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Modeling 3-D global atmosphere-surface interactions on contemporary Pluto

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Abstract

Atmosphere-surface interactions on Pluto are of great importance to creating and maintaining the atmosphere variations and heterogeneous surface that have been observed in the past two decades. This work begins to investigate these processes in a multidisciplinary fashion, using a new global climate model (GCM) for Pluto. Existing observations and other constraints are used as model inputs or as items that the model aims to reproduce and further interpret. Early results from this Pluto GCM, using relatively simple configurations/initializations, will be presented.

1. Introduction

The atmospheres of Pluto (and Triton) represent a new frontier of solar system climate science. Enveloping relatively small, distant (~30+ AU from the sun) icy worlds, these substantial (*i.e.*, surface air pressure of > 0.1 Pa) nitrogen-dominated atmospheres long eluded unambiguous detection until Earth-based observations of a Pluto-stellar occultation event in 1988 ([1], [2]) and the Voyager 2 spacecraft flyby of the Neptunian system in 1989 [3]. A wealth and variety of subsequent observations and other work have provided constraints and tantalizing clues into the nature of their climate systems, but little is known or understood in a spatially- or temporally-comprehensive manner.

1.1. Potential lessons from Mars research

A single known fact immediately sets the climates of Pluto and Triton apart from most others in the solar system: on both worlds the primary atmospheric constituent currently coexists with its solid phase. This simple, yet powerful, fact catapults Pluto (and Triton) into a climatic paradigm approached only by Mars' polar carbon dioxide cycle. Such a climate regime inevitably includes regional- and global-scale circulations driven by sublimation of the volatile specie into the atmosphere and its subsequent deposition elsewhere upon the surface. Although fascinating in their own right, such large-scale flows are not the only plausible phenomena. During the long polar winter on Mars, convective CO_2 ice clouds many kilometers deep sporadically punctuate the cold night (*e.g.*, [4], [5]), and as winter yields to spring, myriad plumes of CO_2 gas and dust violently emanate from vents in a blanketing layer of seasonal CO_2 ice tens of cm thick, staining the otherwise bright surface (*e.g.*, [6], [7]). Indeed, potentially analogous dark plumes and surface stains have already been identified in Voyager 2 imagery of Triton (*e.g.*, [8]).

1.2. Setting the stage for 3-D numerical investigation of Pluto

Robust general observations of Pluto and Triton have been amassed for several decades (at least). During that period, Earth-based instrumentation and other observing tools markedly improved, near-Earth spaceborne telescopes were brought to bear, and the Voyager 2 spacecraft observed Triton and its environs in close proximity. The work of many has transformed the raw observations (and theoretical/modeling considerations) into patchy outlines of the (relatively) recent nature and evolution of Pluto's (and Triton's) climate. Significant basic knowledge gaps regarding the climates of these worlds remain, however. A significant part of this shortfall is due to the limited spatial and temporal coverage of prior observations and modeling work, as well as the technical limitations of the same. Common technical limitations include the fact that these atmospheres are dense enough that Earth-based observations of stellar occultation events cannot probe the atmosphere down to the solid surface. Furthermore, many potential phenomena (*e.g.*, condensate hazes/clouds) have not been unambiguously detected on Pluto, but clouds/hazes have been observed on Triton by Voyager 2 [9]. Their existence on Pluto cannot be strictly ruled out due to the relatively poor spatial and temporal coverage of available observations. Finally, there is a dearth of published knowledge about global energy/mass pathways within either climate system. In the case of either Pluto or Triton, the atmosphere is the primary conduit by which energy and/or mass (previously absorbed and/or sequestered by the heterogeneous surface) can be globally or regionally redistributed over "short" timescales. The atmospheric motions (winds) that largely effect this redistribution are three-dimensional (particularly for Pluto, by virtue of its complex global-scale surface albedo heterogeneity [10]) and likely vary significantly with time – they have therefore largely evaded proper investigation via the types of observations and one- and two-dimensional modeling studies published thus far.

2. Current investigative approach

A three-dimensional global climate model (GCM) for Pluto was constructed and exercised to elucidate some key aspects of Pluto's contemporary surface-atmosphere interaction(s). This GCM uses an unstructured horizontal grid, assumes no topography, and simulates the lowest ~100 km of the atmosphere. It incorporates a surface/subsurface submodel capable of tracking the seasonal and diurnal transfer of volatile surface ices, and full surface layer and boundary layer turbulence parameterizations. The "contemporary" climate epoch to be investigated (1988-2018) was chosen partly because it spans the seasonally interesting times of Pluto perihelion and Pluto equinox. Since the atmosphere of Pluto is thought to be in (or near) vapor pressure equilibrium with the surface ices, the changes in insolation during this period should have a large impact on the surface pressures. This epoch was also chosen because it encompasses the existing observational constraints and an expected future dataset (the NASA New Horizons spacecraft flyby of Pluto in 2015). Existing observations and other constraints will be used as model inputs or as items that the model aims to reproduce and further interpret. Early results from this Pluto GCM (relatively simple configurations/initializations) will be presented, with an emphasis on atmosphere-surface interactions.

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