Impact of environmental conditions on baroclinic waves

Inertia-gravity wave emission from baroclinic waves: the role of surface boundary conditions

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In Short

- The heat transfer coefficient is essential for convective boundary conditions. Can we determine it by comparing experiment and simulations?
- What is the role of surface convection and the ratio between fluid stability and rotation for the excitation of inertia-gravity waves?

☐ **Context** Inertia-gravity waves (IGWs) play a fundamental role for the energy and momentum transport from the troposphere into the middle atmosphere where the waves drive the global circulation. These waves have wavelength far below 100km and are part of the subgrid-scale processes that need to be parameterized in weather and climate models. Therefore, all aspects of IGW generation in the atmosphere need to be understood. The complexity of the three-dimensional baroclinic flow pattern, where a large number of interacting processes occur, and distribution of the inertia-gravity wave sources over large areas point towards the need for laboratory experiments and idealised numerical simulations. Fig. 1 gives the experimental setup at BTU C-S used to study multiscale wave processes [1,2].

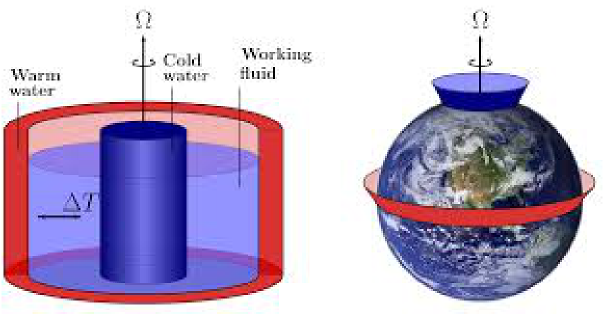

Figure 1: *Sketch of the baroclinic wave tank experiment at BTU Cottbus-Senftenberg (left) and correspondence between the cylindrical geometry of the experiment and the Earth atmosphere right).*

☐ **Problematic** The baroclinic tank cavity as set up in Cottbus is such idealization of the systems of jets and fronts in the atmosphere. Recent comparisons with DNS suggest a certain bias which could be introduced at the free surface. The omission of heat transfer and evaporative cooling might be a source of noticeable discrepancies between experiments and simulations. Therefore, the emission mechanisms of IGWs should be interpreted this type of effect in account. Direct numerical simulations is appealing to predict flows with perfect control of idealized operating conditions, at least if the uncertainties associated with numerical methods are avoided. However, the presence of large-scale baroclinic waves and small-scale IGWs makes use of direct numerical simulations challenging to simulate this multi-scale flow [3,4].

In order to provide insights on the emission IGWs from jets and fronts, we propose to perform direct numerical simulations of the laboratory experiments performed at BTU-CS. Particular attention is paid to the free surface by relying on laboratory experiments.

☐ **Numerical methods** The Navier-Stokes equations expressed in cylindrical coordinates system and in a rotating frame of rotation rate Ω are considered. The configuration of the baroclinic cavity is sketched fig. 1. The governing equations are solved for the velocity $\mathbf{u}$, the pressure p, and the temperature T, being discretized with a mixed Fourier-Galerkin/compact schemes or a Fourier-Galerkin/spectral methods in space. A semi-implicit fractional step method is considered for the time advancement. This reduces the solution of the Navier-Stokes equations to solutions of the Helmholtz/Poisson equations and simplifies the calculation of space derivatives and interpolations [6]. The parallel strategy of our code depends on the local or global nature of the space approximation.

☐ **High Performance Computing** Due to the global nature of higher-order discretization, specific parallel strategies need to be specifically designed. Thus, the computation of derivatives and interpolations with compact fourth-order schemes is based on parallelization using halo communication (neighbour to neighbour). This strategy is called rPDD and has been analysed in [5] for the solution of an incompressible fluid flow. The solution of the Helmholtz/Poisson equations and the spectral calculation of the derivatives are based on global approximations. In this case, the pencil decomposition strategy is used for an efficient and "user friendly" parallelization.

☐ **First findings** We have investigated the sensitivity of the free surface model to the dynamics of the baroclinic flow. For this purpose, two models of free surfaces were considered. The first, so-called

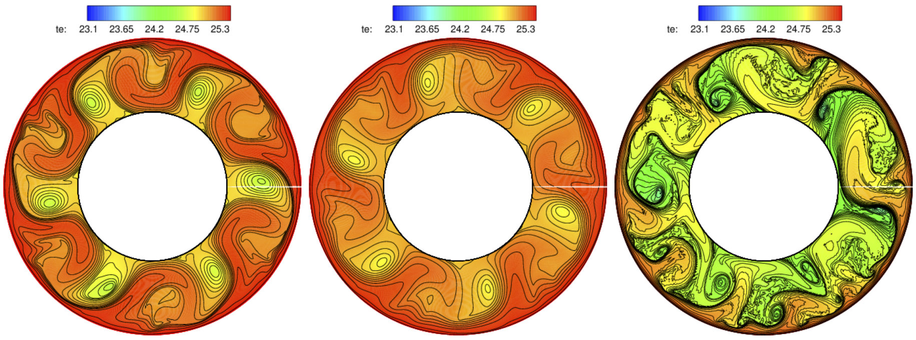

Figure 2: *Effect of the free-surface model. Snapshots of the surface temperature for several models: adiabatic (left) Marangoni (center) and convective (right).*

Marangoni, assumes that the surface tension coefficient depends on the temperature. This is a generalisation of the free-stress boundary conditions. Figure 2 presents a snapshot of the temperature surface computed using this model. The second model accounts for heat exchange between the water in the cavity and the ambient air. This model is derived from Newton's law. It depends on a heat coefficient exchange and the temperature of the ambient air. The right picture in figure 2 shows a snapshot of the temperature surface calculated with this model for a chill ambient. A comparison with the commonly adiabatic boundary (left picture of the figure 2), shows a significant effect of the air-water heat transfer on the flow. A more detailed study based on a parametric variation of the ambient air temperature show that a high ambient air temperature leads to a stronger stratification and suppresses small-scale structures at the surface.
Among the simulations performed in this work, we observed small-scales at the front of the baroclinic wave (figure 3 left). They has been observed for the highest values of N/f that is consistent with the analysis reported in [7]. A coarse preliminary direct numerical simulation of the configuration considered by Borchert et al.[7] made it possible to bring out these small-scales (figure 5 right).

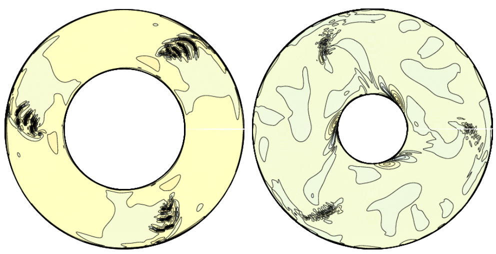

Figure 3: *Snapshots of the horizontal divergence exhibiting small-scales riding on the jet front formed by the baroclinic wave. Atmospheric-like cavity of [1] (left), the slice is located in the vicinity of the bottom wall. Atmospheric-like cavity of [7] (right), the slice is located at mid-height of the cavity.*

These first results clearly point to an effect of air-water heat transfer and the emergence of small-scales at higher N/f values.

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More Information

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Project Partners

Univ Aix Marseille, M2P2; Univ Perpignan Via Domitia, LAMPS

Funding

This project is funded by DAAD and MEAE/MESRI in the frame of a PROCOPE (PHC 46672RE) and by a grant within the BTU-FLAGSHIP program.

DFG Subject Area

404-42