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Elevation-dependant CH_4 condensation on Pluto: what are the origins of the observed CH_4 snow-capped mountains?

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Abstract

Pluto is covered by numerous deposits of methane ice (CH_4), with a rich diversity of textures and colors. However, within the dark tholins-covered equatorial regions, CH_4 ice mostly shows up on high-elevated terrains. What could trigger CH_4 condensation at high altitude?

Here we present high-resolution numerical simulations of Pluto's climate performed with a Global Climate Model (GCM) designed to simulate the present-day CH_4 cycle.

1. Introduction

The exploration of Pluto by the New Horizons spacecraft in July 2015 revealed a surface covered by numerous deposits of methane-rich ice (CH_4), with a rich diversity of textures and colors [1-2]. At high northern latitudes, CH_4-rich ice has been widely detected and may form a thick mantle covering the water ice bedrock [2-5]. In the equatorial regions, eastward of the Sputnik Planitia N_2 ice sheet, massive CH_4-rich deposits form the Bladed Terrain, a distinctive landscape on Pluto exhibiting steep parallel N-S-oriented ridges and situated on high ground, above 2 km [6]. Westward from Sputnik Planitia, the dark tholins-covered Chtulhu region mostly appears depleted in volatile ice, but New Horizons revealed the presence of CH_4-rich frosts on some crater rims and on top of the highest peaks (Figure 1) [3-5].

On the Earth and on Mars, as moist winds blow toward a mountain, it rises and cools adiabatically, leading to condensation and formation of snow on top of the mountain. Could this process apply to Pluto too? Climate simulations show that katabatic downslope near-surface winds dominate everywhere on Pluto [7], therefore suggesting a different mechanism.

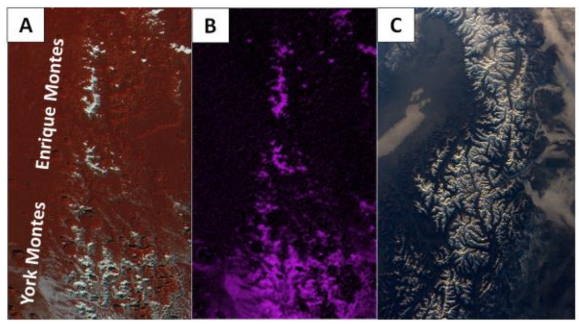

Figure 1: (A) the ~100-km long CH_4 snow-capped ridges of Enrique Montes within Cthulhu Macula (147.0°E, 7.0°S), seen in an enhanced Ralph/MVIC color image (680 m/pixel). The location of the bright ice on the mountain peaks correlates with the distribution of CH4 ice, as shown by (B) the MVIC CH_4 spectral index map of the same scene, with purple indicating CH_4 absorption. (C) Terrestrial water-ice capped mountain chains.

2. Model and simulation settings

We use the Pluto Global Climate Model (GCM) of the Laboratoire de Météorologie Dynamique (LMD), which is designed to simulate the present-day climate and CH_4 cycle on Pluto [7]. To simulate a typical Pluto day as in 2015, we perform a simulation similar to the one presented in [7] except for the following modifications. First, we use the latest topography data of Pluto [8], which covers the northern hemisphere, Sputnik Planitia and its surroundings. We add perennial CH_4 deposits in the equatorial regions where the Bladed Terrains are observed. Second, the initial state of the simulation is obtained for Earth year 1984 from 30 million years simulations performed with the Pluto volatile transport model [9-10]. Last, we use a basic horizontal resolution (7.5° in latitude, 11.25° in longitude) for the years 1984-2014 and a higher spatial resolution of 2.5° in latitude and 3.75° in longitude for the years 2014-2015.

3. Results

3.1 Reference simulation

The model predicts CH_4 condensation at high-altitude in the equatorial regions on top and on the flanks of the highest mountains such as the Enrique Montes, with an excellent agreement with New Horizons observations (Figure 2.). CH_4 deposition is also predicted on top of the Norgay Montes and York Montes, which appears to coincide with brighter zones in Cthulhu. At these locations, a net CH_4 ice accumulation reaching 0.01 kg m^{-2} (~20 μm) per day is obtained with the model.

3.2 Simulation with albedo feedback

On Pluto, once an initial CH_4 frost grows to few millimeters, the surface albedo increases thus decreasing the surface temperature and allowing more CH_4 to condense there. On this basis, we perform another simulation with an albedo feedback parametrization, and obtain a maximum daily CH_4 frost deposition of 80 μm on top of Enrique Montes. Over the last 15 Earth years (beginning of Northern Spring), such accumulation would form a 3-m thick CH_4 frost.

3.3 Mechanisms of the preferential CH4 condensation at high altitude

Why does CH_4 ice accumulate on top of these mountains? We find that this high-altitude condensation is a result of the atmosphere being enriched in gaseous CH_4 at high altitude, thus allowing CH_4 condensation on top of mountains only. This peculiar vertical distribution of gaseous CH_4 in Pluto's atmosphere is mainly controlled by the diurnal N_2 cycle and the induced sublimation flow. At the EPSC-DPS meeting, we will further detail these mechanisms.

4. Acknowledgements

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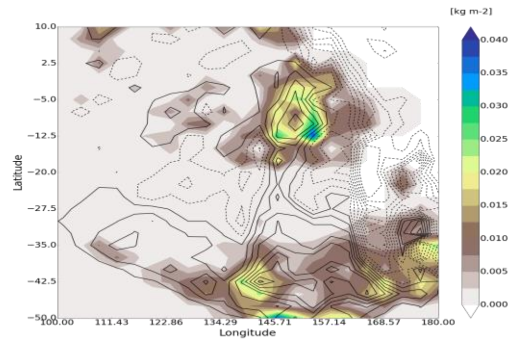

Figure 2: Net diurnal surface CH_4 ice accumulation in the region shown by Figure 1, as obtained in our simulation for July 2015. Superimposed topography contours are at 300-m intervals.

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