The Effect of Surface Ice and Topography on the Atmospheric Circulation and Distribution of Nitrogen Ice on Pluto

*Scot CR Rafkin[1], Alejandro Soto[1], Timothy Michaels[2]

1.Southwest Research Institute Boulder, 2.SETI Institute

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 discretized latitude/longitude horizontal grid and a pressure-based hybrid vertical coordinate. 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 takes into account the 2.3, 3.3 and 7.8 mm 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 super-surface 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. 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. 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. Furthermore, 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. In contrast to expectations, images from New Horizon showed an extremely complex, heterogeneous distribution of surface ices draped over topography of substantial geologic diversity. To maintain such an ice distribution, the atmospheric circulation and volatile transport must be more complex than previously envisioned. Topography, the distribution of nitrogen ice itself, and an overall large-scale atmospheric circulation at least partially 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 Pluto’s volatile cycle and the expression of that cycle in the surface ice distribution requires consideration of atmospheric processes beyond simple vapor pressure equilibrium arguments.

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