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RIGOROUS AND INNOVATIVE RISK QUANTIFICATION FOR BASIN MODELLING

Matthieu Pontet[1], Roger Baudino[2], Jean-Marie Laigle[3],

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Abstract

Assessing petroleum systems using deterministic basin modeling techniques is nowadays widely used in exploration. Decision makers need to rely on the outcomes of basin models whose main results should therefore feature a probabilistic distribution expressing the associated risk. Basin modeling aims at accounting as rigorously as possible for the impact of the numerous parameters controlling petroleum systems, including their subtle coupled effects. Following this, an innovative approach using the experimental design and response surface methodology has been developed and made available within basin modeling tools. The workflow consists first in screening the set of parameters potentially controlling the outcome under evaluation (e.g.: pressure in a targeted reservoir, volume in place) and second in expressing the probability distribution of this outcome taking into account the uncertainty associated to the most influential parameters. This approach is exemplified on a basin model case study from a frontier exploration area of the deep offshore Campos Basin, Brazil.

1. Introduction

The Offshore Campos Basin is located in the Southeastern margin of Brazil and it is part of a succession of basins that opened during Early Cretaceous Times as a consequence of the Gondwana Breakup (Guardado et al., 1989; Estrella et al., 1994). It is by far the most prolific sedimentary basin of the country holding almost 85% of the total proven reserves and actual production.

The Figure 1 shows a stratigraphic synthetic column and a location map of the Campos Basin main fields. The reservoir ages span a wide stratigraphic interval from the Early Cretaceous Syn-rift clastics and carbonates to Late Tertiary turbidites. The main source rocks of the Campos Basin are the lacustrine black shales and marls of the Neocomian to Aptian Lagoa Feia Fm. (Mello et al., 1994; Guardado et al., 2000). Another characteristic of the petroleum system is the existence of the thick salt layer of Aptian age that separates the Lagoa Feia Formation from the Upper Cretaceous and Tertiary reservoirs with critical implications on the migration pathways and thermal regime.

The first offshore well was drilled in 1971 in shallow water depth. Following the improvement in drilling and seismic acquisition techniques the exploration moved to deeper settings resulting in the first deepwater discovery in 1984 (Albacora Field). From the mid eighties to 1998 a series of giant fields was discovered cumulating a total reserves of 10700 MMBOE in water depth approaching in some cases the 2000 m (e.g. Roncador Field) with several depth world records reached by the national company Petrobras. From 1999 drilling reached areas of water depth greater than 2000 m and this date also coincides with the opening of exploration to foreign companies.

The search for oil and gas at such water depth implies millionaire inversion for companies with low success rates related to the geological context but also to the elevated minimum economic accumulation needed to be encountered. Geologically speaking, the interpretation of seismic data must face a great number of uncertainties resulting from the low number of existing wells, especially when looking at deep targets rarely or even never drilled in these areas.

[1] MSc. Geologist – Beicip Tecnologia – Rio de Janeiro – Brazil
[2] PhD. Geologist – RepsolYPF do Brasil – Rio de Janeiro – Brazil
[3] MSc. Geologist – BeicipFranlab – Rueil-Malmaison - France

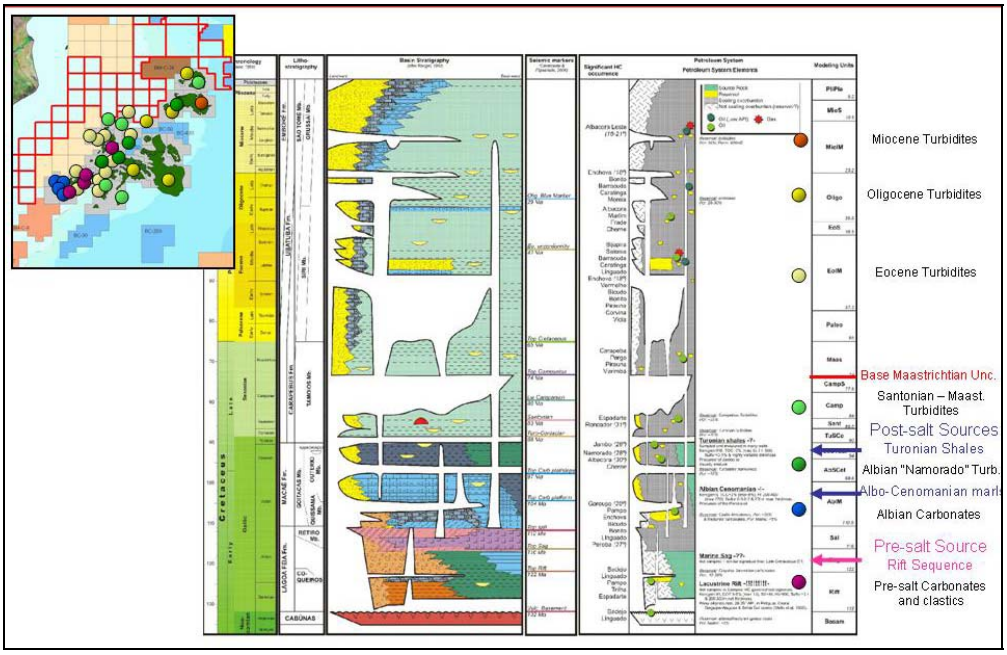

Figure 1. Campos Basin synthetic litho-stratigraphic column and location map of the main fields

The use of basin models has then become an indispensable tool when assessing the potential of this kind of frontier exploration areas. It allows estimating the efficiency of the petroleum system(s) and help decision makers to define strategies. However, the scarcity of calibration data also affects the construction of models and requires the modeler to test a great variety of hypothesis regarding many of the components of the petroleum system (e.g. source richness, source efficiency, fault permeability, reservoir porosity and permeability, thermal regime, etc…).

Evaluating the all range of uncertainty regarding each parameter involved in the petroleum system by performing hundreds of simulations cannot be considered since this would require an unaffordable time and computer capabilities consumption. To overcome the limitation and help defining the most sensitive parameter(s) a rigorous risk analysis is necessary. This paper illustrates the use of a rigorous and innovative risk analysis technique applied to a basin model case study of the deep offshore Campos Basin

2. Study context and objectives

The Figure 2 shows the location of the study area. The risk analysis was performed for a basin model in the deep offshore area of the Campos Basin.

In this area a little number of wells was drilled and none of them reached the Lagoa Feia Formation that contains the organic reach levels sourcing the very great majority of the analyzed oils found in the Campos Basin. However, the thickness map of the pre-salt sequence (containing the Lagoa Feia Fm.) of the figure 2 shows that a basement high separates a northwestern sub-basin (dotted circle) from other depocenters at the south east. The first sub-basin was drilled and contains up to 300m of organic rich levels with total organic carbon (TOC) up to 9%. Source-oil correlations and fetch areas mapping show that it corresponds to the main kitchen of the Campos basin giant fields. South of the basement high oil shows and non-commercial accumulations have been found confirming the existence of an active petroleum system but the oil origin is unknown and the effectiveness of the Lagoa Feia Fm. source yet to be proven.

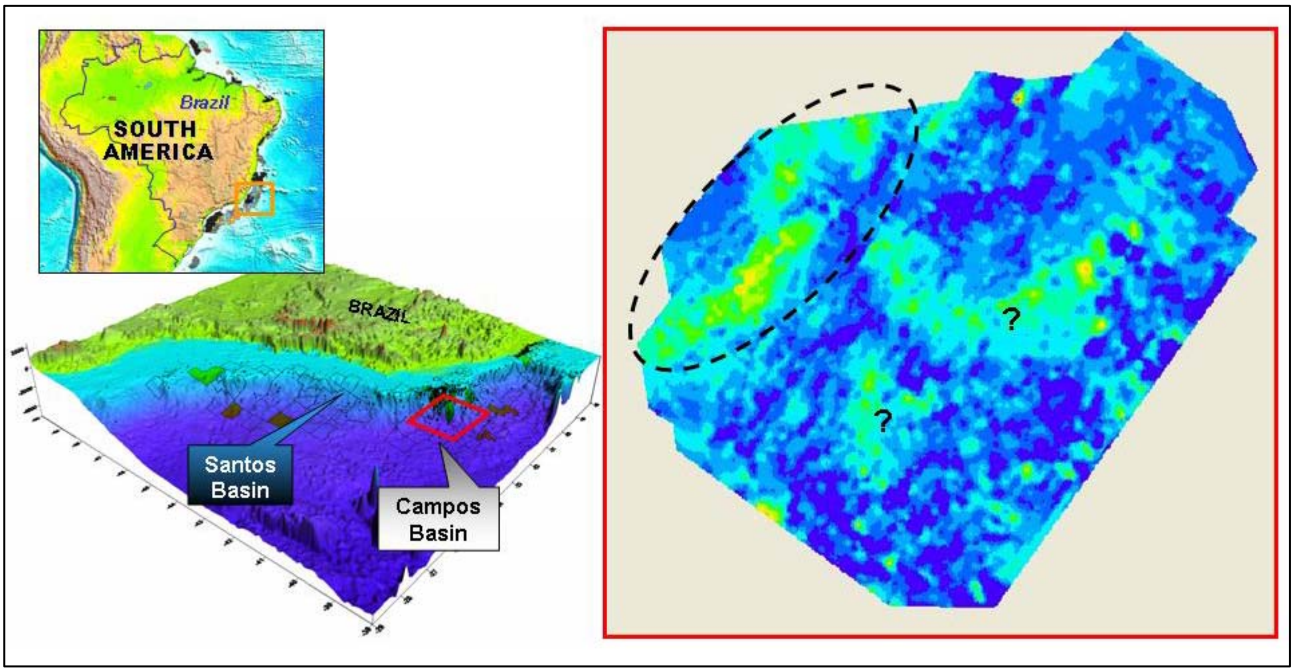

Figure 2. Location map of the study area (left) and Pre-salt sequence thickness map (right)

The basin model built to assess the petroleum potential of the area has then to consider the uncertainty on the richness and effectiveness (type and maturity) of the pre-salt sequence and the area. To evaluate the uncertainty on this crucial parameters a rigorous risk analysis was performed along section models. The Figure 3 shows an example of section.

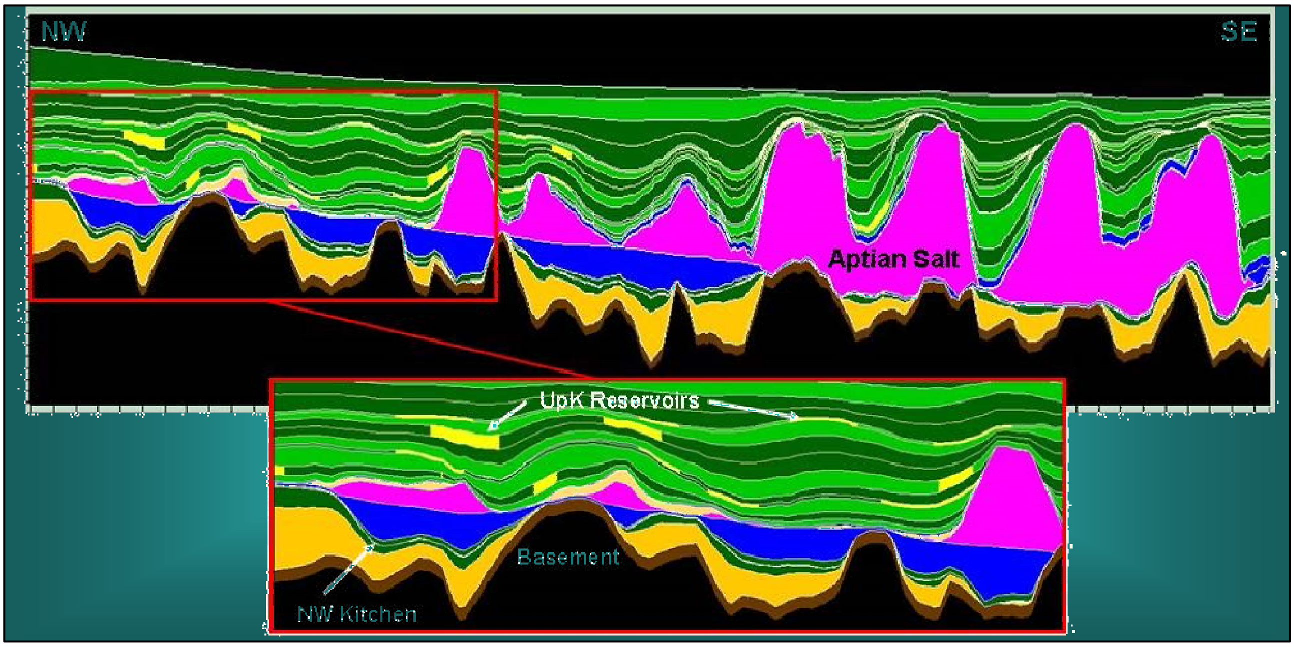

Figure 3. Example of section model on which simulations and risk analysis were performed

3. Sensitivity and Risk Analysis Methodology

3.1. General concepts

Basin Modeling technologies imply numerical simulations on 1D, 2D or 3D geological models, tentatively reproducing the geological, physical and geochemical processes occurring in the nature. By introducing first, geological concepts to describe these phenomena, then parameters to feed the algorithms and laws of the model, the basin modeler deals with numerous uncertainties which impact the accuracy of the results.

Although simulation results calibration with real data ensures a global reliability of the geological model, a modern detailed study requires a finer understanding of petroleum system controlling parameters. It can be achieved by a better identification of the influential parameters (**sensitivity analysis**) and by quantifying the impact of a given parameter on a given result (**risk analysis**).

The degree of knowledge of the explored area defines the approach to be applied:

- On a frontier area, most uncertain parameters are not well known. Thus, the main concern will be to identify which are the ones being the most influential on the response. This is the **Sensitivity analysis** (figure 4).

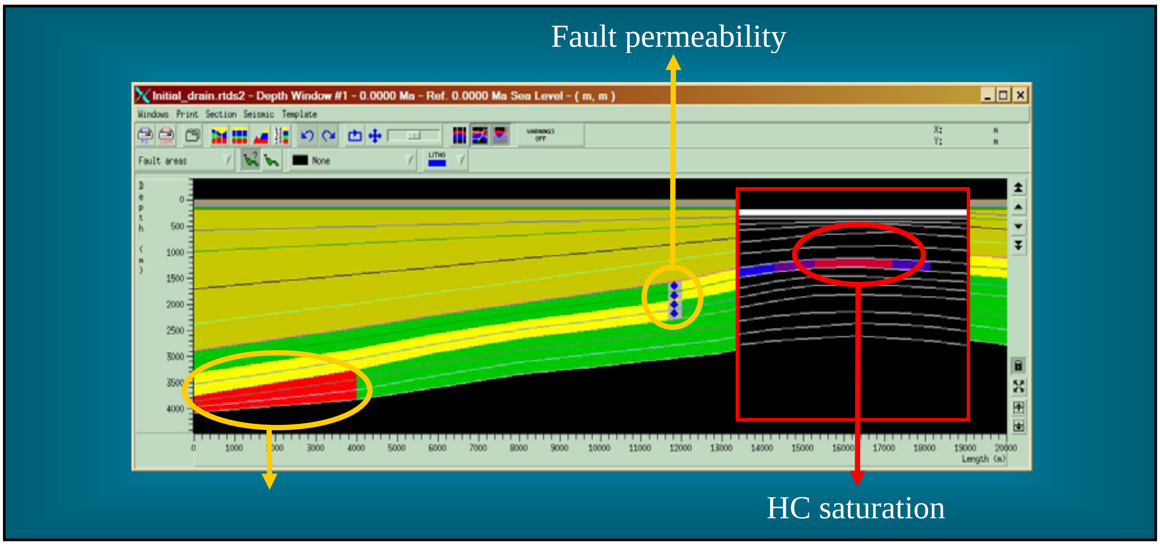

Figure 4. Sensitivity analysis. Which parameter (TOC or fault permeability) is the **most influentia**l on the HC saturation in the main trap?

- On a mature area, the main uncertain parameters are well known and the main concern is to quantify how a variation of one uncertain parameter (or the combined effect of several) will impact the simulation result. For example, what will be the impact of the permeability of the shale onto the pressure at the location of the target? **Risk analysis** in this case, is input driven (figure 5).

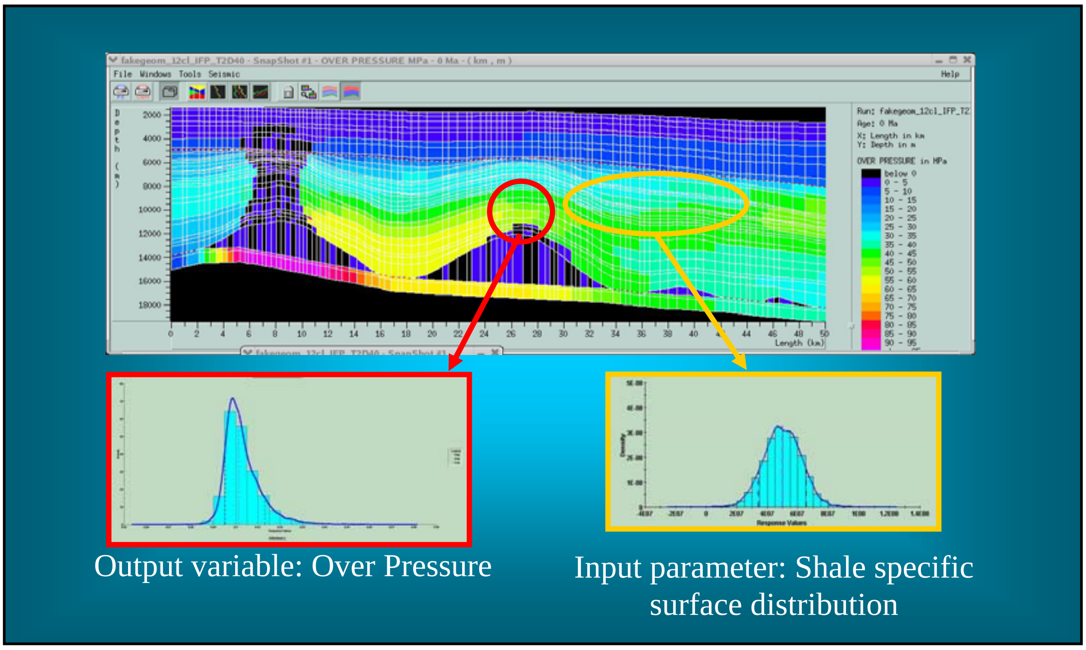

Figure 5. Risk analysis. How does the **uncertainty on input parameters** impact on the **output variables**?

3.2. Applied Methodology

Qubs software (for Quantifying Uncertainties in Basin Simulation) is an innovating approach using the experimental design and response surface methodology. This allows going beyond the limitations of basic Monte Carlo sampling and traditional probability of success calculation: the high number of parameters controlling petroleum systems make these methods irrelevant.

A basin modeling calculator applies physical, geological and geochemical laws onto input parameters and delivers output data as an answer (Figure 6). **The main philosophy of Qubs is to model the calculator behavior by a 1st or 2nd order response surface** (RSM) (Figure 7) and only then to apply a Monte Carlo sampling over the RSM.

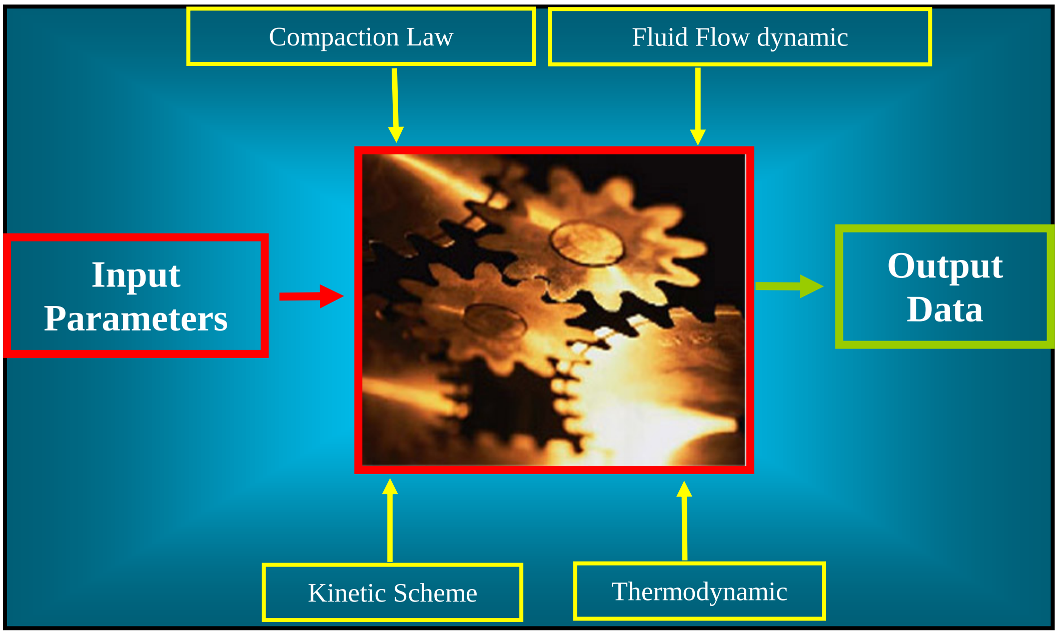

Figure 6. Computation of output data by the basin modeling simulator applying algorithms to input parameters.

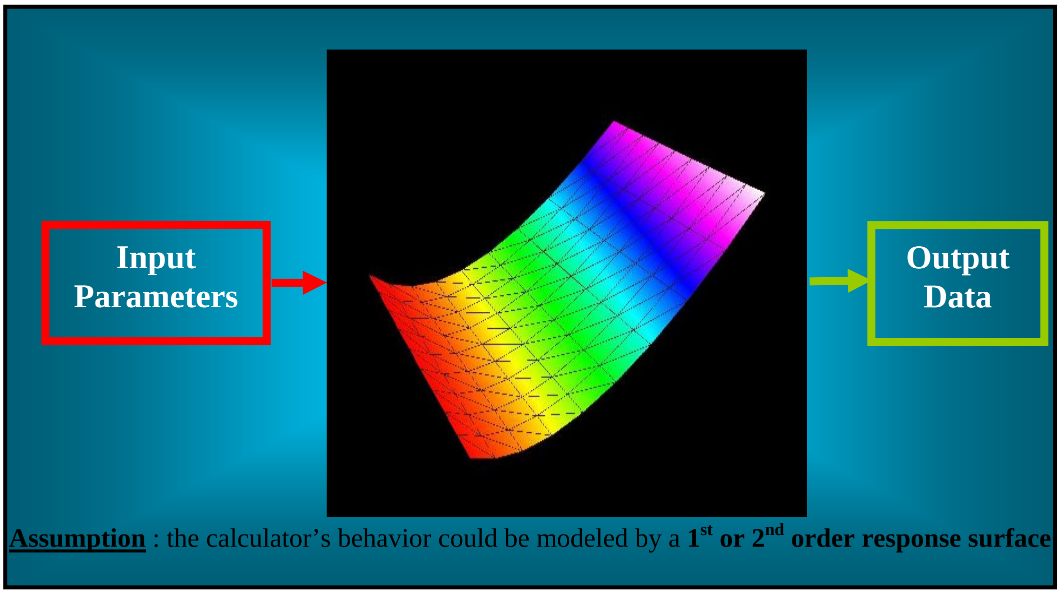

Figure 7. Simulation of the basin modeling calculator behavior by the Response Surface.

The main Experimental Design techniques manage to calculate the most reliable RSM depending on the number of input parameters and the required degree of accuracy (Figure 8).

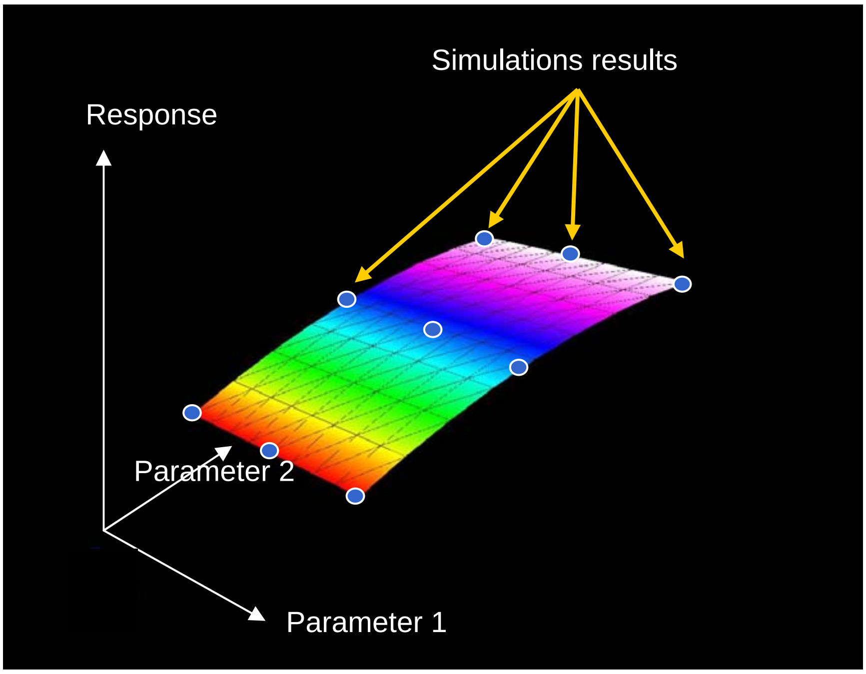

Figure 8. RSM performed using 2 parameters (min, max and mid values, the other parameters stay constant) and 9 simulations

3.3. Results

The first result from Experimental design and RSM optimization is a ranking list of parameters (and combined parameters) classified according to their relative contribution to a given simulation answer. This contribution can be positive or negative. A calculated threshold (parameter dependant) allows defining influential and non influential parameters (or any combined parameters) (Figure 9).

The Sensitivity Analysis determines which parameters the modeler should further investigate and reduce uncertainties.

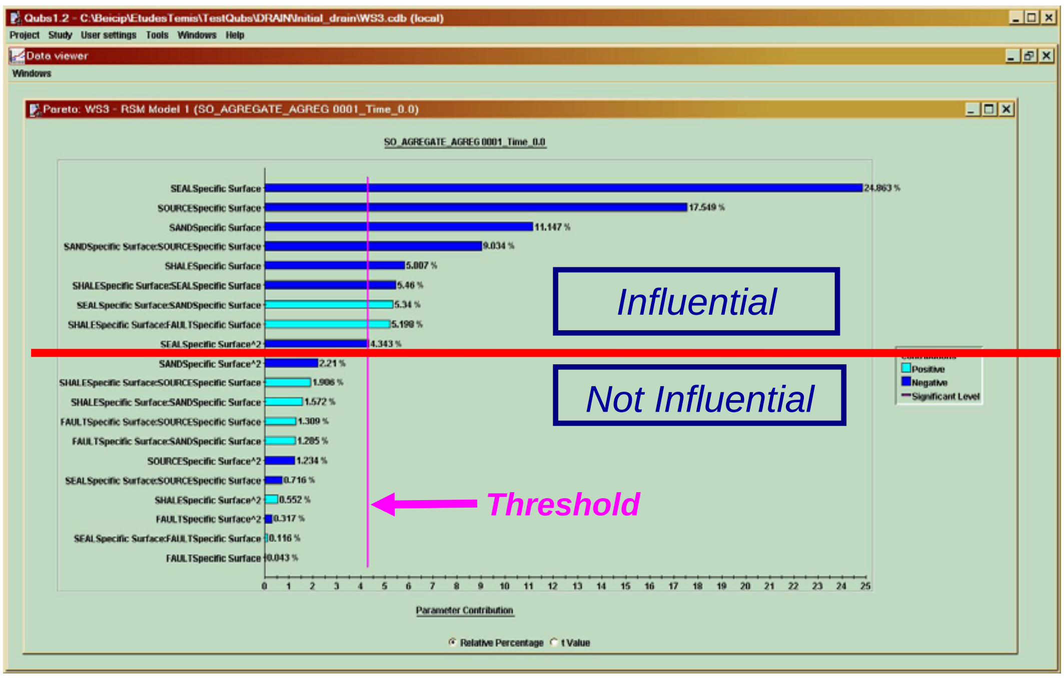

Figure 9. Sensitivity analysis determines the influential parameters of a given answer

Following the sensitivity analysis, the risk analysis aims to quantify the impact of the uncertain parameters onto the final results. Risk analysis requires a high resolution RSM (generally 2nd order) to apply an accurate Monte Carlo sampling. The distribution law of the uncertain parameters needs to be defined.

As a result, Qubs Risk Analysis module, delivers distribution of percentile of occurrence (P10, P50, P90) for a given answer (Figure 10).

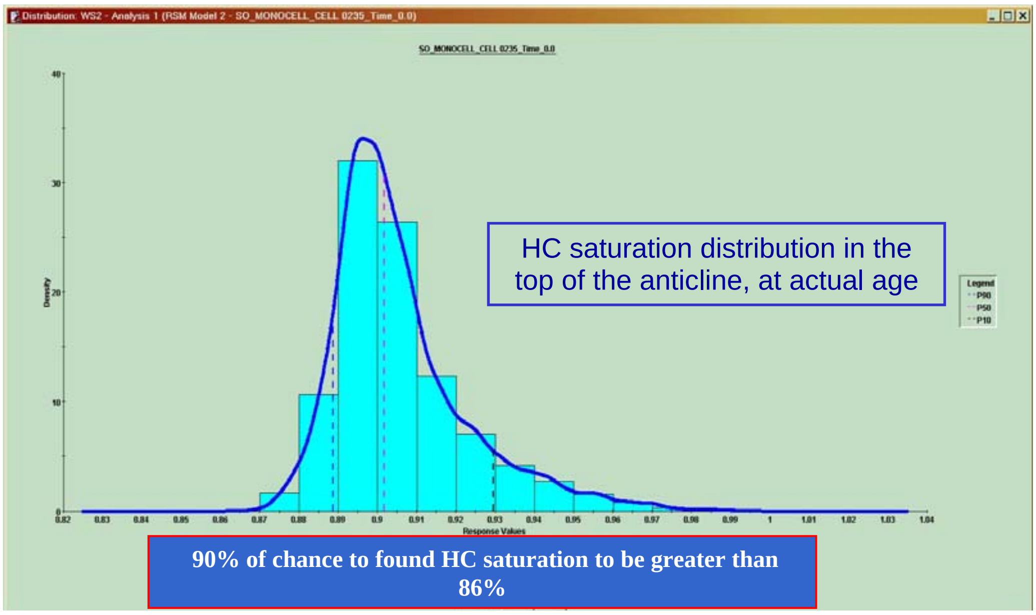

Figure 10. Percentiles P10 and P90 of occurrence for the HC saturation.

4. Conclusions

A new methodology for Sensitivity and Risk analysis has been developed and made available for Basin Modeling. The Sensitivity Analysis helps defining which are the most influential parameters of the geological model and their impact on the simulation results, allowing to focus investigation. This tool is of great help when working in frontier areas such as the Deep and Ultra-Deep Campos basin where uncertainties are high due to the lack of drilling information. The Risk Analysis quantifies the uncertainties on key parameters determining expected volumes and drillability of the target, thus helping to take strategic decisions.

5. Acknowledgements

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