Sensitivity Analysis of Surface-based geostatistical Model parameters on data conditioning

Antoine Bertoncello and Jef Caers
Introduction

• Surface-based models recreate realistic subsurface structures and heterogeneities
• The models require a large number of uncertain input parameters

Sensitivity analysis to understand the impact of parameters on the generated models for response analysis:

- Inverse modeling
- Response analysis
- Uncertainty modeling
Recall: Hybrid model

Statistics & rules

Sequentially simulate sets of 2D lobe thickness with featured geometry

Construct 3D model

(Pyrcz and Deutsch, 2004; Michael et al., 2010; Leiva, 2009; Zhang, 2009)
AIM: randomization of the geometry

Recall: Hybrid model
Conditioning issues

Forward model  \[\rightarrow\] \[\rightarrow\] \[\rightarrow\] Fwd lobe \[\text{end}\]

Match / Mismatch ?

Initial conditions (seed, paleotopography, source location...)

Inverse problem that requires iterations
Conditioning issues example: well data

Cannot force the lobe to fit the data while respecting the geological rules.
Conditioning issues example: well data

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Conditioning issues example: well data

Top as interpreted from seismic

base
Conditioning issues example: seismic

Top as interpreted form seismic

base
Conditioning issues example: seismic
Conditioning issues example: seismic
Conditioning issues example: seismic

Need to honor the thickness constraint AND deposition rules

Top as interpreted form seismic
Challenge of inverse modeling: *possible input parameters*

Very uncertain input parameters:

All of them can be perturbed

*discrete, continuous, spatial temporal parameters...*

- Volume of the reservoir
- Location of the Source
- Size of the Lobes
- Shapes of the Lobes
- Paleotopography
- Model of deposition used
- Model of erosion used
- Variance of the noise added
- Covariance of the noise added
- Presence of shale
- ...

Input parameters can be perturbed (discrete, continuous, spatial temporal parameters...).
Challenge of inverse modeling: *Output response*

**Data to match:**

- **Seismic and well data**
  - Seismic amplitude
  - Top surface *from seismic*
  - Thickness *from seismic*
  - Reservoir shape
  - Oil water contact *from seismic*
  - Log data

- **Production**
  - Well tests
  - Production
  - Connectivity
  - ...

**DIFFICULT DATA INTEGRATION**
Motivations

Surface-based models reproduce the key heterogeneities and have conditional capabilities

*How to efficiently create conditional models?*

1- Define the most influencing input parameters
   *Sensitivity analysis*

2- Develop a conditioning strategy (*cf. yesterday*)
Sensitivity analysis

Inputs variance
Seed 1

+ Spatial uncertainty
Seed 2

= output variance

Sensitivity analysis
Variability of the model

Both seeds are changing

Mean = 2.4
Variance = 3.1  Log variance 1.2
Variability of the model

Only the input parameters are randomized

Mean = 2.5
Var = 2.7 Log variance
Variability of the model

Account only for the spatial uncertainties

Mean = 2.3
Var = 1.6  Log Var = 0.7
Selection of the input parameters and data to match

**Input parameters**
- Location of the Source
- Size of the Lobes
- Paleotopography
- Model of deposition used
- Model of erosion
- Variance of the noise added
- Covariance of the noise added
- Volume of the reservoir
- ...

**Data to match**
- Seismic
- Top surface
- Wells
- Shape
- OwC
- Well tests
- Production data
- Oil Water Contact
- Connectivity
- ...

Selection of the input parameters and data to match
Explaining Inputs parameters

- Thickness of the lobes
- Location of the sediments source

The sediments source controls the location of the first deposited lobe
Explaining Inputs parameters

Covariance Range of an isotropic gaussian variogram

Sequential Gaussian Simulation
Deposition’s model of simple lobe

- Statistics approach
  - Progradation distribution
  - Migration distribution
- Geologic approach
  - Elevation
  - Gradient
- Mixed approach
  using Tau model

Input parameters= Tau value [0 1]
Methodology for the sensitivity analysis
(Scheidt and Caers, 2009)

MDS and kernel transforms are used to investigate non-linear structures of the data and remove noise effects.
Methodology for the sensitivity analysis

In feature space, the points have better spatial distribution (linear), the clustering is easier in this space (using K-Mean).
For each cluster, it is possible to compute a standardized average value of input and output parameters of all realizations within each cluster.
Methodology for the sensitivity analysis

Tornado Charts

Input 1

Input 2

slope

Input 1

Output

Input 2

Output

Methodology for the sensitivity analysis
Volume constraint on the simulation

EXXON II Model

The forward model is stopped when it reaches the reference volume of sediments

Base Surface

Top surface
Target output: ratio length / width

Interpreted from seismic

Flat topography

High slope
Target output: ratio length / width

Interpreted from seismic

The model controls the stacking of the lobes on top of each other.
The lobes size and the variance defines the thickness of each lobes.
Target output: single well mismatch

Output = \Delta \text{ (well horizon data/simulated well horizon)}

The variance and model of deposition controlled mostly the vertical thickness variation of lobes
Output: correlation between wells

What impacts whether two wells (given a distance) have similar succession of lobe thickness

The correlation between wells is controlled mostly by the covariance.
Output: match with seismic

Case 1: High resolution seismic data

Case 2: Low resolution seismic data
The model of deposition, the covariance and the variance of the added noise controls the spatial repartition of the lobes.
Conclusion on the sensitivity analysis

Overall ranking of the parameters

1) Model of deposition
2) Covariance
3) Variance
4) Ys
5) Size of the lobes
6) Xs

Define conditioning strategies

(Bertoncello and Caers; SCRF 2010)
Conclusion on the sensitivity analysis

- Main influencing parameters: additional gaussian Noise
Future work

-The parameters has been ranked one-by-one by order of importance: one way sensitivity analysis.

-Parameters are interacting with each other

→ Analysis of the combinations that are best suited to match data (Mariethoz; SCRF 2010)
Questions ?

Thank you !