Local Grid Refinement Methods for Basin Modeling

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Local grid refinement (LGR) is applied in reservoir simulation routinely for structured and unstructured grids and implemented in commercial simulators. It is used to add detail where justified by data availability and to keep a coarse resolution where less data are available.

In basin modelling, LGR has not yet been implemented. It could be used in situations where seismic data are available at individual structures or prospects but not elsewhere in kitchen areas or within the sedimentary cover. Even more importantly, for appraisal studies, a data set may be available at reservoir resolution that may have to be integrated with the basin scale to model the impact of basin scale fluid flow on the reservoir.

Presently, tartan grids allow to refine the grid in the x and y directions but waste a lot of grid cells in areas where refinement is neither necessary nor wanted. Vertical grid refinement is performed where the stratigraphic grid needs to be enriched to model fluid flow. In order to better represent data availability (basin versus prospect/structure of interest) and to save computing time, it is preferable to have a lateral and vertical grid refinement that only treats areas where information is available

The Basin LGR project has developed numerical methods that allow to treat two or more imbricated Cartesian grids refining in all three spatial directions with several levels of refinement. Fluid flow is performed on refined grid while heat transfers are computed on the coarse grid. Both kerogen cracking and migration are represented and illustrated on an example displaying the advantages of a LGR model.

Introduction

The main purpose of basin simulation is to represent the sediment deposition during long time period (millions of years). 3D models (Schneider et al., 2000) allow to simulate the thermal history, the pressure evolution, the hydrocarbon generation and multiphase flow migration in the basin. They are useful tools to understand the basin nature and can help for oil exploration and for evaluating the basin potential. Present basin simulators are based on 3D evolutive regular or Scottish Cartesian grids where layers are added during the simulation. The mesh evolution is based on the basin history which defines the type of deposited sediments and on the compaction effects of the sediment layers under the stress of the weight of the sediment column.

A need for accurate representation of zones of interests (reservoirs for instance) has recently appeared and the geologist would like to mix different grid blocks scales in the same simulation. This problem was first addressed using Scottish grids but this technique generates huge amount of useless data.

In this paper, we propose to use Local Grid Refinement (LGR) techniques to efficiently mix different grid blocks scales in fully coupled basin simulation. These techniques need efficient and accurate numerical schemes for non coincident mesh, a good representation of the compaction effects during the sediment deposition and the addition of sub events for the deposition of different sediments in the sub meshes.

Moreover, Cartesian meshes have also limitations to accurately represent basin structural features (such as faults, irregulars borders, reservoir zones) which are not defined on the Cartesian grids. Using present simulators, the real basin geometry is deformed and aligned on Cartesian meshes. So, in this article, we have coupled LGR techniques with Corner Point Geometry (CPG) grids which allows to accurately integrate basin geometric features. These new models are also integrated in a global workflow from data generation to result visualisation.

In the following sections, we first recall the equations and the basin modelling, then we describe how we have integrated these new features and the construction of non coincident numerical schemes for CPG grids. Some examples (one validation case and a real study) are also displayed and discussed.

CPG integrated workflow for basin simulations

This numerical scheme is integrated in a basin simulator. This simulator is a part of a workflow (Fig. 1) from data generation to 3D or 2D results visualisation. The user starts the basin study with fine scale data in a data set. He can generate a CPG horizontal map following structural features. Then, reservoir zones (sub-grids) may be added and associated with sub events which would be integrated during the basin simulation. Both the fine scale data and the CPG grids are mixed for the up-scaling process which aims at populating the CPG grids with geological coarse scale properties.

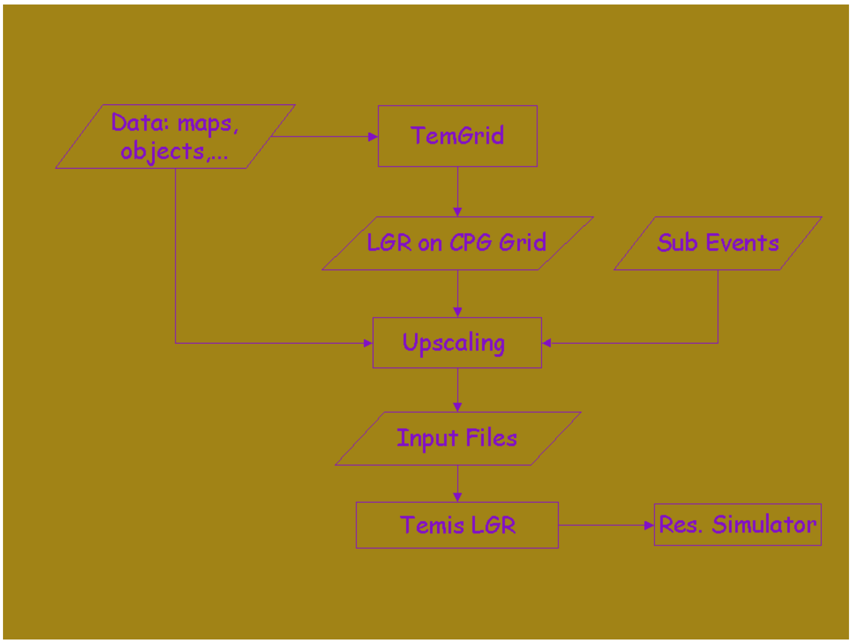

Fig. 1 : Integrated workflow

The basin simulation is made and the results can be exported in 3D or 2D viewers. Moreover, this CPG geometry and schemes is fully compatible with those developed at IFP. So, the user may add wells to the data set generated at the present day by the basin simulator. Then, a reservoir simulation may be made on the basin mesh with initial and limit conditions generated by the basin simulation. So, we propose an integrated workflow for geological and reservoir studies where the same data model is used and where the reservoir simulation could be better matched using data from the basin large scale simulation.

Results and Discussion

Validation case study

This simple Cartesian case has a 5*5*11 coarse grid. Two types of sediments are deposited (clay and sand) and the basin history spans from –110 Ma to present days which are equally divided in 11 events. The first layer is also a source rock which may generate oil under pressure and temperature conditions. Several meshes are built (LGR and Scottish) and simulation results are compared. The oil migration is well represented using LGR mesh with an oil segregation near the clay level which is similar to the results obtained on a Scottish grid. Moreover, smaller grid blocks allow a better representation of the oil segregation than coarse grid cells.

This case shows the advantages of LGR techniques which mix accurate physical representation and good numerical performances. The LGR test requires 3 times lesser cells than the Scottish case and runs 4 times faster.

Franklin case study

In this section, we present some results obtained on the Franklin study. Some materials on this study have already been published (Schneider et al., 2000; Schneider & Wolf, 2000) using classical Cartesian approach. We can compare our results and our methods with those elements. The Franklin basin is located in the Central Grabben in the North Sea and we focus on a 15km*12km zone where two reservoirs are present (the Franklin main structure and a satellite). These reservoirs are HPHT (High pressure : up to 120 MPa, High Temperature : up to 190°C). The history of the basin spans from -256 Ma to the present days and is divided in 20 periods. Some sediments are source rocks and the contained organic materials can be cracked under pressure and temperature conditions. The fine scale grid has a 75*75m horizontal resolution and was up-scaled to 600*600m grid blocks in previous Cartesian studies.

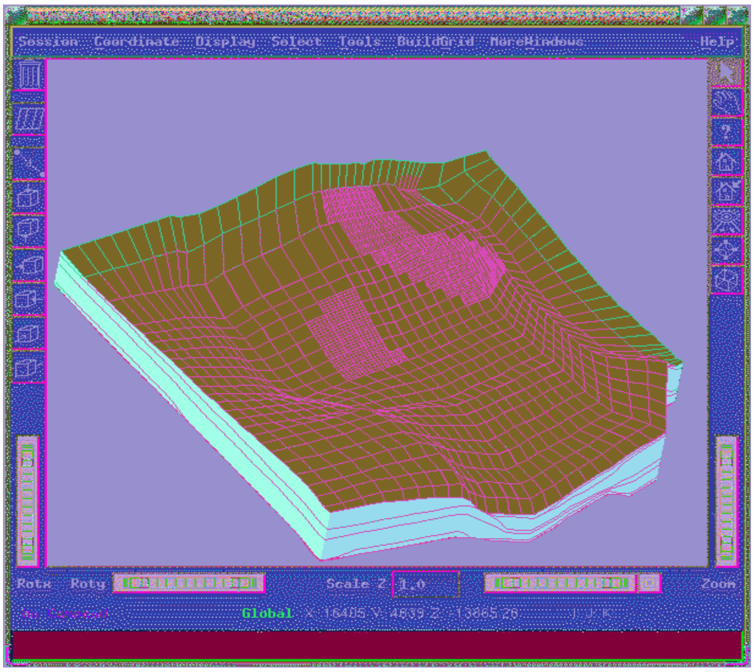

Fig. 2 : Validation case study

Using our presented workflow, we want to build a case study on these structural elements using a Corner Point Grid approach. We build a horizontal CPG grid on these structural features and the grid blocks have a 500*500m average resolution. The resulting coarse grid is 33*24*22. Some layers are refined (Franklin reservoir and satellite) using an average 75*75m resolution (Fig. 2). Fine scale data are then up-scaled to the coarse CPG grid.

The basin simulation displays good results in agreement with both previous Cartesian results and measured data. The calculated temperature in the Franklin reservoir is 183°C (measured data : 182 °C). The burial shape of the basin is also similar to the cross-section extracted from previous studies. The computed overpressure is also very similar to measured data (58.5 MPa vs. 57.5 MPa). The oil generation and migration is also well represented and the both structures are full at the end of the simulation with some leaks at the reservoir top.

The monophasic simulation requires less than 3 minutes on a Pentium4 3Ghz for 16000 active cells, so the integrated CPG techniques are not very time consuming compared to Cartesian models (in our case, we went faster). The CPG algorithms have been optimised and use unstructured data for the resolution of the equations. Moreover, the CPG grid fit better the faults and others elements than a Cartesian grid and a better balanced simulation may result from that.

Conclusions

The presented results show the advantages of CPG and LGR techniques for basin modeling. We have proposed an integrated workflow from the generation of data (upscaling) and geometry (CPG, LGR) to the basin simulation and links to reservoir simulation. This approach is very smooth and user friendly (in our case, the geological elements constraint the mesh opposed to Cartesian approach). It is also possible to link basin and reservoir simulation using our methods for more efficient integrated studies.

Some perspectives to this work may be seen in the optimisation of the global workflow, better thermal simulation, paralleled algorithms.

References

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