PLUTO'S ATMOSPHERE DYNAMICS: HOW THE NITROGEN HEART REGULATES THE CIRCULATION. T. Bertrand[1], F. Forget[2], A. Toigo[3], D. Hinson[4,5], [1]Space Science Division, NASA Ames Research Center Moffett Field, CA 94035, USA (tanguy.bertrand@nasa.gov), [2]Laboratoire de Météorologie Dynamique, IPSL, CNRS, Sorbonne Université, Paris, France (forget@lmd.jussieu.fr), [3]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, United States (anthony.toigo@jhuapl.edu), [4]Carl Sagan Center, SETI Institute, Mountain View, CA 94043, USA,[5]Department of Electrical Engineering, Stanford University, Stanford, CA 94305, USA (dhinson@stanford.edu)

Introduction: Pluto's tenuous atmosphere is mainly nitrogen and is in solid-gas equilibrium with the surface nitrogen ice [1]. Over the past three decades, Earth-based stellar occultations have been an effective method to study the evolution of its temperature, composition, pressure, and density [e.g. 2-7]. In particular, these datasets revealed (1) a much warmer atmosphere (70-100 K) than the surface (40 K), with a strong inversion in the first 20 km above the surface, (2) a threefold increase of surface pressure since 1988, and (3) global-scale oscillations in the vertical density and temperature profiles [8-10], which could be due to inertia-gravity waves and atmospheric tides forced by diurnal variations of N_2 sublimation [11,12]. This unique atmospheric structure and activity hinted at an exotic atmospheric circulation regime.

In 2015, the observations made by the New Horizons spacecraft revealed an astonishing world and provided unprecedented constraints on the nature of Pluto's surface and on the state of its atmosphere [13-16]. Although no atmospheric diurnal variations were observed nor were clouds unambiguously detected [17,18], hints of dynamical activity were highlighted by magnificent haze layers, possibly due to gravity waves arising from sublimation and orographic forcings [19]. Evidence of eolian activity was provided by some observed surface features, interpreted to be wind streaks and linear dunes [20].

Finally, Global Climate Models of Pluto's atmosphere (GCMs) have recently emerged to explore in deeper details the dynamics of Pluto's atmosphere [21,22].

At the Pluto conference, we will review our knowledge of Pluto's dynamics and present the latest results obtained with a post-New Horizons version of the Pluto GCM developed at the Laboratoire de Météorologie Dynamique (LMD).

Challenges of modeling Pluto's atmosphere: Because Pluto orbits far from the Sun, its seasonal cycle is much longer than on the Earth (one Pluto year is 248 Earth years). Above all, Pluto receives very little energy, which results in low sublimation-condensation rates and slow surface processes. This is an issue for Pluto GCMs because simulations need to be performed over many Pluto years in order to be insensitive to the initial state, which requires significant computing time. To solve this issue, a volatile transport model of Pluto is used to create initial states for the GCM which are the results of 30 million years of volatile ice evolution and contain equilibrated combinations of surface conditions, such as soil temperatures and ice distributions [23]. This approach enables 3D GCM simulations of Pluto to be performed typically from 1984 to 2015, the first 20 years corresponding to a spin-up time for the atmosphere.

Near surface circulation: GCM studies showed that near-surface winds on Pluto are controlled by the topography and the N_2 condensation-sublimation flow [21,22]. They showed that down-slope katabatic winds unavoidably dominate everywhere on Pluto's globe, as a result of the surface being much colder than the atmosphere. At the locations close to N_2 ice deposits, katabatic winds may be balanced during daytime by N_2 sublimation flows, and strengthened during nighttime by condensation flows.

Within Sputnik Planitia, the prominent equatorial N_2 ice sheet, the LMD GCM predicts an intense near surface western boundary current in 2015, which is consistent with the dark wind streaks observed on the icy plains of this region. This atmospheric current could also explain the differences in ice composition and color observed in Sputnik Planitia, and could play a role in the formation of the cold near-surface atmospheric layer south of the basin as seen by New Horizons [23].

General circulation in the upper atmosphere: In addition, we find that this peculiar near-surface flow inside Sputnik Planitia leads to a significant transport of N_2 from the northern to the southern hemisphere, which is enough to trigger westward winds at all latitudes, by conservation of angular momentum. Thus, we find that the general circulation of Pluto's atmosphere is dominated by a retro-rotation, with zonal westward winds reaching 8-13 m s^{-1} at altitudes 20-250~km. Similar results are obtained regardless of the N_2 ice distribution outside Sputnik Planitia.

Multi-year simulations of Pluto's climate: We extended the LMD GCM simulation at relatively low resolution to about three Pluto years. We find that the retro-rotation regime is maintained during most of Pluto's year, with maximum westward winds centered above Sputnik Planitia. This is because there is always enough cross-equatorial transport of gaseous N_2 in Sputnik Planitia (and outside), from north to south in northern spring and summer or south to north at the opposite season.

This exotic circulation regime could explain many of the geological features and longitudinal asymmetries in ice distribution observed all over Pluto's surface, such as (1) The presence of the CH_4-rich Bladed Terrain Deposits east of Sputnik Planitia, and that of the volatile-free dark region of Cthulhu at the opposite longitudes, (2) The formation of the bright eastern part of Tombaugh Regio (the right lobe of the heart), covered by covered by N_2-rich and CH_4-rich frosts, (3) The formation of the so-called blades on top of the Bladed Terrain deposits, which display a dominant N-S orientation.

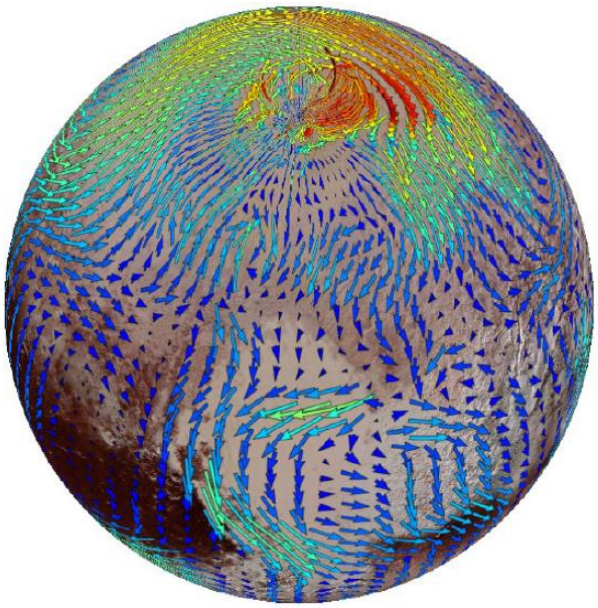

Figure 1: Map of the horizontal winds at 1 km above the local surface, obtained from an LMD GCM simulation at the date of July 14, 2015 (the local time at longitude 180° is 2:00pm). At the center of the figure, within the bright half-heart shaped Sputnik Planitia ice sheet, we obtain a western boundary current (~5 m s^{-1}) crossing the basin from the north to the south. These winds, induced by the sublimation of nitrogen in the northern latitudes of the basin and the Coriolis force, transport cold nitrogen air toward the southern latitudes of the basin.

Conclusions: Despite a frozen surface and a tenuous atmosphere, Pluto's climate is remarkably active. The nitrogen icecap within Sputnik Planitia seems to be the heart of this climate system, since it controls the evolution of surface pressure, regulates the general circulation, and triggers atmospheric waves and tides.

References:

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