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3D GCM of Jupiter's stratosphere

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Abstract

To examine the importance of different types of forcing on stratospheric circulation, we have built a 3D GCM (general circulation model) of Jupiter's middle atmosphere with a speed-optimized version of the correlated-k radiative transfer scheme including gas and haze opacities. Here we show the effects of accurate radiative forcing and mechanical forcing from the tropospheric dynamics on the circulation, temperature structure, and zonal jet generation in the stratosphere of Jupiter.

1. Introduction

The middle atmospheres of gas giants show compositional and thermal variations resulting from a combination of chemistry, dynamics, and radiation. Radiative forcing, which consists of differential diabatic heating from solar radiation and infrared cooling, competes with underlying tropospheric processes such as upwardly propagating waves. Eddy forcing, or deviations from zonal mean flow, may play a large role in temporal and spatial variation of wind and temperature, due to the zonal torques eddies exert when they are damped. A lack of literature on the fundamental physical processes controlling circulation in giant planet stratospheres opens the door for powerful 3D models to investigate forces controlling meridional circulation, temporal changes in composition, and wave interactions in the middle atmosphere.

Historically, 2D models have been used to study the stratospheres of Jupiter and Saturn [1,6], and many fundamental questions remain unanswered about forcing in the stratosphere and upper troposphere. The extent that circulation is controlled by radiative forcing—heating from solar insolation and infrared cooling from hydrogen and hydrocarbons—or conversely by forcing from below due to waves propagating from the underlying troposphere is unclear and still being debated [1,7]. Here, we provide a 3D GCM with accurate radiative transfer to answer questions about radiative and mechanical forces controlling circulation and wave generation in the Jovian stratosphere.

2. Methods

We use the MITgcm to solve 3D hydrostatic primitive equations in a cubed-sphere grid of constant-pressure surfaces and 73 vertical layers, and include a correlated-k radiative transfer scheme to calculate gas opacity at infrared and visible wavelengths [4]. Radiative flux is calculated using a two-stream DISORT solver to simulate multiple scattering. The model is tested over a range of physical parameters including horizontal resolution of 2.8°, 1.4°, and 0.7°, and variation of wind drag timescales for relaxation of the bottom boundary to measured tropospheric winds.

3. Results

Our models are started from rest and allowed to evolve for several Jupiter years with forcing from diabatic heating and zonal wind stress imposed at the lower boundary. We present the zonal mean temperature and zonal mean zonal wind structure generated by the models, and will discuss the influence of eddy energy on meridional circulation and wave generation. Fig 1a. shows the simulated zonal mean temperature, while Fig. 1b shows the TEXES/IRTF retrieval of the zonal temperature field from Dec 2014 [2]. Similar wave structures are apparent in the equatorial between 10^2 and 10^4 Pa. Fig. 2a shows the GCM zonal mean zonal wind for the same model as Fig. 1a, for comparison to Fig. 2b., thermal wind calculated from temperature retrieval [2]. The model produces a strong equatorial jet that fluctuates in top speed but remains close to the observed Jupiter equatorial jet. Off-equatorial jet structure begins at lower levels and eventually appears throughout the vertical extent of the stratosphere.

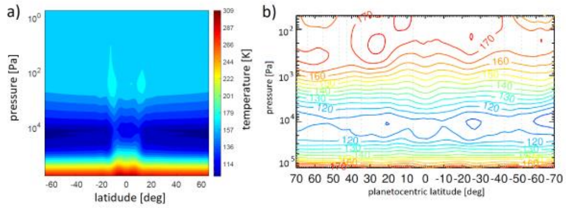

Figure 1a: Model zonal cross-section of the temperature field for a 1.4° horizontal resolution. 1b: Retrieved zonal temperature field from TEXES/IRTF in Dec 2014, contours every 10 K [2].

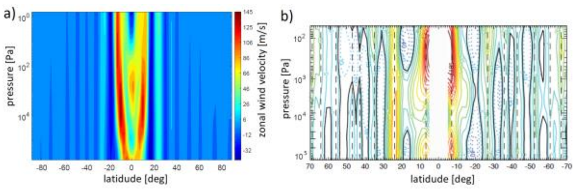

Figure 2a: Model zonal mean zonal wind for a 1.4° horizontal resolution, 1b: Zonal mean thermal wind derived from the temperature field from TEXES/IRTF in Dec 2014; contours every 20 m/s [2].

4. Discussion

Our model is able to reproduce the strong equatorial zonal jet present in the Jupiter stratosphere without the requirement of random temperature perturbations used to simulate short wavelength eddy forcing, which was necessary for some previous giant planet 3D GCMs [3,5]. The equatorial and off-equatorial zonal wind jets shape the variations in the zonal mean temperature structure in the middle atmosphere. We will further discuss the evolution and stability of the stratospheric circulation, the influence of eddy fluctuations and wave propagation, and the possible connection between meridional circulation and hydrocarbons important to radiative transfer. This project is the first step in a fully coupled radiative and chemical model of Jupiter's stratosphere and upper troposphere.

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