LARGE-SCALE CIRCULATION REVERSALS IN A 2D RAYLEIGH-BÉNARD CELL

Podvin Berengere[1], & Sergent Anne [2]
[1]*LIMSI-CNRS, Orsay , FRANCE*
[2]*UPMC, Paris, France*

Abstract We consider the numerical simulation of a two-dimensional Rayleigh-Bénard cell in the turbulent regime $Ra = 5\ 10^7$ and $Pr = 4.3$. The flow is dominated by a large-scale inclined roll, the orientation of which switches intermittently in time. We use Proper Orthogonal Decomposition to identify the most energetic modes. We find that the first two modes respectively correspond to an antisymmetric and a symmetric mode. The next most energetic mode breaks the symmetry of the flow. During reversals, sharp variations in the temporal amplitudes of the modes are observed. We derive a low-dimensional model based on the first three most energetic modes which is able to reproduce the large-scale circulation reversals, in quantitative agreement with the simulation.

POD ANALYSIS OF THE FLOW

The flow in a square Rayleigh-Bénard cell at $Ra = 5\ 10^7$ is characterized by a large roll roughly aligned with one of the diagonals of the square, with two smaller rolls in the opposite corners. Chandra and Varme [1], [2] have shown that a quadrupolar mode became predominant during reversals. We have applied POD to the field - different formulations using a joint representation for the velocity and the temperature were used, but results were very similar. Figure 1 shows the first three modes corresponding to a joint velocity/temperature formulation. The most energetic mode (denoted L) is a anti-symmetric mode representing a single roll mode. The next most energetic mode is a quadrupolar, purely symmetric mode, corresponding to hot flow going up along the bottom portion of the lateral walls, while cold flow is coming down from the top portion. Most of the heat transfer is contained in the first two modes. The third mode (denoted S) corresponds to a stack of two rolls and breaks the vertical reflection symetry of the flow. Figure 2 represents the temporal variations of the coefficients. The first mode oscillates between two opposite values. One can see that sharp variations occur during reversals. Occasionally the third mode hovers near a non-zero value.

POD-BASED MODELLING OF THE REVERSALS

We use a Galerkin projection of the equations to derive a model for the evolution of the amplitudes of the three most energetic modes. The model displays several types fixed points. Some of these fixed points are located in the S=0 subspace and correspond to a state where the large-scale circulation is well established (L-equilibria). Both positive and negative values can be found for the L-equilibria corresponding to the direction of the large-scale circulation. Other fixed points are located along the pure S axis (S-type equilibria). For both types of fixed points (L- and S-), some are stable while others are saddles. The key points are that (i) there is a robust connection between saddle of the L-type (resp. S-type) and stable fixed points of the S-type (resp. L-type); (ii) L-saddles and L-equilibria are relatively close in phase space, so that the presence of noise can create a connection between L-equilibria of opposite signs, therefore mimicking reversals. The connection is shown in figure 3. The travel time from one equilibrium to another is in good agreement with the simulation.

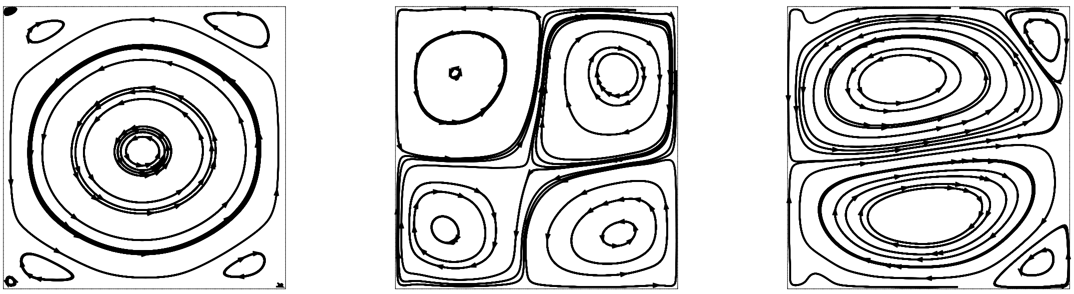

Figure 1. Dominant POD modes a)n=1(L) b)n=2 c)n=3(S)

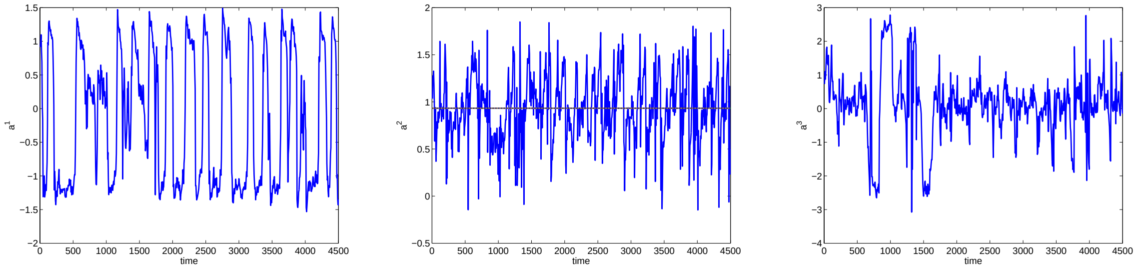

Figure 2. Evolution of the normalized amplitude of the n-th POD mode a)n=1(L) b)n=2 c)n=3(S)

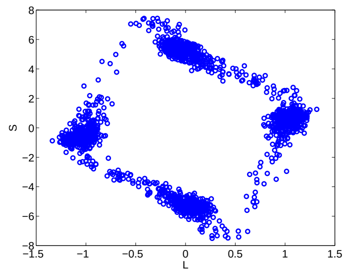

Figure 3. Heteroclinic cycle in the model in the L-S plane

References

[1] M. Chandra and M.K. Verma. Dynamics and symmetries of flow reversals in turbulent convection. *Physical Review E*, **83**:067303, 2011.

[2] M. Chandra and M.K. Verma. Flow reversals in turbulent convection via vortex reconnections. *Physical Review Letters*, **110**:114503, 2013.