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Introduction

In geological surface modelling, uncertainty analysis is used to provide information about the reliability of the three-dimensional (3D) geological model. The uncertainty analysis of interpolated surfaces can be calculated by the estimation error, which is the difference between the estimated values in the interpolated surface and the reference dataset. Geostatistical tools are used to assess the uncertainty related to how closely the interpolated surface honours the geological dataset.

Most geological surfaces, within the 3D models developed at the Alberta Geological Survey (Figure 1) are modelled using Petrel's convergent interpolation algorithm because it typically produces a more realistic representation in areas of complex geology compared to algorithms in other software. Unfortunately, it is difficult to assess the uncertainty for these surfaces using the current surface modelling methodologies in

To solve this problem, a unique workflow for assessing prediction uncertainty was developed using a combination of Python, Matlab code, and Petrel software. Two separate workflow methodologies have been developed to assess both the global and local uncertainty of our geological surfaces (Figure 4).

Figure 1: 3D Provincial Geological Framework Model of Alberta, Version 2 (3D PGF model v2).



Detect and Manage Uncertainty

There are different sources of uncertainty that can affect the surface modelling and cause higher uncertainty. Uncertainty analysis methodologies can improve surface modelling by helping find the sources of uncertainty and guiding approaches to reduce it (Figures 2 and 3).

1 - Data Quality

- Extremely high and low values (outliers) - Managing the outliers may decrease the uncertainty

2 - Data Density

- Lack of data / sparse data of the stratigraphic

- More data can reduce the uncertainty in these

3 - Geostatistical Model Parameters

- Poor choice of geostatistical parameters - Selection of appropriate estimation methods parameters

4 - Geological Complexity

- Areas of high geological complexity or structure A significant and unavoidable cause of high uncertainty

Figure 3: Precambrian top surface uncertainty map.

Figure 2: Precambrian top

picks data and modelled

surface.



Local and Global Uncertainty Implementations

Global Uncertainty:

- Summarizes the estimation errors at the data locations with a single value and does not have enough extra information about other locations.

- Root-mean-square-error (RMSE) value is a measure of evaluating the global uncertainty

- $z_1, z_2, ..., z_n$ observed values in n locations - $\hat{z}_1, \hat{z}_2, ..., \hat{z}_n$ corresponding estimated values

Local Uncertainty:

- Identifies the areas of high and low uncertainty in the modelled surface by standard deviation uncertainty maps.

estimation error.

- Uncertainty map based on standard deviation provides graphical representations of estimation error on locations with no data (Figure 3).

Implementation:

This methodology of assessing the RMSE and standard deviation uncertainty maps (Figure 4) has been applied to:

- 28 geological pick datasets from the Alberta Geological Survey's 3D Provincial Geological Framework Model of Alberta V.1 (Branscombe et al., 2018 a, b).

- 47 geological pick datasets from the Alberta Geological Survey's 3D Provincial Geological Framework Model of Alberta V.2 (AGS, work in progress).





Uncertainty Analysis in Geological Surface Modelling (Duvernay Formation / Muskwa Formation and Leduc Formation Case Studies)

es
$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\hat{z}_i)}$$

- Local uncertainty gives more information about the locations with higher



Figure 5: Average and variance of uncertainty values based on different subset values of various percentages taken from the reference dataset.

Sensitivity Analysis:

A sensitivity analysis was applied to the Duvernay Formation / Muskwa Formation pick dataset to come up with the optimal parameters for the number of realizations (N) and the percentage of the data taken from the reference pick dataset (P).

- The standard deviation maps were calculated on three P and five N values (Figure 5): P = 50%, 70%, 80% N = 5, 7, 10, 15, 20, 25

- Uncertainty map values were calculated for each combination of P and N values. The objective of this study was to figure out where the average and variance of uncertainty are stabilizing.

- At P = 50% the average of uncertainty is increasing as the N value increases and stabilizes after 10 to 15 realizations (Figure 5-A1). The variance of uncertainty slightly decreases with increasing N values (Figure 5-A2).

- At P = 70% the average of uncertainty is increasing, has a significant increase at the10th realization and stabilizes after that (Figure 5-B1). The variance of uncertainty slightly decreases at first, then has a significant increase at the10th realization, stabilizes, and then decreases (Figure 5-B2).

- At P = 80% the average of uncertainty is increasing as the N value increases and stabilizes after 10 to 15 realizations (Figure 5-C1). The variance of uncertainty decreases with increasing N values and stabilizes after 10 to 15 realizations (Figure 5-C2).

- For each P value, the average and variance of uncertainty values are optimized stabilizes after 10 to 15 realizations and no additional realizations are necessary.

- P = 80% is the optimal value as this percentage introduces some uncertainty which stabilizes after 10 to 15 realizations. Indeed for P = 50% and P = 70%, the variance of uncertainty values is either high for all N values or does not stabilize.

Case Studies: Duvernay Formation / Muskwa Formation and Leduc Formation Two case studies:

- Duvernay Formation / Muskwa Formation zone from 3D PGF model v2 (Figure 6) and standard deviation uncertainty map P = 80% and N = 10 (Figure 7). - Leduc Formation zone from 3D PGF model v2 (Figure 8) and standard deviation uncertainty map, P = 80% and N = 10 (Figure 9).

Figure 6: Duvernay Formation / Muskwa Formation top picks and modelled zone.





Conclusions and Future Work

Conclusions:

- Global and local uncertainty workflow shows higher uncertainty on surfaces with low density dataset and more complex geological structures.
- Uncertainty map represents the more uncertain areas by mapping higher standard deviation values resulting from the presented workflow.
- The code developed for this methodology is software independent and can be applied to other modelled surfaces (Babakhani, work in progress)

Future Work:

References

Branscombe, P., MacCormack, K.E. and Babakhani, M. (2018 a): 3D Provincial Geological Framework Model of Alberta, Version 1 - methodology; Alberta Energy Regulator, AER/AGS Open File Report 2017-09, 114 p. Branscombe, P., MacCormack, K.E., Corlett, H., Hathway, B., Hauck, T.E. and Peterson, J.T. (2018 b): 3D Provincial Geological Framework Model of Alberta, Version 1 (dataset, multiple files); Alberta Energy Regulator, AER/AGS Model 2017-03.



Figure 7: Duvernay Formation / Muskwa Formation top surface uncertainty map.



- Variability of quality within a pick dataset is not considered as a variable in assessing the uncertainty in this workflow and will be assessed in further studies. - The optimal N and P values presented here are stable in these case studies. For other studies with different sources of uncertainty, a reassessment of the optimization values is needed.