BAROCLINIC INSTABILITY AND DOUBLE-DIFFUSIVE CONVECTION IN A ROTATING LABORATORY TANK

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Abstract A laboratory study of a flow driven by the interplay of rotation, vertical salinity stratification and horizontal temperature difference.

The differentially heated rotating annulus is a widely studied experimental apparatus for modeling large-scale features of the mid-latitude atmosphere (planetary waves, cyclogenesis, etc.). In the classic set-up, a rotating cylindrical tank is divided into three coaxial sections: the innermost domain is kept at a lower temperature, whereas the outer rim of the tank is heated. The working fluid in the annular gap in between thus experiences a lateral temperature difference. These boundary conditions imitate the meridional temperature gradient of the terrestrial atmosphere. The Coriolis effect arising due to the rotation of the tank modifies this azimuthally symmetric basic flow markedly, and leads to *baroclinic instability*, and the formation of cyclonic and anticyclonic eddies in the full water depth.

In the present work, we study a modified version of this experiment, in which – besides the aforementioned radial temperature difference – vertical salinity stratification is also present. If the ratio of the (vertical) salinity-induced density difference and the (horizontal) thermal density difference exceeds a certain critical threshold, *double-diffusive convection rolls* develop.

In the experimental runs discussed here, the lateral temperature difference was set to a constant ΔT, and a continuously stratified salinity profile was prepared in the cavity before each measurement with the standard two-bucket technique. After turning on counter-clockwise, i.e. “northern hemisphere”-like, rotation, the Coriolis force tended to push the horizontal flow branches of the emerging *double-diffusive staircase* to their right: at large enough values of rotation rate Ω this action yielded strong zonal flows in the system, with directions alternating with depth.

Particle Image Velocimetry (PIV) measurements were conducted using horizontally illuminated laser sheets at different water depths, which were observed from a co-rotating camera platform above the tank (as depicted in the figure below). Based on the PIV data, we introduced statistical “order parameters” to quantify the extent of baroclinic instability at a given depth and analyzed the connections between this depth-dependence and the vertical salinity profiles.

The non-dimensional Taylor number Ta, that characterizes baroclinic instability, changes inversely with the depth scale of the flow (baroclinic instability occurs if Ta exceeds a certain value of Ta^{crit}). We found such flow states, where the Ta calculated with the full water depth D does not exceed Ta^{crit}, but the “local” Taylor number Ta_{λ}, taken with the thickness of a given convective cell ($\lambda < D$) is already above the threshold. The multicellular double-convective flow was therefore, rather counter-intuitively, found to enhance baroclinic instability (and thus, mixing) in a local sense.

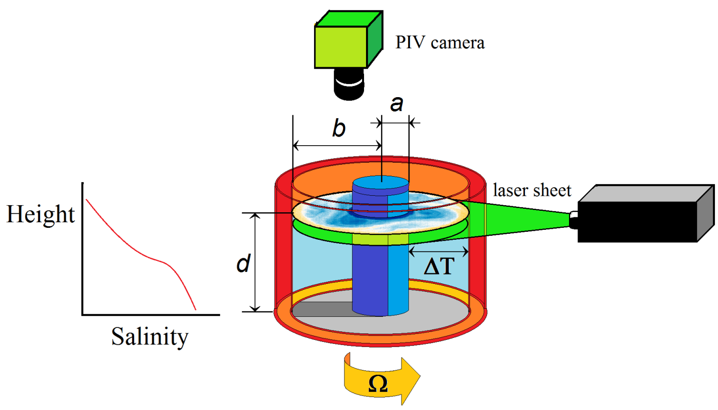

Figure 1. The schematic drawing of the experimental set-up.