Treatment of the superrotation-induced atmospheric oblateness of Venus and Titan in hydrostatic general circulation models

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Superrotation in the middle atmospheres of Venus and Titan with wind speeds in excess of 100 m/s causes an equatorial bulge or oblateness by the centrifugal force that acts perpendicularly to the planetary spin axis. This superrotation-induced equatorial bulge has a thickness of \(~1\) km and \(~30\) km in Venus’ and Titan’s middle atmosphere, respectively, and thereby constitutes a substantial portion of the latitudinal variation in the geopotential. Hydrostatic general circulation models (GCMs) do not represent this equatorial pressure bulge since the vertical component of the centrifugal force does not appear in the hydrostatic equation, which replaces the vertical momentum equation. This causes a systematic misrepresentation of the meridional pressure gradient force, especially on Titan. One possible explanation for the relative weakness of the superrotation in many hydrostatic Venus and Titan GCMs is the inherent absence of the pressure gradient force in balance with the wind-induced equatorial bulge. The wind-induced atmospheric oblateness can be represented in hydrostatic Venus and Titan GCMs only if the hydrostatic equation is corrected by adding the vertical component of the centrifugal force. Non-hydrostatic GCMs can naturally capture this effect.