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The seasonal cycle of hazy atmospheres in eccentric orbits

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Abstract

Organic aerosol hazes are common in planetary atmospheres. They form through methane photolysis by UV light and ensuing photochemistry. Planets in eccentric orbits are expected to have a seasonal cycle in their haze production. I model the haze seasonal cycle for Titan using a GCM coupled to an aerosol microphysics model (TitanCAM). The solar flux at Titan varies by about 20% between periapsis and apoapsis, thus the dissociation of CH_4 and the total production of aerosols are expected to have a similar seasonal dependence. However, the seasonal amplitude of aerosol mass density and optical depth above 340 km are larger than expected from the haze production alone due to feedback mechanisms in the atmosphere. Published estimates of haze extinction in Titan's tropical upper atmosphere have much larger variations that are most likely explained by atmospheric heating and expansion.

1. Introduction

Aerosol haze is a common feature in planetary atmospheres. In our solar system, both Titan and Pluto have organic haze layers. The exoplanet GJ1214b is also thought to have optically thick clouds or haze based on transmission spectra [1]. These particles, which form fractal aggregates, are efficient scatters at visible wavelengths and affect the energy budget of the planet.

Organic aerosols found in our solar system form through the dissociation of methane by UV light and subsequent photochemistry. Orbital parameters affect planetary UV flux and thus haze formation. Specifically, eccentricity will induce a seasonal cycle in haze production [2]. The detection of this signal depends on the planet's eccentricity, period, and the residence time of aerosol particles. Along with haze formation, planets in eccentric orbits also seasonally increase their atmospheric temperatures, thus inflating their atmospheres.

Here, Titan is used as an example to study the effects of orbital eccentricity on hazy atmospheres. Saturn's 0.054 eccentricity causes the UV flux to vary by about 20% throughout its orbit. Titan's haze was simulated with constant haze production and production scaled to the UV flux using a 3D GCM coupled to an aerosol microphysical model [3].

2. Model Results

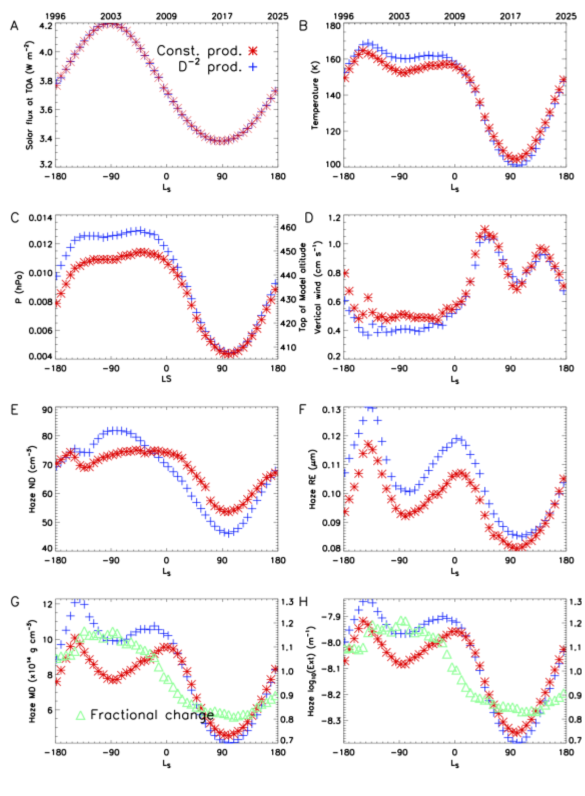

Figure 1: Comparisons between two simulations of Titan's haze with and without production scaled to the UV flux.

Titan's haze is simulated with and without a production term scaled to the UV flux. At 400 km altitude, both simulations display a strong seasonal cycle in atmospheric properties such as temperature, pressure, vertical wind speed, and haze mass and optical depth (Figure 1). Much of the seasonal cycle is driven by increased atmospheric heating. The simulation with haze production scaled to the UV flux showed an increased seasonal cycle in these quantities. The fractional change between these simulations, indicates that half of the seasonal cycle in haze mass and extinction can be explained by the direct changes to aerosol production, while the other half is a product of atmospheric feedback mechanisms (Figure 2 G,H).

3. Cassini Observations

Evidence of a seasonal cycle in haze production was not found in Cassini observations (Figure 2). The observations cannot distinguis between these two simulations because the variation between the observations is much larger than the difference between the simulations. Seasonal fluxuations in the high altitude haze are dominated by by atmospheric expansion and contraction associated with different heating rates as Titan moves closer and farther from the sun. For a given altitude, this effect is much larger than the change in haze abundance due to the UV prodcution term.

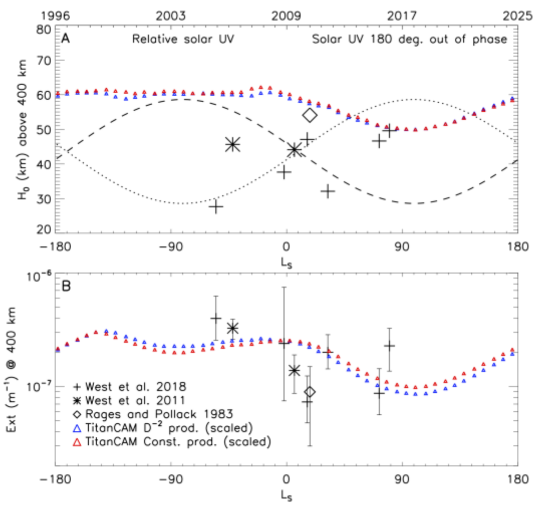

Figure 2: Observations of Titan's upper atmospheric scale height and extinction compared with TitanCAM simulations [4,5,6].

4. Summary and Conclusions

The TitanCAM model predicts that Titan's haze above 350 km undergoes seasonal fluctuations in optical depth on the order of ± 20% due to haze seasonal production, roughly twice the change expected due to the production term alone. This change, however, cannot be detected in published extinction profiles of Titan's haze, which generally have order of magnitude uncertainties. This work however highlights the importance of considering the effects of orbital eccentricity on haze production and distribution. Intermittent or seasonal haze production could be important for explaining phenomenon seen in other atmospheres and exoplanets.

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