EPSC Abstracts
Vol. 13, EPSC-DPS2019-1315-1, 2019
EPSC-DPS Joint Meeting 2019

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

Three-dimensonal Mixing of Photochemical Hazes in the Atmospheres of Hot Jupiters

Maria E. Steinrueck (1), Adam P. Showman (1), Tommi Koskinen (1) and Panayotis Lavvas (2)
(1) Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, (2) Groupe de Spectrométrie Moleculaire et Atmosphérique, Université de Reims Champagne Ardenne, Reims, France
(msteinru@lpl.arizona.edu)

Abstract

The transmission spectra of many hot Jupiters show signatures of high-altitude aerosols. The nature and composition of these aerosols is unknown—they could form through photochemical processes high in the atmosphere or through condensation of gaseous species as they are being mixed upwards and cool. The vast majority of cloud and haze models trying to shed light on this question are one-dimensional. However, one-dimensional models have to make strongly simplifying assumptions about the strength of vertical mixing. Furthermore, they ignore that the strong day-night contrast on hot Jupiters and the interaction with the atmospheric circulation can lead to inhomogeneous aerosol distributions. General circulation models (GCMs) are needed to better understand how aerosols are mixed by the atmospheric circulation, what the resulting 3D aerosol distributions are, and how 1D modelers can make more informed choices to represent 3D processes as accurately as possible in a 1D framework. Especially for the case of photochemical hazes, there are no previous GCM studies looking at how they are distributed by the atmospheric circulation. As hazes are produced at much higher altitudes than condensate clouds and are expected to have small particle sizes [6], they may interact differently with the atmospheric circulation: The zonally averaged circulation on tidally locked exoplanets typically exhibits downwelling at the equator and upwelling at midlatitudes, resulting in a depletion of condensate clouds near the equator [1, 2, 3]. For photochemical hazes being produced near the top of the atmosphere, the opposite is expected: downwelling should lead to an enhanced abundance of hazes in equatorial regions. Furthermore, when simulating short-lived photochemically produced species, Zhang and Showman [4, 5] found non-diffusive effects can dominate the global-mean tracer distribution. In some cases in their study, this resulted in mixing of the tracer towards the source region in a global-mean sense. Describing such a situation in a 1D framework requires a negative eddy diffusion coefficient K_{zz}. The horizontally non-uniform production of these species was a major driver of these non-diffusive effects. While photochemical hazes differ from the photochemical species in their study in that hazes are long-lived and cannot be expected to relax toward a prescribed local equilibrium value, their non-uniform production could drive similar non-diffusive effects.

We present results from GCM simulations of hot Jupiter HD 189733b to explore the mixing of photochemical hazes and other aerosols. With an equilibrium temperature near 1,200 K, this well-studied planet is cool enough that photochemical hazes and condensate clouds with a variety of compositions are both expected to exist. We use passive tracers representing photochemical hazes as well as condensate clouds to study how hazes and clouds are transported by the atmospheric circulation. While the focus of this study is on photochemical hazes, we include condensate clouds for comparison. We present the resulting 3D distributions of each species for different constant particle sizes. Furthermore, we analyze the efficiency of vertical mixing and derive effective eddy diffusion coefficients that describe resulting global-mean particle distribution, to be used in 1D models. Our study also addresses sensitivity to initial conditions of the tracer abundance and the long-term behavior of the simulations.

Acknowledgements

This work was supported by NASA Headquarters under the NASA Earth and Space Science Fellowship Program - Grant 80NSSC18K1248.

References

[1] Parmentier, V., Showman, A. P. and Lian, Y.: 3D mixing in hot Jupiters atmospheres I . Application to the day / night cold trap in HD 209458b, Astronomy & Astrophysics, 558, A91, 2013.

[2] Charnay, B., Meadows, V. and Leconte, J.: 3D Modeling of GJ1214b's Atmosphere: Vertical Mixing Driven by an Anti-Hadley Circulation, The Astrophysical Journal, 813, 1, 15, 2015

[3] Lines, S., Mayne, N. J., Boutle, I. A., et al.: Simulating the cloudy atmospheres of HD 209458 b and HD 189733 b with the 3D Met Office Unified Model, Astronomy & Astrophysics, 615, A97, 2018

[4] Zhang, X. and Showman, A. P.: Global-mean Vertical Tracer Mixing in Planetary Atmospheres. I. Theory and Fast-rotating Planets, The Astrophysical Journal, 866, 1, 1, 2018

[5] Zhang, X. and Showman, A. P.: Global-mean Vertical Tracer Mixing in Planetary Atmospheres. II. Tidally Locked Planets, The Astrophysical Journal, 866, 1, 2, 2018

[6] Lavvas, P. and Koskinen, T.: Aerosol Properties of the Atmospheres of Extrasolar Giant Planets, The Astrophysical Journal, 847, 1, 32, 2017