

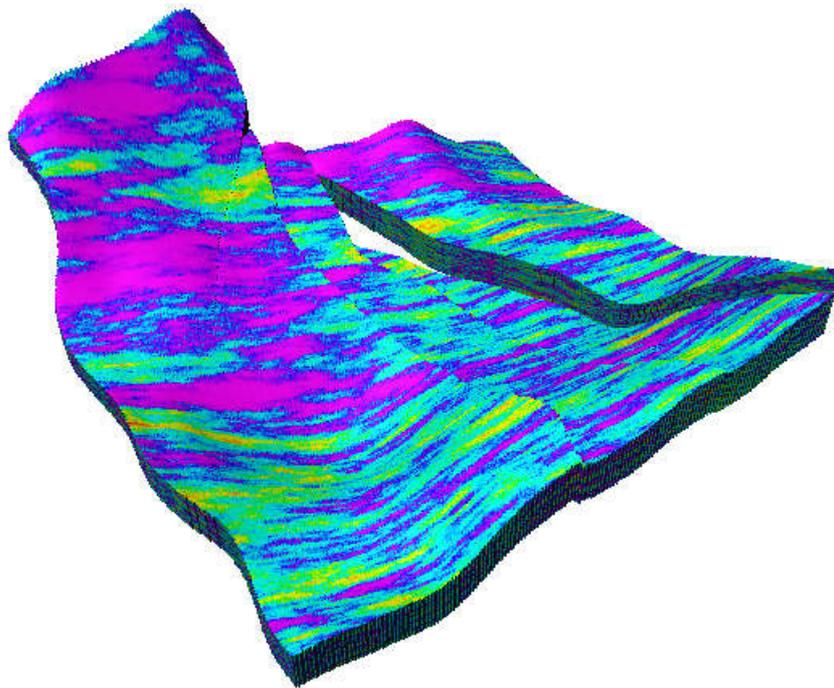


Terra3E

TransTerra™

User's Guide

Version 2015.1.1





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1 INTRODUCTION

Reservoir engineering procedures, such as production forecast, history matching, production optimization (well placement, production rate, etc.) or uncertainty analysis, require simulation runs which are performed on reservoir grid using upscaling properties of the geological model. The upscaling process affects the estimations of recoverable hydrocarbons especially as the properties of the reservoir are heterogeneous.

For representing reservoir heterogeneities, most of geological models need several tens of millions of cells. Even though reservoir simulators are quicker and quicker, it is most of the time requested to average the properties representing these heterogeneities on larger cells for simulating the multi-phase flow.

Methods to average reservoir properties have been studied for several years by many authors. For averaging absolute permeabilities, two main approaches are met:

- Approach #1: Averaging first the permeabilities and using the averaged value when discretizing the equations, leading to average transmissibility (Guérillot et al., 1989; Terpolilli and Hontans, 2011);
- Approach #2: Calculating directly the averaged transmissibilities from the high-resolution permeabilities (Samier 1990; Ding and Urgelli 1997; Urgelli 1998).

This plug-in is in line with the second approach, considering adjacent volumes on both sides of the boundaries between cells in a manner that the contrast of heterogeneities is better conserved.

Compared to this previous work, we use the shifted block approach using the finite volume principles combined algebraic methods providing upper and lower bounds of the upscaled transmissibilities.

Two methods are proposed:

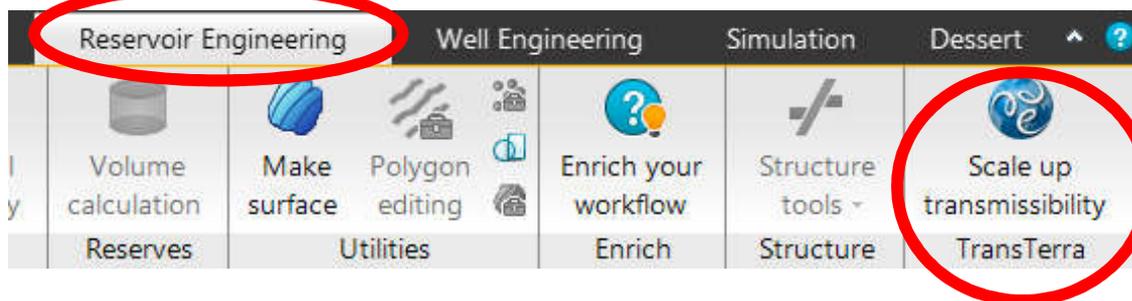
- Terra 3E algorithm
- Power law

For the both methods improvements are due to the computation is done on the half domains on either side of the boundary. We recommend using the combined approach which is more close to the real flow behavior, but we have proposed the power law method because it's a popular method, flexible and used within Petrel. The proposed power law implementation is more accurate because the computation is done on the half domains.

2 GETTING STARTED WITH TRANSTERRA

2.1 PETREL 2015 USER INTERFACE (RIBBON STYLE)

The TransTerra plug-in appears in a “TransTerra” group on the “Property Modeling” and “Reservoir Engineering” tab.



2.2 PETREL 2013 USER INTERFACE (CLASSIC USER INTERFACE)

In Petrel, open a project. Then click on the “Upscaling” folder of the “Processes” pane. Click on “TransTerra” to start the process and display the process dialog.

 **Processes**

- ▲ **Input**
 -  Import data
- ▷ **Stratigraphy**
- ▷ **Geophysics**
- ▷ **Structural framework**
- ▷ **Corner point gridding**
- ▷ **Property modeling**
- ▲ **Upscaling**
 -  Scale up structure
 -  Scale up properties
 -  **TransTerra: Transmissibility Upscaling**
- ▷ **Fracture network modeling**
- ▷ **Well engineering**
- ▷ **Simulation**
- ▷ **Utilities**
- ▷ **Plug-ins**
- ▷ **Terra 3E - Volumetrics**
- ▷ **Terra3E**



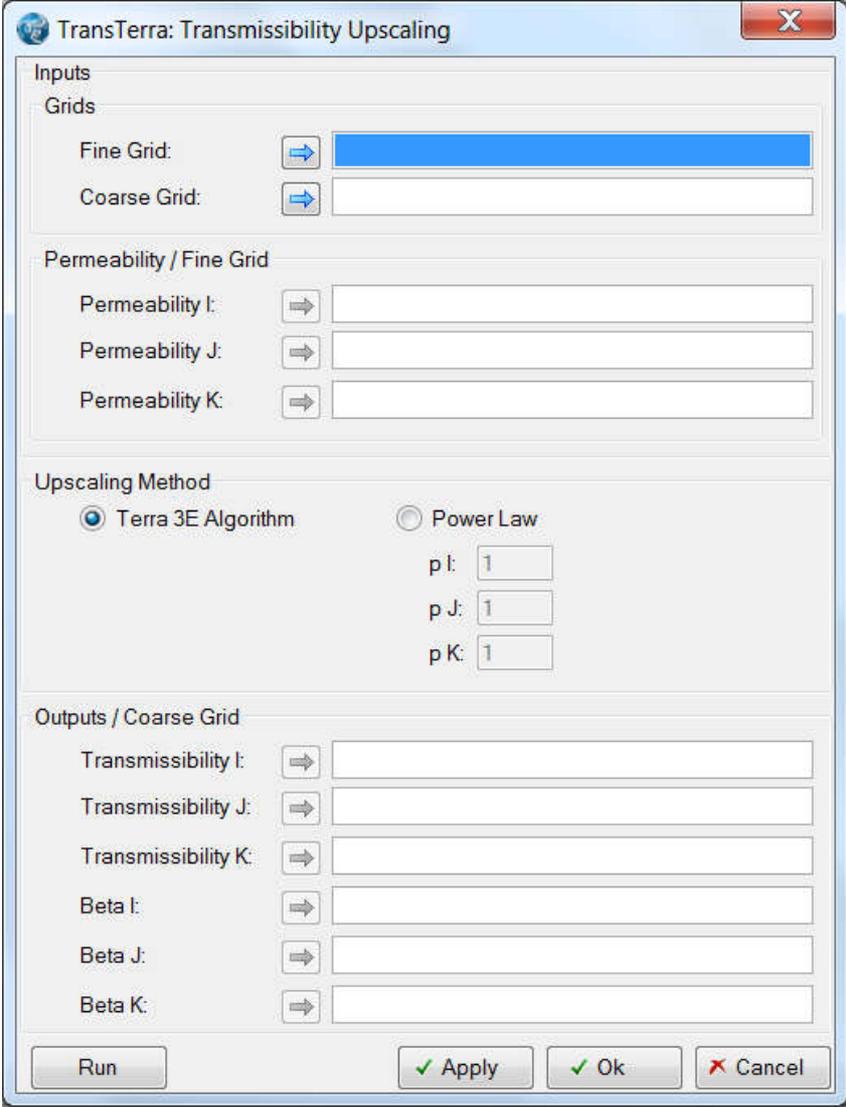
Figure 1 - Start the process

2.3 DATA MANAGED

Data managed are the properties available in the “Properties” folder of your models available in the “Models” pane:

- The user must import the requested data using the blue arrow of Petrel.
 - Input data are:
 - Fine grid
 - Fine permeability I, J and K
 - Coarse grid
 - Algorithm are:
 - Terra 3E algorithm (selected by default)
 - Power law
 - Output data are:
 - Coarse transmissibility I, J and K
 - Coarse grid of β values identifying where the gridding should be revisited.
 - Only available with Terra 3E algorithm.

2.4 TRANSTERRA INTERFACE



TransTerra: Transmissibility Upscaling

Inputs

Grids

Fine Grid:

Coarse Grid:

Permeability / Fine Grid

Permeability I:

Permeability J:

Permeability K:

Upscaling Method

Terra 3E Algorithm Power Law

p I:

p J:

p K:

Outputs / Coarse Grid

Transmissibility I:

Transmissibility J:

Transmissibility K:

Beta I:

Beta J:

Beta K:

Figure 2 - TransTerra Interface

To import data in the process, the user select a Petrel object in "Models" pane then click on the blue arrow.

To delete a data in the process, the user clicks on a white box containing the object, and then clicks on "suppr" key of the keyboard.

To select the algorithm, the user clicks on a radio button. By default, "Terra 3E algorithm" is selected.

Button "Cancel" closes the window.

Button "Run" launches the process and compute the upscaled transmissibilities.

2.5 WORKFLOW

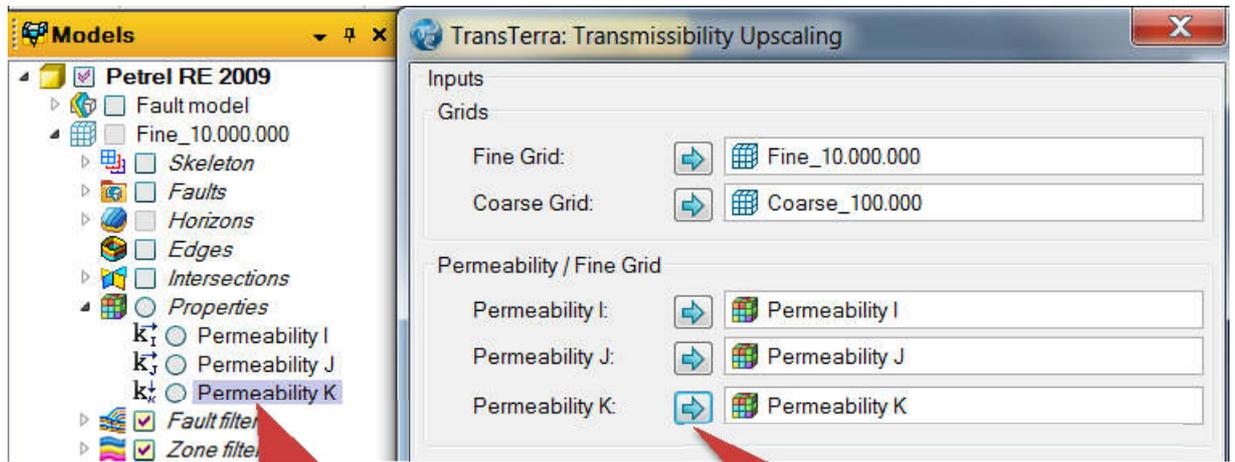
- The user launches the process from the "Processes" pane or from the "Property Modeling" tab or from the "Reservoir Engineering" tab.
- Using the blue arrow, the user drops a **fine grid** and a **coarse grid** from the "Models" pane.



1. Select a grid

2. Click on the blue arrow

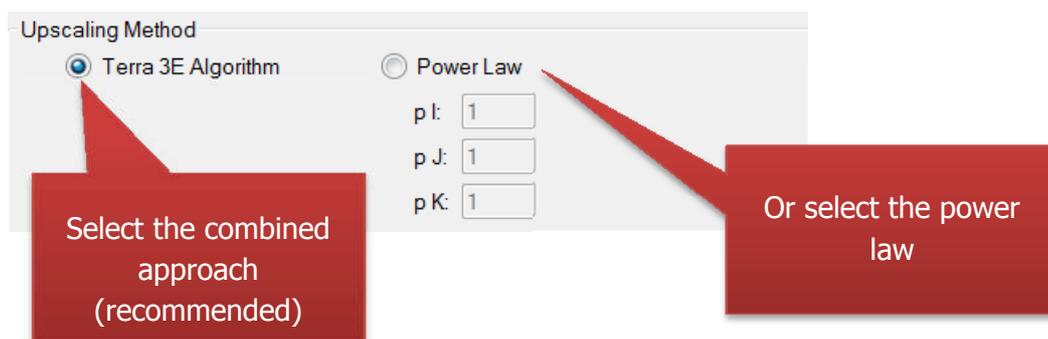
- Using the blue arrow, the user drops the fine permeability grids associated to the fine grid.



1. Select a permeability grid

2. Click on the blue arrow

- Using the radio button, the user selects the upscaling method.

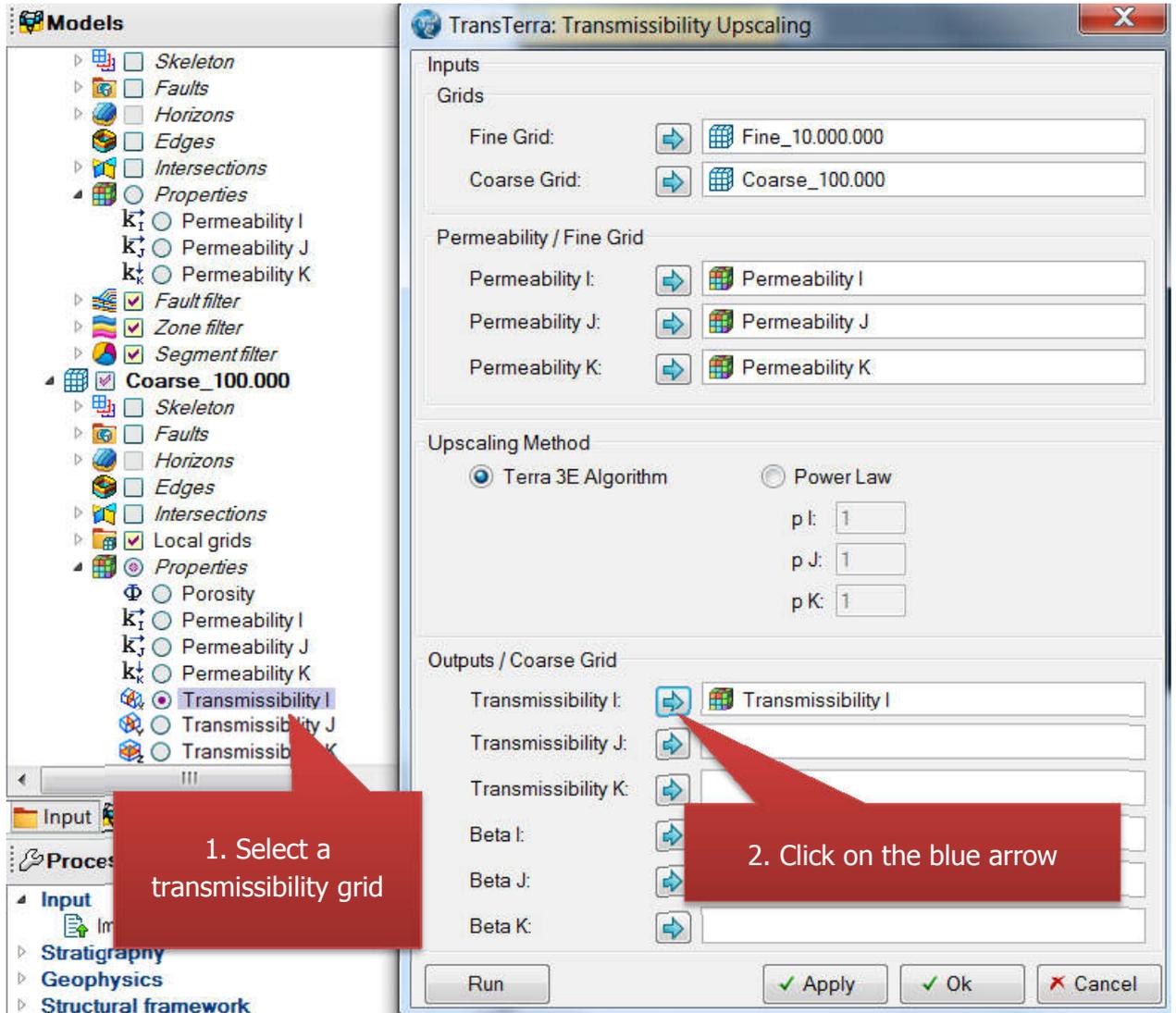


Select the combined approach (recommended)

Or select the power law

For the power law : reservoir engineers use a value near to 1 (0.9) to homogenize in X or Y direction; and a value near to -1 (-0.9) to homogenize in Z direction.

- The user may override existing transmissibility grids on the coarse grid. If no transmissibility grids are selected, the process will create all transmissibility grids in the coarse grid properties folder.



Models

- ▶ Skeleton
- ▶ Faults
- ▶ Horizons
- ▶ Edges
- ▶ Intersections
- ▶ Properties
 - Permeability I
 - Permeability J
 - Permeability K
- ▶ Fault filter
- ▶ Zone filter
- ▶ Segment filter
- ▶ **Coarse_100.000**
 - ▶ Skeleton
 - ▶ Faults
 - ▶ Horizons
 - ▶ Edges
 - ▶ Intersections
 - ▶ Local grids
 - ▶ Properties
 - Porosity
 - Permeability I
 - Permeability J
 - Permeability K
 - **Transmissibility I**
 - Transmissibility J
 - Transmissibility K

TransTerra: Transmissibility Upscaling

Inputs

Grids

Fine Grid:

Coarse Grid:

Permeability / Fine Grid

Permeability I:

Permeability J:

Permeability K:

Upscaling Method

Terra 3E Algorithm Power Law

p I:

p J:

p K:

Outputs / Coarse Grid

Transmissibility I:

Transmissibility J:

Transmissibility K:

Beta I:

Beta J:

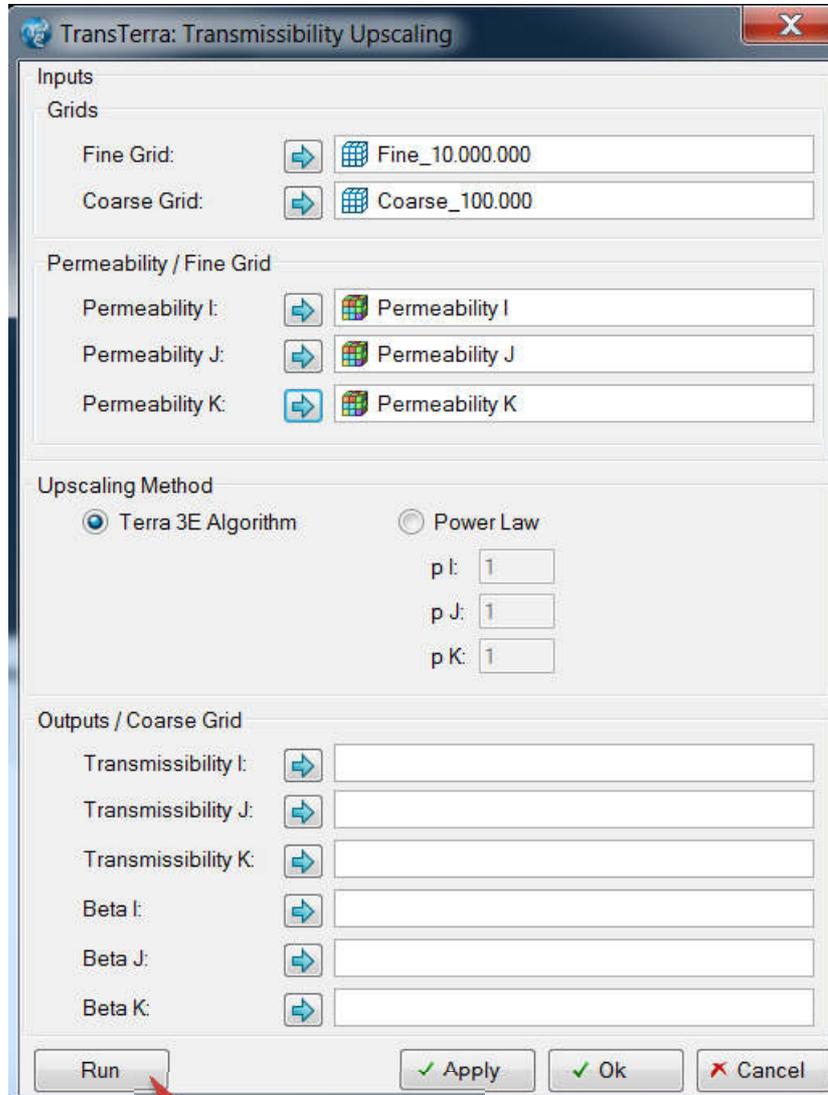
Beta K:

Run

1. Select a transmissibility grid

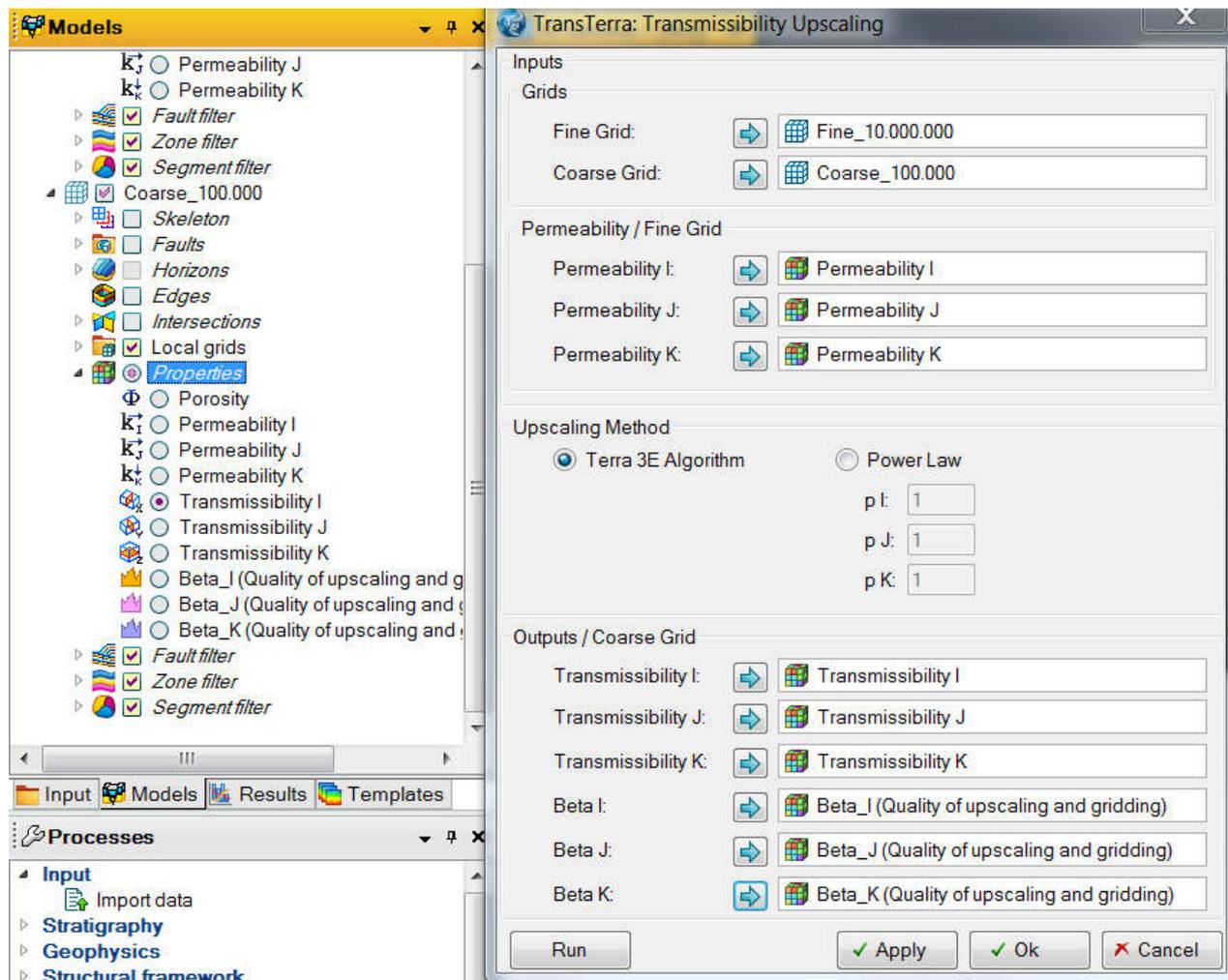
2. Click on the blue arrow

- The user runs the calculation of upscaled transmissibility by a click on "Run".



Click on Run

- When the computation is done, upscaled transmissibilities are added in the Properties folder of the coarse grid located in the "Models" pane. If the user had selected "Terra 3E Algorithm", quality indexes are calculated and added in the "Properties" folder of the coarse grid located in the "Models" pane.



A "Beta" quality indexes near 1 means that the upscaled transmissibility can be considered as good. A "Beta" quality indexes larger than 10 means that the mesh should be revisited. For a technical description of these indexes, please refer to next section.

2.6 TECHNICAL DESCRIPTION OF THE ALGORITHMS

2.6.1 INTERBLOC TRANSMISSIBILITY

The transmissibility is given as following:

$$t_{i,n(i)} = \left(\frac{1}{\tau_i} + \frac{1}{\tau_{n(i)}} \right)^{-1}, \quad (1)$$

with:

- τ the half-transmissibility for the adjacent cells, i and $n(i)$, to the surface grid defined as:

$$\tau_\alpha = k_\alpha \frac{n_\alpha s r_\alpha}{|r_\alpha|^2}, \quad \alpha = i, n(i), \quad (2)$$

with:

- k_α the cell permeability in the direction α ,
- n_α a normal vector going through the center of the face,
- s the cell interface area,
- r_α a vector connecting the center of the cell with the center of the interface.

2.6.2 TERRA 3E

We propose to upscale transmissibilities extending the algebraic upscaling methods introduced by Guérillot et al. in «An Integrated Model for Computer Aided Reservoir Description: from Outcrop Study to Fluid Flow Simulations, Improved oil Recovery», 5th European symposium, Budapest, Apr. 25-27, Proc., 651-660, 1989, called Cardwell & Parsons.

Here, we propose a version of this approach applied to the transmissibility. This approach, largely based on upscaling of permeability methods, allows taking into account the spatial arrangement of local transmissibility and increasing the accuracy of the calculation considering adjacent volumes on both sides of the boundaries between cells in a manner that the contrast of heterogeneities is better conserved.

The competitive advantages of the algebraic method are that they provide upper and lower bounds: T_+ and T_- .

Using these bounds, the quality of the upscaling and gridding will be controlled. In fact, for each cell where the ratio of T_+ and T_- is lower than a defined value, the equivalent transmissibility is given by the geometric mean of bounds. A ratio of bounds upper than a defined value shows that the gridding should be revisited.

To upscale transmissibilities between two blocks, we isolate the half blocks on either side of the boundary of the two blocks. For each cell, we consider 6 local domains: East, West, North, South, Front and Bottom. An illustration is given Figure 3.

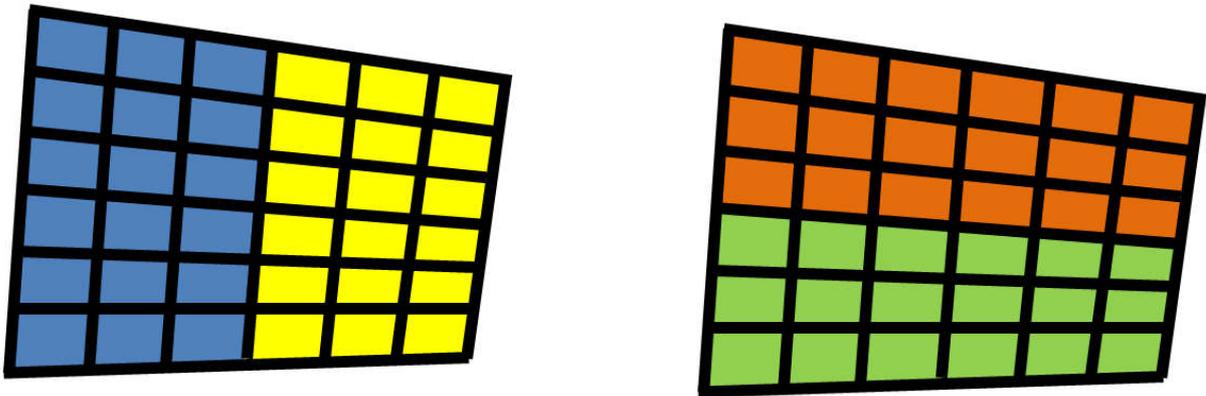


Figure 3 - Illustration in 2D of the: (left) East and West local domain and (right) North and South local domain.

2.6.2.1 LOWER BOUND TRANSMISSIBILITY

On each local domain, n steady-state incompressible single-phase for 1D flow are considered without gravity and boundary conditions, with n the number of fine cells at the interface between the two coarse cells.

These one-dimensional systems with finite volume discretization of Darcy's law can be written as:

$$t_{i-1,i} (p_{i-1} - p_i) + t_{i,i+1} (p_{i+1} - p_i) = 0. \quad (3)$$

This equation is solved using pressure boundary condition. The pressure is assigned as 1 on a boundary and 0 on the other boundary. This leads to solve a tri-diagonal linear system:

$$Au = b, \quad (4)$$

with:

- A the matrix containing the transmissibility terms of dimension $(n_{ct} + 2) \times (n_{ct} + 2)$,
- n_{ct} the number of cells in each "tube",
- u the vector containing the pressure unknown,
- b the vector of boundary conditions.

The Darcy's flux at the interface can be written as:

$$q_{i,i+1} = (\tau)_{i,i+1} (p_i - p_{i+1}). \quad (5)$$

Then, the half-transmissibility can be expressed as:

$$T_{\frac{1}{2}(\beta,d)}^- = \sum_n q_n, \quad (6)$$

with:

- β is the coarse cell index
- d is the domain : east, west, north south, top or bottom
- n the number of fine cells at the interface between the two coarse cells,
- q_n the fine scale flux,

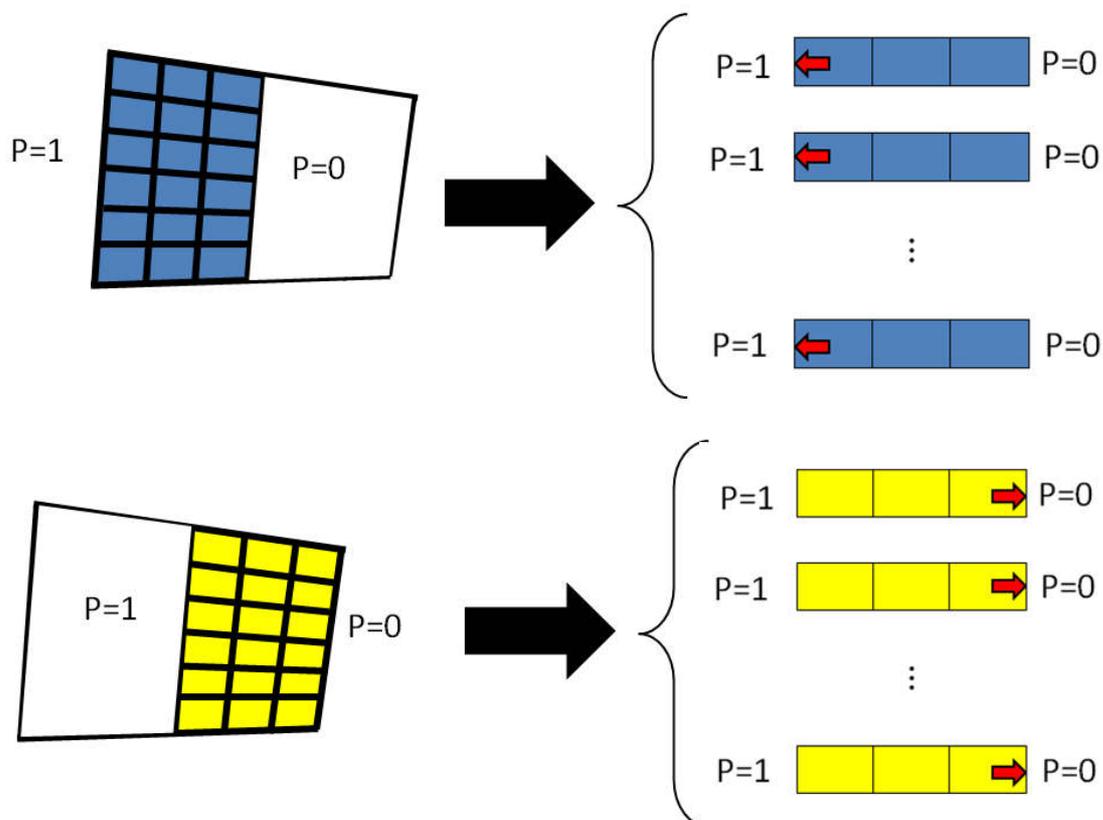


Figure 4 - Illustration in 2D of the half transmissibility of the West local domain (Blue) and East local domain (Yellow).

The low bound transmissibility between two coarse cells A and B can be express as following:

$$T_- = \left(\frac{\mathbf{1}}{T_{\frac{1}{2}(A,d)}^-} + \frac{\mathbf{1}}{T_{\frac{1}{2}(B,\bar{d})}^-} \right)^{-1}, \quad (7)$$

with:

- \bar{d} is the opposite domain of the domain d : East-West; North-South; Top-Bottom.

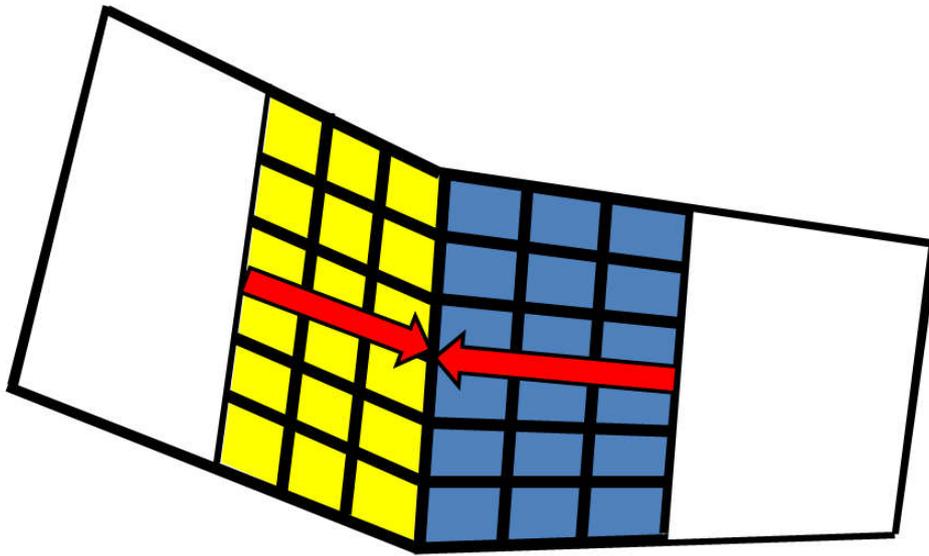


Figure 5 - Illustration in 2D of the low bound transmissibility between two coarse cells. Red arrows are the half transmissibilities of the East domain of the left cell and West domain of the right cell.

2.6.2.2 UPPER BOUND TRANSMISSIBILITY

On each local domain, the cells are grouped to form slice perpendicular to the considered direction.

The half-transmissibility between two slices (Eq. 2) is computed as following:

- Permeability k_α is the arithmetic mean on each slice perpendicular to the direction. In fact for permeability, the upper bound of the admissible value and the exact value pour a stratify medium with a flow parallel to the state is given by arithmetic mean.
- n_α is normalized vector of the arithmetic mean of normal vectors through each cell.
- s is the sum of fine cell interface areas.
- r_α is the arithmetic mean of the vector connecting the center of each fine cell with the center of the fine interface.

The transmissibility across each slice is computed using the Eq. 1. Then, with the same approach that the lower bound, a steady-state incompressible single-phase for 1D flow is considered. The pressure equation is solved using constant boundary condition and the flux at the interface can be computed.

The Darcy's flux at the interface can be written as:

$$\mathbf{q}_{i,i+1} = (\boldsymbol{\tau})_{i,i+1} (\mathbf{p}_i - \mathbf{p}_{i+1}). \quad (8)$$

Then, the half-transmissibility at the interface can be expressed as:

$$\mathbf{T}_{\frac{1}{2}(\beta,d)}^+ = \mathbf{q}, \quad (9)$$

with:

- β is the coarse cell index,
- d is the domain : east, west, north south, top or bottom,
- n the number of fine cells at the interface between the two coarse cells,
- q the flux at the interface.

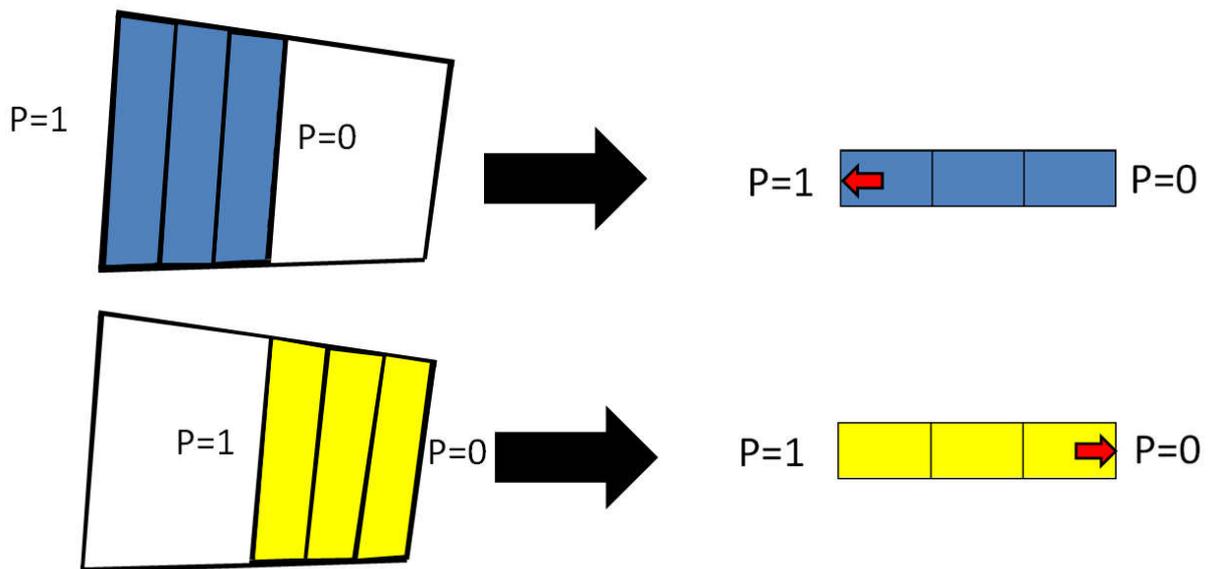


Figure 6 - Illustration in 2D of the half transmissibility of the West (Blue) and East (Yellow) local domain.

The upper bound transmissibility between two coarse cells A and B can be express as following:

$$\mathbf{T}_+ = \left(\frac{\mathbf{1}}{\mathbf{T}_{\frac{1}{2}(A,d)}^+} + \frac{\mathbf{1}}{\mathbf{T}_{\frac{1}{2}(B,\bar{d})}^+} \right)^{-1}, \quad (10)$$

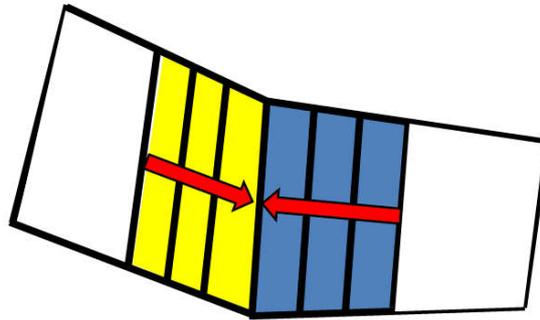


Figure 7 - Illustration in 2D of the upper bound transmissibility between two coarse cells. Red arrows are the half transmissibilities of the East domain of the left cell and West domain of the right cell.

2.6.2.3 QUALITY CONTROL

Using these bounds, the quality of the upscaling and gridding will be controlled. In fact, for each cell where the ratio of $T_{\alpha+}$ and $T_{\alpha-}$ is lower than a defined value, the equivalent transmissibility is given by the geometric mean of bounds. A ratio of bounds upper than a defined value shows that the gridding should be revisited.

- For each cell with $\frac{T_{\alpha+}}{T_{\alpha-}} < \beta$: $T_{\alpha} = \sqrt{T_{\alpha+}T_{\alpha-}}$.
- For each cell with $\frac{T_{\alpha+}}{T_{\alpha-}} > \beta$: revisiting of gridding or making a local calculation in single phase.

2.6.3 POWER LAW

The main different with the power law available within Petrel is that the computation is done on the half domains on either side of the boundary.

The permeability of each local domain is calculated with a power law:

$$K_{\alpha} = \left(\frac{1}{n} \sum_{i=1}^n (k_{\alpha_i})^{\beta} \right)^{\frac{1}{\beta}} \quad (11)$$

with,

- α is the flow direction,
- n is the number of cells in the local domain,
- β is a parameter to determine.



With $\beta = -1$, $\beta = 1$ and β tends to 0, the equation (11) is equivalent respectively to the harmonic, arithmetic and geometric means.

The use of this method requires identifying the value of β . Usually, reservoir engineers use a value near to 1 (0.9) to homogenize in X or Y direction; and a value near to -1 (-0.9) to homogenize in Z direction.

The half-transmissibility $T_{\frac{1}{2}(A,d)}^\alpha$ of each local domain is computed using the equation (2).

The transmissibility between two coarse cells A and B can be express as following:

$$T^\alpha = \left(\frac{1}{T_{\frac{1}{2}(A,d)}^\alpha} + \frac{1}{T_{\frac{1}{2}(B,\bar{d})}^\alpha} \right)^{-1}, \quad (12)$$

3 CONTACT

For more information contact e-mail: **jb@Terra3E.com**.