Brazilian Journal of Geophysics (2021) X(X): X-X

ISSN 0102-261X
DOI: 00.0000/xxxx.0000.00.000

2D/3D seismic survey optimization of a hybrid (seabed node/towed streamer) project in a challenging environment

Otimização de levantamento sísmico 2D / 3D de um projeto híbrido (nó do fundo do mar / streamer rebocado) em um ambiente desafiador

Area: Marine Geophysics and Physical Oceanography

Received: December 1, 2021; Accepted: date; Published: date

ABSTRACT. This article describes how 2D and 3D seismic data acquisition programs were accomplished by a single vessel in a short, weather constrained shooting season. Detailed operational optimization and novel acquisition methods were the key to successful project execution. For the 3D towed streamer segment of the project a time and space variant current model was used to estimate and minimize infill. Ocean bottom nodes were placed around a production platform to acquire data under the platform without using a second vessel. The planned program was adapted to deal with a slow moving obstruction drifting across the survey area.

Keywords: marine data acquisition; Survey design; optimization; streamer; node

RESUMO. Este artigo descreve como os programas de aquisição de dados sísmicos 2D e 3D foram realizados por uma única embarcação em uma curta temporada de tiro com condições climáticas limitadas. Otimização operacional detalhada e novos métodos de aquisição foram a chave para a execução bem-sucedida do projeto. Para o segmento de streamer rebocado 3D do projeto, um modelo de corrente variante no tempo e no espaço foi usado para estimar e minimizar o preenchimento. Nós do fundo do oceano foram colocados em torno de uma plataforma de produção para adquirir dados sob a plataforma sem usar um segundo navio. O programa planejado foi adaptado para lidar com uma obstrução de movimento lento que se desloca pela área de pesquisa.

Palavras-chave: aquisição de dados marinhos; Desenho de pesquisa; otimização; flâmula; nó

INTRODUCTION

As the margins for E&P success and failure get ever smaller, geophysical surveys play an increasingly critical role in the exploration and production enhancement workflow. Each project represents a significant investment, with many stakeholders having subtly different, and potentially conflicting objectives. Geoscientists would like data that is of sufficient quality to meet their objectives. Managers want data delivered as soon as possible. Stockholders want to ensure that data is acquired with the lowest possible cost. Society demands that environmental impact is minimized. Optimization that balances all these factors is the key to a successful project. In this article, we illustrate how this multivariate optimization can be accomplished for a project comprising both 2D and 3D elements. The 3D portion of the project is acquired using a combination of towed streamer and seabed nodes deployed around a fixed obstruction. The entire project is constrained to a short data acquisition window as a result of seasonal weather conditions.

In this paper we show how careful pre-survey planning can be used to reduce risk, cost, environmental impact and time to acquire a survey based on thorough analysis and integration of a-priori knowledge of the environment. We also illustrate how the survey plan must be continuously updated as unexpected conditions arise.

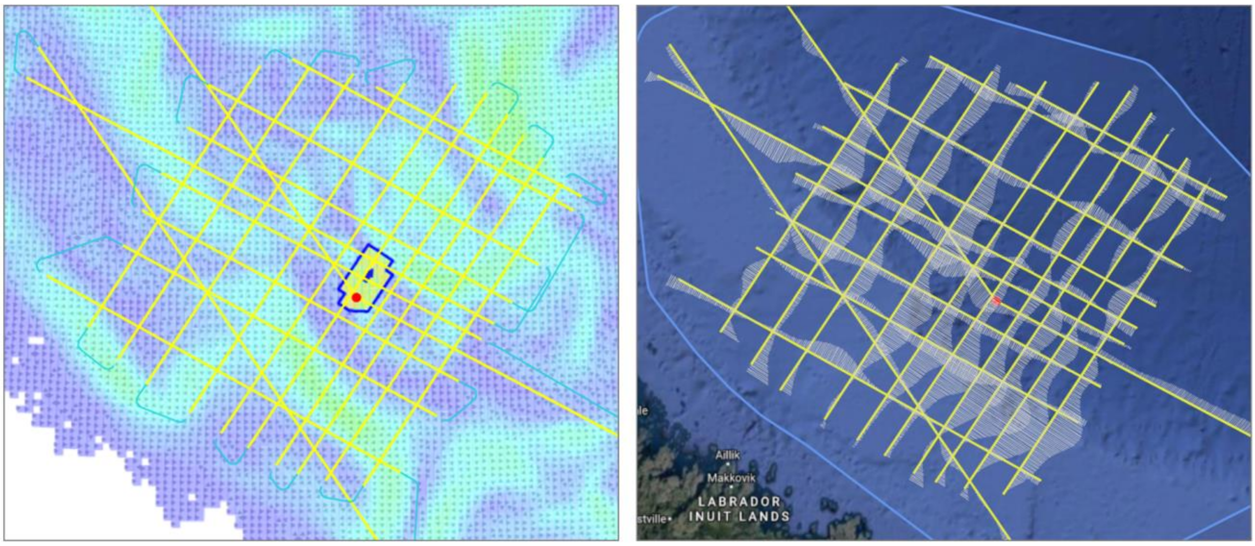
PROJECT BACKGROUND

The offshore East Canada project considered here illustrates many features of a typical E&P project that can be encountered anywhere in the world. The "project" is used extensively in our software testing and user training. A regional 2D grid is designed to infill a pre-existing sparse 2D grid, and tie to a recent discovery well. A small 3D survey will be acquired to delineate the reservoir and qualify near field prospects close to the discovery location.

The survey area is offshore Labrador (Canada). The ideal data acquisition window extends from mid-June to mid-September. Outside of this window, adverse weather conditions can prove expensive, and increase the safety risk exposure. Early in the season, icebergs can often be observed drifting southwards across the survey – their trajectories driven by prevailing currents and winds. It is worth noting that in April 1912, the Titanic met its iceberg about 1,000 km south of this survey area !

Figure 1 : Bad weather conditions in November

Another feature of the project area is seabed topography. The edge of the continental shelf runs across the project area, and this creates strong regional currents as shown in Figure 2.



(a) (b)

Figure 2 : (a) 2D and 3D surveys shown with predicted ocean current for June 19th (b) 2D program shown with bathymetry and predicted streamer feathering based on preliminary shooting plan.

THE BIG DECISION

Figure 3 illustrates the key decision required in planning the acquisition program for the season.

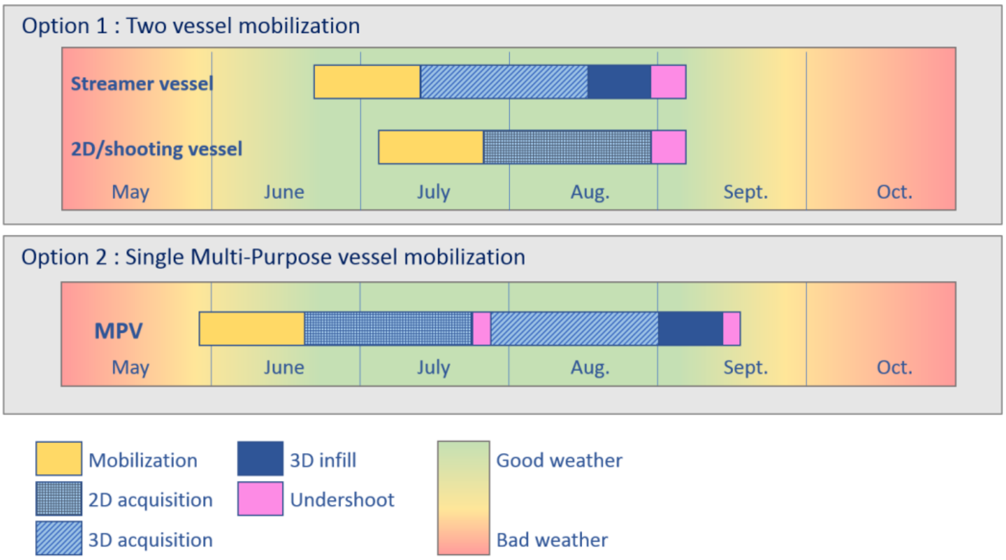


Figure 3 Program options

Option 1 represents the “traditional”, more conservative approach to the project, in which 2 vessels are mobilized. In addition to the multistreamer 3D vessel, a smaller 2D vessel is mobilized to acquire the 2D program. The 2D vessel can then be used as a shooting vessel to undershoot the production platform. This approach offers the benefit that the project can safely be accomplished within the summer acquisition season, with minimal technical risk. However, there are a number of concerns with this approach.

1) The 2D vessel will be shooting at the same time as the 3D vessel, resulting in significant seismic interference. Note that in the following discussion, we will suggest that this is not a major concern with modern processing technology.
2) Option 1 requires the 2 vessels to complete their work at the same time in order to be ready to perform the undershoot. This choreography is rarely accomplished perfectly, and some standby time on one vessel or the other is highly probable.
3) Mobilizing 2 vessels is expensive and the addition of a vessel represents a significant increase in cost and emissions. This is the primary reason to evaluate the viability of Option 2.

In Option 2 we will use a single vessel to acquire the 2D program, then reconfigure for 3D and acquire the 3D. We will assume that the vessel is a multipurpose vessel (MPV) capable of deploying a number of nodes around the platform that will continuously record data from the 3D survey and that the MPV cost is not significantly more than the streamer vessel in Option 1.

This approach reduces cost and eliminates seismic interference, but the big concern is whether or not the entire project can be acquired within the preferred shooting season of 80-90 days.

The primary objective of this survey planning exercise is to determine the viability of Option 2. Our approach will be to estimate the optimum time to acquire each element of the survey.

SEISMIC INTERFERENCE

As we mentioned earlier, Option 1 would require simultaneous shooting, with energy arriving from all directions at certain times during the survey. In the past, such shooting would require that vessels “time share” : a highly inefficient approach. One side effect of recent advances in simultaneous shooting and deblending is that the removal of seismic interference is now a routine and effective process. Figure 4 illustrates the effectiveness of the technique. The example shown is from an ocean bottom node survey, but the same principles and methods are equally applicable to towed streamer data. On the left (4a), we see a raw shot gather. Figure 4 (b) shows the same shot gather marked up with the various energy sources. The shot interval is around 3 seconds, so shot energy is visible from 4 discrete shots from the primary vessel. The primary shot is shown in red with other shots from the primary vessel (sometimes referred to as “self-interference”) shown in purple. Another vessel is also shooting at the same time, and energy from the other vessel is highlighted in red.

Figure 4 (c) shows the same shot gather after deblending. In this example, an inversion based deblending has been applied but other techniques can also be effective, particularly since we have accurate knowledge of the timing and location of the shots from both vessels. For this project, we discount the issue of seismic interference.

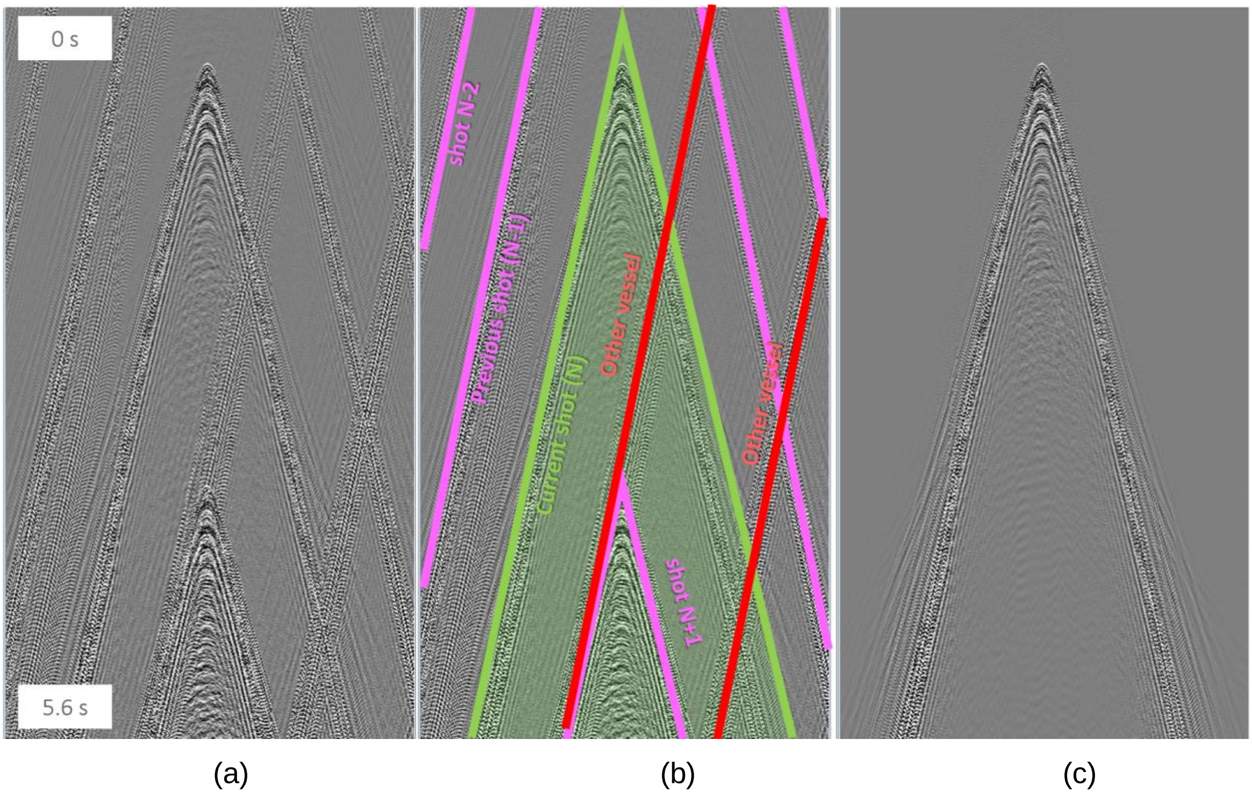


Figure 4 : Common shot gathers (OBN data) (a) and (b) before and (c) after deblending (Data courtesy of DUG and Axxis Geosolutions)

SEQUENCE OF ACQUISITION

For Option 2, we must choose to shoot either the 2D or the 3D first. Examination of a time and space variant current model (Figure 5) shows that ocean currents in the survey area are highest and have the largest spatial variation across the survey area in July. Consequently, it was decided to acquire the 2D portion of the survey in June and July, so that the most favorable (ie smaller) currents would be encountered during the acquisition of the 3D survey. This was considered beneficial because of the desire to minimize infill for the towed streamer component of the project.

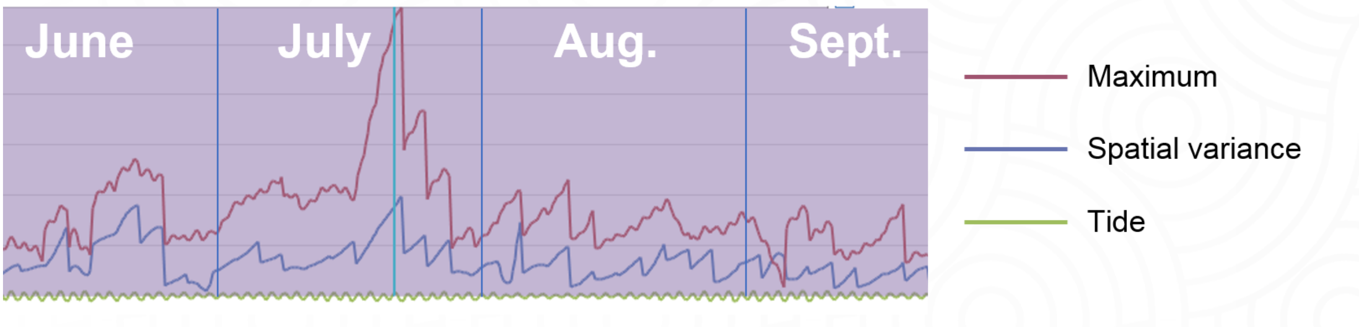


Figure 5 : Crossline component of current for 3D surveys area (Data courtesy of Seisintel)

PRELIMINARY PLAN

The 2D portion of the project comprising 224,000 shots, a 10km streamer and 5,591 towed km was estimated to take 35.6 days, including 10% downtime.

For the 3D program, 10 x 8km streamers were selected, with 5 single string source arrays, resulting in roughly symmetrical in-line and crossline bin sizes. The survey was initially divided into 2 "racetracks" consistent with the turn radius of the vessel in order to minimize the acquisition time as shown in Figure 6. After allowing for a total of 20% downtime, including technical and weather related issues, the optimized 3D program was estimated to take 39.3 days using an average vessel speed of 4.5 knots.

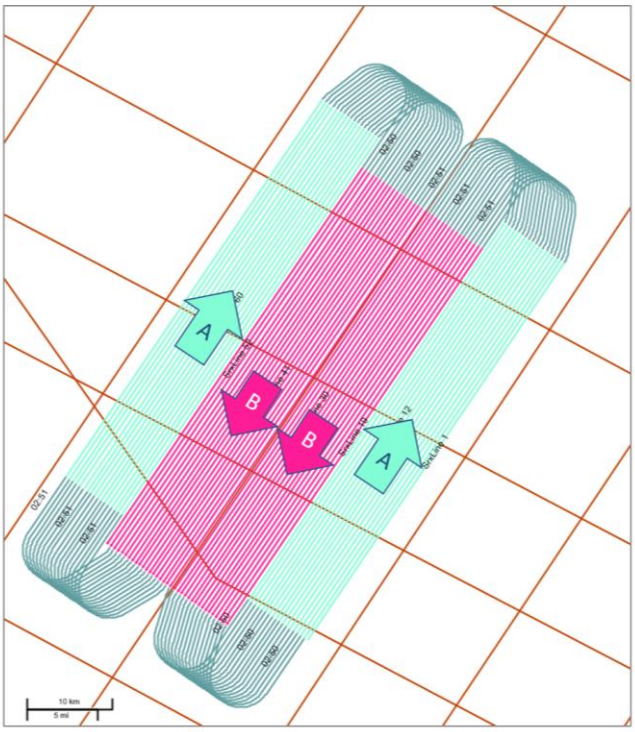


Figure 6 : Preliminary 3D Acquisition plan (with portions of 2D program)

INFILL

When a streamer is towed behind a seismic vessel, it is susceptible to ocean currents that cause the longer offset sections of the streamer to deviate from the desired location in the bins behind the vessel : a phenomenon we call "feathering". In an ideal world, if the adjacent vessel pass is acquired with a similar feather, offsets lost from a bin with the first vessel pass are made up from the second vessel pass. However, in the real world, ocean currents are rarely this obliging and mismatched feather angles between adjacent lines can result in contiguous blocks of bins that are missing certain offset ranges. Where these coverage holes are deemed to be significant enough that they cannot be filled in seismic processing using techniques such as 5D interpolation, additional "infill" lines must be recorded to fill in the holes. Part of the planning process for this project was to model the streamer feathering based on the expected ocean currents and estimate the infill. The expected fold coverage for a portion of the survey is displayed in Figure 7.

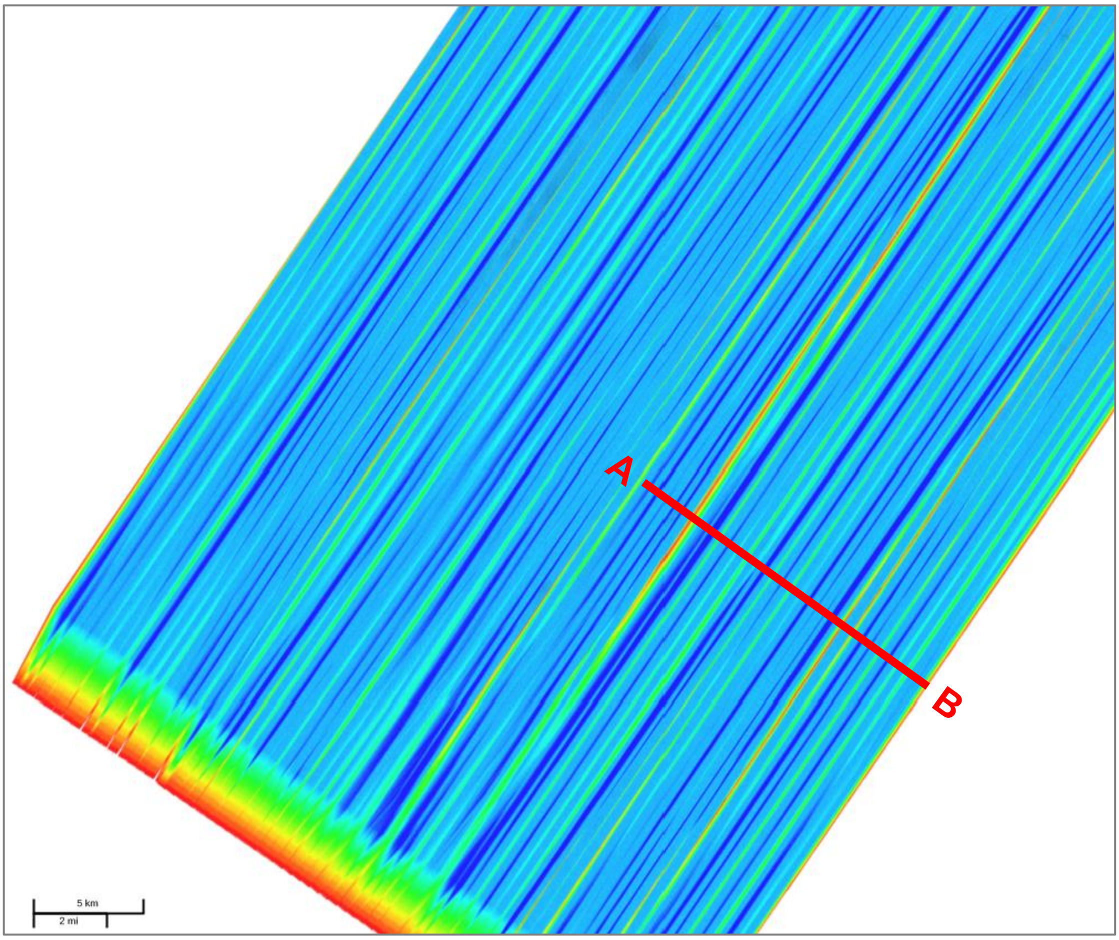
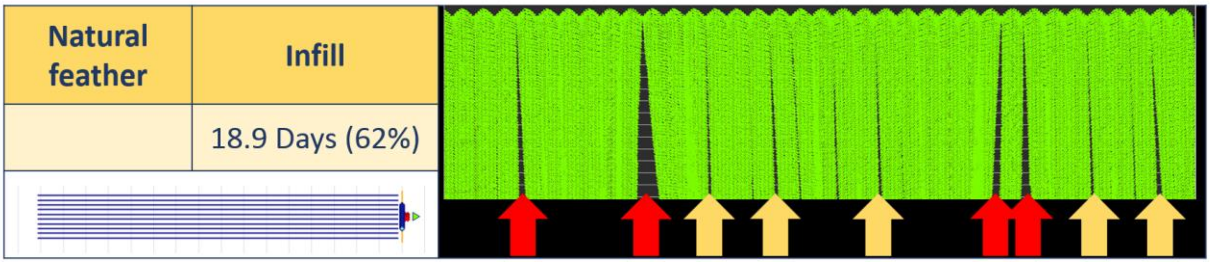


Figure 7 : Expected Fold (Parallel streamers)

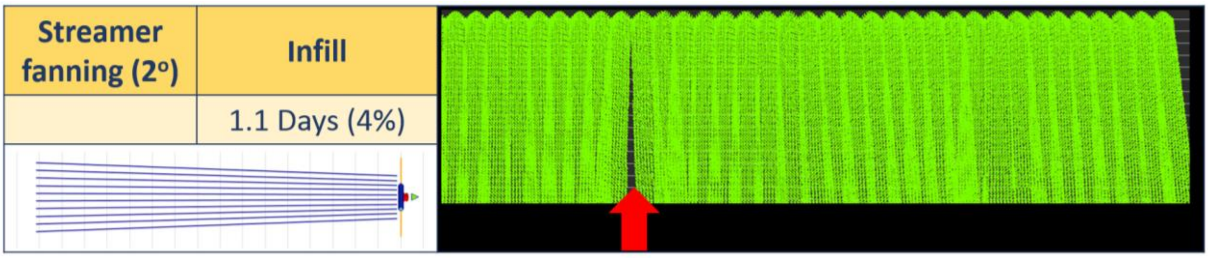
Algorithms, and more recently machine learning techniques, have been used to choose data acquisition sequences to minimize feather mismatch between adjacent lines, and therefore minimize infill acquisition. Detailed discussion of the specifications for infill is beyond the scope of this article, but in general, larger holes in coverage can be tolerated at longer offsets. This can be thought of in terms of the frequency content of the data which is typically lower for deeper targets and longer offsets.

Figure 8(a) shows the offset distribution along the red line AB indicated on Figure 7. Note the holes in the coverage indicated by the red arrows. Each of these holes were considered large enough to require infill. The holes indicated by the orange arrows were large enough to be acquired only if they could be acquired at minimal cost "en route" between infilling the larger holes. Based on the predicted coverage an infill program shown in Figure 9(a) was developed. Note that although the number of line km of infill is only about 15% of the total 3D program, the infill comprises a large number of short line segments resulting in 18.9 days of additional acquisition. Considered in combination with the rest of the program, this amount of additional acquisition would jeopardize the success of the entire program.

Most towed streamer seismic crews now have the ability to influence streamer feather within 2-3 degrees. This capability can be used to match streamer feathering, but a more effective technique is known as streamer “fanning”. In the fanning technique, the streamer separation is increased towards longer offsets. This approach can be shown to reduce, and in many cases almost eliminate infill, as shown in Figure 8(b) and Figure 9(b).

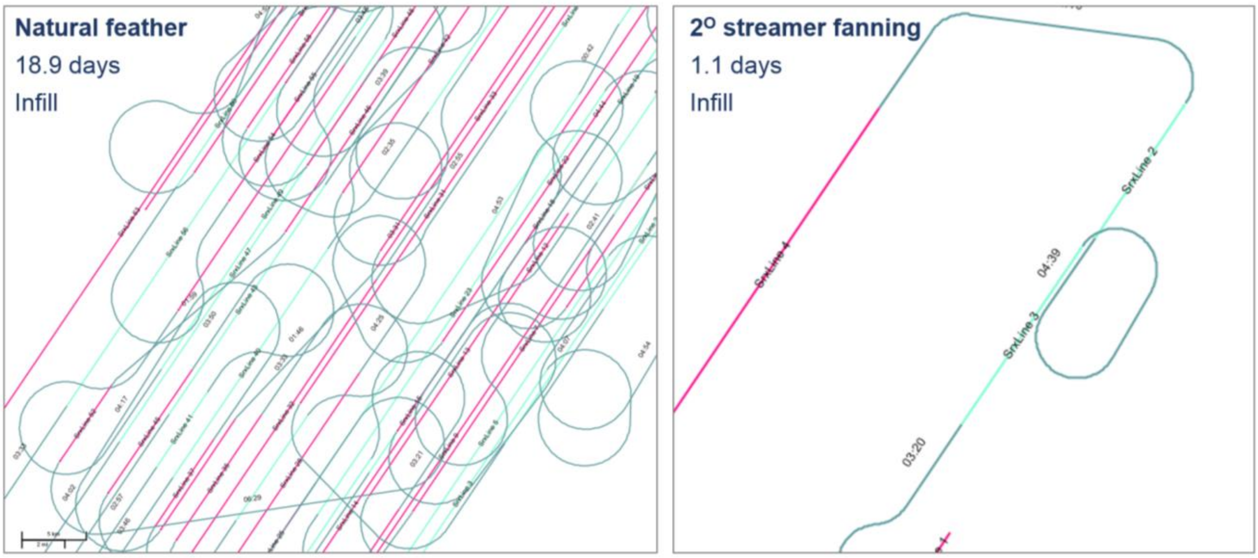


(a)



(b)

Figure 8 Offset distribution and infill estimate along line AB in Figure 7 for (a) parallel streamers and (b) fanned streamers



(a) (b)

Figure 9 Infill plan (a) parallel streamers and (b) fanned streamers

STATIC OPTIMIZATION

The first step in optimization is simple route optimization – often referred to as the “travelling salesman problem” (or TSP). The TSP is posed like this. A salesman must visit a number of locations during a day (perhaps Flamengo, Copacabana, Botafogo and Ipanema, as shown in Figure 10). What sequence of visits will minimize his travel time ? Clearly it would be very inefficient to start at Botafogo then go to Ipanema, Flamengo and Copacabana. One correct answer is to start at Flamengo, then Botafogo, Copacabana and finally Ipanema. The reverse order is another legitimate solution. This simple problem may become more complicated if additional time variant factors must be considered – perhaps a demonstration planned for Noon in the Botafogo area or a client with stated preference for a meeting time could make it advisable to change the route from that suggested purely based on the geography.

A similar logic can be applied seismic surveys. A crew might be asked to acquire specific lines first in order to enable fast track velocity analysis, and they must deal with many types of hazards, both static (rigs, reefs etc.) and dynamic (pipelaying barges, ships, marine mammals, tides etc.).

It should be noted that an optimized survey is not just the most cost-effective solution, it is almost always the solution having the lowest environmental impact, due to reduced sound emissions (less shots) and reduced IMO regulated emissions of $CO2$, NOX and SOX etc. associated with reduced vessel survey distance.

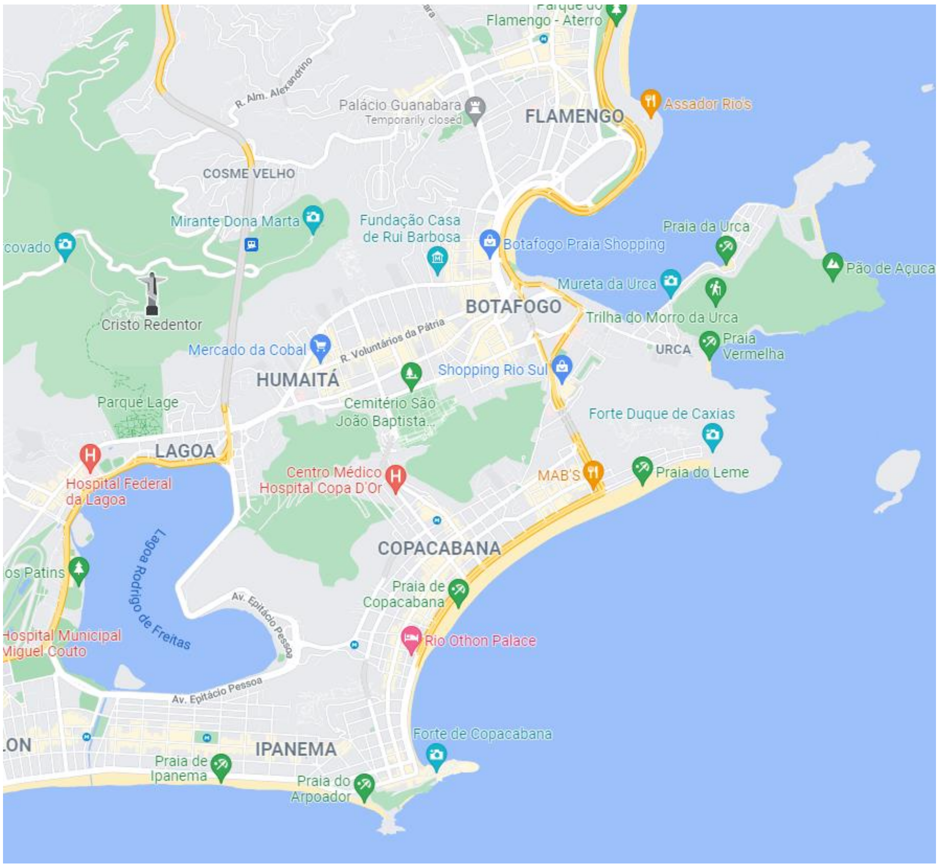


Figure 10 : The Travelling Salesman Problem

DYNAMIC OPTIMIZATION

For this project, the preliminary optimization was fairly simple. However, soon after the project started, an unusually late iceberg was identified to the north of the survey drifting slowly across the survey area. The track of the iceberg, with a suitable safety avoidance radius was entered into the planning software and the acquisition plan was re-optimized to avoid the iceberg as shown in Figure 12. This re-optimization added only 4 hours to the estimated survey time.

Figure 11 : An iceberg offshore East Canada

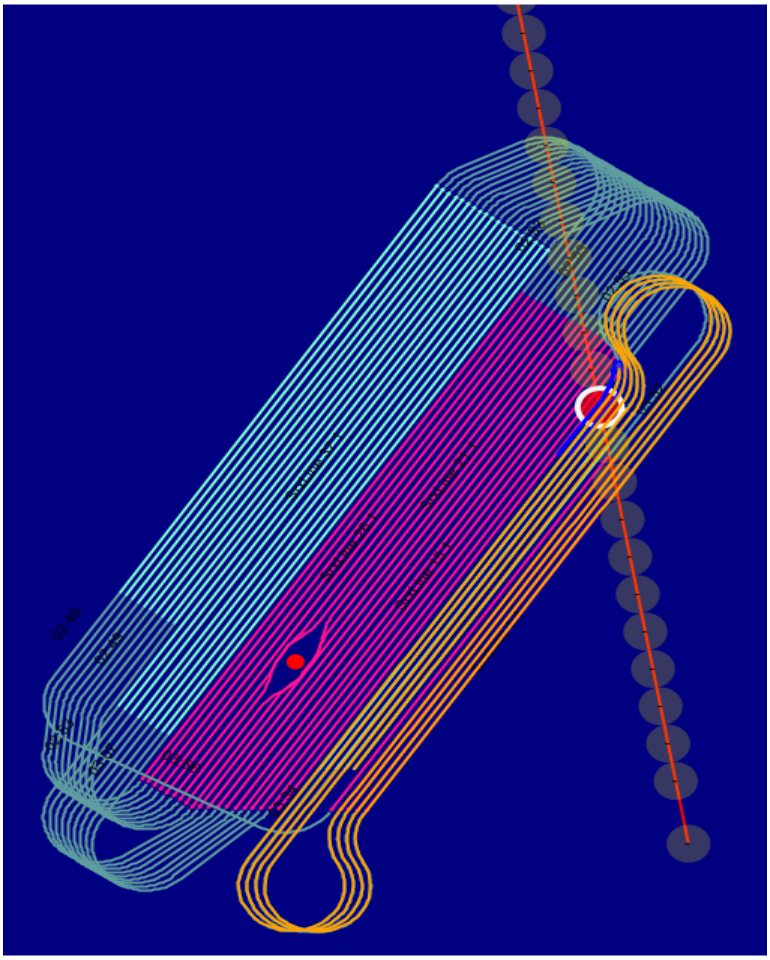
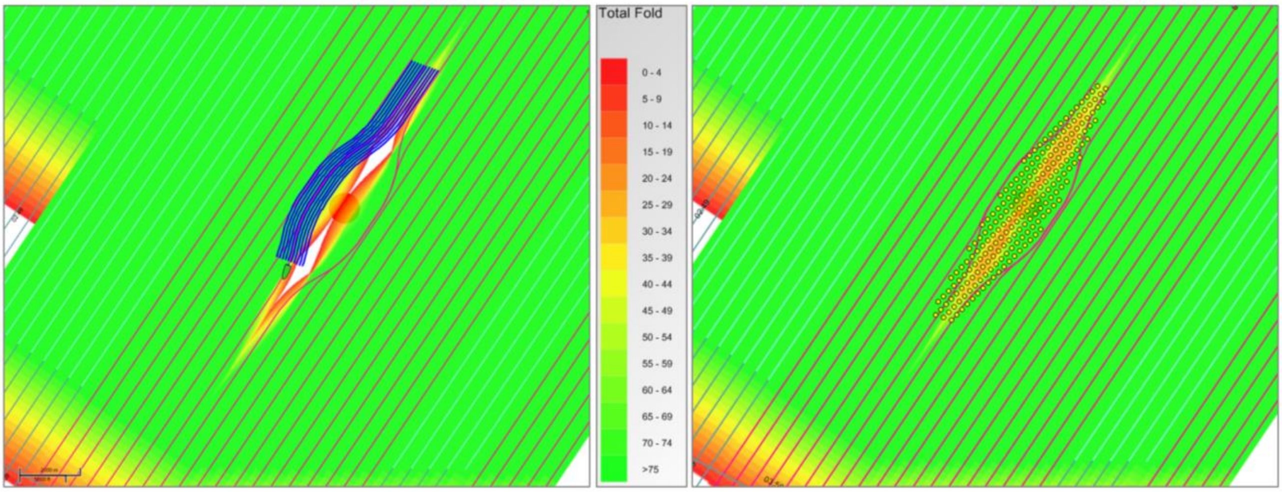


Figure 12 : Final shooting plan, after re-optimizing to avoid the iceberg

UNDERSHOOTING WITH NODES

Acquiring data underneath production facilities in a survey area can be expensive. The conventional approach is to use a streamer vessel on one side of the obstruction with a shooting vessel on the other side. This acquisition may only take 1-2 days, but if the second vessel must be mobilized from the North Sea (10 days) or the Gulf of Mexico (12 days) then the cost of undershooting is significant. The recent emergence of autonomous recording nodes has introduced a number of interesting alternatives for undershooting obstructions. For this project 207 free fall ocean bottom nodes were deployed around the obstruction prior to the start of the 3D acquisition. These nodes recorded data throughout the 3D acquisition and were recovered at the completion of the infill program. The total time to deploy and recover the nodes was less than 2 days. The coverage obtained around the structure by combining towed streamer and node coverage is illustrated in Figure 13.



(a) (b)

Figure 13 Fold maps (a) streamer data only, prior to application of ocean currents (b) streamer data with node data

SUMMARY AND CONCLUSIONS

The proposed program can be acquired using a single vessel within the available shooting season.

2D	35.6 days
3D	39.3 days
3D Infill	1.1 days
OBN “undershoot”	1.6 days
Unplanned dynamic hazard avoidance (iceberg)	0.2 days
TOTAL	**77.8 days**

Careful survey planning, parameter selection and complex optimization was used to eliminate the need for a costly second vessel mobilization and minimized the number of vessel days. Streamer fanning and the use of seabed nodes were critical factors in the success of the project. By reducing the number of vessel-days, we reduced cost, personnel risk exposure and environmental impact, both in terms of reduced emissions and reduced impact on marine mammals.

REFERENCES

1) Damian A. Hite & Dave Ridyard, (ACTeQ), “Optimizing Marine Data Acquisition and Infill”, 2nd EAGE Marine Acquisition workshop 25-26 August 2020