A Unified Perspective on the Dynamics of Axisymmetric Hurricanes and Monsoons

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This presentation provides a unified perspective on the dynamics of hurricane- and monsoon-like vortices by identifying them as specific limiting cases of a more general flow system. This more general system is defined as stationary axisymmetric balanced flow of a stably stratified non-Boussinesq atmosphere on the f-plane. The model is based on the primitive equations assuming gradient wind balance in the radial momentum equation. The flow is forced by heating in the vortex center, which is implemented as relaxation towards a specified equilibrium temperature T_e. The flow is dissipated through surface friction, and it is assumed to be almost inviscid in the interior. The heating is assumed supercritical, which means that T_e does not allow a regular thermal equilibrium solution with zero surface wind, and which gives rise to a cross-vortex secondary circulation. Numerical solutions are obtained using time stepping to a steady state, where at each step the Eliassen secondary circulation is diagnosed as part of the solution strategy.

Scaling analysis suggests that for a given geometry essential vortex properties are controlled by the ratio $\mathcal{F} = \alpha_T/c_D$, where α_T is the rate of thermal relaxation and c_D quantifies the strength of surface friction for a given surface wind. For large $\mathcal{F}$ the temperature is close to T_e and the vortex shows properties which can be associated with a hurricane including strong cyclonic surface winds. On the other hand, for small $\mathcal{F}$ the vortex shows properties which can be associated with a monsoon, i.e. the surface winds are small and the secondary circulation keeps the temperature significantly away from T_e. The scaling analysis is verified by numerical solutions spanning a wide range of the parameter space. It is shown how the two limiting cases correspond with the respective approximate semi-analytical theories presented previously. The results imply an important role of α_T for hurricane formation.

Depending on the location in parameter space, some vortices have an eye and others don't. An eye is defined to be associated with maximum upwelling at a finite radius away from the origin. "Eye-ness" turns out to be a function of $\mathcal{F}$ only, with a sharp transition between 'no eye at all' and a 'fully developed eye'. The mechanism for eye formation is purely inviscid, while the maintenance of an eye in steady state requires viscous processes.