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An analytical theory for the Hadley in nearly-inviscid, axisymmetric radiative-convective atmospheres

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The central goal of theoretical GFD is to predict major circulation features from first principles, given only external parameters and without recourse to numerical simulation. A successful example is the theory for the axisymmetric component of the global atmospheric circulation, whose currently accepted form was devised in the late 1970's by Schneider, Lindzen, Held and Hou. The theory has become a cornerstone of modern climate dynamics, playing a key role in interpretations of Hadley cell structure in global warming scenarios, paleoclimates and planetary atmospheres. However, it assumes a Boussinesq atmosphere, and the background stratification is externally prescribed, so that the theory cannot really claim to be "first principles". Here, we remove both constraints, presenting an analytical theory for the width and depth of the Hadley cell in a compressible, radiative-convective atmosphere. Radiation is treated using the semi-gray approximation. Convection assumes relaxation towards a dry or moist adiabat. The theory converges to the classical result in the Boussinesq limit. We show that naive application of the classical theory can be misleading in some cases.