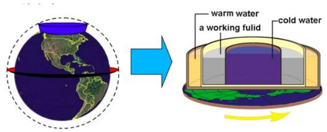
ATMOSPHERIC-LIKE ROTATING ANNULUS EXPERIMENT: GRAVITY WAVE EMISSION FROM BAROCLINIC JET

COSTANZA RODDA, ION BORCIA, UWE HARLANDER, *Brandenburg University of Technology Cottbus-Senftenberg, Germany*

ABSTRACT

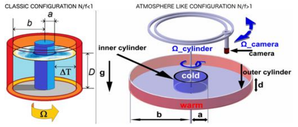
Large-scale balanced flows can spontaneously radiate meso-scale inertia-gravity waves (IGWs) and are thus in fact unbalanced. While flow-dependent parameterizations for the radiation of IGWs from orographic and convective sources do exist, the situation is less developed for spontaneously emitted IGWs. Observations identify increased IGW activity in the vicinity of jet exit regions. Examining spontaneous IGW emission in the atmosphere and validating parameterization schemes confronts the scientist with particular challenges. Due to its extreme complexity, GW emission will always be embedded in the interaction of a multitude of interdependent processes, many of which are hardly detectable from analysis or campaign data. The benefits of repeated and more detailed measurements, while representing the only source of information about the real atmosphere, are limited by the non-repeatability of an atmospheric situation. This argues for complementary laboratory experiments, which can provide a more focused dialogue between experiment and theory. Indeed, life cycles are also examined in rotating- annulus laboratory experiments. Thus, these experiments might form a useful empirical benchmark for theoretical and modelling work that is also independent of any sort of subgrid model. In addition, the more direct correspondence between experimental and model data and the data reproducibility makes lab experiments a powerful testbed for parameterizations.

BAROCLINIC WAVE TANK



The differentially heated rotating annulus and its analogy with the Earth's atmosphere. The inner side wall of the annulus is cooled whereas the outer one is heated. The tank is mounted on a turntable. The two most relevant factors of cyclogenesis, rotation and meridional temperature gradient, are quite well captured in this simple arrangement (Figure by P. Read A&G, Vol. 51, 2010).

At the BTU there are currently two differentially heated rotating annulus experiments, one with classical geometry and a larger one with atmospheric-like properties (see table below). A detailed description of the experiment can be found in [1].



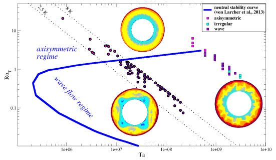
Measurement techniques:

1. Infrared thermography to measure the fluid temperature at the surface
2. PIV using spherical tracer and a co-rotating camera to measure the velocity field.

Geometrical and experimental parameters

			Classic	Atmosphere like
(a) Geometric dimensions				
gap width	$b-a$ (mm)	=	75	350
fluid depth	D (mm)	=	135	40
(b) Experimental conditions				
difference of temperature	ΔT (K)	=	8	5
rotation rate range	Ω (rpm)	=	$4-6$	$0.3-0.8$

FLOW REGIME



Varying the magnitude of the temperature difference or the rotation rate four different flow regimes can develop: axisymmetric flow, steady waves, vacillation and irregular flow. They can be described by the Taylor number, Ta, and the thermal Rossby number, Ro_T:

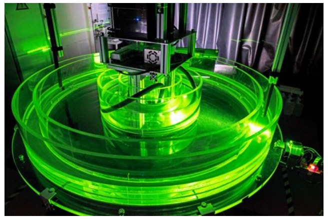
$$Ta = \frac{4\Omega^2(b-a)^5}{\nu^2 D}, Ro_T = \frac{Dg\alpha\Delta T}{\Omega^2(b-a)^2}$$

REFERENCES

[1] Uwe Harlander, Thomas von Larcher, Yongtai Wang, and Christoph Egbers. Piv-and ldv-measurements of baroclinic wave interactions in a thermally driven rotating annulus. *Experiments in fluids*, 51(1):37–49, 2011.

[2] Miklos Vincze, Ion Borcia, Uwe Harlander, and Patrice Le Gal. Double-diffusive convection and baroclinic instability in a differentially heated and initially stratified rotating system: the barostrat instability. *Fluid Dynamics Research*, 48(6):061414, 2016.

COMPARISON WITH NUMERICAL SIMULATIONS



The big rotating annulus is functional at the BTU facility since end of March 2016. This new configuration allows to reach values of the ratio N/f higher than one. This assures near-horizontal phase propagation of high frequency IGWs, like in the Earth's atmosphere. For this reason, the IGW propagation is expected to be qualitatively similar to the atmospheric case. The process of spontaneous emission of IGWs from the baroclinic jet is studied by performing laboratory experiments (at the BTU) and numerical simulations (at the Goethe-Universität Frankfurt am Main and at the Leibniz-Institute of Atmospheric Physics).

The comparison between the temperature data from the laboratory experiment and the numerical simulations shows a very good agreement for the large scale baroclinic wave regime.

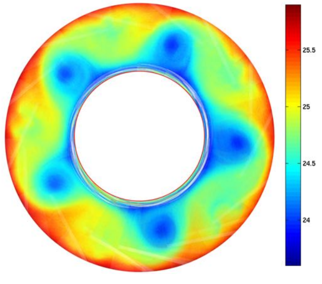


Figure 1: Temperature contour plot BTU experiment

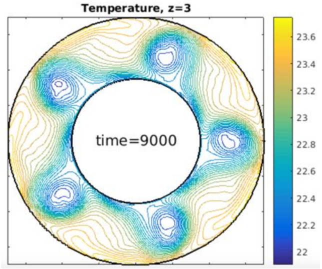
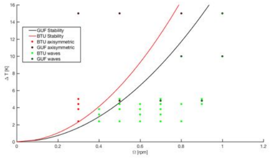


Figure 2: Temperature contour plot numerical simulations. Courtesy of Steffen Hien

STABILITY DIAGRAM



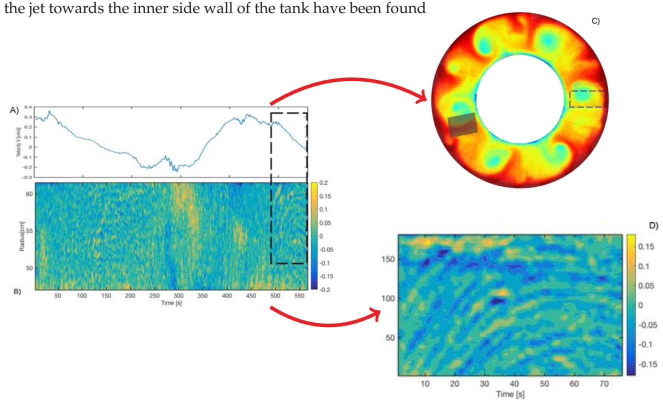
Stability diagram showing the transition between baroclinically stable and unstable flow in terms of temperature difference ΔT and rotation speed Ω. The two curves give the separation between stable (left) amd unstable (right) regions as derived from the Eady model.

CONTACT INFORMATION

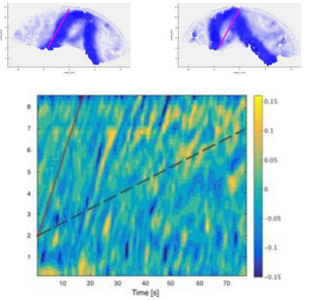
Web: http://www-user.tu-cottbus.de/~haruwe/
https://ms-gwaves.iau.uni-frankfurt.de/
Email: haruwe@b-tu.de

IGWS SIGNAL ALONG THE BAROCLINC JET

A space-time (Hovmöller) plot of the horizontal divergence (B) shows wave packets like structures in correspondence of the exit region of the baroclinic wave (grey area in C). A mean of the radial velocity plot to indicate the phase of the baroclinic wave with respect to the small features is shown in A). Note that we see just a small part of the tank in our PIV measurement (highlighted by the dashed rectangle in C). The enlarged plot for 500s < t < 570s (D) suggests that the wave packets propagate with different speeds. Similar features can be found in the numerical simulations, where gravity waves packets generated in the jet exit region and subsequently advected by the jet towards the inner side wall of the tank have been found



COMPARISON WITH THE BAROSTRAT EXPERIMENT



In a modified version of the classical baroclinic experiment, where the working fluid is initially prepared with a constant salinity profile [2], wave packets with characteristics matching the ones of IGWs have been found in the horizontal divergence field. The Hovmöller plot of the divergence shows the wave packets moving faster than the baroclinic wave (drift speed indicated by the dashed line) but are attached to it and move with the speed of the jet (red line). The most prominent travelling waves (15s < t < 30s) can be observed when the red line (in the figures above) are along the jet.

ACKNOWLEDGMENTS

This work was supported by the Spontaneous Imbalance project (HA 2932/8-1) part of the research group MultiScale Dynamics of Gravity Waves funded by DFG (FOR1898). The authors thank Ludwig Stapelfeld, Robin Stöbel, Vilko Ruoff for technical support and Patrice Le Gal and Miklós Vincze for the helpful discussion.