EPSC Abstracts
Vol. 13, EPSC-DPS2019-750-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Radiative-equilibrium model of Jupiter's atmosphere and application to estimating stratospheric circulations

Sandrine Guerlet (1), A. Spiga (1), H. Delattre (1) and T. Fouchet (2);
(1) Laboratoire de Météorologie Dynamique (LMD-IPSL), Paris, France (2) LESIA, Observatoire de Paris, Meudon, France
(sandrine.guerlet@lmd.jussieu.fr)

1. Introduction

Jupiter's stratospheric circulation is still poorly known to this day. Observations of trace species reveal several features (for instance, the puzzling distributions of ethane and acetylene, by-products of the photochemistry ; or that of CO_2 and HCN, by-products of comet Shoemaker-Levy impact) left unexplained by current models coupling chemistry with simple parametrization of meridional and vertical transport. We aim at developing a 3D General Circulation Model (GCM) from the troposphere to the upper stratosphere to address these questions. In this context, the calculation of heating and cooling rates has to be robust and fast, as these quantities need to be computed on a high-resolution grid, every few Jupiter days and for several Jupiter years. This abstract focuses on an efficient 1-D radiative-convective model (as part of an under-development 3D GCM). After reviewing the main ingredients of our 1-D model, we present the thermal structure obtained at equilibrium and compare it to temperatures derived from thermal infrared spectrometers (Cassini/CIRS and TEXES/IRTF). We then use the net heating rates to estimate the residual-mean circulation, under the assumption that eddy heat flux convergence is negligible compared to diabatic forcing.

2. Radiative-equilibrium model

Our Jupiter radiative-convective model is adapted from its Saturn counterpart [5]. These two giant planets share many characteristics and the main physical parametrizations are the same: a k-distribution model is used to compute gaseous opacities, a two-stream approximation solves the radiative transfer equations (including multiple scattering) and a convective adjustment scheme relaxes the temperature profile towards the adiabatic lapse rate when unstable lapse rates are encountered. An internal heat flux, set to 7.48 $W.m^{-2}$, is also taken into account. Our vertical grid consists of 64 layers, from 3 bar to 3 μbar.

We take into account gaseous opacity from the three main hydrocarbons (methane, ethane and acetylene), ammonia, and collision-induced transitions by H_2-H_2 and H_2-He. Regarding aerosols, we include an ammonia cloud with a clouddeck at 800 mbar, a tropospheric haze layer extending from 150 to 700 mbar, an optically thin stratospheric haze layer, and another more opaque stratospheric haze of putative auroral origin. The latter comprises fractale aggregates and its optical properties and latitudinal distribution is taken from [7], being more abundant poleward of 50S and 30N.

3. Comparisons to observations

Our radiative-convective model is run for 10 Jupiter years until equilibrium is reached. We show in Figure 1 the temperature as a function of latitude at the 10-mbar and 0.5-mbar pressure levels, compared to the temperature measured by Cassini/CIRS and ground-based TEXES/IRTF observations [3]. We also show, for comparison, the equilibrium temperature obtained when neglecting auroral aerosols. Including auroral aerosols improves the agreement with observations by warming high latitudes by $\sim$15K at the 10-mbar level. The small north-south asymetry between 60N and 60S observed at 10-mbar is well reproduced by our model and results from seasonal radiative forcing. However, at pressures lower than 1 mbar, our modeled temperatures are systematically lower than observations at low latitudes, pointing to a missing mechanism (a missing radiative contribution, or heating by wave deposition for instance).

4. Residual-mean circulation

Stratospheric circulation is driven by a combination of diabatic and mechanical forcings, resulting in a combination of transport processes: advection, stirring and mixing. On the Earth stratosphere, it has been shown that the Transformed Eulerian Mean (TEM) circulation was a good approximation to the Lagrangian

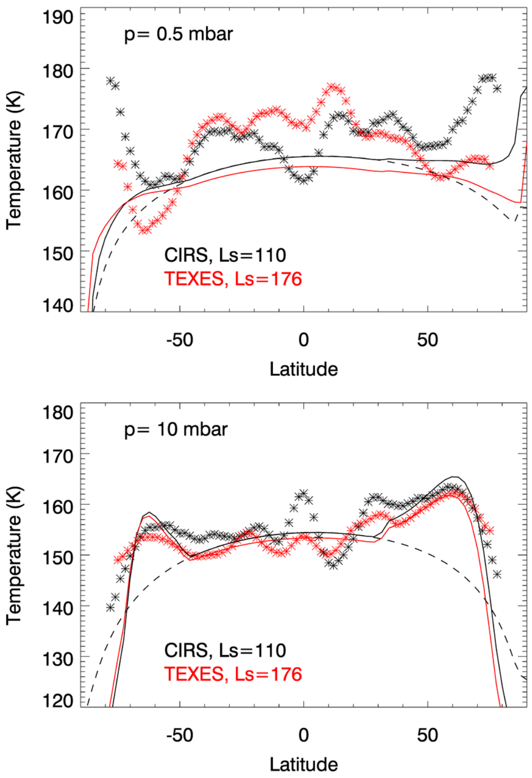

Figure 1: Temperature at radiative equilibrium (solid lines) compared to Cassini/CIRS and TEXES observations (stars). The dashed line is for a simulation neglecting stratospheric auroral aerosols.

mean circulation (relevant to tracer transport) in regions where wave breaking and dissipation was relatively weak [2, 1]. We follow this approach to estimate the two components (v^*, w^*) of the residual-mean circulation. We combine a mass-conservation equation:

$$\frac{1}{a\cos\phi}\frac{\partial(\cos\phi\, v^*)}{\partial\phi}+\frac{1}{\rho_0}\frac{\partial(\rho_0\, w^*)}{\partial z}=0 \tag{1}$$

with an energy-conservation equation:

$$\frac{\partial\overline{\theta}}{\partial t}+\frac{v^*}{a}\frac{\partial\overline{\theta}}{\partial\phi}+w^*\frac{\partial\overline{\theta}}{\partial z}=\mathcal{Q}+\mathcal{E} \tag{2}$$

where overlines denote zonal averages, θ potential temperature, ρ_0 density, a planetary radius, ϕ latitude, z altitude, $\mathcal{Q}$ the net radiative heating rate and $\mathcal{E}$ the heating rate related to eddies forcing the mean flow.

Equations 1 and 2 are solved using an iterative method under the approximations $\mathcal{E} \simeq 0$ (we neglect the eddy heat flux convergence term) and $\partial\overline{\theta}/\partial t \simeq 0$.

In the lower stratosphere (1 to 20 mbar), the residual-mean circulation we obtain is characterized by two meridional cells with rising motion at high latitudes - where the polar stratospheric haze induces significant net radiative heating - and subsidence at 10S. In the lower (20-80 mbar) and upper (0.01-1 mbar) stratosphere, the residual-mean circulation exhibits upwelling motion at the equator and subsidence at both poles, which is a consequence of the net radiative heating at low latitudes and net radiative cooling at the poles. Between 30 and 1 mbar, our residual mean stratospheric circulation resembles that obtained by [6], derived from Voyager temperature fields. However, as discussed by [4], this circulation is too weak and fails to explain the rather rapid dust migration observed after SL-9 impact. Future work will be devoted to estimate the contribution of eddies to the meridional circulation, which can be done with our GCM.

Acknowledgements

The authors acknowledge funding by the French ANR under grant agreement ANR-14-CE23-0010-01 and by CNES as support of Cassini/CIRS data interpretation.

References

[1] Butchart, N.: The Brewer-Dobson circulation, Reviews of Geophysics, Vol. 52, p.157-184, 2014.

[2] Dunkerton, T.: On the Mean Meridional Mass Motions of the Stratosphere and Mesosphere. Journal of Atmospheric Sciences Vol. 35, p. 2325-2333, 1978.

[3] Fletcher, L. N. et al.: Mid-infrared mapping of Jupiter's temperatures, aerosol opacity and chemical distributions with IRTF/TEXES, Icarus Vol. 278, p.128–161, 2016.

[4] Friedson, A. J. et al.: Transport and Mixing in Jupiter's Stratosphere Inferred from Comet S-L9 Dust Migration, Icarus Vol. 138, p.141–156, 1999.

[5] Guerlet, S. et al.: Global climate modeling of Saturn's atmosphere. Part I: Evaluation of the radiative transfer model. Icarus Vol. 238 p.110-124, 2014.

[6] West, R. A., Friedson, A. J. and Appleby, J. F.: Jovian large-scale stratospheric circulation. Icarus Vol. 100, p.245-259, 1992.

[7] Zhang, X. et al.: Stratospheric aerosols on Jupiter from Cassini observations, Icarus Vol. 226 p.159–171, 2013.