Forced oscillations and tidal dissipation in fluid planets with atmospheres

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What is the proper boundary condition for forced atmospheric oscillations? Numerical models (which have a finite extent and a lid at the top) general impose a zero vertical velocity at the upper boundary. This is a reasonable approach to simulate atmospheric modes that decay exponentially with height. Such modes are usually referred to as evanescent and need not dissipate any energy. They therefore correspond to the atmospheric part of fluid planetary free oscillations. Another class of atmospheric waves propagates to infinity with a constant energy density. These waves give rise to the radiation condition which requires that the sense of the wave energy flux be outward (which in turn usually corresponds to an inward phase propagation). However, there is a third class of waves — especially important in rapidly rotating atmospheres where $4a\Omega^2 \sim g$, these modes have equivalent depths much greater than the atmospheric scale height — that grow more slowly with height. While the energy density of these waves therefore decreases as a function of height, their outward energy flux is constant (a mathematical property of all solutions of the wave equation). These motions — which cannot be neglected in forced oscillation problems — therefore lead to additional dissipation of energy. In the study of tidal dissipation in giant planets this class of modes has heretofore been ignored (or treated as evanescent), leading to an underestimate of the atmospheric energy flux by some three orders of magnitude! When this effect is properly included, the calculation of tidal dissipation in Jupiter and Saturn yields a quality factor $Q \sim 10^5$ which is of the correct magnitude to explain the tidal evolution of the satellite systems of these bodies. The corresponding wave energy flux is large enough to affect the upper atmospheric structure. The tidal dissipation results are insensitive to details of both the interior and atmospheric structure of the bodies in question and therefore can be easily extended to considerations of other giant planets including extra-solar hot Jupiters.