Comparison of Signalworks and BP Processing and Interpretation of ALF MkII Survey Data

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Summary

Several airborne laser fluorosensor (ALF) surveys were acquired by BP in Australia between 1990 and 1991 and originally processed by BP immediately after acquisition. The survey data was reprocessed by Signalworks Pty Ltd in 2000 and 2001 with significant differences in the number of oil fluorescence spectra (fluors) picked and oil seepage distributions interpreted.

A comparison of the data processing and interpretation techniques shows similar methods were used by both companies. The main difference with the Signalworks interpretation is that a larger number of lower confidence fluors were picked and used to determine the seepage distributions.

Low signal to noise ratio (S/N) in the MkII ALF spectra recorded by the system is the main cause of data analysis difficulties and differences between the two interpretations. This problem was greatly reduced in the later developed MkIII system, which resulted in more consistent interpretations between processing companies.

A problem with ALF surveys covering very large areas is the changing background fluorescence / Raman area ratios (F/R), which affects the distribution of picked fluors. Both BP and Signalworks use an averaging technique to determine the background F/R levels over the survey.

The BP analysis resulted in few picked fluors and little information about seepage patterns. The Signalworks analysis has attempted to pick sufficient fluors to define seepage patterns but is affected by the low S/N and background F/R patterns.

1. Introduction

Airborne laser fluorosensor (ALF) data acquired by BP in Australia between 1990 and 1991 was originally processed by BP immediately after acquisition and later reprocessed by Signalworks Pty Ltd in 2000 and 2001. Differences in the data processing sequences and interpretation methods have resulted in different seepage distributions. This report documents the data processing and interpretation methods used by each company and compares the differences between the fluorescence anomalies (fluors) picked.

The BP ALF data was acquired using the MkII acquisition system. Because of technical limitations with the available hardware, this system acquired data with a relatively low signal to noise ratio (S/N) leading to low interpretation confidence. The biggest S/N reduction was caused by the 10 spectra averaging stage used by the MkII system before data recording. This step was required to slow the recording requirements down to a rate that could be achieved by the available computer hardware. The averaging process tended to filter out the fluorescence response of small isolated oil films. This is demonstrated in Appendix 4 where a strong fluor identified on a MkIII ALF survey is averaged with adjacent non-fluorescing spectra.

The MkIII ALF system developed later by World Geoscience Corporation (WGC) significantly improved the S/N ratio by changing the wavelength of the excitation laser and recording the spectra at the full detection rate of 50Hz. This is reflected in the similarities between the interpretation results of WGC and Signalworks in more recent reports.

1.1 Specifications for ALF MkII and MkIII Acquisition Systems

Table 1 lists the technical specifications of the MkII and MkIII ALF acquisition systems.

Parameter	MkII	MkIII
Laser Type	Eximer	NdYAG
Laser wavelength	308nm	266nm
Frequency	50Hz	50Hz
Detector range	280-720nm	255-720nm
Detector channels	512	512
Recorded channels	176	176
Sample interval	15m (approx)	1.5m (approx)
Sample rate	5Hz (after 10 spectra averaging)	50Hz (no averaging used)
Navigation type	Inertial	GPS
Navigation accuracy	400m	5m
Raman peak	344nm	293nm
Fluorescence range	370-580nm	320-580nm

Table 1. Technical Specifications for the ALF MkII and MkIII Systems.

The sample rates for the recorded spectra were 5Hz for the MkII and 50Hz for the MkIII ALF acquisition systems. These correspond approximately to sample intervals of 15m and 1.5m, but depend on the flying speed of the acquisition aircraft.

2. ALF Data Processing

The ALF survey technique is used to detect oil seepage on the sea surface through the fluorescence response of the oil which can be identified on a recorded ALF spectrum. The shape of the recorded spectrum is the sum of other noise and signal responses as well as any oil fluorescence response. The addition of the other spectrum components interferes with the shape of the oil response and can make identification and analysis difficult. Table 2 lists many of the components of a typical spectrum.

ALF data processing stages usually applied to ALF data include:

1. correct noise and distortions in the recorded spectra
2. calculate diagnostic parameters from the ALF spectra
3. select records showing oil fluorescence response
4. estimate properties of the oil seepage based on the fluorescence response
5. map the oil seepage and oil property distributions

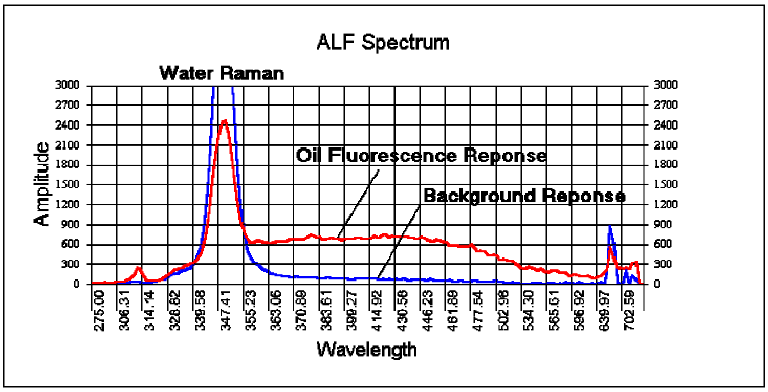


Figure 1. MkII ALF Spectrum Examples.

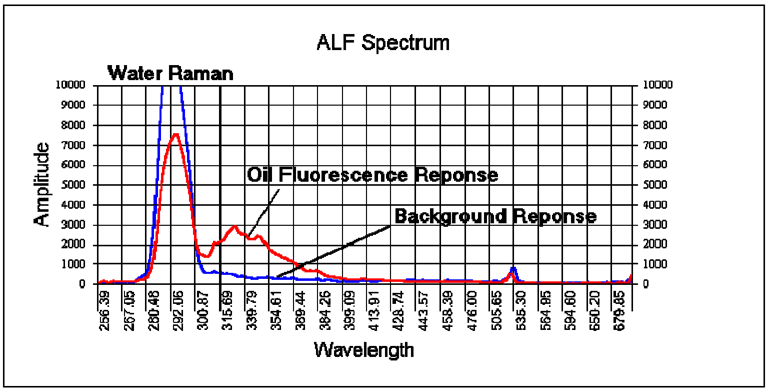


Figure 2. MkIII ALF Spectrum Examples.

Figures 2 and 3 show MkII and MkIII ALF spectrum examples. Non-fluorescing and fluorescing spectra are plotted in blue and red respectively. A very strong fluorescence example is shown in Figure1 to show the oil fluorescence response. A typical MkII fluor response is much weaker than this.

Factor	Effect	Treatment
Water composition & state:		
Water Raman	Characteristic peak at 344nm (293nm for MkIII)	Estimated response may be subtracted during detailed analysis
Water fluorescence	Weak response over oil fluorescence region	Estimated response may be subtracted during detailed analysis
Suspended matter fluorescence	May produce fluorescence response over oil fluorescence region	Use averaging to estimate background response
Water temperature	May affect Raman wavelength and water response	None in standard processing
Water salinity	May affect Raman wavelength and water response	None in standard processing
Sea state	Breaks up oil films	Preferably acquire data in calm seas (Beaufort 0-2)
Non-oil responses:		
Pollution fluorescence	Fluorescence response over oil fluorescence region	Identify from video records
Algae fluorescence	Fluorescence response over oil fluorescence region	Identify from video records
Sun glint	Fluorescence response over oil fluorescence region with high amplitudes at long wavelengths	Identify from spectrum response
Acquisition parameters:		
Laser power	Amplitude of detected spectra	Data normalised to a constant fixed laser power
Acquisition altitude	Amplitude of detected spectra (also affects focus of acquisition telescope)	Data normalised to a constant altitude
Acquisition speed	Distance between samples	None
Recording gain	Amplitude of detected spectra	Data normalised to a constant gain
Diode detector array response	Systematic distortions in the recorded spectra	Measure background response and diode sensitivity variations. Apply corrections.
Spectra averaging (MkII data)	10 spectra averaging (used on MkII data) attenuates size of isolated fluors	Apply more sensitive fluor detection methods
Recording system noise	Adds noise to the recorded spectra	Calculate noise level parameters and ignore noisy records
Oil response:		
Oil composition	Light components increase short wavelength response.	Use fluor shape for oil classification
Film thickness	Very thin films have weak fluorescence response	Attempt to detect weak fluors
Area of slick	Large slicks show fluorescence response of adjacent records	Detect adjacent or closely spaced fluors
Freshness of slick	Light components dissipate first and change the fluor shape	None in standard processing

Table 2. Factors Affecting Recorded ALF Spectra.

2.1 The BP Processing Sequence

BP developed the ALF MkII data acquisition system and data processing system used to map offshore oil seeps. The MkII system used a customised excimer laser which emits ultraviolet light at a wavelength of 308nm. The detected ALF spectra data is logged with navigation information and environmental data from other sensors. Every 10 detected spectra were averaged to reduce the data recording rate to match limitations of the available disk storage system.

2.1.1 Field Processing and QC

The raw data are transferred to a field computer for initial processing, back-up and quality control. Corrections are made for fluctuations in laser power and sensitivity differences in the detector array before writing the data to tape. The data is previewed to identify acquisition problems. The raw data backup tape and field processed tape are sent to the processing centre for further processing and analysis.

2.1.2 Incorporation of Navigation Data

Navigation data is logged at a slower rate than the ALF spectra during data acquisition. The navigation data is interpolated and latitude and longitude values are added to each recorded spectrum.

2.1.3 Calculation of Diagnostic Fluorescence Parameters

A set of four diagnostic fluorescence parameters are calculated from the recorded ALF spectra data:

Backscatter: The 308nm laser light that has been reflected directly from the sea surface.

Raman: Fluorescence response caused by scattering of the laser light by the water molecules. The Raman response forms a peak centred on a wavelength of 345nm.

Fluorescence: Oil fluorescence will have a response between 330 and 580nm. The area of the spectrum between 370 and 580nm provides and estimate of the fluorescence response with the Raman response excluded.

Fluorescence / Raman: The ratio of the fluorescence and Raman parameters, which tends to cancel the effects of fluctuating signal levels while producing large values for records showing oil fluorescence.

2.1.4 Data Analysis

Anomalous spectra are picked automatically using the calculated F/R ratio. Selection criteria are used in an attempt to discriminate between genuine fluorescing spectra and noisy records. The F/R value must be 2 to 3 times the peak to trough F/R noise along the line. The selected spectra should also be spatially discrete, as is expected for an oil patch on the sea surface caused by natural seepage.

Anomalous spectra are displayed and examined visually. Any records affected by noise such as sun-glint may be rejected. The background water response is subtracted from the spectrum to obtain the residual fluorescence that is due to the oil. The background response is obtained by averaging spectra from a clean section of the line close to the anomaly.

The fluorescence peak wavelength is determined by a curve fitting algorithm for well defined spectra or by manual estimation otherwise. The peak wavelength is used to categorise the “colour” of the fluor. A peak in the range 400 to 440nm is “indigo”, 440 to 480nm is “blue” and 480 to 520nm is “green”.

2.1.5 Fluor Characterisation

Each anomaly is recorded along with examples of adjacent background spectra. The anomalies are graded according to relative strength of the fluorescence peak. The four strength categories or classes are Weak, Low Moderate, High Moderate and Strong.

2.1.6 Documentation of Results

The BP ALF Interpreted Data report includes summaries of the ALF technique, data acquisition operations, interpretation method, interpretation results and conclusions. The selected fluors are tabled with location, fluor number code, class, wavelength, colour and comments. A map of the survey area is shown with survey lines and fluor picks plotted.

2.2 The Signalworks *ALF Explorer*™ Processing Sequence

The *ALF Explorer*™ processing and analysis system was developed by Signalworks Pty Ltd to extract oil seepage information from the raw ALF survey data. The system consists of a database linked to a set of processing, analysis and mapping modules. SQL queries and a scripting language are used to control data selection and processing stages among the separate modules.

The *ALF Explorer*™ processing sequence consists of six main steps from project preparation to fluor mapping. These steps are usually followed by geological model integration and documentation stages:

1. Project preparation
2. Data loading
3. Data QC
4. Fluor detection
5. Spectra parameter calculation
6. Fluor mapping
7. Geological model integration
8. Processing and Interpretation Report

2.2.1. Project Preparation

ALF surveys are supplied in a number of formats depending of the vintage of acquisition and the preliminary data processing that has been applied. The ASCII records usually have 175 spectrum channel fields but the header fields included in each record may differ. Table 2 shows the fields in each format. This table includes MkIII formats provided by World Geoscience Corp.

MkII (1) (BP 1989 short header)	**MkII (2)** (BP 1989 long header)	**MkIII (1)** (WGC 1994)	**MkIII (2)** (WGC 1997)	**MkIII (2)** (WGC 1998)
Line	Line	Line	Line	Line
Point	Point	Time	Flight	Flight
Longitude	Longitude	Point	Sortie	Sortie
Latitude	Latitude	Longitude	Date	Date
R	Backscatter	Latitude	Point	Point
F	Raman Peak	Lidar	Time	Time
F/R	Raman Area	Amplitude	Longitude	Longitude
Channel 1 to 175	Fluorescence Area	Flt/R	Latitude	Latitude
	F/R	Raman Peak	Lidar	Lidar
	Channel 1 to 175	Raman Area	Amplitude	Amplitude
		Fluorescence Area	Channel 1 to 175	Raman Area
		F/R		Channel 1 to 175
		Lmid		
		Fwidth		
		F/Rmean		
		Flr/Rmean		
		ResF/R		
		ResLmid		
		ResFlt /R		
		Rmean		
		Channel 1 to 175		

Table 3. ALF Survey Formats.

2.2.2. Data Loading

The raw ALF data is loaded into an ALF data table in the *ALF Explorer*™ database. This table is usually named “RawAlfData”. The ASCII data import function in Microsoft Access is used to rapidly read the data files into the table.

Additional raw data tables (RawAlfData2 etc) will be required for ALF MkII projects that use repeated survey line and point numbers within the same survey. Line and point values cannot be repeated within a data table because they are used to uniquely identify each ALF spectrum.

A separate data conditioning utility program may be required to convert unusual line and field delimiter strings into standard ones recognised by the Access import module. (The FixText program was developed and used by Signalworks Pty Ltd to do this.) The most common corrections required are removal of repeated delimiter characters (such as double spaces used instead of single spaces), mixing of different delimiters (tab character used as well as spaces), replacing the asterisk character with carriage return and line feed characters (CrLf) and replacing the line feed character (Unix end of line character) with the carriage return and line feed characters (Windows end of line characters). The conditioning program may also remove unwanted header characters.

2.2.3. Data QC

A table of line end points is automatically generated or updated in the *ALF Explorer*™ database each time the contents of an ALF data table are changed. This table can be viewed by selecting the Line End Points option from the Line Utilities menu.

Create Navigation Data Table:
A navigation data table is created in the database that contains the coordinates used to plot the survey lines. The spacing between plotted points is specified. Some lines consist of separate line segments having the same line name. A minimum gap between adjacent points is specified to indicate a break in a line.

Create QC Navigation Tables:
A table of navigation QC parameters is calculated for each line. The following four parameters are calculated at the selected point increment:
1. Lateral flight path deviation
2. In-line distance deviation
3. Altitude deviation
4. Aircraft speed

The selected point increment is usually set at 100.

ALF survey flight lines are usually planned to be straight. The lateral flight path deviation is a measure of how far the flight path has deviated from the straight line specified by the first and last points on the line.

ALF survey lines should ideally be flown at constant speed. The inline point deviation is a measure of the distance between a recorded point and its ideal location if the flying speed had been constant along the line.

Lines are programmed to be flown at a nominal altitude. The altitude deviation is the difference between the actual flying height and the programmed height.

The aircraft speed is calculated from the navigation data in the ALF record header fields.

The Navigation QC parameters are plotted for each line to quickly check for navigation problems.

Create QC Data Acquisition Tables:
A table of data acquisition QC parameters is calculated for each line. The following three parameters are calculated at the selected point increment:

1. Average Raman peak
2. Average Raman variance
3. Data clipping

The selected point increment is usually set at 100.

The Raman peak value is averaged over the point increment interval. This parameter provides an indication of the data recording level but is affected by the water properties.

The Raman variance is calculated over the point increment interval. Anomalously high variance values can indicate data acquisition problems.

Data clipping is indicated by Raman peak levels at or above the selected clipping level. Data clipping occurs when spectrum amplitudes are larger than the maximum value that can be recorded. When this occurs, the amplitude is clipped to the maximum recordable amplitude. The Raman response is usually the part of the spectrum with the highest amplitude and most likely to be clipped. Data clipping produces errors in the calculated Raman peak and area values. If the ALF records have been rescaled, the clipping level will vary and the clipping parameter will have reduced accuracy.

The Data Acquisition QC parameters are plotted for each line to quickly check for acquisition problems. These parameters can also be displayed on a map, which shows the QC parameters over the whole survey.

2.2.4. Fluor Detection

Fluor detection is achieved by selecting records from the raw data table using criteria based on the raw data fields or parameters calculated from these fields. SQL queries are used to make the selection. If required, the initial selections can be manually checked for record quality and identification confidence.

For a high quality MkIII ALF survey extending over a limited area, a simple fluor section criteria based on a ratio of spectra channels may be adequate. The selections can be checked manually and noisy or low confidence records rejected.

When a more sensitive method is required or the survey extends over a large area and is affected by regional F/R variations, the selection criteria can use addition parameters calculated from the raw records. The *ALF Explorer*™ software can calculate several parameters to assist fluor detection, including:

1. Backscatter area - (direct reflection of the laser beam by the water surface back to the detector)
2. Raman area (R)
3. Fluorescence area (F)
4. F/R ratio
5. Average F/R
6. Relative F/R (F/R / Average F/R)
7. Light fluor area (L)
8. Heavy fluor area (H)
9. L/H ratio
10. Backscatter area 2 - (secondary backscatter peak at double the main laser wavelength)
11. Fluorescence jitter (the average difference between samples in the fluorescence region. A measure of the noise level)
12. F jitter / F area
13. Maximum fluorescence jitter - (the maximum difference between samples)
14. Maximum F jitter / F area

An appropriate SQL query is designed to select potential fluors by restricting the allowable ranges of parameters.

2.2.5. Spectra Parameter Calculation

A number of additional spectra parameters can be calculated for the identified fluors. Using these parameters in map displays can help identify fluorescence patterns over the survey area.

Parameters that can be calculated from the detected fluors include:
1. Backscatter peak
2. Raman peak amplitude
3. Raman peak wavelength
4. Fluorescence peak amplitude
5. Fluorescence peak wavelength
6. Raman area (R)
7. Fluorescence area (F)
8. F/R ratio

The fluor detection parameter table also contains many useful spectra parameters that can be extracted for each identified fluor.

There are several ways of displaying spectra parameters. Cross-plotting Raman peak or area against the point along a line can show acquisition problems on the line. Cross-plotting F/R against the point along a line can show potential oil fluorescence records on a line. Plotting a histogram of F/R for the picked fluors shows the fluor size distribution for the survey.

2.2.6. Fluor Mapping

The *ALF Explorer*™ system includes a mapping module that is used to display the seepage distribution and patterns in the variation of fluor parameters. Spectra records can be interactively selected from the map display to investigate variations in the fluor shape.

Several cultural data overlays can be plotted along with the fluor parameter values on a map. The data overlay types include:
1. Survey lines
2. Easting – northing grid
3. Latitude – longitude grid
4. Wells
5. Permit boundaries
6. Map titles

The ALF spectrum parameters can be used to control the size and colour of a symbol at each spectrum location.

A map definition can be saved as a text script file. These files are easily edited to produce new maps.

3. Comparison of the Signalworks and BP Interpretations

ALF surveys processed by both BP and Signalworks are shown in green shading on the map below (Figure 3). More detailed maps over the Northern and Western Australia regions are shown in Figures 4 and 5. The areas shaded in blue are the more recent MkIII ALF surveys acquired and processed by World Geoscience Corporation and reprocessed by Signalworks. The MkII ALF data was supplied to Signalworks by Fugro Airborne Surveys.

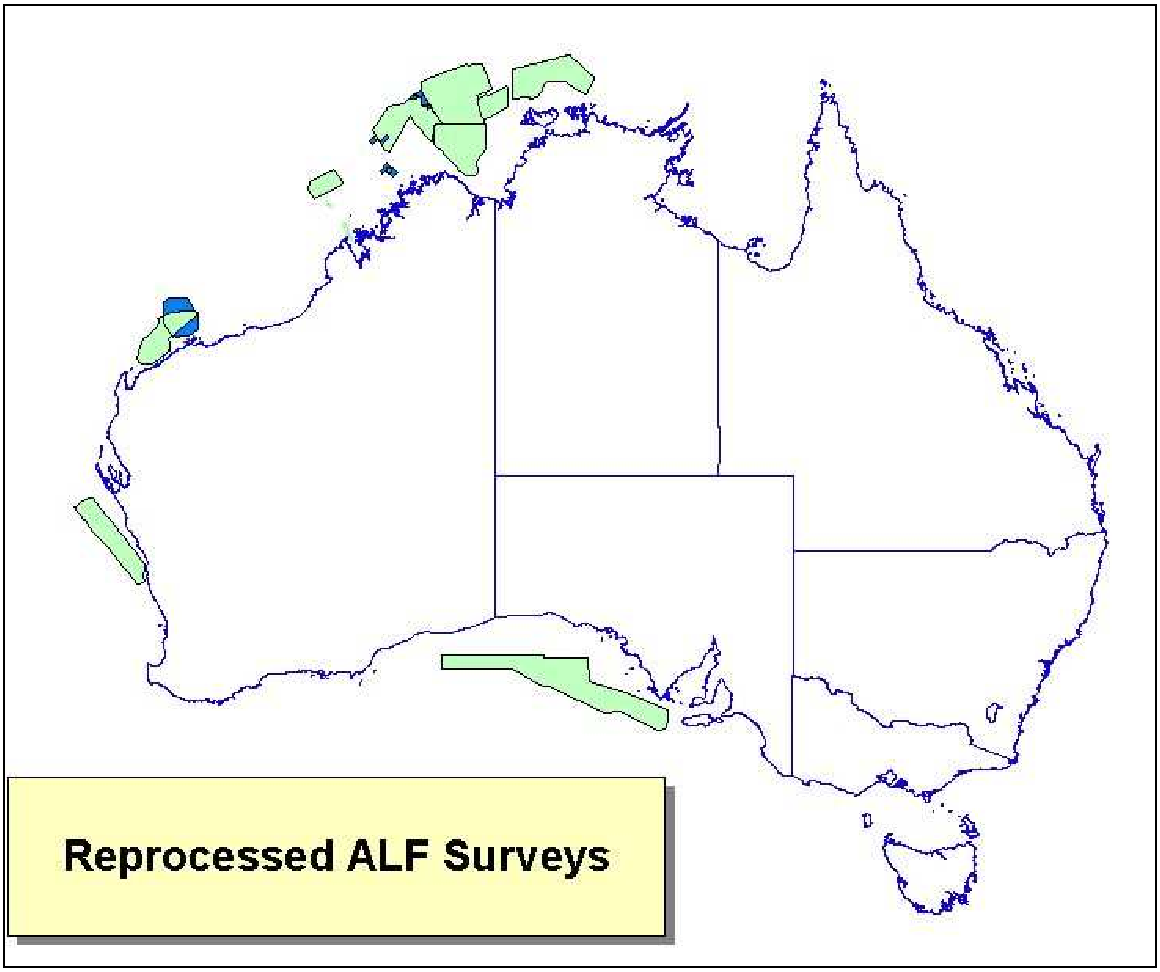


Figure 3. Location Map of Reprocessed ALF Surveys.

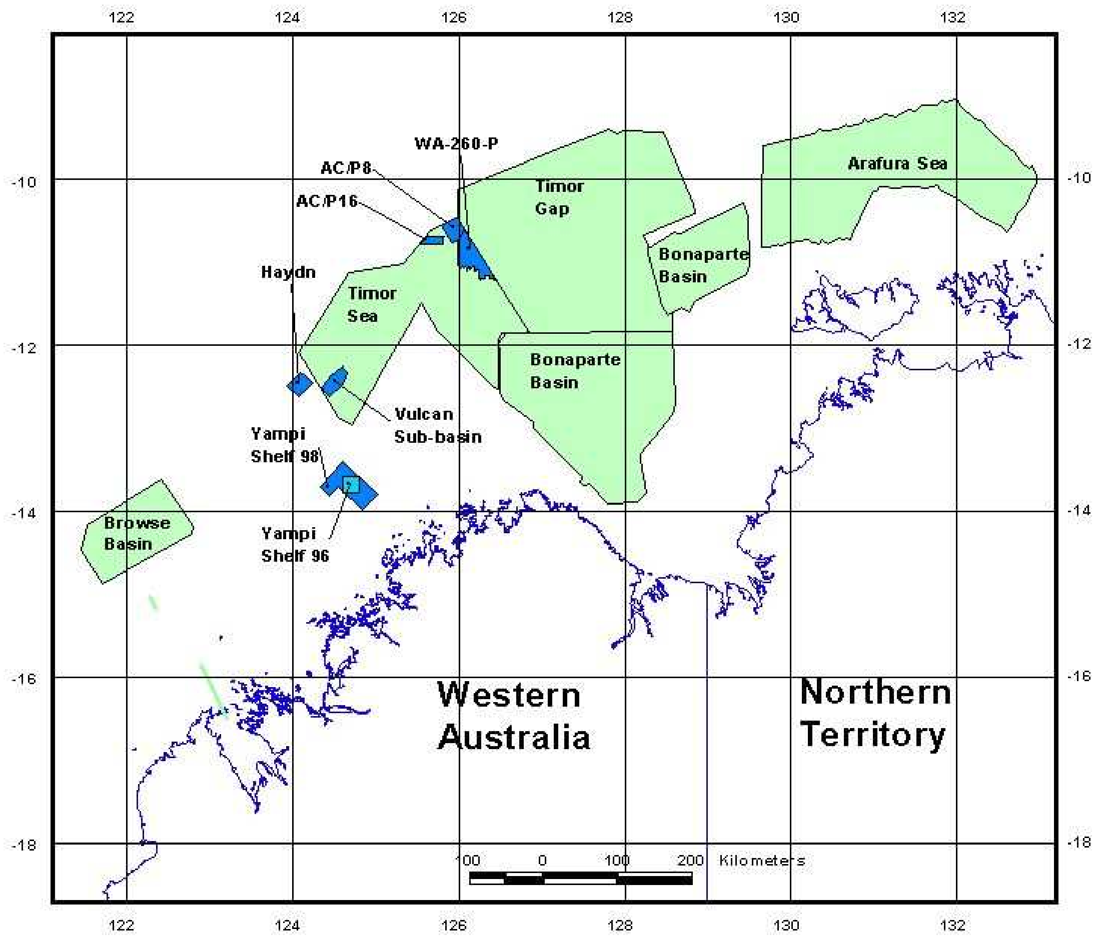


Figure 4. Map of Reprocessed ALF Surveys Over Northern Australia.

BP interpretation reports were available for six of the surveys in this data processing comparison. These reports were: Arafura Sea, Bonaparte and (West) Timor Sea, Browse Basin, Timor Gap and Carnarvon Basin.

Basic data reports were available for the Bonaparte and (West) Timor Sea and the Carnarvon Basin surveys.

The Basic Data Reports contain a chapter describing the principles of the technique and an operations summary including survey statistics and sea state. The reports contain maps showing total fluorescence recorded along each flight line.

The Interpreted Data Reports contain the chapters describing the principles of the technique and an operations summary. The reports also contain chapters describing the interpretation method, the results summary and controls on the ALF results.

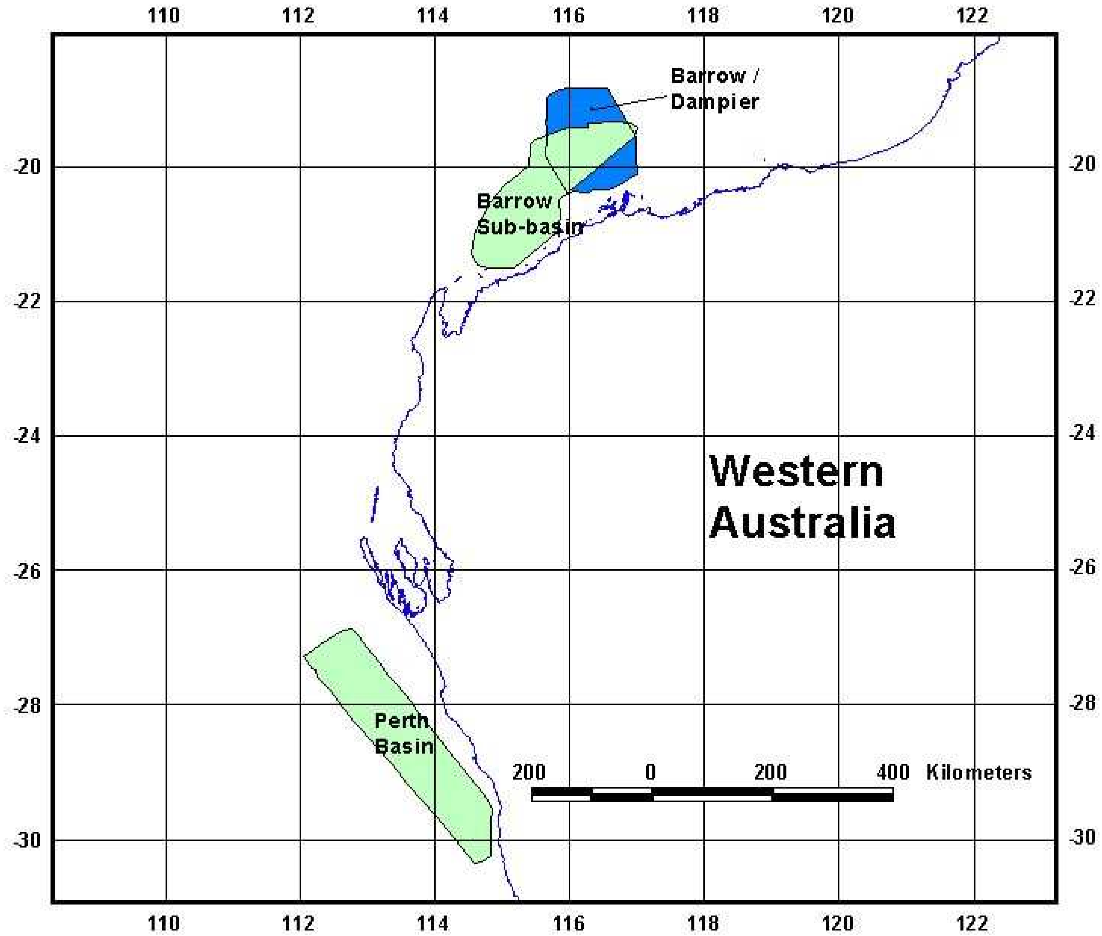


Figure 5. Map of Reprocessed ALF Surveys Over Western Australia.

Table 4 shows the number of ALF spectra recorded in each MkII ALF survey and the number of fluors picked by BP and Signalworks. (BP interpretation reports were not available for the Bight and Perth Basin ALF surveys.)

MkIII ALF surveys have a typical fluor density of 50 to 300 fluors per million recorded spectra. Because the average of ten detected spectra is recorded in a MkII ALF survey, the fluor density should be about ten times higher. Table 4 shows a fluor density range for the Signalworks picks of 500 to nearly 6,000 fluors per million spectra. This is equivalent to a density range of 50 to nearly 600 fluors per million spectra on a MkIII survey.

Only the Timor Gap report produced by BP contained comparable fluor location information allowing a direct comparison of the BP and Signalworks interpretations. The other BP reports (produced at an earlier date) contained differences in fluor latitude and longitude values when compared with corresponding spectra identified in the *ALF Explorer*™ database by the shape of the spectrum. The difference may be due to navigation corrections being applied to the ALF data supplied for the *ALF Explorer*™ database. The remaining BP and Signalworks interpretations were compared but in less detail.

Survey	Recorded Spectra	BP Fluors	Signalworks Fluors	Fluor Density (ppm)
Arafura Sea	534,022	44	1,894	3,547
Barrow Sub-basin*	328,565	12	1,451	4,416
Bight	1,824,227	na	941	516
Bonaparte Basin	872,412	136	1,689	1,936
Browse Basin	133,125	16	776	5,829
Perth Basin	510,500	na	1,355	2,654
Timor Gap	1,860,650	75	5,441	2,924
Timor Sea	439,972	221	392	891

Table 4. Summary of Number of Spectra Recorded and Fluors Picked for Each Survey.

* BP called this survey the Carnarvon Basin ALF Survey

3.1. Arafura Sea MkII ALF Survey Fluor Location Comparison

The Interpreted Data reports usually contain a plot of one of the picked fluor spectra which allowed identification of the corresponding record in the *ALF Explorer*™ database. Figure 6 below shows the example included in the BP Arafura Sea Interpretation Report. This report does not identify the line and point values for each fluor but does include latitude and longitude coordinates. Figure 7 shows the same fluor identified in the Signalworks database and is located on line 65 at point 13041.

The single fluor example plotted in the BP Arafura Sea ALF interpretation report can be identified in the Signalworks project. There is a distance discrepancy of 175m between the location provided in the BP report and the location provided by Fugro. This difference may be because the data supplied by Fugro had navigation corrections applied.

Details of the fluor location in the Signalworks and BP analyses are listed below:

<u>Arafura Sea MkII ALF Survey Datum and Projection Specifications:</u>
Latitude and longitude datum: AGD66
Projection: AMG, Southern UTM, Zone 52, Central Meridian 129 degrees east.

The geodetic coordinates of all the supplied ALF data used the AGD66 geodetic datum. Because of inconsistencies in the AGD66 datum, there is no single set of transformation parameters that can accurately transform the coordinates into the WGS84 or AGD84 datums. The AGD66 datum coordinates were assumed to be approximately equal to the AGD84 coordinates for the accuracy of mapping required in this report. In the Arafura Sea region the difference between coordinate locations using the AGD66 and AGD84 datums is about 4 to 5 metres.

<u>Signalworks Fluor Location:</u>

Dec Latitude:	-10.44967285	Dec Longitude:	132.5934082
Latitude:	-10° 26′ 58.82″	Longitude:	132° 35′ 36.27″
Northing:	8,842,625	Easting:	893,512

<u>BP Fluor Location:</u>

Dec Latitude:	-10.44997222	Dec Longitude:	132.5949805
Latitude:	-10° 26′ 59.90″	Longitude:	132° 35′ 41.93″
Northing:	8,842,590	Easting:	893,684

<u>Separation Distance:</u>
North: 35m
East: 172m
Distance: 175.5

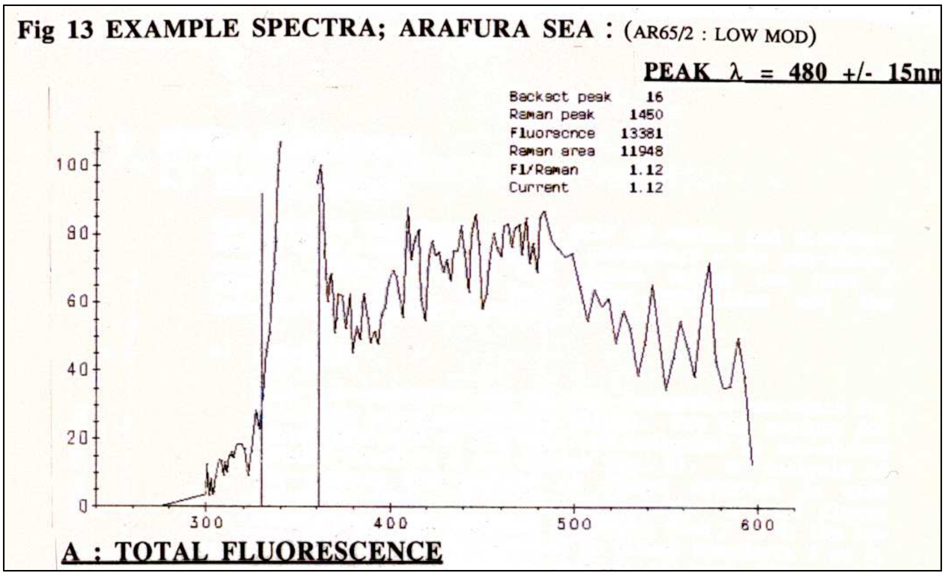


Figure 6. BP Arafura Sea MkII ALF Survey Fluor Plot, AR65/2.

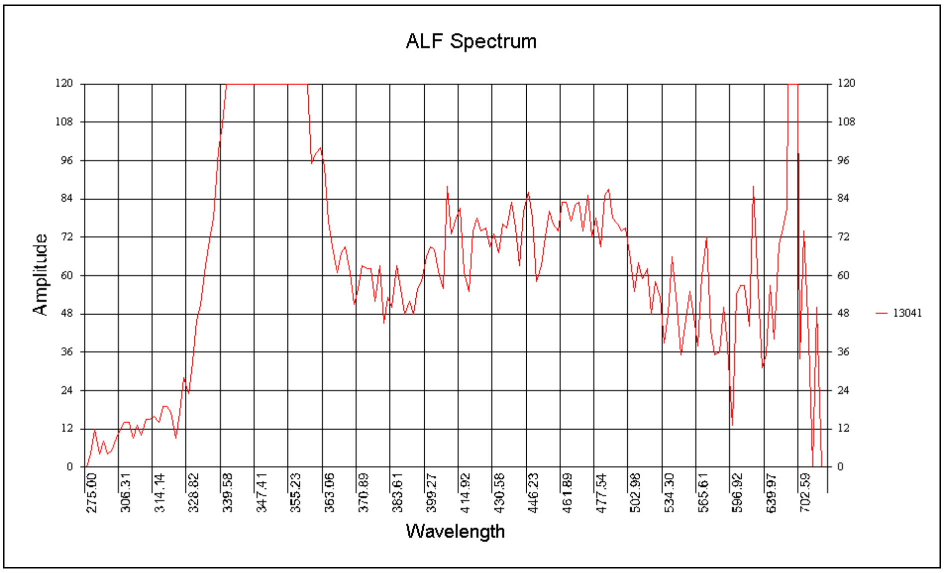


Figure 7. Signalworks Arafura Sea MkII ALF Survey Fluor Plot, Line 65, Point 13041.

The BP reports for the Barrow Sub-basin, Bonaparte Basin, Browse Basin and Timor Sea surveys had the same navigation inconsistencies with the data supplied to Signalworks.

3.2. Arafura Sea MkII ALF Survey Comparison of Fluor Maps.

Although a direct comparison of fluor picks cannot be made between the BP and Signalworks interpretations of the Arafura Sea survey, maps of the fluor distributions can be compared. The BP and Signalworks picked fluor distributions are shown in Figures 8 and 9 below.

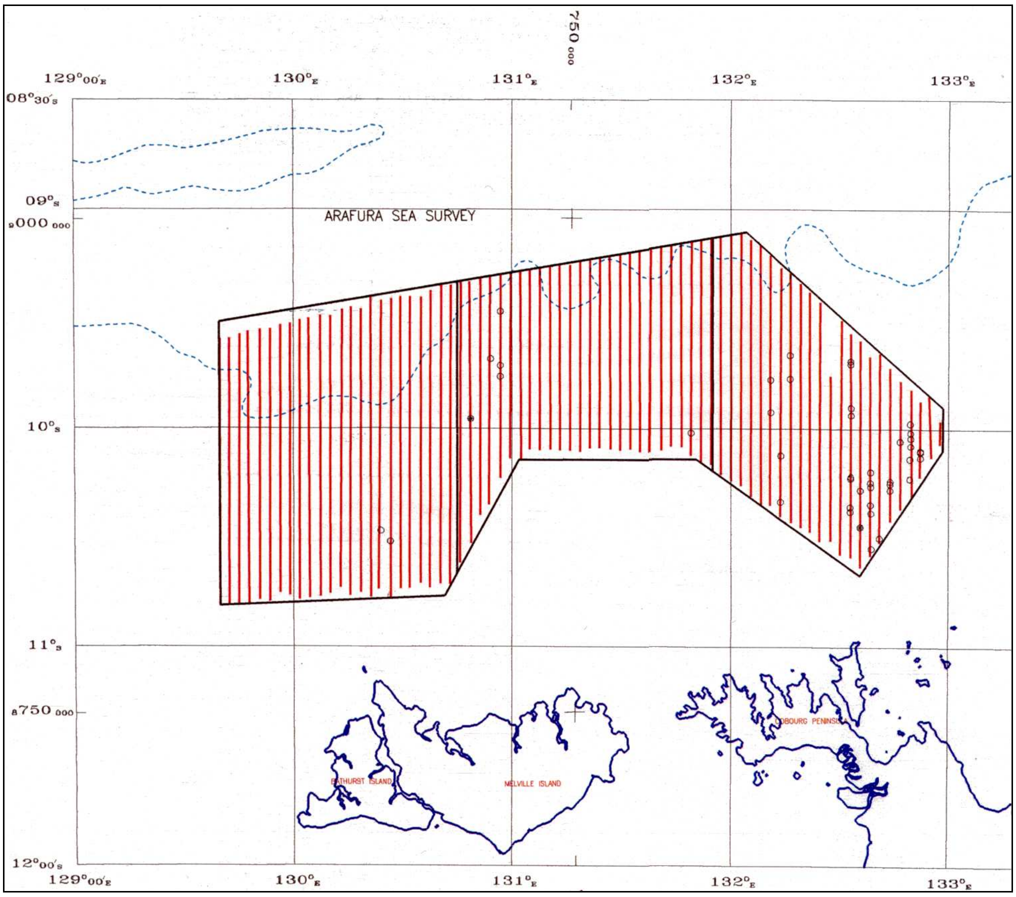


Figure 8. BP Arafura Sea Fluor Map.

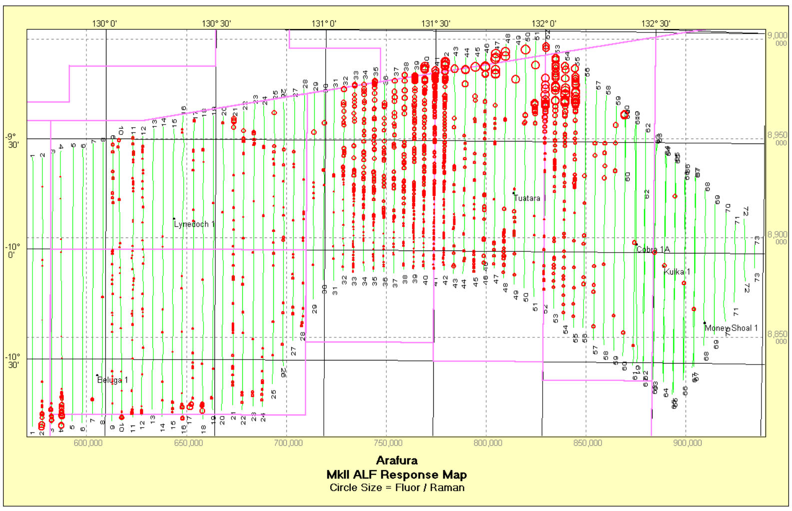


Figure 9. Signalworks Arafura Sea Fluor Map.

BP has picked far fewer fluors (44 compared with 1,894 Signalworks picks) with many lines having no fluor picks at all. Most lines in the Signalworks analysis have fluor picks. The densest distribution of fluors lies near the middle of the survey but may be affected by background fluorescence patterns.

3.3. Barrow Sub-basin MkII ALF Survey Comparison of Fluor Maps

The BP and Signalworks picked fluor distributions for the Barrow Sub-basin (Carnarvon Basin) MkII ALF survey are shown in Figures 10 and 11 below. BP has picked only 12 fluors compared to 4,416 by Signalworks.

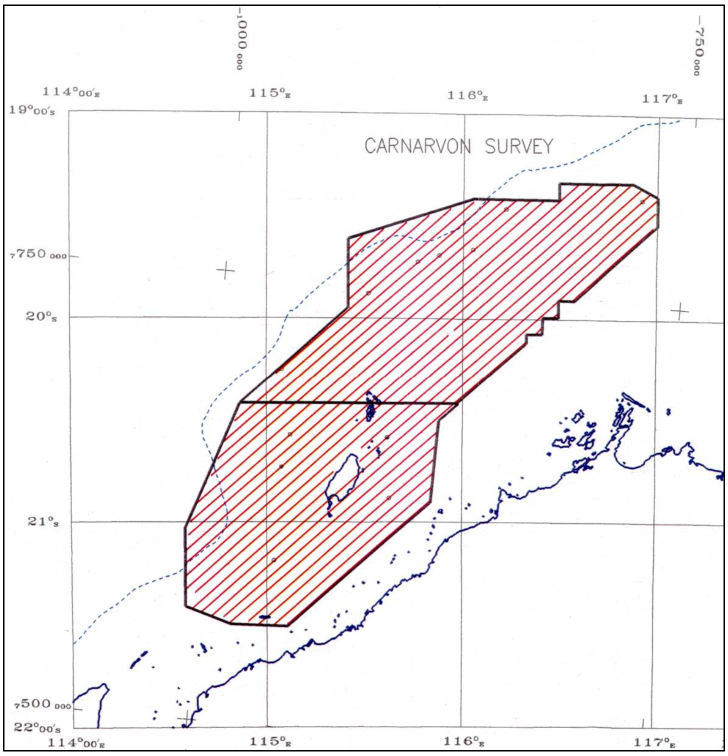


Figure 10. BP Barrow Sub-basin (Carnarvon Basin) Fluor Map.

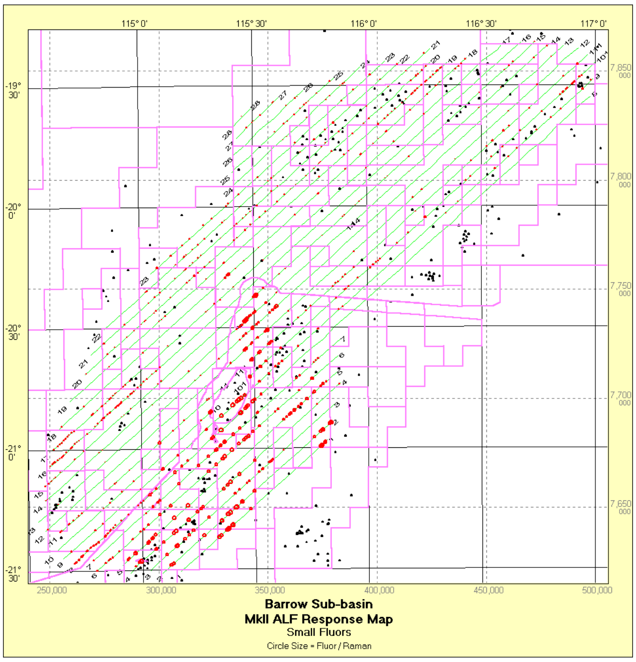


Figure 11. Signalworks Barrow Sub-basin Fluor Map.

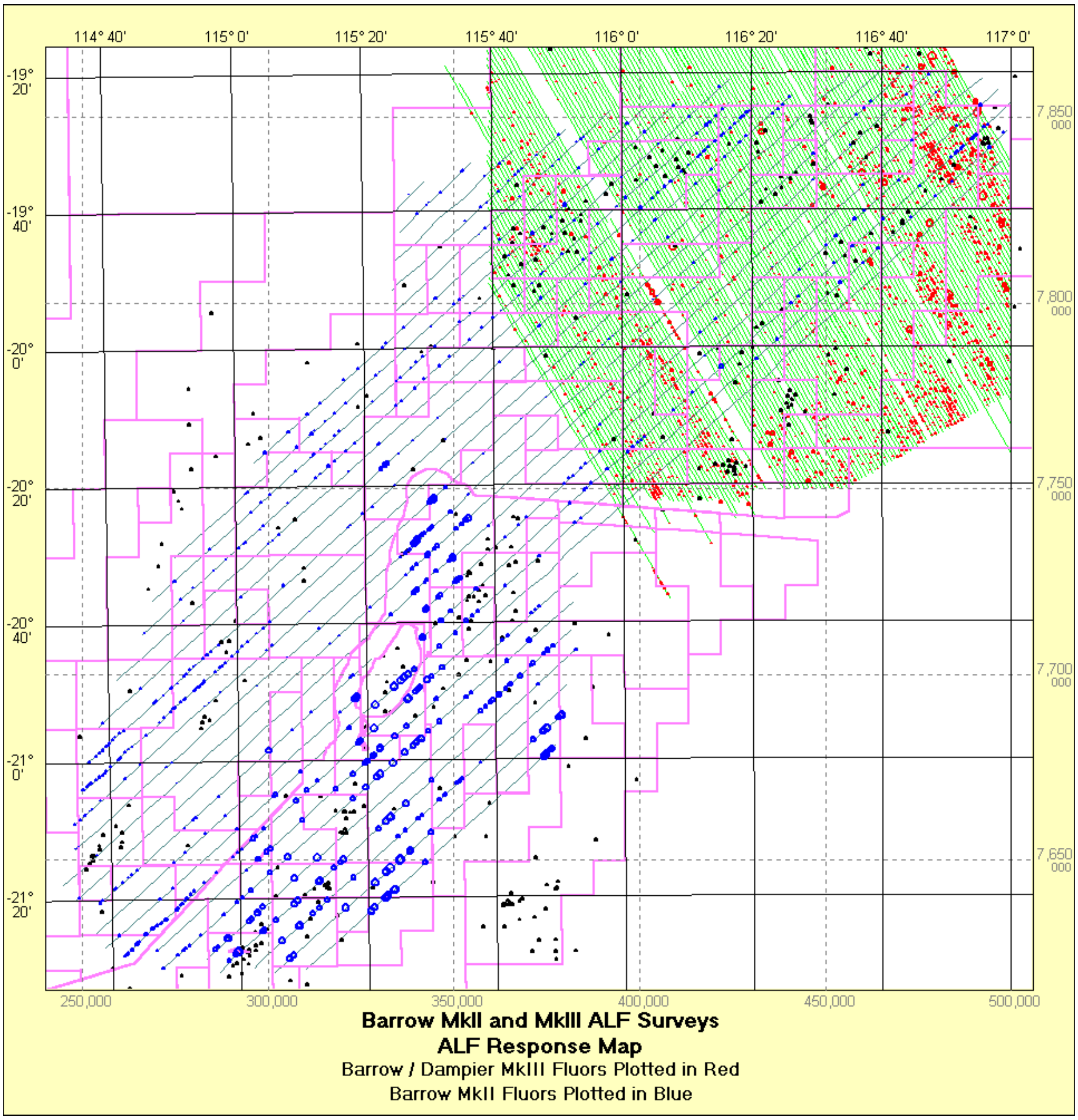


Figure 12. Map of the Signalworks Barrow MkII and MkIII Fluor Picks.

This MkII ALF survey is overlapped by the more recent Barrow / Dampier MkIII survey in which fluors can be picked with much higher confidence.

Figure 12 shows the Barrow (or Carnarvon) MkII fluors plotted in blue together with the Barrow / Dampier MkIII fluor picks plotted in red. Signalworks Pty Ltd interpreted both data sets shown here. The MkIII fluors can be picked reliably and the map indicates a relatively high fluor density over parts of the MkIII survey area. The MkII fluors cannot be picked with as much confidence but the sensitive picking method used has detected a similar fluor density over some of the overlapping areas.

The BP interpretation has picked very few fluors in the overlapping region. They probably used more stringent picking criteria and missed many possible fluors.

3.4. Timor Gap MkII ALF Survey Fluor Location Comparison

The BP Timor Gap Interpreted Data Report included Line and Point numbers in the list of validated fluors. The location of these fluors corresponds exactly with the corresponding records in the Signalworks project. Figure 13 shows the fluor example displayed in the BP Timor Gap ALF Survey Interpretation Report. The same fluor (shown in Figure 14) can be found in the Signalworks ALF Explorer database from the latitude and longitude coordinates. The BP report also includes line and point values in the list of pick fluors, which confirm the matching Signalworks pick.

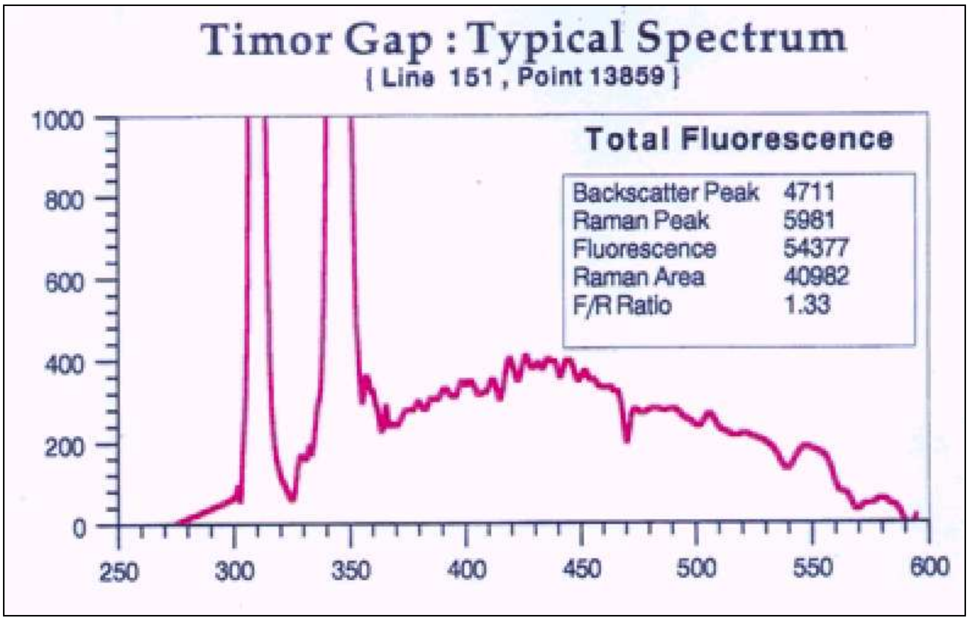


Figure 13. BP Picked Fluor on Line 151, Point 13859.

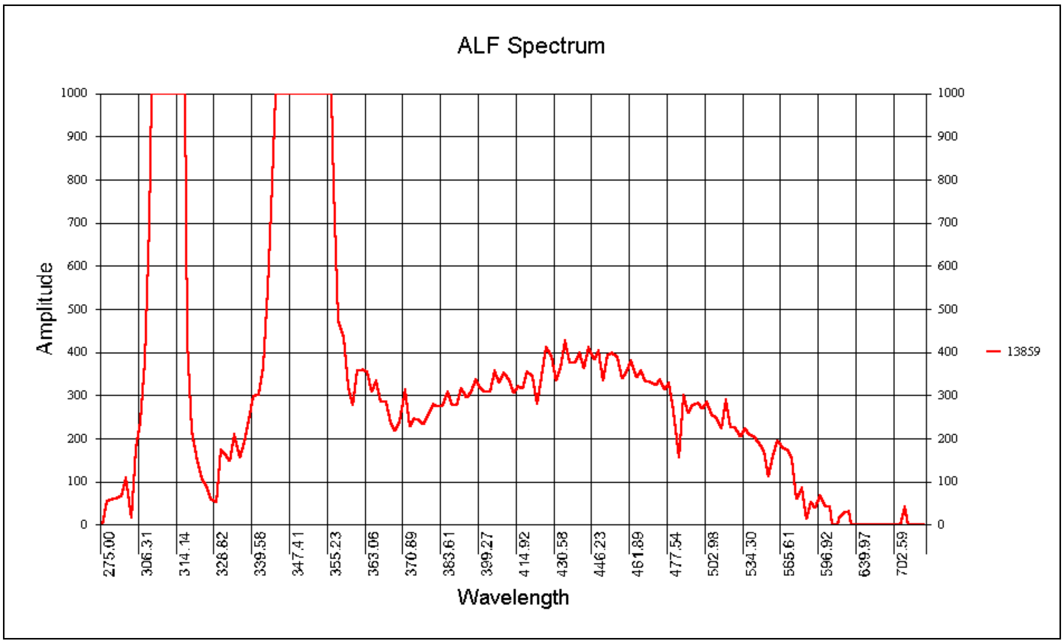


Figure 14. Signalworks Fluor Display of Line 151, Point 13859.

Details of the fluor location in the Signalworks and BP analyses are listed below.

Datum and Projection Specifications:
Latitude and longitude datum: AGD66
Projection: AMG, Southern UTM, Zone 52, Central Meridian 129 degrees east.

Signalworks Fluor Location:
Line 151, Point 13859

Dec Latitude:	-11.72039917	Dec Longitude:	126.9927832
Latitude:	-11° 43′ 13.44″	Longitude:	126° 59′ 34.02″
Northing:	8,703,581	Easting:	281,231

BP Fluor Location:
Fluor pick TIM151/9

Latitude:	-11° 43′ 13.44″	Longitude:	126° 59′ 34.02″

3.5. Comparison of BP and Signalworks Fluor Picks.

BP picked 74 fluors while Signalworks picked 5,441 fluors. Appendix 2 shows the table of BP fluor picks. Maps of these fluor picks are shown in Figures 15 and 16. Forty five (61%) of the BP fluors were also picked by Signalworks.

Sixty seven (90%) of the BP fluors were picked on only two lines (lines 151 and 153). The Signalworks data acquisition QC shows that these lines have anomalously high Raman peak and variance levels. The Raman peak averaged over each line is 25 and 21 for lines 151 and 153 compared to below 10 for other nearby lines. The other seven BP fluor picks are located on lines 78 and 82. The QC curves show some regions of high Raman variance on these lines.

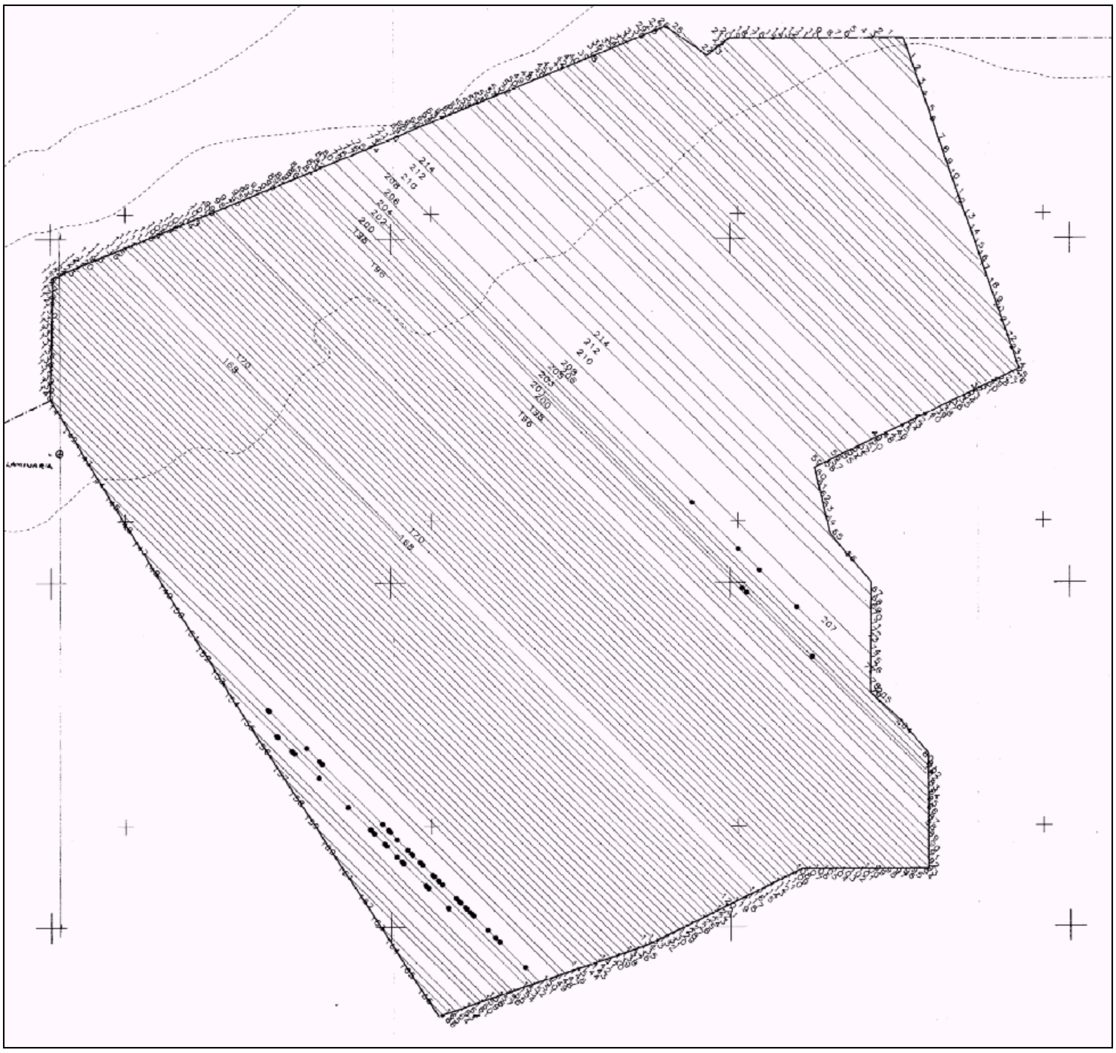


Figure 15. Map of BP Timor Gap ALF Survey Fluor Picks.

The BP interpretation found fluors on only four lines (Figure 15) and was probably strongly affected by variations in the acquisition parameters.

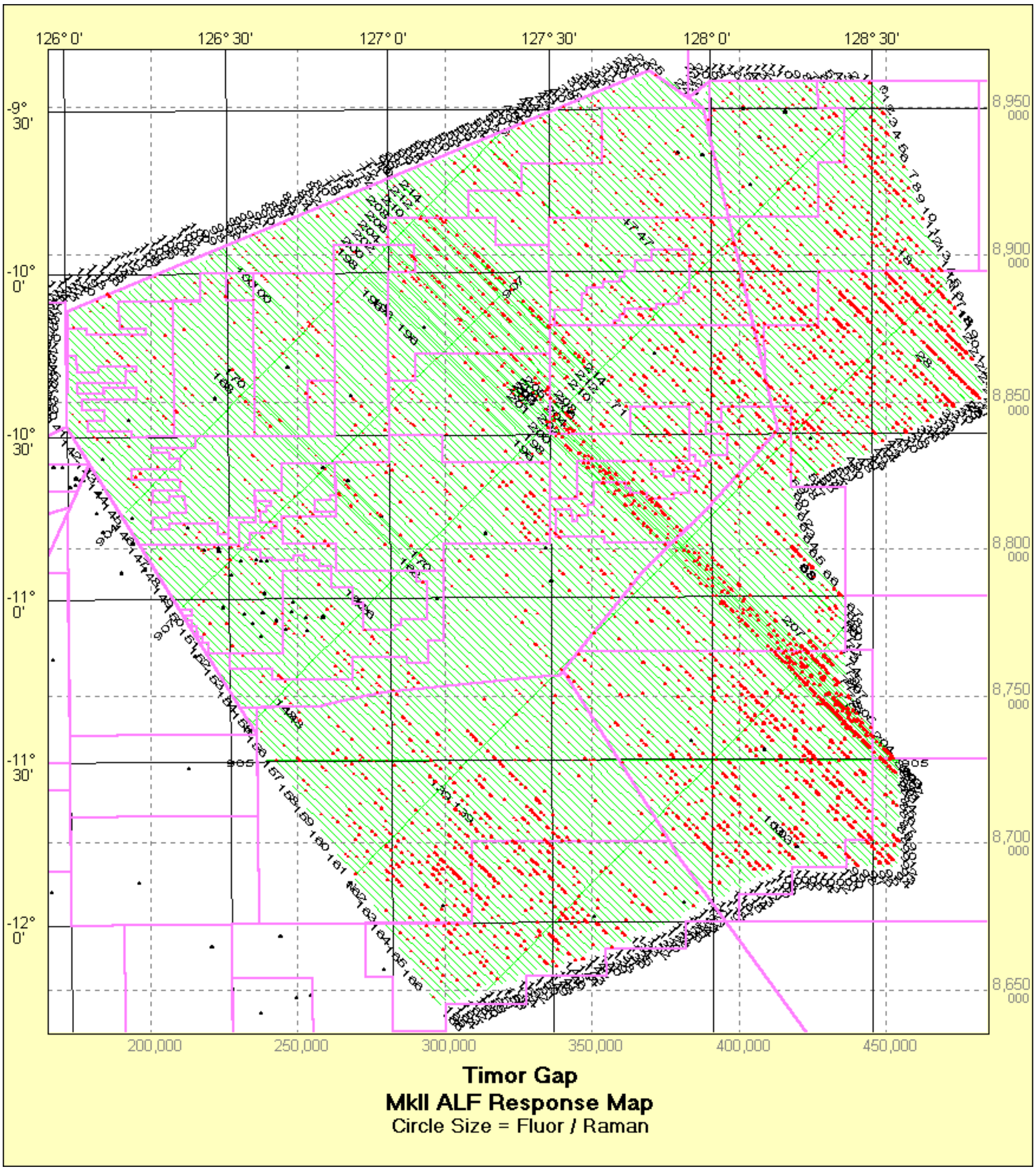


Figure 16. Map of Signalworks Timor Gap ALF Survey Fluor Picks.

The Signalworks interpretation has picked a much larger number of fluors, which provides a better image of potential leakage distributions (Figure 16).

Unless an oil film is thick and extensive the oil fluorescence response in a MkII survey will not be far above background levels. This can be seen in the background and interpreted fluor spectra shown in Figures 17 and 18. The very large MkII fluor shown in Figure 1 is from an extensive slick located near an oil production facility.

The fluor shown in Figure 18 was picked by both BP and Signalworks on the Timor Gap survey.

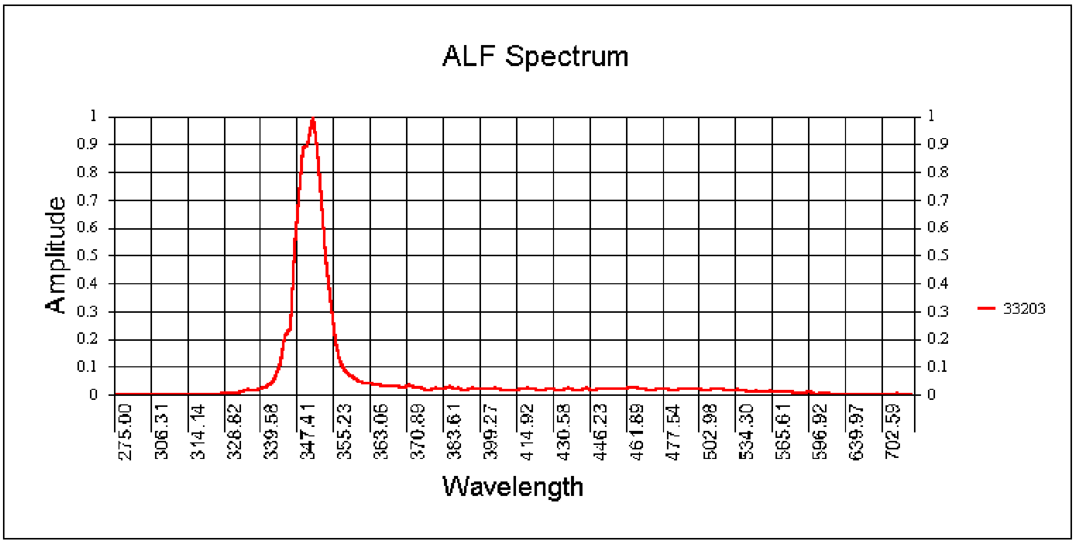


Figure 17. Line 152 No Fluor.

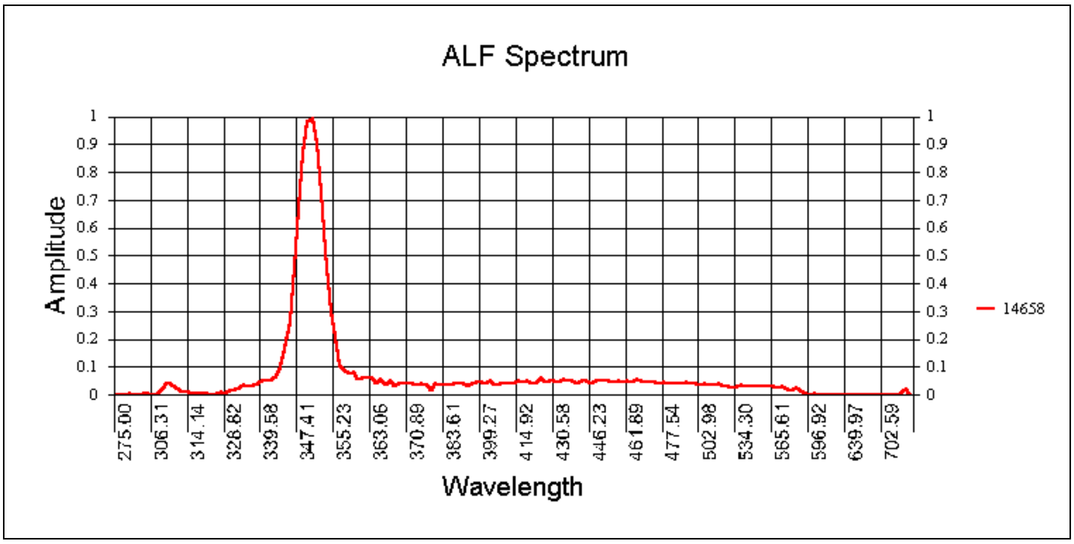


Figure 18. Line 151 Fluor Picked by Both BP and Signalworks.

Figures 19 and 20 show fluors picked only by Signalworks and BP. Both possible fluors are low intensity and suffer from low signal to noise ratio. These low confidence fluors lie near the edge of the fluor selection criteria. Because of differences in the BP and Signalworks selection criteria they were not selected in both interpretations.

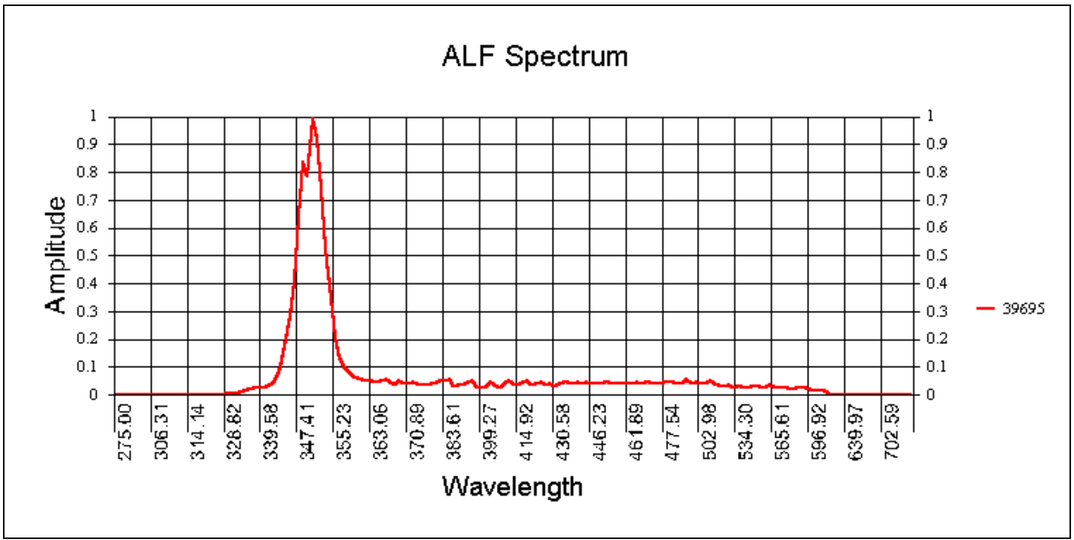


Figure 19. Line 152 Fluor Picked Only by Signalworks.

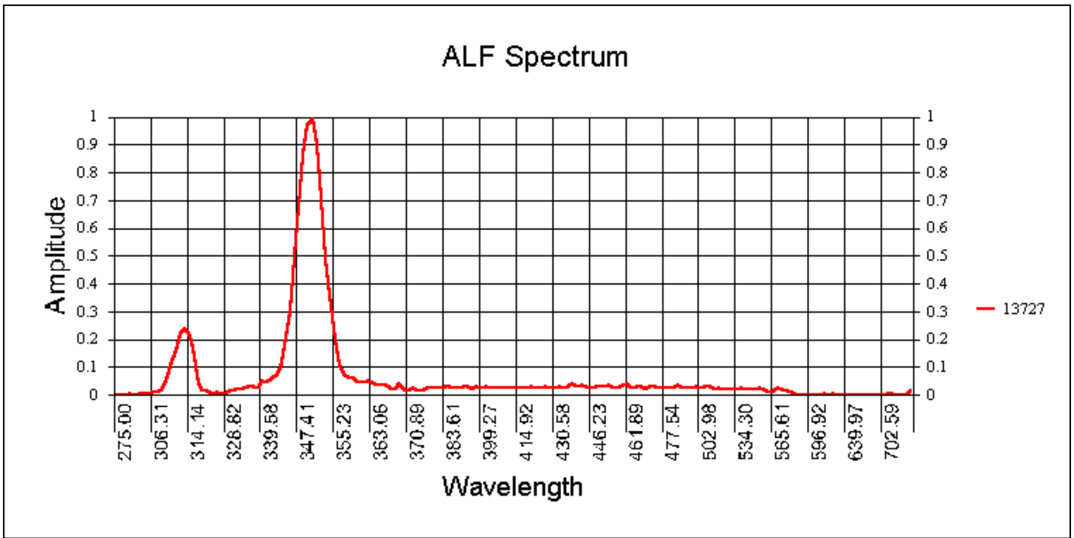


Figure 20. Line 151 Fluor Picked Only by BP.

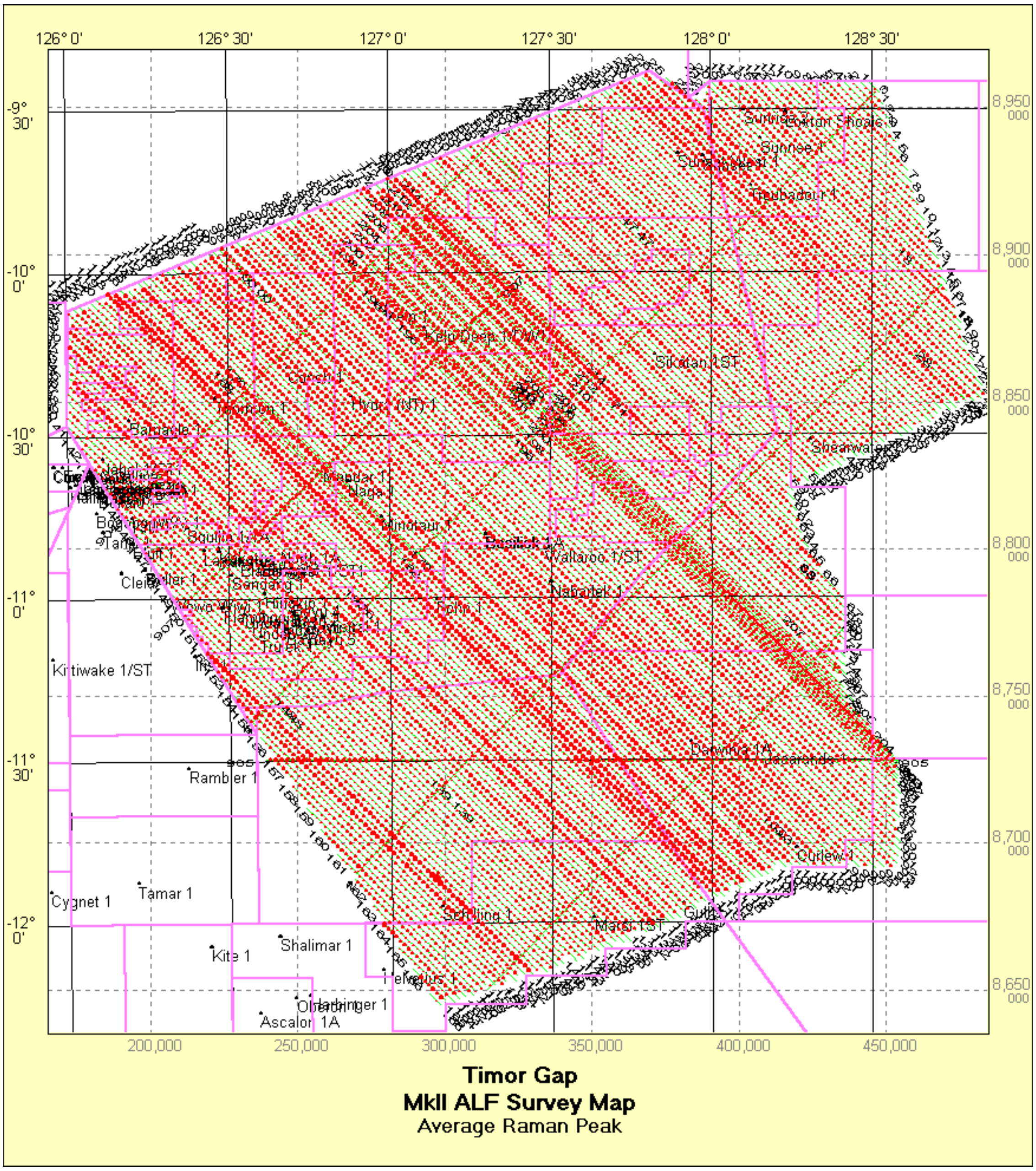


Figure 21. Average Raman Peak Over the Timor Gap ALF Survey.

A map of the Raman peak is shown in Figure 21. This map shows the higher Raman levels along each of lines 151 and 153 near the south western edge of the survey.

Figure 22 shows the average Raman area along line 151. The fluctuating high levels are probably caused by acquisition problems. Adjacent line 152 (Figure 23) shows the more usual Raman area levels.

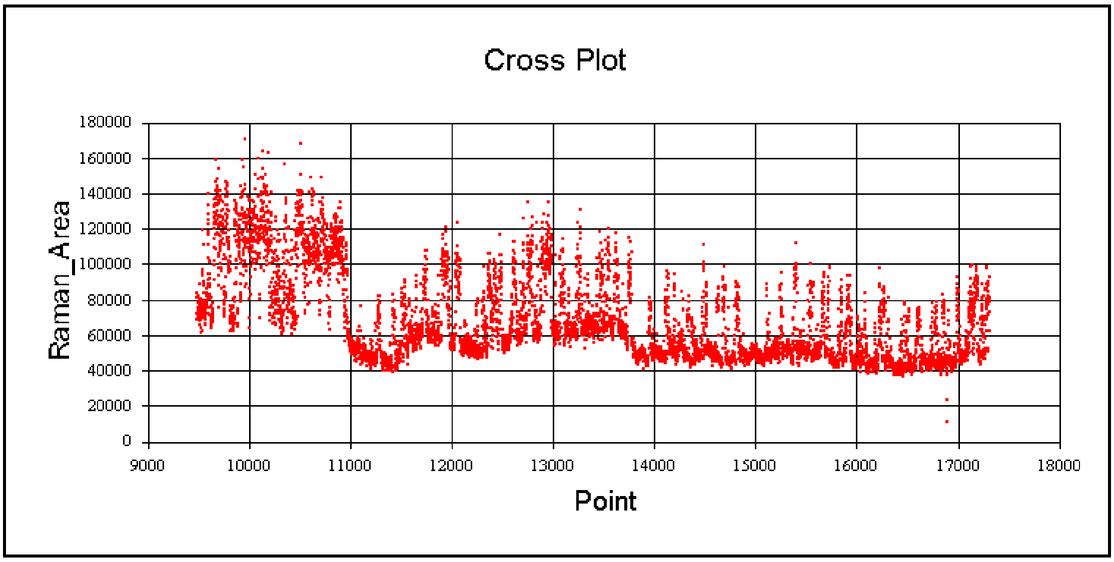


Figure 22. Line 151 Average Raman Area.

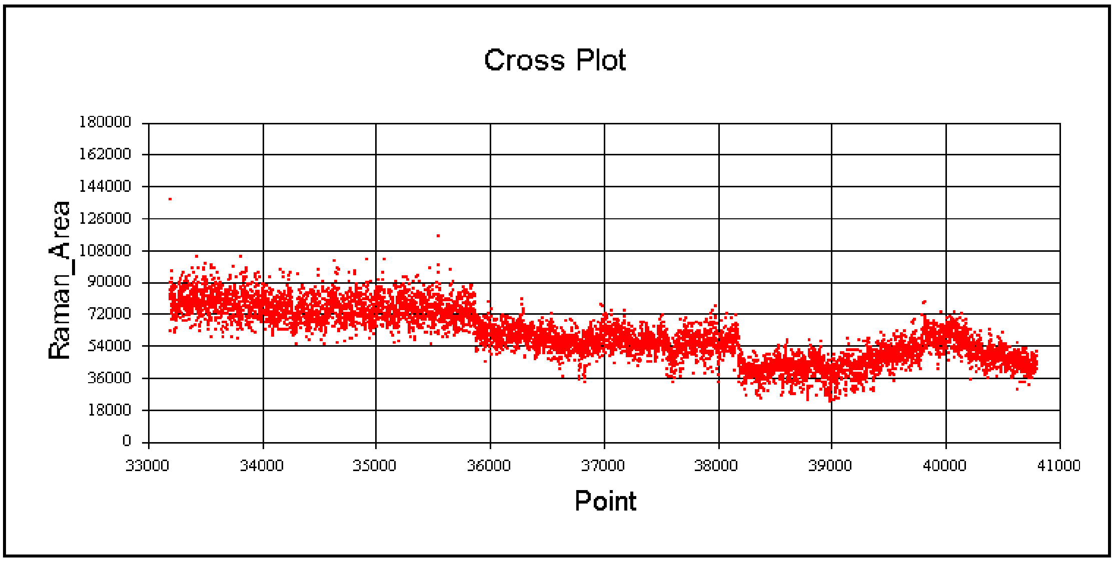


Figure 23. Line 152 Average Raman Area.

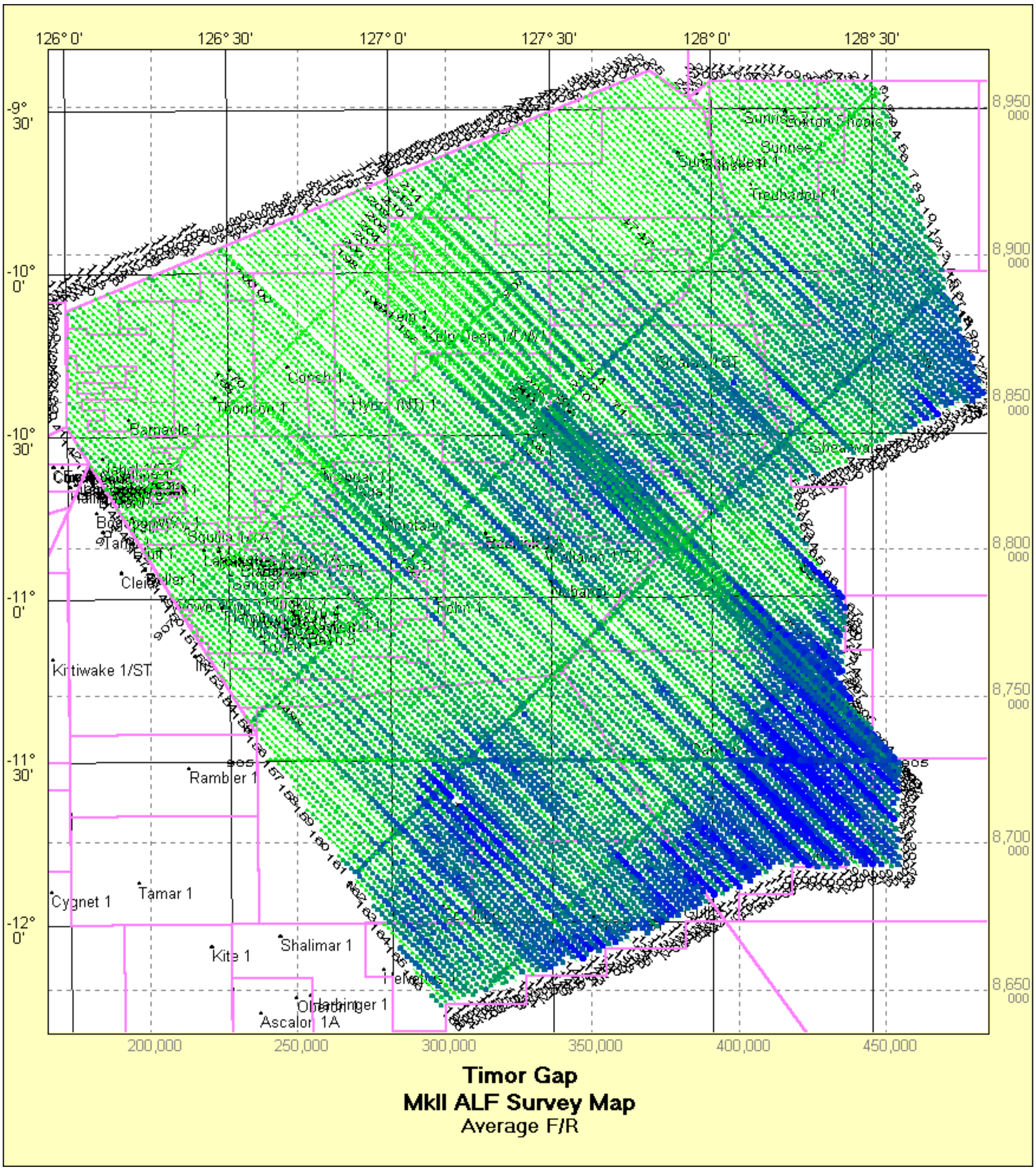


Figure 24. Smoothed F/R Over the Timor Gap ALF Survey.

A map of the averaged F/R levels over the survey (Figure 24) shows areas having relatively high levels. Higher F/R values are plotted in blue with larger symbols. An attempt was been made to compensate for these changing background F/R levels during interpretation. The correspondence between increases in interpreted fluor density (Figure 16) and high background F/R levels (Figure 24) suggests that the Signalworks fluor picking has been influenced by the background levels.

Figure 25 shows the F/R values plotted in red along line 151. The 101 point average level is shown in blue. The average level provides an estimate of the background level, which can vary significantly over a large survey like this.

Figure 26 shows the F/R values plotted for the adjacent line 152. This line show similar average levels but with less fluctuations. Signalworks used a cutoff value of 120% of the average level to select possible fluors from line 151 but only 110% for line 152. (Other criteria were used at later stages to refine the final fluor selection.) The cutoff was manually set at suitable levels for each line by examining the F/R plots.

BP selected 45 fluors on line 151 and none on line 152. Signalworks selected 40 fluors on line 151 and 12 on line 152.

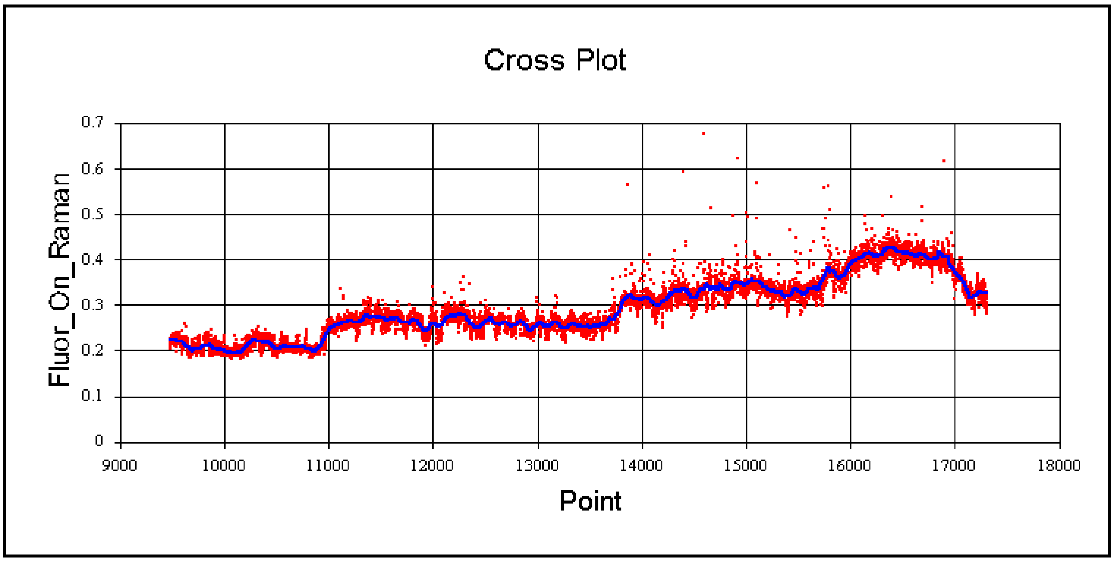


Figure 25. Line 151 F/R Plot.

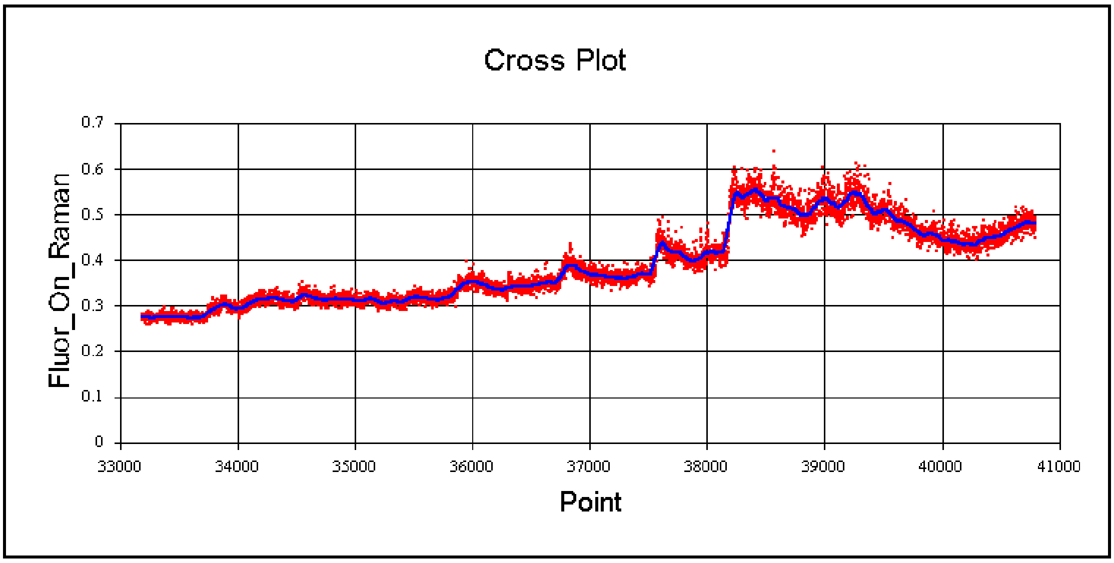


Figure 26. Line 152 F/R Plot.

4. Conclusions

Background F/R variations form consistent patterns over ALF surveys covering large areas. The cause of these are presently unknown but may be due to temperature, salinity or other water property variations and may be related to ocean currents. Compensation for these variations is applied during data processing but they can affect the pattern of picked fluors.

BP processing tends to reject possible fluors having low signal to noise ratio (S/N). Signalworks processing attempts to identify a larger number of fluors which are needed to define the oil seepage patterns.

Low S/N in the MkII ALF data used is the main cause of data analysis difficulties and differences between interpretations. This problem was greatly reduced in the MkIII system developed later which results in more consistent interpretations between companies.

It may be possible to improve the confidence of fluor picking on the MkII ALF survey data by investigating improved signal and noise identification methods.

The BP interpretation report for the Timor Gap survey was the only one providing unambiguous fluor location data. The other reports used different geographic coordinate data (possibly uncorrected coordinates) from the Signalworks data set and did not provide line and point values to confirm the fluor locations. Because of this it was only possible to make a direct comparison of the BP and Signalworks fluor picks on the Timor Gap ALF survey.

The BP fluor picking of the Timor Gap survey was probably strongly affected by data acquisition variations. Most of the fluors (90%) were picked on only two lines having anomalously high Raman amplitude and variance levels. The Signalworks interpretation picked many more fluors than BP (5,441 compared to 74) which allowed possible seepage trends to be mapped with more precision. The Signalworks interpretation does however appear to be affected by background F/R level variations.

Experience with MkIII ALF survey data, which has a much improved signal to noise ratio, shows that fluor size distribution increases rapidly towards the small fluor size. The distribution declines towards the very small fluor sizes only because the very small fluors cannot be confidently identified above the background noise levels.

Appendix 1. List of BP and Signalworks ALF Survey Processing Reports

1. Williams, A.K. and Mackintosh, J.M. 1990a. ALF Survey of the western margin of Australia. 1. **Bonaparte and West Timor Sea Basins.** Volume 1, A – Basic Data Report; Volume 2, B – Interpretive Data Report; Volume 3, C – BP In-house Report. Remote Sensing Group, BP Exploration (unpubl. report).

2. Williams, A.K. and Mackintosh, J.M. 1990b. ALF Survey of the western margin of Australia. 2. **Perth Basin.** Volume 1, A – Basic Data Report; Volume 2, B – Interpretive Data Report; Volume 3, C – BP In-house Report. Remote Sensing Group, BP Exploration (unpubl. report).

3. Williams, A.K. and Mackintosh, J.M. 1990c. ALF Survey of the western margin of Australia. 3. **Arafura Sea.** Volume 1, A – Basic Data Report; Volume 2, B – Interpretive Data Report; Volume 3, C – BP In-house Report. Remote Sensing Group, BP Exploration (unpubl. report).

4. Williams, A.K. and Mackintosh, J.M. 1990d. ALF Survey of the western margin of Australia. 4. **Browse Basin.** Volume 1, A – Basic Data Report; Volume 2, B – Interpretive Data Report; Volume 3, C – BP In-house Report. Remote Sensing Group, BP Exploration (unpubl. report).

5. Williams, A.K. and Mackintosh, J.M. 1990e. ALF Survey of the western margin of Australia. 5. **Carnarvon Basin.** Volume 1, A – Basic Data Report; Volume 2, B – Interpretive Data Report; Volume 3, C – BP In-house Report. Remote Sensing Group, BP Exploration (unpubl. report).

6. Walker, N.S. 1991a. 1991 **Timor Sea** Airborne Laser Fluorosensor Survey for BP Developments Australia Ltd. Basic Data Report. (Timor Gap Survey.) (unpubl. report).

7. Walker, N.S. 1991b. 1991 **Timor Sea** Airborne Laser Fluorosensor Survey for BP Developments Australia Ltd. Interpreted Data Report. (Timor Gap Survey.) (unpubl. report).

8. Cowley, R., 2000a. Comparison of AGSO North-West Shelf Airborne Laser Fluorosensor Survey Interpretations. Australian Geological Survey Organisation (AGSO) Record 2000/27.

9. Cowley, R., 2000b. 1996 **Nancar Trough, Northern Bonaparte Basin (AC/P16)** Airborne Laser Fluorosensor Survey Interpretation Report. AGSO Record 2000/28.

10. Cowley, R., 2000c. 1996 **Laminaria High, Northern Bonaparte Basin (AC/P8)** Airborne Laser Fluorosensor Interpretation Report. AGSO Record 2000/29.

11. Cowley. R., 2000d. 1998 **Yampi Shelf, Browse Basin** Airborne Laser Fluorosensor Survey Interpretation Report. AGSO Record 2000/30.

12. Cowley. R., 2000e. 1996 **Yampi Shelf, Browse Basin** Airborne Laser Fluorosensor Survey Interpretation Report. AGSO Record 2000/31.

13. Cowley. R., 2000f. 1996 **Vulcan Sub-basin / Browse Basin Transition** Airborne Laser Fluorosensor Survey Interpretation Report. AGSO Record 2000/32.

14. Cowley. R., 2000g. 1996 **Vulcan Sub-basin** Airborne Laser Fluorosensor Survey Interpretation Report. AGSO Record 2000/33.

15. Cowley. R., 2001a. Airborne Laser Fluorosensor (MkIII) Survey Reprocessing and Interpretation Report: **Barrow and Dampier Sub-basins, Carnarvon Basin**, North West Shelf, Australia. AGSO Record 2001/16, AGSO CAT 34393.

16. Cowley. R., 2001b. Airborne Laser Fluorosensor (MkIII) Survey Reprocessing and Interpretation Report: **WA-260-P, Timor Sea**, Australia. AGSO Record 2001/17, AGSO CAT 35929.

17. Cowley. R., 2001c. MkII Airborne Laser Fluorosensor Survey Reprocessing and Interpretation Report: **Great Australian Bight**, southern Australia. AGSO Record 2001/18, AGSO CAT 34395.

18. Cowley. R., 2001d. MkII Airborne Laser Fluorosensor Survey Reprocessing and Interpretation Report: **Perth Basin**, Western Australia. AGSO Record 2001/19, AGSO CAT 35927.

19. Cowley. R., 2001e. MkII Airborne Laser Fluorosensor Survey Reprocessing and Interpretation Report: **Barrow Sub-basin, Carnarvon Basin**, North West Shelf, Australia. AGSO Record 2001/20, AGSO CAT 35738.

20. Cowley. R., 2001f. MkII Airborne Laser Fluorosensor Survey Reprocessing and Interpretation Report: **Browse Basin, North West Shelf**, Australia. AGSO Record 2001/21, AGSO CAT 35634.

21. Cowley. R., 2001g. MkII Airborne Laser Fluorosensor Survey Reprocessing and Interpretation Report: **Arafura Sea**, Australia. AGSO Record 2001/22, AGSO CAT 35926.

22. Cowley. R., 2001h. MkII Airborne Laser Fluorosensor Survey Reprocessing and Interpretation Report: **Timor Sea**, Australia. AGSO Record 2001/23, AGSO CAT 34394.

23. Cowley. R., 2001i. MkII Airborne Laser Fluorosensor Survey Reprocessing and Interpretation Report: **Bonaparte Basin, Timor Sea**, Australia. AGSO Record 2001/24, AGSO CAT 35930.

24. Cowley. R., 2001j. MkII Airborne Laser Fluorosensor Survey Reprocessing and Interpretation Report: **Timor Gap, Timor Sea**, Australia. AGSO Record 2001/25, AGSO CAT 35635.

The following BP reports were available for this data processing comparison:

Bonaparte and West Timor Sea Basins Basic Data Report
Bonaparte and West Timor Sea Basins Interpreted Data Report (on CD)
Arafura Sea Interpreted Data Report
Browse Basin Interpreted Data Report (on CD)
Carnarvon Basin Basic Data Report
Carnarvon Basin Interpreted Data Report
Timor Sea (Timor Gap) Interpreted Data Report (on CD)

Appendix 2. BP Fluor Picks on the Timor Gap ALF Survey

No.	Latitude			Longitude			Point	Sortie	Line	Fluor
	Deg	Min	Sec	Deg	Min	Sec				
1	11	4	25.92	128	11	49.95	1677	19	78	78/1
2	10	57	48.64	128	5	5.58	2562	19	78	78/2
3	10	54	8.96	128	1	22.79	3057	19	78	78/3
4	10	48	1.52	127	53	11.1	4142	19	78	78/4
5	11	1	0.78	128	2	8.36	22137	19	82	82/1
6	11	1	43.67	128	2	51.49	22234	19	82	82/2
7	11	13	3.18	128	14	29.59	23785	19	82	82/3
8	11	56	43.15	127	10	12.18	4947	35	153	153/1
9	11	53	16.95	127	6	43.35	4798	35	153	153/2
10	11	52	50.1	127	6	16.03	4858	35	153	153/3
11	11	52	49.21	127	6	15.12	4860	35	153	153/4
12	11	46	0.98	127	2	22.98	5358	35	153	153/5
13	11	48	42.17	127	2	3.26	5400	35	153	153/6
14	11	47	50.37	127	1	10.14	5506	35	153	153/7
15	11	45	56.83	126	59	14.62	5761	35	153	153/8
16	11	45	44.22	126	59	2.24	5789	35	153	153/9
17	11	45	43.77	126	58	1.75	5790	35	153	153/10
18	11	45	34.6	126	58	52.61	5810	35	153	153/11
19	11	43	47.19	126	57	3.97	6040	35	153	153/12
20	11	43	42.44	128	58	59.3	6050	35	153	153/13
21	11	43	10.61	128	58	28.01	6120	35	153	153/14
22	11	43	7.94	126	58	25.34	6126	35	153	153/15
23	11	43	3.45	126	56	20.84	6136	35	153	153/16
24	11	39	12.66	128	52	25.85	6637	35	153	153/17
25	11	34	6.59	126	47	15.56	7303	35	153	153/18
26	11	29	52.86	126	42	58.25	7851	35	153	153/19
27	11	29	34.14	126	42	39.02	7883	35	153	153/20
28	11	29	27.16	126	42	31.71	7909	35	153	153/21
29	11	27	0.52	126	40	2.02	8227	35	153	153/22
30	11	25	46.1	126	39	49.29	11113	35	151	151/1
31	11	22	16.25	126	39	16.27	11113	35	151	151/1
32	11	22	26.55	126	38	28.57	11139	35	151	151/2
33	11	22	29.53	126	38	29.55	11140	35	151	151/3
34	11	28	58.45	126	45	3.59	11993	35	151	151/4
35	11	31	12.72	126	47	20.63	12290	35	151	151/5
36	11	31	13.68	126	47	21.68	12292	35	151	151/6
37	11	31	42.75	126	47	51.39	12351	35	151	151/7
38	11	42	11.01	126	58	29.61	13727	35	151	151/8
39	11	43	13.44	126	59	34.02	13859	35	151	151/9
40	11	43	33.63	126	59	54.66	13905	35	151	151/10
41	11	44	50.06	127	1	10.66	14072	35	151	151/11
42	11	46	41.02	127	3	3.69	14315	35	151	151/12
43	11	46	41.47	127	3	4.15	14317	35	151	151/13
44	11	47	21.35	127	3	44.58	14403	35	151	151/14
45	11	47	29.75	127	3	53.12	14421	35	151	151/15
46	11	47	32.5	127	3	55.9	14427	35	151	151/16
47	11	48	47.49	127	5	12.93	14594	35	151	151/17

48	11	49	17.86	127	5	43.65	14658	35	151	151/18
49	11	51	0.05	127	7	27.05	14878	35	151	151/19
50	11	51	13.47	127	7	40.48	14909	35	151	151/20
51	11	51	14.89	127	7	41.67	14911	35	151	151/21
52	11	51	15.1	127	7	42.09	14912	35	151	151/22
53	11	51	57.08	127	8	24.7	15004	35	151	151/23
54	11	51	57.98	127	8	25.58	15008	35	151	151/24
55	11	52	4.25	127	8	31.84	15020	35	151	151/25
56	11	52	39.58	127	9	7.63	15100	35	151	151/26
57	11	52	40.4	127	9	8.51	15102	35	151	151/27
58	11	55	5.85	127	11	36.05	15415	35	151	151/28
59	11	55	49.23	127	12	21.02	15513	35	151	151/30
60	11	56	40.2	127	13	12.7	15622	35	151	151/31
61	11	56	50.51	127	13	23.5	15645	35	151	151/32
62	11	57	30.52	127	14	3.89	16734	35	151	151/33
63	11	57	32.28	127	14	5.68	15738	35	151	151/34
64	11	57	36.64	127	14	10.18	15748	35	151	151/35
65	11	57	37.51	127	14	11.05	15750	35	151	151/36
66	11	57	38.81	127	14	12.4	15753	35	151	151/37
67	11	57	39.7	127	14	13.31	15755	35	151	151/38
68	11	57	53.5	127	14	27.45	15783	35	151	151/39
69	11	58	3.8	127	14	37.99	15804	35	151	151/40
70	12	0	38.07	127	17	11.63	15138	35	151	151/41
71	12	0	35.56	127	17	12.12	15137	35	151	151/42
72	12	1	54.8	127	18	31.39	16306	35	151	151/43
73	12	2	38.74	127	19	13.83	16389	35	151	151/44
74	12	7	2.5	127	23	46.64	16973	35	151	151/45

Table 5. BP Fluor Picks from the Timor Gap ALF Survey.

APPENDIX 3. The WGC / Fugro MkIII ALF Processing Sequence

World Geoscience Corp bought the ALF technology from BP and improved the specifications to produce the ALF MkIII system. The most significant changes in the new system were a shorter laser wavelength of 266nm and a fluorescence spectra recording rate increased to the detection rate of 50Hz.

A3.1. Pre-Survey Calibration

Prior to running each survey, the optics of the ALF system are adjusted to ensure correct alignment.

The ALF spectra are measured using a spectrometer and array of detectors. Non-linear response of each channel and sensitivity variations between the channels introduces systematic distortions of the recorded spectra. These distortions can be minimised by applying correction factors to the recorded data.

The correction factors can be determined by measuring the background response (called "dark current") of each channel and the response of each channel to a standard light source.

The correction factors are measured at regular intervals and after any equipment maintenance.

A3.2. Field QC

Quality control checks are applied to the ALF data immediately after acquisition. Data not meeting the survey specifications are re-acquired.

Field QC checks are made for the survey flight path, acquisition altitude and laser power. QC plots of these parameters are made using the navigation, lidar and laser power measurements recorded during the survey.

A3.3. Data Normalisation

The ALF spectra is normalised for variations in acquisition parameters including: background subtraction, laser power normalisation, altitude normalisation, gain normalisation and spectral calibration

A3.4. Incorporation of Navigation Data

Navigation data is logged at a slower rate than the ALF spectra during data acquisition. The navigation data is interpolated and latitude and longitude values are added to each recorded spectrum.

A3.5. Calculation of Oil Indicators

A number of parameters are calculated from each ALF spectra which help identify the presence and type of oil fluorescence.

<u>Raman peak</u>: the maximum intensity of the spectrum between 278nm and 308nm. For an accurate measure of Raman peak, any overlapping

fluorescence response should be subtracted. The Raman signal is produced by scattering of the laser beam by the water molecules, producing a narrow peak response centred at a wavelength of 293nm.

Raman area: the area of the Raman response which lies between the wavelengths of 278nm and 308nm.

Fluorescence Area: the area of the fluorescence response which is usually calculated between the wavelengths of 320nm and 580nm. The backscatter response should not be included in the calculation for an accurate value.

Fluorescence / Raman: The fluorescence area divided by the Raman area.

Landa Mid: The midpoint of the fluorescence spectrum usually calculated between the wavelengths of 320nm and 600nm.

F Width: The width of the fluorescence spectrum. This is usually calculated between the wavelengths of 320nm and 600nm.

Re-scaled F/R: F/R value rescaled to remove the effects of sea water variations.

Light Oil Indicator: The fluorescence area between the wavelengths of 320nm and 380nm, divided by the Raman area.

Medium Oil Indicator: The fluorescence area between the wavelengths of 460nm to 520nm, divided by the Raman area.

Heavy Oil Indicator: The fluorescence area between the wavelengths of 620nm to 680nm, divided by the Raman area.

A3.6. Final Processing

Several final process steps are required to produce the set of selected fluors. A dynamic filter is applied to compensate for variations in background response. ALF anomalies are selected from a cross-plot of the rescaled F/R against Landa Mid. The anomalies are categorised as either blue shifted (short wavelength) or red shifted (long wavelength). Blue anomalies are checked for noise and chlorophyll fluorescence caused by algae. Red shifted anomalies are checked for noise, white cap response and sun glint.

Possible fluors are examined along with neighbouring spectra and noisy or spurious points rejected. Blue shifted anomalies are further classified according to peak wavelength, intensity and degree of certainty.

Anomalies are checked against the recorded video image. The video image can help resolve possible algae fluorescence.

The confidence in picking ALF fluors and the number of fluors picked is affected by various parameters including ALF system sensitivity, sea water background fluorescence and weather conditions. An attempt is made to normalise the data by assuming the seepage levels will be similar between adjacent lines.

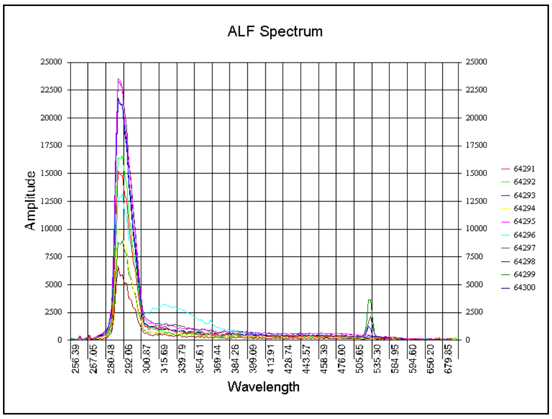
Natural neighbour interpolation is used to produce fluor density grids which can be displayed as image or contour maps. The normalisation procedure can be repeated if the fluor density grid indicates a normalisation problem.

The ALF data and grids can be combined with other datasets including magnetics, bathymetry and seismic to integrate the seepage patterns with a geological model.

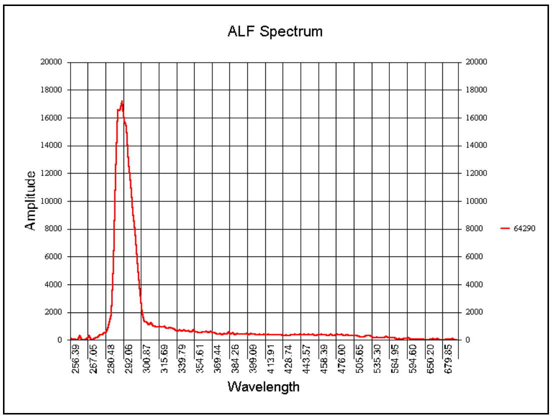
Appendix 4. Comparison of MkII and MkIII ALF Survey Data

Figure 27 shows a comparison of ALF MkIII survey data from the Skua region of the Timor Sea with the Timor ALF MkII data. Figure 27a shows a typical isolated MkIII fluor within ten adjacent spectra. Figure 27b shows a typical non-fluorescing spectrum. A medium intensity fluor is shown in Figure 27c. When the fluor is averaged with the surrounding non-fluor spectra (Figure 27d), the response is difficult to distinguish from the non-fluor spectra. The averaging process has tended to filter out the fluorescence response and enhance the more consistent water response.

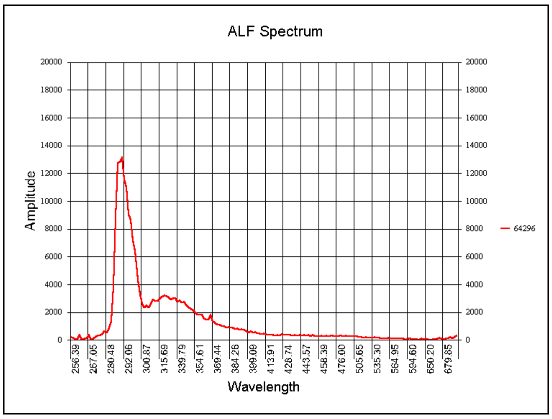
Figures 27e and 27f show a typical non-fluor and interpreted medium intensity fluor from the Timor MkII ALF survey. The refined interpretation method is required to distinguish the more subtle MkII fluors.



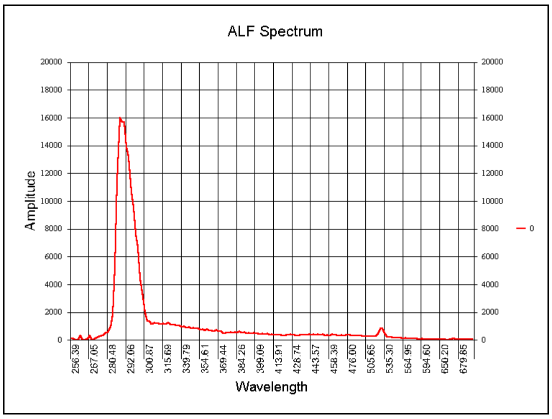
a) **Skua ALF MkIII Ten Adjacent Spectra**



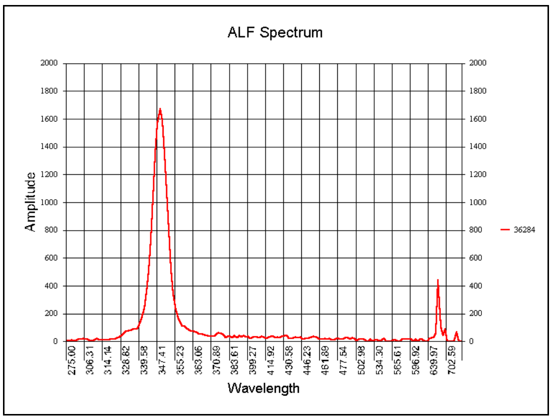
b) **Skua Line 30130 No Fluor**



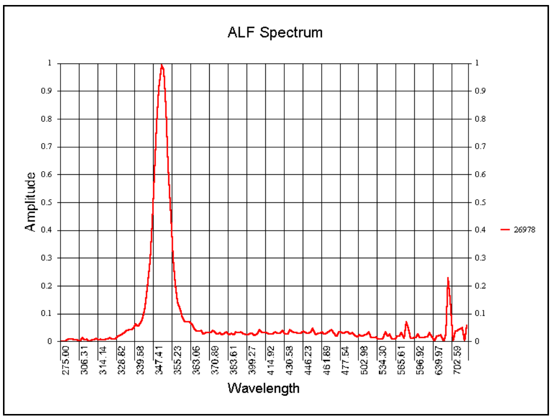
c) **Skua Line 30130 Medium Fluor**



d) **Skua Line 30130 Ten Spectra Averaged**



e) **Timor MkII Line 15 No Fluor**



f) **Timor MkII Line 21 Medium Fluor.**

Figure 27. Comparison of Skua MkIII and Timor Sea MkII ALF Data.