EPSC Abstracts
Vol. 13, EPSC-DPS2019-745-1, 2019
EPSC-DPS Joint Meeting 2019

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

EPIC Modeling of Large Scale Dynamical Features of the Gas Giants

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Abstract

We use the Explicit Planetary Isentropic Coordinate General Circulation Model (EPIC GCM), which includes an explicit calculation of cloud microphysics for various condensing species (e.g. ammonia, water, methane and hydrogen sulfide) to investigate dynamical features observed in gas giant atmospheres. The evolution of these features are strongly coupled to the structure of the atmosphere, and thus, these models help constrain the temperature structure, composition and winds speeds on these planets. We present results from our study of Jupiter's 24°N jet and Neptune's dark spots. On Jupiter, we simulate the formation of convective plumes, which are driven by latent heat release from water condensation. Our initial results show that the convective activity is strongly constrained to specific latitude bands, likely due to the meridional temperature structure. On Neptune, we study the shape oscillations and latitudinal drift of the GDS-89 and more recent vortices such as the Northern Dark Spot (NDS-2018). The dark spot shows a sharp contrast in the methane vapor density within and outside the vortex. We present results of the drift rate and shape oscillation, which match previous studies, and also a radiative transfer analysis relating the change in albedo within the vortex to the dynamics of the atmosphere.

1. Neptune Vortices

A recent observation as part of Hubble Outer Planet Atmosphere Legacy (OPAL) program revealed a new dark spot with bright companion clouds in Neptune's northern hemisphere, NDS-2018. The structure is the most recent of large scale geophysical features to be observed on the ice giants, and their dynamical properties need to be further constrained. The anticyclonic structures exhibit surprising variability in terms of vortex evolution, shape, drift, cloud distribution, and shape oscillations. In the case of the Great Dark Spot observed by the Voyager spacecraft (GDS-89), equatorial drift was observed [1, 2] as opposed to the poleward drift of other recent dark spots, such as the SDS-2015 [3, 4]. These observations can be used to diagnose the local atmospheric conditions.

An analysis of overlying orographic cloud features shows promising insight into the dynamics of clouds on Neptune, as the features are directly impacted by the underlying atmospheric structure. To that end, it is necessary to apply a cloud microphysical model to make a more complete representation of dark spots. Consequently, we use an updated microphysics calculation implemented in the Explicit Planetary Isentropic Coordinate (EPIC) GCM [5, 6] to account for the condensation of methane, and we investigate the dynamics of vapor and subsequent cloud formation on Neptune by modelling large scale vortices.

We seek to answer the following questions: (i) What causes the "darkness" of large scale vortices? (ii) How does the effect of active methane condensation affect the evolution of the vortex? (iii) How is the vorticity in the spot coupled to the vapor field? To investigate these questions, we use an increased grid resolution and increased number of vertical layers in the column compared to previous studies.

1.1 Results

We run up to 100 day simulations to investigate stability, drift rate, and companion clouds throughout the model, with the ultimate goal of achieving similarities to the observations of GDS-89 and other vortices. Influencing factors include initial vortex coordinates, size, and velocity as well as atmospheric deep abundance and relative humidity of methane. As shown in Figure 1, we match the equatorial drift of the GDS and show that in terms of vapor, the spot grows as the vor-

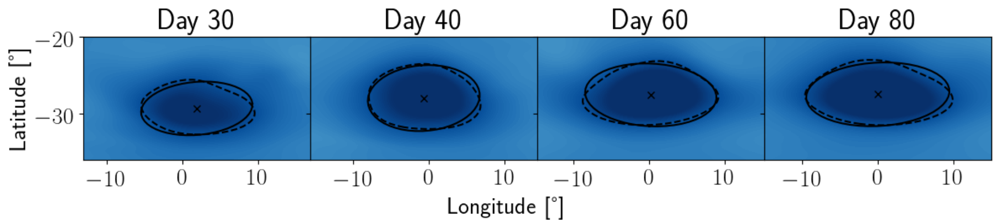

Figure 1: Select timesteps from a 100 day simulation of Neptune's GDS-89 using the EPIC model with active microphysics for methane and 40 times solar carbon abundance. The blue is integrated column density of methane vapor with darker regions indicating areas of low density. The solid line is the fitted ellipse using dashed line, which is the vapor field contour.

ticity decreases. Integrated vapor density is related to the mean opacity in the atmosphere, and as such, we consider vapor density to be better correlated with the observational data, as opposed to potential vorticity. Consequently, it is a better parameter for characterizing the vortex, and tracking its features. Simulations of the NDS-2018 and other vortices and radiative transfer analysis will continue to constrain the dynamics of these dark spots.

2 Moist convective plume formation on Jupiter

On Jupiter, convective plume formation has been observed to occur periodically. These plumes are perceived to be strongly coupled to the dynamics of the banded structure. [7] proposed that the generation of convective plumes due to latent heat release from water condensation in the South Equatorial Belt was responsible for the morphology of the size and color of the belt. Similarly, in the 24°N jet, plumes of white condensibles (likely ammonia) have been observed [8, 9]. With the EPIC model, we simulated the region surrounding the 24°N jet, and instilled random perturbations to promote convective instabilities. The evolution of the vapor field due to the perturbations would lead to regions of high water humidity, which on condensation drives the plumes. We find that the plume formation is restricted to specific latitude bands: the jet and the North Equatorial Belt are conducive of convection, while the North Tropical Belt is not. To fully study the nature of plume development and resolve the cloud formation, we are adding a moist-convective scheme to the EPIC model.

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