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`THOR-ISO`: a Global Circulation Model for Exoplanets on an Icosahedral Grid

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Abstract

In this presentation I will describe the details and first results of our new dynamical code for exoplanet atmospheres. This model is part of the Exoclimes Simulation Platform (ESP), and is a project of the Exoplanet and Exoclimes Group (see www.exoclime.org). The model I will present solves the complex physical and dynamical equations that include fundamental principles of atmospheric fluid dynamics and various idealisations of radiative transfer and dry convection, among others. I will also show the results of the first successful benchmark tests for this model, where we explore the results of the model for Earth-like and Hot-Jupiter like conditions. The analysis of the results from this complex and detailed model, will help us to have a better understanding of the diversity of climates and atmospheric circulations that we expect to find in the multitude of exoplanets already discovered.

1. Introduction

The study of extrasolar planets has become important since the discovery of a large number of these astronomical objects. The diversity of planetary characteristics observed raises questions about the variety of different climates. The influence of the astronomical and planetary bulk parameters driving new atmospheric circulations continues to be poorly understood. In the solar system the results from planetary spacecraft missions have demonstrated how different the planetary climate and atmospheric circulations can be. The study of exoplanets is going to require a study of a far greater range of physical and orbital parameters than the ones that characterise our neighbour planets of the solar system. For this reason the study of exoplanets will involve an even greater diversity of circulation and climate regimes.

The new model Thor-ISO is intended to be flexible enough to explore the large diversity of planetary atmospheres. The part of the model presented here includes the scheme which represents the resolved fluid dynamical phenomena in the atmosphere. In general the model solves the atmospheric fluid equations in a rotating sphere (fully compressible – nonhydrostatic system). The complex fluid equations are solved in a grid called icosahedral (see Fig. 1). A brief description of the methods used are included in the sections below. The results of the model are currently being analized and validated with other model results. These crucial experiments are explained in section 3.

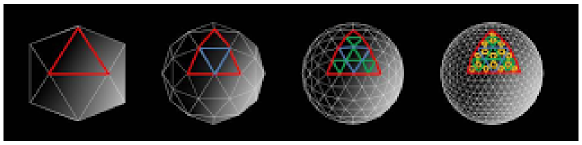

Figure 1: Model grid at different resolutions.

2. Model

The model developed solves the compressible Euler's equations:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0, \tag{1}$$

$$\frac{\partial \rho \mathbf{v}}{\partial t} + \nabla \cdot (\rho \mathbf{v} \otimes \mathbf{v}) = -\nabla p - \rho g \hat{\mathbf{k}} - 2\rho \Omega \times \mathbf{v}, \tag{2}$$

$$\frac{\partial p}{\partial t} + \nabla \cdot (p \mathbf{v}) = -(\gamma - 1) p \nabla \cdot (\mathbf{v}) + (\gamma - 1) q_{heat} \tag{3}$$

where $\mathbf{v}$ is velocity, ρ is the density and p is the pressure. The equations solved by the model do not include any of the well knonw “traditional approximations”, such as shalow atmosphere or hydrostatic approximation. The grid chosen to solve the equations is an icosahedral grid (Fig. 1), which is a quasi-uniform grid and avoids the so-called pole problem. To increase the numerical accuracy, smooth the grid distortions and move the points of the control volumes to the gravitational centres, we apply a “spring dynamic” method to the grid (Tomita et al 2001). The space

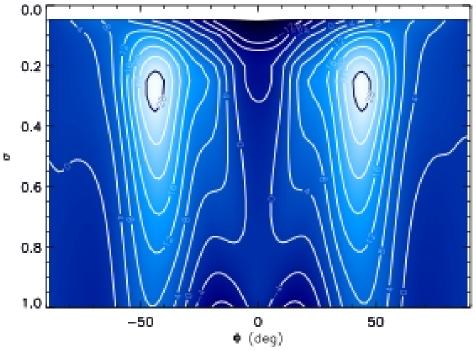

Figure 2: Earth benchmark test from Heng et al. 2000. The colours represent zonal winds averaged in time and longituude.

integration is based on a finite-volume method from Tomita and Satoh 2004. The time discretisation is based on a horizontally explicit and vertically implicit scheme. Using this method we avoid numerical instabilities due to the fast propagation of the sound waves in the tipically fine vertical resolution while keeping a reasonable time step.

To preserve numerical stability we include horizontal diffusion. This parameterisation removes the numerical noise and also represents the physical phenomena of eddy viscosity and turbulence on the subgrid scale. This model also allows us the possiblility to study deep atmospheres, which can be done by rescaling the equations by a factor which depends on the thickness of the atmosphere.

3. Three-dimentional test cases

This new model is aimed at probing a large range of planetary conditions. The two experiments explored represent a sample of this large diversity. We start exploring the "Held-Suarez" test which is an Earth benchmark test proposed in Held and Suarez 1994 and followed by a typically tidally locked hot-Jupiter benchmark test proposed by Heng et al. 2000. The results of the winds are expected to be similar to the ones shown in Fig. 2 and 3. Using our new model, we will show in this presentation how the results were achieved, what are the main mechanisms driving the atmospheric circulation in these planets and what are the advantages of using our new platform against the models that have been used recently to do exoplanet studies.

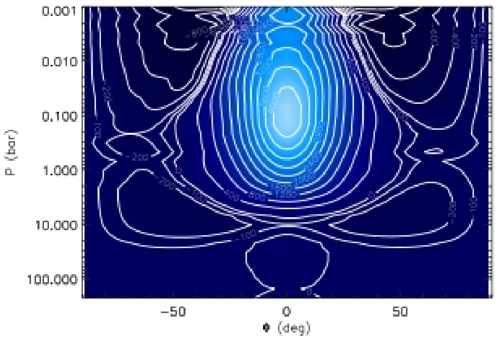

Figure 3: Hot-Jupiter benchmark test from Heng et al. 2000. The colours represent zonal winds averaged in time and longituude.

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