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Benchmarking in a differentially heated rotating annulus experiment: Multiple equilibria in the light of laboratory experiments and simulations

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In the framework of the German Science Foundation’s (DFG) priority program ’MetStröm’ various laboratory experiments have been carried out in a differentially heated rotating annulus configuration in order to test, validate and tune numerical methods to be used for modeling large-scale atmospheric processes.

This classic experimental set-up is well known since the late 1940s and is a widely studied minimal model of the general mid-latitude atmospheric circulation. The two most relevant factors of cyclogenesis, namely rotation and meridional temperature gradient are quite well captured in this simple arrangement. The tabletop-size rotating tank is divided into three sections by coaxial cylindrical sidewalls. The innermost section is cooled whereas the outermost annular cavity is heated, therefore the working fluid (de-ionized water) in the middle annular section experiences differential heat flow, which imposes thermal (density) stratification on the fluid. At high enough rotation rates the isothermal surfaces tilt, leading to baroclinic instability. The extra potential energy stored in this unstable configuration is then converted into kinetic energy, exciting drifting wave patterns of temperature and momentum anomalies. The signatures of these baroclinic waves at the free water surface have been analysed via infrared thermography in a wide range of rotation rates (keeping the radial temperature difference constant) and under different initial conditions (namely, initial spin-up and "spin-down").

Paralelly to the laboratory simulations of BTU Cottbus-Senftenberg, five other groups from the MetStröm collaboration have conducted simulations in the same parameter regime using different numerical approaches and solvers, and applying different initial conditions and perturbations for stability analysis. The obtained baroclinic wave patterns have been evaluated via determining and comparing their Empirical Orthogonal Functions (EOFs), drift rates and dominant wave modes. Thus certain "benchmarks" have been created that can later be used as test cases for atmospheric numerical model validation. Both in the experiments and in the numerics multiple equilibrium states have been observed in the form of hysteretic behavior depending on the initial conditions. The precise quantification of these state and wave mode transitions may shed light to some aspects of the basic underlying dynamics of the baroclinic annulus configuration, still to be understood.