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Pre-Exploration Measurement and Monitoring of Background Landscape Methane Concentrations and Fluxes in the Beetaloo sub-Basin, Northern Territory

Fire Season Baseline Methane Concentrations:

Interim Report for GISERA Project G5

Cindy Ong, Bruce Maney, Mederic Mainson, David Down and Stuart Day

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Interim Report for GISERA Project G5 - Pre-Exploration Measurement and Monitoring of Background Landscape Methane Concentrations and Fluxes in the Beetaloo sub-Basin, Northern Territory

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Executive Summary

The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory submitted its final report to the Northern Territory Government in March 2018. Among other things, the Inquiry recommended that baseline monitoring of methane be undertaken ahead of the granting of exploration approvals for unconventional gas. Specifically, Recommendation 9.3 of the Inquiry's final report states:

> *That baseline monitoring of methane concentrations be undertaken for at least six months prior to the grant of any further exploration approvals. In areas where hydraulic fracturing has already occurred, the baseline monitoring should be undertaken at least a year prior to the grant of any production approvals.*

In response to this recommendation, the Northern Territory Government commissioned CSIRO through GISERA to conduct baseline methane monitoring in the Beetaloo Sub-basin which is a prospective gas production region in the NT.

This report documents the interim results from the second survey conducted as part of the "GISERA Project G5 - Pre-Exploration Measurement and Monitoring of Background Landscape Methane Concentrations and Fluxes in the Beetaloo sub-Basin, Northern Territory" project.

As documented in the first report (Ong et al. 2018), the overall aim of the project described in this interim report is to provide:

- background landscape concentrations of methane in the Beetaloo Sub-basin; and,
- Investigate methane emission rates (fluxes) and identify the sources of any elevated methane levels found.

In this report, we present the results of the second of a total of three surveys to be conducted in the Beetaloo Sub-basin. This survey was conducted over a 9-day period during the fire season between the 6th and 15th November 2018. An additional survey is planned for the region at the end of January to February 2018. The timing and extend of the third survey is dependent on road trafficability and environmental conditions during the wet season.

Like the first field campaign, this second set of surveys of atmospheric methane concentrations within the Beetaloo Sub-basin region was conducted using mobile surveys with two gas analysers mounted in a four-wheel-drive vehicle. Although methane was the principal gas of interest, CO_2 was also measured during many of the surveys to assist with identifying the source of emissions. The use of two analysers was important to provide a level of redundancy in the event of equipment failure in the remote and harsh operating conditions of the survey region.

The vehicle surveys covered approximately 5,300 km on trafficable roads and tracks during the 9-day survey period. The tracks predominantly replicated the ones traversed during the first set of surveys except for some areas across the Origin lease areas which were not trafficable due to previous rain. The area that was covered was sufficient to represent the area which will be explored in the future for Origin (Kernke, personal communication). Similar to the first set of surveys, most of the surveys were conducted on pastoral land, crown land and exploration leases. Where accessible, targeted surveys made during the first survey were replicated at 10 of the 11 plugged and abandoned or suspended petroleum wells, and 16 of the 21 water bores visited during the first survey, and three additional water bores. Measurements were repeated around the above ground infrastructure along the section of the Daly Waters to McArthur River Gas Pipeline adjacent to the Carpentaria Highway where slightly elevated methane levels were found in the first survey. In addition, measurements were collected around the Cow Creek water well where preliminary results during the GISERA 'Groundwater Characteristics In The Beetaloo Sub-Basin' project found small elevated dissolved methane in the water samples collected at this site.

In summary, similar to the first survey, overall the majority of methane concentrations recorded during the surveys were within the range of 1.77 to 1.85 parts per million (ppm) with a median value of 1.81 ppm recorded by the PICARRO. This is close to the normal background concentrations of approximately 1.8 ppm

expected in rural or natural areas (see for example, Ong et al., 2017). Isolated pockets of slightly elevated methane concentrations were observed in some areas; the sources of these were identified as:

- grazing cattle;
- urban areas; and,
- fires.

Most of the elevated methane levels detected were in the vicinity of grazing cattle, which was also the case during the first surveys made during July and August 2018. The data reiterated the observations from the first survey that the methane elevations were quite small, with a maximum concentration of 2.21 ppm, which is about 0.4 ppm above background (1.81 ppm).

Data collected at townships along the Stuart Highway showed small elevated methane concentrations of between 1.85 to 2.09 ppm. These levels were close to levels recorded in the first survey.

The third source of elevated methane levels detected during this survey was a small fire close to Larrimah. Concentrations of up to 2 ppm were measured for a short duration along the stretch of the Larrimah West Creek Road. Although this survey was conducted during the fire season, no other fire was observed in close vicinity to the survey area and hence no further elevated methane concentrations due to fire were detected. As indicated in the first report, this source of methane is more challenging to quantify with mobile surveys because of the large spatial extent and the challenges with accessing areas close enough to fires for detection.

A survey of the wetlands surrounding the Mataranka and Bitter Springs was repeated to determine the contribution of this natural source of methane to the survey area. The survey performed only along access tracks leading to the springs detected no elevated methane concentration.

Methane concentration measurements were repeated along the above-ground section of the Daly Waters to McArthur River gas pipeline where slightly elevated methane concentrations were detected in the previous survey. The concentration of methane detected during this survey was approximately 0.07 to 0.08 ppm above background (1.81 ppm). Because of the very low levels of methane detected even within close proximity to the pipeline, flux measurements of this source were not conducted. No flux measurements were made because the levels were very low, that is, below 2 ppm above the background value.

Where accessible, measurements were replicated in close proximity to the petroleum wells and water bores that were visited during the first survey. In addition, measurements were collected at the Cow Creek water bore where small elevated dissolved methane levels were detected in water samples collected for the well. No elevated atmospheric methane concentrations were detected at any of these sites.

1 Introduction

The Northern Territory Government's 'Scientific Inquiry into Hydraulic Fracturing' Final Report requires that methane measurement and monitoring occur before the advent of exploration and production activities by gas companies (Andersen et al. 2018). Specifically, Recommendation 9.3 of the Final Report requires:

> '*That baseline monitoring of methane concentrations be undertaken for at least six months before the grant of any further exploration approvals. In areas where hydraulic fracturing has already occurred, the baseline monitoring should be undertaken at least a year before the grant of any production approvals.'*

This project (GISERA Project G5) specifically addresses the first component of this Recommendation that refers to the measurement and monitoring of 'methane concentrations' before the granting of exploration approvals.

For clarity, concentration is in this report mean a measure of the abundance of gas (in this case methane (CH_4)) in the air, defined as the proportion of the total volume it accounts for (units are parts per million (ppm) or parts per billion (ppb)). Flux or emission rate is defined as the rate of flow of gas per unit time (for example in m^3 per unit time on a volumetric basis or in g or kg per unit time on a mass basis). Both measurements are required to be able to provide a baseline and quantify the natural and anthropogenic CH_4 emissions, identify where these background emissions are occurring and how much CH_4 is being released to the atmosphere.

The objective of this project is to quantify the landscape background concentration levels of CH_4 and identify the locations of sources where elevated CH_4 levels are found and, where applicable, quantify the fluxes related to these sources.

This interim report documents the findings of the second survey conducted over a 9-day period between 6th – 15th November 2018 where CH_4 concentrations in the region were measured using two gas analysers mounted in a four-wheel-drive vehicle. A total of 5,300 km was traversed during this survey, and CH_4 measurements were acquired continuously along the route. Data collected during this survey provides an indication of the background CH_4 concentrations during the fire season of 2018 and provides an indication of the main sources of CH_4 during this season.

2 Experimental Method

The experimental method employed for this survey was the mobile survey method. As discussed in the first interim report, taking into account the time constrains, this method was used as it is the most rapidly deployable. Additionally, this method is one of the most widely used, reliable and well-developed techniques for undertaking baseline measurements of landscape CH_4 concentrations and fluxes and has been used in Australia, the United States and United Kingdom (Ong et al., 2017; LTE, 2007; Phillips et al., 2013; Zazzeri et al., 2015). Comprehensive discussions on the mobile survey method can be found in the first interim report (Ong et al., 2018).

3 Instrumentation

This survey was performed using two CH_4 analysers:

- Picarro G2301 $CO_2/CH_4/H_2O$ analyser, which is a cavity ringdown spectrometer.
- Los Gatos Research (LGR) Ultraportable $C_2H_2/CH_4/H_2O$ Methane/Acetylene Gas Analyzer s a tracer gas in experiments designed to measure emission rates from some methane sources). The LGR is an OA-ICOS system.

Both instruments are capable of reliably detecting changes in CH_4 concentration as low as 2 ppb and have high levels of stability necessary for mobile operation (e.g. Crosson, 2008).

During the previous surveys made in July and August 2018, a third analyser was also used; an AERIS Technologies PICO Analyser. This instrument is housed in a compact package with low power requirements and was mainly deployed during the first surveys to assess its performance in the field with the view to developing a fixed monitoring system based on the analyser. The AERIS is currently undergoing longer term monitoring and development in Darwin and consequently, was not available for the surveys made during November 2018.

As well as measuring CH_4, the PICARRO instrument simultaneously measures CO_2 concentrations. This instrument also has the capability of measuring the ratio of $^{13}C/^{12}C$ in both CH_4 and CO_2. Isotopic ratios can in some cases provide information on the origin of the source of CH_4, provided concentrations are sufficient for reliable measurements.

The LGR measures CH_4 and C_2H_2 (acetylene) simultaneously. Acetylene is often used as a tracer when determining emission fluxes from some sources, but this method was not used during this field trip as the elevated methane concentration found were not sufficiently large to warrant flux measurements. Generally, flux measurements are conducted in cases where elevated concentrations larger than 2-3 ppm is found. If suitable CH_4 sources are located during subsequent campaigns, the tracer method may be employed to measure fluxes.

Each analyser had its own dedicated GPS receiver (Garmin 18X, Hemisphere R330 DGPS and Gill Maximet GMX500, respectively) to enable positional data to be recorded simultaneously with the gas concentration data. Local meteorological data (wind speed and direction, temperature and humidity) was measured with the Gill Maximet GMX500 Compact Weather Station fitted to the top of the field vehicle (Figure 1). Note that wind speed and direction measurements were made only when the vehicle was stationary. Because of the large and variable nature of the meteorology conditions, the temperature and humidity are important to monitor the performance of the instruments to understand the impacts on the resulting measurements. Where these impacts are found to be significant these meteorological data may be used to account for departures related to meteorological conditions. Positional data were combined with the gas concentration data to produce maps of CH_4 concentration across the study region.

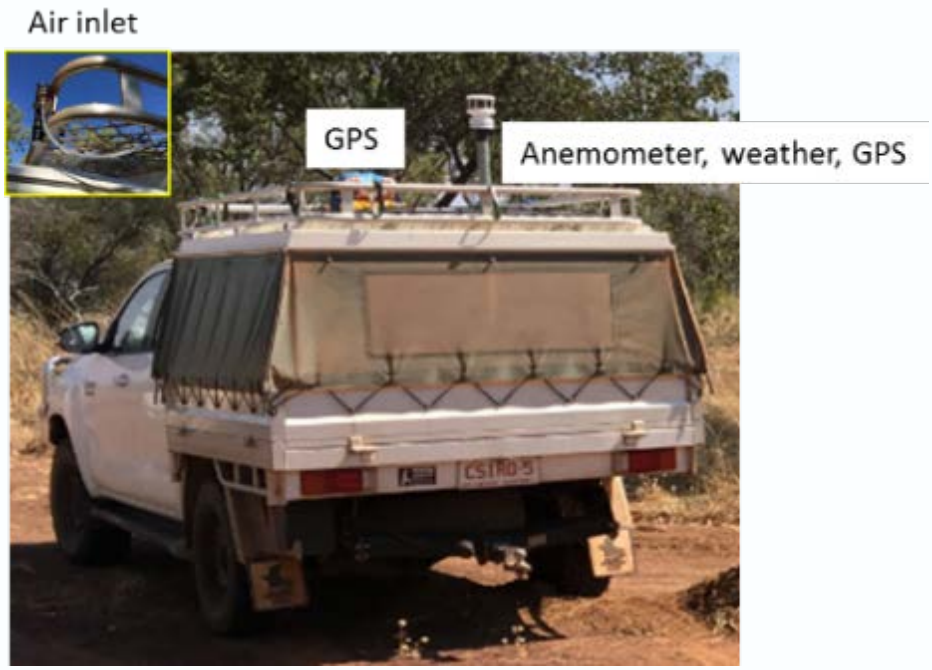

Figure 1: Survey vehicle showing the location of sampling lines, GPS and combined anemometer, GPS and weather station.

The survey vehicle is shown in Figure 1. The GPS for the LGR analyser was located on the roof rack at the front middle of the vehicle, and the Gill combined anemometer, weather station and GPS were also located on the roof rack at the front right-hand side of the vehicle. The inlet of the sampling line was located on the roof rack (see insert on the top left of Figure 1) on the front left-hand side of the vehicle. The location of the inlet was such that it was not affected by the vehicle's exhaust while travelling. The same sampling line was used for both analysers and during surveying air was drawn from the front of the vehicle to the rear of the vehicle via a single pump. The air stream from the inlet line was then distributed via two separate lines to each analyser located at the tray of the ute (shown in Figure 2). The distances between the two distribution lines were small, and the length of lines between the intake and each analyser was approximately equal.

The analysers were fitted in the rear seat in the vehicle's cabin as shown in Figure 2.

Figure 2: PICARRO and LGR analysers mounted in the rear of the field vehicle. Note that the back seat has been removed.

3.1 Daily surveying procedure

Prior to field deployment, a schedule of work was prepared. Stakeholders were contacted, and a daily route was agreed that minimising the impacts on the environment, farming and community activities. Wherever possible the surveying route was the same as that used during the initial surveys.

A typical daily survey involved start up procedures for the vehicle and the equipment, route planning and liaisons with local stakeholders. Once mobile, gas concentrations were automatically logged; periodic recording of weather observations was manually completed while the vehicle was stopped. Any methane spikes were recorded in the log as they occurred to assist with the later analysis.

Before departure, daily prestart checks on the equipment followed a set procedure to ensure the computers, PICARRO, LGR, weather station and GPS were all in good working order. Prestart checks on the vehicle were completed to ensure the daily task could be completed safely. Any activity on private land required a local site liaison to escort the test equipment on site. Verification of the route and road conditions and any other

important information that may affect the relationships with stake holders were discussed prior to deployment.

With safety in mind, vehicles typically travelled in convoy with consideration for minimising interference from the escort vehicle's emissions or a disturbed dusty road. This was achieved by setting designated meeting points and staggering the start of each vehicle. A log was kept to record time, date, location and weather observations throughout the day. Typically every 30 minutes the vehicle was stopped to log wind speed, wind direction, temperature, humidity and barometric pressure. If a significant deviation in methane was observed the vehicle speed was reduced or stopped, the peak gas concentration was logged and efforts made to identify the source of methane. As repeated weather observations were recorded, it was reasonable to conclude that cattle seen up wind of the equipment would be the most likely source of methane spike. Conversely, cattle downwind of the equipment would not trigger a response from either analyser, again verifying the equipment was functioning correctly. Particular interest was given to dams and water troughs supplied from underground sources and gas well and gas pipelines and where possible the vehicle was positioned down wind, or a circuit of the site was performed.

At the end of each surveying day, calibration checks were performed on both instruments using four reference gasses with compositions as shown in Table 1. No adjustments were made to the equipment (in accordance with the manufacturers' instructions), but any corrections were applied during the processing of the data. All of the data and the daily log were sent back to Perth for overnight analysis. Comparisons of the recorded data from the PICARRO and LGR confirmed a successful survey and authorisation given to continue with the next day's scheduled program of work.

Table 1. Reference gas compositions used for calibration checks on the PICARRO and LGR analysers.

	Methane (ppm)	Acetylene (ppm)	CO_2 (ppm)	Oxygen (%)	Nitrogen
Reference 1	1.02	1.00	-	20.8	Balance
Reference 2	3.02	-	496	20.9	Balance
Reference 3	4.07	3.97	-	20.9	Balance
Reference 4	10.2	-	1010	20.9	Balance

4 Data Processing

The main data processing performed on the data collected during this survey include:

- correction of the measured concentration data to account for humidity;
- alignment of each of the respective data to a common reference to account for the different response time of each analyser; and
- where there were gaps in one of the dedicated GPS for one of the analysers to fill these in with the GPS data that was acquired simultaneously.

It should be noted that although moisture concentration data are not strictly required for the methane and CO_2 analyses, the varying levels of moisture present in the atmosphere affect the concentrations of these species over long and short timeframes. Hence, to allow direct comparison with data collected under different humidity conditions, the methane and CO_2 concentratons are often reported on a 'dry air' basis (i.e. the methane/CO_2 are corrected to a moisture content of 0 %). Methane and CO_2 concentrations reported from global monitoring stations (e.g. the CSIRO Cape Grim station in Tasmania) are generally reported on a dry basis.

Before commencing the first field programme, each analsyer was subjected to a multi-point calibration using up to five reference gasses in the CSIRO Kensington laboratories in Perth. The calibration standards contained CH_4 at concentrations ranging from approximately 1.8 ppm (close to ambient air concentration) up 102 ppm (similar to the maximum CH_4 concentration measured during the field campaign). At the time of the calibration, all instruments were linear over this range. This calibration exercise will be repeated at the end of the third survey.

This survey was conducted under more extreme weather conditions with higher temperatures and larger variations in humidity than during the first surveys made in July and August 2018. The temperature variations was mitigated with the installation of the instrumentation in the cabin of the vehicle. However, the high humidity levels were found to have a significant impact on the measurements. Both the PICARRO and LGR have the ability to measure water vapour. Ideally, these measurements which would have been acquired simultaneously with the CH_4 and CO_2 concentrations would be used to correct for humidity impacts. However, investigation of the water vapour measurements found that the sensor on the PICARRO was not functioning properly and was recording spurious levels. This meant that humidity impacts were not properly accounted for in the PICARRO data. This impact is illustrated in Figure 3 where the CH_4 concentration recoded by the instruments is plotted as a function of the measured water vapour concentration. The left graph shows that the water vapour concentrations recorded by the PICARRO were very low and inconsistent with the humid conditions; many of the values were also negative or very close to zero. There also appears to be four discrete sets of data indicating that there may be four different sets of estimations for water vapour. In comparison, the water vapour measurement to the CH_4 concentration for the measurements recorded by the LGR as shown on the right graph, the water vapour values was as would have been expected from the weather conditions and there was a clear linear relationship between the concentration of CH_4 and water vapour.

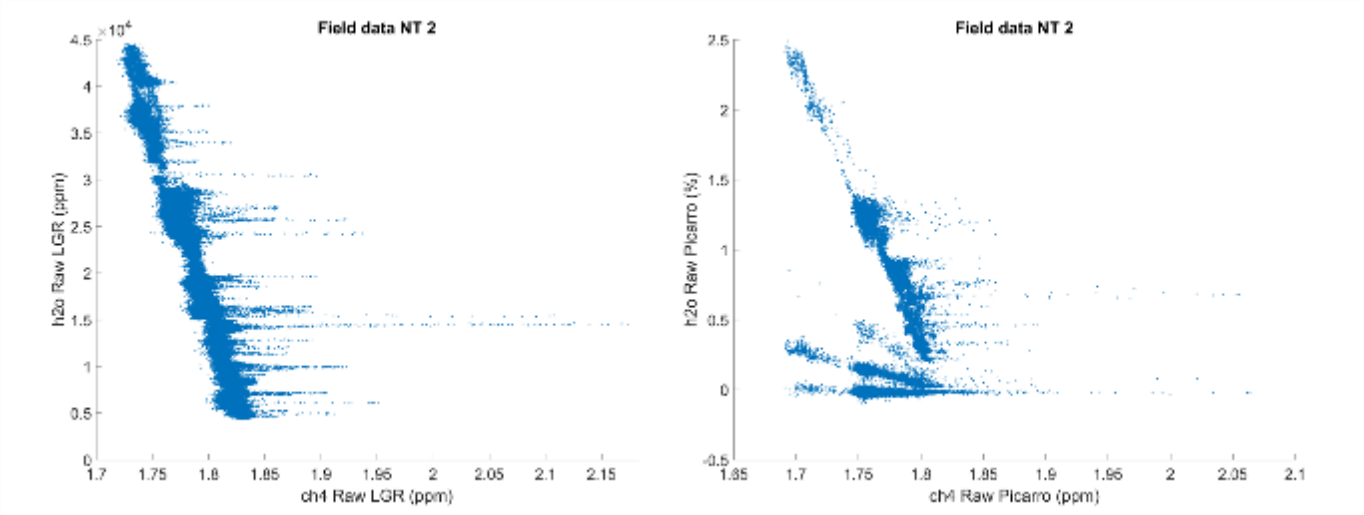

Figure 3: Left: Raw PICARRO CH_4 concentration plotted against the H_2O vapour measurements. Right: Raw LGR CH_4 concentration plotted against the LGR H_2O vapour measurements. Note that the H_2O vapour is measured in percent water for the PICARRO and in ppm for the LGR.

As the humidity impact was significant, it was important that these impacts were removed. Examination of the water vapour measurement recorded by the LGR and illustrated on the right graph in Figure 3 indicate that they were sensible. Therefore, a correction was implemented where the water vapour measurements from the LGR was used to correct the PICARRO data using the simplified equation below. The same equation was also applied to the LGR data to ensure that both datasets were corrected similarly.

$$CH4corrected = \frac{CH4raw}{(1 - H2O)}$$

Where *CH4corrected* is the corrected CH_4 concentration (ppm), *CH4raw* is the raw CH_4 concentration (ppm), and *H2O* is the water vapour concentration (%).

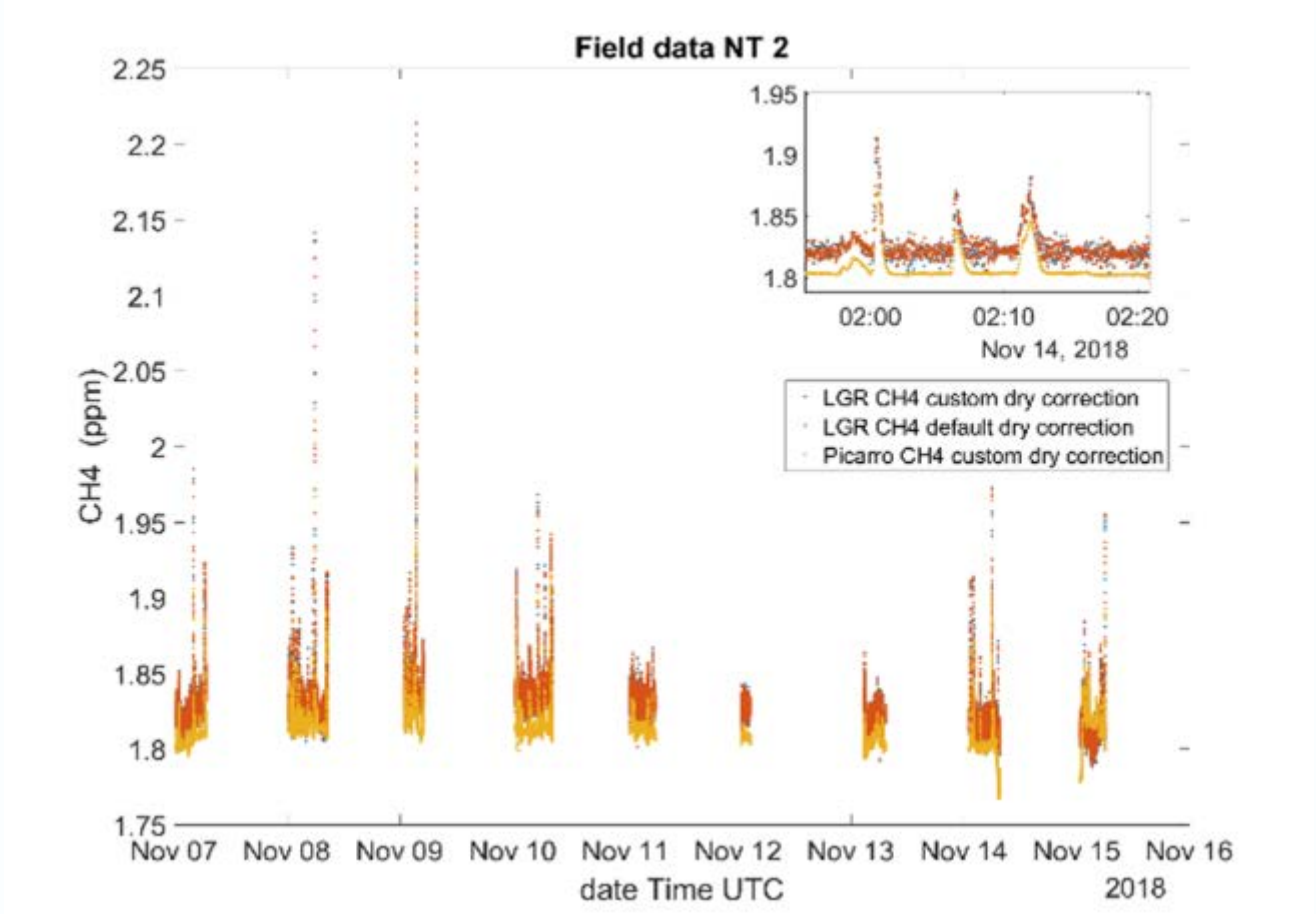

Figure 4: Corrected PICARRO (orange dots) and LGR (blue dots) CH_4 concentration using the customised method described above and automated dry CH_4 values provide by correction implemented by LGR (red dots).

Figure 4 which plots the results of the correction shows that the humidity impact has been accounted for as indicated by similar average baseline values for all dates. Additionally, the graph shows that the customised correction produced similar results to the correction implemented by LGR.

Figure 5 shows the correlation between the PICARRO and LGR methane measurements. The figure illustrates the influence of humidity on the raw methane measurement (plotted in blue) where the baseline level varied from 1.75 to 1.85 ppm. After the correction, this baseline remained constant at 1.85 ppm (plotted in orange).

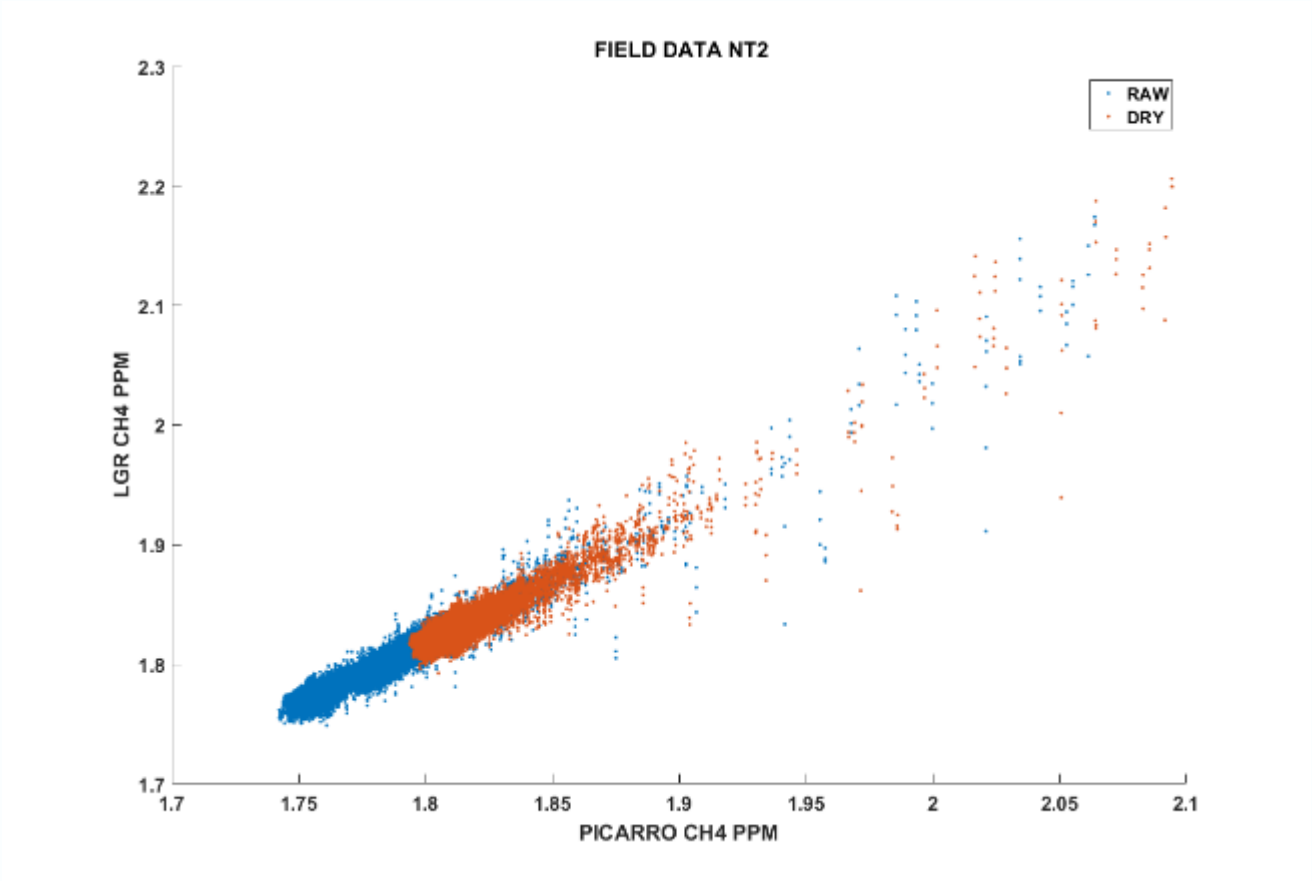

Figure 5: Correlation between the PICARRO and LGR raw (blue) and dry (corrected for humidity effects in orange) methane concentration measurements.

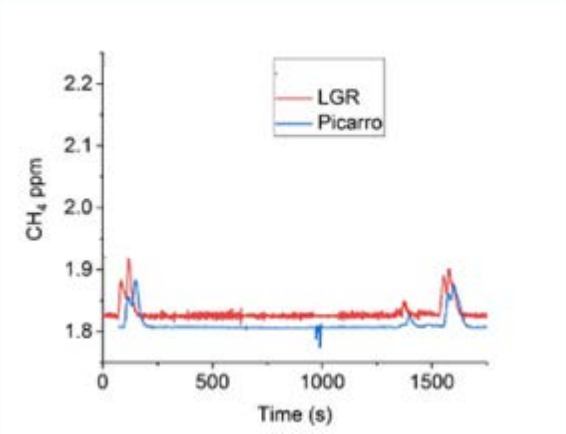

Figure 6: CH_4 detected by the PICARRO and LGR analysers before realignment for the response time difference.

The response time of each analyser is a function of the size of the sample cell within the instrument, the flow rate of the gas into the analyser which in turn is a function of the pump capacity and size of the inlet valve into the analyser. An example of the differing instrument response time is shown in Figure 6 where the response time difference related to a herd of cattle is illustrated. This example illustrates that the PICARRO (blue line) has a slightly slower response time to the LGR (red line), but in general the profiles are similar. As a consequence, when the survey vehicle was moving, CH_4 peaks detected by each instrument appeared to be spatially offset. Time corrections were applied to each instrument's results to ensure CH_4 peaks were properly aligned.

Although there were two GPS units used on some occasions, the GPS dedicated to the LGR failed to provide a signal. Hence it was necessary to link the LGR measurements to the PICARRO's GPS. This was performed by synchronising the time stamp on the LGR data to the other GPS's time stamp.

5 Results

A total of approximately 5,300 km was traversed during the period 6th – 15th November 2018. Typically, between about 200 and 600 km was covered each day. The area of coverage was guided by the previous survey. That is, where accessible, the areas covered in the first survey were replicated as closely as possible. It is important to note that because of the weather conditions, some of the tracks especially across the Origin lease area were no longer trafficable. Figure 7 shows the heavy rain and the water on the tracks at the boundary between Amungee and Shenandoah. Consultation with Origin personnel (Kernke, personal communication) confirmed that despite some limited access, the areas covered were sufficient to represent the area which will be explored by industry in the next 6-12 months.

Figure 7: Photos showing heavy rain on tracks at the boundary between Amungee and Shenandoah in Origin lease area. Photos supplied by Origin.

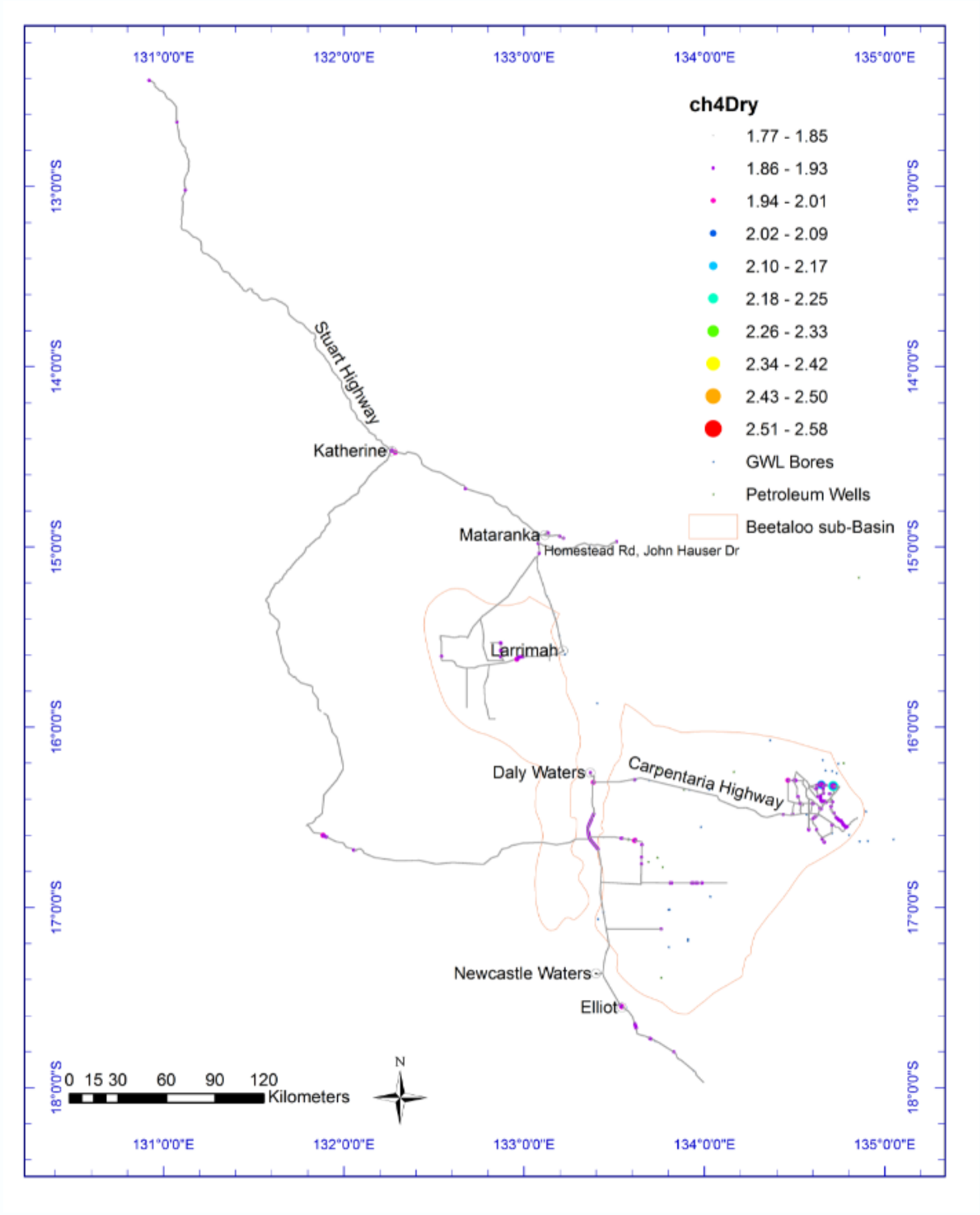

Figure 8: CH_4 concentration measured using the LGR analyser along tracks and roads across the Beetaloo sub-basin.

Figure 7 shows a map which represents a summary of the CH_4 concentration measurements collected by the LGR across the area traversed during the entire survey. The CH_4 concentration (in ppm) is colour coded, and the markers are sized relative to the gas concentrations. Similar to the first survey, the bulk of the data shows a concentration level between 1.77-1.85 ppm. These concentrations would be representative of the natural ambient/background levels across the study area. As a guide, these values are equivalent to or below the global CH_4 level of 1.85 ppm (Dluugokencky 2018).

Across the survey, there were pockets of elevated concentrations of CH_4 measured. The main sources of these elevated levels were predominately grazing cattle, townships and to a smaller degree, fire.

Throughout the survey, most of the elevated concentrations measured could be attributed to cattle when the vehicle passed herds of cattle on the side of the tracks travelled. This was the case for the bulk of the elevated levels detected along the west and east of the Stuart Highway. For example, the largest number of elevated concentrations were detected furthest west on the Santos lease area. Except for a small elevated concentration close to an above ground section of the Daly Waters to MacArthur River gas pipeline, each of other elevated concentrations can directly be attributed to herds of cattle passed along the tracks travelled.

The other main sources of elevated CH_4 concentrations detected were townships as indicated at Katherine, Mataranka, Larrimah, Daly Waters and Elliot along the Stuart Highway (Figure 7). The sources of these elevated values were likely to be attributed to commonly known anthropogenic sources at townships such as fuelling stations, seepages of natural gas from domestic or commercial usage, vehicles or sources such as sewerage/waste treatments and landfills. The elevated values were generally similar to the values measured in the first survey although some of the smaller towns such as Elliot and Larrimah were slightly higher when compared to the first survey.

The other elevated CH_4 concentrations that are visible on the regional scale displayed in Figure 7 can be attributed to fires. The source was a grass fire close to the roadside on Larrimah Western Creek Road detected on the 14th November 2018. This fire was detected for an extended period while the vehicle was travelling on the side of the road. The concentration of CH_4 detected by the PICARRO and LGR is shown in more detail in Figure 8. There is a good correlation between the concentrations measured by both analysers and the maximum value detected was close to 1.98 ppm detected by the LGR.

CO_2, which is the main gaseous composition of bushfires (Urbanski et al. 2008) was also detected and showed similar trends to the CH_4 (also in Figure 8). Unlike the previous fires detected in the first survey, there is a better correlation between the CH_4 and CO_2 suggesting that both gasses are derived from the same source.

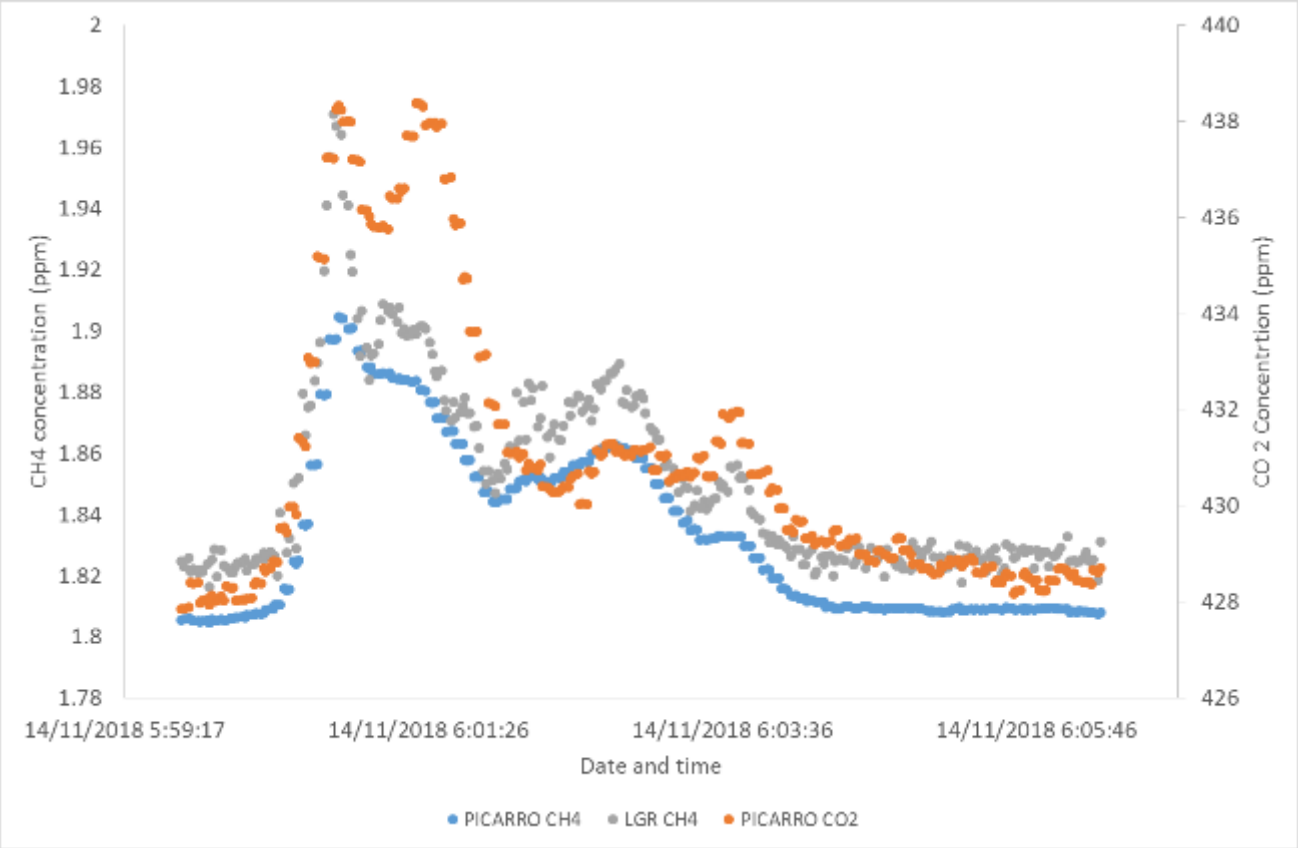

Figure 9: Concentration of CH_4 and CO_2 detected by the PICARRO and LGR analysers at a roadside grass fire on 14th November 2018.

Figure 10 shows the CH_4 concentration measurements collected by the PICARRO analyser during the survey. There is good agreement between Figure 4 (LGR results) and Figure 10 where similar background concentrations were detected and areas where the sources were static such as at extended periods at townships, similar concentrations were measured by both analysers. However, for a more dynamic source such as those produced by cattle, the concentrations vary by a small amount. For example, the highest value detected throughout the survey can be attributed to cattle at the far western side of the survey at 2.21 ppm as detected by the LGR analyser. At this location, the PICARRO detected a peak value of 2.09 ppm. This difference is a function of the different response time of the LGR and PICARRO, and, the dynamic nature of the plumes. In addition, the moving vehicle is another factor contributing to the small 120 ppb difference. These results are consistent with the findings from the first survey.

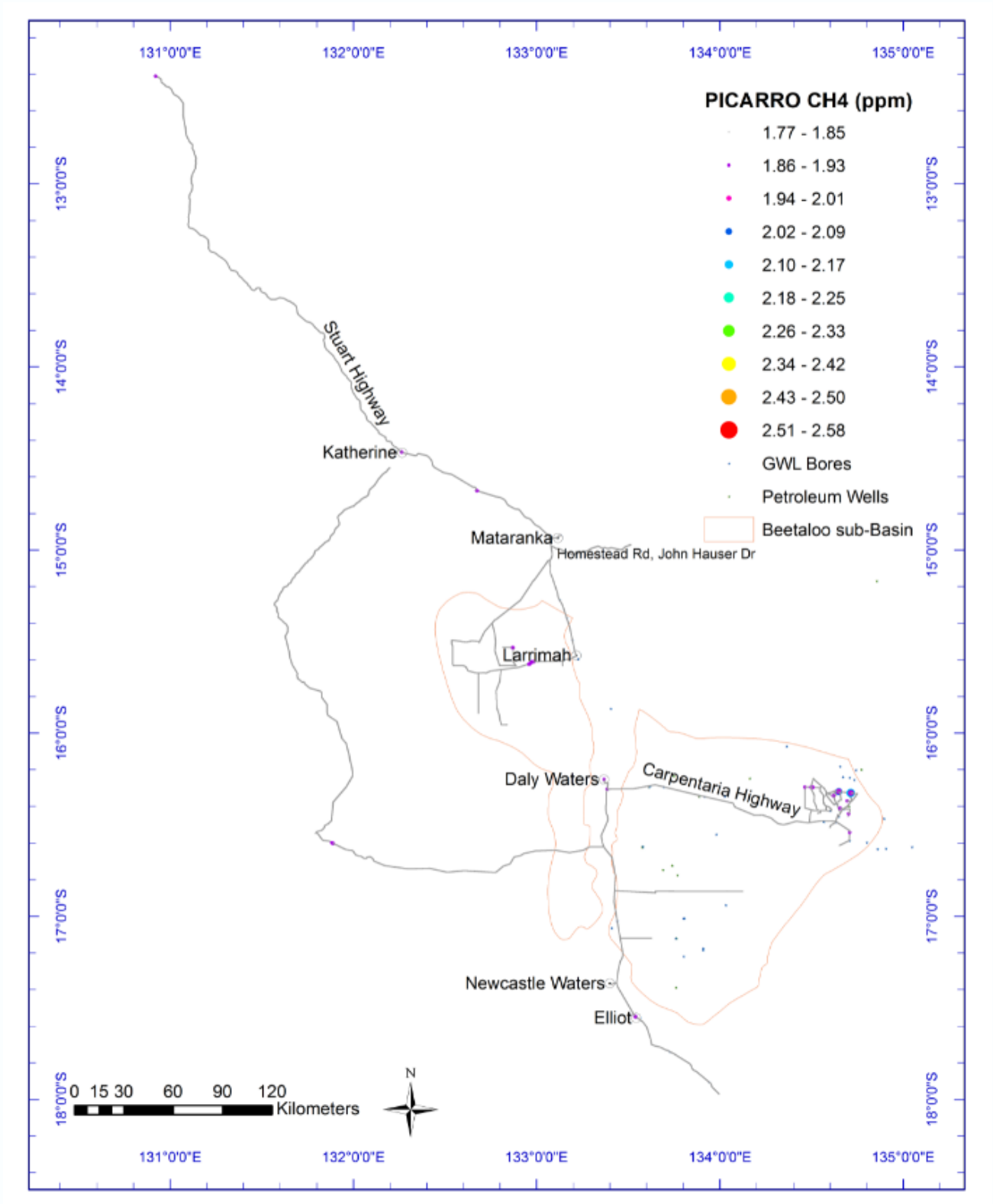

Figure 10: Methane concentration measured using the PICARRO analyser along tracks and roads across the Beetaloo sub-basin.

During the surveys, a total of 9 of the 11 plugged and abandoned and suspended wells visited during the first survey were revisited (or were close to pastoral tracks where measurements were made). Details of these wells are shown in Table 1 and highlighted in yellow. No elevated CH_4 concentrations were detected at any of the well sites visited.

Table 2: List of plugged and abandoned and suspended petroleum wells visited during the survey.

Well ID/Name	Latitude, Longitude (locations are mostly shown in Figure 4, Figure 10 and Figure 20)	Comments
1. Tarlee 1	15°57'16"S,132°50'23"E	PNA
2. Tarlee 2	15°53'32"S,132°41'4"E	PNA
3. Birdum Creek 1	15°37'50"S,133°8'35"E	PNA (see Figure 11)
4. Kalala S1	16°17'38"S,133°36'49"E	Suspended (drive by along Carpenteria)
5. Amungee	16°20'50"S,133°53'4"E	Suspended (Drive along Carpenteria)
6. West Beetaloo 1*spikes related to vehicle	17°7'14"S,133°45'42"E	Suspended (see Figure 12)
7. Shenandoah 1	16°37'11"S,133°34'44"E	PNA
8. Burdo	16°15'4"S,134°30'37"E	PNA, historical 1980s bore (drive by)
9. Tanumburini 1	16°23'57"S,134°42'14"E	Drive along pastoral track close to bore?

In addition to the petroleum wells, methane concentration measurements were repeated at (or close to) 16 of the 21 water bores examined during the first survey. Details of the water bores are shown in Table 2.

Elevated concentrations were not detected in the vicinity of most of these bores. At a small number of these bores (marked with * in Table 2), elevated values were detected, but there were also cattle close by. It was not possible to discriminate between methane produced by the cattle and those that may be seeping from the water bores. However, as the size of the herd was usually quite large, cattle is likely to be the dominating influence. Elevated concentrations were found close to the Daly Waters Motel (marked with #) again. As discussed in the previous report, this bore is only approximately 250 m away from a septic tank. It is likely that the septic tank is a confounding influence. In addition, the fuel station is also less than 500 m away from the water bore which may have influenced the results.

Although slightly elevated methane concentrations were measured, the elevation above background in the vicinity was less than 1 ppm (generally below 2 ppm total concentration measured) and collected approximately 500 m from the well, and therefore did not warrant flux measurements to be undertaken.

In addition to the water bores repeated from the first survey, additional measurements were collected close to another three water bores. No elevated methane measurements were detected at any of these bores.

Table 3: Water bores investigated

Water Bore Name	Latitude, Longitude (locations are mostly shown in Figure 4, Figure 10 and Figure 20)	Comments

1.	Motel Bore# RN24618	16°18’28”S, 133°23’9”E	Measurement collected approximately 500 m from the bore at Daly Waters Motel
2.	Unnamed water bore at Beetaloo Station	16°41’27”S, 132°58’52”E	Measurement collected close to the bore
3.	RN029012	15°16’16”S, 133°8’32”E	Drive along Stuart Hwy close to the bore
4.	RN038810	15°22’24”S, 133°9’55”E	Drive along Stuart Hwy close to the bore
5.	RN038811	15°29’23”S, 133°11’42”E	Drive along Stuart Hwy close to the bore
6.	RN005942	15°16’16”S, 133°8’32”E	Drive along Carpentaria Highway close to bore along Carpentaria Highway
7.	RN005764	15°17’35”S, 133°36’44”E	Drive along Carpentaria Highway close to bore along Carpentaria Highway
8.	RN5844	15°20’51”S, 133°54’54”E	Drive along Carpentaria Highway close to bore along Carpentaria Highway
9.	RN037655	16°28’58”S, 134°33’59”E	Drive along pastoral tracks close to the bore
10.	RN033608*	16°27’22”S, 134°38’53”E	Drive along pastoral tracks close to the bore
11.	RN039693	16°29’9”S, 134°38’11”E	Drive along pastoral tracks close to the bore
12.	RN038179	16°25’28”S, 134°36’7”E	Drive along pastoral tracks close to the bore
13.	RN008101*	16°24’57”S, 134°40’27”E	Drive along pastoral tracks close to the bore
14.	RN007659*	16°19’42”S, 134°42’48”E	Drive along pastoral tracks close to the bore
15.	RN033671*	16°23’8”S, 134°38’1”E	Drive along pastoral tracks close to the bore
16.	RN38818	133.941119 -17.907635	Stuart Hwy
17.	RN38817	133.721827 -17.743166	Stuart Hwy
18.	RN38815	133.443144 -17.030469	Stuart Hwy
19.	RN031244	16°35’14”S, 134°42’27”E	Drive along pastoral tracks close to the bore

A revisit of one of the sources of natural sources of CH_4 expected in the area from wetlands and natural geological sources such as springs was made. A survey was conducted along the public roads: Homestead Rd and John Hauser Rd to determine the possible presence of CH_4 from the wetlands area around Bitter Springs and Mataranka Springs. No elevated concentrations were detected along these roads similar to the findings form the first survey.

During first survey CH_4 measurements made alongside a section of the underground Daly Waters to McArthur River Gas Pipeline (photo in Figure 12) found small elevated values at a section of the pipeline that was above ground. A revisit of this above ground area was made specifically, and data were collected around the site. The measurements made during this survey confirmed the presence of elevated methane levels at the site. This is shown in Figure 11 where the maximum elevated values above the background is 0.07-0.08 ppm. No further investigations were performed to measure flux because the elevated levels were small, equivalent to the levels detected in the region for cattle.

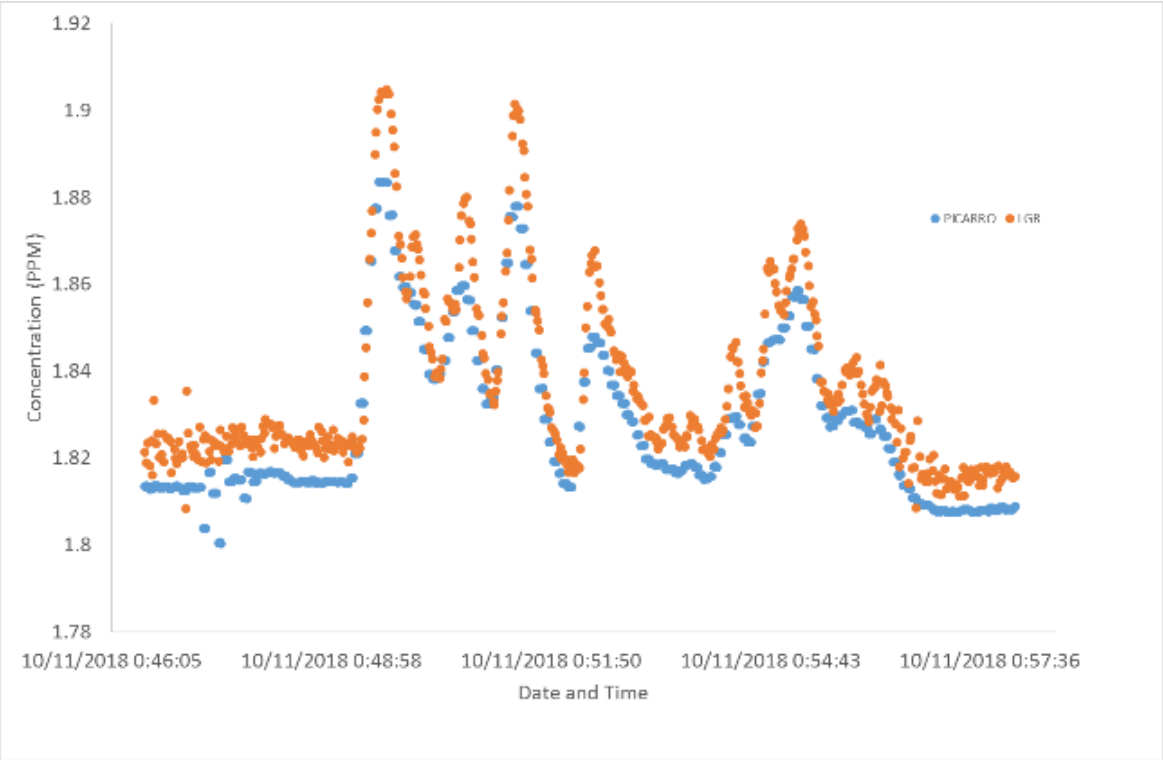

Figure 11: PICARRO and LGR CH_4 concentrations detected around a section of the Daly Rivers to MacArthur River pipeline.

Figure 12: Photo of the above ground section on the Daly Waters to MacArthur River gas pipeline where small elevated CH_4 values were found. The geographic location of the site is 16.5437°S, 134.7087°E.

6 Discussion

Overall, the CH_4 concentrations recorded across the survey area during this survey were similar to the findings from the first survey. That is, the majority of elevated CH_4 concentrations recorded in the survey area were related to cattle. This is in line with the fact that cattle production is currently the dominant industry in the area and is the main source of CH_4. As discussed in the previous report, mobile surveys can be used to detect these sources and where there is a large compound full of cattle as in the case of a feedlot, it is possible to collect measurements related to flux for such feedlots (Day et al., 2016). However, in the case of the survey area in the Beetaloo sub-basin, where the cattle were free ranging, it is more appropriate to use well established emission factors related to cattle (Charmley et al. 2016; Eady et al. 2016; Navarro et al. 2016; Tomkins et al. 2011), which can be used to quantitatively calculate the flux from these dispersed sources. The estimation of the flux from the cattle were provided in the first report.

Also consistent with the first survey, secondary sources of elevated CH_4 concentrations of between 1.85 to 2.09 ppm were recorded at townships along the Stuart Highway. These concentrations are similar to values recorded at other towns or cities and are believed to relate to multiple factors including domestic and industrial natural gas usage, landfills, sewage and waste treatment.

Although the survey was conducted during the fire season, only one fire was sufficiently close to the survey tracks to be detected. As discussed, in the previous report, for such large fires where it is typically challenging to access the plumes via mobile survey and are usually spatially large, methods which provide the spatial comprehension incorporating spatial data such as remote sensing could potentially provide better quantification of flux. Examination of fire scars mapped using remote sensing produced by Northern Australia Fire Information for the period of the survey showed a fairly large fire scar mapped in the vicinity confirming the presence of a fire. This is shown in Figure 13 which plots the CH_4 concentration measured by the LGR overlaid with the fire scars mapped from remotely sensed data during the survey period. Further examination of Figure 13 indicates that there were additional areas where elevated CH_4 concentrations detected by the LGR coincided with fire scars mapped from remote sensing. Specifically, these were 1) the elevated CH_4 concentrations detected south of Elliot, and, 2) the area close to the cross road between Buntine and Buchanan Hwy. Cross checking with the CO_2 concentrations measured by the PICARRO analyser shown in Figure 14 shows that elevated CO_2 were also detected at these locations. Therefore, it is likely that fires were present as mapped with remote sensing.

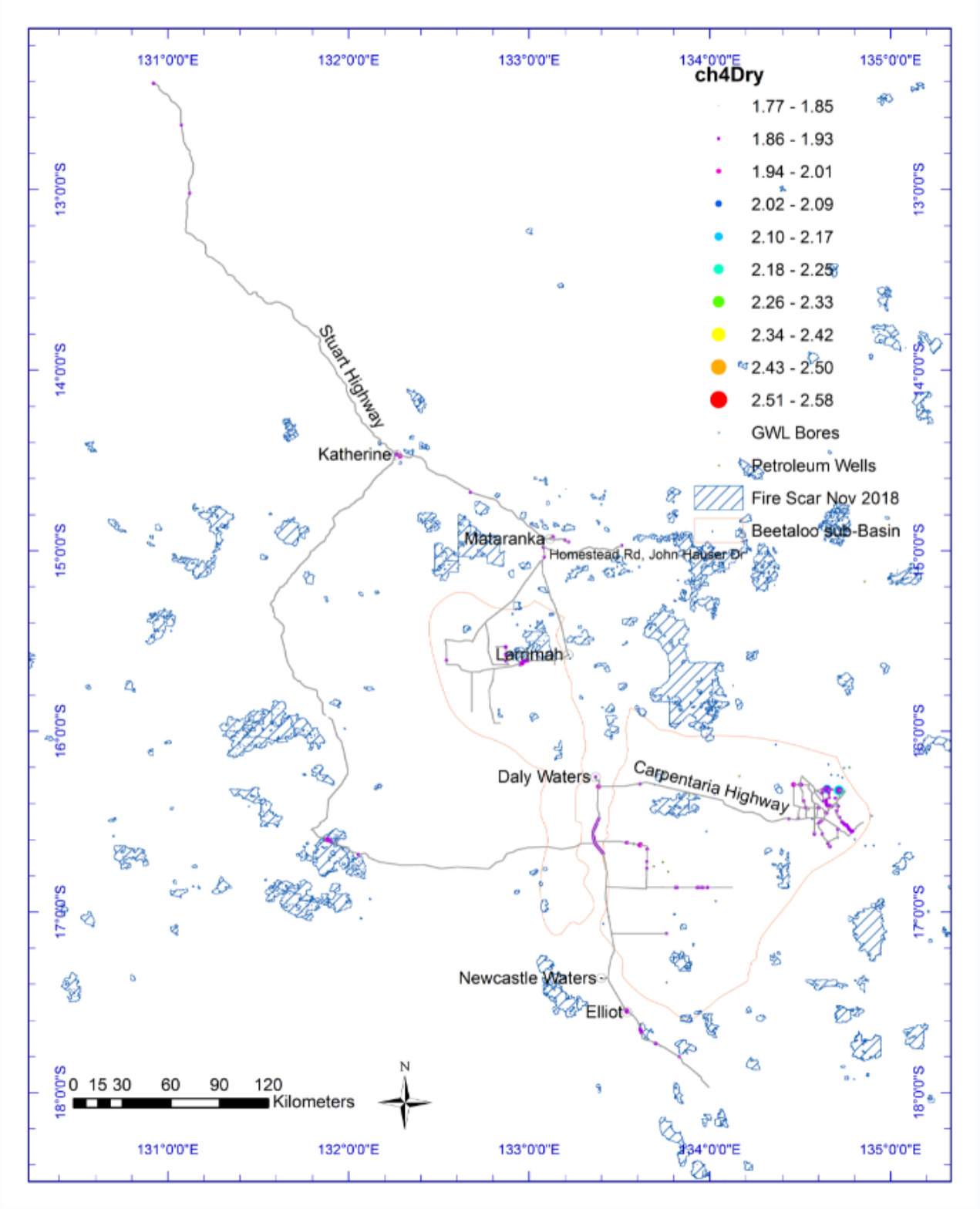

Figure 13: Methane concentration measured using the LGR analyser along tracks and roads across the Beetaloo sub-basin. The cross hatched area shows fire scars mapped from remotely sensed data extracted from NAFI.

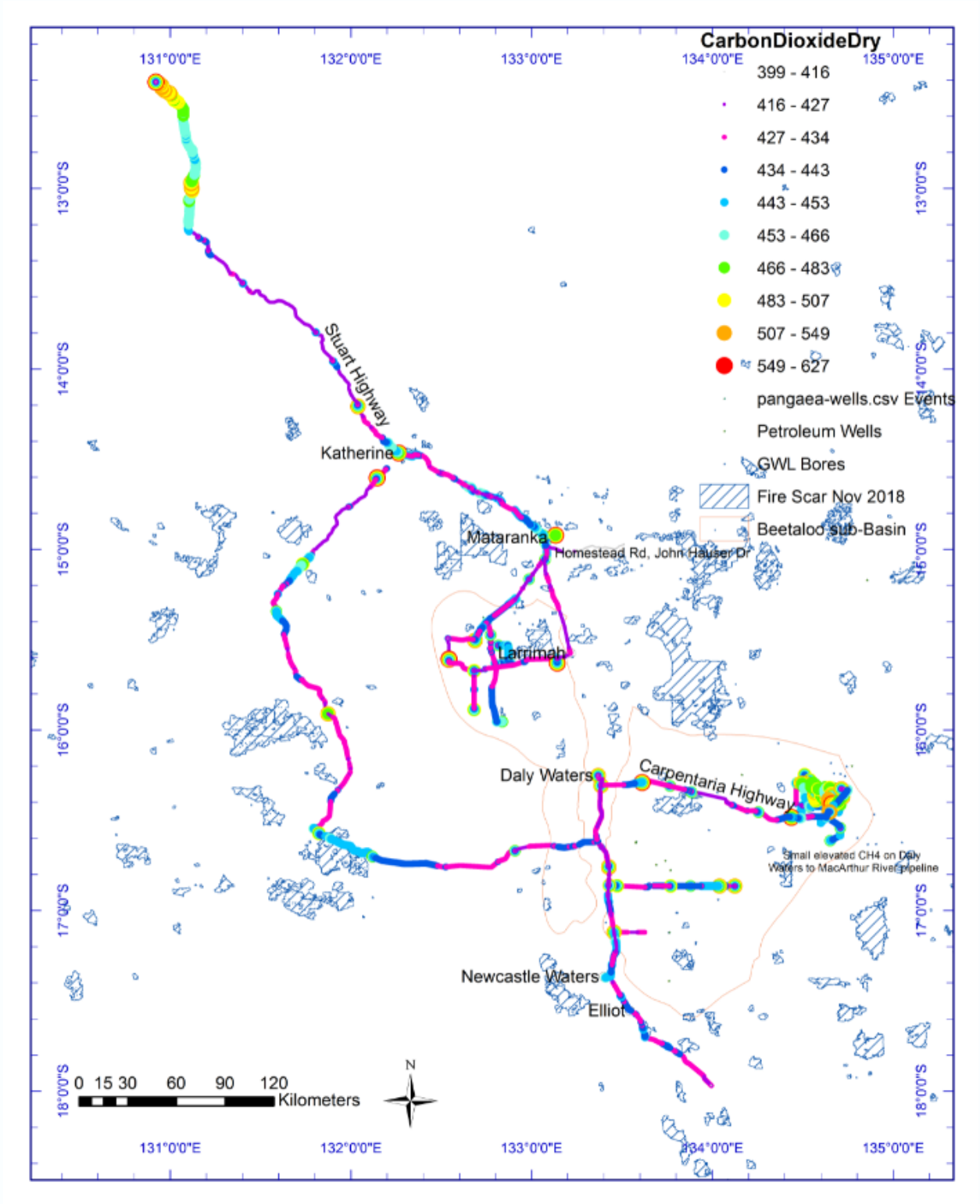

Figure 14: Carbon dioxide concentration measured using the PICARRO analyser along tracks and roads across the Beetaloo sub-basin. The cross hatched area shows fire scars mapped from remotely sensed data extracted from NAFI.

Related to plugged and abandoned petroleum wells and water bores, the findings from this survey were consistent with the previous survey. That is, no elevated CH_4 concentration was found at any plugged and abandoned wells visited, and, small elevated concentrations were observed at a small number of water wells which were proximal to other potential CH_4 sources like cattle or other more significant sources such as a fuel station and a septic tank. Although, it was not possible in this handful of instances to conclusively determine the source of the CH_4 detected, the locations of elevated concentrations were not consistent between the

surves indicating that for the wells which exhibited some elevated concentrations in the first survey but not replicated in the second survey, it is likely that transient sources such as cattle were the likely source.

A survey of the wetlands surrounding the Mataranka and Bitter Springs was repeated to understand the contribution of this source of CH_4 to the survey area during this season. No elevated CH_4 concentration was detected again along the access routes. As the survey was conducted before the wet season, the lack of elevated concentrations recorded during this survey could be a function of the season as found by other studies indicating that CH_4 emissions were higher in the wet seasons compared to the dry seasons (Grand and Gaidos 2010).

The area adjacent to the above ground section of the Daly Waters to McArthur River gas pipeline where small elevated CH_4 concentrations were measured in the first survey was revisited to confirm the potential presence of a small leak. Small elevated values of between 0.07-0.08 ppm were detected during this occasion which indicates that there is a small leak present. However, the levels of CH_4 detected were too small to warrant further investigations with flux measurements. Additionally, it must be noted that this is a small leak and would likely fall under the threshold of "reportable leak" as defined as by the Queensland Government's Code of Practice that, at a measurement distance of 150 mm immediately above (and downwind) of the source, gives a sustained reading of greater than 10,500 ppm (DNRM 2018).

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