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ME 5311: Computational Fluid Dynamics

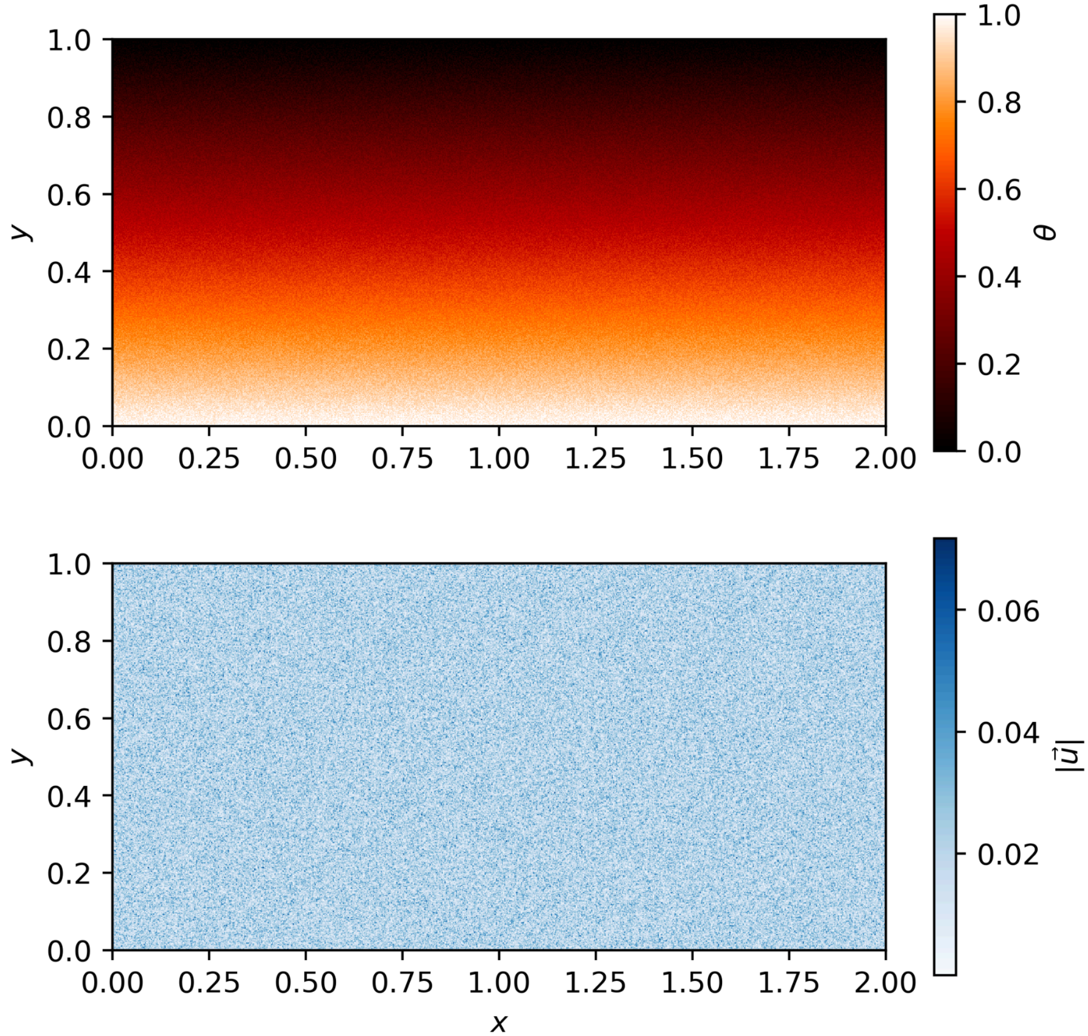
Final Project

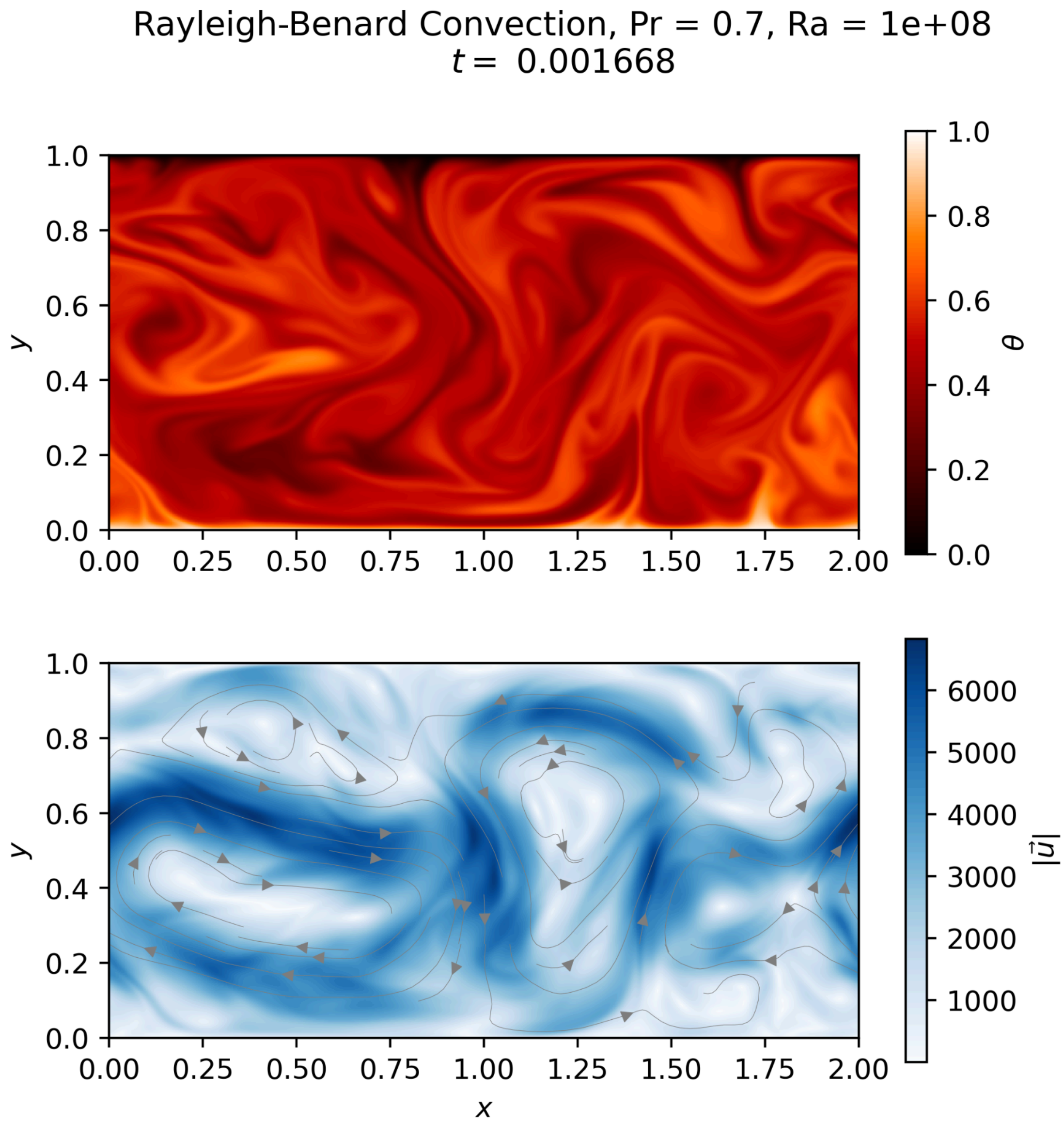
The following plots were created using a variable Δt, using a diffusion-dominated CFL = 0.2, convection-dominated CFL = 1.0. It should also be noted that the computational dimensions were (M, N) = (1024, 512). All other parameters are clearly listed in the titles of the figures. The u, v fields were initialized as random perturbations of magnitude 0.05, and θ as a linear gradient in accordance with top/bottom boundary conditions, with a random perturbation magnitude of 0.05. The "rb_run.py" script would save .npy array files to a temporary folder, which were then read off by the "rb_plot.py" (static plot), "rb_anim.py" (animation plot), and "rb_fluxplot.py" (heat flux/time plot) to create the plots.

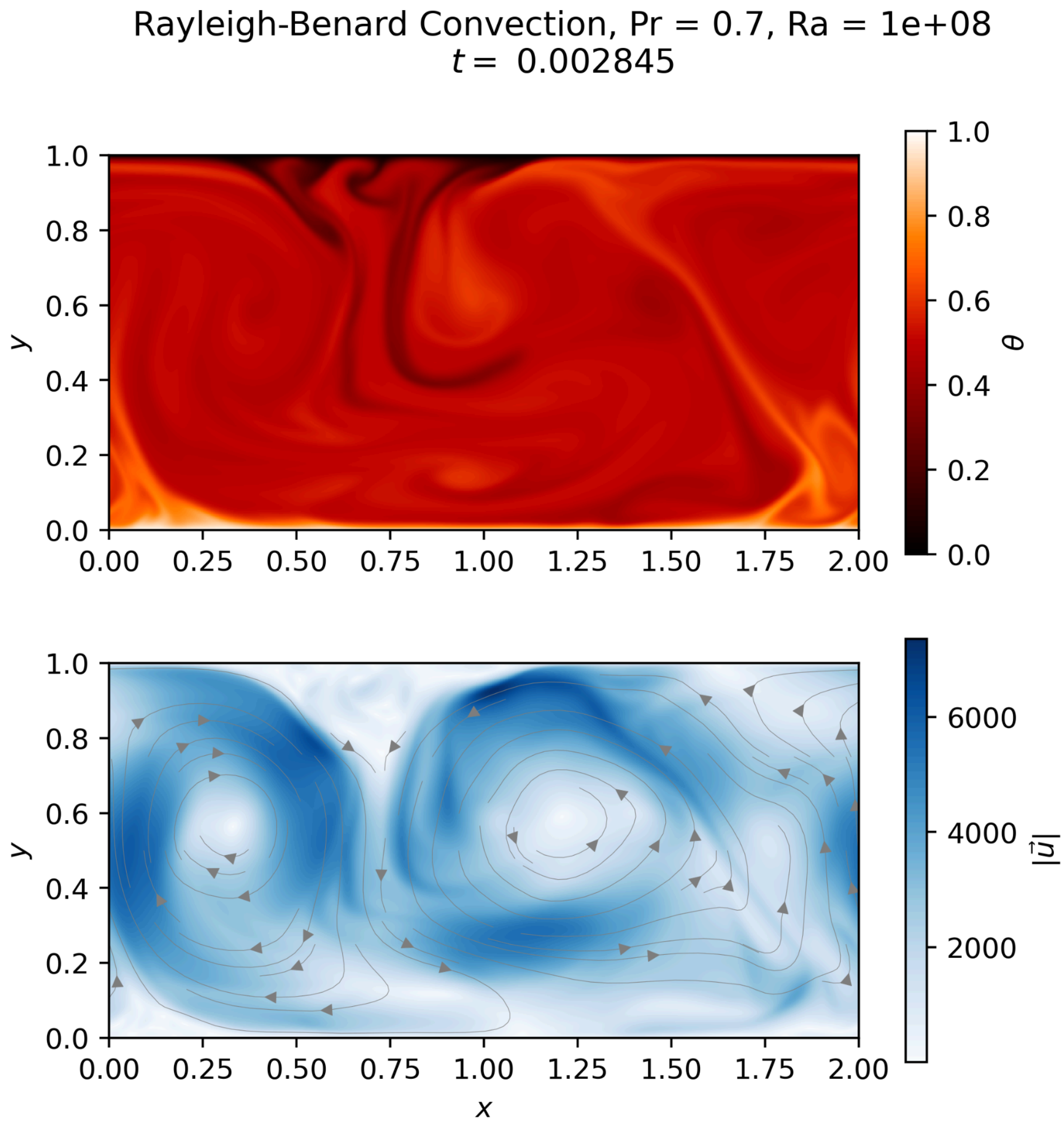
It should be noted that the divergence-form of the nonlinear convection terms was completed, following the method described in "Fully Conservative Higher Order Finite Difference Schemes for Incompressible Flow" by Morinishi et al. However, due to the indexing differences between MATLAB and Python, the terms are defined at a slightly different location than in the class notes.

The figures below show the evolution of this Rayleigh-Benard instability to the quasi-steady 'mushroom clouds'. (the streamlines at $t = 0$ are disabled to make the plot a little clearer).

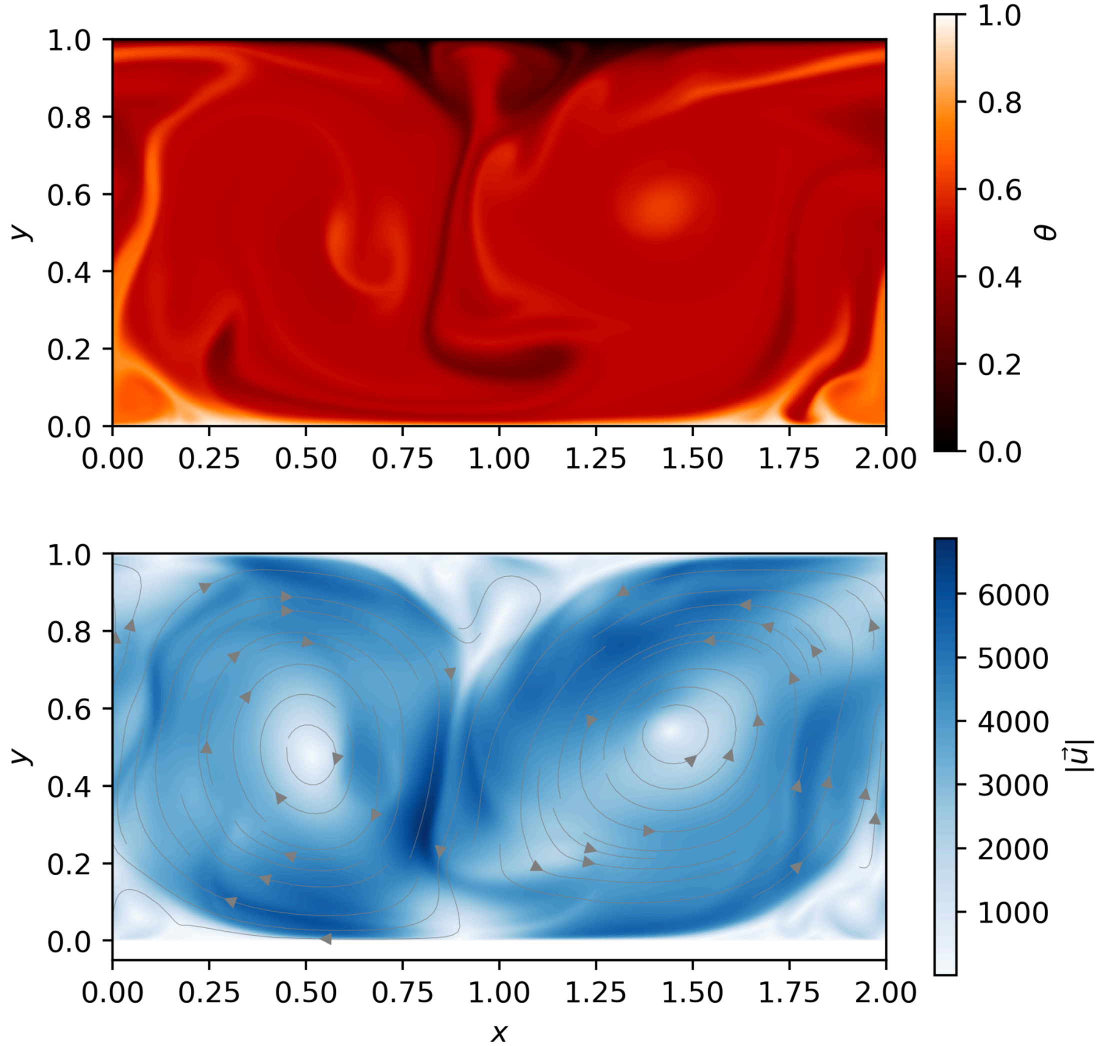
Rayleigh-Benard Convection, Pr = 0.7, Ra = 1e+08
$t = 0.000000$

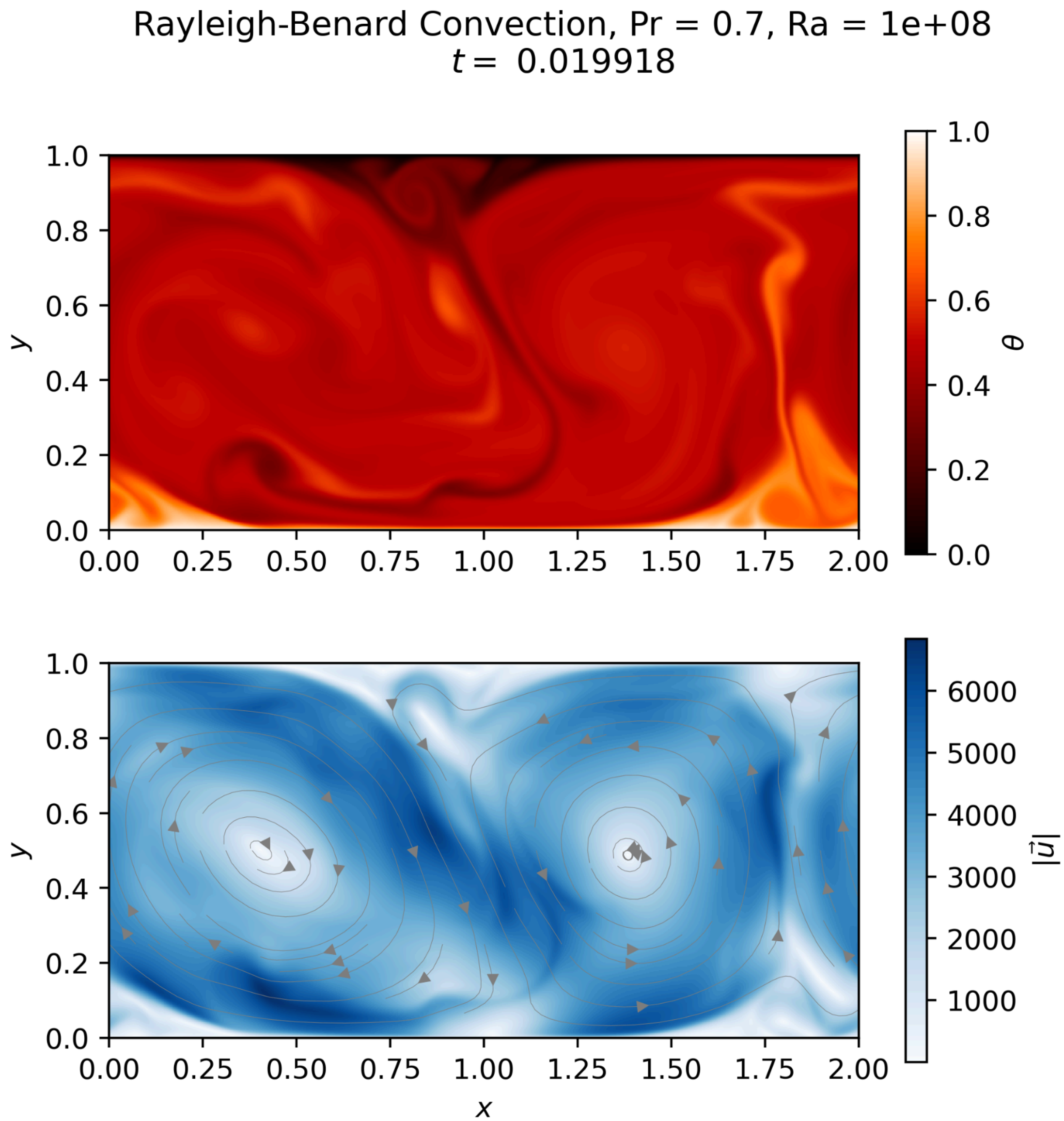



Rayleigh-Benard Convection, Pr = 0.7, Ra = 1e+08
$t =$ 0.001668
y
x
θ
|u⃗|
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
0.0 0.2 0.4 0.6 0.8 1.0
1000 2000 3000 4000 5000 6000


Rayleigh-Benard Convection, Pr = 0.7, Ra = 1e+08
$t =$ 0.002845
y
x
θ
$|\vec{u}|$
0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
0.0 0.2 0.4 0.6 0.8 1.0
2000 4000 6000

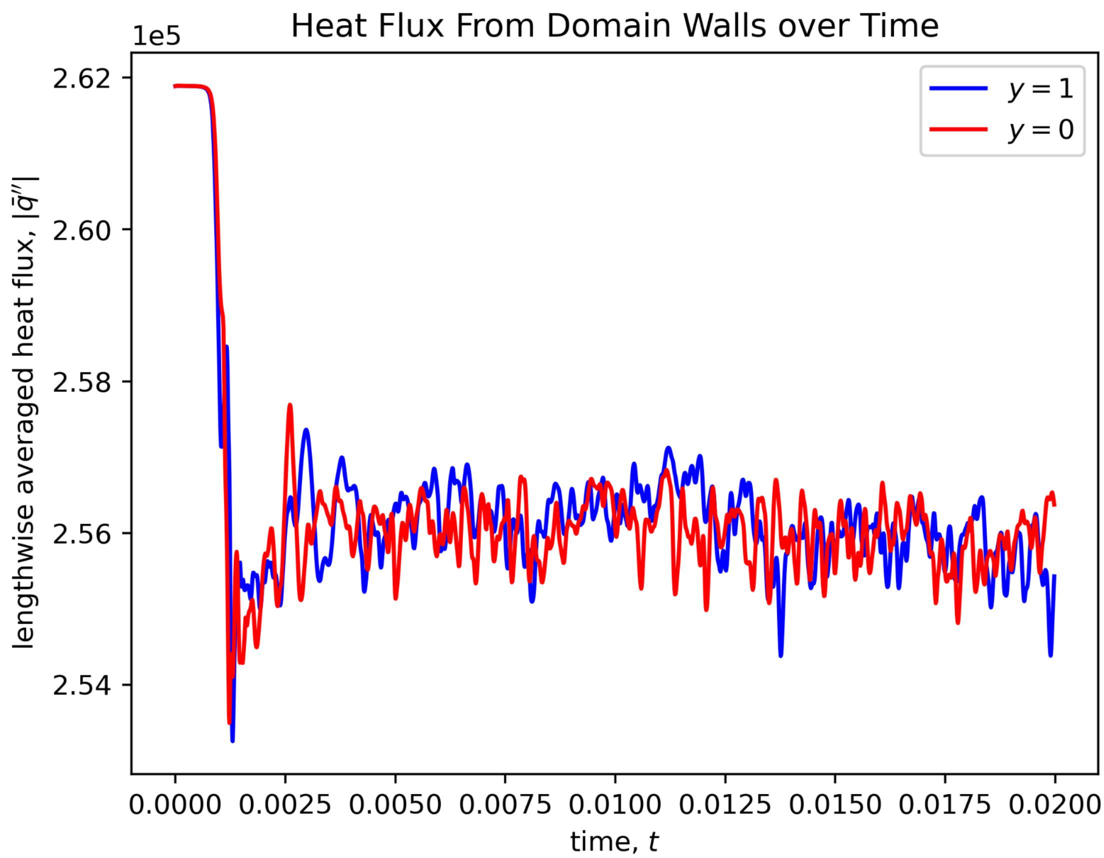
Rayleigh-Benard Convection, Pr = 0.7, Ra = 1e+08
$t =$ 0.013403





Rayleigh-Benard Convection, Pr = 0.7, Ra = 1e+08
$t =$ 0.019918
y
θ
y
x
$|\vec{u}|$

The non-dimensionalized, lengthwise averaged, heat flux was found by finding the mean of the θ[:, 0] vector (the first row of the θ array, directly adjacent to the bottom wall) and subtracting that from 1, which is the defined boundary condition. A similar procedure was completed on the top boundary. To avoid assigning a positive direction for the heat flux, only the magnitude was plotted.



The full animation of the evolution of this instability was submitted along with this document, and the parameters were as follows:

M	N	L	Pr	Ra	t_end
128	64	2.0	0.7	1e+06	0.02
512	256	2.0	0.7	1e+07	0.02
1024	512	2.0	0.8	1e+08	0.02

All diffusion-dominated CFL = 0.2, all convection-dominated CFL = 1.0.