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A Numerical Examination of Companion Cloud-Vortex Morphology on the Ice Giants

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Abstract

Some ice giant vortices have been accompanied by long-lived cloud features. Numerical simulations of these cloud-vortex systems have shown that the clouds may have potentially significant effects on the vortex behavior. Simulations with greater details will further define the physical relationship between the vortices and their companion clouds.

1. Introduction

Large geophysical vortices or "dark spots" on Uranus and Neptune have often been paired with sizeable, long-lived clouds features. These "bright companions" are likely orographic in nature, forming as a consequence of surrounding gas being lifted to higher altitudes in the vicinity of the vortex, in turn leading to condensation as the temperature decreases with altitude. The observed shape, size, and dynamics of the cloud are therefore dependent on the nature of the vortex.

In turn, the existence of a companion cloud appears to influence the nature of vortex. Recent computational simulations of the original Great Dark Spot of Neptune (GDS-89) have shown that vortices without companion clouds tend to exhibit more prominent shape oscillations and less stability when compared to similar vortices with companion clouds. Likewise, simulations on Uranus have shown that clouds can stabilize and significantly increase the life spans of vortices. These interactions suggests that these phenomena are more properly considered as cloud-vortex systems, in which the dynamics and morphology of each component influences the other.

Two particular targets have been selected for this investigation. The first is the archetype vortex-companion cloud system, GDS-89. Observed by Voyager II, this system exhibits a complex morphology, with the vortex oscillating in shape and orientation with an eight-day period while steadily drifting towards the equator at more than a degree in latitude per month. The Bright Companion cloud likewise changes appearance in this process, located along the southern edge of the vortex but changing size and shape as the vortex oscillates. The second target is the "Berg" cloud feature. This feature persisted for many years in the vicinity of 34 degrees south latitude, but then from roughly 2005 to 2009 it appeared to drift towards the equator, eventually fading from view [1]. This gradual drift suggests that the Berg may not have simply been an isolated cloud feature but part of a cloud-vortex system similar to GDS-89. While the vortex remains unobserved in this case, the changes in the observed cloud structure as it drifted equatorward are distinctive, making it an interesting subject for cloud morphology simulation.

2. Computational Methodology

The simulation approach employed uses the Explicit Planetary Isentropic Coordinate General Circulation Model (EPIC GCM) [2]. The methodology for this work is to first define a set of initial conditions known to generate stable vortices and companion clouds. This configuration includes a uniform distribution of methane humidity in each layer and induced perturbations designed to generate the vortex. Once a basic configuration is established, simulations are allowed to evolve without external influence and the resulting dynamics are analyzed and compared to observations. Initial conditions are then varied in a parametric fashion to determine the effect of changing the initial model assumptions. Over time, this process yields reasonable matches to the observations and can potentially reveal the role of various physical processes within the phenomena.

3. Current Results

Most of the work to date has emphasized simulation of the vortex—the cloud model was relatively simple and was considered satisfactory if it produced a cloud of roughly the desired size and location (Fig. 1). This emphasis on the vortex motions required longer runs of several simulated months, and as such favored lower resolution grids, particularly in the vertical direction [3]. These simulations have shown that a companion cloud can change the dynamics of the vortex—in GDS-89 simulations, vortices that developed companion clouds had lower amplitude shape oscillations compared to comparable vortices that failed to form clouds due to lower initial global humidity (Fig. 2). On Uranus, the addition of the cloud model has stabilized vortices that had previously tended to shear away, allowing them to persist for multiple months [3].

The inclusion of a more complete ice giant microphysics model, based on one previously developed for EPIC simulations of Jupiter [4], has opened the possibility of more accurately representing the cloud. This requires a different approach emphasizing higher resolutions over shorter time scales. Using this approach further illustrates the physical interaction of the cloud and vortex. In addition, better modeling allows consideration of the morphology of cloud and what conditions will generate companion clouds that match the observed sizes, shapes, and dynamic motions. This is particularly relevant to simulations of the "Berg", as here only clouds are visible.

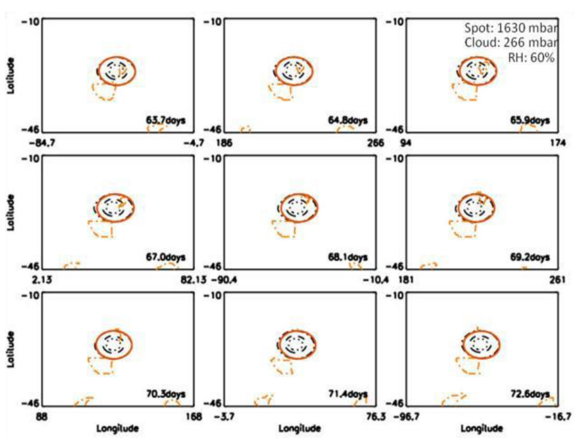

Figure 1: Simulation of a GDS-89 vortex with methane cloud companion. Black dashed lines are contours of potential vorticity, the solid red line an elliptical fit to the vortex in the 866 mbar layer, the dashed orange contour to the southwest of the vortex is the companion methane cloud.

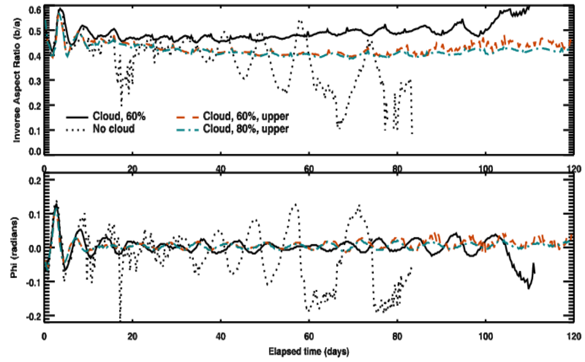

Figure 2: GDS-89 simulated shape oscillations in aspect ratio and major axis angle (Phi) for an unstable, cloud-free vortex (No cloud) and more stable, lower amplitude oscillations for the remaining cases with companion clouds with a similar vortex.

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