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Canadian Wildland Fire Monitoring System (CWFMS): Calibration, Pre-processing and Georeferencing of MWIR Airborne Data

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Abstract

In this technical report we describe the methodology for the pre-processing and georeferencing of mid-wave broadband infrared imaging as a precursory step in the production of fire intensity maps. In addition, an informal calibration approach and initial testing of the mapping system are briefly described, with a final summary of the acquired data. This project was part of NRC's support to Natural Resources Canada – Canadian Forestry Services (NRCan) effort to assess wildland fires in real time to quantify their intensity and duration. Data processing was focused on the Forward Looking Infrared (FLIR) Mid-wave Infrared airborne data acquired from NRC's Twin Otter aircraft for two Being Observed Burns (BOB) located near Pickle Lake, Northern Ontario, from August 1st to 3rd, 2017. This project implemented a FLIR proprietary data collection technique of superframing that uses multiple integration times to capture the full temperatures of a naturally occurring fire.

The prime failure was the Inertial Measurement Unit (IMU), which only recorded its raw data at rates of 1 Hz instead of 100 Hz, thereby removing any ability to Kalman filter and get proper pitch, roll, and yaw attitude data. In addition a navigation system failure (i.e. IRIG Time B) was a motivation for the development of a new and specific geocorrection methodology that was applied to the FLIR data. The system failure resulted in the FLIR pixels being unable to automatically obtain accurate GPS and attitude data (i.e. pitch, yaw and roll angles). Therefore, an alternative procedure was tested and implemented, wherein a preliminary process converted FLIR video into geocorrected mosaics and a secondary georeferencing process improved the overall accuracy. This produced geocorrected flight lines with an average RMSE of approximately 10.66 m, which is a substantial improvement on the raw data which had no positional information and an average Root Mean Square Error (RMSE) of 223.86 m. Once the data was geocorrected, a methodology to calculate different thermal parameter maps was implemented. An example of the maps for measured counts, calculated radiance ($W/m^2/sr/um$) and temperature (K) values of the BOB fire SLK-37 recorded on August 3, 2017 is shown for all acquired integrations times (i.e. 1.4 ms, 0.3 ms, 0.04 ms, and 0.0021 ms). The navigation system failure was thus resolved, and the method developed in this report may be utilized in many situations in which limited positional information is unavailable.

One of the objectives of this project was to compare the wildfires airborne data with large spatial resolution monitoring satellites for the same area such as the European Space Agency's satellite constellation Sentinel-3. However Sentinel-3 experienced a safe protective shutdown from July 31st to August 6th, 2017 (see Appendix 1), which was only

released to the public weeks later, making this analysis impossible. The center point latitude and longitude coordinates for all the collected flight lines are detailed in Appendix 2, and Appendix 3 shows the Trial Plan that outlines detailed information about the cameras and Pickle Lake deployment specifications.

The recommended next phase in this research is to compute additional fire products, including fire radiative power (FRP), fire intensity (FI) and assess the benefit of additional data processing methods including atmospheric correction on the quality control and assessment.

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1. Overview

With forest fire occurrences on the rise internationally, having an understanding of the precursory contributors, real time monitoring, post analysis mapping, and computation of fire mapping products are key to understanding the life cycle of fires, mitigating their potential damage, and combatting them in real time. Wildfire mapping is conducted on multiple scales – from ground to air to space. Having an understanding of the limitations at each level is key to efficient testing and analysis. In this project, Mid-Wave InfraRed (MWIR) sensors were installed on NRC's Twin Otter aircraft to collect real time data over naturally occurring fires in Northern Ontario to support of Natural Resources Canada Canadian Fire Services (NRCan-CFS) fire research program. This airborne infrared data was to be compared to coincident satellite imagery, specifically the Sentinel-3 SLSTR, for multi-scale analysis and ultimately produce fire mapping products.

2. Equipment

There were multiple sensors used in this project: FLIR SC8300 (NRC), FLIR SC6700 (NRCan-CFS), FLIR T62102 (NRCan) and Xenics Onca (King's College, UK). Specifications on these cameras can be found in the Trial Plan in Appendix 3. The SC8300 and SC6700 are nearly identical in form, fit and function. The main difference between these two MWIR imagers are: the SC8300 has a higher image resolution compared to the SC6700, and the SC6700 also has an internal filter wheel. All three infrared cameras were equipped with a narrow bandpass flame filter at 3.74 µm. This flame filter has the same spectral location as the filter utilized on the Sentinel-3 SLSTR satellite. This report will focus on the SC8300 data, as it was the principal sensor used for this flight campaign while the other cameras were used for supplementary purposes.

3. Ground Testing

As with any other measuring device, the FLIR systems required ground testing to ensure accuracy of the measurements. Additionally, when collecting infrared data, it is important to identify optimal integration times. An integration time is synonymous with shutter speed or exposure setting and defines the length of time in milliseconds (ms) that the shutter is open for a single frame. As wildland fires are unique situations that have a very broad array of temperatures that range from ambient up to nearly 1000°C, the integration time will impact the imagery collected by the FLIR camera. Short integration times will only capture high temperature values, while long integration times are required to measure low temperature values. As such, the ability to collect multiple images at different integration times will allow for a high-resolution image and minimize saturation by extreme values.

The FLIR SC8300 is capable of superframing, a process that takes successive measurements at various integration times which may be combined in post-processing into one ideal superframe. This allows for visualization of features with extreme temperature differences. FLIR allows up to four integration times to be designated and measured during the superframing recording process. A drawback for this particular application is that since the camera is installed on a moving platform, in this case the Twin Otter, successive frames will have a small physical offset on the ground. This offset distance between frames will be a combination of the aircraft's speed and the image sampling frequency. As such, any combined superframe image will have some discontinuities in imaged features.

In any digital imager the measured energy causes the detector to produce a signal voltage that is transferred to an A/D converter that results in a specific digital count related to the voltage amplitude. The SC8300 14-bit dynamic range creates count values ranging from 0 to 16,383 (16,384 in total) proportional to the incident energy at that integration time. These digital counts can then be transformed into temperature and radiance values via calibration relationships that are specific to the individual camera. The integration times are selected so that the dynamic range of the signal counts can be maximised to ensure proper confidence in the measurement and visualization of the fire.

Prior to installation aboard the aircraft, laboratory measurements were conducted with the FLIR instruments on site at the NRC Flight Research Laboratory (FRL) on July 20, 2017. NRCan's blackbody radiometric source was placed at one end of a table with the SC8300 positioned directly opposite at a distance of 88cm. The SC6700 was situated next to the SC8300 so that both instruments would constantly measure the temperature at the blackbody port. The SC6700 had previously been calibrated using a flame filter of 3.74um and therefore was the reference data set for the SC8300 measurements. A third FLIR camera, the T62101 Long-Wave InfraRed (LWIR), was used as redundancy as LWIR cameras are more stable at higher temperatures, when MWIR sensors often become saturated. The T62102 camera was handheld and directed at the blackbody port. Figure 1 shows the lab set-up and equipment used for the calibration procedure.

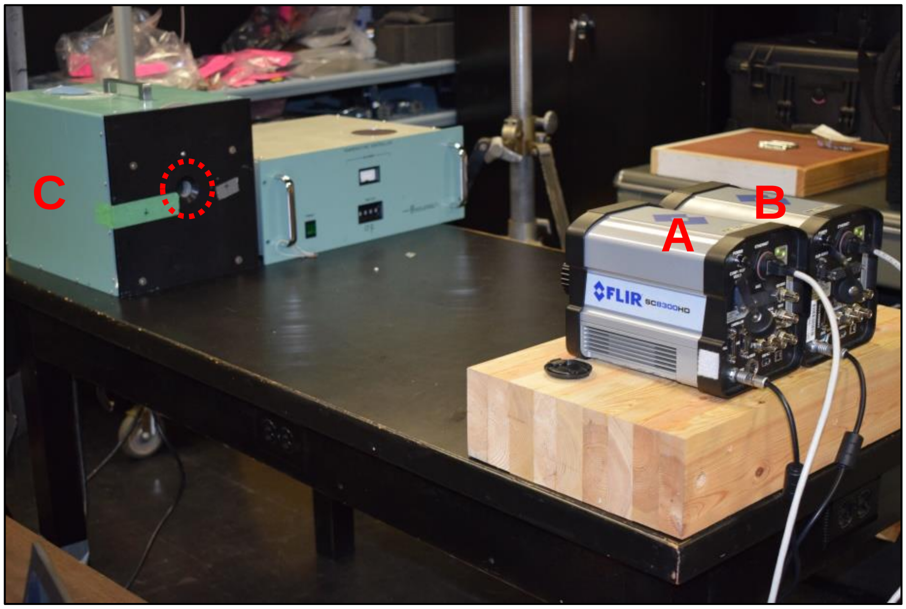

Figure 1. Laboratory set-up. The FLIR SC8300 (A) and FLIR SC6700 (B) were located 88cm perpendicular to the blackbody's (C) exit port (dashed circle). The LWIR camera, not pictured, was handheld and directed at the blackbody's exit port as well.

Within FLIR's native data capture and processing software, ResearchIR, a circular ROI was created directly over the blackbody exit port (Figure 2) in the ResearchIR interface from each camera. The statistics of the ROI were then monitored as the blackbody settings were modified. For this testing, we used a minimum of 3000 (coolest target) to a maximum of 13000 (hottest target). Outside of these values (<3000 and >13000), the detectors' behaviours are highly non-linear and may either induce noise or provide false measurements. It is assumed that the ratio of blackbody setting to temperature is 10:1 where a maximum setting of 10000 would be about 1000°C based on NRCan's previous blackbody experiments.

1. A long first integration time (>1ms) was selected to determine where the blackbody setting of 0 produces counts of 3000 within the ROI. The blackbody setting was increased by an assumed increment of 100°C until a measurement of 13000 counts within the ROI was reached;
2. The integration time was then substantially reduced (e.g. from 1.5ms to 0.5ms) and step 1 repeated;
3. The above steps were repeated until the highest blackbody setting of 10000 was reached.

When the blackbody setting reached 8400, the temperature was only measured using the T62101 (LWIR) and SC8700 (MWIR) camera because the image on SC6700 (MWIR) was fully saturated and could not accurately measure the temperature of the blackbody.

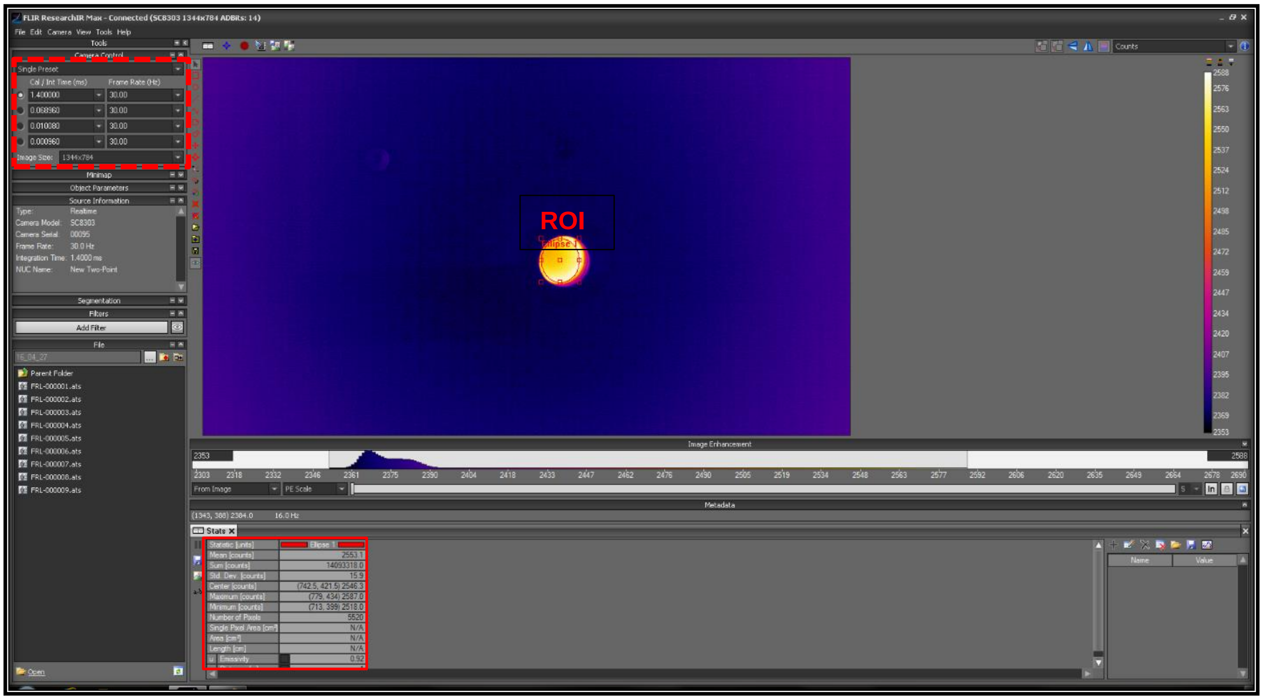

Figure 2. ResearchIR interface during temperature stabilization of the blackbody. A circular ROI was used to identify the statistics (red solid box) of the blackbody portal at a specific integration time (red dashed box).

The exact temperature to setting value was not specifically known as the blackbody did not have an accompanying manual. The blackbody setting relative to temperature as measured by the SC6700 and FLIR T62101 is shown in Figure 3 and displays a near linear relationship of 10:1. This shows that the initial assumption on the operation of the blackbody was nearly correct (e.g. a setting of 4000 is equivalent to ~428.244°C based on this experiment). As there is no information available on the blackbody and the temperature measurements rely on previous calibrations of the SC6700 and T662101, this is a best guess scenario and provides a high-level guidance on the operation of the blackbody.

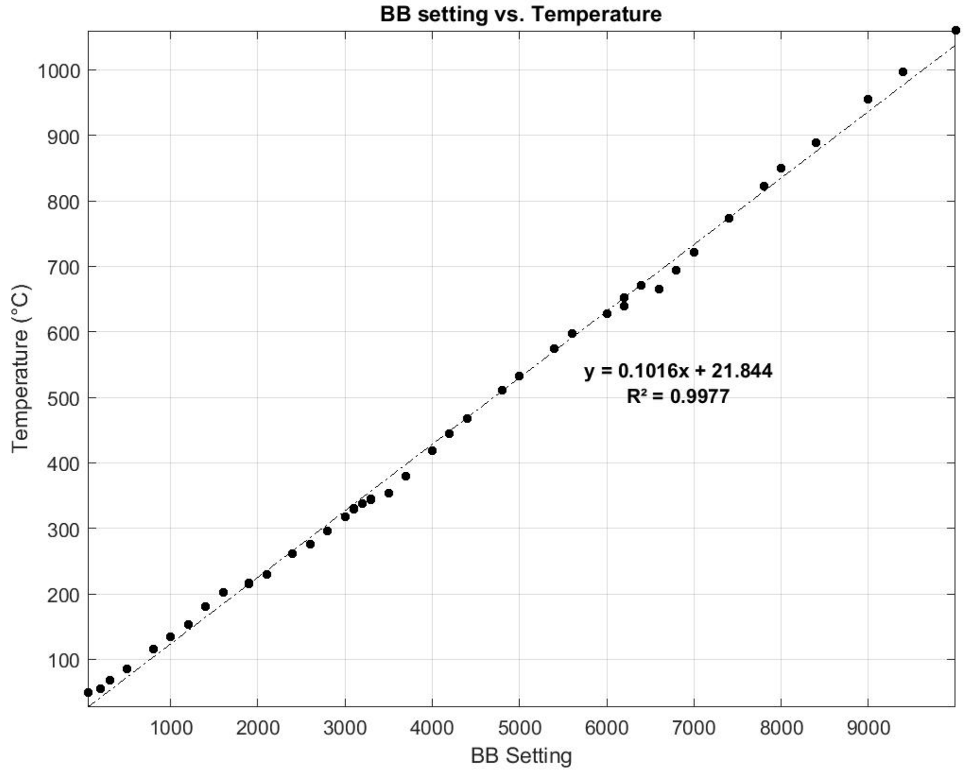

Figure 3. Scatterplot of blackbody (BB) setting versus Temperature (C°) as measured by the FLIR SC6700 and FLIR T62101 (latter used above a setting of 8400). The variability is due to the statistical average taken over the ROI from Figure 2, especially near the edges.

The results of the blackbody setting relative to the measured counts and temperatures for a series of integration times are shown in Figure 4. Figure 4 shows that as the blackbody setting and temperature increase so too does the count value within each integration. The four integration times that captured the full range of the blackbody source (0 – 9999) were 0.002ms, 0.04ms, 0.3ms, and 1.4ms.

As counts and temperature are directly measured, the radiance is then calculated from the temperature using the Planck Function:

$$R(\lambda, T) = \frac{a}{\lambda c^5 (e^{\frac{b}{\lambda c T}} - 1)} \times \frac{1}{c}$$

where λ is wavelength (μm) and in this case equal to the flame filter, 3.74μm, T is brightness temperature, R(λ, T) is radiance in $Wm^{-2}\ sr^{-1}\ \mu m^{-1}$, and a, b, c are constants of values 1.191044024 × 10−16 Wm^2, 1.4387687 × 10^{-2} mK, and 10^6 respectively. The results are shown in Figure 5. Depending on the integration time of the frame being viewed, the radiance values for each pixel can be interpolated from these graph results and a final radiance image produced. Computation of radiance is important to compute fire products.

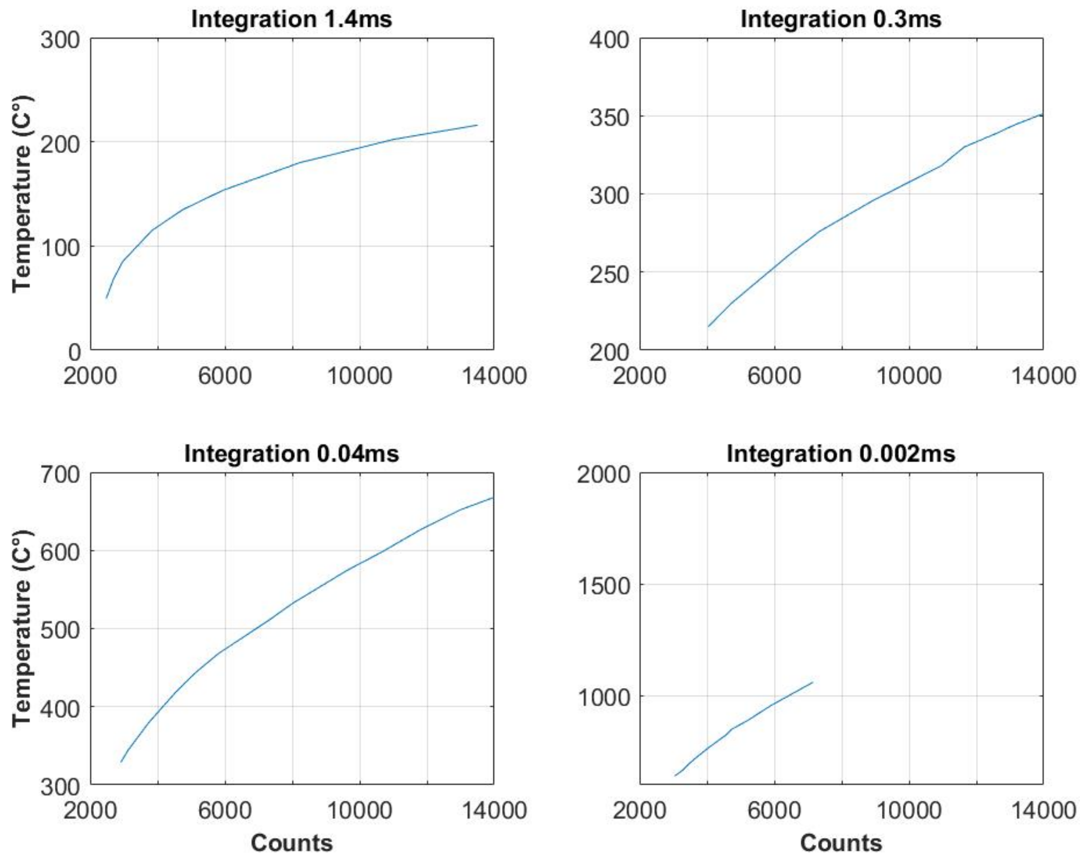

Figure 4. Counts as measured by the FLIR SC8303 and Temperature (C°) as measured by the FLIR SC6700 and FLIR T62101 (above a BB setting of 8400) at integration times of A) 1.4ms, B) 0.3ms, C) 0.04ms, and D) 0.002ms. Different temperature ranges are shown due to the count limits (3000 - 15000) for each integration time. This figure shows us that the count to temperature relationship is not exact and that as the limits of the counts are approached, the reliability of the temperature is less reliable.

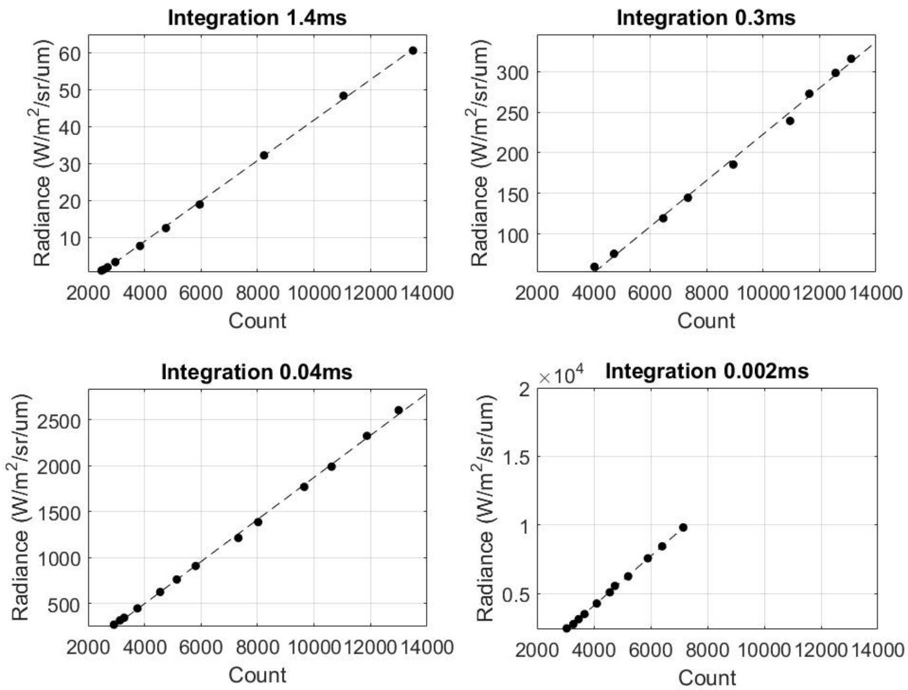

Figure 5. Counts as measured by FLIR SC8300 versus calculated radiance using Planck's Function and a wavelength of 3.74µm at integration times of A) 1.4ms, B) 0.3ms, C) 0.04ms, and D) 0.002ms. The equations yielded by the trend line at each integration time can be used to calculate radiance across each frame recorded by the FLIR SC8300. As shown, the shortest integration time (0.002ms) yields the highest radiance values and reached the maximum blackbody setting of 1000 at a count of 7400.

4. Pre-deployment Test Flight

A pre-deployment test flight (shakedown flight) was conducted on Friday, July 28th, 2017 to test and ensure that all onboard equipment was working properly before deploying to the experiment site. The flight plan for this test can be found in Appendix 3. For this test, a small fire (relative to a wildfire) was created on site at Ottawa MacDonald-Cartier International Airport under the guidance and supervision of the Ottawa International Airport Authority Fire Crew. The fire was built in a log cabin configuration on a 2m x 2m pan immediately north of Runway 32 (Figures 6 and 7). The fuel was a mixture of commercial firewood (primarily maple and ash) with diesel as the igniter. The FLIR T62101 LWIR camera was stationed on a tripod next to the fire on the ground to monitor the temperature in real time. During the period of the shakedown, the weather conditions were: average temperature of 22°C, wind speed of 24 km/h, and mainly clear. The role of wind contributed to the way the fuel burned as wind supplies more oxygen for the combustion process.

Figure 6. Location of pan fire (red circle) at Ottawa International Airport Fire Hall. Source for baseline imagers: GeoEye.

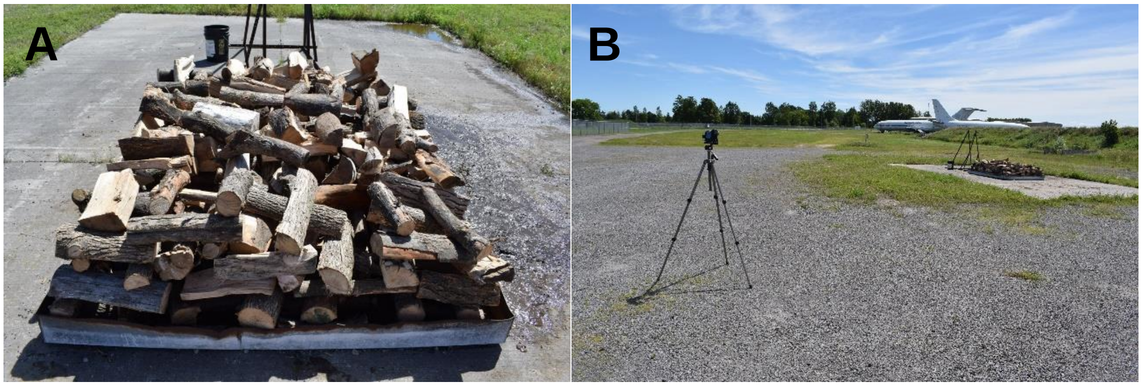

Figure 7: (A) Log cabin structure recommended by NRCan-CFS Services to allow optimal airflow, resulting in flames. The wood was primarily maple and ash, which was doused with diesel as the ignition source. (B) Ground testing set up with the FLIR LWIR camera recording the fire throughout all overhead flights. Photo is facing southeast.

When the wood was ignited with diesel, the fire immediately burned hot at about 630°C during the combustion of the diesel and then began to increase in temperature with an average temperature around 800°C and maximum temperature of 900°C (Figure 8). The fire's temperature varied throughout the experiment due to changes in wind conditions. As the total fuel load decreased with time, so did the overall temperature of the fire.

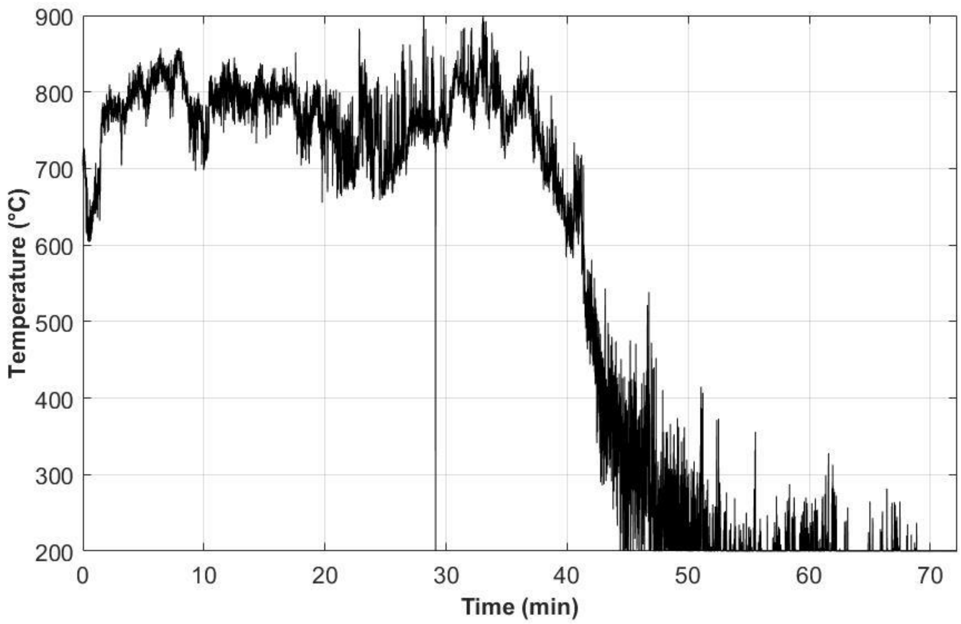

Figure 8: Temperature plot (°C) for one of the hottest parts of the fire over a period of 75 minutes as recorded by the LWIR camera. The trend of increasing temperature to a stabilized temperature of around 800°C until the fuel is nearly consumed and the temperature decreases to 200°C (the lower limit of measurement of the LWIR camera). Intermittent drops in temperature observed around 2 minutes and 10 minutes are attributed to a change in wind conditions decreasing, decreasing oxygen supply for the combustion process.

The Twin Otter completed six passes over the fire along a heading of 320° at three nominal heights above ground level (AGL): 915m, 1525m and 2745m. These AGL's were selected as they would be used on the deployment to Pickle Lake. They represented safe operational heights that would also ensure optimal resolution per pixel for the expected size of fires being investigated. Images from the fire at ground level during passes at altitudes of 915 m and 1525 m are shown in Figure 9 and Figure 10, respectively. The shakedown went well and the pan fire was imaged at all three altitudes and each integration time. Figure 11 shows images of the fire for each integration time for the 2745m pass over the fire.

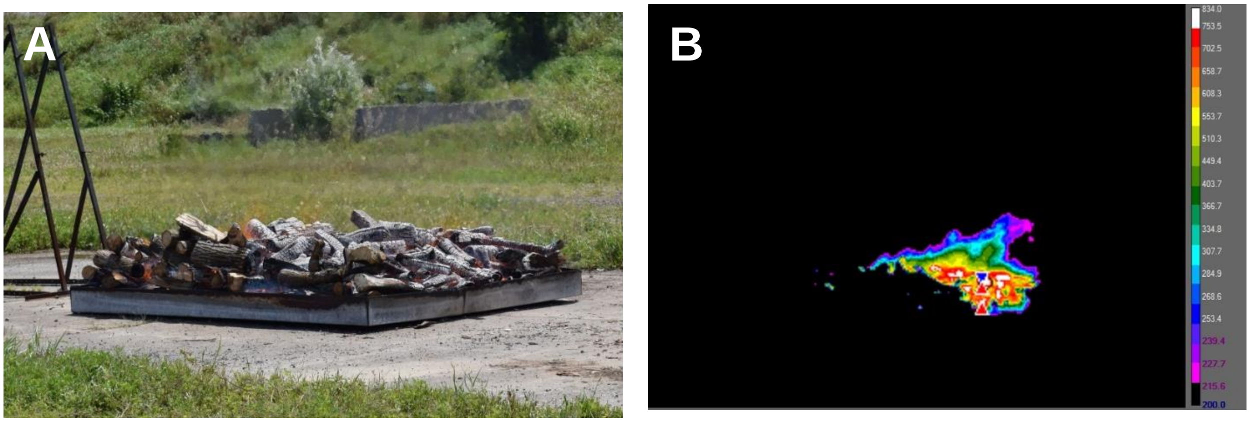

Figure 9: (A) Photo of the fire when the POK made first pass over at 915 m at 12:47 pm. (B) LWIR image over the fire. The hottest part of the fire is in white. Scale is in °C.

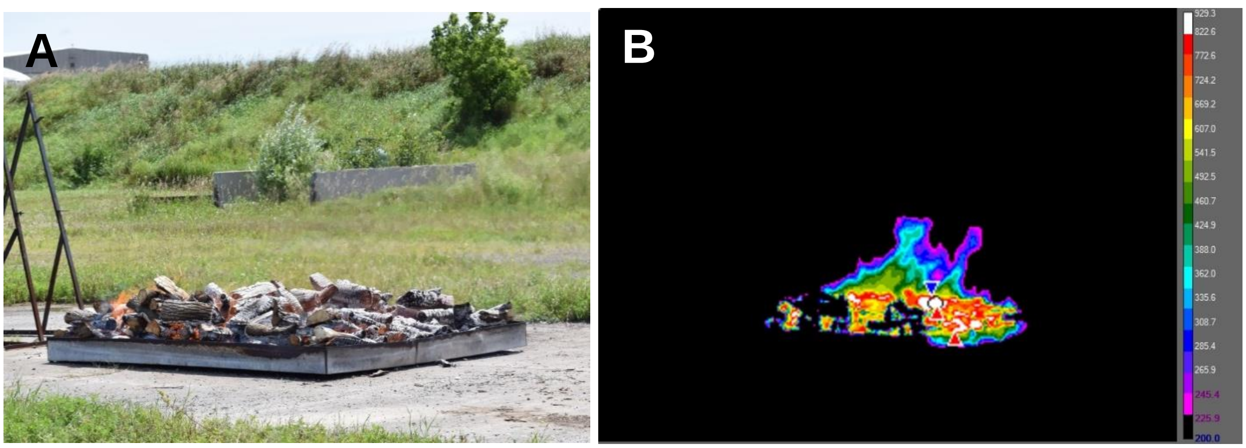

Figure 10: (A) Photo of the fire when POK made its second pass over it at 1525m’ at 12:56 pm. (B) LWIR image over the fire. The hottest part of the fire is in white. The scale is in °C.

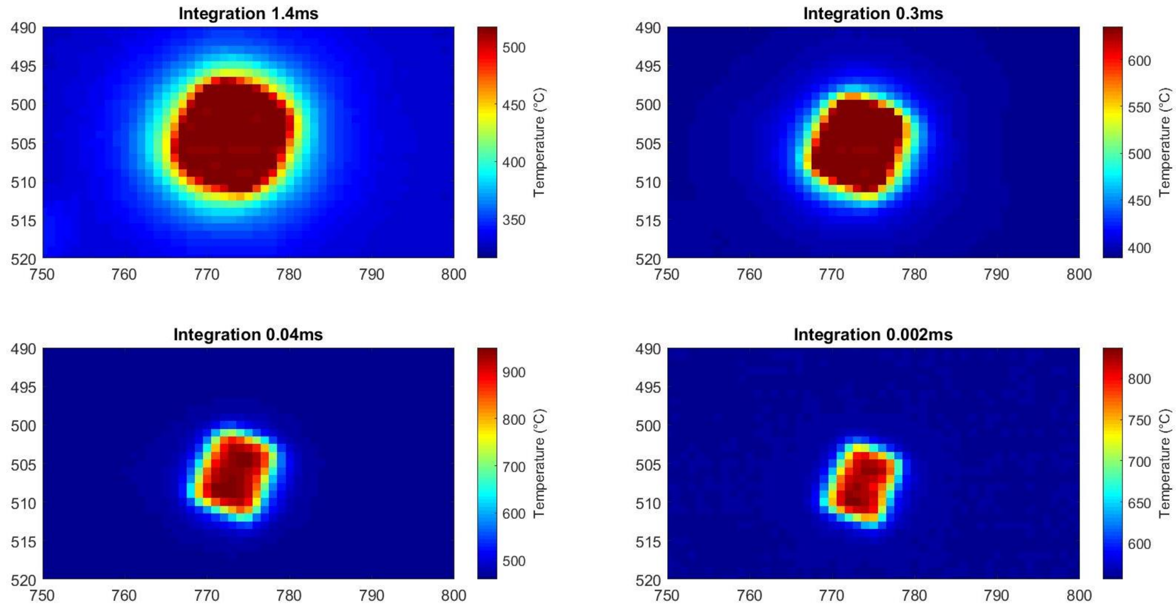

Figure 11. Controlled pan fire at 2745m AGL at each integration time. Localization of the heat source (2mx2m pan) is apparent with a decrease in integration time due to a higher temperature window. These temperature ranges calculated from the airborne data are similar to the temperature ranges measured at the ground by the LWIR camera. Horizontal and vertical axis represent pixels.

5. Airborne Deployment

Between August 1st and August 3rd, 2017, the Wildfires Monitoring project flew NRC's Twin Otter (CPOK) aircraft near Pickle Lake, ON to collect airborne FLIR imagery and complementary data (i.e. HD video and King's College MWIR Xenics Camera equipped with an identical flame filter). The flight plans for the deployment can be found in Appendix 3. In total, six flights (F-01 through F-06) were planned for this deployment, however weather and technical issues resulted in only four flights (F-02 through F-05) being carried out resulting in a total of 63 flight lines (FL-##) collected over these flights. The parameters of the six flights are shown in Table 1. The flight patterns were flown in successive alternating directions, designed to provide some degree of overlapping data at the edge of each flight path. The overlapping data ensures total coverage of the area and also allows for the development of good quality orthorectified images when combined into one large mosaicked image.

Table 1. Summary of thermal imagery acquired over the study areas during the 2017 campaign. Average altitude and ground speed were extracted from the CPOK GPS system.

Flt No.	Date	Time Period	Site	No. of Lines	Start Time (EST)	End Time (EST)	Altitude (m MSL)	Ground Speed (knots)
F-01	Aug. 1	Morning	Cancelled due to technical issues (Nav.)					
F-02	Aug. 2	Afternoon	SLK-17	16	17:54	18:45	2913.6	96.2
F-03	Aug. 2[a]	Night	SLK-37	16[b]	22:20	23:37	2888.2	92.5
F-04	Aug. 3	Morning	SLK-37	16[b]	10:26	11:41	2915.1	93.9
F-05	Aug. 3	Afternoon	SLK-37	15	16:54	18:00	2269.5	92.6
F-06	Aug. 3	Evening	Cancelled due to clouds					

[a] UTC = Local (EST) +5

[b] Eight flight lines acquired twice.

Two naturally occurring wildfires within the Sioux Lookout (SLK) district were selected for data collection, SLK-17 and SLK-37 (Figure 12). Data was originally collected over SLK-17 but then after discussion on site, it was decided that the SLK-37 wildfire would be a better option based on fire characteristics (Figure 13). The main wildfire area (SLK-37), was selected by NRCan over which 47 of the 63 flight lines were acquired. These 47 flight lines were collected during both daytime and nighttime operations between August 2 and August 3, 2017 (Appendix 2). Taking into account the dynamic nature of a fire, the flight lines were planned according to the information provided by the reported fire parameters on the ground. In order to cover the full extent of the fire over SLK-37, 8 flight lines were preplanned and collected twice, once during flights F-03 and once during F-04. Of these 8 flight lines, 5 were identified as optimal for data analysis. The total area covered by these five flight lines (FL-02 to FL-06) and their overlapping area are shown in Figure 14.

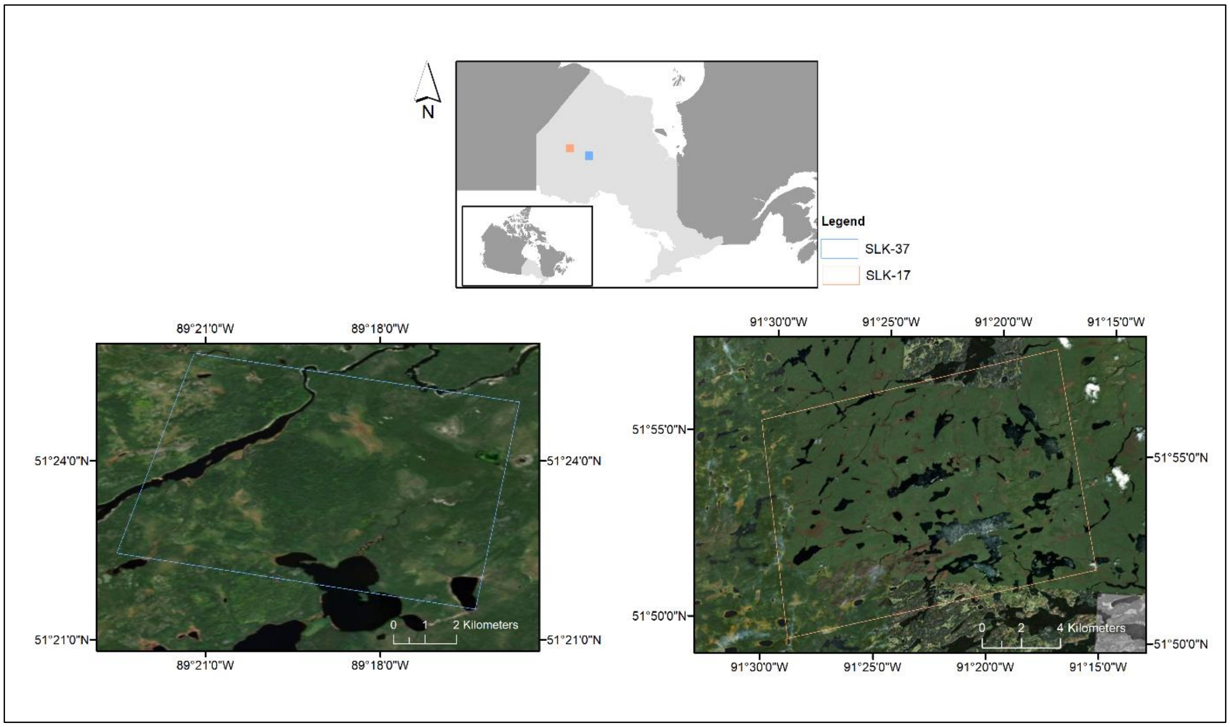

Figure 12. Locations of the two study sites, SLK-17 (blue box) and SLK-37 (orange box), in Northern Ontario where BOB fires were reported and flight data collected. Study area polygons overlaid GeoEye imagery (Source for baseline satellite imagery: ESRI, Digital Globe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community).

Figure 13. Photograph over SLK-37 at 11:27am local time on August 3, 2017.

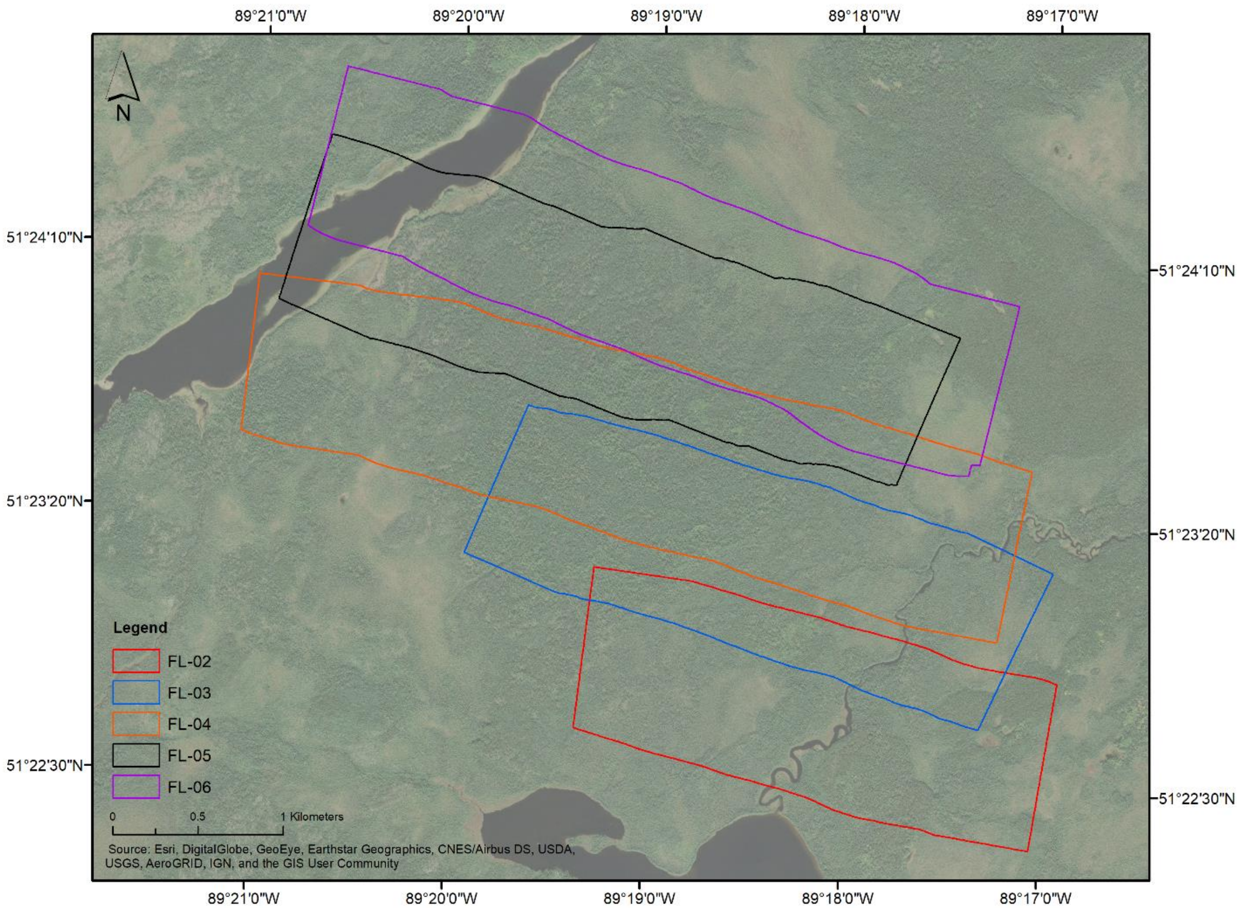

Figure 14. Boundaries of the five flight lines (FL-02 to FL-06) acquired during flight F-03. Their overlapping areas can be seen and are used for geocorrection. These flight lines were selected as they had both fire present and notable points of interest in the imagery, making them appropriate for geocorrection and georeferencing.

6. Airborne Data Processing and Discussion

a. Image geocorrection

Image geocorrection refers to the process by which a raw image is corrected from its native system (e.g. aircraft image, roll, pitch, yaw motions) to a Earth-based coordinate system that is well known (e.g. UTM in this case). In typical applications, the data obtained from the INS is applied to the image in order to transform each native image pixel into a pixel that is representative of the area on the Earth that was imaged.

Operation of the FLIR SC8300 onboard the Twin Otter can be described to include three separate systems. First, the SC8300 collects image frames (784 x 1344) at a sample rate of 30 Hz, and is GPS time tagged by the IRIG Time B system that is fed from the Twin Otter. The second system is the Databoss, which is used for secondary inspection in real-time of the FLIR SC8300 data. The FLIR recording system has the limitation of displaying imagery in real time on the laptop while recording, resulting in dropped frames. The Databoss records a subset of the FLIR imagery (480 x 640) at 30 Hz, as well as real-time GPS information (such as GPS time, latitude, longitude, and heading) at 1 Hz from the aircraft. Finally, the Twin Otter data acquisition system (DAS) collects raw IMU data at 100 Hz and GPS data at 1 Hz.

One end-goal for the data collection was to produce geocorrected imagery of the FLIR SC8300 airborne imagery. Therefore the processing would follow as such: the Twin Otter raw GPS is processed using a nearby GPS base station to arrive at differential GPS data, and this is combined with the raw IMU data in a Kalman filter. This process outputs a combined GPS/IMU solution at 100 Hz which is then associated with the GPS-time tagged FLIR imagery, and each pixel is given an approximate GPS location. This process can be seen in the flowchart below (Figure 15).

Unfortunately, there were two separate points of failure during data acquisition: the FLIR never received proper timing information from the IRIG Time B and the Twin Otter's IMU failed to record at the correct frequency. This meant that there was no GPS timing information to associate the FLIR imagery with actual GPS information, and that no high-resolution combined solution could be calculated. To get around these issues, a new methodology was developed to associate imagery in the Databoss with the FLIR imagery, and find the GPS time at this point (Figure 16). Then this time was aligned with the GPS time of the differentially-calculated GPS information from the Twin Otter. With this initial reference time identified, every 30th frame was assigned with the next 1 Hz GPS measurement. Unfortunately no roll or yaw information was collected. As such, an iterative process of frame registration and gridding was applied within Matlab to account for the platform motion. This modified geocorrection method was applied to flight lines FL-02 through FL-06 from flight F-03 to test the method's resolution. For example, this modified geocorrection method resulted in a RMSE ranging between 100.63 and 304.74 m with an average RMSE of 233.86 m for FL-04 collected on August 3, 2017 over the SLK-37 site.

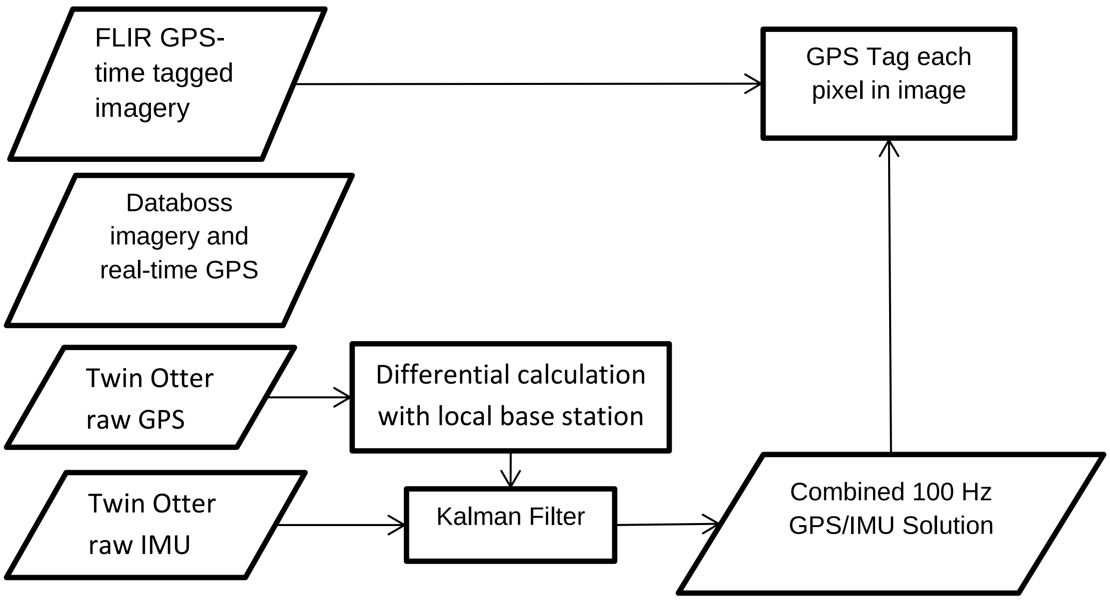

Figure 15. A flowchart representation of the data and processing to compute GPS-tagged pixels for the FLIR imagery.

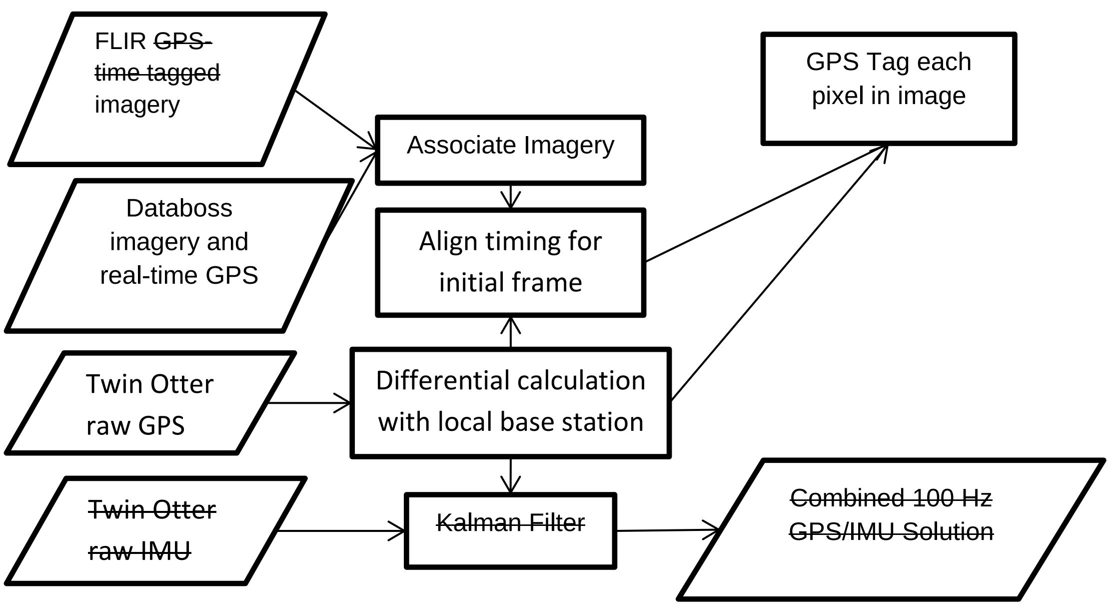

Figure 16. A flowchart representation of the adjusted data and processing to compute GPS-tagged pixels for the FLIR imagery. Strikethrough wording shows points of failure and subsequent incomplete processes.

b. Geocorrection Assessment and Georeferencing

The geocorrection solution required further improvements to reduce the geolocation error to a more acceptable threshold for comparison to mid-resolution satellite sensors (≤ 30-300 m). A georeferencing methodology was developed using GeoEye satellite imagery available in the software kits ArcGIS 10.6 (Environmental Systems Research Institute, Redlands, California) and ENVI 5.5 (Exelis Visual Information Solutions, Boulder, Colorado) to decrease the geolocation error of the geocorrected FLIR imagery (Figure 17). Geocorrection data (X and Y coordinates) and FLIR data in counts (Z dimension) were exported from MATLAB and a geocorrected FLIR imagery was built in ENVI using *the Georeferencing from IGM* tool. An Input Geometry (IGM) file contains the map information of the image in bands for each pixel: one for the x coordinate (i.e. longitude or easting) and one for y coordinate (i.e. latitude or northing). To improve the geolocation error the *Georeferencing Image to Map* tool in ENVI was used where the image is the geocorrected FLIR flight line and the Map is represented by the GeoEye satellite imagery available in ArcMap (see Figure 18). To facilitate the selection of ground control points (GCPs) a point grid of 50 m by 50 m over the study area was created over the GeoEye imagery (available within ArcGIS) for the georeferencing process. The first GCP was selected over a recognizable area, such as a river bed, the rest of the points were selected automatically at different distances from the initial point. To reduce errors, multiple locations were selected, such as image corners, and were widely scatted throughout the image. Once the best GCPs were established, the FLIR imagery was georeferenced with an assigned UTM Zone 16 N, WGS84 coordinate system and a pixel size of 1 m. Each processed integration time (i.e. 1.4ms, 0.3 ms, 0.04ms and 0.0021ms) was georeferenced for all the processed flight lines. A standalone detailed description of this process will be completed in a separate peer-reviewed document.

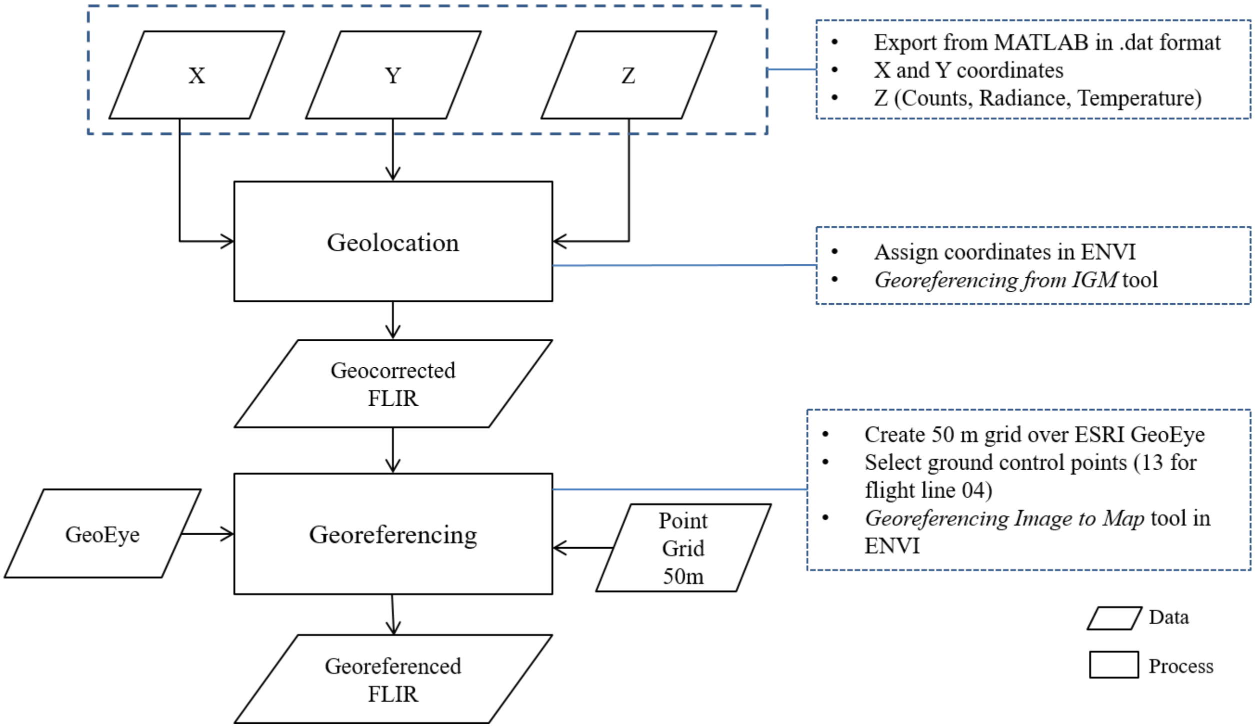

Figure 17. Workflow displaying the georeferencing methodology developed to improve the geolocation error of the acquired FLIR imagery.

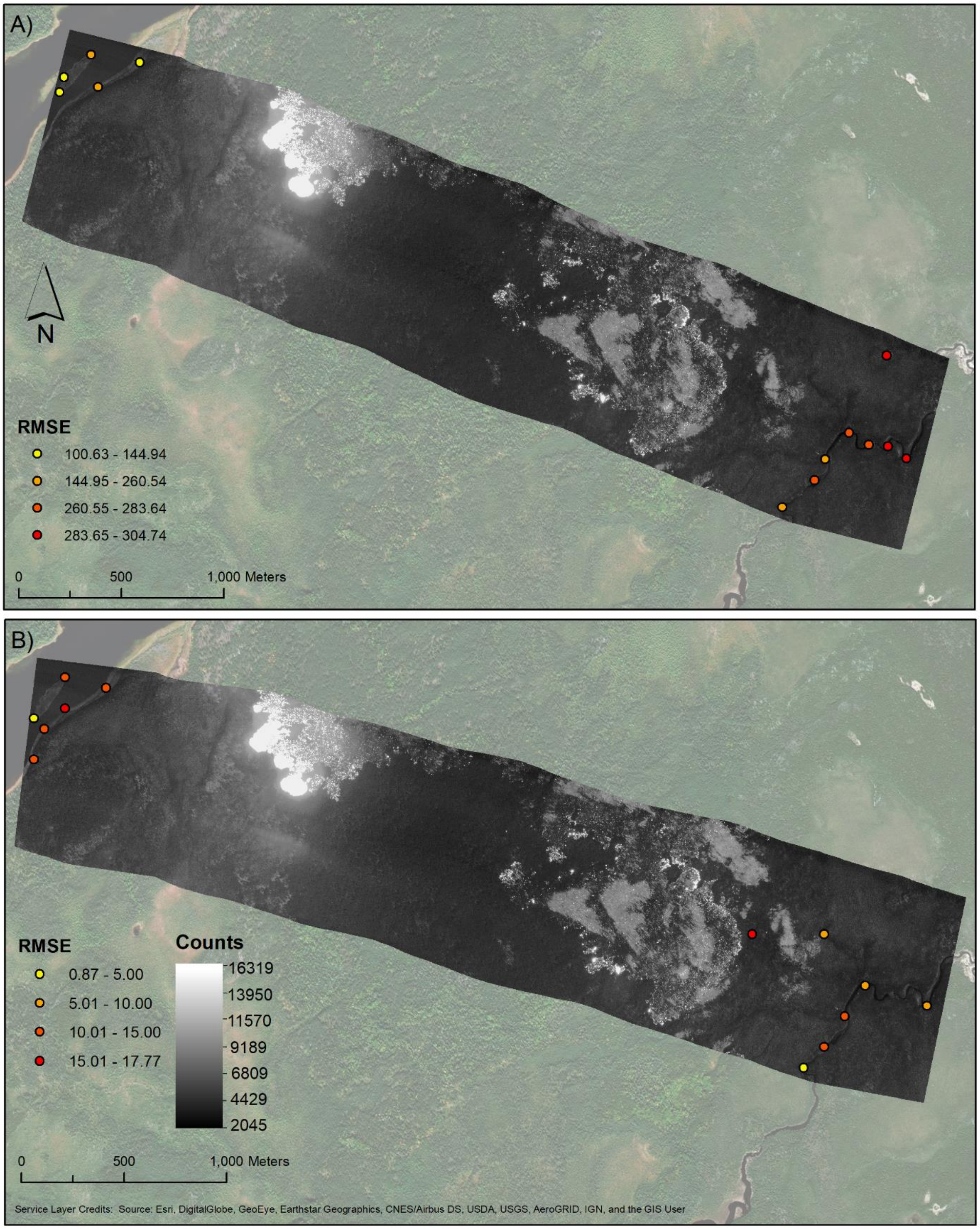

Figure 18. Example of RMSE error of (A) before and (B) after the georeferencing process of FLIR imagery flight line FL-04 acquired during flight F-03 on August 3, 2017, over the SLK-37 site. RMSE errors displayed on greyscale FLIR imagery (IT 1.4ms) and ESRI baseline map.

As discussed, the preliminary geocorrection was found to have a RMSE ranging between 100.63 and 304.74 m with an average RMSE of 233.86 m for FL-04 collected on August 3, 2017 over the SLK-37 site (Figure 18A). Following the secondary geocorrection process, the geolocation RMSE was reduced to an average of 10.66 m with values ranging between 0.87 m and 17.77 m for the same flight line (Figure 18B). Table 2 shows the RMSE and number of GCPs for each of the processed flight lines collected during F-03 on August 3, 2017. The RMSE ranges between 7.84 m for FL-02 IT of 1.4ms and 17.44 for FL-05 IT 0.04ms. In order to assess the initial geocorrection, GCPs were selected and compared between registered FLIR coordinates and GeoEye imagery.

Table 2. Reported RMSE (m) of ground control points (GCPs) for data acquired during flight F-03 on August 3, 2013 over the SLK-37 site.

Flight Line	IT (ms)	GCPs	RMSE (m)
FL-02	1.4	10	7.84
	0.3	10	7.84
	0.04	9	8.73
FL-03	1.4	9	14.28
	0.3	9	14.28
	0.04	9	14.93
FL-04	1.4	13	11.76
	0.3	13	11.76
	0.04	12	12.58
	0.0021	12	12.39
FL-05	1.4	10	16.65
	0.3	10	16.65
	0.04	12	17.44
	0.0021	12	17.33
FL-06	1.4	10	13.84
	0.3	10	13.84
	0.04	12	14.64
	0.0021	12	14.62

c. Counts, Radiance and Temperature products

Based on the blackbody bench experiment in Section 1, conversion from raw counts to temperature and radiance were obtained for the different integrations times used in this project (i.e. 1.4 ms, 0.3 ms, 0.04 ms, and 0.0021 ms). Figure 19 shows an example of calculated counts, radiance (W/m2/sr/um) and temperature (K) values for all acquired integrations times of SLK-37 along FL-04 collected during flight F-01. All pixels with negative radiance values were classified as 0.

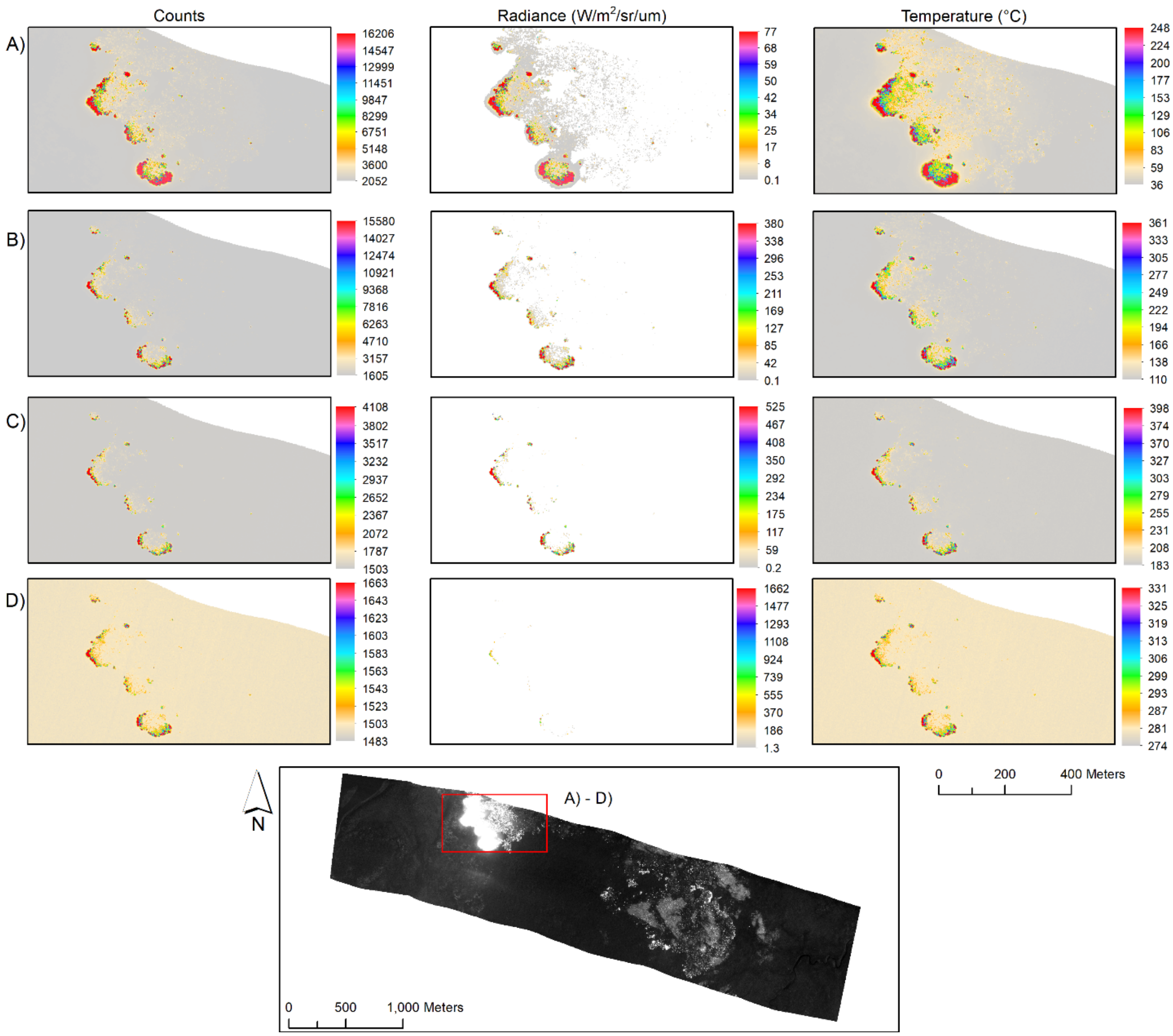

Figure 19. Example of calculated counts, radiance (W/m^2/sr/µm) and temperature (°C) values over SLK-37 fire from FL-04 collected during F-01 on August 3, 2017 for all acquired integrations times: (A) 1.4 ms, (B) 0.3 ms, (C) 0.04 ms, and (D) 0.0021 ms.

7. Comparison with Satellite Observations

The initial plan was to compare the airborne infrared imagery to coincident satellite imagery to complete a multiscale analysis, specifically the Sentinel-3 SLSTR, which suffered a protective shutdown during the flight campaign (Appendix 1). Although the main reason for the Sentinel-3 onboard error is ultimately unknown, the Sentinel-3 suffered this error as it passed through the South Atlantic Anomaly, an area of increased radiation due to increased proximity to Earth's surface. Satellites are vulnerable in this region to increased radiation effects and in the event of a magnetic storm, the radiation can increase since the Van Allen radiation belt is composed of solar wind particles. On July 30, 2017, there was an increase in the geomagnetic field as measured by Canada's Magnetic Observatory Network as shown in Figure 20, by Fort Churchill Station, located within the Auroral Zone.

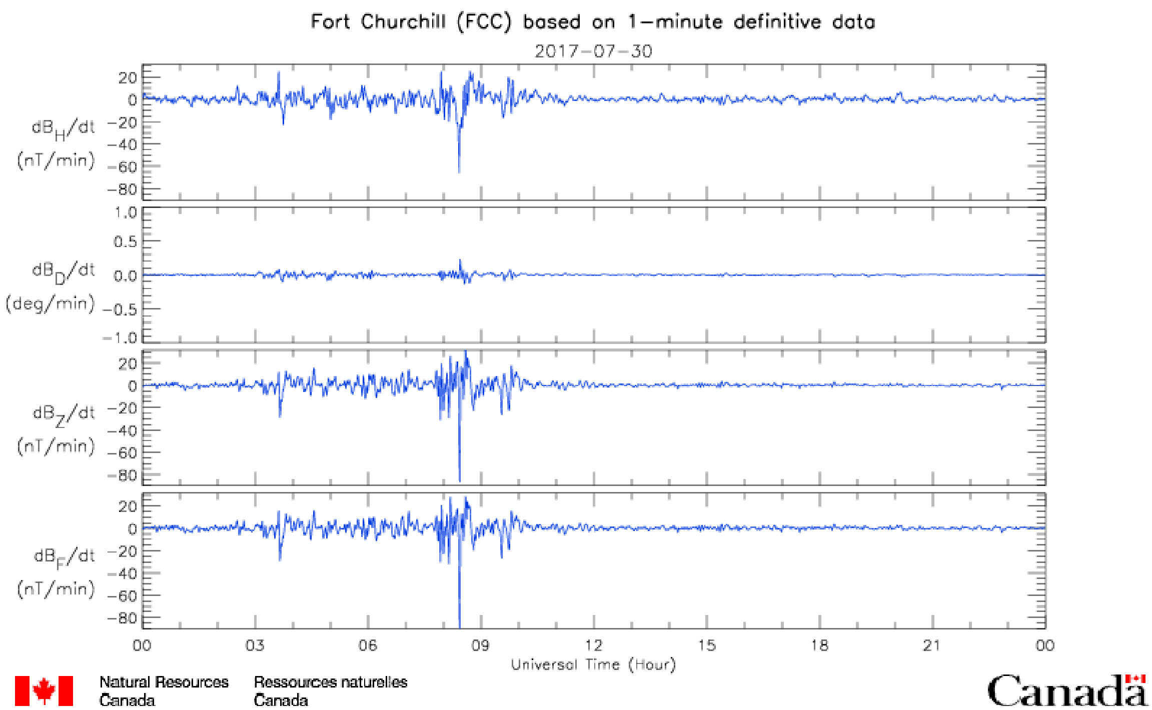

Figure 20. The change in ambient magnetic field (B) (nanoTesla/min) along the horizontal (dB_H/dt) component, the declination (dB_D/dt), vertical (dB_Z/dt) component and the Total Field (dB_F/dt). Fort Churchill (FCC) station was selected from Canada Magnetic Observatory Network as it is located within the Auroral Zone and will display larger variations due to geomagnetic storms.

8. Conclusion

A preliminary infrared calibration method was carried out through the comparison of measured temperature of a blackbody source between three commercially available FLIR, the SC8303, SC6700, and T62101 infrared imagers. Four integration times were identified through this process that would be best suited for the anticipated temperature ranges to be measured over a naturally occurring fire. A shakedown over a controlled burn and a total of 63 flight lines were carried out over naturally occurring fires in Northern Ontario in August 2017 with imagery acquired by the NRC FLIR SC8300 MWIR imager.

Although the INS onboard the Twin Otter failed and no position or aircraft attitude information was collected, we were able to devise a methodology to geocorrect and geolocate the FLIR imagery through a coarse- and fine-grained iterative process. As shown through the final figures, the RMSE of the final imagery was on average 10.66 m, with values ranging between 0.87 m and 17.77 m for the same flight line through this process. This allowed for the production of preliminary infrared maps, including counts, radiance, and temperature. The modified geocorrection method may be applied to any imagery that has at least some positional information available. Moving forward, calculated fire products for SLK-37 may be calculated from the geocorrected airborne imagery and investigation into multiscale analysis with other available satellites (e.g. GOES) at the time of data collection.

Appendix 1. Sentinel-3 failure report

European Commission EUMETSAT esa European Space Agency

sentinel-3

→ A BIGGER PICTURE FOR COPERNICUS

MISSION STATUS : 7 September 2017

OVERALL MISSION

- The overall status of the spacecraft is nominal, with all subsystem performing nominally.
- All instruments, including OLCI, SRAL, SLSTR and MWR, are switched on and performing as expected.
- The Flight Operations Segment (FOS) for Routine Operations is operating nominally.
- The Payload Data Ground Segment (PDGS) for Land and Marine are operating as expected in the final stages of the mission ramp-up phase, with full operational capacity achieved on 5th July, which will be formally confirmed at the S3A Routine Operations Readiness Review on 16 October.
- The SLSTR instrument experienced a computer double bit-error on 30 July whilst passing through the South Atlantic Anomaly. As a result the instrument performed a safe, protective shutdown. The instrument decontamination started on 31 July and the instrument returned to nominal mode on 6 August. IR channel outage lasted from 14:33 on 30/7 to 11:04 on 6/8 and VIS channel outage from 15:50 on 31/7 to 08:39 on 4/8
- The orbit phasing between S3A and S3B has been confirmed to shift from 180 to 140 degree, as agreed for implementation by the EC in December 2016, implementation of this change is ongoing in the Ground Segment.
- ESA and EUMETSAT have jointly finalised the assessment and reached a technical agreement for the implementation of a Tandem phase, i.e. flying Sentinel-3B around 30 seconds apart from Sentinel-3A during the Sentinel-3B commissioning phase. The Tandem phase is planned to last 4-5 months with two drift phases of up to 6 weeks, one before and one after the Tandem period. The final implementation has been agreed with the Commission and activities have now started.

MISSION MANAGEMENT

- The Sentinel-3A mission has now reached the full operational capacity.
- The joint ESA-EUMETSAT mission management activities continue nominally.

DATA AVAILABILITY AND ACCESSS

- All Level 1 core data products have been released.
- OLCI and SLSTR Level 2 core data products over land and ocean were released to all users on 5 July 2017 (note: SRAL level 2 core data products over land and ocean have been released already at the end of 2016).
- Since June 2017 sample products for the Level 2 synergy product are available to expert users, with an official release being planned for autumn 2017
- The definition and implementation of the two new core data products, as requested by the European Commission, namely the Aerosol Optical Depth (AOD) and Fire Radiative Power (FRP) is on-going with sample products being available towards the end of 2017/early 2018 and an official release being planned shortly thereafter.
- The reprocessing of the SRAL data, including the commissioning phase, is completed and the data are now in the process of being made available to all users.
- A further SRAL reprocessing and the reprocessing of the OLCI and SLSTR data, including the commissioning phase, is planned for end of 2017/early 2018.

USER INTERACTION

- The next Sentinel-3 Quality Working Groups will take place for
  - SLSTR: winter 2017/2018 TBC
  - OLCI: autumn 2017 TBC
  - Altimetry: 14 November 2017
- The Joint ESA-EUMETSAT Routine Operations Readiness Review (RORR) is foreseen for 16 October 2017.

OUTLOOK

- Formalisation of Sentinel-3A full operations at the RORR in October 2017.

Report prepared by the ESA and EUMETSAT Sentinel-3 Operations Team

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Appendix 2. Flight lines summary

Table A3. Central latitude and longitude of the flight lines acquired during the 2017 Pickle Lake campaign.

Site	Flight	Flight Line	Latitude (deg.)	Longitude (deg.)
SLK-17	F-02	FL-01	51.8725	-91.3642
High Altitude		FL-00	51.8663	-91.3678
		FL-0x	51.8619	-91.3656
		FL-0y	51.8574	-91.3634
		FL-02	51.8772	-91.3680
		FL-03	51.8820	-91.3726
		FL-04	51.8862	-91.3786
		FL-05	51.8916	-91.3816
		FL-06	51.8960	-91.3844
		FL-07	51.9011	-91.3862
		FL-08	51.9056	-91.3901
		FL-09	51.9101	-91.3938
		FL-10	51.9147	-91.3971
		FL-11	51.9198	-91.3997
		FL-12	51.9248	-91.1022
		FL-13	51.9297	-91.4045
SLK-37	F-03 & F-04	FL-01	51.3787	-89.3272
High Altitude		FL-02	51.3829	-89.3217
		FL-03	51.3879	-89.3180
		FL-04	51.3926	-89.3186
		FL-05	51.3974	-89.3127
		FL-06	51.1025	-89.3113
		FL-07	51.4083	-89.3119
		FL-08	51.4134	-89.3130
SLK-37	F-05	FL-01	51.3778	-89.3238
Low Altitude		FL-02	51.3804	-89.3223
		FL-03	51.3826	-89.3209
		FL-04	51.3856	-89.3199
		FL-05	51.3878	-89.3190
		FL-06	51.3906	-89.3178
		FL-07	51.3926	-89.3164
		FL-08	51.3954	-89.3153
		FL-09	51.3980	-89.3144
		FL-10	51.4002	-89.3132
		FL-11	51.4026	-89.3120
		FL-12	51.4054	-89.3114
		FL-13	51.4078	-89.3106
		FL-14	51.4104	-89.3093
		FL-15	51.4128	-89.3077

Appendix 3. Wildland Fire Monitoring: Trial Plan

National Research Council Canada | Conseil national de recherches Canada

NRC·CNRC

2017-07-31

Produced for: Trial participants: NRC and NRCan trial teams.

Wildland Fire Monitoring: Trial Plan

July 31, 2017

1. Background

This project involves the implementation of multiple sensor payloads on board a NRC full scale fixed-wing aircraft to monitor wildland burns in Northern Ontario over a period in summer/fall 2017. These burns will either be naturally occurring (Being Observed Burns - BOB) or controlled burn (Prescribed Burn – PB). EO/IR sensors are crucial to identification of the severity of burns and projecting burn vectors. The altitude of flight and the payload would be analogous to UAVs or for satellite calibration/validation measurements. UAVs and satellites play an important role as most fire monitoring is presently conducted by manned aircraft at low altitudes and limit the ability for continuous monitoring. This project will allow for testing a variety of high-resolution Canadian designed payloads that will be validated with specialized monitoring satellites and assessment of capability with unmanned aircrafts.

2. Objectives

Research will be led by NRCan to assess precursory characteristics leading to wildland fire burns and dictate the intensity and longevity of wildland fires. This will first entail geolocating optical broad-band imagery with multi-band hyperspectral imagery and calibration of MWIR imagers with appropriate spectral filters. The consultation, acquisition, and analysis of thermal measurements over the defined wildland fire test sites will be carried out. Testing sites include: NRC-FRL (Ottawa, ON), NRCan Rose Site (Sault Ste. Marie, ON), and BOB/PB burn sites (Northern Ontario). Ultimately, the objective is to assess transitioning remotely-sensed fire monitoring from a large-scale fixed-wing airborne platform to a small high-altitude platform.

Canada

3. General Work Plan

PHASE I: September 2016 through to March 2017

The first phase will be calibrating thermal imagers specific to wildland fire monitoring and test flights over small, controlled burns. The FLIR SC8300 and Xenics thermal cameras with specialized band filters will be installed onboard NRC's Twin Otter.

Milestone 1: due April 31, 2017

- Installation of filter onto NRC FLIR SC8300;
- Bench testing with blackbody calibration source;
- Ground testing of FLIR SC8300 Xenics;
- Geolocation of thermal imagery methodology;
- Project plan for burn testing.

PHASE II: April 2017 through to October 2017

The second phase will be monitoring naturally occurring Being Observed Burns (BOB) in Northern Ontario. The BOB region is near Pickle Lake, Ontario within the Northwestern Ontario region. Data will be collected in coincidence with Sentinel-3 satellite overpasses over the study area each day at a defined time. FLIR SC8300 and Xenics thermal camera with specialized band filters equivalent to that on the Sentinel-3 will be installed onboard NRC's Twin Otter. The altitude of flight will be approximately 10 000' AGL.

Milestone 2: due October 31, 2017

- Test flight over a calibration site (YOW and/or Rose Site);
- Flight testing over BOB* fires and/or PB*
  - *coincident with Sentinel-3 flyovers.

PHASE III: November 2017 through January 2018

The final phase will encompass delivery of all acquired and processed data, along with final report writing.

Milestone 3: due January 31, 2018

- Delivery of all raw and processed flight and ground data acquired to support project research activity;
- Final report summarizing geolocating and fire intensity analysis methodologies.

4. Deliverables

- FLIR raw imagery;
- Xenics ONCA raw imagery;
- A short report, summarizing geolocating and fire intensity analysis methodologies.

5. NRC Responsibilities

NRC will be responsible for installing the NRCan filters onto NRC FLIR SC8300. Preliminary objectives will be to calibrate the sensors to the appropriate research environment. This entails fastening a filter to NRC's FLIR SC8300 MWIR imager. The MWIR imager will undergo calibration with NRC's approved blackbody source. It is important to stress that the operating temperatures for wildland fires can be exceedingly high, on the order of >800°C. The internal software of the imager will need to operate at minimum with superframing to minimize saturation of the image.

The FLIR SC8300 currently does not collect any positional information and geolocation is conducted in post-processing at a high level. Alternative methods are identified to rectify this issue, including an IRIG box to GPS time all imagery and installation with a trigger cable to allow post-acquisition time alignment.

Lab testing to validate sensors will be conducted at the NRCan Rose Test Site and/or NRC-FRL. If work is conducted at the NRCan Rose Site, NRC's calibrated FLIR SC8300 imager would be positioned in conjunction with NRCan's FLIR SC6700 imager above a small controlled burn. This controlled burn would approximate the size of a tennis court at the Rose Test Site and smaller dimensions at the NRC-FLIR test site. The FLIR SC8300 has a higher resolution; however for the purpose of cross-validation, both will be operated at the same resolution.

All participants (NRC, NRCan, KC) will work together to design the parameters of the flight test to ensure that the necessary data is collected in a safe and efficient manner. All raw and pre-processed flight and ground data acquired will be circulated to support project research activity. A report, summarizing geolocating and fire intensity analysis methodologies will be delivered at the end of the project.

6. Experimental, monitoring, and support equipment

- *NRC*
  - FLIR SC8300 w/ laptop
  - Visual spectrum camera
  - Twin Otter

- *King's College*
  - Xenics MWIR Camera w/ laptop
  - SLSTR 3.74um filters for Xenics and FLIR cameras

Sentinel-3 Satellite

Sentinel-3 measures systematically Earth's oceans, land, ice and atmosphere to monitor and understand large-scale global dynamics (Figure 1). It will provide essential information in near-real time for ocean and weather forecasting. The Sea and Land Surface Temperature Radiometer (SLSTR) measures global sea- and land-surface temperatures every day to an accuracy of > 0.3 K. Both the FLIR SC8300 and Xenics are equipped with filters at an identical band of 3.74um.

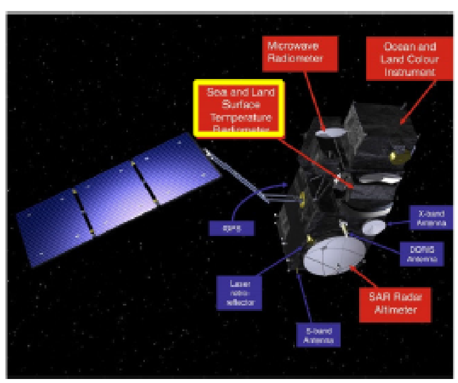

Figure 1. The Sentinel-3 satellite with instrument payload identified. The SLSTR is the instrument (yellow box) to which the FLIR SC8300 and Xenics ONCA will be compared to.

FLIR SC8300 Mid-Wave Infrared (MWIR)

The principal instrument for flight testing is FLIR (Forward Looking Infrared) MWIR (Figure 2). NRC's SC8300 has a higher resolution and will be the camera configured with a permanent 3.74um flame filter equivalent to the SLSTR filter on Sentinel-3 to focus on four temperature bands for the purpose of superframing:

0°C – 150°C
140°C – 350°C
340°C – 750°C
740°C – 1000°C

	SC8300	SC6700
Spectral Range	3.0-5.0µm	3.0-5.0µm
Detector Pitch	14µm	25µm
Frame Rate (full window)	125Hz	125Hz
Resolution	1344x784	640x512
Standard Temperature Range	-20°C to 350°C ± 2°C or 2% of reading	-20°C to 350°C ± 2°C or 2% of reading
Operating Temperature Range	-40°C to 50°C	-40°C to 50°C
Weight w/o lens	4.5kg	4.5kg
Power	24VDC	24VDC

Table 1. Specifications of the SC8300 to SC6700 FLIR Infrared MWIR cameras. The SC8300 is compared to the SC6700 as the latter is what has been operated in the past.

Figure 2. NRC's FLIRSC8303 installed in the nose of NRC's Twin Otter POK.

Xenics Onca MWIR Camera

The Xenics MWIR camera (Figure 3) will be used as redundancy for the FLIR MWIR camera with two filters (3.74um and Neutral Denisty+3.74um) located on filter wheel slots D and E. It will be installed over the belly port along with a visual spectrum camera. For operation requirements please refer to the Xenics operation manual and project specific operations by K. Hyll.

Note: Both filters do not have the same focal length and therefore the Xenics should be set to slot D infinity.

Figure 3. King's College Xenics Onca MWIR camera.

NRC Twin Otter

NRC's DHC-6 Twin Otter (CPOK) is a utility, dual engine aircraft with short takeoff and landing capabilities (Figure 4).

Figure 4. NRC's Twin Otter POK. Location of the Xenics MWIR within belly port indicated with red square; FLIR 8303 indicated with red circle.

7. Flight Testing

Test 1: YOW Small Scale Burn and Shakedown – July 28, 2017

Complete a local shakedown flight to test the spectral range, filter and resolution of the MWIR imagers installed onboard POK. The burn location is selected in proximity of NRC FRL as YOW (Figure 5). Permission and support will be provided by YOW Fire Department. The pan will be 2m x 2m and the combustibles will be comprised of 1 face cord of wood, pine needles, branches, and fuel (Figure 6). The combustibles will be provided by NRC and NRCan. POK will fly at multiple altitudes between 1000ft AGL up to 10 000ft AGL at an average speed of 80kn. Heading and altitude will be dictated by YOW airport due to proximity to active runway 14/32. The main objective is to capture video of the small scale burn by the infrared imagers.

Figure 5. Pan located at YOW airport (red circle) in proximity to active runway 14/32 (45.315295° -75.656227°)

Figure 6. Pan located at YOW airport that can be used to contain the combustibles. The fire truck would remain on standby.

Test 2: Northern Ontario B.O.B – July 31 – August 5, 2017

i. OVERVIEW

The main test will be approximately four days to conduct multiple passes over the flame front of a BOB fire in the Northwest Region of Ontario (Figure 6). The BOB burn selection will largely be controlled by accessibility. POK will fly over the flame front repeatedly each day at a maximum altitude of 10 000ft AGL in conjunction with Sentinel-3 pass overs. The exact time to be provided by King's College based on Latitude and Longitude of the flame front.

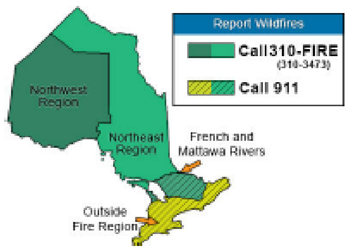

Figure 6. Map of Ontario showing the division of fire monitoring by the Ministry of Natural Resources. This deployment will operate over fires in the Northwest Region.

As of July 25, 2017, there are a number of BOB fires in Northern Ontario, with the area of interest being the Northwest Region. It is determined that deployment will operate out of Pickle Lake, ON (YPL) with Fort Hope/Eabamet Lake (YFH). There are multiple BOB fires within 200km radius of YPL, including NIP009 which is >13000ha, which is the main target (Table 2, Figures 7-8). The Sentinel-3 overpasses occur around 17h00 UTC (Table 3).

NAME	SIZE (ha)	DISTRICT	STATUS	CAUSE	DATE STARTED
NIP009	13047	Nipigon	Not Under Control	Lightning	July 1, 2017 16:37
NIP012	566	Nipigon	Being Observed	Lightning	July 6, 2017 16:43
NIP018	15	Nipigon	Being Observed		July 22, 2017 16:14
NIP011	91.5	Nipigon	Being Observed	Lightning	July 6, 2017 16:25
SLK017	5	Sioux Lookout	Being Observed	Lightning	July 24, 2017 18:18

Table 2. Active fires within the Pickle Lake region as of July 25, 2017. The main target is NIP009 highlighted.

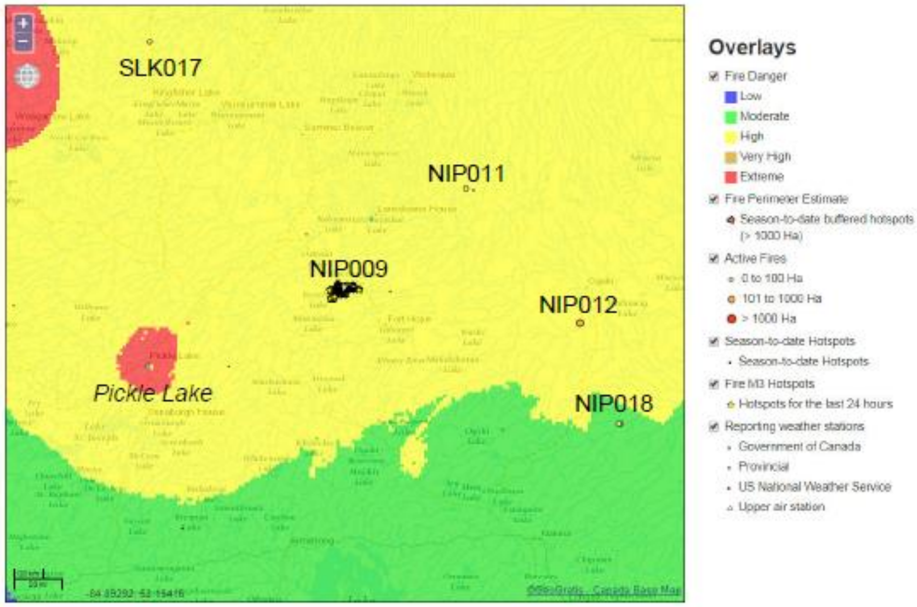

Figure 7. Canadian Wildland Fire Information System with Fire Danger, Fire Perimeter Estimate, Active Fires, Hotspots, and Weather Stations shown. The active fires as of July 25 in proximity of Pickle Lake are labelled with additional information in Table 2.

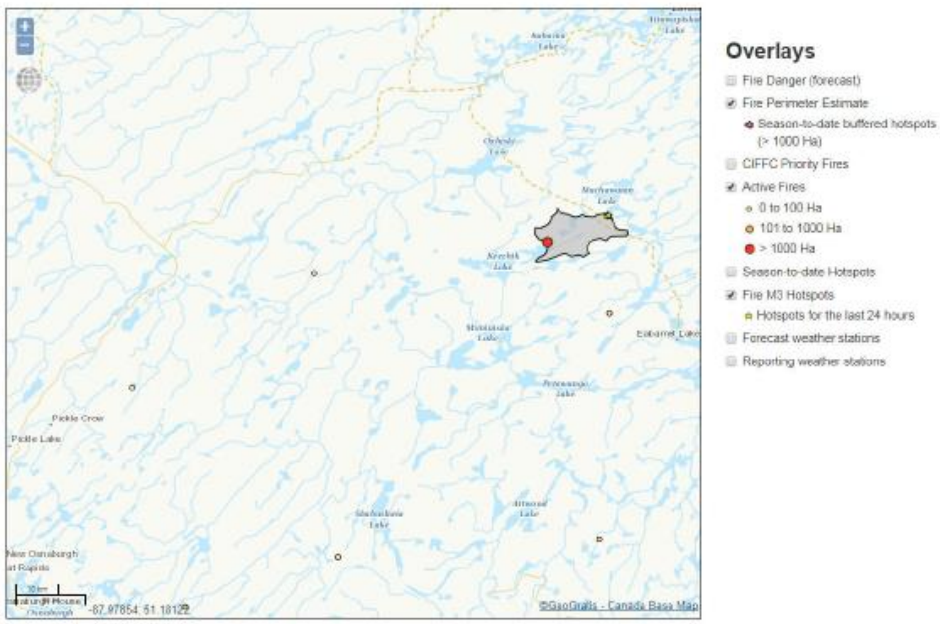

Figure 8. Canadian Wildland Fire Information System with Fire Perimeter Estimate, Active Fires, and Hotspot with focus on the region between Pickle Lake and Fort Hope/Eabamet Lake. NIP009 is approximately 13000ha, 15km radius, and located at 51.78°N -88.38°W.

ii. SATELLITE OVERPASSES

Sentinel-3 satellite overpasses are the main objective for data collection and therefore flights are to be coordinated with the intended passes over the flame front (Figure 9).

DATE	OVERPASS TIME (UTC)	OVERPASS TIME (LOCAL UTC -5)	OVERPASS TIME (LOCAL UTC -4)
AUGUST 1, 2017	16H45	12H45	11H45
AUGUST 2, 2017	16H19	12H19	11H19
AUGUST 3, 2017	TBD	TBD	TBD
AUGUST 4, 2017	TBD	TBD	TBD

Figure 9. The calculated Sentinel-3 overpass times at 51.78°N -88.38°W from the European Space Agency. Pickle Lake is located on the far eastern edge of the Central Time Zone (-4 UTC) and as such operators should follow UTC time in flight planning.

King's College also delivers GOES FRP PRODUCT twice every hour for Canada and the US. The imaging times for the Pickle Lake area as the flowing UTC times:

- 17mins past each hour
- 47mins past each hour.

If there is a cloud free window and the aircraft is in proximity of the fire, it would be beneficial to re-image the fire at the next GOES Imaging time (or at least the flame front part). GOES has substantially larger pixels that SLSTR so the flaming area would need to be around 2000m^2 minimum to be detected by a GOES pixel, as opposed to the minimum of only 100 m^2 for SLSTR.

iii. NAVIGATION SYNCHRONIZATION

As there are multiple kits on board, it is recommended to complete at least one flight to resolve possible navigation synchronisation problems. As a good starting point it is useful to use the opposite flight direction flight lines to solve for roll and pitch. As a roll error will manifest itself as an across track shift and a pitch error as an along track shift. Be wary though that heading errors will also appear as a mixture of across and along track shifts. Heading errors are best identified using parallel lines with a 50% along track overlap. This is achieved with the following:

I. **Opposite and overlapping:** e.g. 1 line North and 1 line South
II. **Parallel and overlapping:** e.g. 2 lines East
III. **Third direction**: e.g. NorthEast

Ensure that during all passes that all equipment is synced to the same IRIG-B GPS receiver timing, ideally in UTC.

The field of view for the Xenics with the 13 mm lens should be 40° x 30°. So a maximum off nadir viewing angle of 20° either side of image center. With the long image axis parallel to the flight direction, at 9000' AGL (3000 m) the Xenics image width on the ground should be 2.2 km (it would be 1.6 km if the short image axis is parallel to the flight direction).

The field of view for the FLIRSC8300 with the 50mm lens should be 21.31° x 12.53°. With the long axis parallel to the flight direction, at 9000' AGL the FLIR SC8300 image width on the ground should be 1.1 km (it would be 650m if the short image axis is parallel to the flight direction).

iv. FLIGHT REQUIREMENTS

FLIGHT #	DATE	TIME (UTC)	GROUND SPEED (kn)	ALTITUDE (ft AGL)	OBJECTIVE	PERSONNEL
001	AUG 1	17h00*	80	~9500	Navigation correction Burn overpass w/ Sentinel-3	P Kissman (NRC) P Arroyo (NRC) J Johnston (NRCan) R Mariotti (NoT)**
002	AUG 2	17h00*	80	~9500	Burn overpass w/ Sentinel-3	P Kissman (NRC) P Arroyo (NRC) J Johnston (NRCan) R Mariotti (NoT)**
003	AUG 3	17h00*	80	~9500	Burn overpass w/ Sentinel-3	P Kissman (NRC) P Arroyo (NRC) J Johnston (NRCan) R Mariotti (NoT)**
004	AUG 4	17h00*	80	~9500	Burn overpass w/ Sentinel-3	P Kissman (NRC) P Arroyo (NRC) J Johnston (NRCan) R Mariotti (NoT)**

*Synced with Sentinel-3 overpass. Timing confirmed by King's College once Latitude and Longitude of flame front provided

**TBD if he will be on each flight

v. DATA COLLECTION / BACK UP

- At end of each day, data is to be back upped. Data includes:
  - FLIR SC8300 video
  - DATABOSS video and GPS
  - Xenics video
  - HD camera video
- Back up locations:
  - King's College FTP
    - FTP = 137.73.142.19
    - user = volcano
    - pass = grainofsand
    - directory = "Wooster"
    - CanadaFlights
  - NRC My Book 4Tb Drive

vi. ONSITE REQUIREMENTS

- NRC to contact Aircraft Management Officer (AMO) daily with details (807) 937 7218;
- Aviation, Forest Fire and Emergency Services (AFFES) is not responsible for flight watch, however, they will monitor 126.7 & 122.8;
- Fort Hope/Eabamet Lake (YFH) is a backup to Pickle Lake (YPL) as AFFES are operating ignition machines out of this site and therefore jet-a is available, however it is not a fully operational airport;
- Crew is staying at the Winston hotel and J. Johnston will shuttle them around.

Optional Testing: Rose Experimental Burn Station

60 Ha of forest in Rose township north of Thessalon, Ontario originally used for spray trails by CFS in the 1980s (Figure 9A). Jack and Red Pine forest with large clearing in the NE corner of the plot. NRCan's Rose Site is composed of 30m scaffold tower, burning pit, lab, and accommodation trailers (Figure 9b).

Burn protocol is ignition by applying a drip torch line across the read of the pad 0.5m into the fuel bed. The fuel bed is 50m x 100m and the combustibles will be comprised of pine needles, branches, and fuel (Figure 9c). Burns are allowed to smoulder until virtually all visible smoke was gone unless the winds are too strong.

Figure 9. Rose Site, Ontario (A) Satellite View (B) Combustible material over controlled area (C) Bird eye view of time lapse of drip line ignition of combustibles.

8. Safety and Risk Management

All NRC and non-NRC participants will complete waivers and undergo an aircraft safety review prior to working and travelling onboard NRC's Twin Otter. While onboard aircraft, participants will wear appropriate field attire and PPE.

Due diligence will be completed to ensure a safe work environment for all project participants and at any time, any participant should raise awareness of any safety concerns. As the aircraft will be in operation of forest fires, safe operation is of the utmost importance and flight maneuvers will be reviewed by the Chief Pilot and Project Lead on site.

9. Contacts

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