Modelling the atmosphere of a template "hot Jupiter" exoplanet

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Modelling the atmosphere of a template "hot Jupiter" exoplanet

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Abstract

Many models are used to study the possible atmospheric conditions of extrasolar gas giants, in particular "hot Jupiters" (e.g. [1]), gas giant planets closer than 0.1 AU to their parent stars, with orbital periods of the order of a few Earth days. It is important that the respective responses of these models to this relatively new regime be known, allowing the effects of using different models to be understood. Here, the use of an adapted form of the PUMA model is explored by carrying out an intercomparison test.

1. Introduction

"Hot Jupiter" exoplanets are now known to be common throughout the galaxy. With no examples present in our own Solar System, modelling must complement observation in determining their properties. Tidal locking combined with the extreme stellar irradiation these planets receive, orbiting between 0.01 and 0.1 AU, results in a variety of previously unexpected properties, representing an entirely new region of planetary environments.

Multiple models are used to predict the atmospheric circulation on exoplanets, each with its own characteristics and suite of definable parameters. For a degree of confidence to be established about the spread of the models' results, such results must be obtained with each model for a well-defined test case, or benchmark test. One such test was proposed by [5] and elaborated on in [3]. Here, an idealised "hot Jupiter" is specified, with the majority of model parameters tightly constrained. Such a simulation permits differences in model behaviour to be exposed that might otherwise have been a result of different input options.

2. The intercomparison test

To study exoplanetary atmospheres, an adapted version of the PUMA model (original version specified in [2]) was used. It is a 'simple' spectral GCM based on the work of [4]. Since it was designed as a model for Earth's atmosphere, various modifications were carried out to render it suitable for use on hot Jupiters. Simulations were set up as described by [5] and the 'shallow' hot Jupiter case of [3]. In each case, the model was run for a period much longer than that required to reach statistical equilibrium: model runs covered periods of over 1,000 Earth days (maximum run length: 4,000 Earth days), with the spinup time found to be 30-40 Earth days.

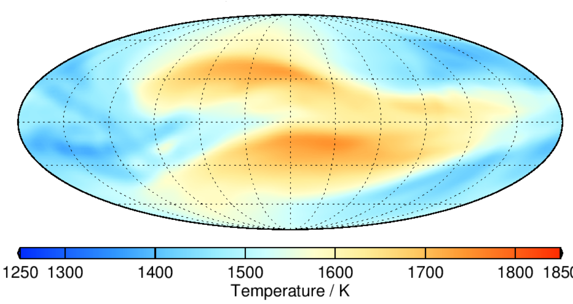

Figure 1: Temperature 'snapshot' from a model run at T42 L15 resolution, demonstrating a similar pattern to that seen in [5].

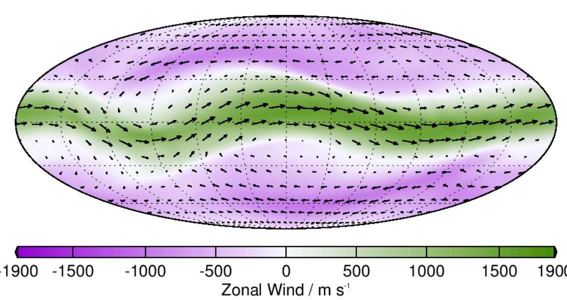

Figure 2: Wind 'snapshot' from a model run at T42 L15 resolution, from the same timestep as the image in Figure 1. Colours represent zonal (west-east) wind only, arrows full wind vectors.

Representative temperatures at specific locations (see Figure 3) are on average on the order of 10-20K higher than in the corresponding locations in [5], but the overall structure of temperature and wind fields corresponds well.

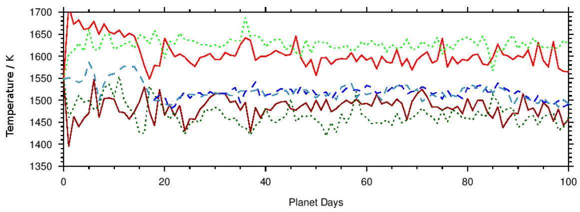

Figure 3: Representative temperature time series from a model run at T42 L15 resolution. Colours represent different locations on the planet: reds are the sub- and anti-stellar points, greens the limbs (light: east; dark: west), and blues the poles.

The effects of model resolution and certain parameter settings are also investigated, including the alteration of orbital period and thermal forcing. As well as the diagnostics shown above, which are directly comparable to those displayed in [3] and [5], time means and higher-order diagnostics are also calculated and analysed. We propose some additional statistics that could be used to better characterise model time mean states and variability in future hot Jupiter intercomparison studies.

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