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Hyperspectral Data Processing

Final Report

Guillaume Gagné
AEREX Avionics Inc.

Defence Research and Development Canada – Valcartier

Contract Report
DRDC Valcartier CR 2013-035
March 2012

Canada

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AEREX Avionics Inc.

Prepared by:
AEREX Avionics Inc.
324, Saint-Augustin Avenue
Breakeyville (Québec) G0S IEI

Contractor's document number: 2011-92854-1
Contract project manager: Daniel Pomerleau, 4I8-832-1040
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CSA: François Leduc, Defence scientist, 418-844-4000 x4703

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IMPORTANT INFORMATIVE STATEMENTS

The scientific or technical validity of this contract report is entirely the responsibility of the contractor and the contents do not necessarily have the approval or endorsement of the Department of National Defence of Canada.

Abstract

Hyperspectral data were collected for different explosions during the Northern Lights I (2002) and II (2005) trials at DRDC Suffield with the PIRATES imaging system. The AIRIS imaging system measured explosions only in 2005. In this study, intensity-time curves were processed for each event regardless of the atmospheric transmittance. The curves were evaluated for bands 2.04 to 5.26 μm for AIRIS and PIRATES and for each LEGACY band. Transmittance-corrected intensity-time curves for LEGACY bands were analyzed to identify which bands were the best to discriminate the explosion elements (charge, composition, container shape, and container material). Bands S4 and S5 for the short wave infrared detector and bands M4, M5, and M6 for the medium wave infrared detector were the best options to discriminate explosions according to all events. The bands S7 and M4 were considered the best only when AIRIS measurements were considered. The difference between results of both imaging systems is probably due to their different altitude and angle of observation. The conclusions agree with the use of the bands S4, S7, and M5 by LEGACY during the Northern Lights II trial.

This work was conducted in the framework of Public Works and Government Services Canada contract number W7701-092854/001/QCL on behalf of Defence Research and Development Canada –Valcartier. This work was also done in support of a classified project.

Résumé

Des mesures hyperspectrales d'explosions ont été prises avec le système d'imagerie PIRATES lors des essais Northern Lights I (2002) et II (2005) à DRDC Suffield. Le système AIRIS a acquis des mesures uniquement en 2005. Dans ce rapport, la courbe d'intensité en fonction du temps de chaque événement est évaluée en corrigeant ou non l'impact de la transmission de l'atmosphère. Ces courbes sont estimées pour la bande 2.04 à 5.26 μm d'AIRIS et de PIRATES et pour chaque bande du capteur LEGACY. L'analyse des courbes d'intensité évaluées pour chaque bande de LEGACY et corrigées pour la transmission a été réalisée dans le but d'identifier quelles bandes sont les meilleures pour discriminer les caractéristiques de l'explosion (quantité, composition, forme et matériel du contenant). Les bandes S4 et S5 pour le détecteur infrarouge à ondes courtes et les bandes M4, M5 et M6 pour le détecteur infrarouge moyen sont les meilleures pour identifier les caractéristiques des explosions selon tous les événements analysés. Les bandes S7 et M4 sont identifiées les meilleures quand uniquement les données mesurées par AIRIS sont considérées. La différence entre les résultats des deux systèmes est probablement causée par leur altitude et angle d'observation différents. Les conclusions sont en accord avec l'utilisation des bandes S4, S7 et M5 par LEGACY lors de l'essai Northern Lights II.

Les travaux ont été menés dans le cadre du contrat W7701-092854/001/QCL émis par Travaux publiques et service gouvernementaux Canada pour le compte de Recherche et Développement pour la Défense Canada – Valcartier. Ce travail est également mené en support à un projet classifié.

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Executive summary

Hyperspectral Data Processing: Final Report

Guillaume Gagné; DRDC Valcartier CR 2013-035; Defence Research and Development Canada – Valcartier; March 2012.

Introduction or background: Hyperspectral imaging is an active research and development area in the majority of scientific domains. Military uses of this technology are concentrated on surveillance, tracking, and identification. Defence Research & Development Canada (DRDC) Valcartier develops airborne (AIRIS) and terrestrial (PIRATES) imaging systems for these usages. Both systems are based on the same technology.

Results: Hyperspectral data were collected for different explosions during the Northern Lights I (2002) and II (2005) trials at DRDC Suffield with PIRATES imaging system. AIRIS imaging system measured explosion only in 2005. In this report, intensity – time curves are processed for each event considering or not the atmospheric transmittance. These curves are evaluated for bands 2.04 to 5.26 μm for AIRIS and PIRATES and for each LEGACY band. Transmittance corrected intensity – time curves for LEGACY bands are analyzed to identify which bands are the best to discriminate the explosion elements (charge, composition, container shape and container material). This work has been conducted in the framework of Public Works and Government Services Canada contract number W7701-092854/001/QCL on behalf of Defence Research and Development Canada –Valcartier. This work is also done in support of a classified project.

Intensity – time curves were evaluated for all events measured during Northern Lights I and II for the bands 2.04 to 5.26 μm of AIRIS and PIRATES and for each LEGACY bands. Atmospheric transmittance correction was or was not applied to the intensity curves. Curves analysis demonstrated that it is possible to discriminate explosion elements with the use of the LEGACY bands. Bands S4 and S5 for the short wave infrared detector and bands M4, M5, and M6 for the medium wave infrared detector are the best to discriminate explosions according to all events. The bands S7 and M4 are considered the best when only AIRIS measurements are considered. The difference between results of both imaging systems is probably due to their different altitude and angle of observation. The conclusions agree with the use of the band S4, S7 and M5 by LEGACY during the Northern Lights II trial.

Significance: This work demonstrates the usefulness of the LEGACY sensor in the discrimination of explosion elements.

Future plans: More data should be taken in the future to improve the accuracy of the discrimination values. Also, development should be performed to increase LEGACY accuracy in this explosion discrimination domain.

Sommaire

Hyperspectral Data Processing: Final Report

Guillaume Gagné ; DRDC Valcartier CR 2013-035 ; Recherche et développement pour la défense Canada – Valcartier ; mars 2012.

Introduction ou contexte : La recherche et le développement sur l'imagerie hyperspectrale est en essor dans la majorité des domaines. L'utilisation militaire de cette technologie est concentrée sur la surveillance, la poursuite and l'identification. RDDC Valcartier développe des systèmes d'imagerie aéroporté (AIRIS) et terrestre (PIRATES) basées sur les mêmes technologies pour répondre à ces besoins.

Résultats : Des mesures hyperspectrales d'explosions ont été prises avec le système d'imagerie PIRATES lors des essais Northern Lights I (2002) et II (2005) à DRDC Suffield. Le système AIRIS a acquis des mesures uniquement en 2005. Dans ce rapport, la courbe d'intensité en fonction du temps de chaque événement est évaluée en corrigeant ou non l'impact de la transmission de l'atmosphère. Ces courbes sont estimées pour les bandes 2.04 à 5.26 μm d'AIRIS et PIRATES et pour chaque bande du capteur LEGACY. L'analyse des courbes d'intensité évaluées pour chaque bande de LEGACY et corrigées pour la transmission a été réalisée dans le but d'identifier quelles bandes sont les meilleures pour discriminer les caractéristiques de l'explosion (quantité, composition, forme et matériel du contenant). Les travaux ont été menés dans le cadre du contrat W7701-092854/001/QCL émis par Travaux Publique Canada pour le compte de Recherche et Développement pour la Défense Canada – Valcartier. Ce travail est également mené en support à un projet classifié.

Les courbes d'intensité en fonction du temps ont été évaluées pour toutes les mesures prises lors des essais Northern Lights I and II pour les bandes 2.04 à 5.26 μm d'AIRIS et de PIRATES et pour chaque bande de LEGACY. Une correction atmosphérique sur la transmission a été ou non appliqué sur les courbes d'intensité. L'analyse des courbes démontre qu'il est possible de discriminer les caractéristiques de l'explosion en utilisant uniquement les bandes de LEGACY. Les bandes S4 et S5 pour le détecteur infrarouge à ondes courtes et les bandes M4, M5 et M6 pour le détecteur infrarouge moyen sont les meilleures pour identifier les caractéristiques des explosions selon tous les événements analysés. Les bandes S7 et M4 sont identifiées les meilleures, quand uniquement les données mesurées par AIRIS sont considérées. La différence entre les résultats des deux systèmes est probablement causée par leur altitude et angle d'observation différents. Les conclusions sont en accord avec l'utilisation des bandes S4, S7 et M5 par LEGACY lors de l'essai Northern Lights II.

Importance : Ce travail démontre l'utilité du capteur LEGACY dans la discrimination des caractéristiques de l'explosion.

Perspectives : Plus de données devront être prises dans le futur pour améliorer la précision des valeurs d'identification des caractéristiques. La poursuite du développement du capteur pourrait aussi être menée dans le but d'accroître sa précision dans ce domaine.

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Acknowledgements

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1 Introduction

Data was collected during Northern Lights I (2002) and II (2005) trials in Defence Research & Development Canada (DRDC) Suffield. AIRIS and PIRATES imaging systems were used to study hyperspectral behaviour of explosions in short and medium infrared. Tasks 5 and 6 of contract W7701-092854/001/QCL "spectral and geospatial imagery" involved processing hyperspectral data collected during Northern Lights trials. In the first section of this report, intensity with respect to time is evaluated for each explosion during the trials for AIRIS and PIRATES for each LEGACY bands. Then, in the second section, intensity for each LEGACY band is analysed to find which bands are the best to discriminate explosions according to their composition, charge, container shape, and container material. All data processing is explained in this document through an example. This work is also done in support of a classified project.

2 Intensity evaluation

The objective of this section is to obtain the intensity of the signal with respect to time in the entire bands (2.04 to 5.26 μm) and the LEGACY bands for explosions performed during Northern Lights trials 2002 and 2005. All explosions events are listed in the Annex A. Two intensities are evaluated: one with the original data and another for which the impact of the transmittance is removed. The processing involves three steps. First, atmospheric transmittance is simulated with MODerate resolution atmospheric TRANsmission (MODTRAN) for all events. Second, pixels containing the explosion are identified for both imaging systems. Finally, the total intensity of each explosion in the entire band and in the LEGACY bands is evaluated with respect to time from these pixels. Each step is described below.

2.1 Transmittance evaluation

Northern Lights trials did not involve atmospheric soundings or measurements of air optical properties. Transmittance values were generated using MODTRAN5v2r11 software, which needs atmospheric profiles as an input. The "Nasa Langley cloud and radiation research" web site [1] provides an approximation of atmospheric profiles for North America. The sounding plotter uses latitude and longitude to find the 40km RUC gridbox [2] data base that the point falls into, with a one-hour resolution. It doesn't perform spatial interpolation.

Matlab based algorithms TransmodtranAIRIS.m and TransmodtranPIRATESS.m, available in the delivery package, were created to generate transmittance in a txt file format. The algorithms build the input files and run MODTRAN. For all events, the atmospheric profile, all MODTRAN inputs (such as the atmospheric profile in tp5 format) and outputs, as well as the transmittance file are found in the delivery package.

All MODTRAN simulations for Northern Lights use the Mid-Latitude Summer atmospheric model. Transmittance was evaluated between 1800 and 5100 cm^{-1} (1.96 to 5.56 μm) with an interval of 0.1 cm^{-1}. Among the other settings, the atmospheric line-of-sight and the observer's elevation were taken into account for all events. AIRIS is an airborne instrument (plane level) and PIRATES is a ground instrument (ground level). Explosions are assumed to take place at ground level. Examples of the tp5 file used for both situations are presented in Annex B.

A vertical path was used for AIRIS and an horizontal path for PIRATES because target and observer are considered at the same altitude. An example of a transmittance estimated for Northern Lights I trial is presented in Figure 1.

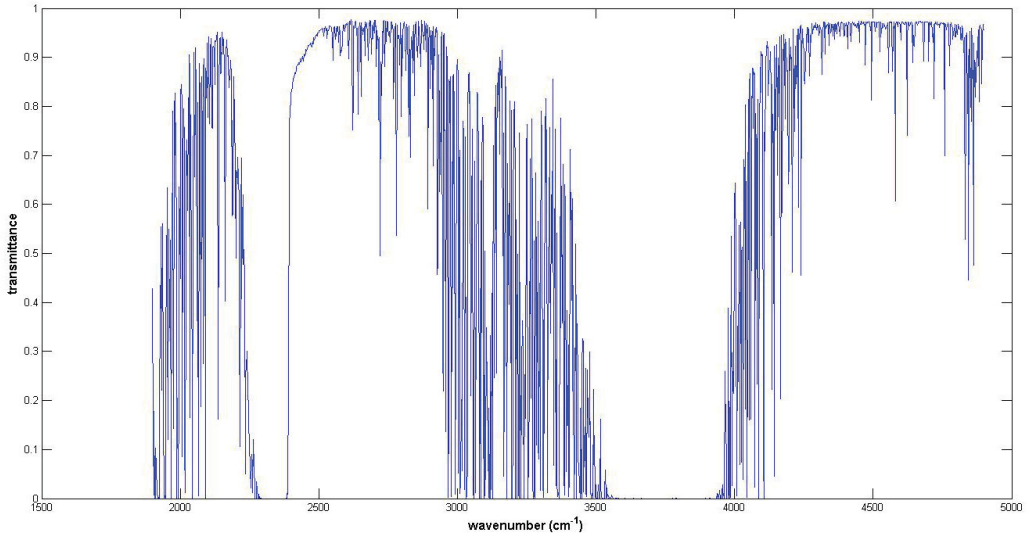

Figure 1 : Transmittance estimated for the first event of the Northern Lights I trial.

2.2 Pixels identifications and intensity evaluation

Explosions were measured using AIRIS and PIRATES imaging systems. They produce spatial data (matrix of 8 x 8 pixels) with a spectral resolution from 1 to 16 cm^{-1}. Each frame consists in 64 spectra. Explosions do not cover the whole field of view. Pixels containing the explosions have to be identified.

Identification of the explosion pixels is based on the algorithms created by the scientific authority, François Leduc. The mathematical process is based on pixel intensity. Values superior to a threshold – based on the background intensity – are considered to be valid. A few improvements were performed on the algorithms in order to eliminate bad pixels. Also, the duration for which pixels are valid was extended to avoid a large gap between the last intensity of the explosion and the background. The cut-off time corresponds to four times the full duration half maximum (FDHM). For Northern Lights II, two background intensities were added before the beginning of the explosion (t=0 ms). These background intensities correspond to the sum of all pixels in two frames before the explosion. No background intensity is added before t=0 ms in the graphics for Northern Lights I, because the first frame corresponds to the beginning of the explosion. The new algorithms are available in the delivery package. All modifications are highlighted.

Once the pixels are identified, the intensity with respect to time can be evaluated. Once again, the algorithms were provided by the scientific authority. The time interval depends on the system resolution and sampling factor (speed of measurement). For Northern Lights II, the sampling factor is set to one and resolution is determined according to the data. Parameters were set manually for Northern Lights I according to documentation accompanying the data.

For each frame, the total intensity is evaluated by summing the intensity of the all pixels containing the event for the entire band (from 1900 to 5000 cm^{-1}) and for the LEGACY bands. The intensity corresponds to $\frac{W}{cm^2 \cdot sr}$. The LEGACY bands are described in the following table. The first band S1 is not computed, because the bandwidth is outside 1900 - 5000 cm^{-1} spectral band.

Table 1 : LEGACY spectral bands

		Bandwidth (µm)		Bandwidth (cm^{-1})	
SWIR	*S1*	*1.89*	*1.95*	*5290*	*5128*
	S2	2.71	2.94	3690	3402
	S3	2.71	3.04	3690	3290
	S4	2.71	3.1	3690	3226
	S5	3.1	3.3	3226	3030
	S6	2.12	3.39	4718	2950
	S7	2.15	2.3	4652	4348
MWIR	M1	4.25	4.35	2352	2298
	M2	4.25	4.42	2352	2262
	M3	4.46	4.53	2242	2208
	M4	4.53	4.6	2208	2174
	M5	4.46	4.65	2242	2150
	M6	4.66	4.79	2146	2088
	M7	3.82	3.99	2618	2506

Finally, the time variation of the total intensity can be plotted. The total intensity value corrected for the effect of transmittance can also be evaluated by dividing the radiance of the target by the transmittance estimated with MODTRAN for each wavenumber. To avoid calculation error, the radiance is divided by the transmittance, if it is over 0.001, and set to zero if the transmittance is under this value. This procedure was approved by scientific authority. Figures 2 to 10 below show the comparison between total intensity evaluated from the original and corrected data of a few events during Northern Lights I and II. They correspond to the intensity for the entire band and for the LEGACY bands. Table 2 presents maximum intensity before correction (W/sr), time of the maximum intensity (ms), mean transmittance, maximum intensity after correction (W/sr) and the FDHM (calculated from the corrected intensity) for the graphics presented in Figures 2 to 10. Maximum intensity corrected does not correspond to the maximum intensity divided by the average transmittance. Intensity correction is very sensitive to transmittance variation due to the estimation process, which considers values for each wavenumber. Small transmittance value, near lower limit (0.001), increases drastically the intensity. Information for the others events are available in the file result.txt in the delivery package described below. The columns in the file are the same as those in Table 2. The first row corresponds to the information of the total intensity for

the entire bandwidth. The others rows are the information for the LEGACY bands from S2 to M7. The rows follow the same order as in Table 1.

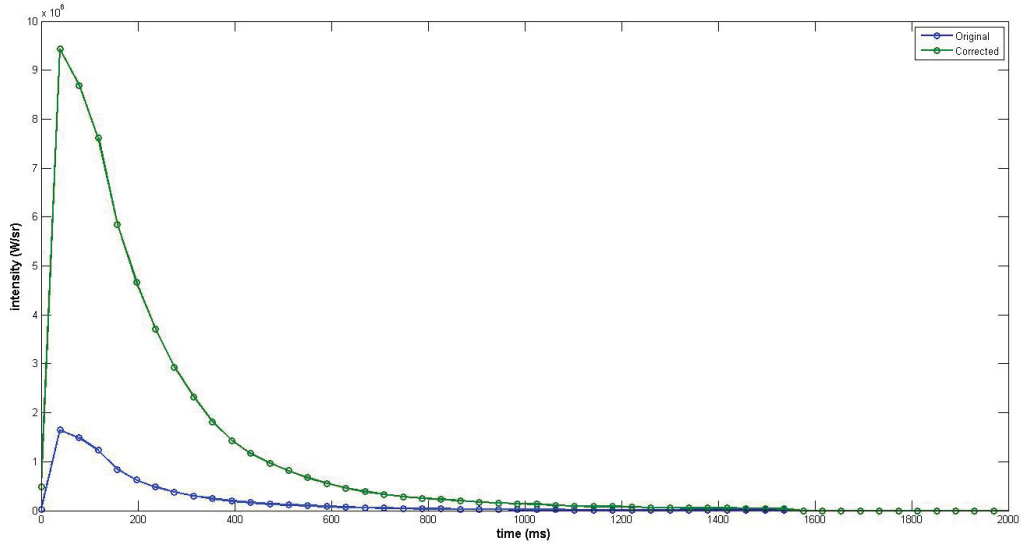

Figure 2 : Original and corrected intensity – time curves for event01 during NL I measured by PIRATES for its entire band (1900 - 5000 cm^{-1}).

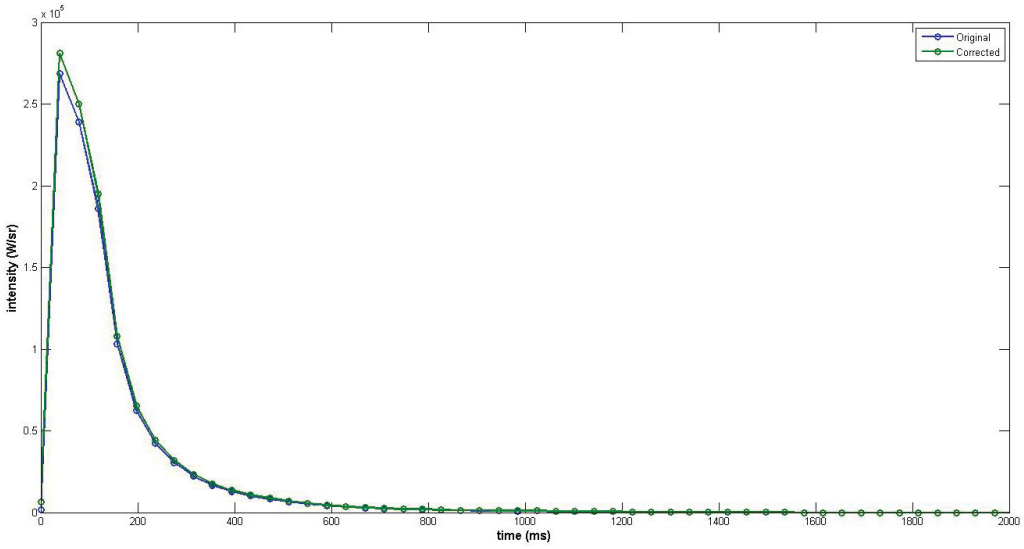

Figure 3 : Original and corrected intensity – time curves for event01 during NL I measured by PIRATES for band S7.

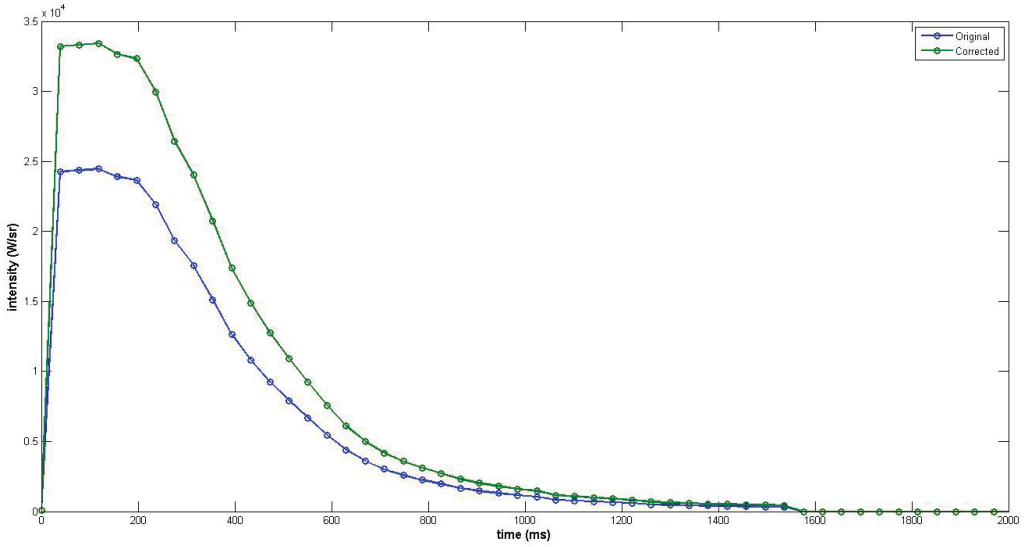

Figure 4 : Original and corrected intensity – time curves for event01 during NL I measured by PIRATES for band M4.

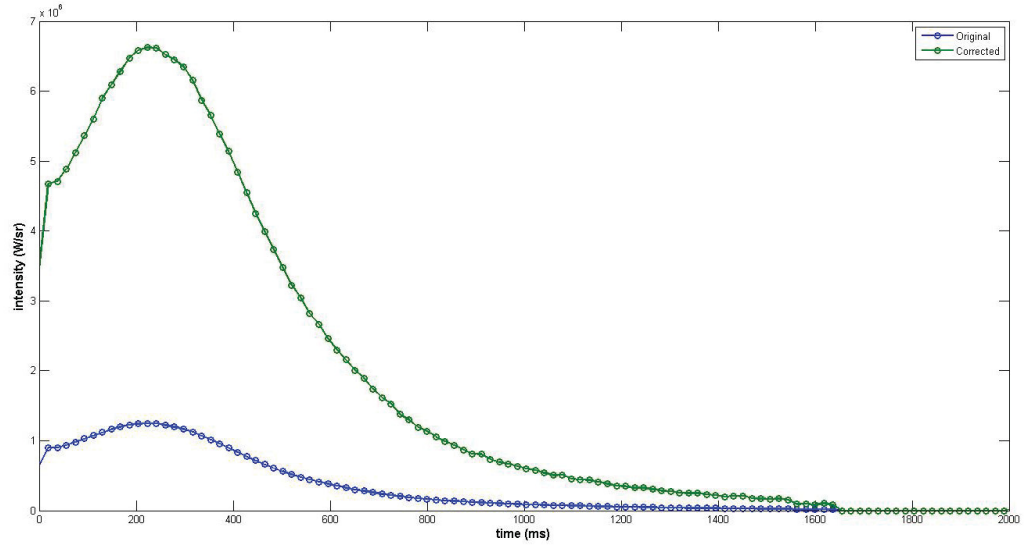

Figure 5 : Original and corrected intensity – time curves for event14 during NL II measured by PIRATES for entire band (1900 – 5000 cm^{-1}).

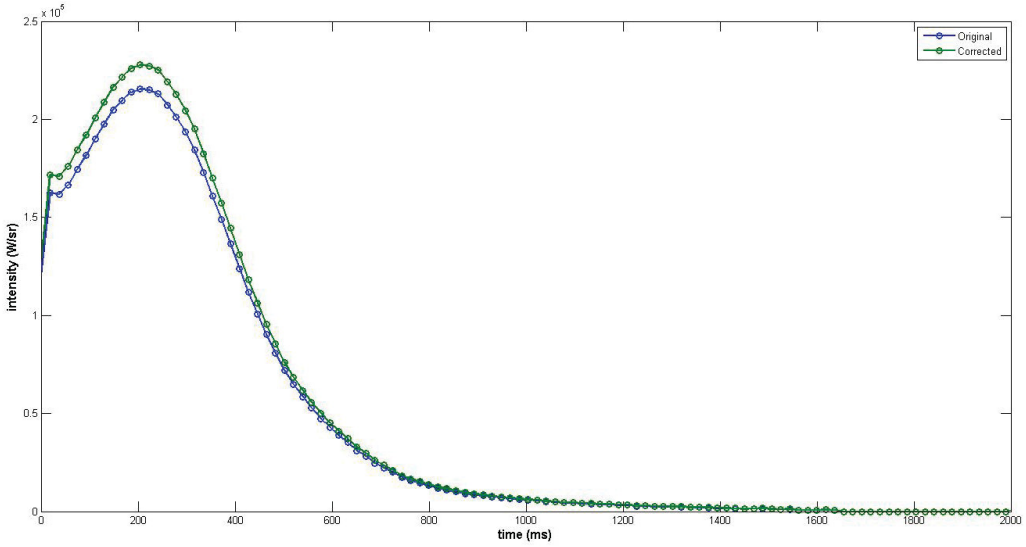

Figure 6 : Original and corrected intensity – time curves for event14 during NL II measured by PIRATES for band S7.

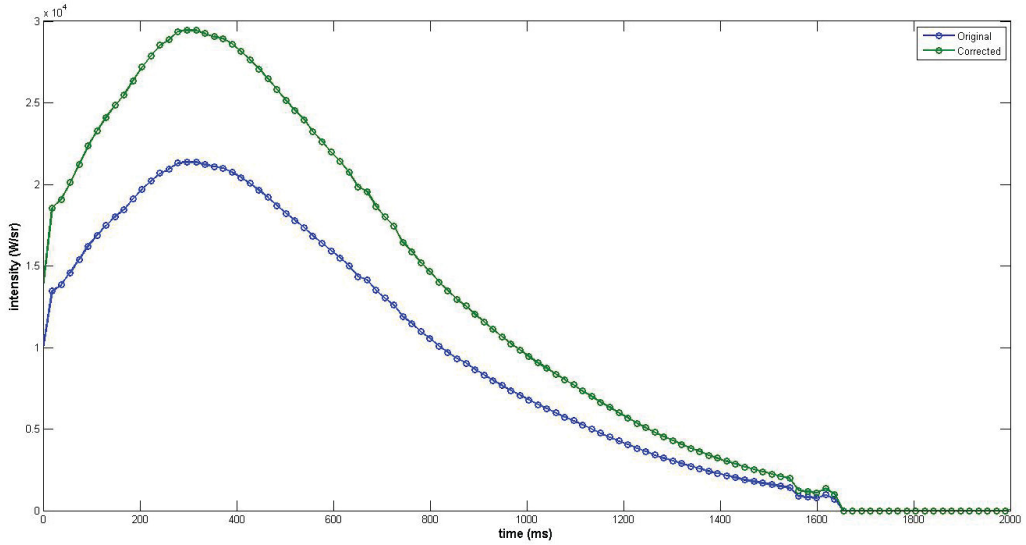

Figure 7 : Original and corrected intensity – time curves for event14 during NL II measured by PIRATES for band M4.

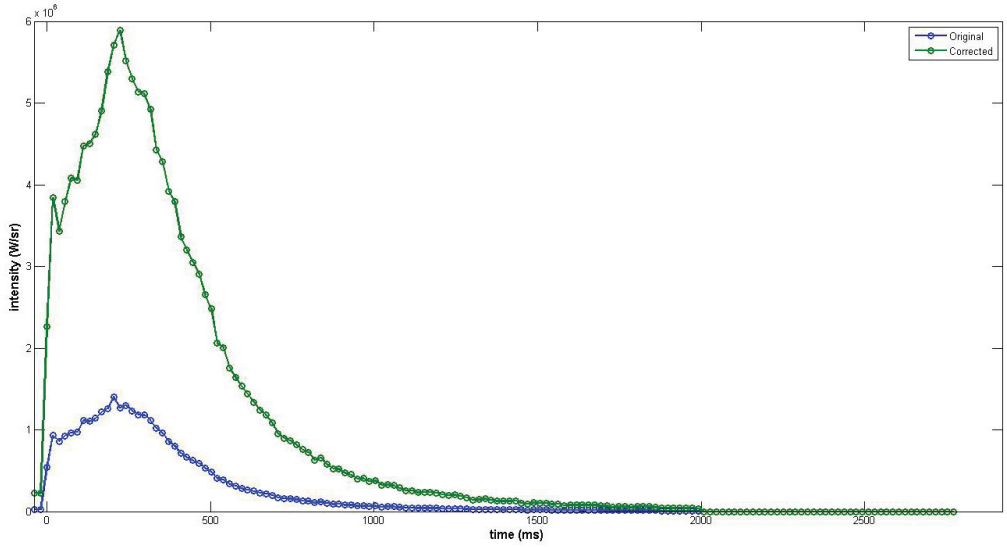

Figure 8 : Original and corrected intensity – time curves for event14 during NL II measured by AIRIS for entire band (1900 – 5000 cm^{-1}).

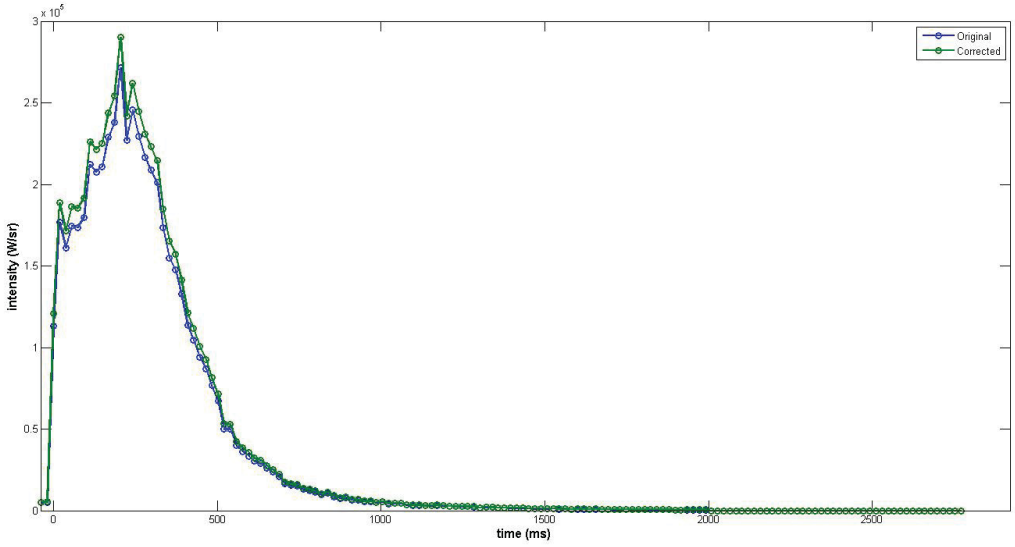

Figure 9 : Original and corrected intensity – time curves for event14 during NL II measured by AIRIS for band S7.

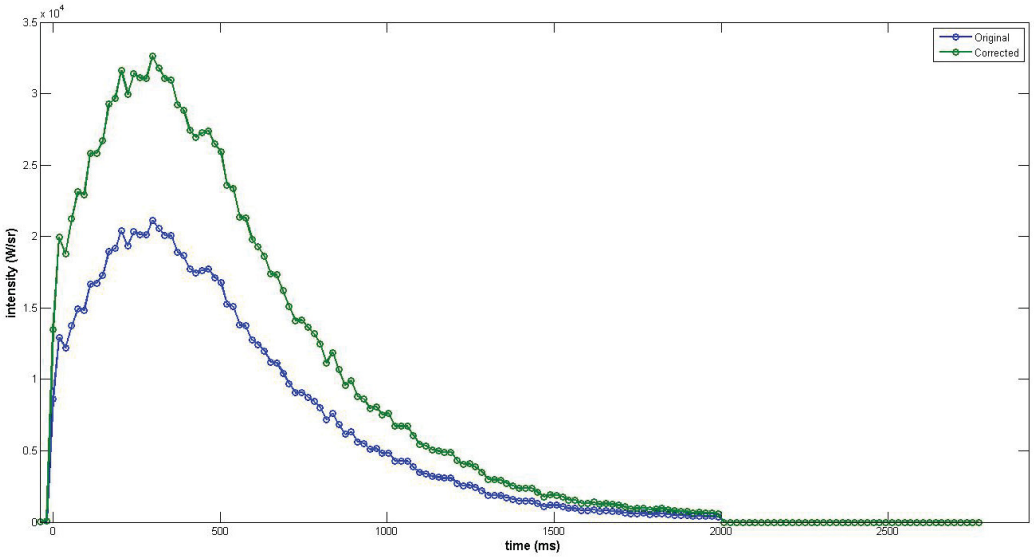

Figure 10 : Original and corrected intensity – time curves for event14 during NL II measured by AIRIS for band M4.

Table 2 : Graphics information

Sample	Data without correction		Transmittance	Corrected Data	FDHM
	Max (W/sr)	Time(ms)	Mean	Max(W/sr)	(ms)
NLI PIRATES event 1					
Full	1.65E+06	39.40	0.57	9.43E+06	118.20
S7	2.69E+05	39.40	0.96	2.81E+05	78.80
M4	2.45E+04	118.20	0.75	3.34E+04	354.60
NLII PIRATES event 14					
Full	1.25E+06	223.20	0.53	6.62E+06	502.20
S7	2.15E+05	204.60	0.95	2.28E+05	427.80
M4	2.14E+04	297.60	0.74	2.94E+04	762.60
NLII AIRIS event 14					
Full	1.40E+06	204.60	0.51	5.89E+06	427.80
S7	2.72E+05	204.60	0.95	2.90E+05	353.40
M4	2.11E+04	297.60	0.67	3.26E+04	651.00

All data, graphs and files required for processing are provided in the delivery package under the structure described in Annex C. X represents the band for the evaluation of the total intensity. The entire band is used if X has no value. In the other case, X corresponds to the LEGACY band.

2.3 Intensity evaluation conclusion

Intensity – time curves for explosions measured by AIRIS and PIRATES during Northern Lights trials were presented in this section. Data processing to achieve this work was also explained in this section. Hyperspectral data collected during the Northern Lights I (2002) and II (2005) trials at DRDC Suffield with the AIRIS and PIRATES imaging systems were processed and the results delivered to the scientific authority. Algorithms and results are also included in the delivery package.

Algorithms provided by the scientific authority were improved in order to evaluate the total intensity with respect to time for the original and corrected data (divided by the transmittance) without bad pixel effects. No problem was encountered during the hyperspectral data processing.

3 Explosion discrimination

The objective of this section is to acknowledge if it is possible to discriminate the characteristics of explosions from events using the LEGACY bands. Characteristics are charge, composition, container shape and container material. Events were measured during Northern Lights I (NLI) with imaging system PIRATES and Northern Lights II (NLII) with imaging system PIRATES and AIRIS. Tables in Annex A give the information on the events measured during NLI (2002) and NLII (2005).

Many characteristics for the NLI events are not identified. Only the composition is known for all events and the charge for a few of them. In the opposite, all characteristics are known for the events of NLII and only event NL16 was not measured.

Discrimination of explosions is based on the intensity – time curves (ITC) evaluated for LEGACY bands of the previous section. The continuous band is not considered. Two analysis methods are used to discriminate the explosions. The first method uses the characteristics of the ITC for each LEGACY band. The second method uses characteristics from combinations of two LEGACY bands, one in the short wave infrared (SWIR) and one in the mid-wave infrared (MWIR). This combination is based on the fact that LEGACY uses two bands at the time, one in the SWIR and another in the MWIR. Based on the works done by Fasquelle [1], the characteristics of ITC are:

Table 3: Intensity – time curves characteristics.

Characteristics	Description	Units
Imax	Intensity maximum	W/sr
Imaxtime	Time when intensity maximum is obtained	ms
Tau	Intensity increase rate from the beginning to Imax	W/[sr·ms]
TauA	Intensity decrease rate from Imax to Imax/2	W/[sr·ms]
TauB	Intensity decrease rate from Imax to Imax/10	W/[sr·ms]
TauAB	Ratio of TauA on TauB	[ ]
TauTauA	Ratio of Tau on TauA	[ ]
Itotal	Total intensity	W·ms/sr
FDHM	Full duration half maximum	ms
Imaxfdhm	Ratio between Imax and FDHM	W/sr·ms
Posihalf	Time when intensity = Imax/2 after Imaxtime	ms
Positen	Time when intensity = Imax/10 after Imaxtime	ms

Events in NLII were produced only once, contrarily to NLI. Analysis is then based on the similarity between the different events. Please note that the compositions of explosion are not the same between NLI and NLII. For example, mix 2 in NLI does not correspond to mix 2 in NLII.

Average value of the ITC characteristics is evaluated from two or more events with a common explosion element (charge, composition, container shape and/or container material). Data from the different events must be close enough to accept this average to discriminate explosion.

Relative standard deviation (RSD) is used to evaluate the dispersion of the data. It corresponds to the absolute value of the relative ratio of the standard deviation and the average. It is a different way to express the coefficient of variation. The average value is accepted if the RSD is less than or equal to 15%. The term representative value (RV) will be used in this document to represent them. Only RV will be presented in the analysis tables of this document. Average values with RSD over 15% will be represented by "0.00" in these tables. A color map is also used to simplify analysis. Values with RSD = [0, 5] are green, RSD =]5, 10] are yellow and RSD =]10, 15] are red. This analysis process is the same for all trials.

The LEGACY bands S1, S2, M1 and M2 were not considered in the analysis. S2, M1 and M2 are in a poor spectral transmission region and S1 is outside the measurement band of the imaging systems AIRIS and PIRATES (1900 – 5000 cm^{-1}).

3.1 Northern Lights I

ITC were evaluated in section 2. The curves start with the beginning of the explosion, so t=0 ms corresponds to the first frame containing the explosion. Some events begin with the maximum intensity. So, few characteristics of the graphics, such as Imaxtime, tau and tautauA, are not usable.

Composition and charge are known for the events of NLI, but the container shape and material are not. These explosion elements will be discussed for each analysis method.

3.1.1 Single band method

3.1.1.1 Composition

From the ITC shape, it is possible to identify the composition of the explosion. Each composition will be presented in this section. Events 11, 12, 20, 21 and 22 are not considered in NLI analysis. Not enough information is available for them.

Mix 1:

Mix 1 can be recognized by its curve shape. Figure 11 shows the ITC for the composition mix 1 in the band S6. The intensity decrease rate changes during the explosion. It diminishes after a short time and returns to its normal rate. Event 7 does not follow the same pattern. The structure could not be seen due the acquisition time frequency longer for event 7 than events 6 and 19 (same time frequency). Imax is similar for events 6 and 7, where the same charge is used. Event 19 has a higher intensity than events 6 and 7 due to its higher charge (150 kg compared to 20 kg). The specific shape of the curve is not perceptible from all LEGACY bands. Only the bands S3, S4, S6, M3, M5 and M6 have the characteristics.

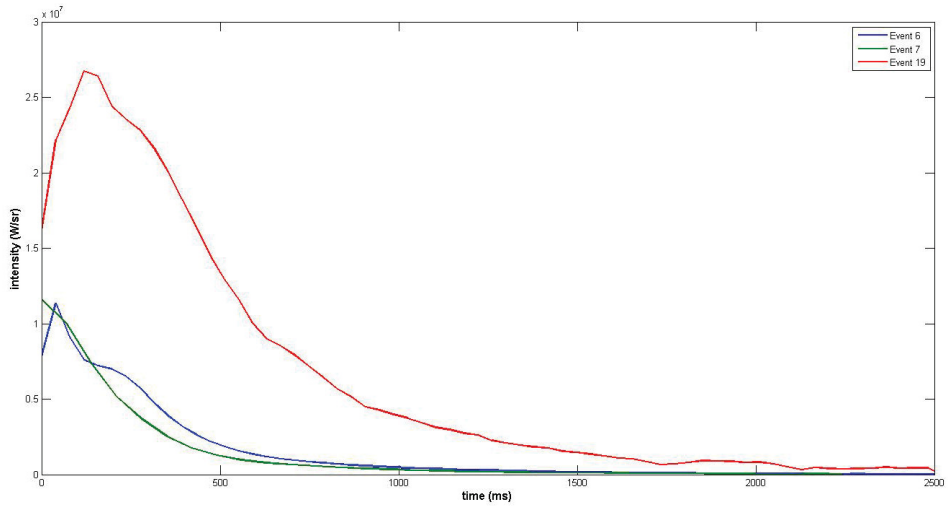

Figure 11 : Intensity – time curve for composition mix 1 of NLI in the band S6.

This mix can also be recognized by the characteristics of the ITC. Table 4 shows the average values of characteristics of the events 6 and 7 using the mix 1 for several bands because they have the same charge in the same container. Event 19 is not considered because a more important charge was used.

Table 4 : Average values of mix 1 intensity – time curves characteristics based on events 6 and 7.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	7.64E+04	9.90E+04	1.02E+05	9.37E+05	3.23E+05	2.19E+04	3.88E+04	9.32E+04	6.78E+04	1.22E+05
tauA	0.00	0.00	262.61	0.00	0.00	32.06	66.26	163.59	160.17	0.00
tauB	0.00	0.00	176.64	2033.84	1081.65	18.59	42.88	99.72	104.56	278.02
tauAB	1.26	1.29	1.49	0.00	0.00	1.73	1.55	1.65	1.53	0.00
FDHM	0.00	0.00	0.00	125.63	106.50	526.55	475.68	468.23	0.00	111.81
Imaxfdhm	0.00	0.00	0.00	7456.09	3028.78	0.00	0.00	0.00	0.00	1092.70
Itotal	3.03E+07	3.79E+07	2.84E+07	1.95E+08	4.88E+07	1.41E+07	2.14E+07	5.17E+07	3.07E+07	2.71E+07
posihalf	0.00	0.00	0.00	125.63	106.50	0.00	0.00	0.00	0.00	111.81
positen	0.00	0.00	538.88	435.22	288.18	1255.00	1006.19	1033.22	755.36	416.49

Mix 2:

Composition mix 2 does not have ITC with a specific shape. But it can be recognized by the characteristics of the curves shown in the Table 5, which shows the average values of characteristics for the events 1 and 2 using mix 2 for several bands. Contrary to mix 1, the majority of values are representative.

Table 5 : Average values of mix 2 intensity – time curves characteristics based on events 1 and 2.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	8.16E+04	1.06E+05	9.65E+04	8.23E+05	2.63E+05	1.45E+04	2.58E+04	6.21E+04	4.79E+04	9.63E+04
tauA	203.05	278.76	391.04	0.00	0.00	19.54	42.05	104.02	0.00	0.00
tauB	162.35	217.18	238.75	2343.34	962.97	16.11	35.70	84.83	0.00	236.02
tauAB	1.25	1.28	1.63	0.00	0.00	1.21	1.18	1.23	1.39	1.80
FDHM	247.66	237.49	169.71	143.47	126.69	436.40	391.15	383.35	297.84	124.78
Imaxfdhm	329.95	449.01	571.78	5754.35	2075.14	33.29	65.85	161.85	160.76	772.68
Itotal	2.33E+07	2.94E+07	2.13E+07	1.59E+08	4.26E+07	7.29E+06	1.15E+07	2.77E+07	1.67E+07	1.85E+07
posihalf	257.22	247.08	179.32	153.16	136.47	445.96	401.05	393.16	307.88	134.58
positen	509.07	497.53	419.28	371.18	300.14	886.00	743.71	752.57	576.23	387.66

Mix 3a:

Figure 12 shows the ITC for the composition mix 3a in the band S6 during the NLI campaign. They correspond to events 4, 13 and 18. The curves have two spikes and they are specific to the mix 3a.

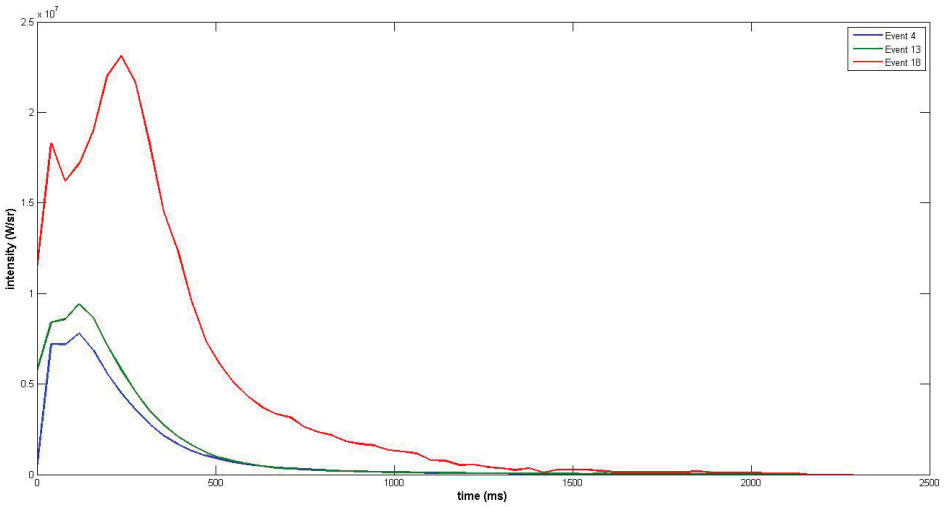

Figure 12 : Intensity – time curve for composition mix 3a of NLI in band S6.

Table 6 shows the average values of characteristics for the events 4 and 13 using the mix 3a for several bands because they have the same charge in the same container. Event 18 is not considered because a more important charge was used. Bands S6, S7 and M7 have the highest number of non-representative elements.

Table 6 : Average values of mix 3a intensity – time curves characteristics based on events 4 and 13.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	1.12E+05	9.57E+05	0.00	1.93E+04	3.46E+04	8.32E+04	6.25E+04	0.00
tauA	0.00	0.00	388.29	3958.34	0.00	38.14	75.54	186.09	185.83	0.00
tauB	0.00	0.00	259.35	0.00	0.00	23.53	52.84	125.87	0.00	0.00
tauAB	1.24	1.26	1.50	0.00	1.20	1.62	0.00	0.00	0.00	1.64
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	399.30	529.74	0.00	0.00	0.00	49.72	94.89	231.82	205.56	0.00
Itotal	0.00	0.00	0.00	0.00	5.37E+07	9.03E+06	1.44E+07	3.47E+07	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	529.37	518.46	0.00	0.00	0.00	877.52	727.76	734.24	586.02	0.00

Mix 3b:

ITC of the composition mix3b have no specific shape. Table 7 shows the average values of characteristics for the events 5 and 14 mix 3b for several bands.

Table 7 : Average values of mix 3b intensity – time curves characteristics based on events 5 and 14.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	1.15E+06	3.75E+05	1.93E+04	3.44E+04	8.28E+04	6.25E+04	1.26E+05
tauA	0.00	0.00	0.00	0.00	0.00	0.00	72.49	179.06	183.34	0.00
tauB	0.00	0.00	0.00	3174.54	1387.66	24.85	52.72	125.99	125.11	0.00
tauAB	1.19	1.21	1.40	1.41	1.26	0.00	0.00	0.00	0.00	1.65
FDHM	227.54	219.07	150.84	128.52	108.02	366.79	339.05	332.84	270.14	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	52.67	101.42	248.79	231.34	0.00
Itotal	0.00	0.00	2.47E+07	1.89E+08	4.95E+07	8.43E+06	1.35E+07	3.23E+07	2.01E+07	1.87E+07
posihalf	227.54	219.07	150.84	128.52	108.02	366.79	339.05	332.84	270.14	0.00
positen	488.83	475.74	380.32	326.17	243.05	799.16	686.58	691.41	549.89	297.75

C4:

ITC of the composition C4 have no specific shape. Table 8 shows the average values of characteristics for events 10 and 24, which used the C4, for several bands. The majority of values in Table 8 are not representative for the C4. Events have the same composition and charge, but the distance above the ground of the explosion is not the same. One was 1.4 meters above ground level and the other one was directly on the ground.

Table 8 : Average values of C4 intensity – time curves characteristics based on events 10 and 24.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	217.61	0.00	0.00	0.00	22.42	39.13	97.26	0.00	0.00
tauB	111.48	138.48	0.00	0.00	0.00	14.67	27.71	65.65	0.00	0.00
tauAB	0.00	1.57	1.87	1.70	1.55	1.53	1.42	1.48	1.79	2.39
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	464.01	4172.66	1454.61	0.00	0.00	0.00	156.56	586.99
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FAE 4:

ITC of the composition FAE 4 have no specific shape. Table 9 shows the average values of characteristics for several bands for events 17 and 23, which used the FAE 4.

Table 9 : Average values of FAE4 intensity – time curves characteristics based on events 17 and 23.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	5.13E+04	9.55E+04	2.30E+05	1.78E+05	0.00
tauA	0.00	0.00	0.00	0.00	0.00	81.27	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	1.32	1.33	1.33	1.41	1.40	1.33	1.28	1.31	1.23	1.75
FDHM	337.25	331.62	292.13	278.19	240.33	475.29	457.20	448.70	375.03	239.73
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	107.99	208.83	511.66	473.18	0.00
Itotal	0.00	0.00	0.00	0.00	7.31E+07	2.63E+07	4.58E+07	1.09E+08	6.89E+07	2.93E+07
posihalf	337.25	331.62	292.13	278.19	240.33	475.29	457.20	448.70	375.03	239.73
positen	611.70	600.42	535.55	524.59	425.95	917.09	847.35	842.77	637.86	0.00

3.1.1.2 Single band method conclusion

Explosions with the same characteristics were performed twice during Northern Lights I. So, many characteristics of the ITC were found easily and tauAB was identified as the characteristic with the highest representative values for the different compositions. Table 10 shows a summary of the representative values of tauAB for each composition used during NLI. Values are the average of tauAB presented in tables 4 to 9.

Table 10 : Summary of average values of tauAB for all compositions used during NLI.

Composition	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Mix1	1.26	1.29	1.49	0.00	0.00	1.73	1.55	1.65	1.53	0.00
Mix2	1.25	1.28	1.63	0.00	0.00	1.21	1.18	1.23	1.39	1.80
Mix3a	1.24	1.26	1.50	0.00	1.20	1.62	0.00	0.00	0.00	1.64
Mix3b	1.19	1.21	1.40	1.41	1.26	0.00	0.00	0.00	0.00	1.65
C4	0.00	1.57	1.87	1.70	1.55	1.53	1.42	1.48	1.79	2.39
FAE4	1.32	1.33	1.33	1.41	1.40	1.33	1.28	1.31	1.23	1.75

In the SWIR, the bands S4 and S5 can be used to discriminate the composition, because a representative value is available for each composition. Average values of tauAB in the band S5 have a better dispersion than band S4. This facilitates the distinction between compositions. In the MWIR the bands M3 to M6 are available for four compositions. This allows more possibilities to the user to discriminate the explosion.

A summary of the number of representative values for each LEGACY band for PIRATES measurement during NLI is given in Table 11. Each row corresponds to the number of times where at least one ITC characteristic (Table 3) has the corresponding relative standard deviation (RSD). I.e. in table 9 for instance, there is one RSD]5, 10%] (yellow) and three RSD=[0, 5%] (green) for band S3, which are counted as 1 RSD]5, 10%] and 1 RSD=[0, 5%].

Table 11 : Number of representative values of intensity – time curves characteristic for each LEGACY band for NLI trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
RSD=[0, 5%]	5	6	6	6	5	6	6	6	6	4
RSD=]5, 10%]	4	4	5	4	4	4	6	6	4	6
RSD=]10, 15%]	2	2	3	3	4	3	4	4	3	1
sum	11	12	14	13	13	13	16	16	13	11

For the SWIR bands, S5 has the highest number of representative values and for the MWIR bands M4 and M5 have the first rank. The bands S6, S7, S4 and S3 follow S5 and the bands M6, M3

and M7 follow M4 and M5. This order is based on the sum of all representative values in Table 11. The rank of each band changes if each RSD is considered separately.

From Table 4 to 9, representative values of SWIR and MWIR bands were combined. This combination consists of taking a SWIR band with a representative value and matching it with a MWIR band having a representative value for the same ITC characteristic. The combination does not consider the RSD value. For example, if tauAB is considered in Table 4, S3, S4 and S5 can be combined with the bands M3 to M6, but S6 and S7 cannot because they have no representative value of tauAB.

Combinations for all ITC characteristics have been summed for Table 4 to 9 but are not presented herein for complexity reason. For example, the sum of combinations for the band S5 in Table 4 is 6 with the band M3, M4, M5 and M6 and 4 with the band M7. Considering all tables 4 to 9 results, the combination which appears the most is S5 combined with M3. This combination is followed by S5 with M4 and M5 and S7 with M3. The number of matches diminishes with the other combinations. If we consider the combination of S bands with anyone of the M bands, the bands S5 gets the highest number of match followed by S7, S6, S4 and S3. If the combination process disregards the characteristics, i.e. we can use different representative characteristics in the combination between the SWIR and the MWIR bands, the same number is obtained by all bands.

Based on the above discussion, the band S5 is the best SWIR band to discriminate explosions. The bands S6 and S7 follow. For the MWIR bands, M4 to M5 have similar results according to Table 11. According to the combination, bands M4 and M5 get the second rank behind band M3.

Due to a lack of information, it is hard to conclude which band is the best to discriminate the explosion. The charge, the container shape and the container material were not analyzed. No information was available for that. So this conclusion is only good if the user wants to discriminate the composition. However, all bands can be used to discriminate the explosion due to the high number of representative values for each band of each composition.

3.1.2 Ratio Method

The ratio method consists of analysing the ratio between the values of ITC characteristics of a SWIR band with a MWIR band. An average and the RSD are evaluated from the ratio values of each event considered. With the same method as single band, the RSD value is used to evaluate if it is a representative value or not. A summary of the number of representative values for the ratio of LEGACY bands for NLI is given in Table 12. Each row corresponds to the number of times, where at least one characteristic has the corresponding RSD. The first row represents the name of the bands. The first number is the SWIR band and the last is the MWIR band. Table 13 shows the sum of the representative values in Table 12 for each LEGACY bands. In this table, the sum is done with and without considering the band M7.

Table 12 : Number of representative values of SWR/MWIR ratio of intensity – time curves characteristics for each LEGACY band for NLI trial.

SWIR/ MWIR	3/ 3	3/ 4	3/ 5	3/ 6	3/ 7	4/ 3	4/ 4	4/ 5	4/ 6	4/ 7	5/ 3	5/ 4	5/ 5	5/ 6	5/ 7	6/ 3	6/ 4	6/ 5	6/ 6	6/ 7	7/ 3	7/ 4	7/ 5	7/ 6	7/ 7
5%	6	6	6	6	5	6	5	6	5	4	6	5	5	5	6	5	5	5	6	6	5	5	5	6	6
10%	6	5	5	5	3	5	5	6	5	4	4	6	6	6	6	4	5	5	5	5	5	5	5	4	4
15%	4	4	4	5	6	2	3	4	5	5	5	4	4	5	5	3	5	5	4	6	2	4	4	3	2
sum	16	15	15	16	14	13	13	16	15	13	15	15	15	16	17	12	15	15	15	17	12	14	14	13	12

Table 13 : Sum of the representative values from the ratio between LEGACY bands for PIRATES during NLI

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
With M7	76	70	78	74	65	68	72	75	75	73
Without M7	62	57	61	57	53	68	72	75	75	0

Table 13 shows that the best SWIR bands are S5 and S3 considering or not band M7. This band is followed by S6, S4 and S7 with M7. Without band M7, the order is still the same. For the MWIR bands, M5 and M6 come first, followed by M7, M4 and M3.

Table 12 shows a different result. The best results are obtained with the ratios from bands S5 and S6 with band M7. This result is not the same as observed with the single band method. The band S5 is still the first but band M7 drops to the last rank in single band method.

3.1.3 Northern Lights I conclusion

From these results, bands S5 and M5 are the best of the SWIR and MWIR bands to discriminate the different compositions. This conclusion is based only on the ITC characteristics of the events with the same composition. Charge, container shape and container material were not analyzed for this trial due to a lack of information. Spectral analysis should be done to evaluate if these bands present specific spectral structure.

3.2 Northern Lights II – PIRATES measurements

ITC were evaluated in section 2. The curves start two frames before the beginning of the explosion and t=0 ms corresponds to the first frame with the explosion. The two frames before t=0 ms correspond to the background intensity.

Composition, charge, shape and material of the container are known for the events of NLII. These elements will be discussed for each method. As shown in Figure 13, events 1 and 18 cannot be analyzed due to the variations in the ITC. Event 16 is also rejected because no data is available for it.

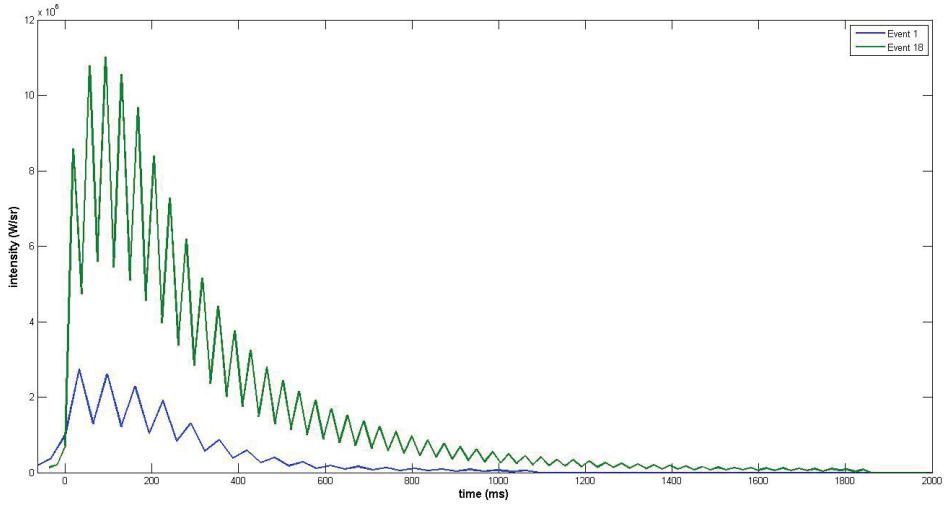

Figure 13: Intensity – time curve for the band S6 of events 1 and 18 during NLII measured by PIRATES.

No particular shape is observable on ITC to discriminate the composition, the container material and the charge. The shape of the container can be observed by width of the peak. However, the width does not guaranty the shape of the container. The container material and the charge also influence it.

3.2.1 Single band method

3.2.1.1 Container material

Three different materials were used in this trial: Polyethylene, Steel and Aluminum. These were analyzed based on the event with a charge of 20 kg.

Polyethylene:

Analysis is based on the events 2 to 10. The charge for these events is 20 kg, but the composition and the shape are different. Considering all these events, no representative value with one band was found to identify the polyethylene. So, the shape of the container was considered in the analysis. Table 14 shows the average values of characteristics of events 3, 5, 8 and 9 using a spherical container of polyethylene for several bands. Table 15 shows the average values of characteristics of events 2, 4, 6, 7 and 10 using a cylindrical container of polyethylene for several bands.

Table 14 : Average values of spherical polyethylene container intensity – time curves characteristics based on events 3, 5, 8 and 9 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	8.71E+04	5.34E+03	9.78E+03	2.33E+04	0.00	0.00
Imaxtime	255.60	237.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	14.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.02	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	0.00	1.31	1.24	0.00	0.00	0.00	0.00	0.00
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	854.45	800.01	792.82	0.00	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	4.84E+06	8.11E+06	1.92E+07	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	854.45	800.01	792.82	0.00	0.00
positen	1097.74	1064.91	941.52	795.59	0.00	0.00	0.00	0.00	0.00	0.00

Table 15 : Average values of cylindrical polyethylene container intensity – time curves characteristics based on events 2, 4, 6, 7 and 10 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	1.68E+04	4.03E+04	2.82E+04	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	63.99	75.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	58.81	0.00	0.00	0.00	0.00	24.22	57.84	0.00	0.00
tauAB	1.38	1.29	0.00	0.00	0.00	1.02	1.10	1.13	1.19	0.00
tautauA	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	304.83	297.08	0.00	147.20	116.78	480.21	0.00	0.00	0.00	119.33
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	19.55	38.15	93.33	81.85	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	307.29	299.27	0.00	147.20	116.78	484.89	0.00	0.00	0.00	119.33
positen	0.00	0.00	0.00	0.00	264.44	786.18	751.92	753.68	0.00	0.00

Only three characteristics can be compared between these two cases; Imax for bands M4 and M5 and FDHM and posihalf for band M3.

Steel:

Analysis is based on events 11, 13 and 15. The charge for these events is 20 kg. The composition and container shape are different. Table 16 shows the average values of characteristics of events 11, 13 and 15 using a steel container of any shape for several bands. Table 17 shows the average values of characteristics of events 13 and 15 using a spherical container of steel for several bands.

Table 16 : Average values of steel container intensity – time curves characteristics based on events 11, 13 and 15 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	2.78E+04	2.54E+05	8.92E+04	5.35E+03	1.02E+04	2.43E+04	1.76E+04	3.69E+04
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	67.33	0.00	145.40	1349.14	472.21	0.00	0.00	0.00	0.00	0.00
tauA	23.41	31.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	0.00	1.62	0.00	0.00	0.00	0.00	1.34	1.80
tautauA	0.00	0.00	3.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	30.80	41.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 17 : Average values of spherical steel container intensity – time curves characteristics based on events 13 and 15 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	1.90E+04	2.50E+04	2.99E+04	2.65E+05	9.07E+04	5.72E+03	1.08E+04	2.57E+04	1.85E+04	0.00
Imaxtime	232.50	232.50	204.60	195.30	195.30	0.00	0.00	0.00	0.00	204.60
tau	71.91	97.57	132.93	1310.02	463.40	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	41.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36	1.71
tautauA	0.00	0.00	3.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	648.43	639.21	564.65	0.00	0.00	0.00	0.00	0.00	732.90	0.00
Imaxfdhm	29.49	39.31	53.28	0.00	0.00	0.00	0.00	0.00	25.47	71.73
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	648.78	639.80	572.55	525.18	0.00	0.00	0.00	0.00	741.19	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

No analysis was performed on the cylindrical container of steel, because there is only one event available for analysis.

Aluminum:

Analysis is based on events 12 and 14. Charge for these events is 20 kg, the shape is spherical and the compositions are different. No cylindrical container of aluminum was used during this trial. Table 18 shows the average values of characteristics of events 12 and 14 using a spherical aluminum container for several bands.

Table 18 : Average values of spherical aluminum container intensity – time curves characteristics based on events 12 and 14 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	213.90	213.90	213.90	213.90	204.60	0.00	0.00	0.00	0.00	213.90
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	0.00	0.00	0.00	1.23	1.33	1.36	0.00	0.00
tautauA	1.63	1.59	1.29	0.00	1.07	0.00	0.00	0.00	1.53	1.13
FDHM	546.24	536.87	476.48	441.96	418.15	877.05	771.78	763.76	611.32	449.42
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	546.74	537.28	479.54	445.57	425.88	877.31	773.87	765.57	614.57	450.95
positen	1157.27	1142.75	1006.99	0.00	0.00	1627.86	1490.60	1501.32	1244.35	0.00

Container material conclusion

Discrimination of the three container materials can be done only with Imaxtime using bands S3 and S4. Other discrimination can be performed but only two at the time. To compare a spherical container made of polyethylene or steel, you can also use tau of band S3 and Imax of bands M3 to M5. For a spherical made of polyethylene or aluminum, FDHM and posihalf for bands M3, M4 and M5 and positen for bands S3, S4 and S5 can also be used. Finally, for a spherical container made of steel or aluminum, Imaxtime in all S bands and M7, FDHM in bands S3, S4, S5 and M6, tautauA in band S5 and posihalf in bands S3, S4, S5, S6 and M6 can be used.

3.2.1.2 Composition

Same as the container material analysis, events with a charge of 20 kg are considered.

Mix 4:

Analysis is based on events 5, 6, 14 and 15. Charge for these events is 20 kg. The container material and shape are different. Table 19 shows the average values of characteristics of events 5, 6, 14 and 15 using mix 4 for several bands.

Table 19 : Average values of mix 4 intensity – time curves characteristics based on events 5, 6 14 and 15 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	1.33	1.28	1.43	0.00	0.00	0.00	1.12	0.00	1.22	0.00
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Just a few values of the characteristics of the mix 4 are representative. Table 20 shows the average values of characteristics of events 5, 14 and 15 using mix 4 in spherical container for several bands.

Table 20 : Average values of intensity – time curves characteristics of the mix 4 in spherical container based on events 5, 14 and 15 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	240.87	240.87	228.47	217.73	200.80	322.67	322.67	322.67	310.27	217.73
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	1.27	1.26	1.37	1.37	1.26	1.15	1.20	1.24	1.23	1.51
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	604.93	595.66	515.93	455.68	428.16	887.91	808.14	798.63	676.69	449.44
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	605.50	596.33	519.76	463.87	436.43	890.19	813.02	802.00	679.47	456.54
positen	1076.87	1045.06	946.65	823.51	734.47	1502.07	1378.56	1392.23	1126.90	867.97

As shown in Table 20, more values are representative for the mix 4 in spherical container. 5 characteristics can be used to discriminate it in all bands.

Mix 2:

Analysis is based on events 3, 4, 11, 12 and 13. Charge for these events is 20 kg. The container material and shape are different. Table 21 shows the average values of characteristics of events 3, 4, 11, 12 and 13 using mix 2 for several bands.

Table 21 : Average values of intensity – time curves characteristics of the mix 2 based on events 3, 4, 11, 12 and 13 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	1.70	1.66	0.00	0.00	0.00	0.00	0.00	0.00
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Just a few values of the characteristics of the mix 2 are representative. Table 22 shows the average values of characteristics of events 3, 12 and 13 using mix 2 with a spherical container for several bands. Table 23 shows the average values of characteristics of events 4 and 11 using mix 2 with a cylindrical container for several bands.

Table 22 : Average values of intensity – time curves characteristics of the mix 2 with a spherical container based on events 3, 12 and 13 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	217.73	217.73	200.80	194.60	194.60	228.47	228.47	228.47	217.73	200.80
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	1.80	1.82	1.86	1.73	1.70	0.00	0.00	0.00	1.71	2.01
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	1702.22	1711.55	0.00	0.00

Table 23 : Average values of intensity – time curves characteristics of the mix 2 with a cylindrical container based on events 4 and 11 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	1.20	1.18	1.45	1.55	1.29	1.08	1.19	1.24	1.29	0.00
tautauA	0.00	0.00	0.00	1.64	1.38	2.02	0.00	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	3.58E+06	6.29E+06	1.49E+07	0.00	9.62E+06
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

T1:

Analysis is based on events 7 and 8. Charge for these events is 20 kg. The container material and shape are different. Table 24 shows the average values of characteristics of events 7 and 8 using composition T1 for several bands.

Table 24 : Average values of intensity – time curves characteristics of the composition T1 based on events 7 and 8 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	1.05	0.00	0.00	1.13	1.04	1.08	0.00	0.00
tautauA	1.46	1.40	0.00	0.00	0.00	0.00	0.00	2.19	1.58	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

T2:

Analysis is based on the events 9 and 10. Charge for these events is 20 kg. The container material and shape are different. Table 25 shows the average values of characteristics of the events 9 and 10 using composition T2 for several bands.

Table 25 : Average values of intensity – time curves characteristics of the composition T1 based on events 9 and 10 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	1.28	1.14	1.06	0.00	1.30	0.95	1.10	1.14	1.13	1.43
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	2.66E+07	5.34E+06	8.48E+06	2.01E+07	0.00	7.77E+06
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Composition conclusion

Identification of the composition is not simple. No specific shape is observable in the ITC of these events. Also, only the characteristics tauAB can be used to discriminate the composition. Table 26 shows a summary of the representative values of tauAB for each composition used during NLII from the Table 19 to Table 25.

Table 26 : Summary of average values of tauAB for all compositions used measured by PIRATES during NLII trial.

Composition	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Mix 4	1.33	1.28	1.43	0.00	0.00	0.00	1.12	0.00	1.22	0.00
Mix 4 Sph	1.27	1.26	1.37	1.37	1.26	1.15	1.20	1.24	1.23	1.51
Mix 2	0.00	0.00	1.70	1.66	0.00	0.00	0.00	0.00	0.00	0.00
Mix 2 Sph	1.80	1.82	1.86	1.73	1.70	0.00	0.00	0.00	1.71	2.01
Mix 2 Cyl	1.20	1.18	1.45	1.55	1.29	1.08	1.19	1.24	1.29	0.00
T1	0.00	0.00	1.05	0.00	0.00	1.13	1.04	1.08	0.00	0.00
T2	1.28	1.14	1.06	0.00	1.30	0.95	1.10	1.14	1.13	1.43

20 kg of mix 4 in a spherical container is the composition with the highest number of characteristics. However, this result includes the shape of the container. Without the shape of the container, only band S5 has a value for each composition. Other values with a higher RSD can be used to identify the composition, but this procedure introduces error.

3.2.1.3 Charge

Analysis on the charge is performed on the events using mix 2 with a charge of 20 and 150 kg. Events with a charge of 150 kg are 17, 19, 20 and 21. Events with 20 kg are those used to obtain the results in Table 21 to Table 23. Considering events 17, 19, 20 and 21, only the characteristic tauAB for bands S3, S4 and S7 is representative. Those values cannot be compared to the values for explosions with a charge of 20 kg because tauAB is only representative for bands S5 and S6 for a charge of 20 kg (refer to Table 21). Table 27 shows the average values of characteristics of events 17, 19 and 20 using a charge of 150 kg of mix 2 in a spherical container for several bands.

Table 27 : Average values of intensity – time curves characteristics of 150 kg of mix2 in a spherical container based on events 17, 19 and 20 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	0.00	1.59	1.44	0.00	0.00	0.00	0.00	0.00
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	1009.79	991.47	923.86	856.95	805.81	1645.74	1487.30	1468.73	1143.30	899.55
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	1026.36	1008.54	935.93	870.22	819.27	1663.21	1499.32	1478.72	1158.34	911.25
positen	2229.23	2188.71	1983.75	1727.71	1548.50	3047.66	2818.97	2828.59	2470.49	1962.69

Representative values appearing for charges of 150 kg (Table 27) and 20 kg (Table 22) are tauAB for bands S6 and S7 in the SWIR and positen for bands M4 and M5 for the MWIR. Intensity maximum divided by ten for a charge of 150 kg is obtained later than for a charge of 20 kg. The value of tauAB for a charge of 150 kg is lower than for a charge of 20 kg.

3.2.1.4 Shape

Two container shapes were used during the NLII trial, cylindrical and spherical. Table 28 shows the average values of characteristics of events 2, 4, 6, 7, 10 and 11 using a charge of 20 kg in a cylindrical container for several bands. Table 29 shows the average values of characteristics of events 3, 5, 8, 9, 12, 13, 14 and 15 using a charge of 20 kg in a spherical container for several bands.

Table 28 : Average values of intensity – time curves characteristics of 20 kg in a cylindrical container based on events 2, 4, 6, 7, 10 and 11 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	1.35	1.31	0.00	0.00	0.00	1.04	1.13	1.17	1.25	0.00
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 29 : Average values of intensity – time curves characteristics of 20 kg in a spherical container based on events 3, 5, 8, 9, 12, 13, 14 and 15 measured by PIRATES during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	239.40	230.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	613.31	0.00	528.32	0.00	0.00	0.00	0.00	0.00	673.64	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	613.52	0.00	531.05	0.00	0.00	0.00	0.00	0.00	676.53	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Only few average values of ITC for the events with cylindrical (Table 28) and spherical container (Table 29) are representative. Combination with another element (charge, composition and container material) can help to distinguish the shape of the container. Also, the average values on

all LEGACY bands of the ratio, of the FDHM, positen and posihalf, between a spherical and cylindrical container with the same container material, charge and composition is over 1.5. Table 30 shows the average ratio for FDHM, posihalf and positen for few combination of events. This observation can be used only to distinguish two events with the same composition, charge and container material. It is based on events using a charge of 20 kg. Events using 150 kg do not give the same result.

Table 30: Average ratio between FDHM, posihalf and positen of events with the same container material, charge and composition.

Events	FDHM	posihalf	positen
3 & 4	2.35276	2.35276	2.56282
5 & 6	2.497432	2.497432	1.664565
7 & 8	3.033663	3.008598	2.551958
9 & 10	1.781749	1.757243	1.5346
11 & 13	2.242811	2.222946	2.482961

3.2.1.5 Single band method conclusion

A summary of the number of representative values for each LEGACY band for PIRATES measurement during NLII is given in Table 31. Each row corresponds to the number of times, where at least one ITC characteristic (Table 3) has the corresponding relative standard deviation (RSD).

Table 31 : Number of representative values of intensity – time curves characteristic for each LEGACY band for PIRATES measurements during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
RSD=[0, 5%]	3	4	6	4	6	3	3	4	7	5
RSD=]5, 10%]	9	9	4	4	6	7	6	5	5	6
RSD=]10, 15%]	7	8	8	6	4	8	8	8	7	2
sum	19	21	18	14	16	18	17	17	19	13

Table 31 shows that the band S4 has the highest number of characteristics with a RSD under 15%. The number of characteristics decreases for the other bands as follow: S3, S5, S7 and S6. For the MWIR bands, M6 has the highest number, followed by M3, M5, M4 and M7. This order is based on the sum on all values under 15%. The rank of each band changes if each RSD is considered separately.

The SWIR bands were combined with the MWIR bands, as explained at the section 3.1.1, to show which combination has representative values for the same case. Combination does not consider the values of RSD and the characteristic. Same as section 3.1.1 the results are not presented herein for complexity reason. The combinations with the highest number of cases are S3 and S4 combined with M6. These combinations are followed by the S3 and S4 with M4, S3

and S4 with M5 and M3 and S5 with M6. Poor results were obtained for other combinations. If we consider the combination of SWIR bands with all MWIR bands, bands S4 and S3 get the highest number followed by S5, S7 and S6. If the combination process considers the characteristics, band S4 comes first followed by S3, S7, S5 and S6 when the sum of all MWIR bands is performed. Order is similar with the exception of the inversion of bands S5 and S7. S6 keeps the last rank.

The bands S3 and S4 are the best SWIR bands to observe explosions. Discrimination is possible using one of these two bands. It is normal to see similar result for these two bands. Their spectral bandwidth is similar S3 (3290 – 3690 cm^{-1}) and S4 (3226 – 3690 cm^{-1}).

Bands M3 to M6 have similar results according to the Table 31. Band M5 is characterized by the largest spectral bandwidth. Its bandwidth includes bands M3 and M4 together. M6 is situated outside this spectral region. According to the combination described above, the results are still similar. In both cases, M6 is the best band to discriminate the explosions. It is followed by bands M4, M5 and M3.

3.2.2 Ratio Method

The ratio method consists of analysing the ratio between the values of ITC characteristics of a SWIR band with a MWIR band. An average and the RSD are evaluated from the ratio values of each event considered. With the same method as single band, the RSD value is used to evaluate if it is a representative value or not. A summary of the number of representative values for the ratio of LEGACY bands for PIRATES measurements during NLII is given in Table 32. Each row corresponds to the number of times, where at least one characteristic has the corresponding RSD. The first row represents the name of the bands. The first number is the SWIR band and the last is the MWIR band. Table 33 shows the sum of the representative values in Table 32 for each LEGACY bands. In this table, the sum is done with and without considering band M7.

Table 32 : Number of representative values of the ratio of intensity – time curves characteristics for each LEGACY band for PIRATES measurements during NLII trial.

SWIR/ MWIR	3/ 3	3/ 4	3/ 5	3/ 6	3/ 7	4/ 3	4/ 4	4/ 5	4/ 6	4/ 7	5/ 3	5/ 4	5/ 5	5/ 6	5/ 7	6/ 3	6/ 4	6/ 5	6/ 6	6/ 7	7/ 3	7/ 4	7/ 5	7/ 6	7/ 7
5%	9	7	7	14	10	9	7	7	14	8	7	8	10	10	10	5	6	7	10	12	6	6	7	8	14
10%	12	14	14	16	8	12	13	13	16	8	13	15	14	16	14	11	13	12	14	15	8	11	12	15	15
15%	11	12	12	13	11	12	14	14	12	12	14	14	14	12	13	13	12	14	15	15	9	11	11	10	14
Σ	32	33	33	43	29	33	34	34	42	28	34	37	38	38	37	29	31	33	39	42	23	28	30	33	43

Table 33 : Sum of the representative values from the ratio between LEGACY bands for PIRATES measurements during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
With M7	170	171	184	174	157	151	163	168	195	179
Without M7	141	143	147	132	114	151	163	168	195	0

Table 33 shows that the best SWIR band is S5 considering or not the band M7. This band is followed by S6, S4, S3 and S7 with M7. Without band M7 the order is S4, S3, S6 and S7. This shows that band M7 as a major importance for bands S6 and S7. For the M bands, M6 is still in the first rank, followed by M7, M5, M4 and M3.

Table 32 shows a different result. The best results are obtained by the ratio from bands S3 and S4 with band M6. This result is the same as observed with the single band method. The same number is obtained for bands S6 and S7 with band M7. However, these bands are the worst when considered alone. Also, bands S6 and S7 are really affected if the combinations with band M7 are not considered contrarily to the other SWIR bands.

3.2.3 Northern Lights II – PIRATES measurements – conclusion

Results presented in this section demonstrate which SWIR and MWIR bands are the best to discriminate the different explosions. Single band method shows that band S4 has the highest number of representative value followed by bands S3 and S5 (refer to Table 31). The combination revealed that bands S3 and S4 with band M6 are the best followed by bands S3 and S4 with bands M4 and M5 and finally band S5 with band M6. The ratio method shows that band S5 has the highest number of representative values followed by bands S4 and S3 (refer to Table 33). Based on these conclusions, in the SWIR bands, S4 is considered the best. The results also demonstrate that bands S5 and S3 obtain good results. S5 gets the first rank in the ratio method and S3 occupies the rank below band S4 for the single and ratio method.

In the MWIR bands, M6 is the best band to discriminate the explosions followed by M4 and M5. This conclusion is based on the single and ratio method results. M7 had a good results based on the ratio method. However, this same method shows that band M7 is sensitive and it is the worst if considered alone.

This conclusion is based only on the ITC characteristics. Spectral analysis should be done to evaluate if these bands present specific spectral structure.

3.3 Northern Lights II – AIRIS measurements

ITC were evaluated as described in section 2. The curves start two frames before the beginning of the explosion and t=0 ms corresponds to the first frame with the explosion. The two frames before t=0 ms correspond to the background intensity.

Composition, charge, shape and material of the container are known for the events of NLII. These elements will be discussed for each method. Many events are not usable for analysis due to the saturation of the sensor AIRIS as observed by Fasquelle [3]. So, the current analysis will be based only on events 14, 15 and 17 to 20. These events are highlighted in yellow in Table A-2.

Contrarily to PIRATES, particular shape is observable on ITC to discriminate the elements of the explosions. This will be shown in the following section.

3.3.1 Single band method

Only events 14, 15 and 17 to 20 can be analyzed. So, each element cannot be taken separately. Combination of elements will be analyzed. There are only two compositions, 150 kg of mix 2 and 20 kg of mix 4. So, direct comparison cannot be performed. Analysis will be presented for mix 2, mix 4 and together to compare the common element.

Mix 2:

Events taken into account are 17 to 20. These events are with a charge of 150 kg of mix 2 and different shape and material container. No representative value is identified if all these events are considered at the same time. So, they are separated for analysis. Table 34 shows the average values of characteristics of the events 17, 19 and 20 using a charge of 150 kg of mix 2 in spherical container of three materials (steel, aluminum and polyethylene) for several bands. Table 35 shows the average values of characteristics of events 17 and 19 using a charge of 150 kg of mix 2 in spherical containers of aluminum and polyethylene for several bands. Table 36 shows the average values of characteristics of events 17 and 18 using a charge of 150 kg of mix 2 in a container of polyethylene for several bands.

Table 34 : Average values of intensity – time curves characteristics of 150 kg of mix 2 in spherical containers of steel, aluminum and polyethylene based on events 17, 19 and 20 measured by AIRIS during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	491.27	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	0.00	0.00	1.53	0.00	0.00	0.00	0.00	2.09
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09
FDHM	0.00	0.00	0.00	654.02	650.24	1169.50	1069.18	1043.48	899.55	665.78
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	769.62	729.67	721.04	1245.82	1156.43	1137.11	963.07	745.61
positen	0.00	0.00	1535.45	1365.26	1314.96	0.00	0.00	0.00	1976.80	1601.92

Table 35 : Average values of intensity – time curves characteristics of 150 kg of mix 2 in spherical containers of aluminum and polyethylene based on events 17 and 19 measured by AIRIS during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	344.10	0.00	0.00	0.00	511.50	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	64.64	149.95	156.91	0.00
tauA	0.00	0.00	0.00	0.00	0.00	17.29	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	1.99	1.99	0.00	0.00	0.00	2.31	1.98	2.23
tautauA	0.00	0.00	0.00	0.00	0.00	1.12	1.17	1.09	0.00	1.02
FDHM	0.00	0.00	0.00	0.00	0.00	1144.38	0.00	0.00	888.59	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	2.87E+07	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	1232.50	1139.56	1120.06	956.38	0.00
positen	0.00	0.00	1635.92	1451.45	1387.41	0.00	2647.90	2652.94	2098.57	1704.01

Table 36 : Average values of intensity – time curves characteristics of 150 kg of mix 2 in a container of polyethylene based on events 17 and 18 measured by AIRIS during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	25768.79	70230.82	171440.90	157442.70	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	0.00	0.00	67.28	172.60	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauAB	0.00	0.00	0.00	0.00	0.00	1.45	0.00	0.00	0.00	0.00
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Itotal	5.65E+07	7.13E+07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

By considering uniquely the events with a spherical shape (Table 34 and Table 35), many representative values are found. However, the results differ when considering three materials (Table 34) or only two (Table 35). The characteristics and the relative standard deviation (RSD) associated with them are different. Without event 20 with the container of steel (Table 35), the

accuracy of the ITC characteristic increases and more representative values are found. Other combinations of materials did not give significant results.

Just a few representative values are found for events 17 and 18 with a charge of 150 kg of mix 2 in a polyethylene container as shown in Table 36. This result demonstrates the importance of the container shape on the ITC.

Figure 14 shows the ITC of events 17 to 20 for the band S4 measured by AIRIS during NLII. The curve of event 20 has a similar shape to events 17 and 19 but the curve of event 20 contains two dominant peaks. Events 17, 19 and 20 had spherical containers. That explains the difference between the Table 34 and Table 35 results. As seen in the Table 36, it is also possible to see the impact of the container shape by comparing event 18 with the others. The curve of event 18 (cylindrical shape) is narrow and the one of events 17, 19 and 20 are wider (spherical shape).

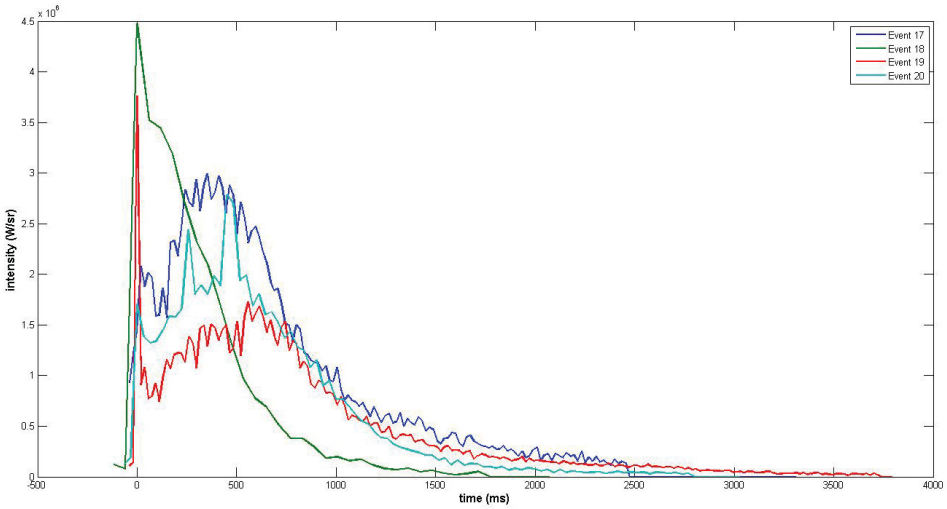

Figure 14 : Intensity – time curves for band S4 of events 17 to 20 during NLII measured by AIRIS.

Mix 4:

Analysis of mix 4 is based on events 14 and 15. These events were performed with a charge of 20 kg in spherical containers made of steel and aluminum. Average values of characteristics of events 14 and 15 using a charge of 20 kg of mix 4 in spherical containers of steel and aluminum for several bands are presented in Table 37.

Table 37 : Average values of intensity – time curves characteristics of 20 kg of mix 4 in spherical containers of steel and aluminum based on events 14 and 15 measured by AIRIS during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	4.73E+04	0.00	5.60E+04	6.48E+05	2.49E+05	9.34E+03	2.22E+04	5.31E+04	4.38E+04	8.89E+04
Imaxtime	0.00	0.00	0.00	0.00	223.20	0.00	306.90	297.60	297.60	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	43.64	107.73	87.44	0.00
tauA	0.00	0.00	0.00	0.00	704.18	9.90	28.28	67.61	71.81	0.00
tauB	62.62	69.82	75.77	1209.02	0.00	6.85	20.26	48.26	54.60	136.43
tauAB	0.00	0.00	0.00	0.00	1.44	1.44	1.40	1.40	1.32	0.00
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	1.54	1.59	1.22	0.00
FDHM	0.00	0.00	453.01	401.65	391.06	696.62	678.50	669.72	584.86	403.69
Imaxfdhm	0.00	0.00	123.45	1620.30	0.00	13.42	32.71	79.30	74.92	220.25
Itotal	1.72E+07	0.00	2.69E+07	2.75E+08	1.02E+08	7.34E+06	1.64E+07	3.87E+07	2.71E+07	4.22E+07
posihalf	0.00	0.00	463.54	411.45	399.94	723.65	699.26	690.39	603.32	411.88
positen	831.18	851.02	829.01	733.32	681.75	1478.73	1293.51	1288.50	1020.02	791.44

Contrarily to the mix 2, many representative values are found for these events. Figure 15 shows the ITC of events 14 and 15 for band S4 measured by AIRIS during NLII. The curves are similar except the two dominant peaks for the event 15.

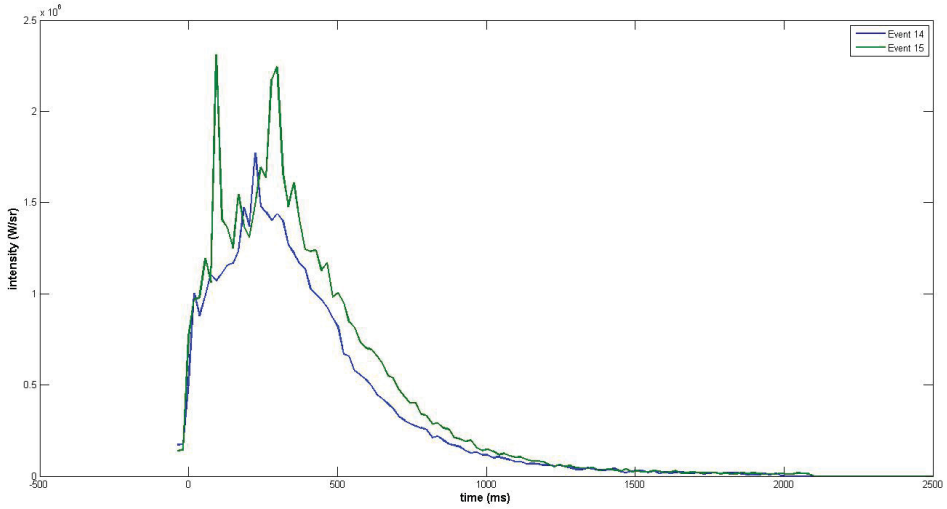

Figure 15 : Intensity – time curves for band S4 of events 14 and 15 during NLII measured by AIRIS.

Mix 2 and mix 4:

Events available for analyzing mix 2 and mix 4 were performed using spherical container. These containers are made of steel or aluminum. Table 38 shows the average values of characteristics of event 15 (charge of 20 kg of mix 4) and 20 (charge of 150 kg of mix 2) using spherical containers of steel, for several bands.

Table 39 shows the average values of characteristics of event 14 (charge of 20 kg of mix 4) and 19 (charge of 150 kg of mix 2) using spherical containers of aluminum for several bands.

Disregarding the charge used for explosions, few ITC characteristics are found in Table 38 and Table 39 to discriminate the spherical container of steel and spherical container of aluminum.

Spherical container of steel can also be recognized by the ITC. Figure 14 and Figure 15 show dominant peaks in the curve of events 15 and 20. No specific shape is observable for the container in aluminum.

Table 38 : Average values of intensity – time curves characteristics of event 15 (charge of 20 kg of mix 4) and 20 (charge of 150 kg of mix 2) in spherical containers of steel measured by AIRIS during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	5.35E+04	6.71E+04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tauA	0.00	0.00	0.00	0.00	719.56	10.20	29.47	71.16	0.00	0.00
tauB	58.27	73.35	0.00	1263.24	0.00	7.85	0.00	0.00	62.10	0.00
tauAB	0.00	0.00	0.00	0.00	1.49	0.00	0.00	0.00	1.29	1.86
tautauA	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	126.11	1550.32	592.46	13.25	36.25	88.71	0.00	0.00
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 39 : Average values of intensity – time curves characteristics of event 14 (charge of 20 kg of mix 4) and 19 (charge of 150 kg of mix 2) in a spherical containers of aluminum measured by AIRIS during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
Imax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxtime	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	320.21
tauA	0.00	0.00	121.46	1700.36	0.00	0.00	0.00	0.00	0.00	0.00
tauB	0.00	0.00	0.00	0.00	0.00	6.46	19.44	46.46	48.77	129.06
tauAB	0.00	0.00	0.00	0.00	1.36	0.00	0.00	0.00	0.00	0.00
tautauA	0.00	0.00	0.00	0.00	0.00	0.00	1.39	0.00	0.00	0.00
FDHM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaxfdhm	0.00	0.00	0.00	0.00	0.00	14.31	0.00	0.00	82.52	229.69
Itotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
posihalf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
positen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.3.1.1 Single band method conclusion

A summary of the number of representative values for each LEGACY band for AIRIS measurement during NLII is given in Table 40. Each row corresponds to the number of times where at least one ITC characteristic (Table 3) has the corresponding relative standard deviation (RSD).

Table 40 : Number of representative values of intensity – time curves characteristic for each LEGACY band for AIRIS measurements during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
RSD=[0, 5%]	2	3	3	2	2	4	4	2	2	3
RSD=]5, 10%]	1	1	2	3	3	4	4	5	4	1
RSD=]10, 15%]	1	1	2	2	4	4	4	3	5	3
sum	4	5	7	7	9	12	12	10	11	7

Table 40 shows that band S7 has the highest number of representative values of ITC characteristics with a RSD under 15% for SWIR bands. The number decreases for other bands as follow: S6, S5, S4 and S3. For the MWIR bands, M3 and M4 have the highest number, followed by M6, M5 and M7. The rank of each band changes if each RSD is considered separately.

The SWIR bands were combined with the MWIR bands, as explained at the section 3.1.1, to show which combination has representative values for the same case. Combination does not consider the values of RSD and the characteristics. If combinations of SWIR bands with all MWIR bands are considered, bands S5, S6 and S7 get the highest number followed by S4 and S3.

If the combination process considers the characteristics, band S7 comes first followed by S6, S5, S3 and S4, when the sum of all M bands is performed.

The best band to discriminate the explosions cannot be chosen with this data. Not enough cases and information can be used to realize a good analysis. Also, the structure (two dominant peaks) noted in this section about the spherical container of steel in the Figure 14 and Figure 15 can be seen only in bands S3 to S6.

3.3.2 Ratio Method

The ratio method consists of analysing the ratio between the values of ITC characteristics of a SWIR band with a MWIR band. An average and the RSD are evaluated from the ratio values of each event considered. With the same method as single band, the RSD value is used to evaluate if it is a representative value or not. A summary of the number of representative values for the ratio of LEGACY bands for AIRIS measurements during NLII is given in Table 41. Each row corresponds to the number of times, where at least one characteristic has the corresponding RSD. The first row represents the name of the bands. The first number is the SWIR band and the last is the MWIR band. Table 42 shows the sum of the representative values in Table 41 for each LEGACY bands. In this table, the sum is done with and without considering band M7.

Table 41 : Number of representative values of the ratio of intensity – time curves characteristics for each LEGACY band for AIRIS measurements during NLII trial.

SWIR/ MWIR	3/ 3	3/ 4	3/ 5	3/ 6	3/ 7	4/ 3	4/ 4	4/ 5	4/ 6	4/ 7	5/ 3	5/ 4	5/ 5	5/ 6	5/ 7	6/ 3	6/ 4	6/ 5	6/ 6	6/ 7	7/ 3	7/ 4	7/ 5	7/ 6	7/ 7
5%	1	1	1	5	4	1	2	1	5	4	4	4	6	6	7	4	5	5	6	7	3	5	6	5	7
10%	3	5	4	2	2	2	5	5	2	2	4	6	6	7	7	4	6	6	6	7	5	6	4	5	6
15%	2	2	2	1	1	2	1	1	0	2	5	7	6	4	5	4	7	6	5	6	5	5	5	6	7
Σ	6	8	7	8	7	5	8	7	7	8	13	17	18	17	19	12	18	17	17	20	13	16	15	16	20

Table 42 : Sum of the representative values from the ratio between LEGACY bands for AIRIS measurements during NLII trial.

	S3	S4	S5	S6	S7	M3	M4	M5	M6	M7
With M7	36	35	84	84	80	49	67	64	65	74
Without M7	29	27	65	64	60	49	67	64	65	0

Table 42 shows that the best S band is S5 considering or not band M7. This band is followed by S6, S7, S3 and S4 with and without band M7. These results show that band M7 does not have a major impact contrarily to the PIRATES results. For the MWIR bands, M7 has the first rank, followed by M4, M6, M5 and M3.

Table 41 shows a different result. The best results are obtained by the ratio from bands S6 and S7 with band M7. This result is not the same as observed with the single band method. In the single band method, band M7 is the worst in the MWIR.

3.3.3 Northern Lights II – AIRIS measurements – conclusion

From these results, it is not possible to choose which LEGACY bands are the best to discriminate explosions. The conclusion with the single band and the ratio method are not the same. Also, the conclusion is not the same from AIRIS and PIRATES analysis. The differences between the conclusions could be attributed to the position of observation of both sensors (altitude = 0 m and a side view of the event for PIRATES while AIRIS was at 3000 m above ground in a NADIR perspective from the event). However, representative values were found for the characteristics of the ITC.

3.4 Explosions discrimination conclusion

During Northern Lights I and II, explosions were measured by imaging systems AIRIS and PIRATES. Fasquelle [3] has shown that it is possible to identify the elements of an explosion from AIRIS measurements during NLII. The same analysis was performed considering the bands of sensor LEGACY. This sensor used one band in the SWIR and another one in the MWIR at the same time. Multiple choices and combinations of bands were available for measurements. This work was conducted to find out which band(s) is (are) the best to discriminate explosion elements such as: charge, composition, container shape and container material. The analysis was based on the characteristics of the ITC considering a single band, combinations and ratios of SWIR bands and MWIR bands.

General conclusions from the analysis of each trial are described below. Table 43, Table 44 and Table 45 summarize the conclusions for each dataset under study, NLI measured by PIRATES and NLII measured by PIRATES and AIRIS. Bands are listed for the SWIR and MWIR in order (first is the best and last the worst) for each method. Single band method corresponds to the results obtained by evaluating the number of representatives values for each band (refer to Table 11, Table 31 and Table 40). Combination method corresponds to the results obtained by evaluating combination between the SWIR bands and MWIR bands (refer to sections 3.1.1.2, 3.2.1.5 and 3.3.1.1). Ratio band method corresponds to the results obtained by evaluating the number of representatives values from the ratio between a SWIR band and a MWIR band (refer to Table 12, Table 13, Table 32, Table 33, Table 41 and Table 42).

NLI events were only measured by PIRATES. Only the composition is known for all events. From the single band method, bands S4 and S5 can be used to discriminate all compositions with the characteristic tauAB (see Table 10). Considering the number of times, where at least one ITC characteristic has the corresponding relative standard deviation (RSD) (see Table 11), bands S5, M4 and M5 have the highest number. Based on all results, band S5 is the best SWIR band to observe explosions. Bands S6 and S7 follow. Bands M4 to M5 have similar results according to the Table 11. According to the combinations, bands M4 and M5 get the second rank behind band M3. Bands S5, M5 and M6 get the first rank using the ratio method. From these results, bands S5 and M5 are the best to discriminate the different compositions considering the PIRATES measurements during NLI. These conclusions and more are summarized in Table 43.

Table 43: Conclusion summary for NLI PIRATES measurements

Method	SWIR Band	MWIR Band
Single Band	S5, S6, S7, S4, S3	M4, M5, M6, M3, M7
Combination	S5, S7, S6, S4, S3	M3, M4, M5
Ratio Band	S5, S3, S6, S4, S7	M5, M6, M7, M4, M3

NLII events were measured by both PIRATES and AIRIS systems. All elements are known for the majority of explosions. This first analysis was based on the PIRATES measurement. From the single band method, bands S3 and S4 are the best SWIR bands to observe explosions. Discrimination is possible using one of these two bands. It is normal to see similar results for these two bands. Their spectral bandwidth is similar: S3 (3290 – 3690 cm^{-1}) and S4 (3226 – 3690 cm^{-1}). For the MWIR bands, M6 gets the first rank followed by M4 and M5. The ratio method puts band S5 first, followed by bands S3 and S4. Band M6 keeps the first rank followed by M7 and M5. From these results, bands S3, S4 and M6 are the best to discriminate the different explosions considering the PIRATES measurements during NLII. These conclusions and more are summarized in Table 44.

Table 44: Conclusion summary for NLII PIRATES measurements

Method	SWIR Band	MWIR Band
Single Band	S4, S3, S5, S7, S6	M6, M3, M5, M4, M7
Combination	S4, S3, S5, S7, S6	M6, M4, M5, M3
Ratio Band	S5, S4, S3, S6, S7	M6, M7, M5, M4, M3

Based on AIRIS measurements during NLII, the single band method gives the best position to bands S7, S6, S5, M3 and M4. In opposite, the ratio method gives band S5 the first rank, followed by bands S6 and S7. The sequence order for the M bands is M7, M4, M6 and M5. From these results, it is not possible to choose which LEGACY bands are the best to discriminate the explosions. The order for each band with the single band and the ratio method are not the same. However, bands S5 to S7 and band M4 are still the best in both cases. These conclusions and more are summarized in Table 45.

Table 45: Conclusion summary for NLII AIRIS measurements

Method	SWIR Band	MWIR Band
Single Band	S7, S6, S5, S4, S3	M3, M4, M6, M5, M7
Combination	S7, S6, S5, S4, S3	
Ratio Band	S5, S6, S7, S3, S4	M7, M4, M6, M5, M3

Overall, considering the rank of each analysis, band S5 is the best SWIR band followed by S4. M4 is the best MWIR band followed by M5 and M6. M4 and M5 are equivalent to discriminate explosions when only results from PIRATES are considered. These results agree with the use of bands S4 and M5 by LEGACY during the NLII trial. Band S7, which was also used during NLII,

obtained the best rank from the analysis of AIRIS measurements. Conclusions are not the same from AIRIS and PIRATES analysis. The differences can be attributed to the positions of the observation of both sensors (altitude = 0 m and side view for PIRATES and 3000 m above ground and NADIR view for AIRIS). The analysis also demonstrates that LEGACY bands S2, M1 and M2 are not usable to discriminate due to their positions in a poor spectral transmission region.

Contrary to the study of Fasquelle [3], the conclusions of this report are only based on the ITC characteristics. No spectral analysis was performed to confirm with the measurement technique of LEGACY. Important information on the explosion elements was also missing for each trial. Only the composition was studied for both NLI and NLII. Charge, container shape and container material were not analyzed for NLI. Only NLII PIRATES' data gave a good diversity for analysis. More events, complete with all details about the explosion elements, would be necessary to improve the analysis accuracy and the identification values of each explosion element.

4 Conclusion

Hyperspectral data were collected from explosions events during the Northern Lights I (2002) and II (2005) trials at DRDC Suffield with AIRIS and PIRATES imaging systems. In this report, intensity – time curves were processed for each event considering or not the atmospheric transmittance. These curves were evaluated for the entire band of AIRIS and PIRATES and for each LEGACY bands. An analysis of the transmittance corrected intensity – time curves for LEGACY bands was conducted to identify which bands are the best to discriminate the explosion elements (charge, composition, container shape and container material). The analysis demonstrates that it is possible to discriminate explosion elements using LEGACY bands.

No problem was encountered during the evaluation of the intensity – time curves for every explosions measured during the trials. However, missing information on the description of the explosions events made difficult the identification of the most discriminating LEGACY bands. More data should be collected in the future to improve the accuracy of this discrimination process. This work has demonstrated the capabilities of the LEGACY sensor to discriminate between explosion elements. Further development efforts could improve these capabilities.

References

[1] Minnis, P. (n.d.). Nasa Langley cloud and radiation research. Retrieved June 2010, from http://www-angler.larc.nasa.gov/cgi-bin/satimage/sounding.cgi

[2] Benjamin, S. (n.d.). Earth System Research Laboratory Rapid Update Cycle (RUC). Retrieved 06 2010, from http://ruc.noaa.gov/

[3] Fasquelle, F., “L’identification d’explosif par imagerie hyperspectrale : Spectromètre par transformation de Fourier aéroporté”, mémoire de maîtrise, Université Laval, 2006.

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Annex A Explosions events during Northern Lights

Table A-1: Northern Lights I (2002)

Event	Shot Number	Date Time Group	Test Article	Location
1	I-2	23-Sep-2002 18:07:15	Mix 2 – 5 US gallon drum	GZ – 1.4 meter HOB
2	I-3	23-Sep-2002 19:35:52	Mix 2 – 5 US gallon drum	GZ – 1.4 meter HOB
3	I-1	23-Sep-2002 20:28:30	C-4 – 5 US gallon drum (25 Kg)	GZ – 1.4 meter HOB
4	I-4	24-Sep-2002 14:23:30	Mix 3a – 5 US gallon drum	GZ – 1.4 meter HOB
5	I-5	24-Sep-2002 16:04:41	Mix 3b – 5 US gallon drum, excess fluid on top decanted off	GZ – 1.4 meter HOB
6	I-6	25-Sep-2002 15:41:05	Mix 1 – 5 US gallon drum	GZ – 1.4 meter HOB
7	I-7	25-Sep-2002 16:17:36	Mix 1 – 5 US gallon drum	GZ – 1.4 meter HOB
8	I-8	25-Sep-2002 16:48:36	TNT – 5 US gallon drum , 29.356 Kg (1.61 g/cc)	GZ – 1.4 meter HOB
9	I-9	25-Sep-2002 17:13:32	TNT + 20% Aluminum, 5 US gallon drum, 30.516 Kg (1.71 g/cc)	GZ – 1.4 meter HOB
10	I-10	26-Sep-2002 14:24:59	C-4 – 5 US gallon drum (25 Kg)	GZ – 1.4 meter HOB
11	(I-14)	26-Sep-2002 15:42:05	Nitro Methane	GZ – 1.4 meter HOB
12	I-13	26-Sep-2002 17:28:50	Hoce-bomb	GZ – 1.4 meter HOB
13	I-11	27-Sep-2002 13:59:53	Mix 3a – 5 US gallon drum	GZ – 1.4 meter HOB
14	I-12	27-Sep-2002 17:32:48	Mix 3b – 5 US gallon drum	GZ – 1.4 meter HOB
15	II-1	28-Sep-2002 14:27:14	C-4 – 30 US gallon drum (150 Kg)	GZ – 2.6 meter HOB
16	II-2	28-Sep-2002 16:40:47	Mix 2 (~150 Kg)	GZ – 2.6 meter HOB
17	II-3	28-Sep-2002 18:21:10	FAE 4 – 66 Liter	GZ – 2.6 meter HOB
18	II-4	01-Oct-2002 16:27:45	Mix 3a – 30 US gallon drum	GZ – 2.6 meter HOB
19	II-5	01-Oct-2002 18:00:45	Mix 1 – 30 US gallon drum	GZ – 2.6 meter HOB
20	II-6	02-Oct-2002 14:39:10	System 2 – Oscar	GZ - ??
21	II-7	02-Oct-2002 19:38:10	DIA1 – AN-Al, 1100 kg (80/20) + 20 lb C4	GZ – 1.4 meter HOB
22	II-8	03-Oct-2002 19:09:50	DIA2 – AN-Al-S, 1100 kg (45/45/10) + 60 Kg C4	GZ – on the ground
23		03-Oct-2002 21:13:28	FAE 4 – 66 Liter	GZ – 2.6 meter HOB
24	I-16	04-Oct-2002 15:38:04	C-4 – 5 US gallon drum (25 Kg)	GZ – on ground

Table A-2: Northern Lights II (2005)

event	Jul-05	MDT	GMT	Target[1]	AIRIS Altitude (m)	PIRATESS	Legacy SWIR-MWIR bands
NL1	11	8:45	14:45	20k-C4-Sph-Pol	n.a.	ok	4-5
NL2	11	13:47	19:47	20k-M1-Cyl-Pol	*3024*	ok	7-5
NL3	11	17:56	23:56	20-M2-Sph-Pol	*3046*	ok	n.a.
NL4	12	10:30	16:30	20-M2-Cyl-Pol	n.a.	ok	n.a.
NL5	12	14:09	20:09	20k-M4-Sph-Pol	*3116*	ok	4-5
NL6	12	16:04	22:03	20k-M4-Cyl-Pol	*3092*	ok	7-5
NL7	13	9:24	15:24	20k-T1-Cyl-Pol	n.a.	ok	n.a.
NL8	13	13:39	19:39	20k-T1-Sph-Pol	n.a.	ok	n.a.
NL9	13	15:35	21:35	20k-T2-Sph-Pol	n.a.	ok	x-x
NL10	13	18:24	00:24	20k-T2-Cyl-Pol	n.a.	ok	n.a.
NL11	14	8:29	14:29	20k-M2-Cyl-Ste	n.a.	ok	n.a.
NL12	14	13:36	19:35	20k-M2-Sph-Alu	*5260*	ok	4-5
NL13	14	15:02	21:02	20k-M2-Sph-Ste	n.a.	ok	x-x
NL14	14	16:19	22:19	20k-M4-Sph/Alu	2794	ok	4-5
NL15	15	14:04	20:03	20k-M4-Sph/Ste	2779	ok	4-5
NL16	15	*15h40*	*21h40*	20k-M4-Cyl-Ste	n.a.	n.a.	n.a.
NL17	18	14:00	20:00	150k-M2-Sph-Pol	3049	ok	4-5
NL18	19	15:00	21:00	150k-M2-Cyl-Pol	2571	ok	7-5
NL19	20	13:41	19:41	150k-M2-Sph/Alu	2693	ok	7-5
NL20	21	13:32	19:32	150k-M2-Sph-Ste	2728	ok	4-5
NL21	22	15:18	21:18	150k-M2-Cyl-Ste	*2775*	ok	7-5

[1] Charge: 20k: 20 kg of explosive, 150k: 150 kg of explosive
Composition: C4: C4, M1: mix 1, M2: mix 2, M3: mix 3, M4: mix 4, T1 & T2 : TSWG 1 & 2
Charge shape: Cyl: cylindrical, Sph: spherical,
Container material: Alu: aluminum, Pol: polyethylene, Ste: steel

Annex B Atmospheric correction

During task 5, atmospheric parameters were estimated using MODTRAN. It uses input file with the extension .tp5. An example of .tp5 file for AIRIS and PIRATES are given below.

TP5 file for AIRIS

```
M   7    2    1    0    2    2    2    2    2    2    2    1    0    .000    .99
f    8   0   330.000   0.00000   0.00000 f t f
p1_2004
    1    0    0    0    0    0    23.000      .000      .000      .000      .780
   18    0    0DEFILTE RUN
 7.800E-01 9.238E+02 3.022E+02 3.072E+01  .000E+00  .000E+00AA2222222222222
 9.800E-01 9.000E+02 2.990E+02 3.114E+01  .000E+00  .000E+00AA2222222222222
 1.480E+00 8.500E+02 2.958E+02 2.102E+01  .000E+00  .000E+00AA2222222222222
 2.000E+00 8.000E+02 2.917E+02 1.547E+01  .000E+00  .000E+00AA2222222222222
 2.550E+00 7.500E+02 2.872E+02 1.731E+01  .000E+00  .000E+00AA2222222222222
 3.120E+00 7.000E+02 2.828E+02 2.846E+01  .000E+00  .000E+00AA2222222222222
 3.730E+00 6.500E+02 2.781E+02 4.073E+01  .000E+00  .000E+00AA2222222222222
 4.380E+00 6.000E+02 2.729E+02 6.631E+01  .000E+00  .000E+00AA2222222222222
 5.070E+00 5.500E+02 2.685E+02 7.996E+01  .000E+00  .000E+00AA2222222222222
 5.820E+00 5.000E+02 2.637E+02 7.224E+01  .000E+00  .000E+00AA2222222222222
 6.620E+00 4.500E+02 2.590E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
 7.510E+00 4.000E+02 2.537E+02 5.865E+01  .000E+00  .000E+00AA2222222222222
 8.490E+00 3.500E+02 2.471E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
 9.580E+00 3.000E+02 2.386E+02 7.865E+01  .000E+00  .000E+00AA2222222222222
 1.083E+01 2.500E+02 2.282E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
 1.228E+01 2.000E+02 2.159E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
 1.405E+01 1.500E+02 2.135E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
 1.663E+01 1.000E+02 2.168E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
    2.779     0.780   180.000     0.000      .000   6371.23    0        0.00000
     1800      5100       0.1       0.1tw       w2a sr
   0
```

```
TP5 file for PIRATES
M   7    2    1    0    2    2    2    2    2    2    2    1    0    .000    .99
f    8   0   330.000   0.00000   0.00000 f t f
p1_2004
    1    0    0    0    0    0    23.000      .000      .000      .000      .780
   18    0    0DEFILTE RUN
 7.800E-01 9.287E+02 2.987E+02 3.735E+01  .000E+00  .000E+00AAH222222222222
 1.020E+00 9.000E+02 2.948E+02 3.943E+01  .000E+00  .000E+00AAH222222222222
 1.510E+00 8.500E+02 2.903E+02 4.869E+01  .000E+00  .000E+00AAH222222222222
 2.030E+00 8.000E+02 2.861E+02 4.446E+01  .000E+00  .000E+00AAH222222222222
 2.560E+00 7.500E+02 2.815E+02 3.753E+01  .000E+00  .000E+00AAH222222222222
 3.130E+00 7.000E+02 2.767E+02 2.698E+01  .000E+00  .000E+00AAH222222222222
 3.720E+00 6.500E+02 2.718E+02 4.629E+01  .000E+00  .000E+00AAH222222222222
 4.360E+00 6.000E+02 2.683E+02 5.326E+01  .000E+00  .000E+00AAH222222222222
 5.040E+00 5.500E+02 2.652E+02 4.479E+01  .000E+00  .000E+00AAH222222222222
 5.770E+00 5.000E+02 2.617E+02 1.499E+01  .000E+00  .000E+00AAH222222222222
 6.570E+00 4.500E+02 2.572E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
 7.450E+00 4.000E+02 2.520E+02 1.811E+01  .000E+00  .000E+00AAH222222222222
 8.420E+00 3.500E+02 2.450E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
 9.510E+00 3.000E+02 2.373E+02 2.046E+01  .000E+00  .000E+00AAH222222222222
 1.076E+01 2.500E+02 2.314E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
 1.225E+01 2.000E+02 2.243E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
 1.410E+01 1.500E+02 2.163E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
 1.667E+01 1.000E+02 2.148E+02 0.000E+00  .000E+00  .000E+00AA2222222222222
    0.780     0.000    90.000     1.200      .000   6371.23    0        0.00000
     1800      5100       0.1       0.1tw       w2a sr
   0
```

Annex C Delivery package structure

All data, graphs and files required for processing are provided in the delivery package under the following structure. X represents the band for the evaluation of the total intensity. The entire sensor band is used if X has no value. In the other case, X corresponds to the LEGACY band.

- NLI(2002)
  PIRATESS
  - Event01
    - Folders
      - cns = calibrated data
      - igms = original data
      - PIRATESS : (.mat file = data, .fig file = graphics and other)
        DataPIRATESSX.mat and .fig = Intensity versus time
        DatacorPIRATESSX.mat and .fig = Intensity corrected versus time
        TransmittancePIRATESSX.mat = Transmittance versus cm^{-1}
        TransmittancePIRATESSwavenX.fig = Transmittance versus cm^{-1}
        TransmittancePIRATESSmicronX.mat and .fig = Transmittance versus micrometer
        IntensityfinalPIRATESSX = Intensity and intensity corrected versus time
        Result.txt = Information about intensity vs time
    - Files
      - profil.txt = atmospheric profile
      - transmittance.plt, .psc, .tp5, .tp6, .tp7, .7sr = files used and created by MODTRAN
      - e1.doc, e1_i.tiff and e1_t.tiff = images of the explosion
  - Event02
  - Event03
  - …
  - Event24

- NLII(2005)
  AIRIS
  - Event14
    - Folders
      - ari = calibrated data
      - cor = original data

      - AIRIS : (.mat file = data and .fig file = graphics)
        DataAIRISX.mat and .fig = Intensity versus time
        DatacorAIRISX.mat and .fig = Intensity corrected versus time
        TransmittanceAIRISX.mat = Transmittance versus cm^{-1}
        TransmittanceAIRISwavenX.fig = Transmittance versus cm^{-1}
        TransmittanceAIRISmicronX.mat and .fig = Transmittance versus micrometer
        IntensityfinalAIRISX = Intensity and intensity corrected versus time
        Result.txt = Information about intensity vs time

    - Files
      - profil.txt = atmospheric profile
      - transmittance.7sc, .plt, .psc, .tp5, .tp6, .tp7, .7sr = files used and created by MODTRAN
  - Event15
  - Event17
  - Event18
  - Event19
  - Event20

  PIRATESS
  - Event01
    - Folders
      - ari = calibrated data
      - PIRATESS : (.mat file = data and .fig file = graphics)
        DataPIRATESSX.mat and .fig = Intensity versus time
        DatacorPIRATESSX.mat and .fig = Intensity corrected versus time

TransmittancePIRATESSX.mat = Transmittance versus cm^{-1}
TransmittancePIRATESSwavenX.fig = Transmittance versus cm^{-1}
TransmittancePIRATESSmicronX.mat and .fig = Transmittance versus micrometer
IntensityfinalPIRATESSX = Intensity and intensity corrected versus time
Result.txt = Information about intensity vs time

- Files
  - profil.txt = atmospheric profile
  - transmittance.7sc, .plt, .psc, .tp5, .tp6, .tp7, .7sr = files used and created by MODTRAN
  - Event01.avi = explosion video
- Event02
- …
- Event21

- Algorithms
  The folder contains all algorithms to process data. File paths should be updated by the user.

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List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
FDHM	Full Duration Half Maximum
ITC	Intensity – time curve
MODTRAN	MODerate resolution atmospheric TRANsmission
MWIR	Medium Wave Infrared
NLI	Northern Lights I
NLII	Northern Lights II
SWIR	Short Wave Infrared
R&D	Research & Development
RSD	Relative Standard Deviation
RV	Representative value

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Hyperspectral data were collected for different explosions during the Northern Lights I (2002) and II (2005) trials at DRDC Suffield with the PIRATES imaging system. The AIRIS imaging system measured explosions only in 2005. In this study, intensity-time curves were processed for each event regardless of the atmospheric transmittance. The curves were evaluated for bands 2.04 to 5.26 μm for AIRIS and PIRATES and for each LEGACY band. Transmittance-corrected intensity- time curves for LEGACY bands were analyzed to identify which bands were the best to discriminate the explosion elements (charge, composition, container shape, and container material). Bands S4 and S5 for the short wave infrared detector and bands M4, M5, and M6 for the medium wave infrared detector were the best options to discriminate explosions according to all events. The bands S7 and M4 were considered the best only when AIRIS measurements were considered. The difference between results of both imaging systems is probably due to their different altitude and angle of observation. The conclusions agree with the use of the bands S4, S7, and M5 by LEGACY during the Northern Lights II trial.

This work was conducted in the framework of Public Works and Government Services Canada contract number W7701-092854/001/QCL on behalf of Defence Research and Development Canada –Valcartier. This work was also done in support of a classified project.

Des mesures hyperspectrales d'explosions ont été prises avec le système d'imagerie PIRATES lors des essais Northern Lights I (2002) et II (2005) à DRDC Suffield. Le système AIRIS a acquis des mesures uniquement en 2005. Dans ce rapport, la courbe d'intensité en fonction du temps de chaque événement est évaluée en corrigeant ou non l'impact de la transmission de l'atmosphère. Ces courbes sont estimées pour la bande 2.04 à 5.26 μm d'AIRIS et de PIRATES et pour chaque bande du capteur LEGACY. L'analyse des courbes d'intensité évaluées pour chaque bande de LEGACY et corrigées pour la transmission a été réalisée dans le but d'identifier quelles bandes sont les meilleures pour discriminer les caractéristiques de l'explosion (quantité, composition, forme et matériel du contenant). Les bandes S4 et S5 pour le détecteur infrarouge à ondes courtes et les bandes M4, M5 et M6 pour le détecteur infrarouge moyen sont les meilleures pour identifier les caractéristiques des explosions selon tous les événements analysés. Les bandes S7 et M4 sont identifiées les meilleures quand uniquement les données mesurées par AIRIS sont considérées. La différence entre les résultats des deux systèmes est probablement causée par leur altitude et angle d'observation différents. Les conclusions sont en accord avec l'utilisation des bandes S4, S7 et M5 par LEGACY lors de l'essai Northern Lights II.

Les travaux ont été menés dans le cadre du contrat W7701-092854/001/QCL émis par Travaux publiques et service gouvernementaux Canada pour le compte de Recherche et Développement pour la Défense Canada – Valcartier. Ce travail est également mené en support à un projet classifié.

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hyperspectral; AIRIS imaging; PIRATES imaging; LEGACY band; Northern Lights II trial; spectral and geospatial imagery

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