THE MECHANISM OF SUPERROTATION IN VENUS AND TITAN LMD GCM. S. Lebonnois[1], [1]CNRS, Laboratoire de Meteorologie Dynamique (4 place Jussieu, box 99, 75252 Paris, France – sllmd@lmd.jussieu.fr).

Introduction: On both Venus and Titan, which rotation rates are much smaller than on Mars or the Earth, a specific feature has been observed in the zonal wind, the superrotation. The bulk of these atmospheres rotates much faster than the solid body of the planet, and the total angular momentum contained in the atmosphere is much larger than what would be contained if the atmosphere was rotating in average as the solid surface (which is the case for the Earth and Mars).

This feature has been investigated for many years, but it is not yet fully understood, though the role of the slow rotation rate seems to be clearly established, through its impact on the mean meridional circulation. A possible mechanism has been discussed in [1] and [2], further noted GRW mechanism. It describes the transport of angular momentum by the mean meridional circulation, and emphasizes the role of waves in the equatorward transport of angular momentum. Other mechanisms have been suggested, especially the role that the thermal tides may play [3,4].

Venus and Titan, with their own specificities, can help understand the superrotation mechanism: the respective role of rotation rate, thermal tides, other types of waves, the impact of seasonal variations on Titan, the role of the opacity layer located in altitude. But this has been a difficult problem to tackle with models, the best tools being General Circulation Models (GCM) that have been difficult to develop.

In this presentation, we investigate some aspects of this question with the most recent GCM of Venus and Titan developed in our team.

Venus GCM: We have developed a Venus GCM that takes into account a realistic radiative transfer scheme and allows a consistent computation of the temperature field [5]. Taking into account the diurnal cycle gives the opportunity to test the impact of the thermal tides. In our most recent simulations, we are using an improved boundary layer scheme that improves the superrotation in the deep atmosphere (below the clouds), though its amplitude is still below observations. When initializing the simulation with an atmosphere already in superrotation, the circulation also stabilizes but with deep-atmosphere winds close to observations and superrotation in and above the clouds stronger than observed. This latter simulation is the most realistic and the modeled temperature structure in and above the clouds compares well with VIRTIS/Venus Express observations, where thermal tides are visible [6].

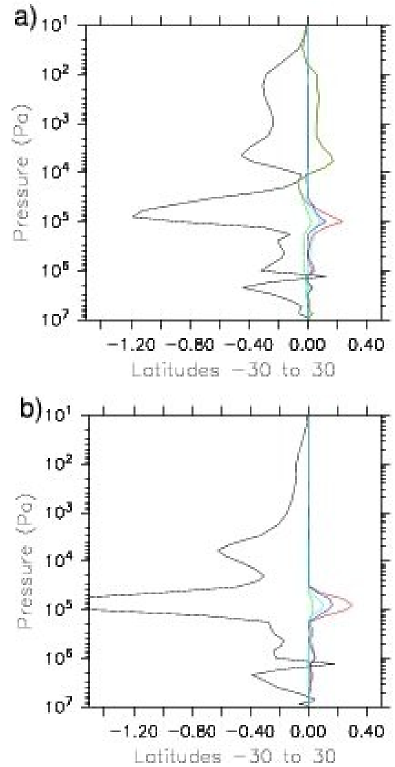

Figure 1: Vertical transport of angular momentum in Venus simulations. The relative angular momentum vertical transport is integrated for latitudes between 30°S and 30°N. Negative values are for upward transport, positive values are for downward transport. Black line: mean meridional circulation; red line: total waves and tides; blue and cyan lines: barotropic waves (mid- and high frequencies respectively); green line: thermal tides. (a) Diurnal cycle included. (b) No diurnal cycle. The contribution of thermal tides appears clearly in the 10^2-10^4 Pa pressure range.

The mechanism maintaining this zonal wind structure appears to be somewhat different from the GRW mechanism. The transport by meridional circulation does play a major role, but the role of thermal tides (inducing vertical transport of angular momentum) dominates the role of other waves (inducing an equatorward transport in the GRW mechanism).

Titan GCM: We have recently developed a Titan GCM [7], with the same dynamical core as the Venus GCM and the same physics as we have been using for our Titan 2-dimensional Climate Model [8]. This model can take into account diurnal variations, but in the case of Titan, the dominant timescale affecting the circulation in Titan's stratosphere is the seasonal oscillation (Titan experiences seasons with an orbital inclination similar to the Earth).

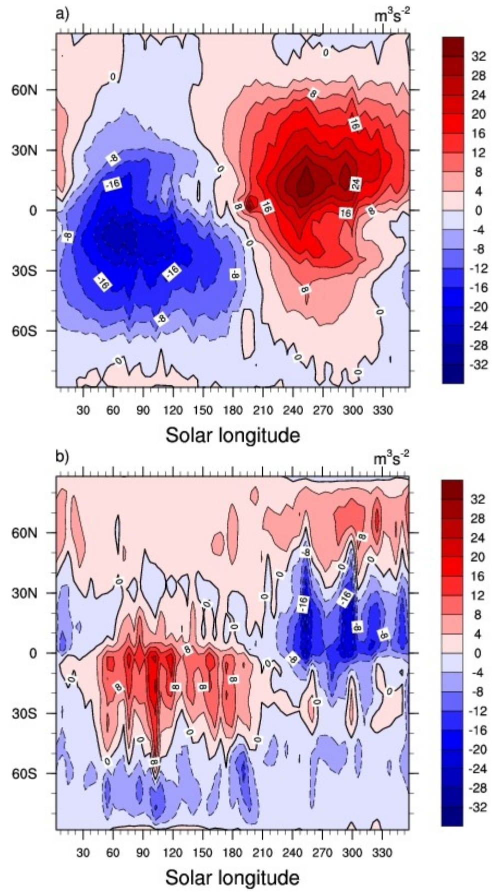

Figure 2: Seasonal variations of the latitudinal transport of angular momentum by (a) mean meridional circulation and (b) transient waves. Unit is 10^3 m^3/s^2, positive values are northward.

In our simulations, the superrotation is maintained similarly as in the 2D-CM, through the GRW mechanism. Transport by the mean meridional circulation from summer to winter hemispheres is compensated by horizontal transport by barotropic eddies mostly occuring in the winter hemisphere (Fig. 2). As first mentioned for simulations done with the TitanWRF GCM [9], this eddy transport occurs in the models mostly through transient episodes when the eddy strength increases. We also note a significant contribution of baroclinic waves occuring at high latitudes close to the surface, and transporting some momentum poleward.

Conclusion: We have now versions of Venus and Titan GCM that help us investigate in details the mechanism of superrotation, and to discuss the respective role of meridional circulation, waves, and thermal tides in the angular momentum budget. Our studies confirm that superrotation arises from the balance between mean meridional circulation and waves (GRW mechanism) but with a major role played by thermal tides (vertical transport) in the case of Venus.

References: [1] Gierasch P. J. (1975) *J. of Atm. Sc. 32*, 1038–1044. [2] Rossow W. B. and Williams G. P. (1979) *J. of Atm. Sc. 36*, 377–399. [3] Newman M. and Leovy C. B. (1992) *Science 257*, 647–650. [4] Takagi M. and Matsuda Y. (2007) *J. of Geophys. Res. 112*, D09112. [5] Lebonnois S. et al. (2010) *J. of Geophys. Res.* 115, E06006. [6] Migliorini A. et al. (2012) *Icarus* 217, 640-647. [7] Lebonnois S. et al. (2012) *Icarus* 218, 707-722. [8] Lebonnois S. et al. (2009) *Phil. Trans. R. Soc. A* 367, 665-682. [9] Newman C. et al. (2011) *Icarus* 213, 636-654.