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## Locating sources of variability in the transition to Structural Vacillation in the baroclinic annulus

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The baroclinic rotating annulus is a classic experiment to investigate the transition from regular waves to complex flows. A well documented transition via Amplitude Vacillation leads to low-dimensional chaos through a sequence of canonical bifurcations. However, the transition to geostrophic turbulence is usually through a regime of 'Structural Vacillation' (SV) which retains the overall spatial structure of regular waves but includes small-scale variability. Even though the SV vacillation occurs with a clear time scale, the dynamics of SV cannot usually be described by low-dimensional dynamics. For example, attractor dimension estimations tend to fail: they may not show any scaling region or converge to an unrealistic values. Explanations of the origin of SV have variously invoked higher radial modes of the fundamental baroclinic waves, local secondary instabilities in the baroclinic waves caused by high thermal gradients (gravity waves) or velocity shear (barotropic instability), or instabilities within the side-wall (Stewartson) boundary layers.

The aim of this paper is to identify where within the fluid different signals of variability are located at different stages in the transition from a steady wave to pronounced SV. To this end, a set of experiments in a water-filled rotating annulus with a free surface (inner radius 45 mm, outer radius 120 mm, fluid depth 140 mm) was carried out covering a temperature difference between the heated outer wall and the cooler inner wall of between 6 and 9.5 K, and a range of rotation rates from 0.84 to 2.29 rad/s ( $Ta = 4.75 \times 10^7 - 3.53 \times 10^8$  and  $\Theta = 0.0617 - 0.629$ ). The flow was observed through an infrared camera capturing the temperatures of the free surface. Images of the flow were recorded for a period of 15 minutes at a sampling rate of 1 Hz at the lower rotation rates and 2 Hz at the higher rotation rates.

The initial processing of the time series of temperature images involved normalisation of the temperatures followed by rotation of the images to a coordinate system co-rotating with the main baroclinic wave mode. The resulting images were separated into the time-mean wave field and the fluctuation field, resulting in a set of normalised temperature fluctuations at fixed points relative to the main baroclinic wave. Each of the time series was then used to calculate the power spectrum at that location. The low-frequency part of the spectra (up until half the tank rotation frequency) was used in a k-means cluster analysis to identify clusters of similar spectral shape and, from this, create a map of which spectral shape was found at which location in the flow field.

The results show isolated locations of a high frequency peak near the inner boundary at the onset of visible fluctuations. Further into the regime of clear structural vacillations, areas of pronounced variability at lower frequencies become visible at the lee shoulder of the cold jets in the fluid interior, followed by activity where the end of the cold jet interacts with the hot jet emanating from the outer boundary layer.

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