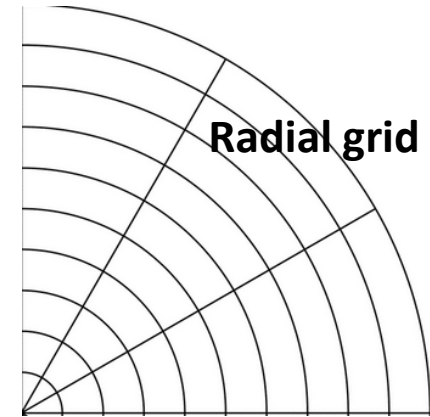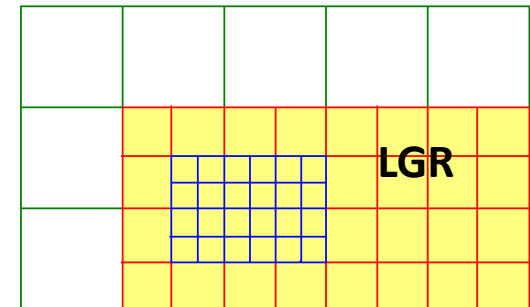# MUFITS
Training Course

Day 4
Radial grids, Fluid-in-place regions, Local grid refinements & Grid decomposition

Program

- Radial grids (scenario 7)

- Fluid-in-place regions

- Local grid refinements (scenario 8)

- Scenario 9

- Grid decomposition

Radial grid

$$A = \int_{domain} a\,\mathrm{d}V$$

LGR

Simulation is parallel using 1 core, 2 cores, 3 cores, … How the simulation is decomposed between the cores?
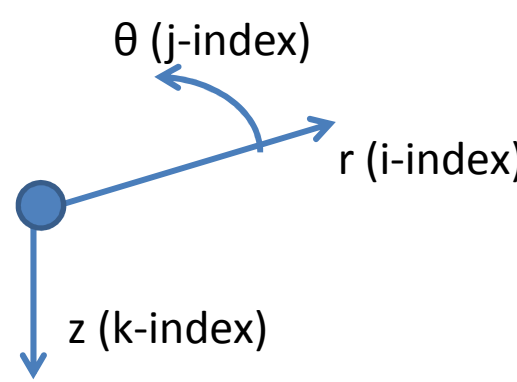
Radial grids

Radial grids

The number of grid blocks along every axis is defined by the keyword **MAKE**

```
MAKE-ENDMAKE syntax
1  -- in GRID section
2
3  MAKE
4    gridtype  ni nj nk /
5
6  -- other keywords
7
8  ENDMAKE
9
10 =================================================================
11
12     gridtype = CART   - Cartesian Grid
13              = RADIAL - Radial Grid
14              = CORNER - Corner-Point grid
15
16         ni - number of grid blocks along i-indexation axis
17         nj - number of grid blocks along j-indexation axis
18         nk - number of grid blocks along k-indexation axis
```

θ (j-index)

r (i-index)

z (k-index)

Select this option

Scenario 7

Simulate scenario for 500 days
reporting distributions every 50 days

Domain: [0,200m]*[0,π/2]*[500m,510m]
Grid: 30*20*1

Fixed parameters
at this boundary

Rock properties:
Porosity = 0.25;
Permeability = 50 mD ;
Rock density = 2800 kg/m^3;
Heat capacity = 1.1 kJ/kg/K;
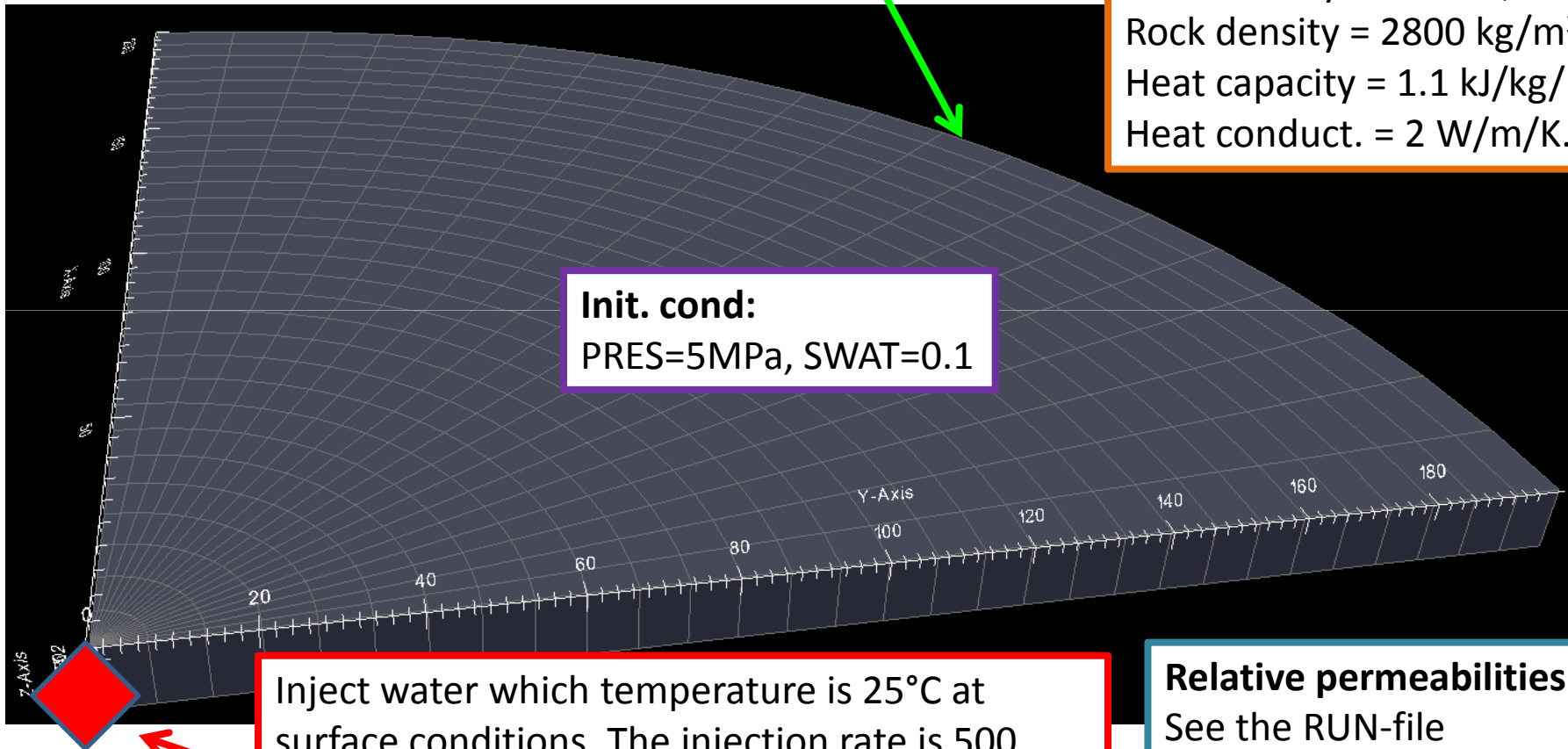Heat conduct. = 2 W/m/K.

Init. cond:
PRES=5MPa, SWAT=0.1

Inject water which temperature is 25°C at
surface conditions. The injection rate is 500
m^3/day at surface conditions.

Relative permeabilities:
See the RUN-file

Day 4. Radial grids, Fluid-in-place regions,
Local grid refinements & Grid
decomposition

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RUN-file (scenario 7)

1. **Open RUN-file in text editor**
2. **Run the simulation**
3. **Open results in ParaView**

Day 4. Radial grids, Fluid-in-place regions,
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Radial grids

The domain boundaries are defined by the keyword **RTZBOUND**

```
                                    ─── RTZBOUND syntax ───
1   -- within MAKE/ENDMAKE brackets.
2
3   RTZBOUND
4      rmin rmax  tmin tmax  zmin zmax   rincr tincr zincr /
5
6   ================================================================
7
8       rmin/rmax - the domain boundaries along axis r (rmin<rmax)
9       tmin/tmax - the domain boundaries along axis theta (tmin<tmax) [rad]
10      zmin/zmax - the domain boundaries along axis z (zmin<zmax)
11      rincr     - the increment of the grid block sizes along axis R. With
12                  increasing i-index every next grid block is xincr times larger
13                  then the previous block;
14      tincr     - the increment of the grid block sizes along axis Theta. With
15                  increasing j-index every next grid block is tincr times larger
16                  then the previous block;
17      zincr     - the increment of the grid block sizes along axis Z. With
                    zincr times larger
```
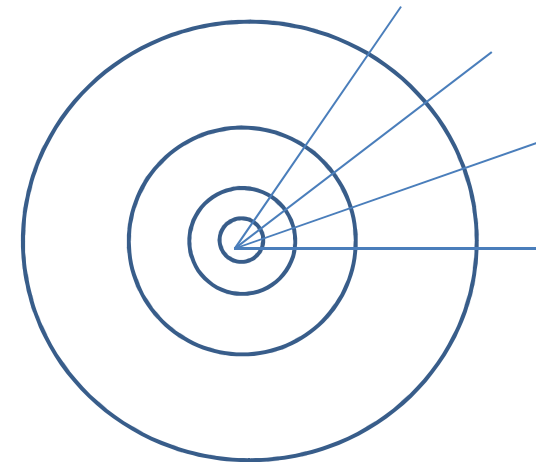
Exercise: Re-simulate scenario 7 using theta range $[0, \pi/4]$

Radial grids

The grid block extensions can be redefined using the **DRV**, **DTHETAV**, **DZV** keywords

```
                              ─ DRV syntax ─
 1 | -- within MAKE-ENDMAKE brackets
 2 |
 3 | DRV
 4 |   dr(1) dr(2) dr(3) ... dr(nr) /
 5 |
 6 | ============================================================
 7 |
 8 |     dr(#) - grid blocks extensions along axis R.
 9 |     nr    - number of grid block along axis R. nr is the 2nd argument of the
10 |             keyword MAKE.
```

Exercise: Re-simulate scenario 7 applying a grid refinement to the center.

Fluid-in-place regions

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Local grid refinements & Grid
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FIPNUM regions

FIP = Fluid-in-Place

FIPNUM region numbers can be used for
- calculate average value in a region of reservoir domain (e.g., avarage pressure, temperature) ;
- integrate a property in a region (e.g., calculate total mass of a component in domain);
- calculate parameters for boundary between two regions of domain (e.g., calculate total mass flux between two region).

To use Fluid-in-Place option you should
1. Define different Fluid-in-Place regions in **GRID** or **INIT** sections using mnemonic **FIPNUM** (by default in all cells **FIPNUM**=0).
2. Specify the properties to be reported for the regions using **RPTFIP** keyword.

You can create consolidated time series data for FIPNUM regions in the **POST** section using **POSTFPCE** and **POSTFPCO** keywords.

Keyword RPTFIP

The output for FIPNUM regions in the file SCENARIO%.####.SUM is controlled by the RPTFIP keyword

```
——————————————————— RPTFIP syntax ———————————
 1  -- in INIT or SCHEDULE section
 2
 3  RPTFIP
 4     mnemonic1  mnemonic2  mnemonic3  ...  /
 5
 6  ================================================================
 7
 8      mnemonic# - is the mnemonic of a property saved in the files *.0000.SUM,
 9                  *.0001.SUM, *.0002.SUM, etc for fluid-in-place regions.
10                  If one of the mnemonics is ASCII then the formatted file is
11                  saved. Mnemonic NOTHING clears the report list.
```

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Keyword POSTFPCE

By using this keyword you can create consolidated time series data for FIPNUM regions.

```
                                      ──── POSTFPCE syntax ────
1  -- in POST section
2
3  POSTFPCE
4    fipnum1  filename1 /
5    fipnum2  filename2 /
6    fipnum3  filename3 /
7    ...
8  /
9
10 =================================================================
11
12       fipnume#  - the fluid-in-place region number for which the output is
13                   required;
14       filename# - output file name (if not specified the program uses default
15                   naming convention).
```

Day 4. Radial grids, Fluid-in-place regions,
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Keyword POSTFPCO

By using this keyword you can create consolidated time series data for boundary between two FIPNUM regions.

```
                                   ──── POSTFPCO syntax ────
 1  -- in POST section
 2
 3  POSTFPCO
 4    fipnuma1   fipnumb1   filename1 /
 5    fipnuma2   fipnumb2   filename2 /
 6    fipnuma3   fipnumb3   filename3 /
 7    ...
 8  /
 9
10  ================================================================================
11
12        fipnuma#    - two fluid-in-place region numbers for which the output is
13         -fipnumb#    required. The flow rate is reported in the direction
14                      from fipnuma# to fipnumb#.
15        filename#   - output file name (if not specified the program uses default
16                      naming convention).
```

Day 4. Radial grids, Fluid-in-place regions,
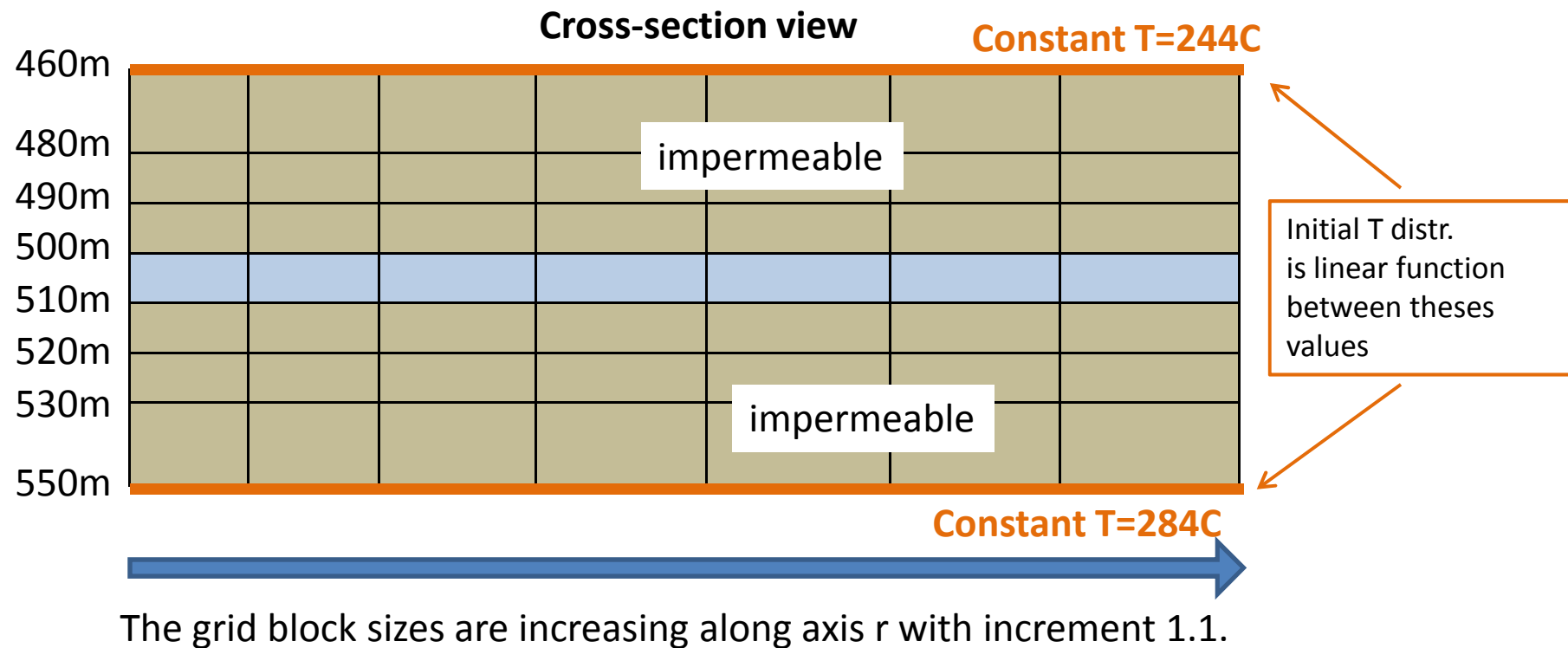Local grid refinements & Grid
decomposition

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Using FIPNUM regions

Exercise: Create the 5 FIPNUM regions shown in the figure. For every region report average pressure, average temperature and total mass of H2O.
For every boundary between two regions report H2O flow rate. Re-simulate Scenario 7 and show all reported results in ParaView.
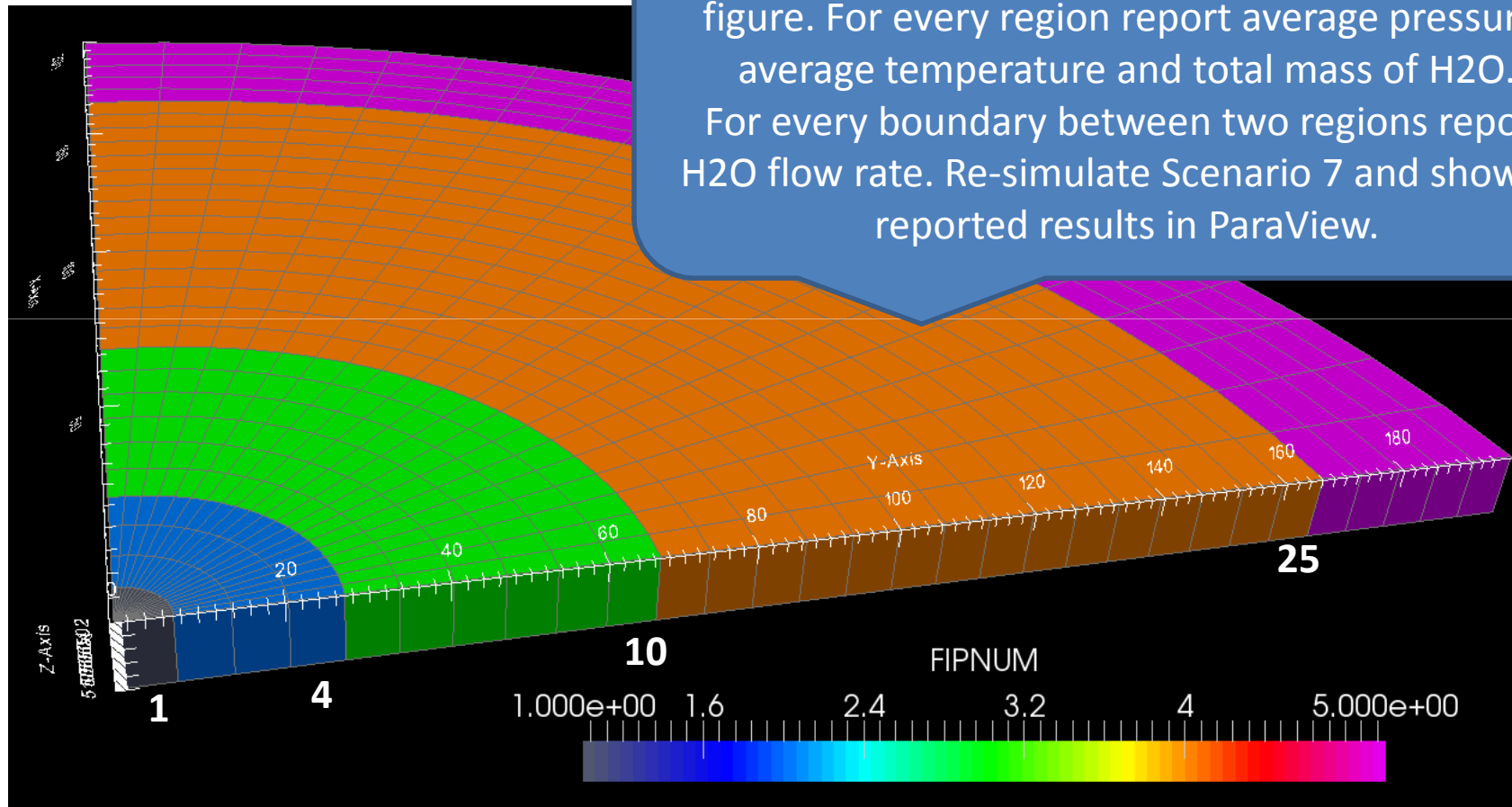
Exercise

Re-simulate scenario 7 using provided heterogeneous distribution of permeability and taking into account heat exchange with impermeable rocks

Cross-section view

Constant T=244C

| 460m |
| 480m |
| 490m |
| 500m |
| 510m |
| 520m |
| 530m |
| 550m |

impermeable

impermeable

Constant T=284C

Initial T distr. is linear function between theses values

The grid block sizes are increasing along axis r with increment 1.1.

RUN-file (scenario 7, exercise)

1. **Open RUN-file in text editor**
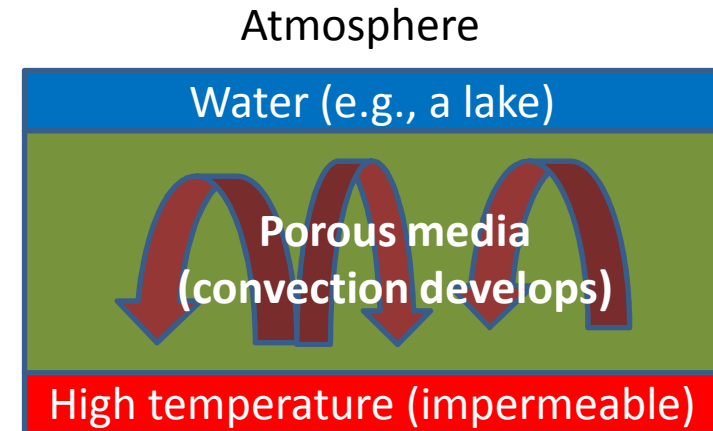2. **Run the simulation**
3. **Open results in ParaView**
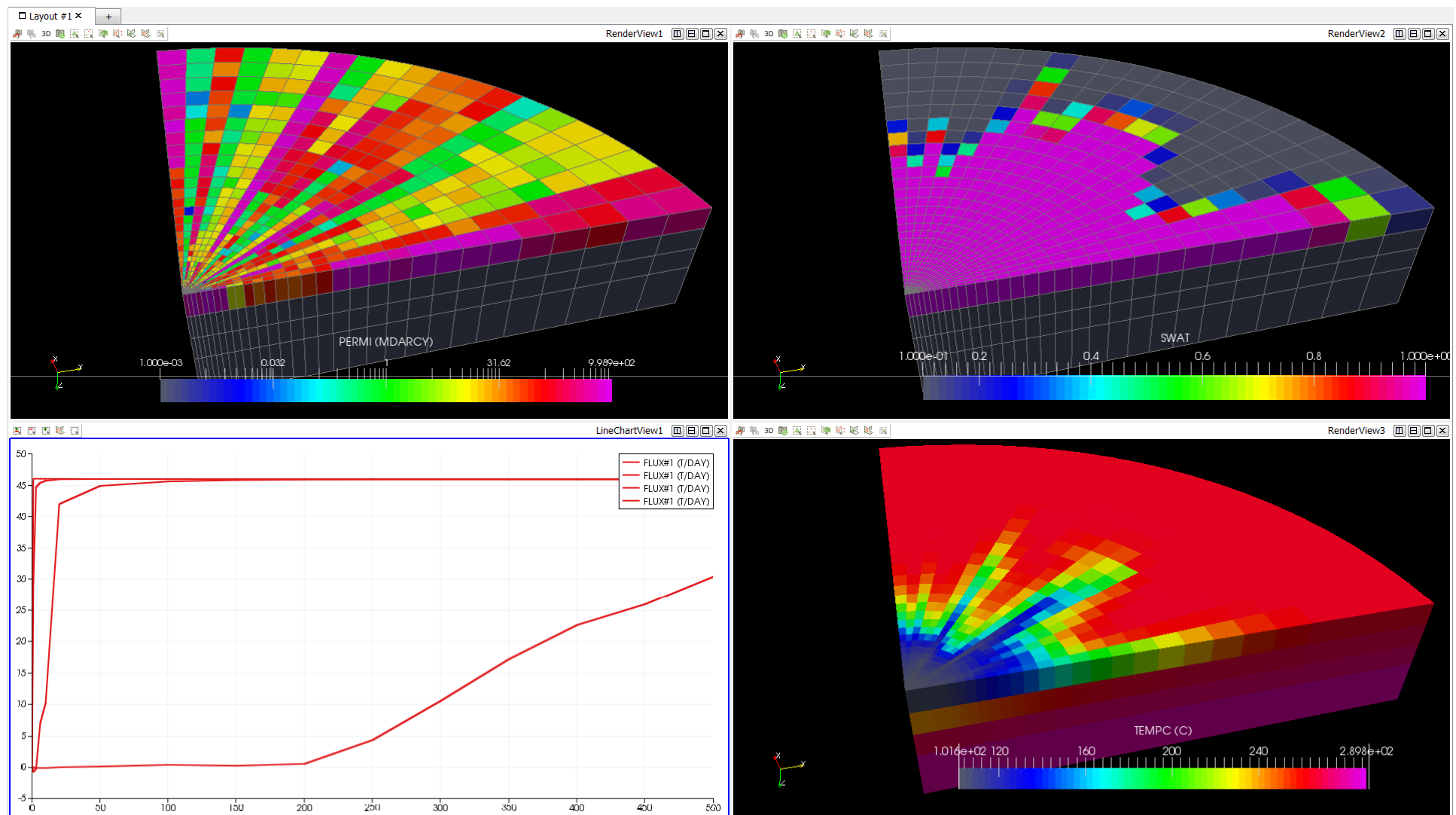
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Results

Local grid refinements (LGRs)

Day 4. Radial grids, Fluid-in-place regions,
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Scenario 8

interpretation →

Atmosphere

Water (e.g., a lake)

Porous media (convection develops)

High temperature (impermeable)

Simulate scenario up to 100000 days reporting distributions every 1000 days
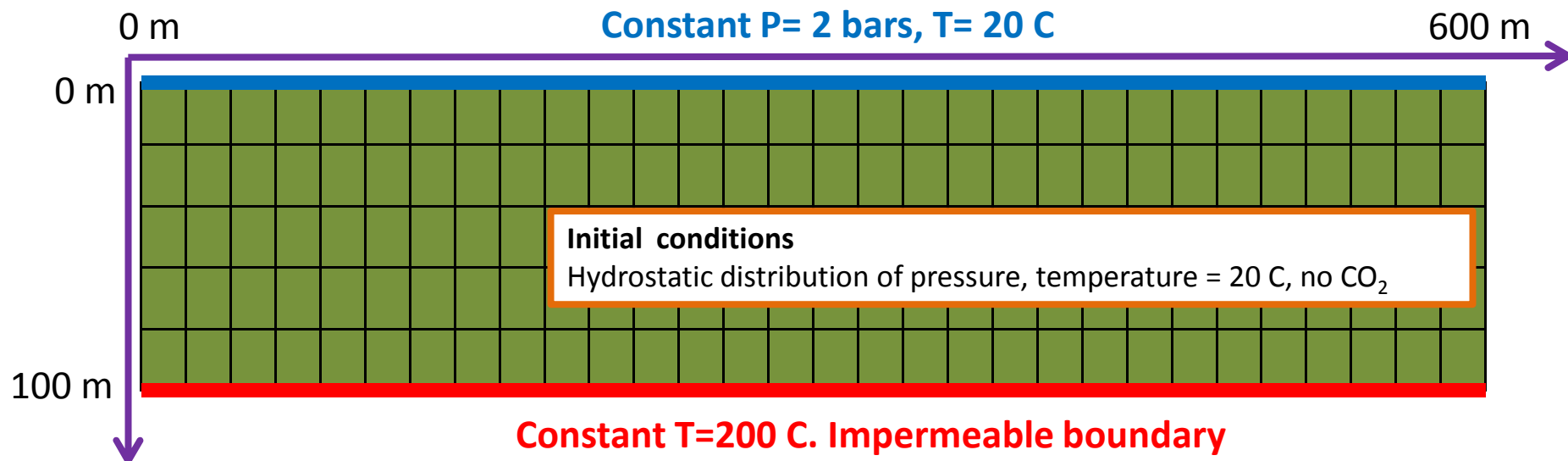
Grid: 30*5. EOS-module: BINMIXT

Rock properties:
Porosity = 0.25;
Permeability = 100 mD ;
Rock density = 2900 kg/m^3;
Heat capacity = 0.84 kJ/kg/K;
Heat conduct. = 2 W/m/K.

Rel. perm:
Brooks & Corey, smin =0.2
smax =0.95

0 m — **Constant P= 2 bars, T= 20 C** — 600 m

0 m

Initial conditions
Hydrostatic distribution of pressure, temperature = 20 C, no CO_2

100 m

Constant T=200 C. Impermeable boundary

RUN-file (scenario 8)

1. **Open RUN-file in text editor**
2. **Run the simulation**
3. **Open results in ParaView**

Day 4. Radial grids, Fluid-in-place regions,
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Result (scenario 8)

Day 4. Radial grids, Fluid-in-place regions,
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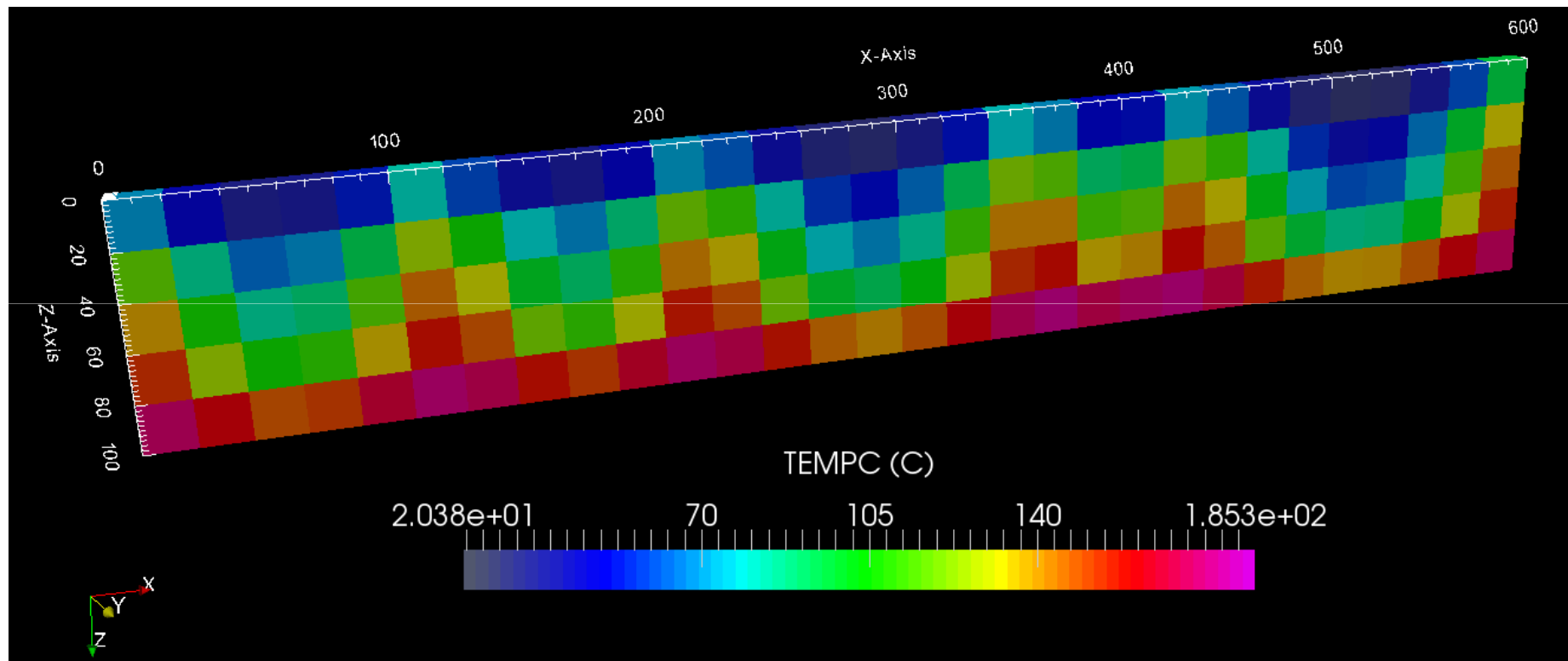
Local grid refinements
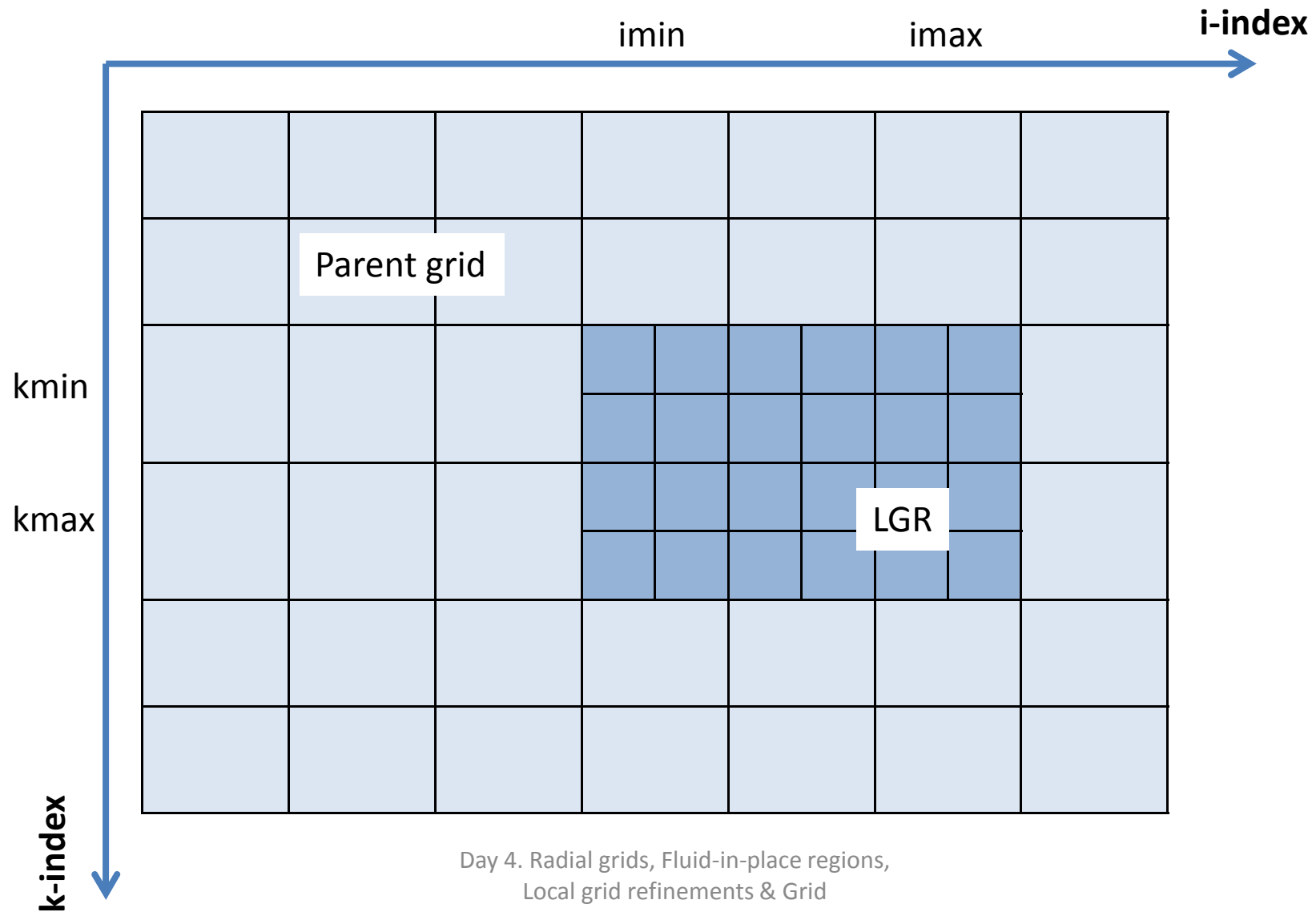
CARFIN keyword

The **CARFIN** keyword defines local grid refinements

```
                                    CARFIN syntax
 1  -- within MAKE-ENDMAKE brackets
 2
 3  CARFIN
 4    name   imin imax   jmin jmax   kmin kmax   nx ny nz   parent /
 5
 6  =========================================================================
 7
 8      name       - name of the refined grid;
 9      imin/imax - the boundaries of the refined grid along i-index direction
10                    in the parent grid;
11      jmin/jmax - the boundaries of the refined grid along j-index direction
12                    in the parent grid;
13      kmin/kmax - the boundaries of the refined grid along j-index direction
14                    in the parent grid;
15      nx         - the number of grid blocks in the refined grid along i-index
16                    direction;
17      ny         - the number of grid blocks in the refined grid along j-index
18                    direction;
19      nz         - the number of grid blocks in the refined grid along k-index
20                    direction;
21      parent     - the parent grid name.
22
```

Day 4: Radial grids, Fluid-in-place regions,
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REFINE & ENDFIN keywords

Keyword **REFINE** selects a grid to be active. It affects the **BOX** keyword and arrays loading. After the keyword **CARFIN** the created grid is active.
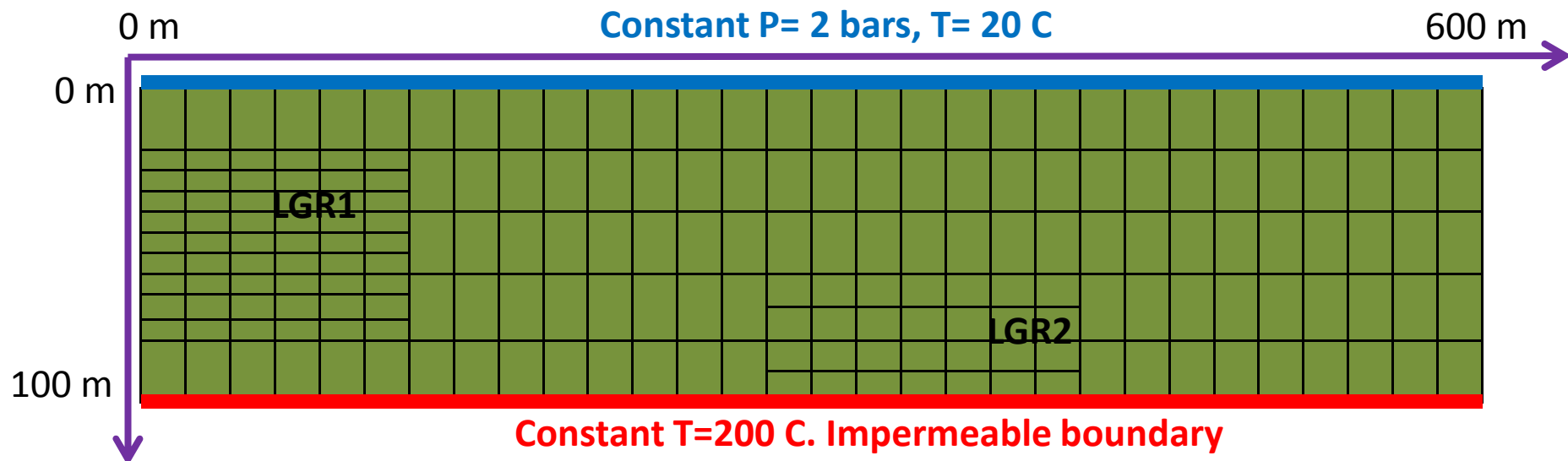
```
                              ──── REFINE syntax ────
1 │ -- in every section except RUNSPEC and POST
2 │
3 │ REFINE
4 │    gridname   resname /
5 │
6 │ ================================================================================
7 │
8 │    gridname - grid name (8-byte character);
9 │    resname  - the name of reservoir in which the grid is defined.
```

Keyword **ENDFIN** resumes the active grid to the initial grid encompassing the whole reservoir

```
                              ──── ENDFIN syntax ────
1 │ -- in every section except RUNSPEC and POST
2 │
3 │ ENDFIN
```

Day 4. Radial grids, Fluid-in-place regions,
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Local grid refinements

Exercise: Re-simulate scenario 8 using the following grid.

0 m   **Constant P= 2 bars, T= 20 C**   600 m

0 m

LGR1

LGR2

100 m

Constant T=200 C. Impermeable boundary

Day 4. Radial grids, Fluid-in-place regions,
Local grid refinements & Grid
decomposition

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Answer

```
 ──────────────────────── Day 4. Answer ────────────────────────
1│-- within MAKE-ENDMAKE brackets
2│
3│CARFIN
4│  LGR1    1  6  1 1  2 4     6  1  9 /
5│CARFIN
6│  LGR2  15 21  1 1  4 5     7  1  4 /
7│ENDFIN
```
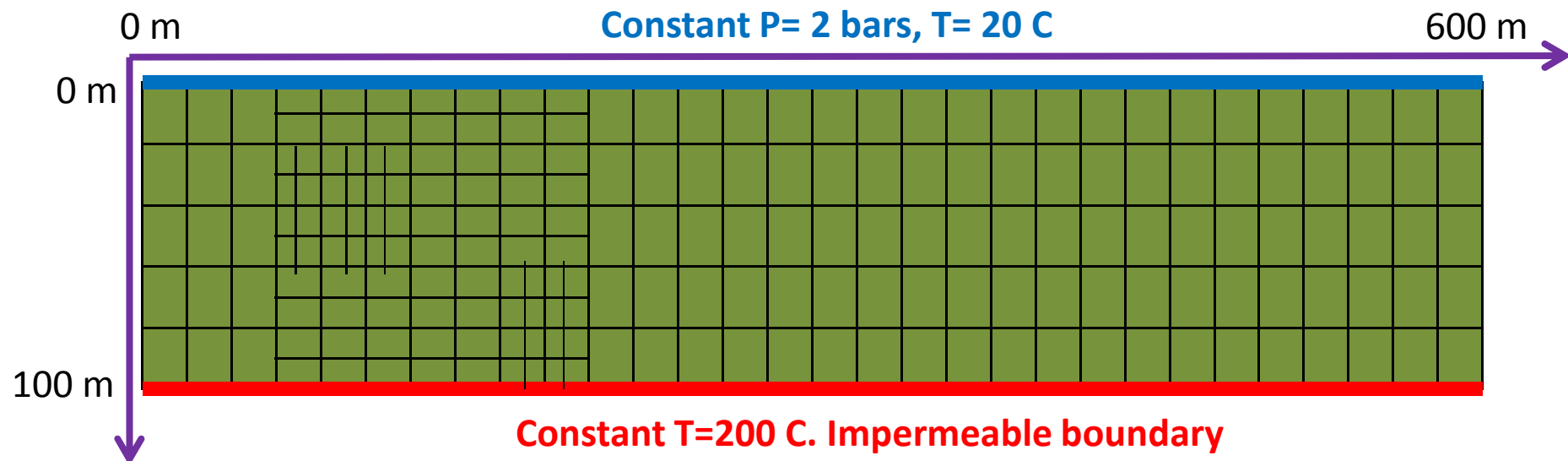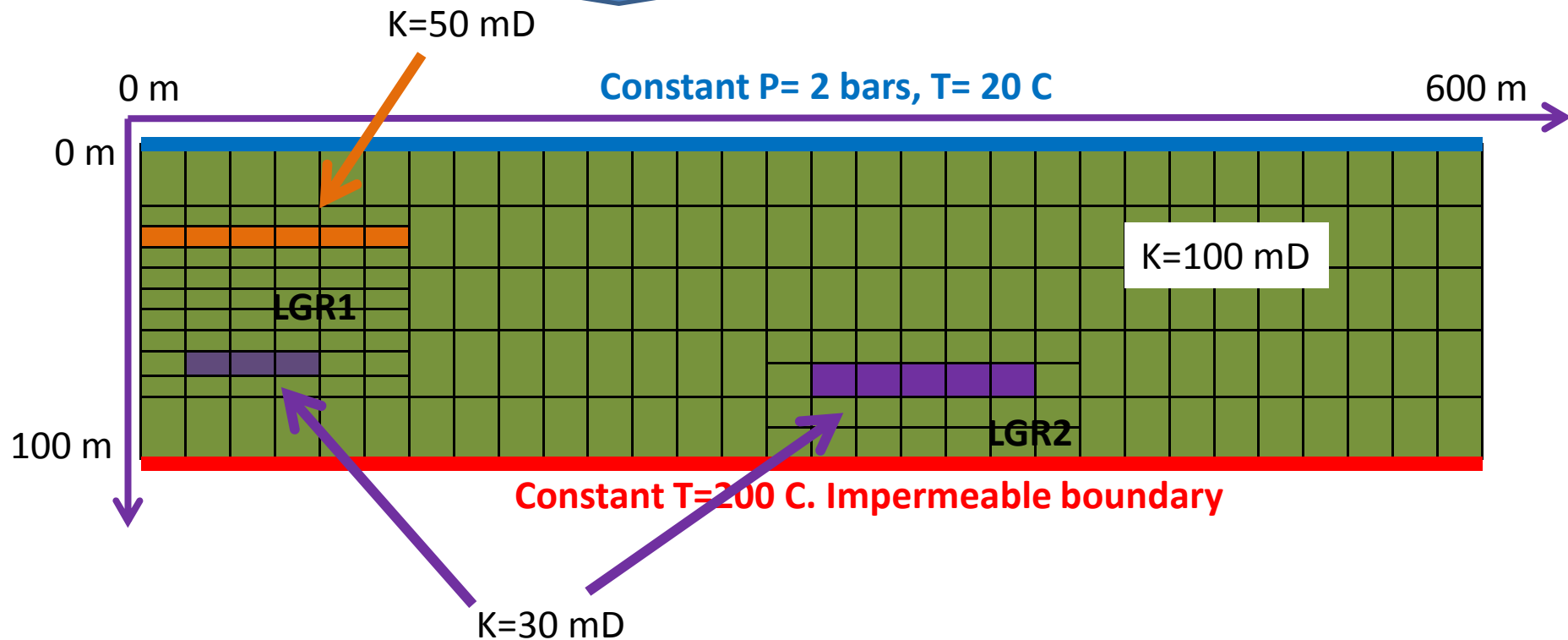
Day 4. Radial grids, Fluid-in-place regions,
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Nested LGRs

Exercise: Re-simulate scenario 8 using the following grid.

0 m   **Constant P= 2 bars, T= 20 C**   600 m

0 m

100 m

Constant T=200 C. Impermeable boundary

Day 4. Radial grids, Fluid-in-place regions,
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LGRs; Arrays loading

Exercise: Re-simulate scenario 8 using the following permeability distribution.

K=50 mD

0 m   Constant P= 2 bars, T= 20 C   600 m

0 m

K=100 mD

LGR1

LGR2

100 m

Constant T=200 C. Impermeable boundary

K=30 mD

LGRs; Arrays loading (answer)

```
                              ──── Day 4. Answer ────
 1 │ -- in GRID section
 2 │
 3 │ ENDFIN
 4 │ EQUALS
 5 │    PERMX 100 /
 6 │ /
 7 │ REFINE
 8 │   LGR1 /
 9 │ EQUALS
10 │    PERMX 50   4*        2*2 /
11 │    PERMX 30   2 4 2*    2*8 /
12 │ /
13 │ REFINE
14 │   LGR2 /
15 │ EQUALS
16 │    PERMX  30  2 6 2*    2*2 /
17 │ /
18 │ ENDFIN
19 │ COPY
20 │   PERMX PERMZ /
21 │ /
```

Day 4. Radial grids, Fluid-in-place regions,
Local grid refinements & Grid
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Local grid refinements

Exercise: Re-simulate scenario 8 using twice as more refined grid as the initial grid. Do not change the MAKE keyword.

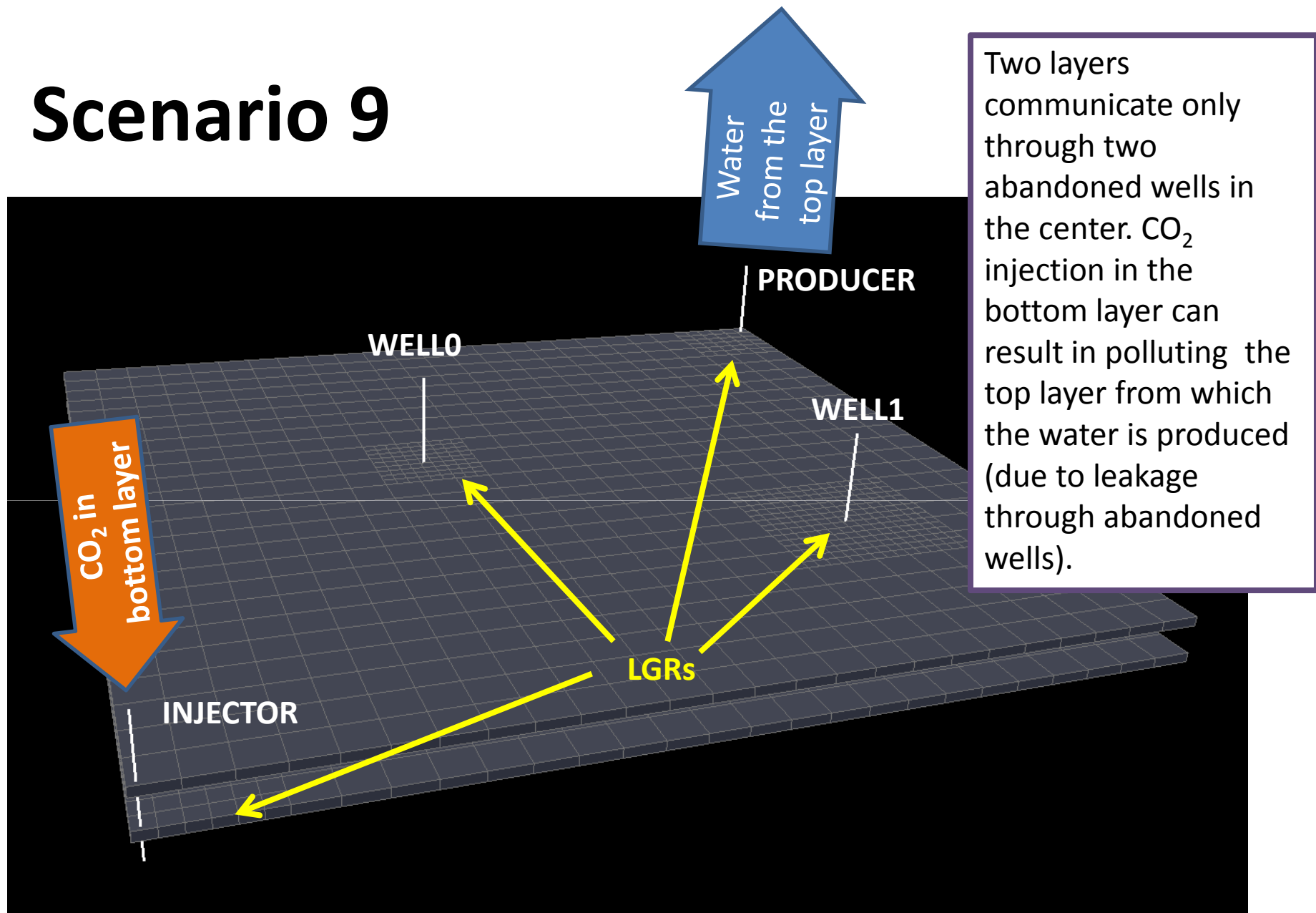Exercise: Apply random porosity variations to the refined grid.

More complicated LGRs

More complicated LGRs can be created using HXFIN, HYFIN, HZFIN, NXFIN, NYFIN, NZFIN keywords (see the Reference manual).

Day 4. Radial grids, Fluid-in-place regions,
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Scenario 9
(simulations with both LGRs and Wells)

Scenario 9

Water from the top layer

PRODUCER

WELL0

WELL1

CO$_2$ in bottom layer

LGRs

INJECTOR

Two layers communicate only through two abandoned wells in the center. CO$_2$ injection in the bottom layer can result in polluting the top layer from which the water is produced (due to leakage through abandoned wells).

RUN-file (scenario 9)

1. **Open RUN-file in text editor**
2. **Run the simulation**
3. **Open results in ParaView**

Day 4. Radial grids, Fluid-in-place regions,
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Results (scenario 9)
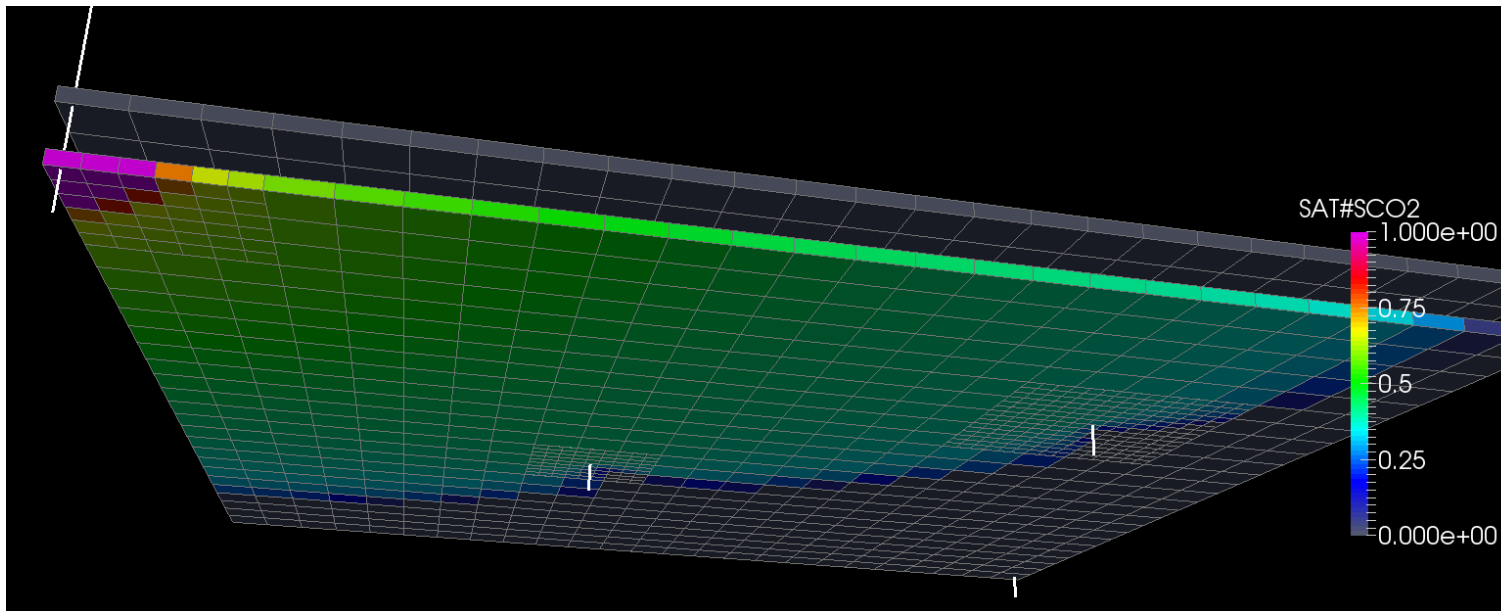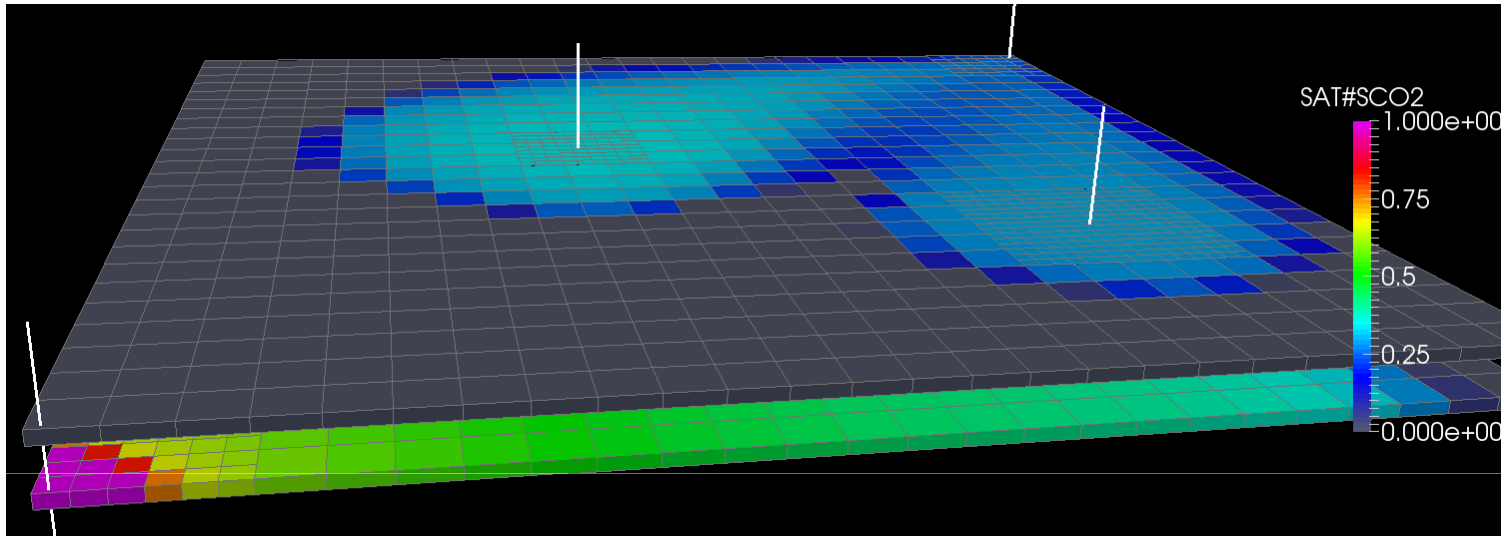
decomposition

Grid decomposition

Grid decomposition

The number of parallel processes (cores) assigned to simulation are specified in the command line when you launch the simulation (an example of commands for 3 processes are below).

Mac:
  mpirun –n 3 ./../../BIN/H64.EXM SCENARIO9.RUN > SCENARIO9.LOG

Linux:
   mpirun –n 3   ./../../BIN/H64.EXL SCENARIO9.RUN > SCENARIO9.LOG

Windows:
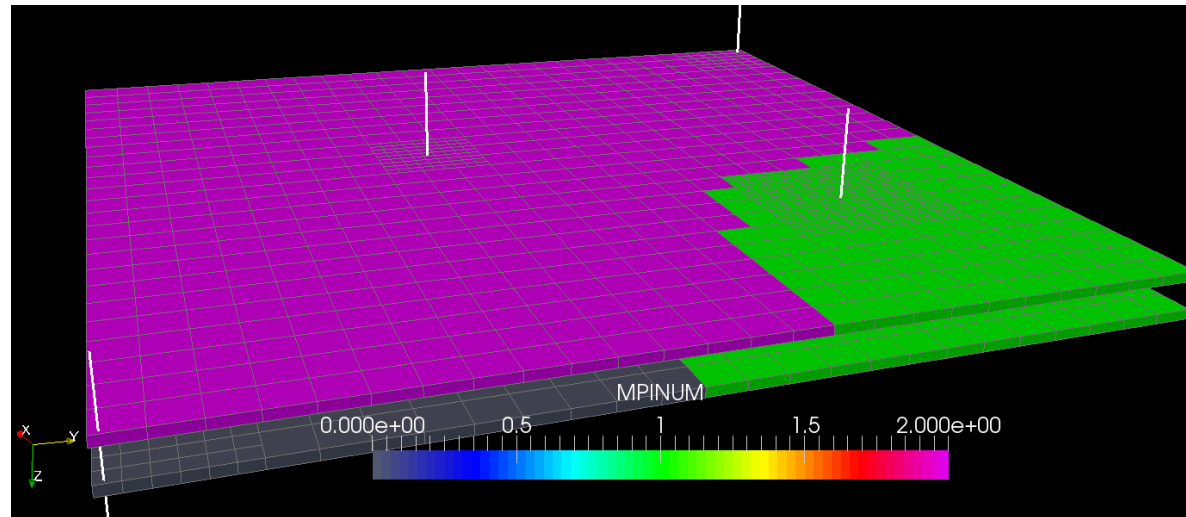 "…mpiexec.exe" –n 3 ../../BIN/H64.EXE SCENARIO9.RUN > SCENARIO9.LOG

By default the simulator automatically balances simulation between cores. The user assistance is not required.
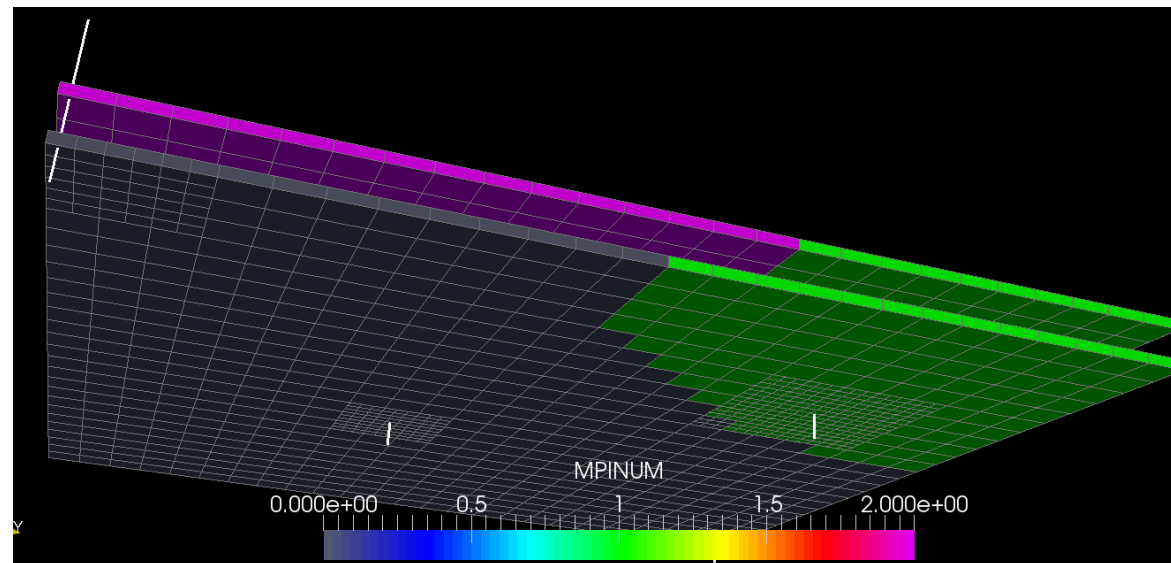
Automatic grid partition

Exercise: Re-simulate Scenario 9 on 3 cores.
Save the MPIRANK and MPINUM property
from the GRID section

Day 4. Radial grids, Fluid-in-place regions,
Local grid refinements & Grid
decomposition

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Result

Top view

Bottom view

MPINUM

0.000e+00　　　0.5　　　1　　　1.5　　　2.000e+00

Decomposition specified by user

There are two options to specify decomposition by user:
1. Using MPINUM keyword;
2. Using the PARTIT keyword.

Normally, when these options are chosen the NOAUTO
keyword should be specified within brackets MAKE-
ENDMAKE. The NOAUTO switch disables automatic grid
partition.

Day 4. Radial grids, Fluid-in-place regions,
Local grid refinements & Grid
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MPINUM region

The MPINUM keyword can be used to specify a user-defined decomposition within MAKE-ENDMAKE brackets. The cells with equal MPINUM number are assigned to the same process. The MPIRANK property can be used to check the created partition.
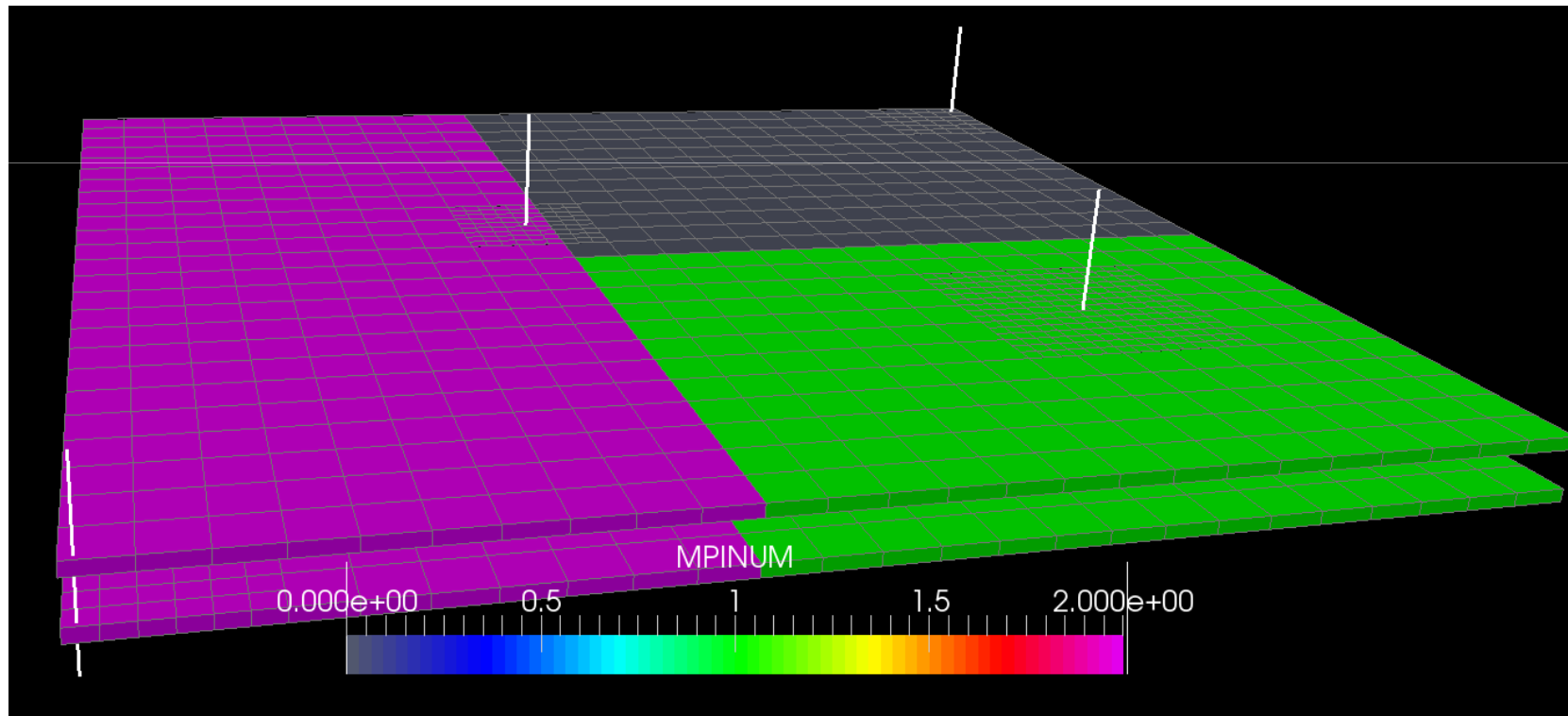
MPINUM

0.000e+00   0.5   1   1.5   2.000e+00

Answer

```
──────── Day 4. Answer ────────
1  NOAUTO
2
3  MPINUM
4     100000*0 /
5
6  BOX
7    1 12 /
8
9  MPINUM
10     100000*1 /
11
12 BOX
13   1 25 1 10 /
14
15 MPINUM
16     100000*2 /
17
18 ENDBOX
```

Day 4. Radial grids, Fluid-in-place regions,
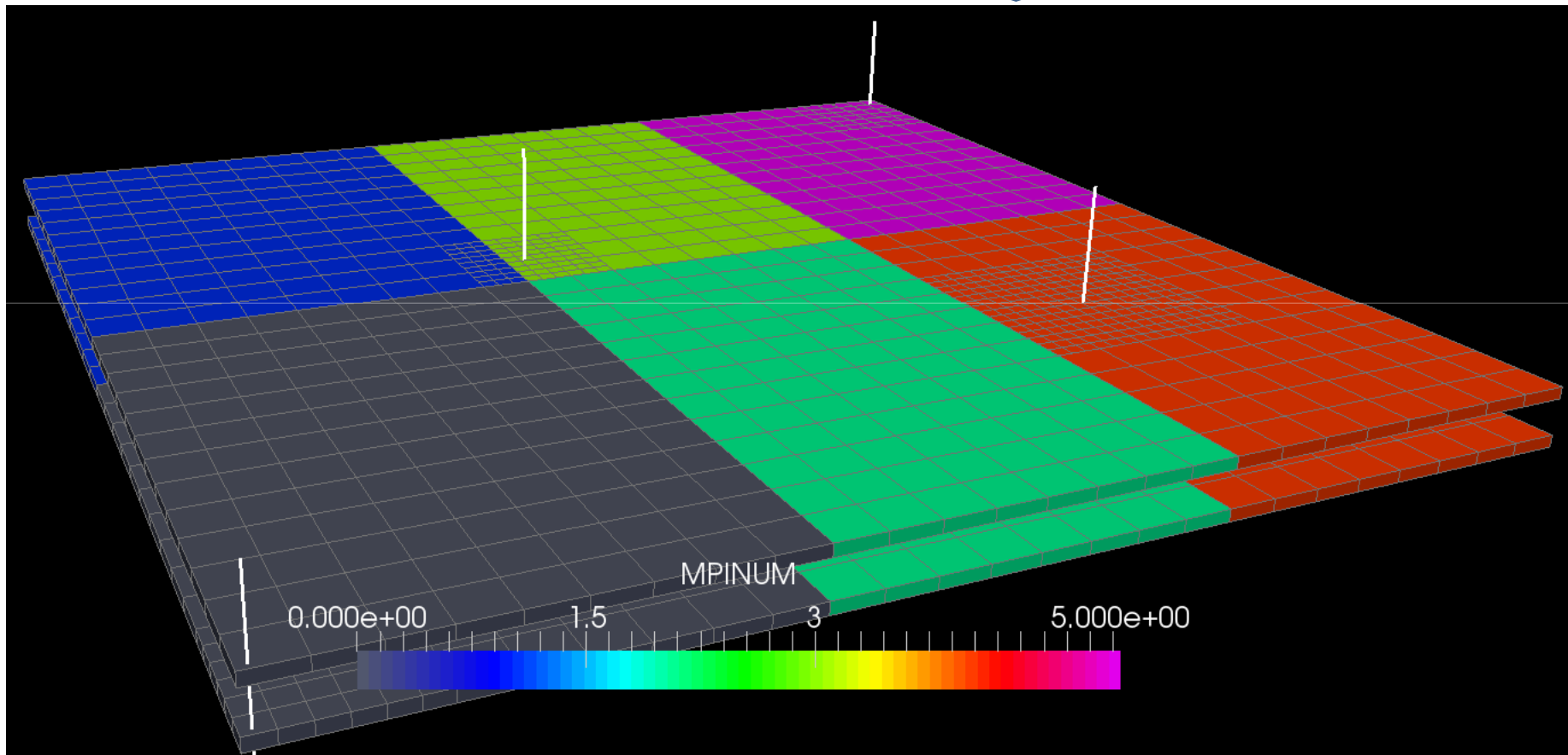Local grid refinements & Grid
decomposition

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Keyword PARTIT

The PARTIT keyword creates a Cartesian grid decomposition. Normally, this keyword should be used with the NOAUTO keyword which disables automatic grid partition.

```
                              ───── PARTIT syntax ─────
 1  -- within MAKE-ENDMAKE brackets
 2
 3  PARTIT
 4     ni  nj  nk  nsrt /
 5
 6  ================================================================
 7
 8     ni   - number of the grid partition regions along i-index direction;
 9     nj   - number of the grid partition regions along j-index direction;
10     nk   - number of the grid partition regions along k-index direction;
11     nsrt - the initial number from which the partition regions are numbered.
12            The MPINUM property is assigned to the regions with i-index cycling
13            the fastest following by the j- and k-indexes.
14
```

More complicated partitions can be created using PARTI, PARTJ and PARTK keywords associated with the PARTIT keyword.

Day 4. Radial grids, Fluid-in-place regions,
Local grid refinements & Grid
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Exercise

Exercise: Specify the grid decomposition using PARTIT keyword and re-simulate scenario 9 using 6 processes. Save MPIRANK and MPINUM properties from GRID section.

MPINUM

0.000e+00   1.5   3   5.000e+00

Day 4. Radial grids, Fluid-in-place regions,
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Answer

```
─────────────────── Day 4. Answer ───────────────────
1  -- within MAKE-ENDMAKE brackets
2
3  NOAUTO
4
5  PARTIT
6    2 3 /
```

Day 4. Radial grids, Fluid-in-place regions,
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Next day

- Corner-point grids
- Faults
- Aquifers
- Onshore/offshore boundary conditions