ATMOSPHERIC CIRCULATION AND DISTRIBUTION OF NITROGEN ICE ON PLUTO DUE TO SURFACE ICE AND TOPOGRAPHY. Alejandro Soto[1], Scot Rafkin[1], Tim Michaels[2], [1]Southwest Research Institute, Boulder, CO, USA; asoto@boulder.swri.edu; [2]SETI, Mountain View, California, USA

Introduction: Prior to the arrival of the New Horizons spacecraft, the expectation was that the volatile surface ice distribution on the surface of Pluto would be strongly controlled by the latitudinal temperature gradient resulting primarily from the slow seasonal variations of radiative-conductive equilibrium [1, 2, 3]. If this were the case, then Pluto would have broad latitudinal bands of both ice covered surface and ice free surface, as dictated by the season. Further, the circulation, and thus the transport of volatiles, was thought to be driven almost exclusively by sublimation and deposition flows (so-called "condensation flows") associated with the volatile cycle [1, 2, 3, 4]. In contrast to expectations, images from New Horizon showed an extremely complex, heterogeneous distribution of surface ices draped over topography of substantial geologic diversity[5]. To maintain such an ice distribution, the atmospheric circulation and volatile transport must be more complex than previously envisioned. Topography, the distribution of volatile ice, and an overall large-scale atmospheric circulation at least partly independent of the condensation flows must play a role.

Simulations where topography, surface ice distributions, and volatile cycle physics are added individually and in various combinations are used to individually quantify the importance of the general circulation, topography, surface ice distributions, and condensation flows. It is shown that even regional patches of ice or large craters, much like that of Tombaugh Regio, can have global impacts on the atmospheric circulation, the volatile cycle, and hence, the distribution of surface ices. This work demonstrates that explaining Plutos volatile cycle and the expression of that cycle in the surface ice distribution requires consideration of atmospheric processes beyond simple vapor pressure equilibrium arguments.

Model description: A newly developed general circulation model (GCM) for Pluto is used to investigate the unexpected and highly heterogeneous distribution of nitrogen surface ice imaged by the New Horizons spacecraft on the surface of Pluto. The GCM is based on the GFDL Flexible Modeling System (FMS) dynamical core, solved on a latitude/longitude discretized horizontal grid and a pressure based hybrid vertical coordinate [6]. Model physics include a 3-band radiative scheme, molecular thermal conduction within the atmosphere, subsurface thermal conduction, and a nitrogen volatile cycle. The radiative-conductive model, which is based on the Yelle-Lunine scheme [7], takes into account the 2.3, 3.3 and 7.8 um bands of CH_4, including non-local thermodynamic equilibrium effects. The subsurface conduction model assumes a water ice regolith. In the case of nitrogen surface ice deposition, additional suprasurface layers are added above the water ice regolith to properly account for conductive energy flow through the nitrogen ice. The nitrogen volatile cycle is based on a vapor pressure equilibrium assumption between the atmosphere and surface.

Simulations: We conducted a suite of simulations for a variety of initial conditions in order to understand the interaction between the atmospheric circulation and Pluto's surface conditions. The initial simulations are simplified, idealized scenarios that provide insight into the basic circulation patterns. We systematically added new surface features, including surface ice and topography to understand how the atmospheric circulation changed in response to these features. The presence of topography and regional ice strongly perturbs the general circulation and volatile cycle. Here we discuss two representative simulations: one without any initial regional ice or topography and one with an initial regional ice patch overlying a topographic pit.

The first simulation was initialized with no surface ice and flat topography. This simulation is the GCM equivalent of previous energy balance model simulations [1, 2, 3]. The simulation was started at perihelion and rapidly deposited nitrogen ice on the poles (see Figure 1). The zonal wind field shows thermal tides in the northern hemisphere and waves in the polar regions, which are associated with the polar ice cap edges (see Figure 1). There is slightly more expansive ice distribution in the south due to the growing polar night in that hemisphere.

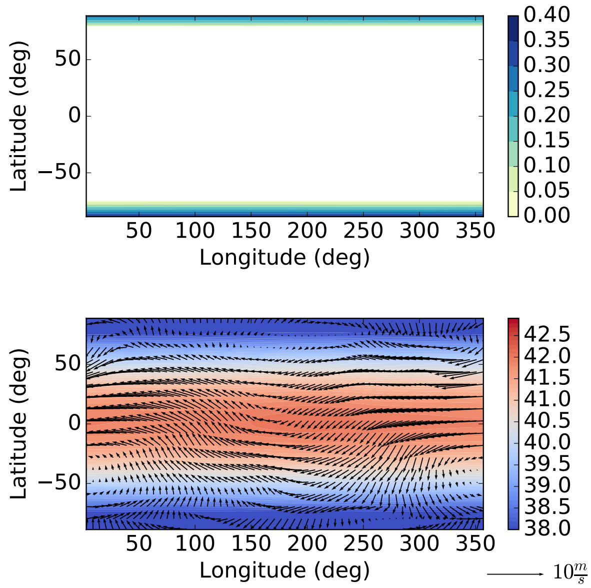

Figure 1: ***Top:*** **Starting with no initial surface nitrogen ice the GCM simulation forms polar caps at 45 Pluto days after perihelion. The color contours show the nitrogen ice depth in units of meters. *Bottom:* The zonal wind after 45 Pluto days, shown as arrows in units of m/s. The color contours are the surface temperature in Kelvin.**

The simulation initialized with a Tombaugh Regio style ice patch, as shown in Figure 2, the resulting circulation is drastically different. The simulation begins with an equatorial patch of ice placed in a 500 meter deep pit, which is intended to simulate Tombaugh Regio in an idealized manner. The existence of this equatorial ice directly affects the atmospheric circulation, as seen in the near surface zonal winds, shown in Figure 2. Figure 2 shows the near surface winds flowing outward from the equatorial pit and interacting with the mean winds. Since there are no polar caps in this simulation, the circulation is dominated by the tropical winds driven by the equatorial patch of ice.

Conclusion: In these two idealized simulations, the different types of surface conditions have drastically different effects on Pluto's atmospheric circulation. By systematically adding each surface feature individually and then as a collection, we can identify the various contributions to the overall atmospheric circulation on Pluto. *Figures 1 and 2*

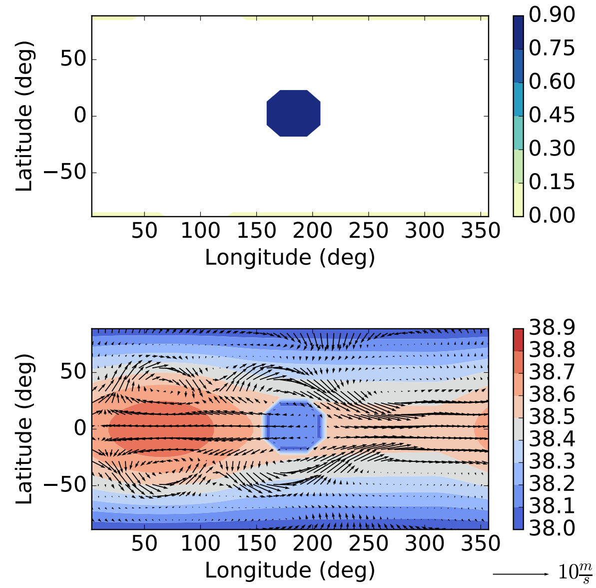

Figure 2: ***Top:*** **The "Tombaugh Regio"-like simulation starts with an equatorial patch of ice placed in a 500 meter deep pit. The color contours show the nitrogen ice depth in units of meters after 5 Pluto days. *Bottom:* The zonal wind after 5 Pluto days, shown as arrows in units of m/s. The color contours are the surface temperature in Kelvin. The equatorial patch of ice is clearly seen in the surface temperature.**

clearly show that the presence of topography and regional ice strongly perturbs the general circulation and volatile cycle.

This work not only provides insight into various circulations likely present in Pluto's current atmosphere, but will also provide the framework for understanding Pluto's atmospheric circulation throughout its history. The currently observed surface features, including the distribution of ice, may or may not have existed throughout the bulk of Pluto's lifetime.This framework will allow us to speculate on how Pluto's atmospheric circulation may have changed through time.

References: [1] C. J. Hansen, et al. (1996) *Icarus* 120(2):247 ISSN 0019-1035 . [2] L. A. Young (2013) *The Astrophysical Journal Letters* 766(2):L22. [3] C. Hansen, et al. (2014) *Icarus* 246:183. [4] A. D. Toigo, et al. (2015) *Icarus* 254(0):306 ISSN 0019-1035 . [5] S. A. Stern, et al. (2015) *Science* 350(6258). [6] GFDL Global Atmospheric Model Development Team (2004) *Journal of Climate* 17(24):4641 . [7] R. V. Yelle, et al. (1989) *Nature* 339(6222):288.