The Value of CSEM Data in Exploration "Best of EAGE"*

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Abstract

Statoil invented in the late 1990's the use of the controlled source electromagnetic (CSEM) method for remote identification of hydrocarbons in marine settings. The method was successfully tested offshore Africa in 2000, and subsequent pilot tests proved CSEM as a tool with the potential to predict hydrocarbons before drilling. The early technical successes of the first test surveys, in particular the Troll calibration survey from 2003, created an enormous commercial interest. The industry quickly adopted the new technology and pushed applications into far more challenging areas. Among the success cases, also several vague and non-conclusive results followed, and the total commercial interest declined. In retrospect, we asked the question: Is CSEM data worth the money?

A recent internal Statoil review of the CSEM performance in exploration shows a clear progress with time from the first early surveys to the more recent surveys. CSEM in hydrocarbon exploration has a short commercial history of less than ten years, and the progress can be explained by improvement during these years in acquisition, processing, interpretation techniques, experience, skills, and tools. The economical value of CSEM data can be predicted for specific exploration settings using standard decision analysis. Based on performance tracking and review of the prediction strength, conservative estimates of the economical value of CSEM data can be more than 10 times above the typical costs for a CSEM survey and analysis.

Introduction

Statoil invented in the late 1990's the use of the controlled source electromagnetic (CSEM) method for remote identification of hydrocarbons in marine settings (Eidesmo et al., 2002). The method, referred to as Sea Bed Logging (SBL), was successfully tested offshore Africa in 2000 (Ellingsrud et al., 2002), and subsequent pilot tests proved CSEM as a tool with the potential to predict hydrocarbons before drilling.

The early technical successes of the first test surveys, in particular the Troll calibration survey from 2003, created an enormous commercial interest. The industry quickly adopted the new technology and pushed applications into far more challenging areas. Among the success cases, also several vague and non-conclusive results followed, and the total commercial interest declined. In retrospect, important questions are: What have we got out of the CSEM data so far? What is the prediction strength and accuracy? Is CSEM data worth the money?

We will discuss these questions in light of an internal review study of Statoil's CSEM database, where the prediction strength of all cases is measured by the degree of risk impact based on Bayesian risk modification. We will then go one step further and show how the economical value of CSEM can be predicted by value of information (VOI) analysis based on decision analysis theory, see e.g. Bratvold et al. (2009) and Eidsvik et al. (2008). The economical value of the CSEM data is directly coupled to how the data affect decisions. For a drill or drop setting, the CSEM data may have a large value if the data can change a decision from drop to drill based on positive CSEM results, and vice versa. The VOI generally increases with the prediction strength of the CSEM information, but risk modifications with no decision impact have per definition no economical value.

Performance tracking

Performance tracking of CSEM is of high interest for qualification of CSEM as a robust exploration tool, and for calibration of the risk assessment to ensure that we correctly appreciate the information in the CSEM data. Two recent studies have been published by Johansen et al. (2008) and Hesthammer et al. (2010). The first concluded positively on technical success, but did not discuss exploration success. The second study presented discovery impact of CSEM based on normalized amplitude ratio only.

Statoil has acquired about 60 CSEM surveys, and the majority of these have been used in prospect evaluation. The database contains 32 cases with well control, and in 21 of these cases CSEM data were available before drilling. The performance tracking has earlier been efficiently summarized using a 2 by 2 hit matrix with cells for correct results on the diagonal (positive CSEM-discovery and negative CSEM-dry well), and cells for false negative and false positive off-diagonal. For the cases classified as positive or negative, only one case fell off the diagonal as a false positive. This case showed a strong normalized amplitude anomaly. However, later post-well analysis with reprocessing and anisotropic inversion did not show increased resistivity at the well position.

We have evaluated the prediction strength of all EM cases in a recent review study. The results show a clear progress with time from the first early surveys to the more recent surveys. The study included a detailed evaluation of the CSEM data, the performed analysis, and the geological setting. The relation between these components and the prediction strength was investigated, and the overall progress in CSEM data predictability found to be explained by improvements in all three components. If one component is bad, this can give inconclusive results, and opposite, if the geology component is very good, the results can be conclusive even if other components are bad. An example is the CSEM data on the Troll West Gas Province where the data quality in 2003 and a simple normalized magnitude curves were sufficient to obtain a convincing result. For more challenging cases, the development of the CSEM methodology has been of crucial importance to improve the accuracy and the robustness of predictions.

Prediction strength

In prospect evaluation, the ultimate goal of geophysical analysis is to make better decisions. Usually, the most important summary for the decision making from geological and geophysical analysis is the risk and volume assessment. There are different definitions of the chance of success, but it is common to couple the success to the discovery of a volume of hydrocarbon larger than a defined minimum volume. In traditional prospect risking, a viable petroleum system is split into a set of required factors, shortly summarized as source, reservoir, and trap. The chance of success for a prospect can be found by multiplication of the chance of success for each of these factors if they are assumed independent.

In order to address the risk impact of the CSEM data, Bayesian risk modification is a practical and statistically valid procedure for including additional information. The modified (posterior) probability for a geological scenario *Si* after risk modification is given by Bayes law as

$$P(S_i \mid D) = P(D \mid S_i)\,P(S_i)/P(D),$$

where *P(Si)* is the prior probability for scenario *i* assessed without CSEM, and *P(D | Si)* is the likelihood of the CSEM data for a given scenario *i*. The normalizing factor

$$P(D) = \sum_{i=1}^{n} P(D \mid S_i)\,P(S_i)$$

with sum over all geological scenarios $i=1,...,n$, ensures that the posterior probabilities sum to one. The Bayesian workflow requires evaluation of all relevant geological scenarios.

The CSEM likelihood can be simplified by reducing and summarizing all scenarios into two classes: success (*S*) and failure (*F*). Figure 1 shows the modification from prior probability to posterior probability for different CSEM likelihood ratios. In the figure, both the success and failure likelihoods go from 0.1 to 0.9 (step 0.1), and the lines corresponds to success/failure ratios 0.9/0.1 (from top) down to 0.1/0.9 (bottom). When the likelihood of success is larger than the likelihood of failure, the probability of success is increased (green lines), and vice versa (red lines). If the likelihoods of success and failure are equal, the CSEM results are inconclusive and have no risk impact (black line).

In the performance tracking of CSEM results within Statoil, several of the old surveys were evaluated as inconclusive. However, the newer surveys do have a risk impact.

Value of information

The value of CSEM data depends on how it affects the exploration decisions. Assume a simple drill or drop setting with drill cost *C*, net present value *V* (excluding drill cost), and a prior chance of success *P(S)* (without CSEM information). The expected (or risked) net present value without CSEM is then

$$E(V) = P(S)V - C.$$

Next, select a simple decision rule where we drill the prospect if the expected value is positive, and drop otherwise. The question is now whether it is profitable to purchase CSEM data before making the drill or drop decision.

The value of the CSEM data is defined as the expected value with CSEM data minus the expected value without CSEM data. The VOI represents the maximum we are willing to pay for the data. We simplify the setting by considering only the impact CSEM has on the chance of success and neglect the possible influence on the prospect volume and net present value. We here define the CSEM response as a binary indicator, where CSEM is positive if CSEM increases the chance of success (the likelihood of success is larger than the likelihood of failure), and negative otherwise.

Figure 2 shows an example on the value of CSEM data as a function of prior chance of success (without CSEM) and net present value when the drill cost is *C* = 100 million USD. The example is based on our experience data base and represents a typical and realistic prospect; the chance of positive CSEM is 0.8 if the prospect is a success case and 0.2 if it is a failure case. The modified (posterior) probabilities are calculated by Bayes law for negative and positive CSEM responses and then the expected net present value of the prospect when CSEM information is included. The decision is based on the modified final probability, not the CSEM indications alone.

The economical value of CSEM data generally increases with increasing prediction strength. It is obvious that inconclusive data have no value, while perfect information represents an upper value limit. The CSEM data should be handled as imperfect information with realistic probabilities for correct and wrong predictions. We remark that a good decision does not always guarantee a desired outcome, but will in the long run be optimal based on the available knowledge.

The VOI is always highest for hard decision settings where the expected value of the project is close to zero and small changes in the input parameters may change the drill or drop decision. From the typical example in Figure 2 we see that the value of CSEM can be more than 50 million USD when it is hard to make a drill or drop decision. The value of the CSEM data are directly related to changed decisions, either by dropping a drill candidate based on negative CSEM, or by drilling a drop candidate based on positive CSEM. If the cost of a CSEM survey is 5 million USD, the example shows that the expected value of the CSEM information can be more than 10 times the cost of the survey. In a drill or drop setting, the absolute upper limit on VOI is the drill cost.

The value of CSEM is lower when the decisions are simpler. If a prospect with high value and high chance of success will be drilled whatever the CSEM data show, the value of the CSEM data is zero. Opposite, if a prospect with low risked value is dropped whatever the CSEM data show, the value is also zero. The VOI will never be negative if the decision analysis is done properly. Since the VOI can be predicted before purchasing the data, we can minimize the number of surveys not worth the money and maximize the value of the CSEM data.

The VOI concept presented here includes only the value related to the actual drill or drop decision, neglecting the potential value of the data in other settings, for example mapping the outline of a prospect, decisions on drill location, and potential later use as calibration for other cases. The real value of the CSEM data may therefore be considerably higher than the predicted VOI.

Conclusions

CSEM in hydrocarbon exploration has a short commercial history of less than ten years, and we see a substantial development and improvement during these years of all elements from acquisition and processing to interpretation techniques, skills and tools. Evaluation of Statoil's CSEM database shows that newer data have a risk impact whereas old data in many cases are inconclusive. The economical value of CSEM data can be predicted for specific exploration settings using standard decision analysis. Based on performance tracking and review of the prediction strength in CSEM data, typical and realistic numbers implies large value of CSEM by improved decisions.

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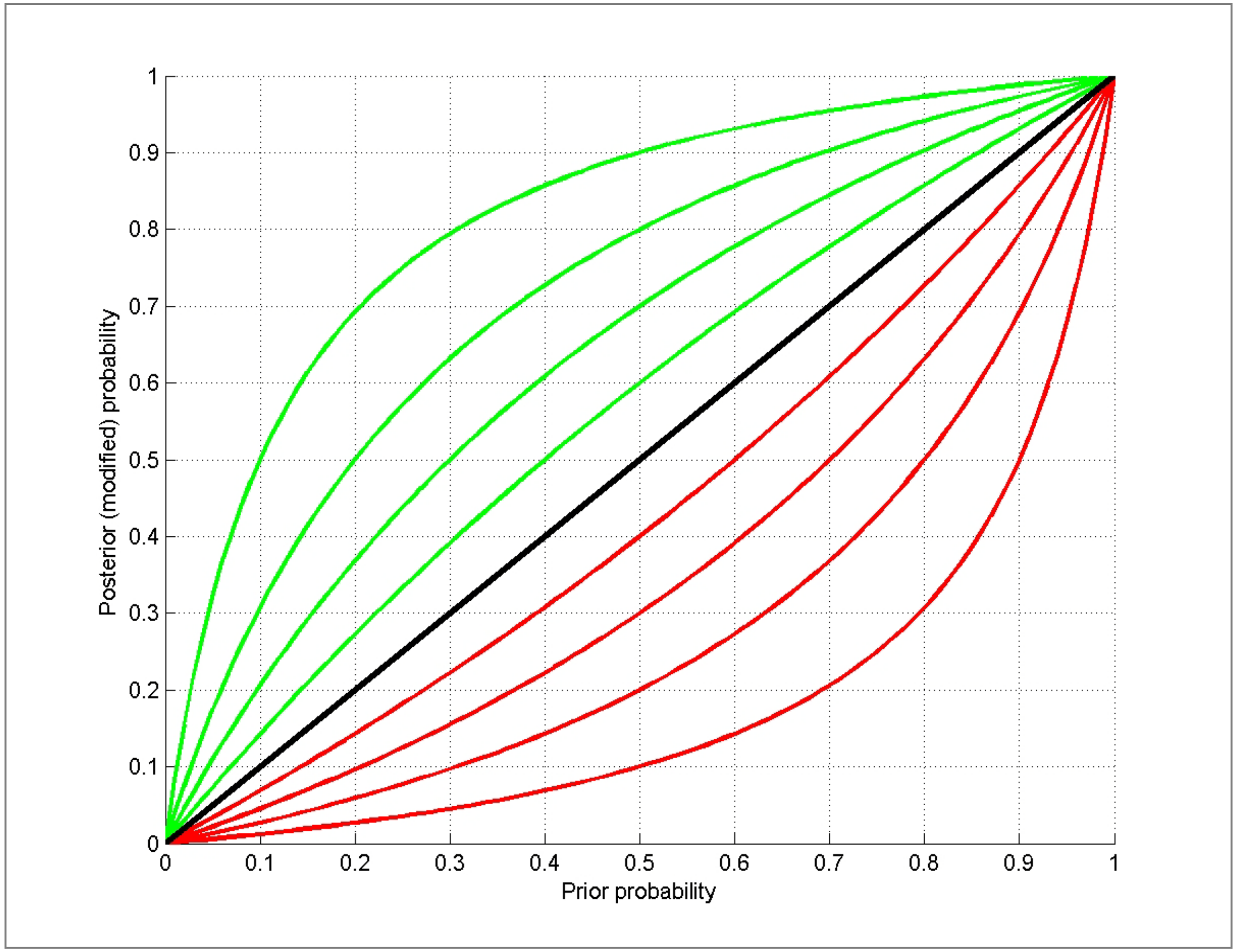

Figure 1. Risk modification effects for different likelihood of success to likelihood of failure ratios.

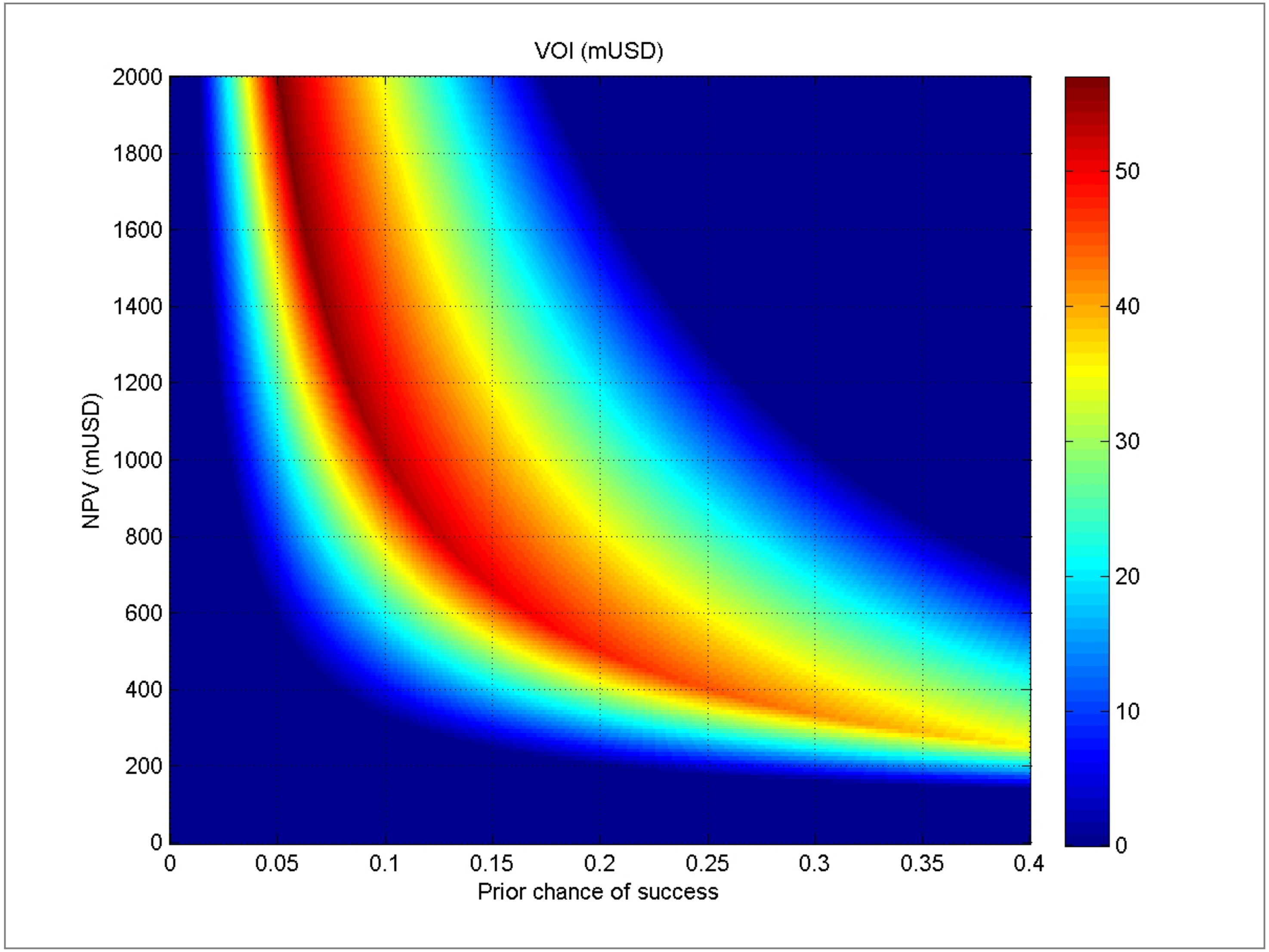

Figure 2. Value of CSEM data (million USD) as a function of prior probability of success and net present value of the project.