Application of advanced methods of time-series analysis for investigating multi-scale flow phenomena in the thermally driven rotating annulus

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The interplay between large-scale and small-scale flow phenomena in the atmosphere, often linked with turbulent mixing processes, has gained growing attention in the past decade. For example, breaking gravity waves and shear instability could cause severe turbulence in the atmosphere, in which energy is deposited to small-scales. Recent observations, e.g., [1], have shown that gravity waves are generated in the vicinity of the large-scale mid-latitude jet stream. Their occurrence is obviously connected with the region of the maximum jet velocity and with its outflow area where the jet stream is curved. Baroclinic instability is the dominating mechanism that cause the meandering jet pattern and it is believed that imbalance of the jet flow is the dynamical mechanism for generating gravity waves.

A well-known elegant experimental set-up, the differentially heated rotating annulus of fluid, has received large attention in investigating principles of baroclinic instability and large-scale atmospheric flows on a laboratory scale. Since the pioneering studies that have been conducted in the 1950s by D. Fultz [2] and R. Hide [3] – F. Vettin [4] introduced principals of the experimental set-up already in 1884 – the baroclinic annulus set-up is still of interest in recent research on atmospheric flow and basic fluid dynamics as well as for validating CFD codes which incorporate new numerical concepts. The latter might be due to the relative simple geometry of the annulus with well defined boundary conditions whereas the flow patterns that are observed show a multifaceted and complex behavior.

In the parameter space with the thermal Rossby number Ro over the Taylor number Ta, where

$$Ro = \frac{g\, d\, \alpha \Delta T}{\Omega^2\,(b-a)} \qquad \text{and} \qquad Ta = \frac{4\,\Omega^2\,(b-a)^5}{\nu^2\, d}, \tag{1}$$

small-scale instabilities, co-existing with the large-scale flow, are usually observed in the (turbulent) irregular flow regime at high Taylor numbers. In (1), $(b-a)$ is the gap width, d is the fluid height, ν is the viscosity, ΔT is the temperature difference, α is the volumetric expansion coefficient of the fluid, g is the acceleration due to gravity, and Ω the rotation rate. (Modulated) Amplitude vacillations and shape vacillating flows are detected, too. In a Ta-Ro-diagram, the former are found in the region of steady waves, the latter are usually observed at higher Taylor numbers towards the irregular regime, e.g., [5]. Furthermore, inertia-gravity waves have been detected in recent laboratory studies with a two-layer fluid, where they were apparently emitted from balanced flow, cf. [6].

Here, we present a study on analyzing DNS data of multi-scale flow patterns found in a recent numerical study on baroclinic driven flows in the rotating annulus, cf. [7]. The data are computed using the geophysical flow solver EULAG as numerical framework. The Navier-Stokes equations in the Boussinesq approximation are solved in the Eulerian flux-form advection scheme. We focus on advanced methods of time series analysis based on the family of **V**ector-valued **A**uto-**R**egressive models with e**X**ternal factors (VARX-models) and used for the data-based construction of stochastic models with inherently nonstationary statistical properties [8]. More precisely, the approach makes use of Finite-Element Method (FEM)-based time series analysis with bounded variation (BV) of model parameters, and it allows for the simultaneous dimension reduction and identification of dynamical models.

References

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