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Climate modeling on Triton with a hierarchy of models

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1. Introduction

In 1989, the Voyager 2 spacecraft flew by Triton and revealed several aspects of its 1.4-Pa N_2 atmosphere. In particular, hints of dynamical activity were provided by the high resolution images of the south pole of Triton, which showed (1) dark wind streaks on the surface, preferentially oriented toward North-East, (2) bright elongated clouds confined within 3 km altitude, (3) plumes of dark material (from the geysers) blown away by horizontal winds at 8 km altitude (tropopause), mostly toward west [1][2].

In addition to the Voyager data, several ground-based observations of Triton's as well as modeling effort have been performed in the last decades, leading to different scenarios for the surface distribution of the volatile and non-volatile ices [3][4][5][6], as well as a record of atmospheric pressure [7][8] and CH_4 and CO column densities [9].

Here we present numerical simulations of Triton's climate performed with a hierarchy of models based on straightforward universal physical equations.

Our goal is to compare the available atmospheric and surface observations with our model results to constrain the surface ice distribution on Triton and the possible atmospheric circulation regime.

2. Methods and models

2.1 The Volatile Transport Model (VTM)

This 2D surface thermal model is derived from the Pluto volatile transport model, and takes into account the volatile cycles of N_2, CH_4 and CO [10], a glacial flow scheme for N_2 ice [11] and the seasonal variation of the subsolar point specific to Triton. This variation is complex, and we used the solution from [12], which we extrapolated to simulate Triton over the last millions of Earth years.

As in the Pluto VTM, we consider that Triton's atmosphere is very thin and almost transparent so that it has a negligible influence on the surface thermal balance. We parametrize the atmospheric transport using a characteristic time for the redistribution of the surface pressure and trace species, based on reference 3D climate simulation. We use the VTM to investigate where the volatile ices tend to accumulate on Triton and compare the results with the available observations. In particular, we try to find a combination of ice distribution that is consistent with Voyager 2 images and ground-based spectroscopic observations and with the evolution of surface pressure as retrieved from stellar occultations.

2.2 The Global Climate Model (GCM)

The 3D model of Triton's atmosphere is also derived from the Pluto 3D GCM [13]. It takes into account the full 3D dynamics, as well as sublimation and condensation cycles of N_2, CH_4, and CO, cloud formation, atmospheric circulation and turbulence, radiative transfer, and formation of organic haze [14].

We use the "best" VTM results (that best match observations) as initial states for our reference GCM simulations, as they contain equilibrated combinations of surface conditions, such as soil temperatures and ice distributions. Our GCM simulations typically cover the period 1970 to the present. We also investigate further the thermal structure of Triton's atmosphere using a 1-D radiative model.

3. Preliminary results

3.1 Surface ice distribution

In most of our VTM simulations, a perennial polar cap of nitrogen forms in the northern hemisphere. Its extent strongly depends on the thermal inertia, the surface albedo used for N_2 ice and the surface bedrock, and the total surface N_2 ice reservoir. CO ice remains mixed within N_2-rich ice. CH_4 ice mostly remains mixed within N_2-rich ice too, but CH_4-rich deposits may exist in the equatorial regions, along the N_2 polar cap, due to N_2 sublimation leaving CH_4-rich behind.

3.2 General circulation

The sublimation of N_2 in the southern hemisphere and its condensation in the northern hemisphere (in the polar night) induce a sublimation flow directed from South to North. By conservation of angular momentum, this leads to a general circulation characterized by retrograde winds reaching up to 10 m s^{-1} above the equator (Fig. 1).

3.3 Horizontal winds above the south polar cap

The near surface winds obtained in the GCM above the south polar cap are in the retrograde direction, which is consistent with the observations of dark surface wind streaks. The prograde winds around 7−9 km above the south polar cap, inferred from Voyager observations, are not reproduced in our reference GCM simulations. Further investigation is required to explain these winds.

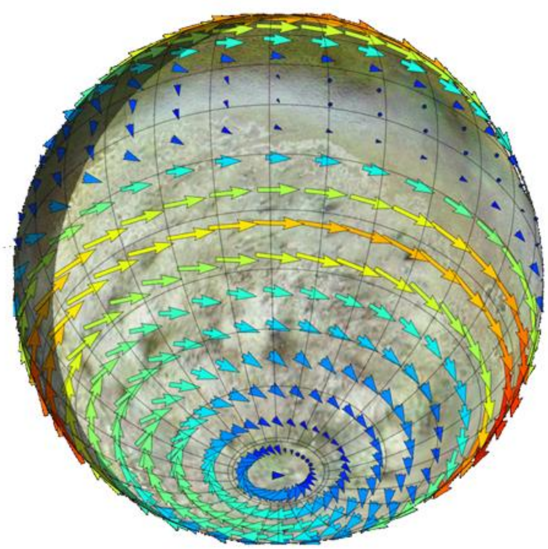

Figure 1: A map of the horizontal winds at 1 km above the local surface, obtained from the LMD GCM simulation in southern summer.

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