EPSC Abstracts
Vol. 11, EPSC2017-579, 2017
European Planetary Science Congress 2017

Cloud modelling for brown dwarfs and young giant exoplanets

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Abstract

We implemented a cloud scheme in ExoREM, a 1D radiative-convective developed for young giant planets. This model computes cloud condensation, sedimentation and mixing. The vertical mixing is parameterized with 3D simulations of convection. The radius of cloud particles is either fixed as a free parameter or determined by comparing the characteristic timescales. The model can also simulate an inhomogeneous cloud cover.

We validated the model by reproducing the LT transition for brown dwarfs. Then, we applied it to young giant planet observed with the VLT-SPHERE instrument.

1. Introduction

Many exoplanets observed by direct imaging seem cloudy as most brown dwarfs or transiting exoplanets. These clouds affect chemistry, temperature and observational spectra. Models used for atmospheric characterization must therefore properly simulate clouds in order to allow atmospheric retrieval and an accurate determination of planetary parameters.

1.1 ExoREM

ExoREM is a 1-D radiative-equilibrium model for young giant exoplanets that we started developing in LESIA [1]. ExoREM solves for radiative-convective equilibrium, assuming that the net flux (radiative+convective) is conservative. The model is essentially valid for planets with effective temperatures between 400 and 1800 K. Opacity sources include the H2-He collision-induced absorption and molecular lines from H2O, CO, CH4, NH3, VO, TiO, Na and K. The vertical profiles of the different absorbers are calculated for a given temperature profile assuming non-equilibrium chemistry for C-, N- and P-bearing compounds by comparing chemical time constants with vertical mixing time.

2. 3D simulations of convection

In order to parameterize the vertical mixing coefficient Kzz (for clouds and chemical non-equilibrium), we performed 3D simulations with a non-hydrostatic mesoscale model [2]. The 3D model is forced with radiative tendencies from the 1D model. Convective cells form in the convective region and gravity waves propagate above. We derived the root mean square of the vertical velocity and parameterized the Kzz profile according to this velocity profile ($K_{zz}=H*w_{rms}$). We also explored the evolution of the fraction of updrafts compared to downdrafts with the effective temperature. This updraft fraction might be related to the cloud fraction.

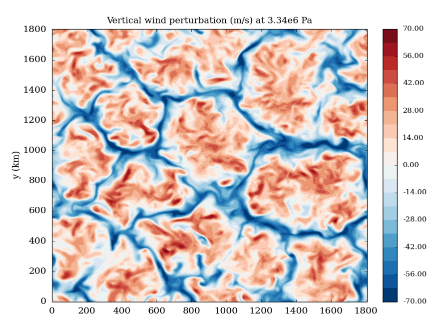

Figure 1: horizontal cross-section of the vertical wind in the convective region (red color for upward winds, blue color for downward winds)

3. 1D Cloud modelling

We implemented a cloud model that takes into account condensation, sedimentation and vertical mixing. We simulate Fe, Mg_2SiO_4, Na_2S, KCl, ZnS and H_2O clouds. The size of cloud particle can be:

1) Fixed as a free parameter
2) Determined by fixing fsed (the ratio of sedimentation velocity by vertical mixing velocity)
3) Determined by comparing the timescale of condensation, coalescence, sedimentation and mixing

We compared these 3 assumptions by simulating the photometry of brown dwarfs and the LT transition (figure 2). While the first two methods are more adapted for retrieval, the third one naturally reproduces the LT transition. With this self-consistent cloud modelling, we also predict that low gravity objects as young giant planets should be redder. Such a trend seems to be observed.
The model can also simulate an inhomogeneous cloud cover, allowing investigating the variability of brown dwarfs and young giant planets.

After validating our cloud model with brown dwarfs, we applied it to young directly imaged planets observed in particular with VLT-SPHERE. Most of these objects appear cloudy and ExoREM seems efficient for characterizing them and for determining their planetary parameters.

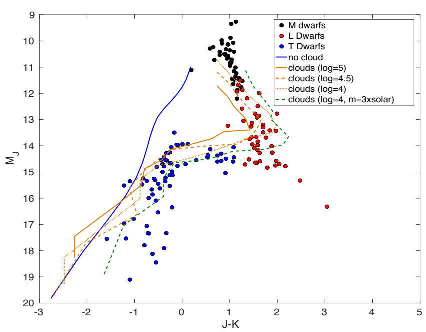

Figure 2: Magnitude-color diagram of brown dwarfs showing the LT transition. Solid and dashed lines are computed with ExoREM with/without Fe and Mg_2SiO_4 clouds.

4. Summary and Conclusions

We developed a cloud model for ExoREM that is realistic, physical and simple in order to be used both for forward modelling and retrieval. The model is validated by reproducing the LT transition for brown dwarfs and appears as an efficient tool for characterizing young directly imaged planets.

References

[1] Baudino et al.: Interpreting the photometry and spectroscopy of directly imaged planets: a new atmospheric model applied to beta-Pictoris b and SPHERE observations, *Astronomy & Astrophysics*, 2015.

[2] Spiga and Forget: A new model to simulate the Martian mesoscale and microscale atmospheric circulation: Validation and first results, *JGR* (*Planets),* 2009.