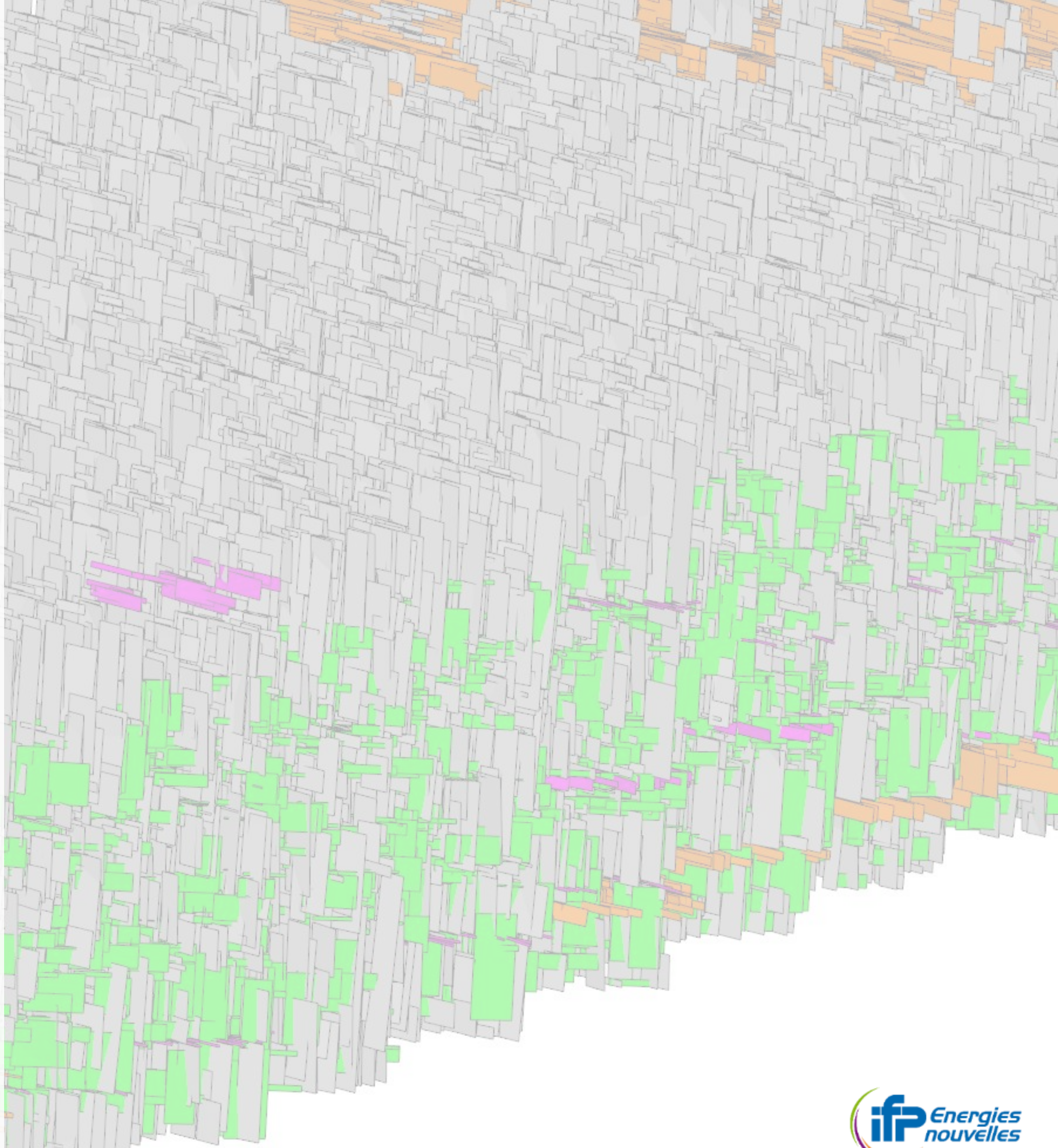
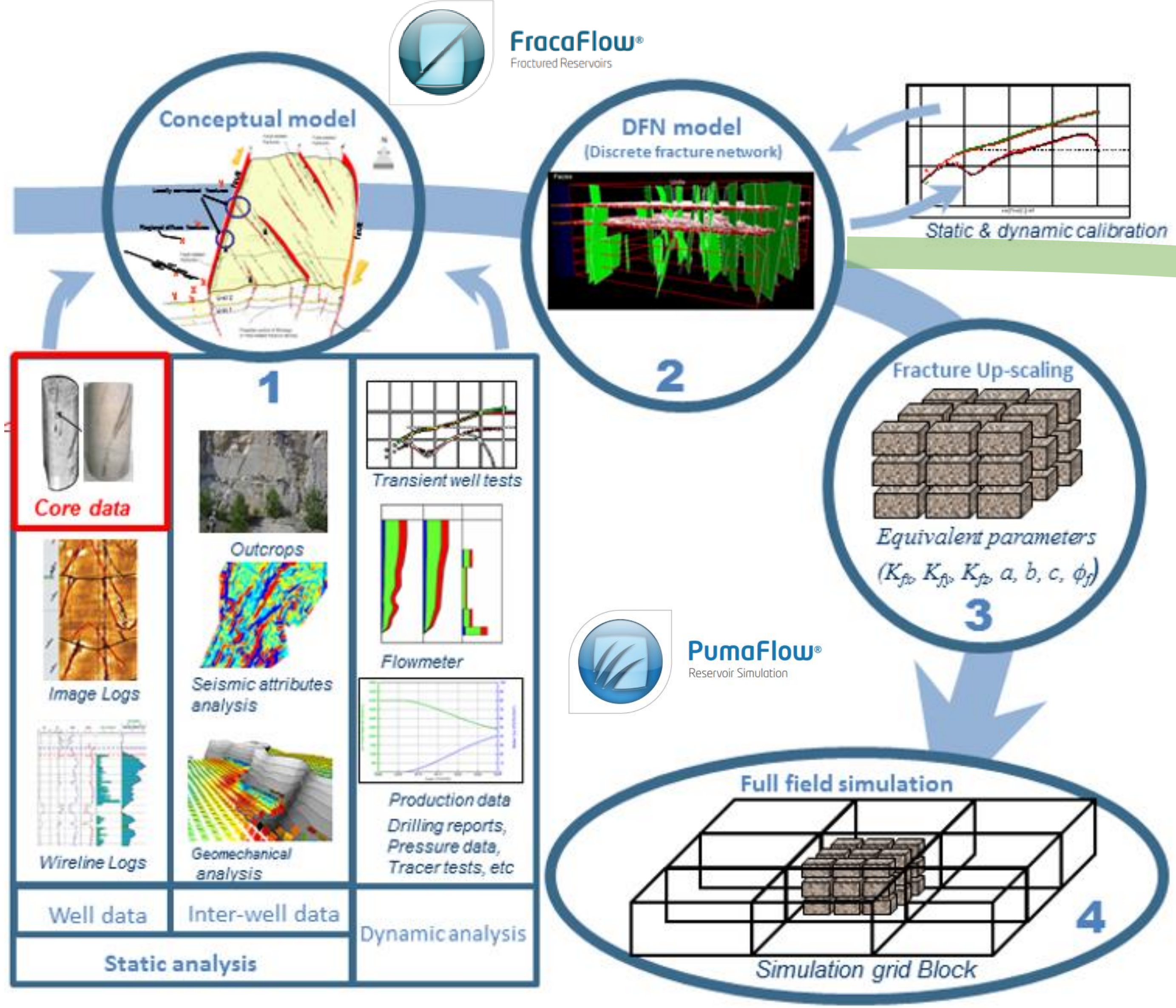
A NEW PARALLEL RESERVOIR SIMULATION TOOL FOR THE PRODUCTION OF FRACTURED GEOTHERMAL RESERVOIRS.

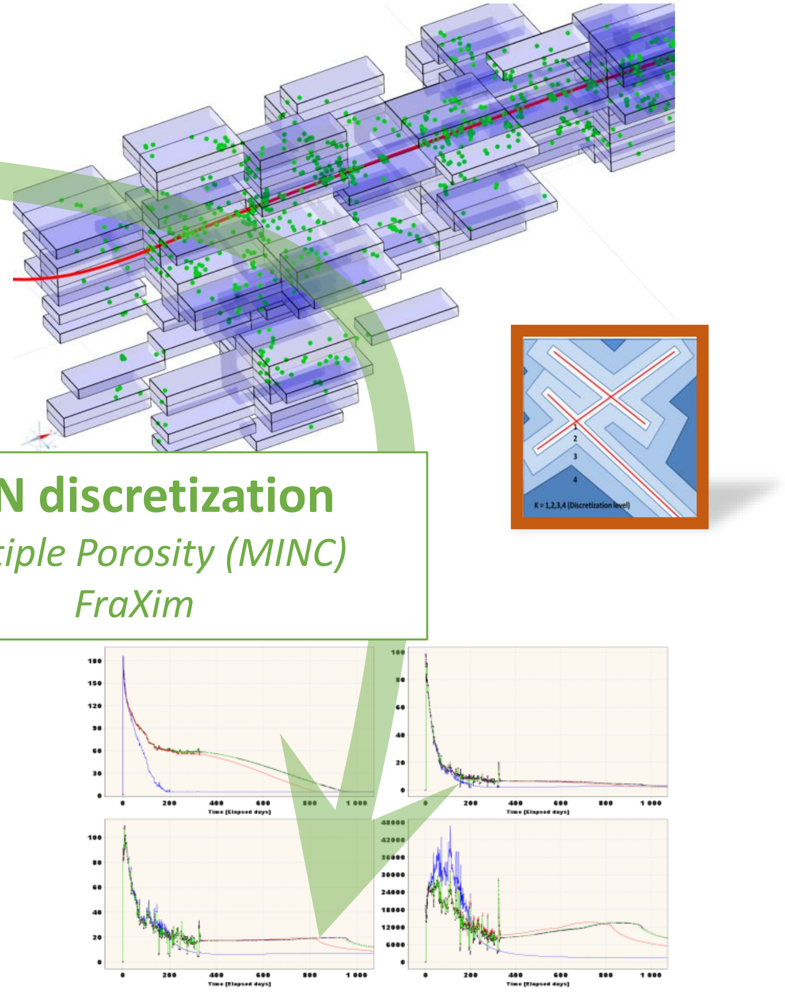
OLIVIER.RICOIS@IFPEN.FR



FROM FRACTURES TO FLOW:
CHALLENGES IN FRACTURED RESERVOIR CHARACTERIZATION, MODELING AND DYNAMIC PREDICTIONS

Renewable energies





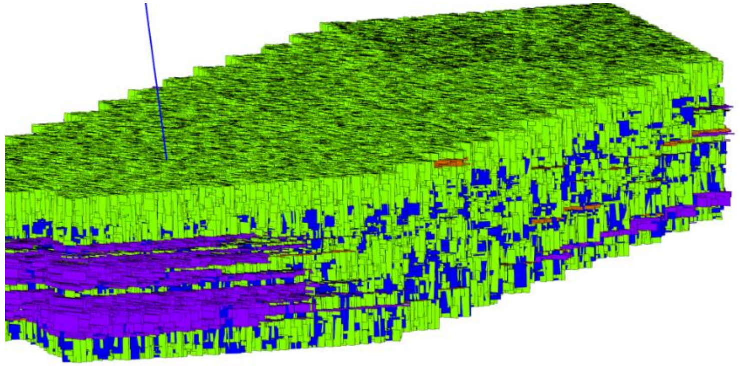
DFN discretization

Multiple Porosity (MINC)

FraXim

IFPEN SOFTWARE SOLUTIONS (1/2):
FOR FRACTURED RESERVOIR SIMULATIONS

Renewable energies



- Model and calibrate fractured reservoirs with **FracaFlow**
  - Static and dynamic data analysis
  - Fracture modeling and DFN generation
  - Dynamic calibration
  - Equivalent fracture properties computation

FracaFlow®
Fractured Reservoirs

- Simulate fractured reservoirs, optimal oil field management with **PumaFlow**(R)
  - 60 fractured fields studied worldwide including 10 of the world’s 50 largest oil fields.
  - Experience in carbonate, sandstone, shale, basement, volcanic

PumaFlow®
Reservoir Simulation

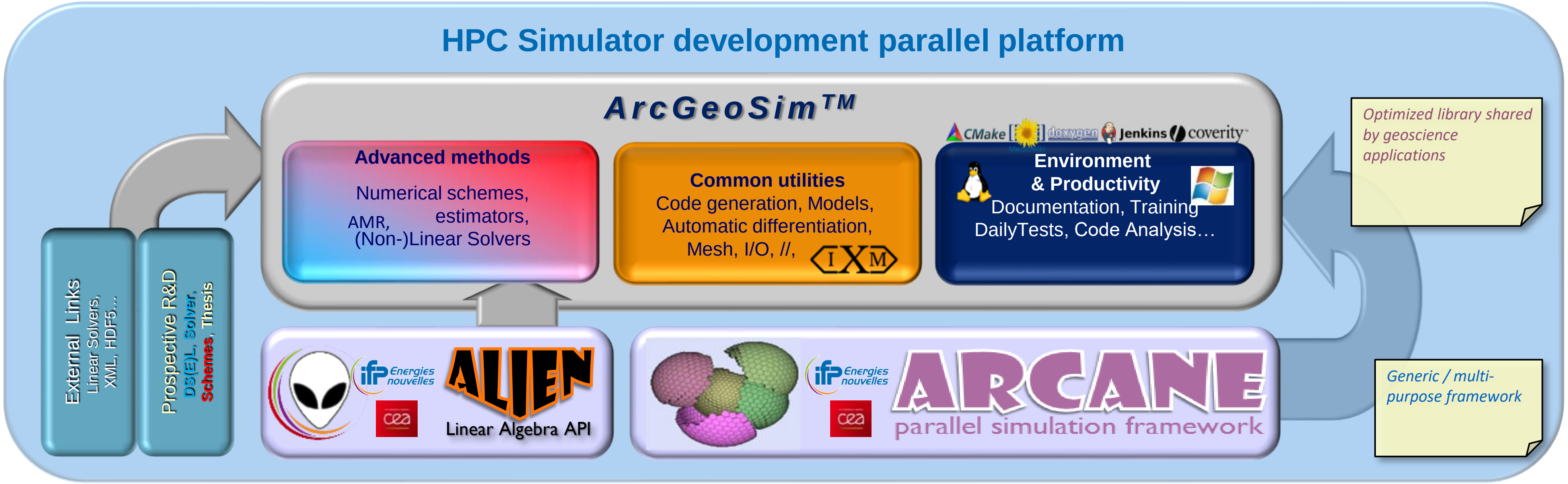
- All-in-one fully interactive platform including model preparation, simulation, post-processing, PVT package, uncertainties and assisted history matching.
- Unrivaled scalability and performances on black-oil and dual medium.
- Versatile simulator including all options (Black Oil, Compositional, Dual Medium, Shale Gas, Chemical and Thermal EOR) in one calculator.
- Excellence in physics

IFPEN SOFTWARE SOLUTIONS (2/2):
FOR FRACTURED RESERVOIR SIMULATIONS

Renewable energies

ARCANE / ArcGeoSim™

An IFPEN/CEA next generation geoscience development platform for parallel applications



A high level design to speed up development:

- Based on C++ Object Oriented language
- For any developer: physicists, numerical analysts, geoscientists
- With common code services for computational sciences (I/O (XML, HDF5), Checkpoint/Restart, Unit System
- With common concepts for mesh oriented simulations

A high level design for lower level optimizations

- Hardware abstraction and performances : Data partitioning/synchronization/migration, message passing parallelism API with MPI/multi-thread/hybrid implementations
- Multi-platform support (Linux/Windows)
- Tested on CEA supercomputer up to 60,000 cores.

FRAXIM PROTOTYPE
FRACTURED RESERVOIR SIMULATOR

Renewable energies

Geochemical
- Chemical Reactive transport
- Update of Φ and K
  Tracking of salinity

Thermodynamic
- 2-phase WO or WG
- EOS, compositional K-values, surface Ki
- BlackOil, Extended BlackOil

Numerics
- Hysteresis of Kr and Pc
- Local, global criteria
- A posteriori estimators
- Fully implicit
- TPFA, MPFA
- Newton relaxation

Grids
- Triangles and dual PEBI grids
- Fully unstructured geometry
- Faulted model and semi-conform schemes
- AMR honoring petrophysical

Wells
- Well path trajectory
  Well discretization (i,j,k)
- Rates (ISC, SC) and pressure targets
- Well coupling equations
- Drawdown constraints

Thermal
- Warn, cold water injection
- Steam Deadoil, compositional K-values, surface Ki
- Steam injection, tracers
- Heating of well
- Under/over burdens
- Neumann and Dirichlet BCs

Fractured
- 2P-2K, 2P-1K models
- **Multiple porosity MINC**
- **SLMD - discretization**
- Geomecanics of fracture aperture

Performance
- HPC MPI parallelization
- In-house // linear solver
- GPGPU linear solver

FRACTURE MODELLING TRENDS

Berre et al. (2018)

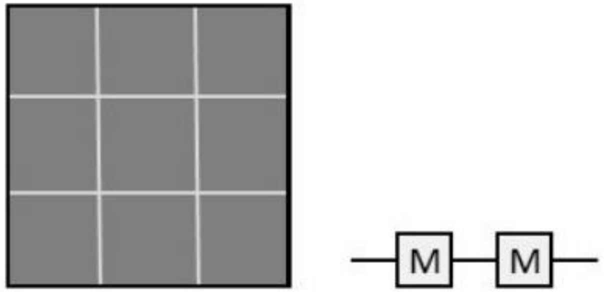
Renewable energies

- **Implicit representation of fractures**
- **continuum models**

- **Flow affected by local fracture geometries**
- **Explicit representation of fractures**

Weakly connected and small fractures

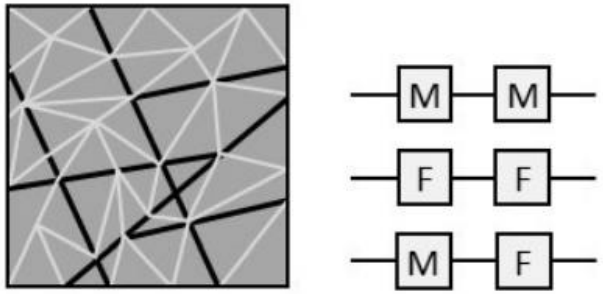
Low level of complexity



Single-continuum model

Meshing issues and complex modeling

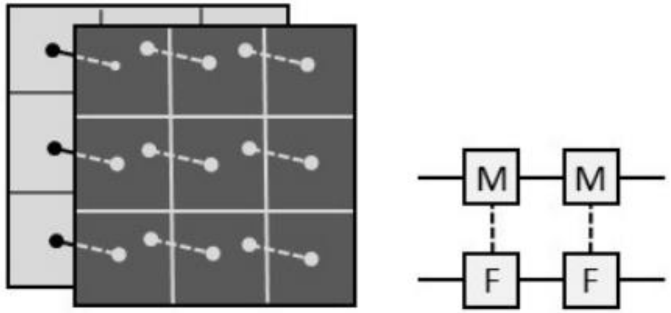
Multi-physics couplings



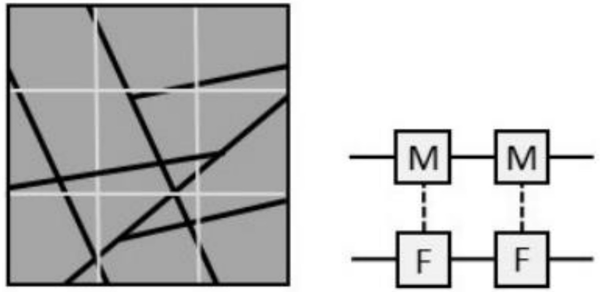
DFM model - conforming mesh

Dense connected networks

Challenging Transfer term



Multi-continuum model



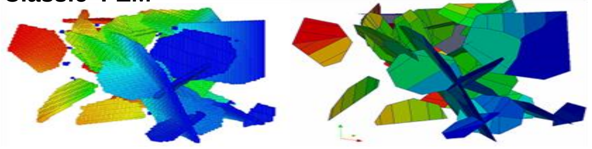
DFM model - non-conforming mesh

Low resolution of fracture–matrix interaction

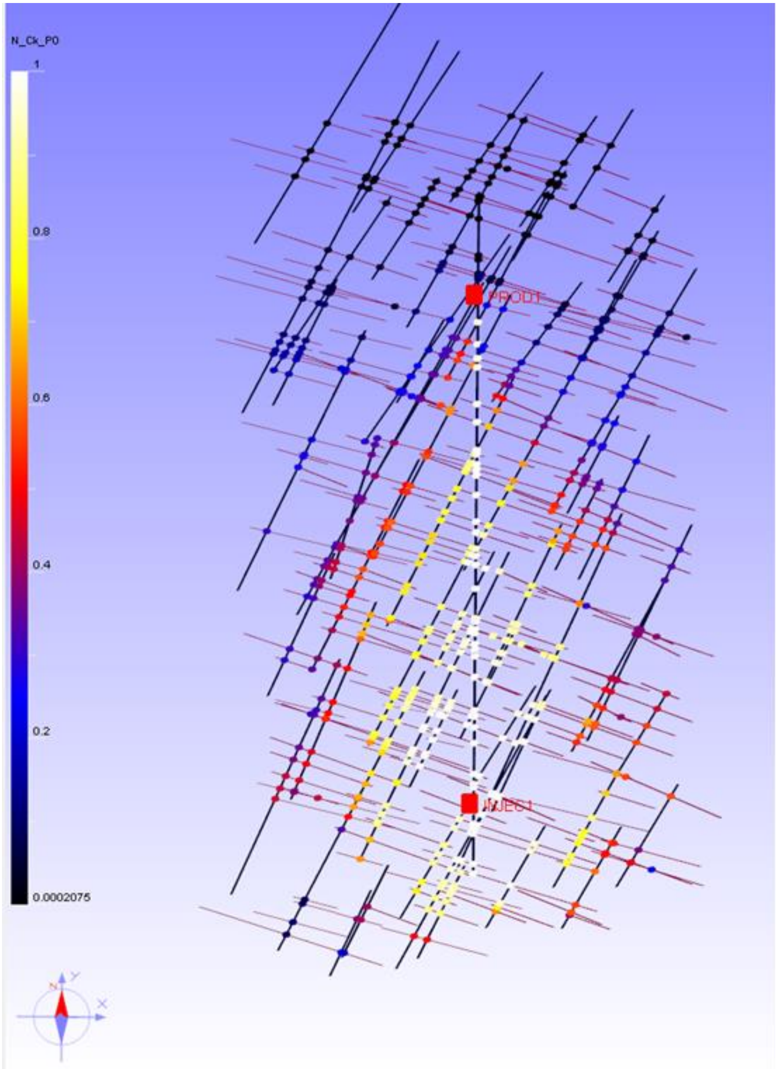
THE MODEL, CHALLENGES AND INNOVATIONS: A TAILORED DISCRETIZATION

- Fractured Media :
  - Flow scheme enables multiphase flow simulations preserving calibrated fracture characterization.
  - Discretization used limits number of nodes :
    - 1 node per intersection of fracture planes
    - Connected pathways only
    - Quick fractures exchanges steady state pressure gradient estimated via a Voronoi - Sweep Lined Mesh 3 D (SLM3D*).

Classic FEM SLM3D



$10^{E}5 \rightarrow 134$ nodes
$K_f < 5\%$

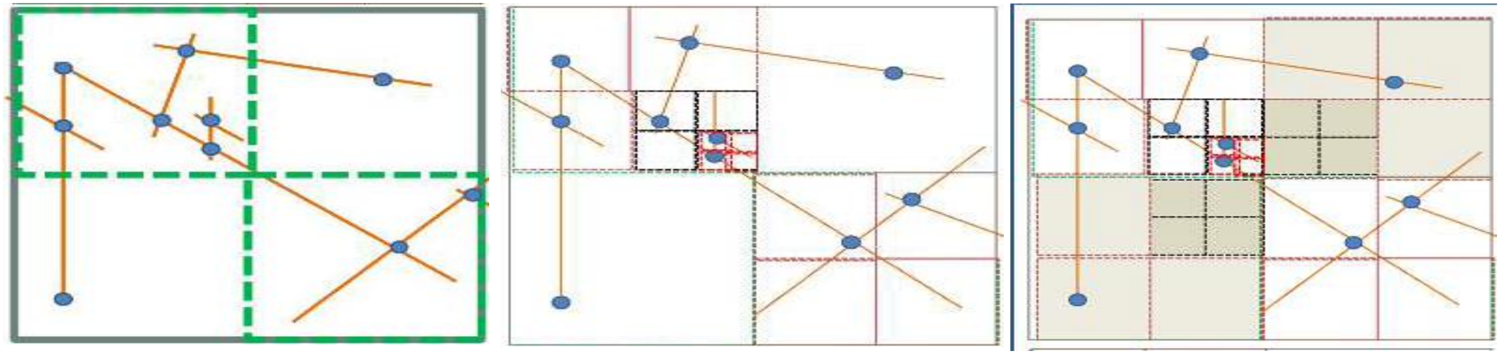


Khvoenkova, N., & Delorme, M. (2011). In IAMG conference (pp. 1238-1249).

THE MODEL, CHALLENGES AND INNOVATIONS:
A TAILORED DISCRETIZATION

Renewable energies

- Porous matrix media :
  - 3D octree* delineation.
  - Approximating pressure gradient in the matrix, close to each fracture, requires to assess the exchange surfaces, thus using an adapted scale allowing an accurate simulation of the chosen control volume:
    - Space is subdivided according to fracture location: the more fractures, the finer matrix control volume.
    - To smooth porous matrix cell volume variation, the octree is equilibrated of first order.



****Khvoenkova & Delorme (2012). Patent No. 13/644,479.USA.***

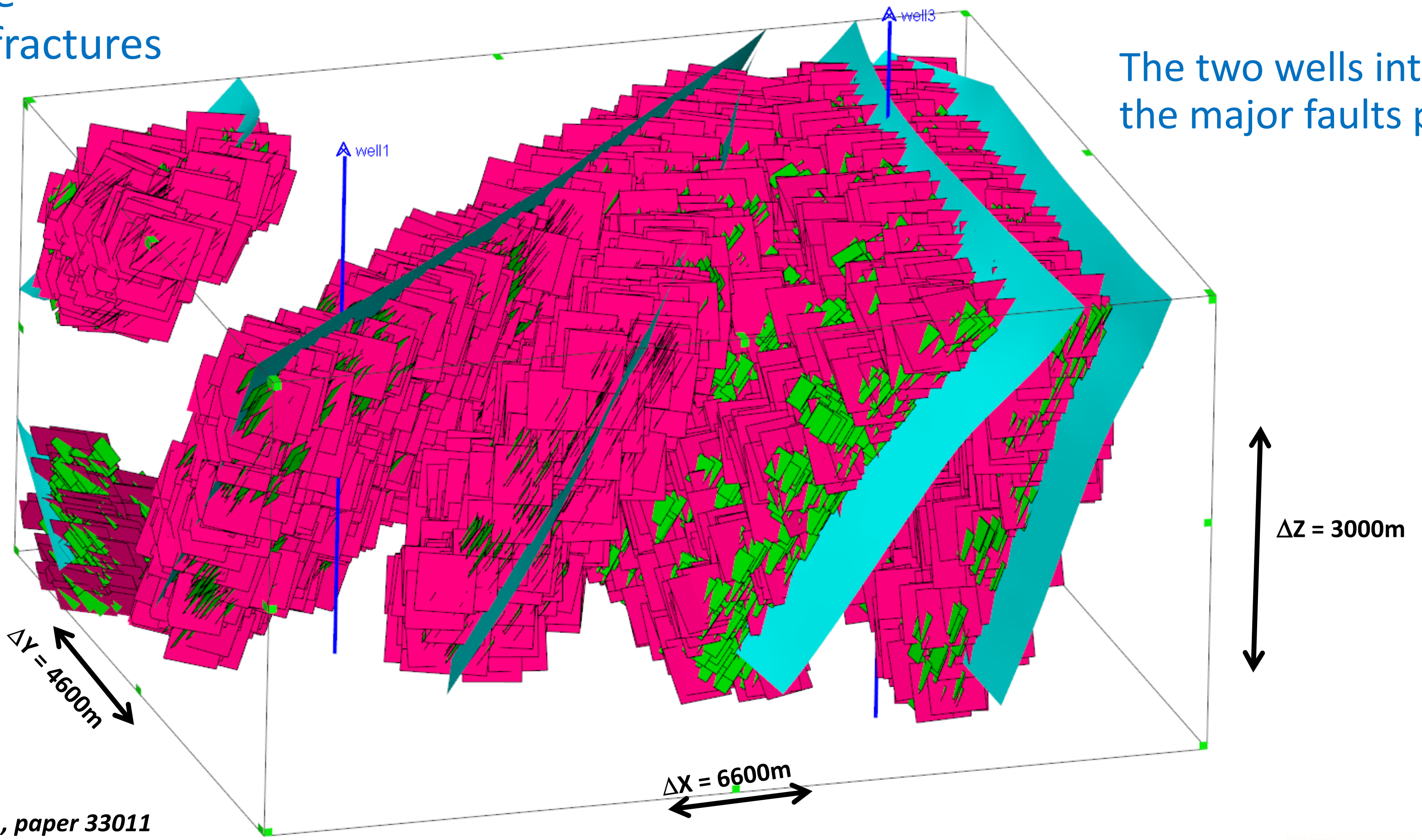
SYNTHETIC FRACTURED GEOTHERMAL RESERVOIR*

Renewable energies

Major faulted zones connected to dense networks of small fractures

The two wells intersects the major faults plans

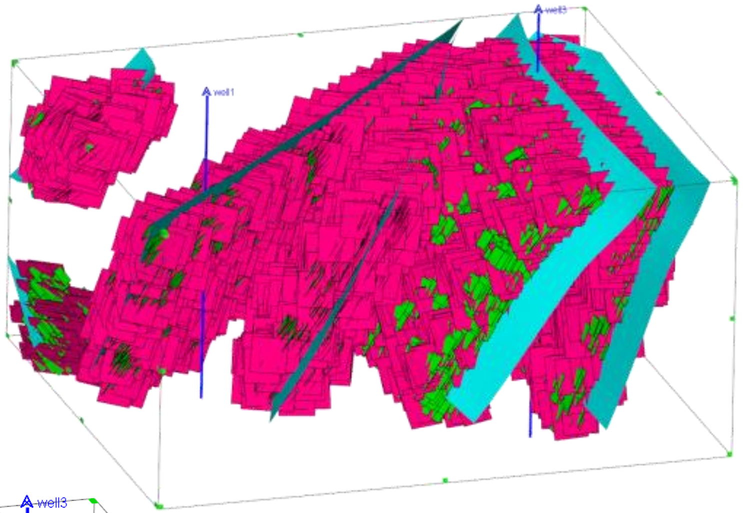
The small-scale fractures are nearly vertical, and the major direction is about N0°E



Ricois et al. (2021), WGC 2020+1, paper 33011

DISCRETIZATIONS

Renewable energies

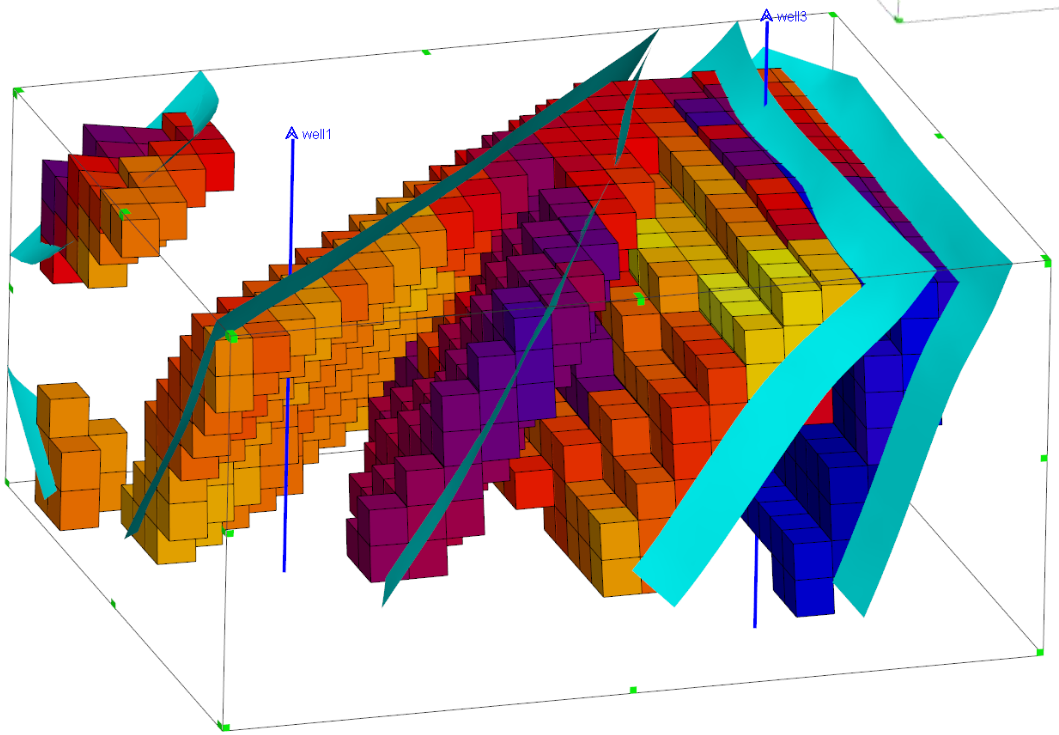


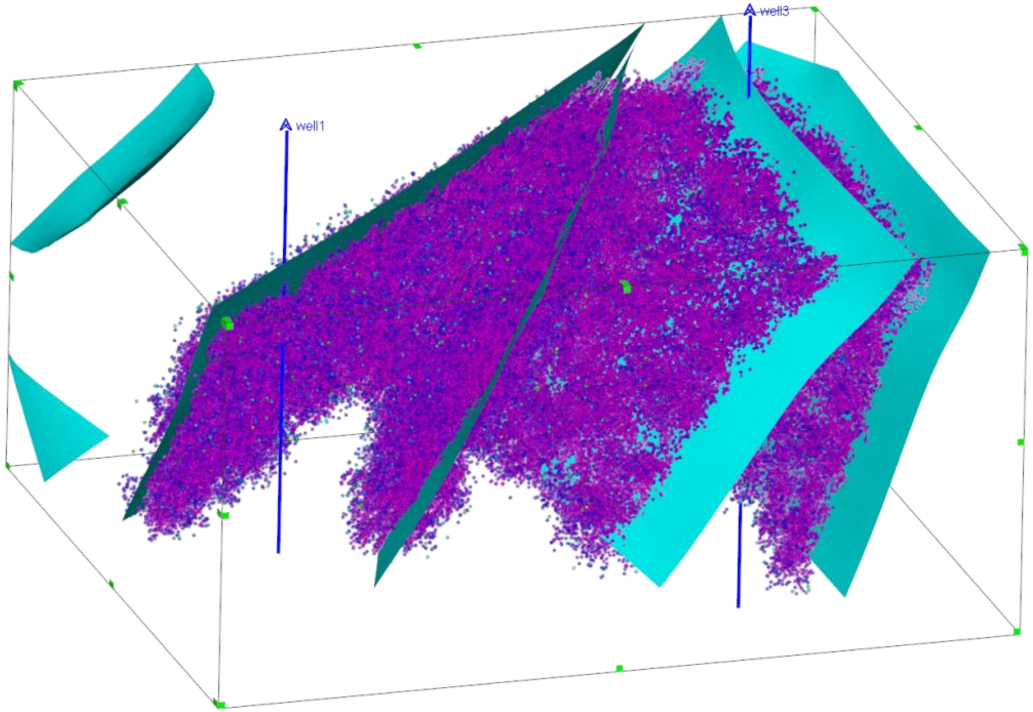
Continuum fracture medium

921 active fracture cells
2 mD < Kf < 8 mD
20 m< Lx,Ly < 50 m,
Lz=300m

DDFN discretization

387792 active fracture nodes located at the intersection of natural fracture planes of the DFN





ifpen Ressources Energétiques

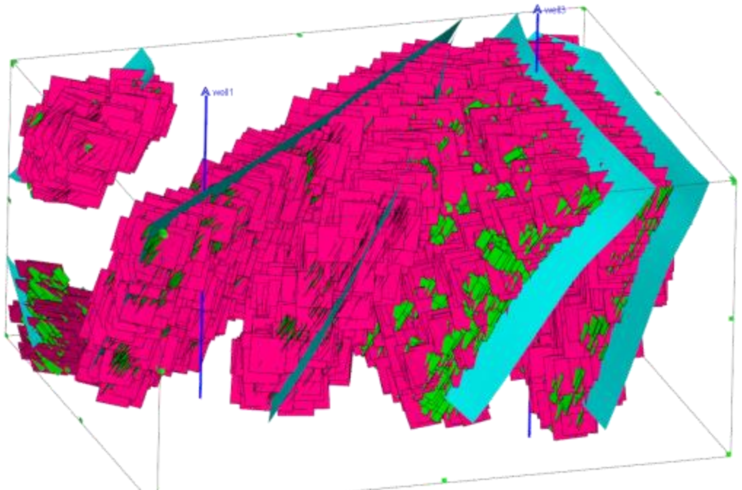
Energies nouvelles

DISCRETIZATIONS

Renewable energies

Continuum fracture medium

921 active fracture cells
3150 active matrix cells

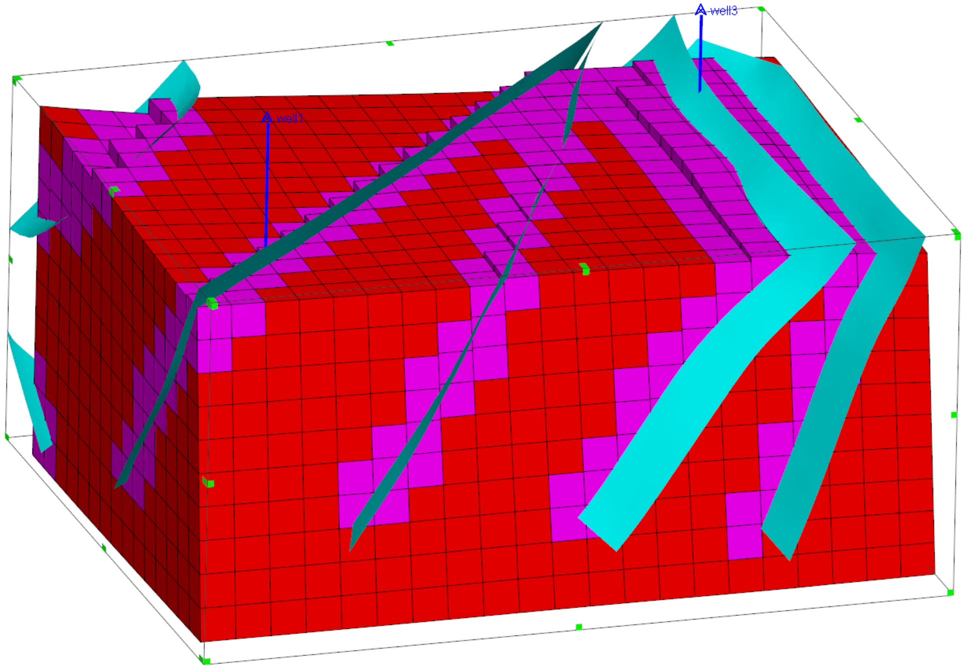


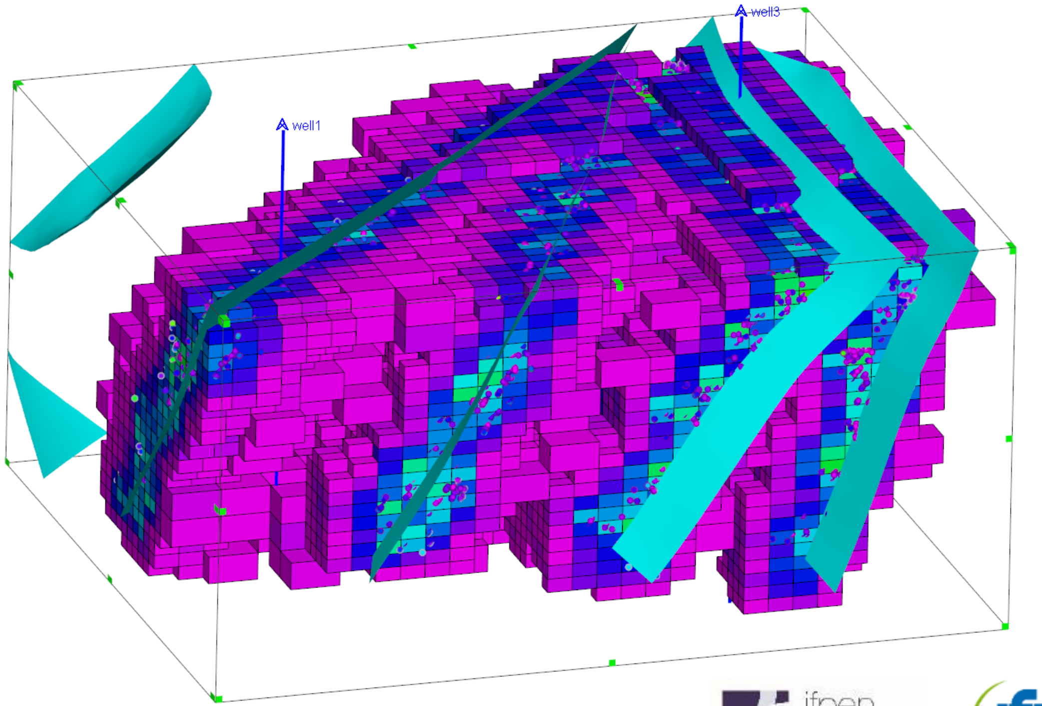
Km=0.001mD, Φm=0.001

DDFN discretization

387792 active fracture nodes located at the intersection of natural fracture planes of the DFN

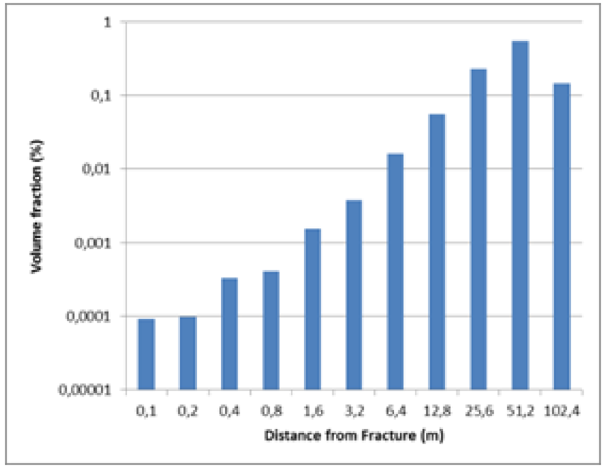
14805 matrix nodes





THE MODEL, CHALLENGES AND INNOVATIONS: A TRANSIENT TRANSFER INFLUENCE FUNCTION*

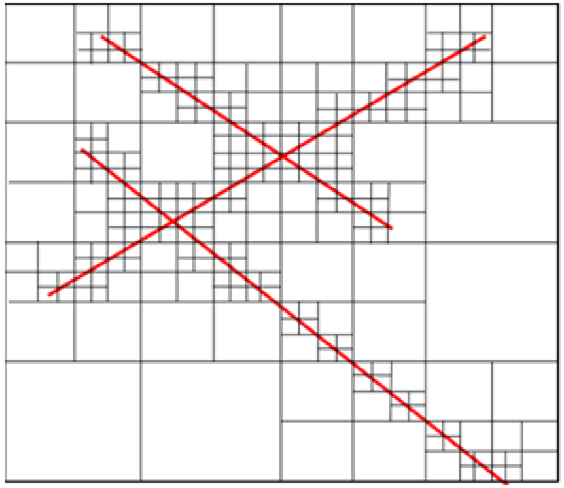
Renewable energies

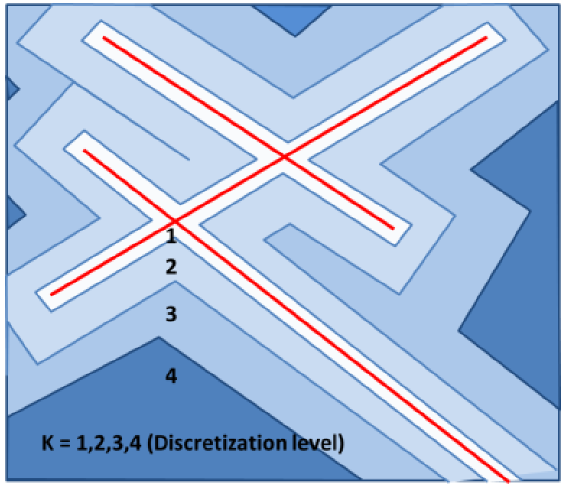


Transient Transfer Influence Functions
given for each matrix cell
$0 < Fv\ (x) = V(L_x)/Vm < 1$

- A matrix block comprises a number of nested sub-regions (k=1,2,…n), which are logically linked together in a one-dimensional sequence
- Matrix-Fracture Flow $T_f^1 = e_1.K_m\left(\dfrac{4.S_f}{L_1}\right)$
- Flow internal to the matrix block

$$T_k^{k+1} = e_k.K_m\left(\frac{2.F_v(L_k).Vm/(L_{k+1} - L_k)}{L_{k+2} - L_k}\right)$$

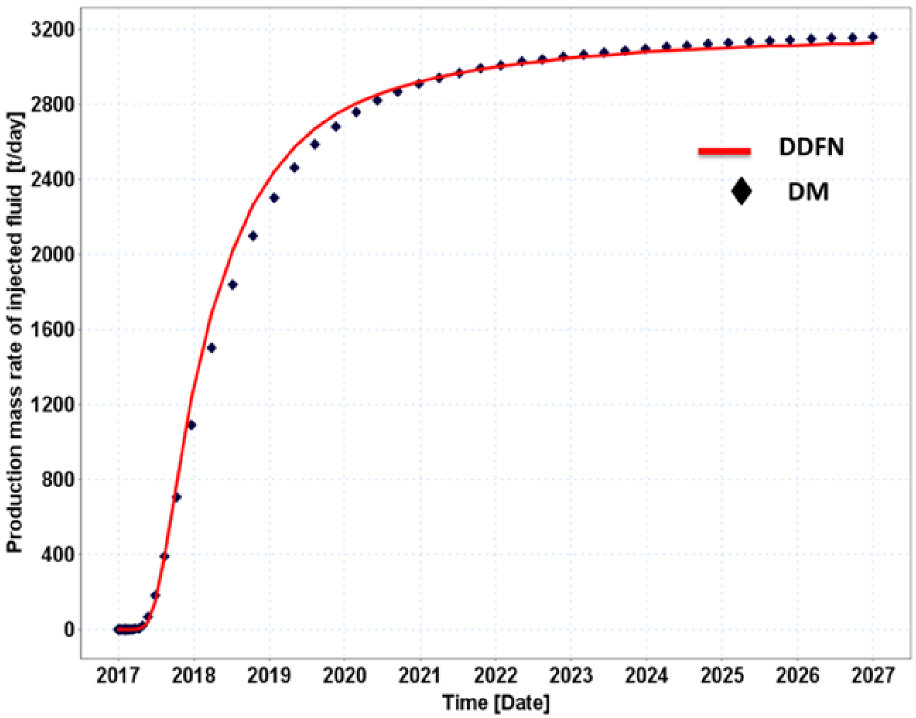




ek: Transmissivity multiplier to account for the matrix damage during hydraulic fracturing
Sf : Surface of fractures in the matrix block
Vm: Volume of the matrix block
Km : Permeability (tensor) of the matrix
Lk: Distance from fracture of nested sub-regions.

*Ricois et al. (2016), doi:10.2523/IPTC-18846-MS

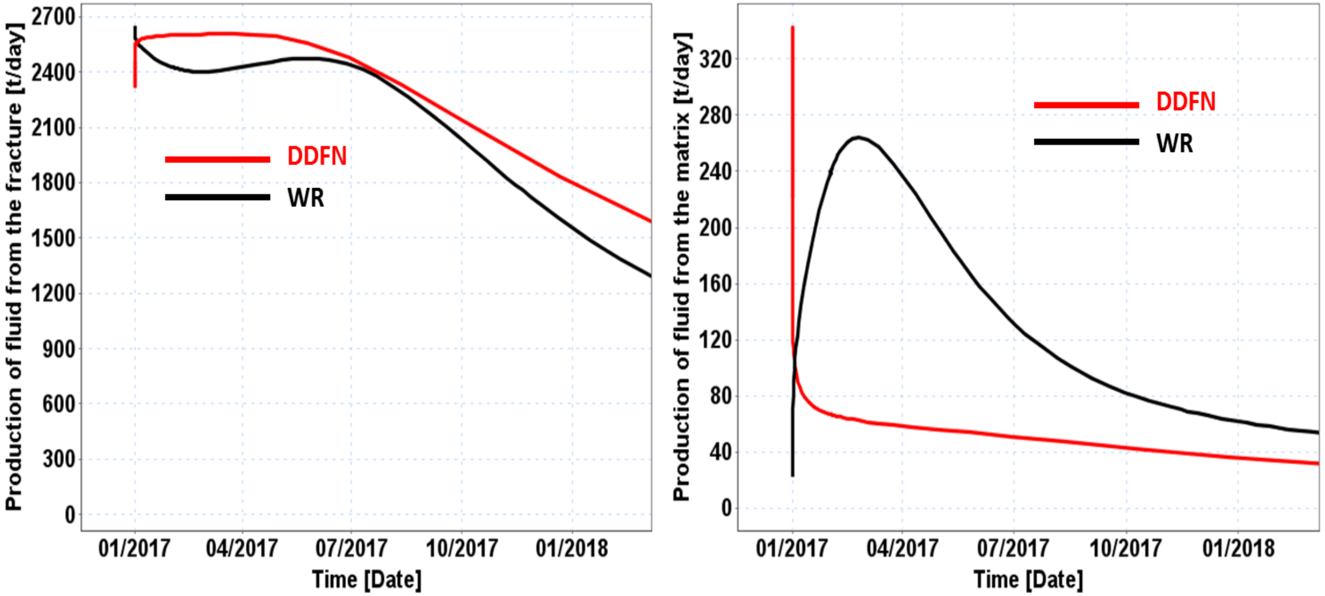
PRODUCTION MASS RATE OF INJECTED WATER (T/D)



Initial reservoir temperature : 160°C

Injection temperature : 60°C

Q = 3000 t/d



Water BT after 1 year

Fracture network features are favorable to continuum approach in this example:

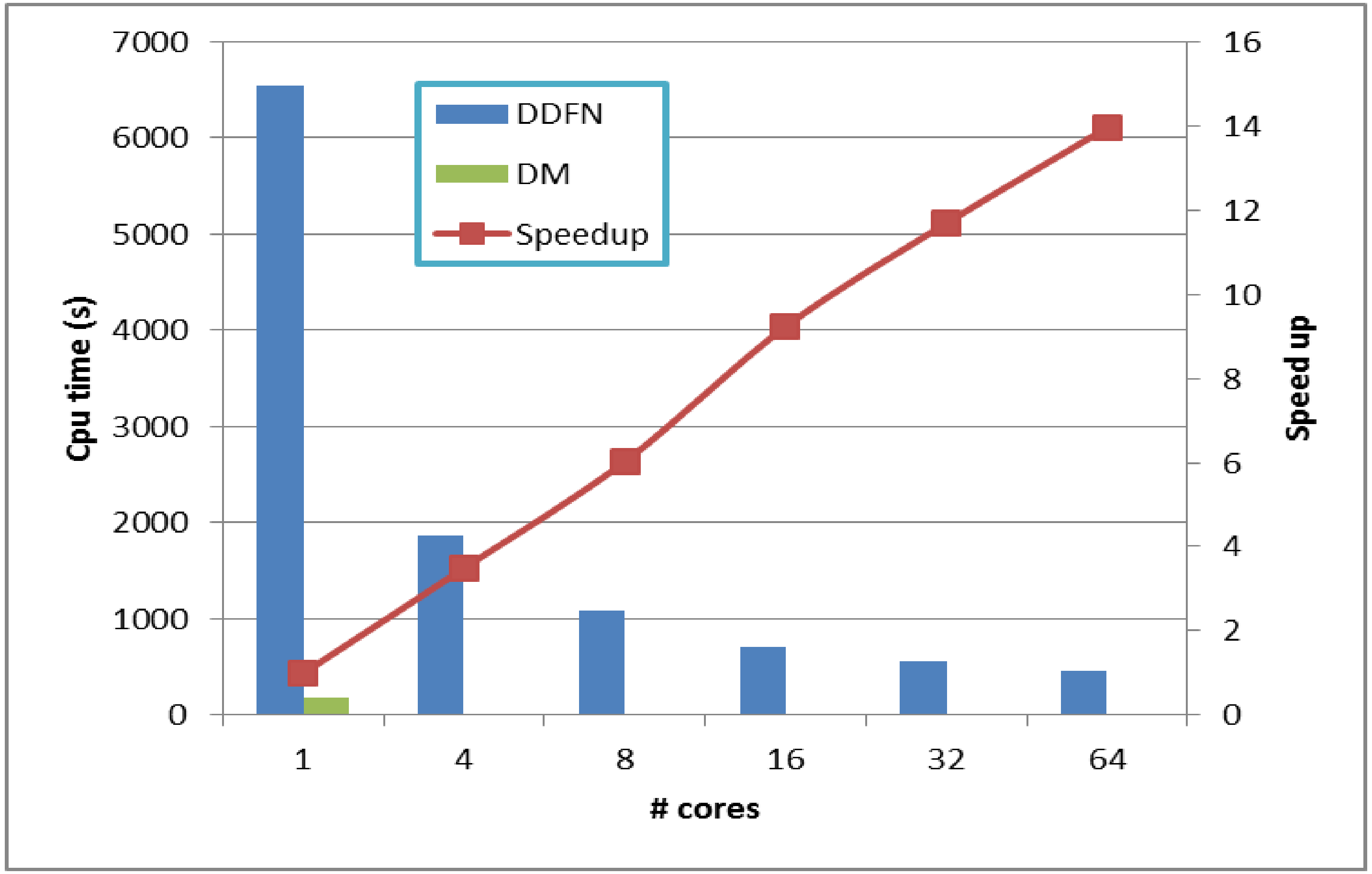
- Quasi-homogeneous small block sizes
- High density of fractures
- Homogenous matrix

WR overestimates the production of water coming from the matrix

kinetics of water production are different

COMPARISON OF CPU TIMES AND SPEED-UPS

Renewable energies



Runs on ENER220, the IFPEN parallel supercomputer (225 Tflops for 120 nodes with 2x18 compute cores on each node)

Optimal #cores function of degrees of freedom of the model

CONCLUSIONS

Renewable energies

- Development of a new parallel reservoir simulation tool for the production of fractured geothermal reservoirs.
- Accounting for “pertinent” scales influenced and inspired the development of a new model (DDFN methodology) using a specific discretization method:
  - Where up-scaling constrains are removed, allowing the integration of several scales (down to the metric one).
  - Well adapted to fractured geothermal reservoirs, given its ability to limit the number of nodes (fracture and matrix).
- Currently it can include up to half a million of natural fractures.
- The problem of the transient effects is solved using an adapted transfer proximity function creating realistic temperature gradients close to the fracture faces.

Innovating for energy

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