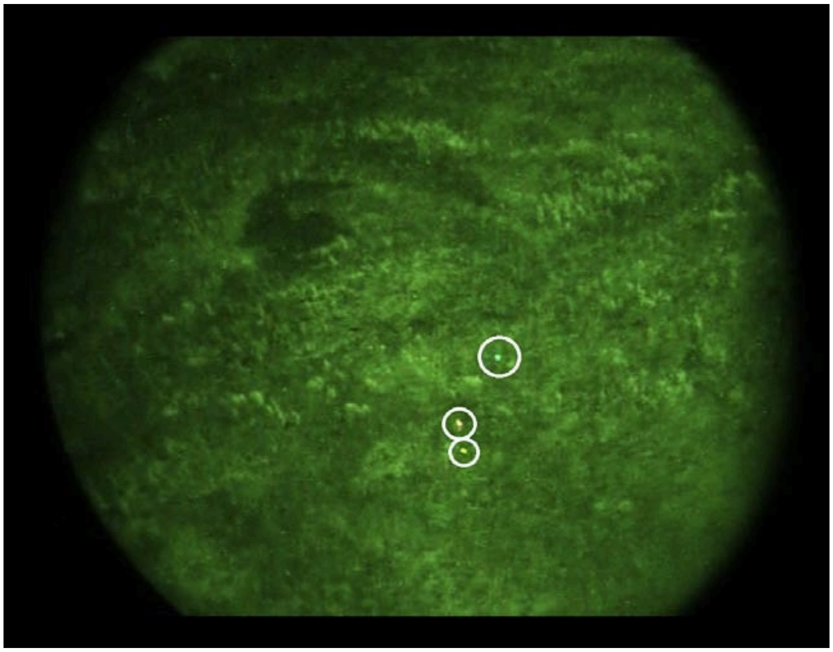

Figure 11: NVD image of plot 104 (top), plot 103 (bottom) and the false alarm (just above 103) believed to be a flash light.

April 25th

Wind speeds were between zero and ten knots. Temperature ranged from 9–16 °C with a dew point between +1 and -1 °C. There was one large fire on this evening, which consisted of a central briquette fire and six smaller torch fires. They were configured so that there were three torch fires on either side of the central briquette fire (Figure 12). Six glow sticks were placed one beside each torch fire. One data logger was placed on the briquette fire and one on a torch fire. Both observers were able to detect this fire; however, neither of them indicated that they could see the glow sticks. Another member of the flight crew for sortie 2 reported that they were able to see the glow sticks with the naked eye but not with the NVDs. In flight, they were not able to discriminate that these light sources were glow sticks, but could simply detect another set of light sources between the torches.

During the final sortie, the observer attempted to take pictures of the fire with an IR camera. Unfortunately, the temperature range setting on the IR camera was too narrow in order to accurately distinguish the fire from the environment. In addition, it was difficult to look through the narrow viewfinder with the goggles on as well as line up a shot through the window of the aircraft. Use of the IR camera in future field studies will use a wider temperature range setting and determine best practices for taking photographs.

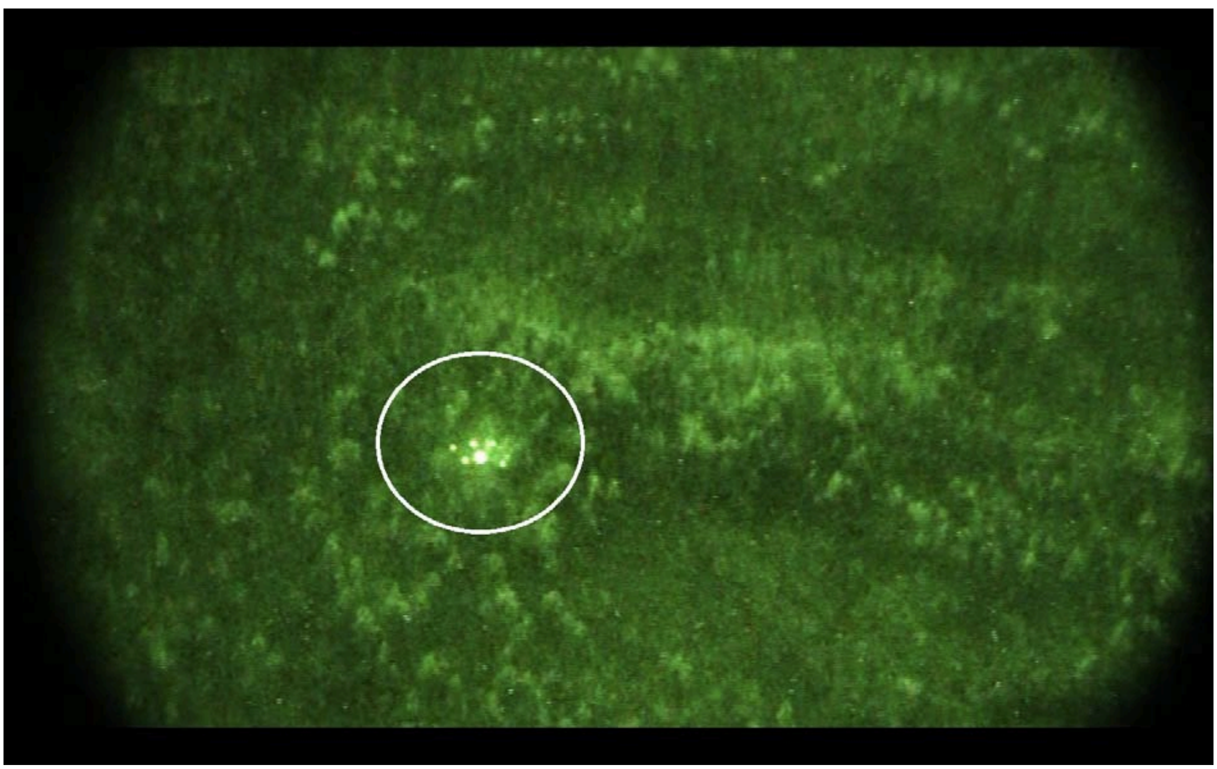

Figure 12: NVD image of large central briquette fire surrounded by six smaller torch fires.

Debrief

After each night the pilots were debriefed by the Fire Duty Officer. In every case, the pilots reported being able to detect and discriminate all the fires. Each observer was required to fill out a debriefing questionnaire that consisted of 32 questions. All observers rated their own ability to cover the search area as good. In addition, they also reported using consistent scanning techniques; the most common technique used was horizontal scanning. Visual performance, spatial orientation and situational awareness were reported as being average or good. One observer reported feeling disorientated when looking up after having been writing on the tablet. It should be noted that several observers were novice helicopter flyers.

Observers were required to rate their confidence in detecting fires on a scale from one to five; one representing not confident and five representing very confident. Most observers reported a confidence level of four, one reported three and another five. In addition, observers reported that both their skills and their confidence in detecting fires increased across sorties. Observers also reported alertness levels both before and after flights. Alertness was rated on a scale from one to five; one representing not alert and five representing very alert. Pre- and post-flight alertness levels were exactly the same for each observer except for one, who rated their alertness as five pre-flight and four post-flight. The most common symptoms experienced during flight were eye strain, headaches and sore necks. Most observers stated that they did not feel overloaded during the flight. However, one observer reported that recording fire characteristics for four targets situated so close together was difficult. This type of scenario is unlikely to occur in a real operational context since forest fires would not be restricted to such a small geographical area. The most difficult task reported, was sifting through the distractions to detect fires.

Both canopy density and altitude were reported as factors affecting task difficulty. A dense canopy made fires more difficult to detect and discriminate. As previously stated, a higher altitude made detection easier, but made discrimination more difficult. Most reported that neither topography nor speed affected their performance. However, one observer stated that the hills were more likely to obscure targets at low altitudes. Terrain relief was modest in the vicinity of the trials.

No one reported any problems with internal aircraft lighting. The only reported problem with external lighting was from one observer who stated that the reflection of the moon on the water was distracting. Observers estimated scanning distance to be between 10 and 20 km; weather reports indicated that visibility was nine statue miles or 14km. Both fuel sources and fire intensity rank were visible to all observers; the lower the altitude the easier it was to determine fire characteristics.

Strategies and Observations

There are no definitive signs for differentiating fires from other sources of light. Ideally, one would use a combination of approaches based on previous fire spotting experience and knowledge of the geographical area. Many light sources appear to flicker from a distance. However, fires usually flicker erratically instead of regularly, as a tower light might. It is important to note that non fire light sources may at first appear to flicker erratically when in fact they are constant. This often happens with rural houses where the tree canopy may occasionally occlude the light, creating the illusion of flicker. Watching a potential light source for a few minutes to see if the flicker becomes steady is one way to avoid false alarms of this nature. GIS data or experience with the area searched can be useful in discriminating man-made light sources from possible fire sources.

Viewing a light source without the NVDs can also yield important information. Yellow, white or red lights are often signs of artificial lights; whereas fires are often either not visible with the naked eye or are orange in colour. These characteristics are dependent on how far one is from the fire as well as fire size. Nearer the fire, flame and smoke are often visible but smoke is a less reliable cue than during daytime ocular detection patrols.

Light sources that appear to move and/or are emitting a concentrated beam of light are usually vehicles (Figure 11). Vehicles along logging roads can be especially problematic because they travel so slowly it may be difficult to see movement. In addition, logging roads are often narrow, bumpy and lined with trees, increasing the likelihood that the light will appear to flicker erratically. Having a crew member with knowledge of the local area will be a vital resource in order to eliminate targets on roads and trails.

Figure 11: NVD image of vehicle travelling along a road. Note the beam of light.

Once a target has been confirmed as a fire it may be difficult to determine if it is a nascent forest fire or a campfire (Figure 12). Look for houses, tents, people, vehicles or boats in the surrounding area in order to rule out the possibility of a forest fire. If a target is located on the shore of a body of water it is most likely a campfire, but may still be worth pursuing, since forest fires have occurred on shore lines and islands in the past and can be a significant threat to values. Another way to distinguish between campfires and forest fires is in the number of ember beds. Forest fires will, depending on size, have multiple ember beds or smouldering light sources; whereas campfires have only one ember bed. Symmetrically organized light sources of the same size and with halos of the same diameter are probably not forest fires; look for an asymmetrical organization of lights of varying sizes and brightness. Since night-time conditions are usually cooler then daytime conditions, forest fires will often appear as smouldering ember beds. This makes them much more difficult to detect compared to open flame or crowning trees. In addition, smoke columns, which are useful for fire detection during the day, can be absent, invisible or very faint with NVDs; they also often 'lay down' closer to ground at night. This means that nascent fires at night are often smaller and less immediately visible than nascent fires during the day. On the other hand, new fires started by lightning strikes need time to develop. Further investigation is required to identify the best time of night for NVD aerial detection patrols taking into account visibility, operational constraints, weather, fire indices and fire behaviour. NVD-aided IR detection patrols also must consider the trade-off between IR contrast, which typically increases as ambient temperature drops overnight, and changing fire behaviour, which typically declines overnight.

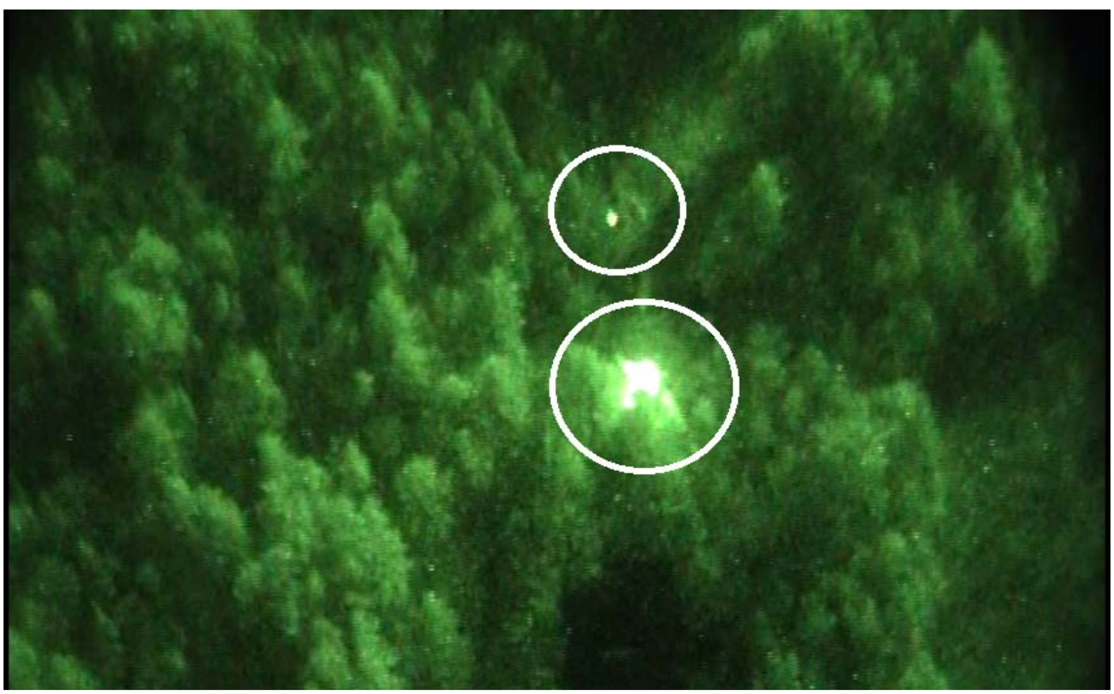

Figure 12: NVD image of campfire (top) in the backyard of a rural home (bottom).

NVDs allow pilots and detection observers to see and navigate under low illumination by amplifying available light. However, they do not turn night into day and there are limitations to visual performance using NVDs. For example, the image is monochromatic, contaminated by image noise at low light levels, the unusual spectral sensitivity can result in contrast inversions and field of view is limited in most devices. These limitations and artefacts presumably underlie the reported deficits in perception of space, depth and motion (for example Bradley & Kaiser, 1994; Braithwaite et al, 1998; DeLucia & Task, 1995; Hughes, Zalevski, & Gibbs, 2000; Macuda et al., 2005; Sheehy & Wilkinson, 1989; Task, 2001). Perceptual issues in NVDs have counted as a causal factor in military helicopter incidents and accidents in a number of countries (see Braithwaite, 1998). Training should take these limitations into account to ensure safe and effective detection patrols.

The image quality of NVDs can be compromised when searching areas that are highly saturated with sources of light. When possible, keep urban centers and bright light sources, such as trains or the moon, behind the aircraft, otherwise it may wash out the image or cause halo (Allison et al, 2010). Conversely overcast or moonless conditions can reduce ambient illumination enough that detector noise becomes an issue in the NVD image (Macuda et al, 2005). Under very low light conditions, automatic gain control in the devices causes scintillating noise (i.e. a 'grainy' appearance similar to a detuned television) that may influence depth, motion, resolution, form, size and distance perception.

It is important to continually scan the area and take frequent breaks to avoid neck and eye strain (Harrison et al, 2007). Scanning the area directly down the side of the aircraft is also valuable because one can see directly down into the tree canopy, decreasing the number of trees occluding a target.

Quantitative Data Analysis [6]

Average Distances

The average detection distance across all nights was 3,584m (95%CI: 2,697m to 4,471m). The average discrimination distance was 1,193m (95%CI: 944m to 1,442m). Figure 13 displays a scatter plot of detection distance against discrimination distance. Campfires were not included in these calculations and plot.

There was no significant correlation between distance and discrimination distances. The scatter plot at figure 13 shows a slight positive trend, such that as detection distance increases so too does discrimination distance. This trend is weakened by the five large detection distance data points in the bottom right corner, perhaps indicating that the positive trend between detection and discrimination distances does not hold for very large detection distances.

[6] Additional data analyses can be found in Appendix D

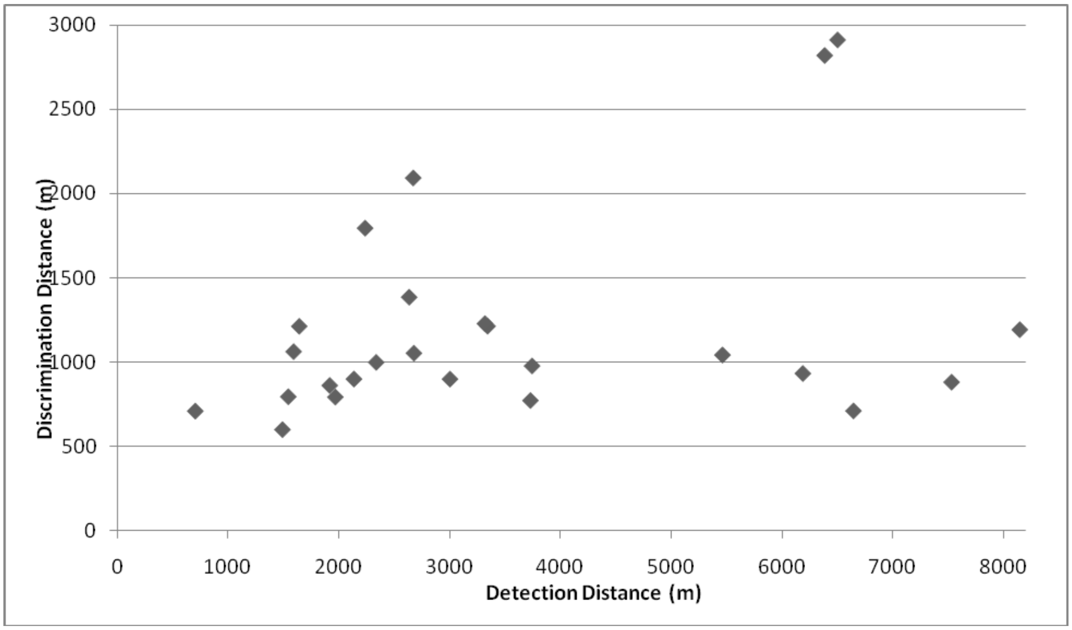

Figure 13: Scatter plot of detection distance agaist discrimination distance (N = 25).

Signal Detection

Table 1 illustrates the rates for hits, correct rejections, misses and false alarms on each night and across all nights. They were calculated by adding up the number of events that fell into those categories. The categories were defined in terms of the fire report generated. Correct rejections were defined as any target that was pursued and correctly identified as something other than a fire. Misses occurred when a fire was not detected or confirmed. When a fire was correctly identified and confirmed it counted as a hit. When an observer falsely confirmed a target as a fire it was a false alarm. The hit rate was calculated by determining the hit rates for each observer (number of fires found divided by number of actual fires) and taking the average of all the hit rates divided by the total number of observers; miss rates were calculated in an analogous manner. Please note that there were five observers on the 24^{th}, however, only four were counted in hit and miss rates because the planned fires were extinguished during the last sortie. All five observers were counted for correct rejections during that night.

Table 1: Signal detection rates across all nights and divided by nights

	N	Hit %	No. of Hits	Miss %	No. of Misses	No. of CR	No. of FA
Apr 23rd	5	50%	9	50%	10	12	0
Apr 24th	4	75%	12	25%	4	13*	1
Apr 25th	2	100%	2	0%	0	5	0
Overall	11	68%	23	32%	14	17	1

N = number of observer, CR = correct rejection, FA = false alarm; campfires not included

* N = 5

Correct rejections were broken down according to the type of distraction (Table 2). Man-made structures, mostly houses, provided the largest challenge for observers since they made up the majority (70%) of distractions. Vehicles accounted for 23 per cent of distracters and seven per cent of distracters could not be identified. The percentage of forest fire events to total events are calculated in Table 3. It is clear that distinguishing fires from other light sources is a major component of the detection task.

The hit rate (Table 1) shows that observers improved over time; there was a 50 per cent hit rate on the first evening and a 100 per cent hit rate by the last evening. It could be that observers were better acquainted with the terrain and could distinguish the IR grid from other areas. Brightness and fire size probably contributed to these improvements as well.

When considering all fire events (both forest fires and campfires) in relation to the total number of events, the overall rate is 44 per cent (Table 3). In other words, of all the events spotted across three nights 44 per cent were actual fires, whereas the other 56 per cent were distractions. For these calculations any event that was not a fire was collapsed into one category. Across all nights there were 59 events in total. Of these 59 events, 26 were fires (three of which were campfires). The other 33 were a mixture of correct rejections and false alarms.

Table 2: Type of distraction for correct rejections

	Structure	Vehicle	Unknown
April 23rd	7	5	0
April 24th	10	2	1
April 25th	4	0	1
Total	21	7	2
Percentage	70%	23%	7%

Table 3: Percentage of fire events to all other events

	Fire	Other	Total	% of Fires
April 23rd	10	14	24	42%
April 24th	14	14	28	50%
April 25th	2	5	7	29%
Total	26	33	59	44%

Campfires included as fire

Discussion and Conclusions

Flight Parameters

Over the mixed forest canopy of the IR detection grid observers found it effective to fly at relatively high altitude (3,000-4,000ft AGL) during search with descent to lower altitude to confirm and characterize the fire. Low-level scanning (1,000ft AGL) was not very effective due to unreliable visibility of the fire when hidden by terrain or canopy. Similarly, scanning could be effectively performed at typical cruising speed (e.g. 90 knots) allowing efficient coverage with circling or slowing over the fire to confirm and characterize. Helicopters are very flexible in this regard. Very low altitude with helicopters is possible but entails a risk of spreading embers with the rotor wash. In these trials, successful NVD characterization was possible from 500–1,000ft AGL. Note that detection with fixed wing aircraft might need different tactics as hovering or low-level circling over the fire is not usually feasible. NVD detection combined with IR characterization might be effective in this regard.

NVD Detection Feasibility

The sources used were very small by typical aerial detection patrol standards. The OMNR would not expect daytime patrols to find fires this small. The smallest fire size typically reported is 0.1 hectare (with all smaller fires classed as a 0.1 ha). Even the largest configurations used in these trials were a fraction of this size and the individual fire sources were essentially point sources. Nevertheless, these fires were detected with a 68% hit rate at an average distance of 3.5 km from a nominal altitude of 4,000ft AGL. Thus it is apparent that small fires can be detected from typical detection patrol altitudes and distances.

IR Detection Grid

While not specifically designed for NVG detection simulations, these trials provided an opportunity to assess the utility of this new OMNR resource. Generally the IR grid provided a high-level of experimental control in the positioning of the target fires. Access to a well-surveyed and controlled environment appropriately prepared for a fire provided a unique opportunity for controlled sources to be presented, for accurate detection and discrimination distances to be calculated and for signal detection statistics to be gathered and verified. The IR grid area had a variety of vegetation and terrain features providing a range of scenarios and was surrounded by other suitable terrain to search over before passing over the IR grid. It was conveniently located near a suitable base in Pembroke airport.

The site had good road access nearby which was important for the considerable ground support needed for the trials.

On the negative side the IR grid is small compared to the size of a typical detection patrol, requiring targets to be concentrated in a fairly small radius. Furthermore, plot choice was limited by trail access. Ground crews navigating in the IR grid and maintaining fires at night require sites with adequate trail access. As such, the targets were often detected in groups or as an ensemble. The limited area also reduced the ability to use the area for subsequent flyovers in repeated-measures type designs due to the observers becoming familiar with the location and terrain. In an IR certification scenario this would likely be of less of a concern as the detection area would be provided to the pilot and repeated exposures would not be likely.

During the first night, observers and experimenters felt over loaded when recording characteristics for six fires. Occasionally, recording characteristics even for four fires was difficult. This difficulty again reflected the size of the IR grid, which required that plots be fairly closely spaced. Fortunately, the IR certification tasks do not require such extensive data recording. Certification is designed to evaluate the ability of an IR scanning service to detect hot spots. Similar to this experiment, ground crews will light a set number of targets at planned locations. After the flight, the IR scanning service personnel give the number of targets found and their locations, but are not required to record any additional characteristics. What may make future use of the IR grid more effective is using the entire length of the grid instead of placing targets one or two plots apart. Spacing targets throughout the full range of IR grid may prove to be more realistic.

The fire plot configurations used varied over the successive nights of the detection patrol. While this provided a variety of scenarios based on the experience of the Fire Duty officer, it also made it more difficult to pool data, because many important source parameters were uncontrolled or varied in concert. This was compounded by temporal decay in the fire temperature and behaviour over the course of successive sorties. Statistical analysis would be aided by more repeatable configurations.

The fire sources served as effective targets. The gel fuel torches burned most uniformly (neglecting flicker and fluctuation) but require frequent relights. The logs and briquettes burned less steadily, with an exponential decay but required less maintenance and were more substantial. All were essentially point sources. Simulation of larger fires required distributed arrangements of these point sources. The data loggers were invaluable in estimating and monitoring these sources and future studies should consider the time course and maintenance requirements of the sources in their design. Standardized placement of the thermocouple would be useful for interpretation of absolute temperature readings.

NVD Discrimination of Light Sources as Fires

Detection of fires from the air is relatively easy as even small fires have a strong signal allowing them to be detected. Identifying them as possible fires and then confirming them as such requires approaching to distances of several kilometres. The main issue with discrimination is the variety of competing light sources that must be filtered and eliminated by the observer. Man-made sources are the most problematic especially vehicle lights and building/landscape lighting. This is particularly difficult when partly occluded by canopy so that they appear to flicker from the moving helicopter. Some types of residential and industrial lighting also flicker in the NVD image although usually the more regular pulsing behaviour can help distinguish these from fires. Camp fires are also regularly detected and, while a true fire event, are obviously distractions. Such interference from non-fire environmental sources may limit NVD aided detection patrols near more heavily populated activities or when human activity is expected to be high (which may require later operational windows).

Knowledge of the area is critical for determining which targets are worth pursuing. Although this study showed that novice observers, unfamiliar with the geographical area, were still able to detect very small fires from other light sources, having knowledge of the area will further decrease the number of distractions pursued. In this study observers were not permitted to take advantage of the pilots' expertise. In a real scenario, however, crew members would actively discuss potential targets. Besides being familiar with the geographical area, the pilots have a number of other qualities that increase their efficacy as observers. They are adept at navigating in an aircraft and are therefore less likely to become disoriented during flight. They also have more experience in fire detection, both during the daytime and at night with NVDs.

Evaluation of NVD Data Collection Protocols

These trials allowed for evaluation of the protocols to be used in aerial detection patrols in the real operational context. The protocols and data collection forms and tools generally worked well. Observers found it difficult to detect, record and respond to up to six fires at once. This is not a likely scenario in a real situation and each fire report will be documented and registered before moving on to continue the search.

Observers were able to handle entry of the fire report data into the tablet computer without excessive workload but redundant voice and written records were invaluable. Adjusting the touch settings on the tablet and providing short cut tablet buttons reduces inadvertent inputs and makes navigation and data entry easier. Data entry forms were designed to minimize the amount of scrolling and pen movements required by the user. Short training sessions, so that observers could familiarize themselves with the tablet and the data forms, were valuable in decreasing workload in flight and the amount of time spent looking down at the display. In flight the tablet display brightness was reduced to its lowest setting in order to minimize the amount of light reflected off the cockpit windows. Despite the reduced brightness and the NVG compatible filter, there was some reflection off the windows which interfered with observation. In these cases the observer placed the tablet close to their body to block the light or covered the display with a piece of thick paper. Initially the NVG caused the tablet pen to stick and jump across the display. This was fixed by covering one side of the filter with an acetate sheet.

Audio and video documentation is a must and can be accomplished by placing the camera in the nose bubble if an operator is not available. We had limited experience recording IR imagery for comparison and this should be addressed in future trials.

Initial Experience with the FireHawk System in a NVD Detection Patrol

These trials allowed for evaluation of a prototype of the FireHawk reporting system in a NVD scenario. As an oversight, the eastern fire region map data was not included with the FireHawk system. This essentially left the map portion of the software useless during detection patrols. The map interface was designed to allow the user to change map resolution, measure distance between several points, add additional map information from an external source (lightning map, fire danger zones), and mark the location of a fire event.

The fire report portion of the FireHawk system is designed to gather characteristics of a particular fire. The FireHawk is capable of recording the location, size, rank, fuel type, and date and time of a fire event. The fire report also includes observer values (human life, industry equipment, transmission lines, etc.) and the detection craft ID. After completing a fire report, the unit is designed to transmit the gathered data back to a fire response centre. However, the FireHawk unit was unable to interface with the EC130's automated flight following unit, therefore no fire reports were transmitted from the helicopter. All fire characteristic data was recorded in a word document. This data was then emailed to the developer of FireHawk in order to generate a fire report.

Users of the FireHawk software commented that it would be useful to have new fire events marked on the map in order to keep track of the locations of previously detected fires. This feature would prevent the possibility of reporting a single event multiple times. This would be especially useful when multiple fires are located in close proximity. It was also noted that there is no means of marking a non-fire event in the software. While this is not an issue during daytime usage, it is likely that some distractions will occur at night. This feature would prevent the detection crew from pursuing non-fire events multiple times.

The most common issue reported with the FireHawk system was that the selectable buttons were too small. While the selection size of an button may have appeared to be small, the button's selection box actually was much larger, and usually encompassed both the label and the button. This led some to believe that they had to precisely select the small button, a task that proved to be difficult in a helicopter at night. The other major issue reported was the small size of the Panasonic Toughbook's display screen. The display size made task performance more difficult for some users.

Overall all users of the FireHawk system saw promise in optimizing the system for use with NVDs. It would likely increase geographical awareness, and improves detection and discrimination tasks would be extremely useful during night-time detection flights. It would likely reduce spatial disorientation and the number of distractions pursued.

Recommendations

Specific recommendations include:

1. Investigate IR/NVD detection scenarios, particularly aircraft mounted FLIR systems. We had limited experience recording handheld IR imagery for comparison so this should be addressed in future trials. Many studies have espoused the benefits of multispectral approaches and the combination of IR and NVD detection has potential for reducing false alarms and better characterizing the fire. NVDs allow for natural egocentric scanning but IR is more tolerant of occlusion and provides a thermal signature. The integration of these tools needs to be explored.

2. Determine the best time of day for NVD detection patrols. Rising humidity and falling temperatures cause the fire to 'lay down' possibly making them more difficult to spot. It is probable that low relative humidity recovery throughout the night will yield greater detection success and improve visibility. An increase in relative humidity inhibits the growth of a fire and often reduces fire behaviour. Conversely, contrast may be enhanced and human activities less distracting with later flight. An analysis of the factors involved is warranted.

3. Aerial detection at 3,000ft AGL and normal cruising speed is appropriate for the scanning phase of an aerial detection patrol. Detection range was adequate. Increased altitude might improve detection range but would make discrimination more difficult and increase the time required to descend to investigate a fire. Descent to lower altitude is helpful for discrimination of fires from other sources and for characterization. If NVD compatible fixed wing detection aircraft are available these parameters may not be transferrable.

4. The IR test grid was a valuable resource for these experiments and provided adequate experimental control. We recommend that data loggers and photo verification of targets, data logger location, site location and site preparation from the ground crew be carried out during test runs. This was the case in the current experiments and was key to eliminating ambiguity. Standardization of the fire sources and the sensor location for data collection will improve the repeatability and experimental control. Weather will also need to be a factor both from the standpoint of safety and repeatability of the conditions. For future NVG trials a measure of NVIS light output as well as temperature would be desirable.

5. The data collection protocols were generally found to be effective and efficient. We have no major recommendations for changes but the tablet interface and data forms have been tweaked to better meet experimental demands.

6. Airborne fire reporting via the FireHawk system is a promising approach but the current device is difficult to use in a night-time scenario. A larger display, consideration of night-time glare, adaptation and visibility issues, and compensation for the difficulty in making precise markings in the dark environment when looking under the NVDs are recommended for development of the night-time variant of FireHawk.

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Appendix A – Experimental Protocol for Characterization of Sources

This appendix will be incorporated on revision of this report. The experiment is planned for Fall 2010.

Purpose

To determine the relationship between temperature and luminance burn cycles for various fuel sources used in the Pembroke series.

Appendix B – Data Collection Forms

Sortie No.

Airport: __________ Aircraft: ______ __

Date: ________

PILOT(S)	**EXPERIMENTER**	**OBSERVER**
Filliter	Allison	Allison
Bain	Zacher	Zacher
Holby	Tomkins	Tomkins
Other: ___________	Other: ___________	Vinnikov
		Milner
		Andriychuk
		Doig
		Other: ___________

	Take Off	Landing
Time		

MOON PHASE

New Crescent

Half Gibbous Full

OBSERVER QUESTIONNAIRE

Do you feel well rested? Yes No

How many hours of sleep did you get last night? ___________

How alert do you feel?
Not Alert 1 2 3 4 5 Fully Alert

How many night flights have you flown this evening? ________

Event No.

MNR Fire No: ________________

DETECTION

Waypoint	Time

Quadrant

1 2

3 4

Flame Descriptors

Flicker

Visible with Naked Eye

Spotter

Name:

Visible Smoke

Yes No

Additional Comments

DISCRIMINATION

Waypoint	Time

Confirmed Fire

Yes No

If not why?

Approx. Fire Size (hectares)

Spotting Distance (ft):

____

Open Flame (% of perimeter):

____

Wind Speed/Direction:

____

Spread Potential

Limited N E S W

How

FIRE LOCATION

Waypoint	Time

Basemap	Block
Sub Block	**Sub Sub Block**
.	

Intensity Rank

1 2

3 4 5

Values (timber assumed)

Human

Structures

Cutwood

Logging Equipment

Other: ________________

Fuel Type

Coniferous

Deciduous

Mixed (% conifer): __________

Grass

Slash

Cutover

Blowdown

Budworm Kill

Plantation

Other: ________________

Access

Helicopter

Fixed Wing

Road

Boat

Pumping Distance (ft)

Direction N E S W

Appendix C – Thermal Profiles

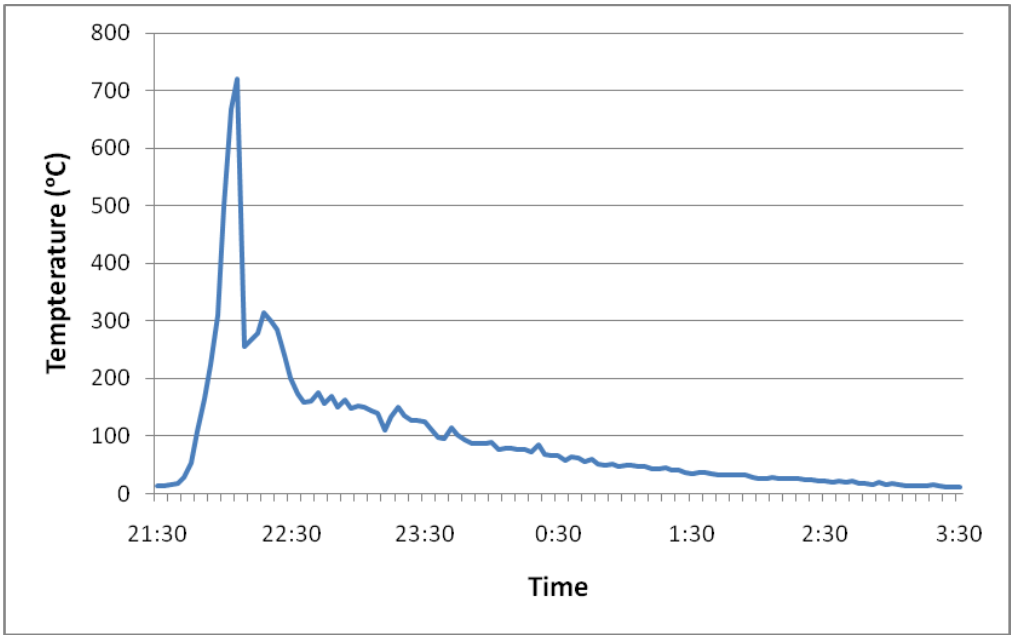

Figure 14: Data logger thermal profile for the briquette fire at plot 46 on April 23rd.

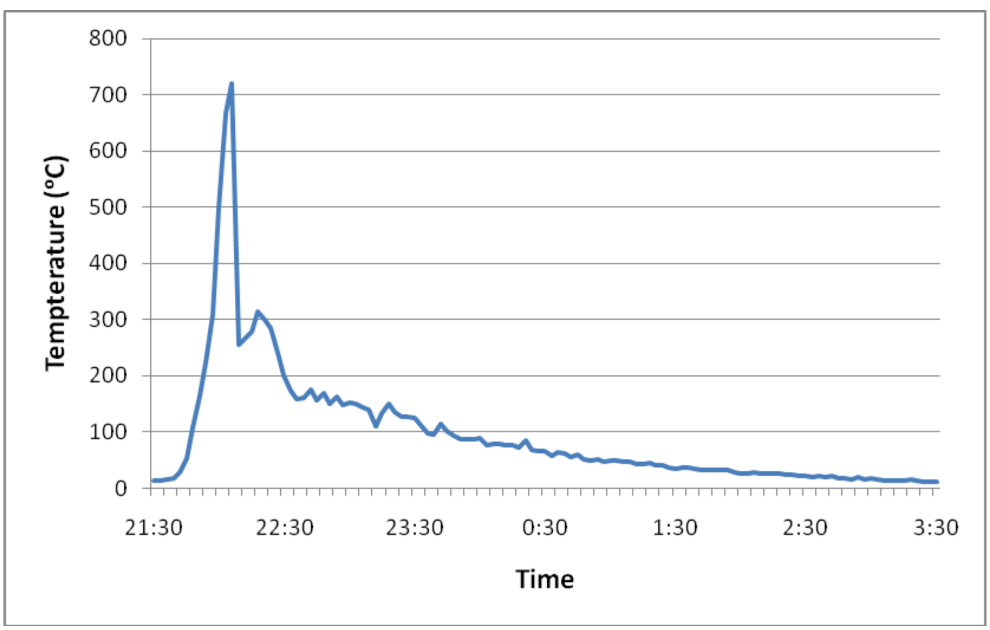

Figure 15: Data logger thermal profile for the log fire at plot 57 on April 23rd.

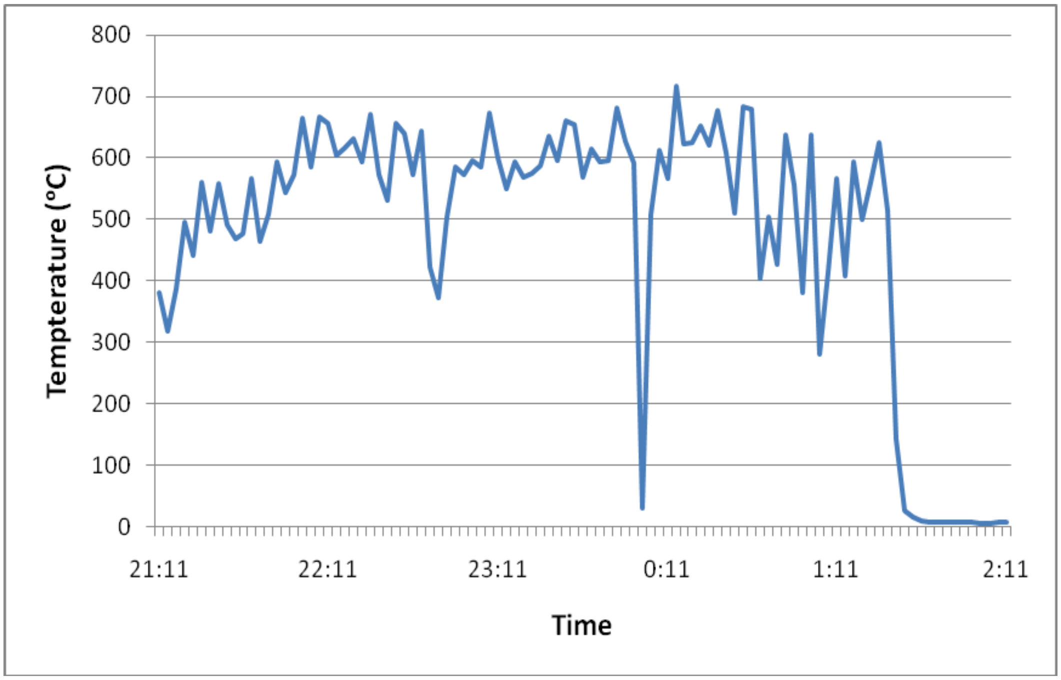

Figure 16: Data logger thermal profile for the torch fire at plot 103 on April 24th.

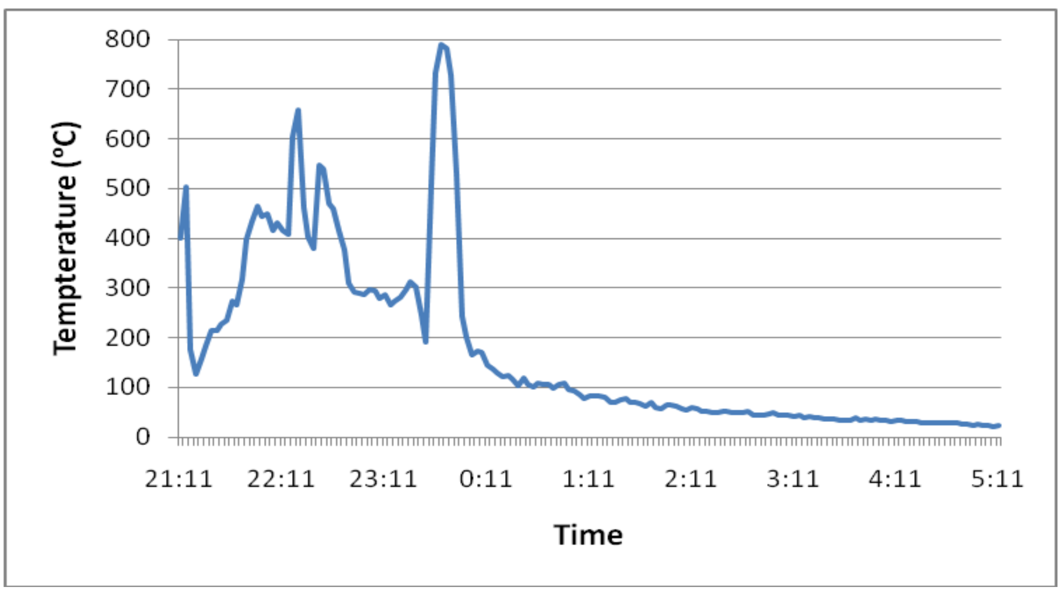

Figure 17: Data logger thermal profile for the briquette fire at plot 57 on April 25th.

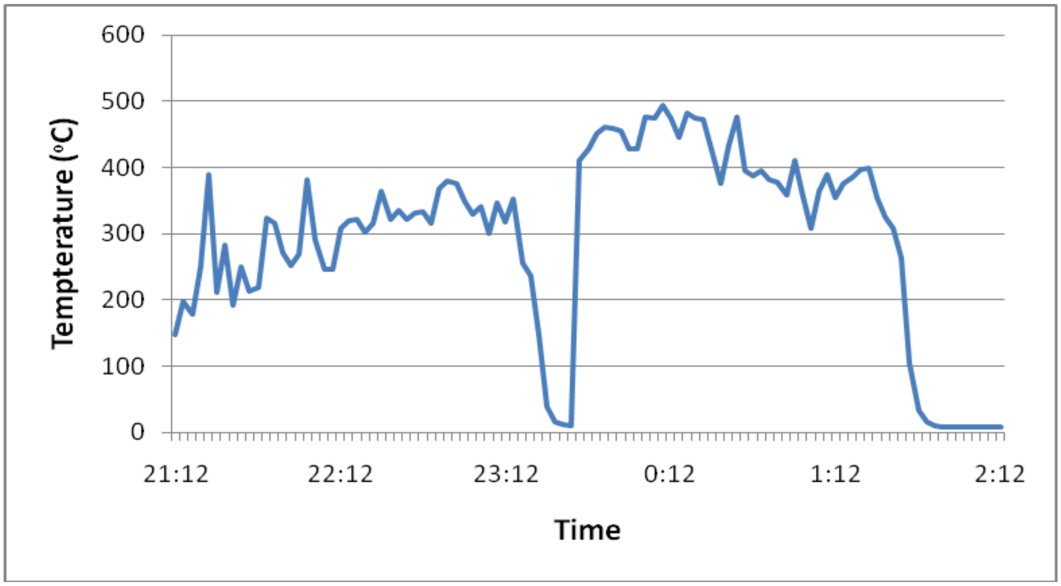

Figure 18: Data logger thermal profile for the torch fire at plot 57 on April 25th.

Appendix D – Additional Data Analysis

By Fire Temperature

Across all nights correlations were calculated between distances and fire temperature. The correlation between detection distance and temperature was not significant ($r(22) = -0.155$, $p > 0.05$) nor was the correlation between discrimination distance and temperature ($r(22) = 0.035$, $p > 0.05$). The correlation between detection and discrimination distances was also not significant ($r(25) = 0.315$, $p > 0.05$).

By Number of Light Sources

In some instances, multiple sources were combined in a single plot to simulate a larger fire. Data was analyzed according to how many light sources were present on each plot; one, two, three or seven sources. Levene's test indicated unequal variance for both detection distance ($F(3,21) = 3.102$, $p = 0.049$) and discrimination distance ($F(3,21) = 9.968$, $p = 0.001$). Due to unequal variance the Brown-Forsythe Robust Test was used for data analysis. The results indicated a significant difference for both detection ($F(3,19.727) = 7.001$, $p = 0.002$) and discrimination ($F(3,10.751) = 3.951$, $p = 0.040$) distances by number of light sources. Post hoc comparisons using the Dunnett T3 test revealed no significant differences in the number of light sources for discrimination distance. For detection distance, however, the mean distance for three light sources (M = 5,179, SD = 1,989) was significantly different than the mean detection distance for two light sources (M = 1,834, SD = 963) and for seven light sources (M = 2,439, SD = 281). These results show that fires with three light sources were detected at significantly greater distances than fires with two or seven light sources.

By Canopy Density

Canopy density differed between IR grid plots. Data was analyzed according to whether the fire was lit on a plot with dense (plot 57 and 46) or semi-dense (plot 99 and 103) canopy. Levene's test indicated unequal variance for both detection distance ($F(1,23) = 18.394$, $p = 0.001$) and discrimination distance ($F(1,23) = 6.370$, $p = 0.019$). The Brown-Forsythe Robust Test was used for data analysis. The results indicated a significant difference of canopy density for both detection distance ($F(1,22.103) = 13.979$, $p = 0.001$) and discrimination distance ($F(1,18.699) = 6.669$, $p = 0.018$). In contrast to expectations, the average distances for dense canopies were larger than the average distances for semi-dense canopies (see Table 4). In other words, fires under dense canopy coverage were detected and discriminated from greater distances than fires under semi-dense canopies. This is the opposite of what one would expect, since a dense canopy means greater occlusion of the fire, thereby requiring observers to be closer in order to detect it. It is important to note that there were almost twice as many data points for fires under dense canopy which may account for these findings. Additionally, the analysis does not account for topography and aircraft approach, which also affected observers' detection abilities.

Table 4: Mean and SDs for detection and discrimination distances by canopy density (dense N = 16; semi-dense N = 9)

	Dense		Semi-Dense	
	Detect	**Discrim**	**Detect**	**Discrim**
Mean	4434	1364	2075	890
SD	2183	690	950	191

Changes in Detection and Discrimination Distance with Experience

Only three out of six observers had enough data to be considered in this analysis. In addition, only the data for the 23rd and 24th were used. The detection distance on the 24th was 50 per cent shorter than the detection distance on the 23rd. For discrimination, the distance on the 24th was 29 per cent shorter than the 23rd. Instead of distances increasing over time, which may reflect observer improvement, distances actually decreased. This could be due to a number of factors, many of which could not be controlled for. For example, observers may have become more familiar with the task and terrain causing them to be more cautious in subsequent nights. Perhaps the fires on the 24th were more difficult to detect than the fires on the 23rd. This latter point is likely to be true because, as stated earlier, observers were drawn to the IR grid by one large bright fire on the 24th. Once they wer circling the area to record fire characteristics, they were able to detect the surrounding dimmer fires.

Appendix E – Flight Paths

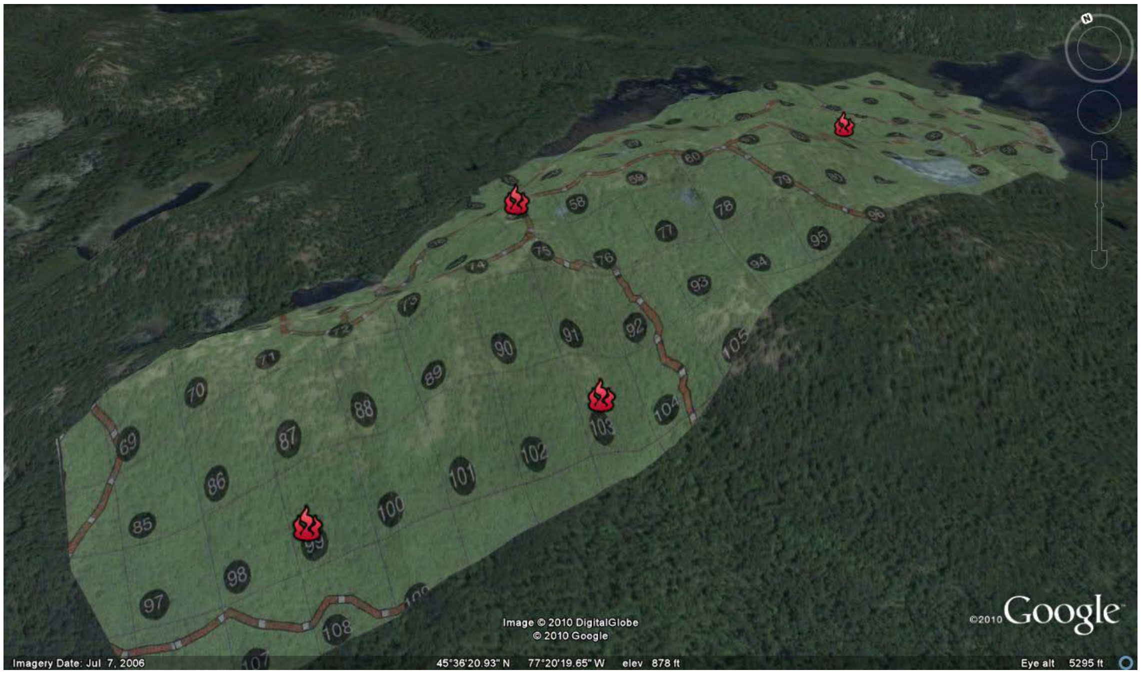

Figure 19: Google Earth image of the IR grid. The fire icons indicate the location of the commonly used plots. Plot 99 is the bottom left, plot 103 is the bottom center, plot 57 is the top center and plot 46 is the top right. The elevation is exaggerated at a setting of 3 in Google Earth.

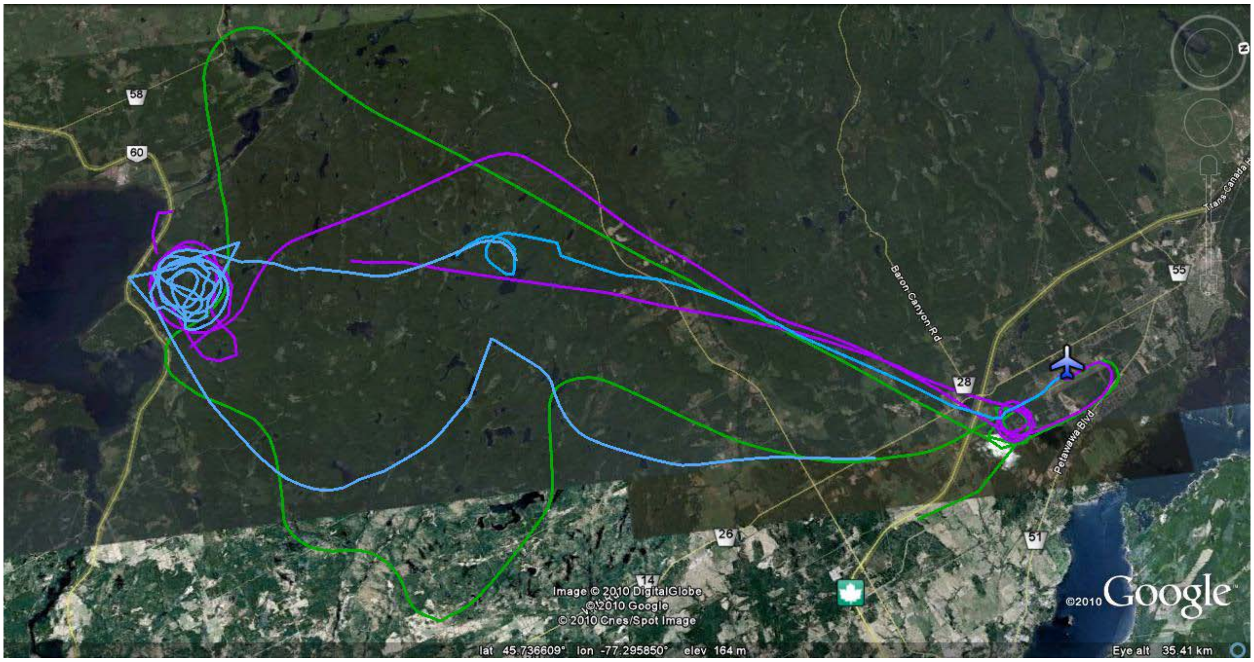

Figure 20: Flight paths on April 23rd. Sortie 1 is green, sortie 2 is blue and sortie 3 is purple. Occasionally the GPS signal was lost leaving some flight paths incomplete.

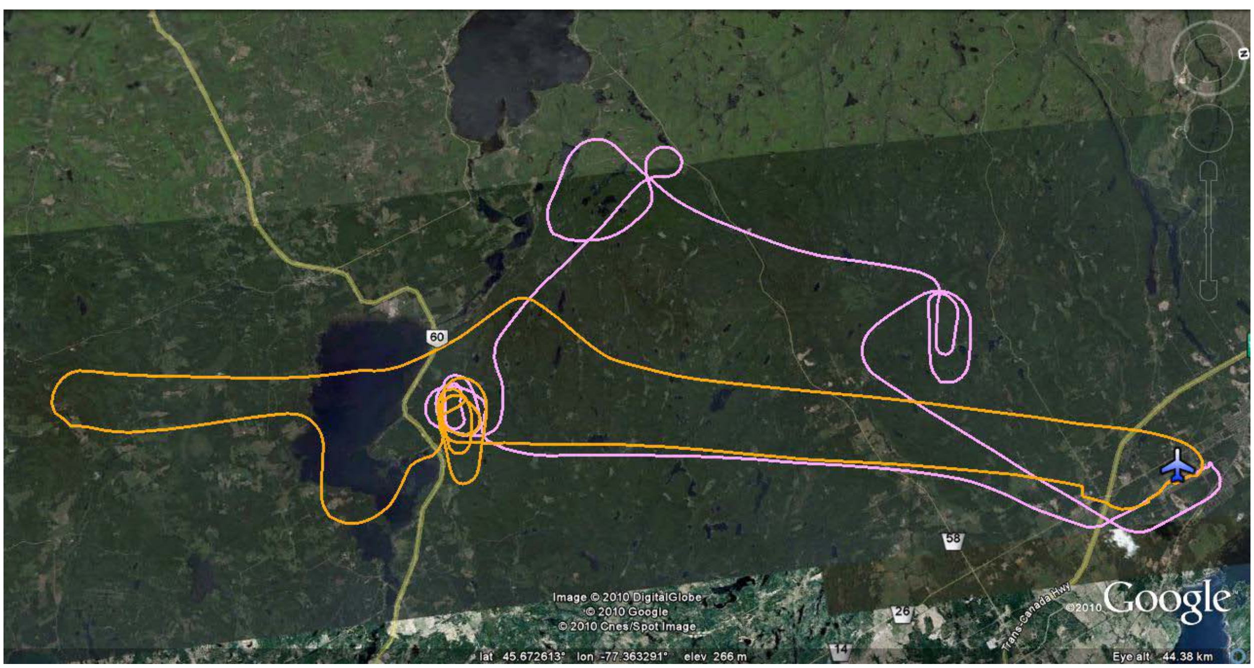

Figure 21: Flight paths on April 23rd. Sortie 4 is pink and sortie 5 is orange.

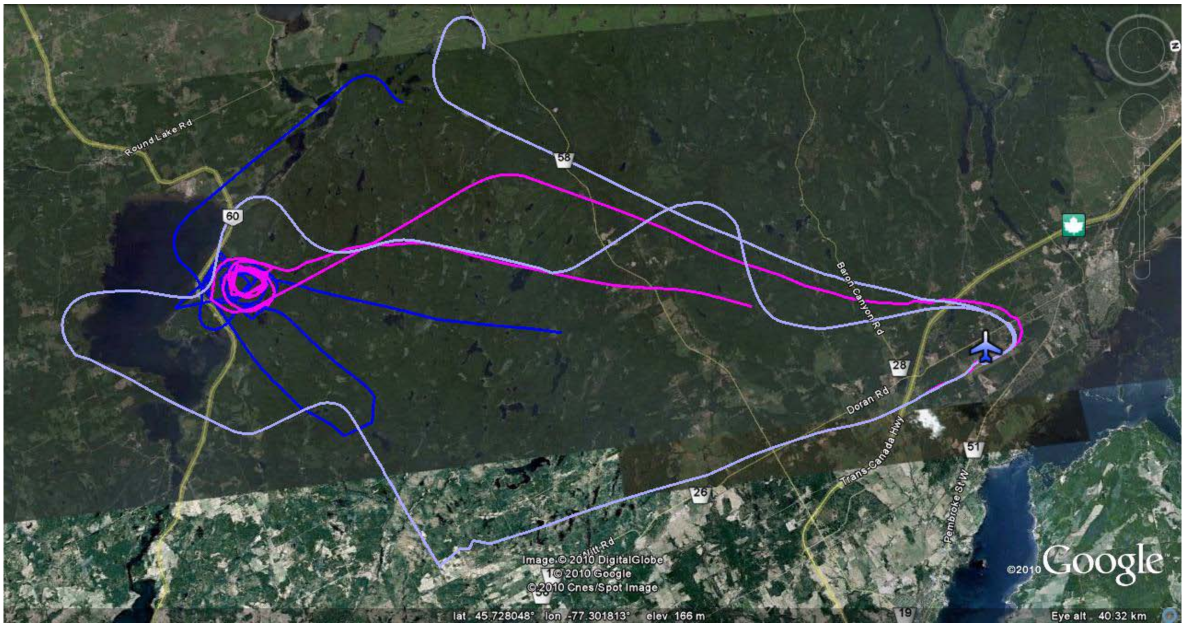

Figure 22: Flight paths on April 24th. Sortie 1 is dark blue, sortie 2 is light blue and sortie 3 is pink. Occasionally the GPS signal was lost leaving some flight paths incomplete.

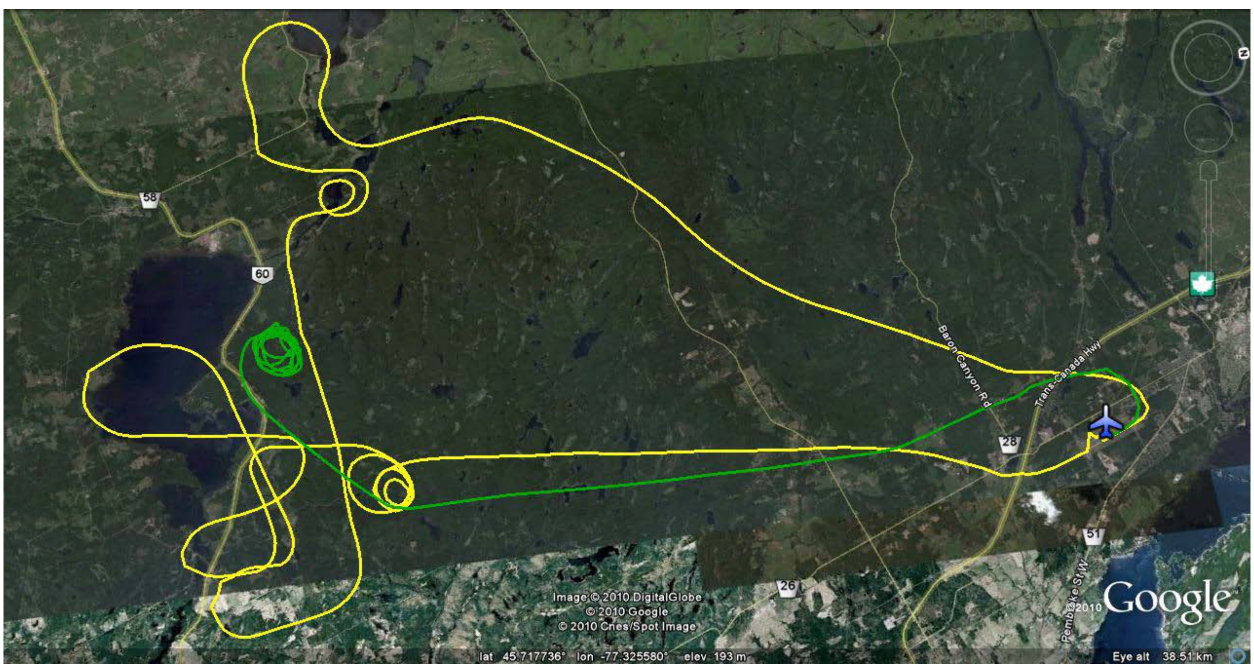

Figure 23: Flight paths on April 24th. Sortie 4 is green and sortie 5 is yellow. Occasionally the GPS signal was lost leaving some flight paths incomplete.

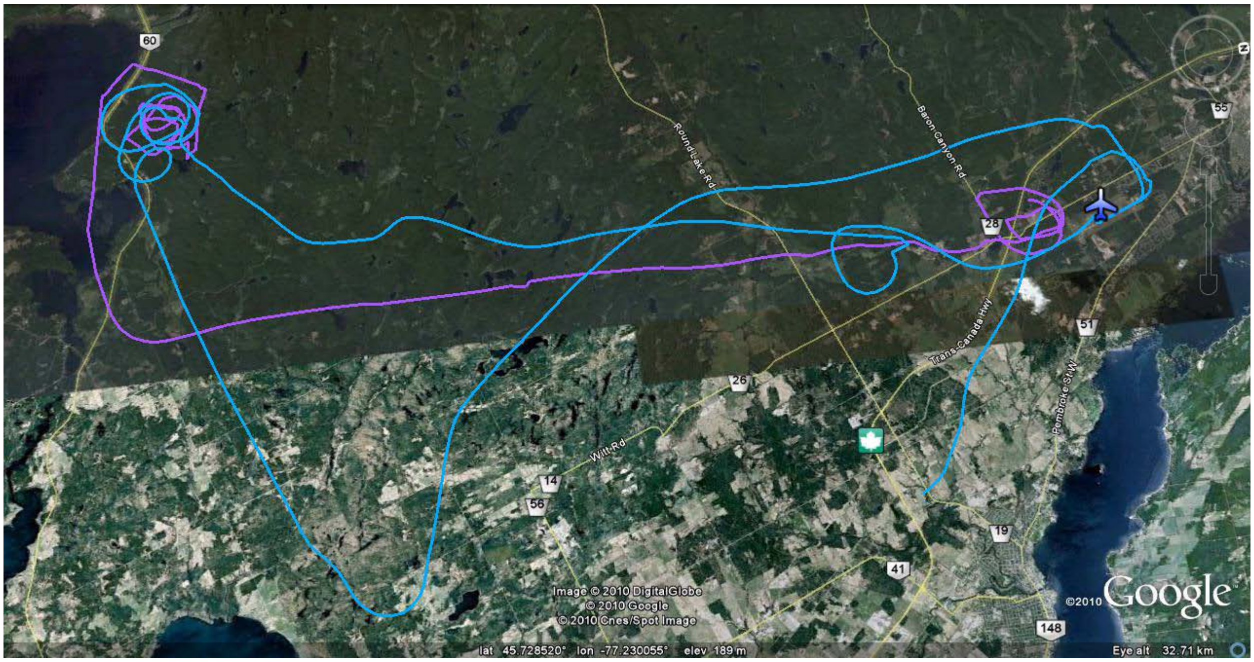

Figure 24: Flight paths on April 25th. Sortie 1 is blue and sortie 2 is purple. Occasionally the GPS signal was lost leaving some flight paths incomplete.