FEMCon

Welcome to **FEMCon**, an easy-to-use thermal convection exploration tool developed for educational purposes.

This is release version FEMCon 1.0.x *beta* of the software. Download here.

See release notes for feature updates and bug fixes.

By downloading FEMCon, you agree to accept the license terms and disclaimer, otherwise you may not use this software.

You can either just go ahead, download FEMCon and play around with it or …
read the short introduction below first to know a little more about what it does.

Downloading and running FEMCon

You can run FEMCon both on Windows and Linux. A Mac OS release is not planned.

FEMCon is freeware. When downloading and using FEMCon, you agree to accept the license terms and disclaimer, otherwise you may not use this software. A copy of the license terms and disclaimer is also included in the downloadable zip-package as text file “License.txt”.

FEMCon does not require installation on your computer. You simply download the zip-file, unzip it on your computer (unzips into directory “FEMCon” by default) and run the executable **FEMConGUI.jar** file either by double-clicking or typing “**java -jar FEMConGUI.jar**” at the command line (in the “FEMCon” directory).
If you can’t run the jar-file, you probably don’t have the Java Runtime Engine (JRE) installed. In that case, download and install the JRE from here. After installation, the JRE might require a system reboot in order to register the Java path (on Windows). If you already have Java on your computer, but the FEMCon GUI doesn’t seem to work properly, it might be advisable that you update to a more recent Java version.

For Windows users, FEMCon uses the “Windows look-and-feel” by default (at least for XP, might not work for more recent Windows versions; those will then use the cross-platform look). If you prefer getting the cross-platform look under Windows anyway, run FEMConGUI.jar from the command line using “java -jar FEMConGUI.jar **-cross-look**”.

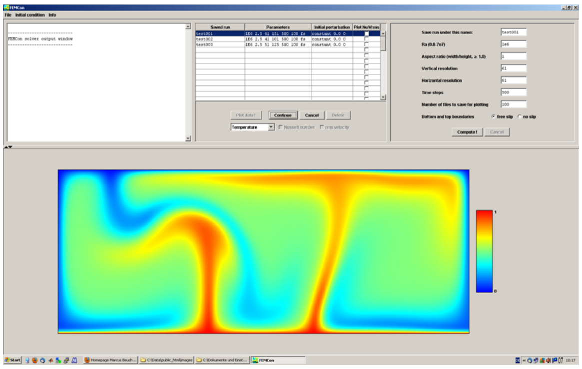
For Linux, the “Look-and-feel” defaults to the Java cross-platform look (Metal/Ocean).

Introduction

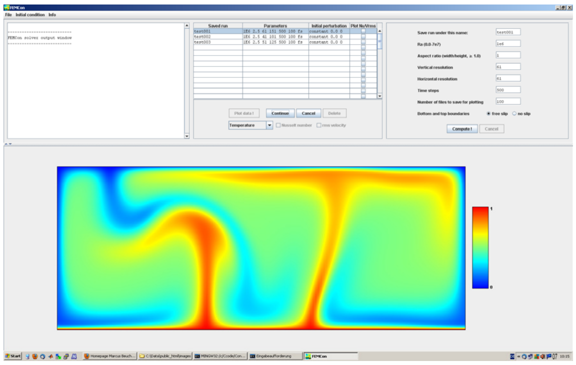
Why are Geoscientists interested in thermal convection? That's because the Earth's mantle is slowly convecting (→mantle convection) due to high thermal gradients at the core-mantle boundary and at the Earth's surface. Mantle convection is the driving mechanism for all the dynamic processes we observe at the Earth's surface and which make our planet so special: continental drift, moutain building, volcanism, earthquakes, ... all of those processes are in the end all related to thermal convection of the Earth's mantle. So it's important to understand how it works.

FEMCon is an interactive tool that lets you explore thermal convection in a nutshell. After choosing a set of parameters, FEMCon solves the incompressible thermal convection equations for a viscous fluid using the Finite Element Method (FEM). Those equations represent e.g. an approximation for modeling mantle convection inside our planet. The grid geometry FEMCon uses is a rectangular box with basal heating (which would correspond to the Earth's hot core) and top cooling (corresponding to the Earth's surface).

And this is how the FEMCon GUI looks like:



Windows look



Cross-platform look

Neglecting internal heating, the "convectivity" of the system can be physically characterized by the bottom-heating Rayleigh number which is the non-dimensional ratio of processes driving and those hindering convection. The higher the Rayleigh number, the more vigorous is the convection in the model. A Rayleigh number of 0 corresponds to a purely thermal conductive state (no thermal advection present).

The Earth's mantle exhibits a Rayleigh number on the order of 10^6-10^7.

Note that since FEMCon uses the non-dimensional Rayleigh number as governing parameter, all other physical variables, e.g. temperature, are also non-dimensional. Therefore, the maximum temperature (at the hot bottom) is always 1 and the minimum temperature (at the top) is 0.

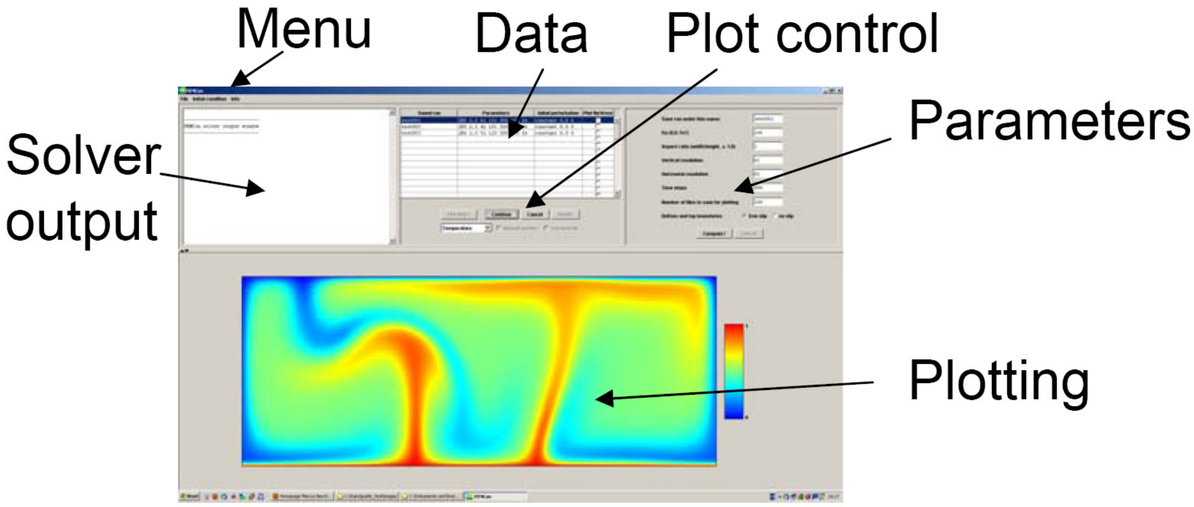
Apart from the Rayleigh number and the aspect ratio of the model box, all other parameters you may specify in FEMCon are numerical in nature, i.e. they are not connected to physics. However, it is still vital to choose the "right" numerical values for your numerical experiments, since the quality of your results critically depends on them.

FEMCon gives you an easy way of exploring (1) how the convectivity of a system depends on the Rayleigh number and (2) how the results depend on the choice of numerical parameters.

FEMCon computes the two most important quantitative geophysical measures characterizing a thermally convecting system, namely the Nusselt number and the root-mean-square velocity, throughout the simulations. Plotting the time evolution of those parameters along with temperature or velocity fields gives you a good feel about how the system evolves depending on the Rayleigh number.

Instructions for use

FEMCon's GUI structure:



For a quick start using a default set of parameters, simply:

- Press the "Compute button !" in the parameter panel
- Choose the results to plot from the data table
- Choose what data (temperature, velocity) you want to plot
- For Nusselt number and rms velocity, use the check boxes in the plot control panel
- Press the "Plot !" button and enjoy the results
- Choose "Save as…" from the Menu to save plot images as png-files (if you want to)

You can plot the results of the current run (or those of previous runs you choose from the table) while the solver is running in the background. Of course it's faster when you do either computing or plotting at a time.

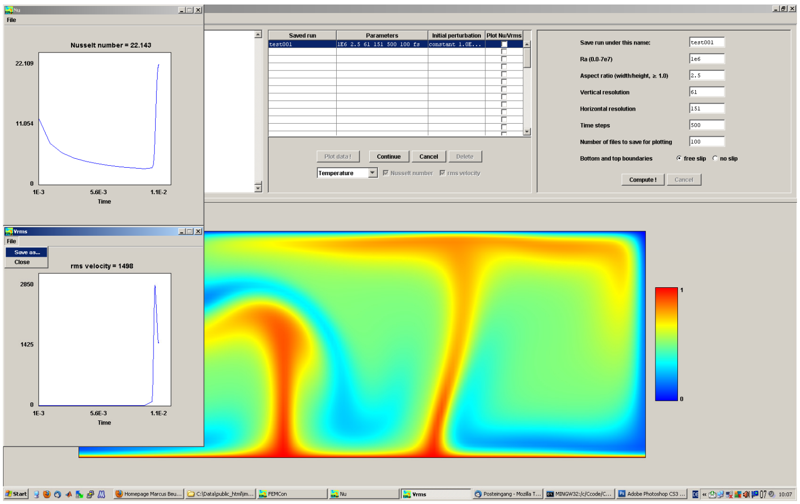
If you want to change the parameters, simply type them in the text fields in the parameter panel and start a new run. If you want to keep previous data, remember to give a different directory name (uppermost text field in the parameter panel, default is "test0001") for storing the data of the new run; otherwise, the previous data is overwritten.

The data table lists the stored runs. The sequence of parameters given in the table corresponds to the parameters chosen in the parameter panel.

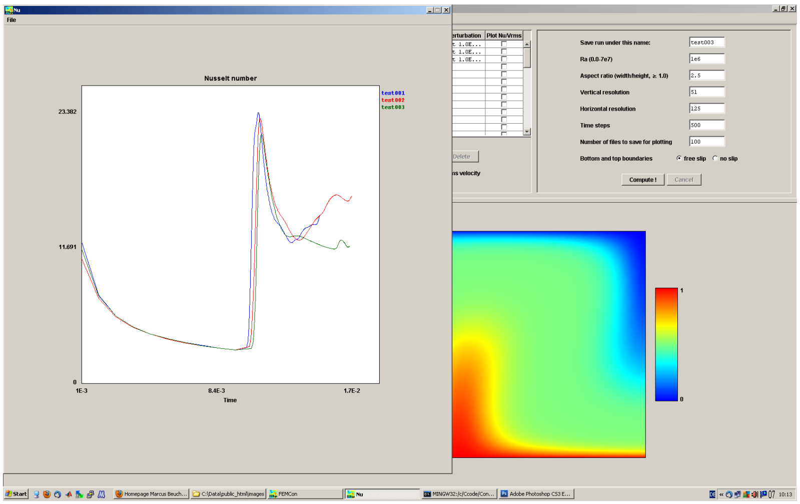
The individual runs are stored in a subdirectory of your "FEMCon" directory called "solver_output". Be aware that the higher the resolution you choose for the computations, the larger the data files written by FEMCon. So make sure you have enough space on your harddisk drive for the data you produce. You should, e.g. not save thousand of data files from one run, simply set the "Number of files to save for plotting" in the parameter panel to some reasonable value, e.g. 100.

Data plots

When plotting temperature or velocity field evolution with time, you can plot Nusselt number and root-mean-square velocity in separate plots along the way (see small data plot windows below) by checking the respective boxes in the plot control panel.



Or, if you want to plot Nusselt number and root-mean-square velocity for several data sets without plotting temperature or velocity field evolution, you check the respective boxes in the data table behind all data sets you want to plot. The color-coded curves in the data plot are labeled according to the data set name in the data table.



Choice of parameters

The higher the Rayleigh number you choose, the more vigorous convection becomes. Be aware that this means you have to choose a higher resolution for higher Rayleigh numbers. Whereas e.g. a resolution of 40 (both vertical and horizontal) is sufficient for Rayleigh number 10^4, a Rayleigh number of 10^7 requires more than 100 grid points resolution. The finer the resolution, the better will your results be resolved for higher Rayleigh numbers. Find the right balance between resolution and computation time.

Using the radio buttons at the bottom of the parameter panel, you can choose to have either free slip or no slip mechanical boundary conditions at the top and bottom. The side boundaries are always free slip.

Remarks:
- FEMCon will always round the resolutions given in the parameter panel up to the next odd number (50->51), since the use of 9-node-elements (see "Solver details" below) requires an odd number of grid points.

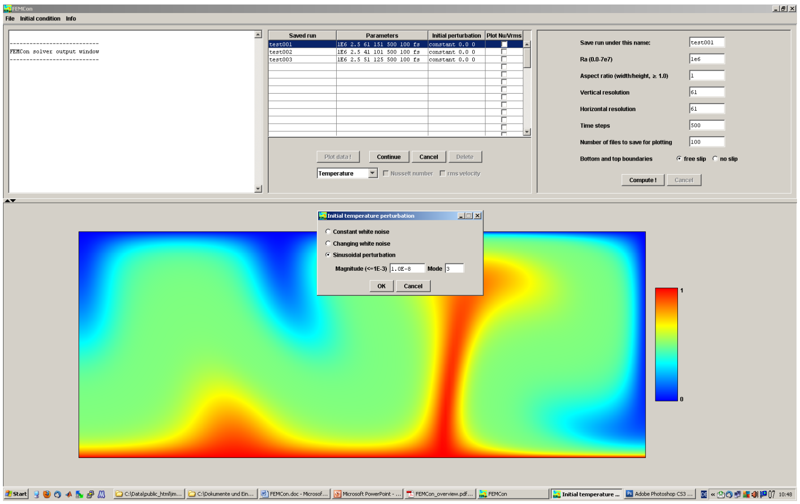
- If you choose a box aspect ratio higher than 1, FEMCon will automatically suggest a horizontal resolution of aspect ratio times vertical resolution. For example: vertical resolution 51, aspect ratio 2.0 -> FEMCon suggests horizontal resolution of 101. You can of course change this suggestion, but I recommend having uniform grid spacing in vertical and horizontal directions to obtain good results.

- If you give a number of time steps that is not a multiple of number of files to save for plotting, FEMCon will automatically adapt the number of time steps to the closest value you chose, just for your information. It will also not allow having more files to save for plotting that number of time steps (which doesn't make sense anyway).

- The maximum Rayleigh number you can choose is 7e7 (10^7), the lowest 0 (which corresponds to the purely conductive solution).

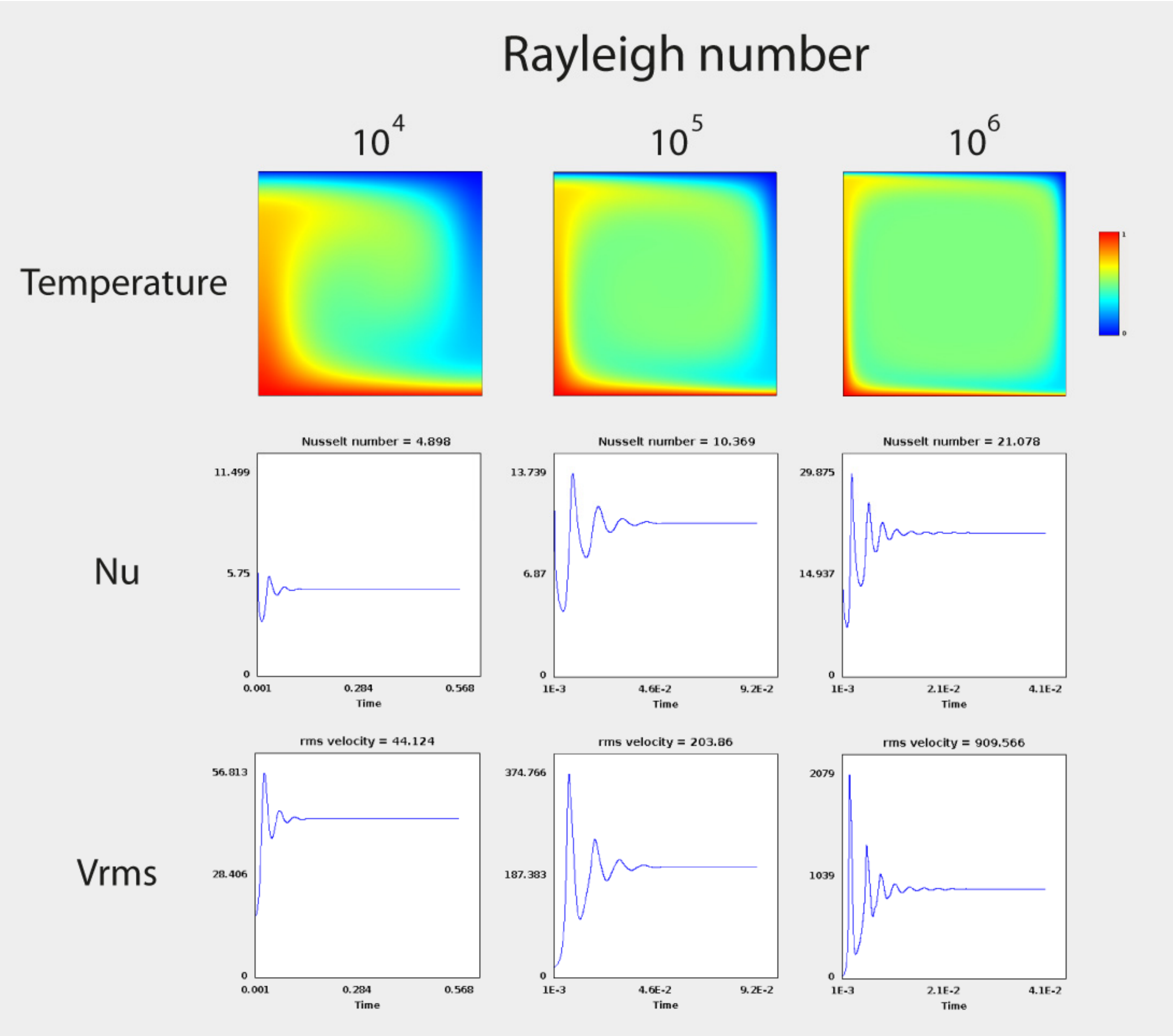
Initial condition

You can specify different initial temperature conditions by selecting "Initial condition" from the menu bar. In the opening small window, you can choose to either put a certain constant random white noise on the initial temperature field, a changing random white noise, i.e. a random distribution that changes from run to run, or a sinusoidal perturbation with a specific mode number.

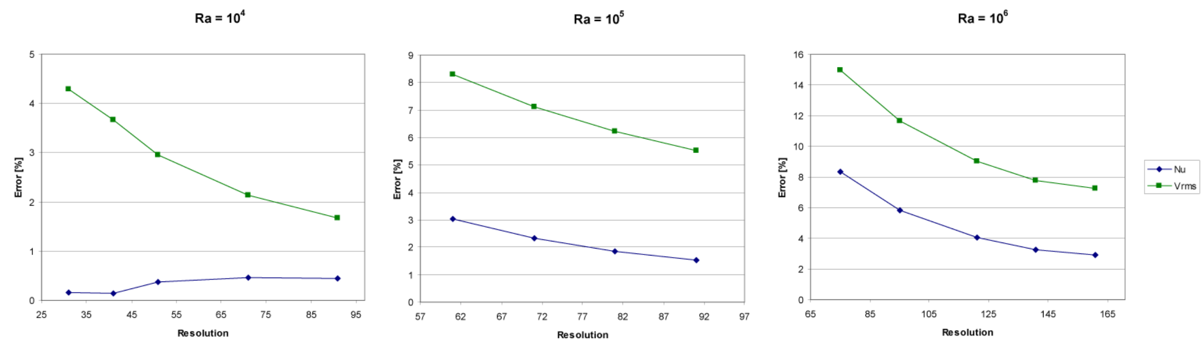


Benchmark

FEMCon was tested against published thermal convection results from Blanckenbach et al. (1989).



FEMCon steady-state results for cases 1a-c in Blanckenbach et al. (1989). Resolutions (left to right): 51x51, 91x91, 121x121. Nu: Nusselt number, Vrms: root-mean-square velocity.



Resolution-dependent relative error with respect to published Benchmark results (Blanckenbach et al. 1989, cases 1a-c) for Nusselt number Nu and root-means-square velocity Vrms (see legend to the right).

Reference:

Blanckenbach et al. (1989): A benchmark comparison for mantle convection codes. Geophysical Journal International, 98, 23-38.

Technical details

FEMCon consists of a fast FEM thermal convection solver written in C and a graphical frontend written in Java that serves to control the solver and to display results.

The FEMCon solver employs the excellent SuiteSparse package written by Tim Davis and the optimized BLAS library from OpenBLAS which is based on GotoBlas2 for solving the FEM matrices. The FEMCon solver was compiled with GNU gcc both on Windows (using MinGW) and Linux.
The FEMCon GUI is written in ”native” Java using Java JDK 6 (no third-party classes were used).

Solver details

The FEMCon thermal convection solver uses linear 4-node elements for temperature and quadratic 9-node elements with a cubic bubble for velocities. FEMCon applies operator splitting to the thermal convection equation and performs thermal advection by means of semi-Lagrangian characteristics using a mid-point Runge-Kutta time stepping scheme.

Acknowledgements

I thank my workgroup for feedback and discussions. Thanks also to Jan Philipp Kruse for discussions about the GUI and to Alexej Ossipov for the good job he did as a test user.

Feedback

If you like FEMCon, have any questions about the software, have suggestions for features to be included in future versions or have a bug to report, I appreciate receiving your feedback at my email address: beuchert -at- geophysik.uni-frankfurt.de.