Geophysical Research Abstracts
Vol. 12, EGU2010-3488, 2010
EGU General Assembly 2010

A low-order model of the role of the Prandtl Number for Amplitude Vacillation in the baroclinic annulus

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The rotating annulus, subjected to differential heating on the sidewalls, has been used for decades as a model of large-scale atmospheric baroclinic waves. Depending on the main operating conditions, the rotation rate and the imposed temperature difference, the fluid in the annular chamber is known to show a wide range of flow regimes, from axisymmetric circulation, through equilibrated waves of a clear wave number, oscillatory modulation of these waves and low-dimensional chaotic flows to full turbulence.

Of particular interest here is transition from steady waves to amplitude vacillation, where the wave structure remains largely unchanged but its amplitude oscillates periodically. In liquid-filled containers (Prandtl number $>\sim 7$), it is well known that this transition occurs when the temperature difference is increased or the rotation rate is decreased. The reverse is found when the gap is filled with air ($\mathrm{Pr} \sim 0.7$).

Low-order models, using the quasi-geostrophic two-layer system show the same tendency as the air-filled tank but these models do not include either the Prandtl number or a representation of the sidewall boundary layers. However, it is natural to expect that the Prandtl number will have a strong effect on the flow. In the low-Pr limit, the heat transfer will be dominated by conduction, and the resulting fluid flow is a relatively passive response the temperature gradients. The presence of baroclinic waves will affect the baroclinicity only to a small extend but provide a mechanism to increase the heat transfer at the same temperature contrast. Here, the main limiting factor for the wave amplitude will be dissipation and resulting Ekman suction.
In the high-Pr limit on the other hand, the heat transfer will be dominated by convection. A significant portion of the total heat transfer will be carried by the Stewartson/Ekman layer system, reducing the temperature contrast available for the fluid interior. Baroclinic waves will also reduce the temperature gradient and reduce the baroclinicity of the fluid interior. This negative feedback will limit the potential for increased heat transfer and provide a different mechanism for amplitude vacillation compared to the low-Pr case.

This contribution aims to embed the QG 2-layer model of the baroclinic fluid interior in a low-order model which also captures the heat transfer by the Stewartson layers together with their effect on the residual temperature gradient in the fluid interior.