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GCM Simulations of Seasonal Change on Uranus

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Abstract

We present the results of our Uranus spin-up experiments with an insolation-based forcing mechanism. Our model's short-wave incoming flux varies seasonally to reproduce the widely varying patterns of insolation found on the planet. We have introduced a novel, computationally efficient radiation scheme to the Explicit Planetry Isentropic Coordinate (EPIC) general circulation model (GCM) to simulate seasonal effects.

We find considerable changes in zonal wind structure that are seasonally dependent. Such seasonally driven variations in circulation may be responsible for observed changes in the planetary cloud cover and banding structure between seasons.

1. Introduction

Uranus is unique among the gas giant planets as it emits little to no internal heat; no other gas giant's effective temperature is as close to its equilibrium temperature (Table 1).

Parameter	Jupiter	Saturn	Uranus	Neptune
Axial Tilt ($^\circ$)	3.12	26.73	97.86	29.56
Effective Temp. (K)	124.4 ± 0.3	95.0 ± 0.4	59.1 ± 0.3	59.3 ± 0.8
Equilbrium Temp. (K)	113	83	60	48
Energy Balance	1.67 ± 0.09	1.78 ± 0.09	1.06 ± 0.08	2.61 ± 0.28

Table 1: Physical parameters of the giant planets. Values from de Pater and Lissauer (2001).

Consequently, the planet's atmospheric energy balance is largely mediated by incoming solar radiation. Combined with its extreme axial tilt of 97°, seasonal forcing of atmospheric dynamics on Uranus is expected to be intense. Considerable changes in cloudiness and banding have been observed between Voyager-era images during solstice and more recent HST and Keck images near equinox. Concommitent changes to the planet's circulation may have occured, as well [1].

2. Method

We simulated these seasonal changes using the EPIC GCM. To drive atmospheric dynamics we implemented a fast radiative transfer routine based on correlated-k methods. We present the results of our spin-up routines from a state of zero winds, and examine the seasonal variation in Uranus' circulation.

We have created a novel radiative transfer routine within the EPIC model that calculates short-wave insolation absorption via methane opacity. Additionally, we our routine handles long-wave infrared emission and absorption from opacity due to H_2-H_2 collision-induced absorption (CIA) as well as methane.

We based our routine on the correlated-k method [2], but replaced the small number of extinction coefficient bins in multiple wavelength regions and constant incoming flux with a large number of bins in a single wavelength region and varying flux. For our shortwave routine, we calculate the solar flux in each extinction bin by ascribing each wavelength in the extinction spectrum with a corresponding flux from a 5770K blackbody spectrum; as each wavelength is placed within an extinction coefficient bin, we simultaneously place the solar flux at that wavelength in the same bin and sum the total flux within each bin. Incoming flux is then propagated from the top layer downwards, absorbing as:

$$A_n = F_0 cos(\theta)(1 - e^{-\frac{\kappa_i \rho_n z_n}{cos(\theta)}}) \quad (1)$$

where A_n is the quantity of flux absorbed by layer n. F_0 is the incoming flux for that extinction bin, $cos(\theta)$ in the solar zenith angle, κ_i is the extinction coefficient of the ith extinction bin, ρ_n is the density of layer n, and z is the thickness of layer n. Flux that is not absorbed by the layer is then transmitted to the next layer downwards as its incoming flux, F_0. This process is repeated for each extinction coefficient bin.

For spectral features in our long-wave scheme, we calculate the opacity of the broad methane feature at 7.8 μm mixed with H_2-H_2 CIA opacity in that wavelength region using our modified correlated-k method.

Emission in this region is found by integrating a variety of blackbodies at different temperatures over this wavelength range, then fitting the temperature dependence to a functional form similar to the Planck function. For continuum long-wave emission, we calculate the Rosseland mean opacity as a function of temperature from the H_2-H_2 CIA spectrum. Continuum emission is then simply given as the Stefan-Boltzmann equation multiplied by (1 - $e^{-\tau}$), minus whatever emission was released in the 7.8 μm region. To propagate this radiation between layers and account for long-wave absorption, we use the method described by Goukenleuque, et al. [3].

3. Results and Discussion

We find considerable differences in spin-up characteristics for equinoctial versus solsticial insolation patterns. The equinoctial case generates two prograde jets at high-latitudes, commensurate with the general zonal wind observations of the planet. The solsticial case produces a notable antisymmetry about the equator, with a strong low-latitude retrograde jet at in the summer hemisphere, and a strong low-latitude prograde jet in the winter hemisphere.

The asymmetry of zonal winds about the equator has been noted in recent cloud-tracking observations of Uranus, although it is unclear if this feature is seasonal or permanent [4]. We hypothesize that this asymmetry is a relic of the most recent solstice in 1986. While the symmetric pattern of prograde zonal jets from equinox spin-up will be reinforced every half-year, the antisymmetric pattern found from solstice spin-up will destructively interfere with the opposite antisymmetry generated from the prior solstice.

4. Conclusions and Future Work

Our model demonstrates considerable changes in global circulation between equinox and solstice spin-up experiments. We attribute the changes observed in planetary cloud cover and banding structure between seasons to these changes in circulation patterns. Furthermore, we believe the asymmetry found in Uranus' zonal wind structure is transient, and will likely change with season.

Future endeavors will focus on active cloud formation, concommitent latent heat release, and radiative effects of cloud formation. We will investigate the subsequent effects of radiative and dynamically active clouds on planetary circulation.

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