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Superrotation Strength Estimated from Algebraic Equations

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We estimate the strength of equatorial superrotation of planetary atmospheres by solving a set of algebraic equations based on Gierasch's model. Gierasch (1975) explained that the equatorial superrotation of Venus is maintained by upward and equatorward angular momentum transport by means of meridional circulation and strong horizontal eddy diffusion, respectively. The parametric dependence of this model was explored by Matsuda (1980). However both Gierasch and Matsuda ignored the effect of meridional thermal advection. By taking account of the effect, we extend their studies.

We derive a set of algebraic equations from the primitive equations of the steady axisymmetric Boussinesq fluid, by substituting unknown scalar variables for unknown functions (i.e., zonal and meridional velocity, and temperature). Coefficients of the algebraic equations consist of the thermal Rossby number, the vertical and the horizontal Ekman numbers, and the relaxation time constant of Newtonian heating and cooling.

Solutions of the algebraic equations are compared with representative values of numerical solutions of the primitive equations for a parametric range of many orders of magnitude. The superrotation strength obtained from the full primitive equations (i.e., latitudinally averaged zonal velocity at the top divided by the planetary rotation velocity at the equator) can be estimated from the solutions of the algebraic equations; the accuracy of the estimates is better than 70% in most cases. The superrotation strength is proportional to the cubic root of the thermal Rossby number for the cases that the dominant balance is between the centrifugal acceleration and the pressure gradient that is weakened by the meridional thermal advection.

Keywords: superrotation, atmospheric general circulation, planetary atmospheres, atmospheric dynamics, geophysical fluid dynamics