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Planetary and atmospheric properties leading to strong super-rotation in terrestrial atmospheres studied with a semi-grey GCM

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Super-rotation is a phenomenon in atmospheric dynamics where the specific axial angular momentum of the wind (at some location) in an atmosphere exceeds that of the underlying planet at the equator. Hide's theorem states that in order for an atmosphere to super-rotate, non-axisymmetric disturbances (eddies) are required to induce transport of angular momentum up its local gradient. This raises a question as to the origin and nature of the disturbances that operate in super-rotating atmospheres to induce the required angular momentum transport.

The primary technique employed to investigate this question has involved numerically modelling super-rotating atmospheres, and diagnosing the processes that give rise to super-rotation in the simulations. These modelling efforts can be separated into one of two approaches. The first approach utilises 'realistic', tailor-made models of Solar System atmospheres where super-rotation is present (e.g., Venus and Titan) to investigate the specific processes responsible for generating super-rotation on each planet. The second approach takes simple, 'Earth-like' models, typically dry dynamical cores with radiative transfer represented using a Newtonian cooling approach, and explores the effect of varying a single (or occasionally multiple) planetary parameters (e.g., the planetary radius or rotation rate) on the atmospheric dynamics. Notably, studies of this flavour have shown that super-rotation may emerge 'spontaneously' on planets with slow rotation rate or small radius (relative to the Earth's; Venus and Titan have these characteristics). However, the strength of super-rotation obtained in simulations of this type is far weaker than that observed in Venus' or Titan's atmospheres, or in tailored numerical models of either planet.

In this work, our aim is to bridge the gap between these two modelling approaches. We will present results from a suite of simulations using an idealised general circulation model with a semi-grey representation of radiative transfer. Our experiments explore the effects of varying planetary size and rotation rate, atmospheric mass, and atmospheric absorption of shortwave radiation on the acceleration of super-rotation. A novel aspect of this work is that we vary multiple planetary properties away from their Earth-like 'defaults' in conjunction. This allows us to

investigate how properties characteristic of the atmospheres of planets such as Venus and Titan combine to yield the strong super-rotation observed in their atmospheres (and realistic numerical models). We are also able to illustrate how features such as increased atmospheric mass and absorption of shortwave radiation modify the weakly super-rotating state obtained in simple, Earth-like models towards one more characteristic of Titan or Venus.