PLUTO’S MINIMUM SURFACE PRESSURE AND IMPLICATIONS FOR HAZE PRODUCTION. P. E. Johnson, L. A. Young, S. Protopapa, B. Schmitt, B. L. Lewis, J. A. Stansberry, K. E. Mandt, O. L. White, and the New Horizons Composition and Atmospheres Teams, Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder (perianne.johnson@colorado.edu), Southwest Research Institute, Institut de Planétologie et Astrophysique de Grenoble, University of California, Los Angeles, Space Telescope Science Institute, Johns Hopkins University Applied Physics Laboratory, NASA Ames Research Center.

Introduction: Pluto’s surface exhibits extreme contrasts in color, albedo, and composition [1]. Pluto’s atmosphere is globally hazy, and haze particles should be deposited onto the surface at a rate of ~1 micron/Pluto year [2, 3]. This deposition should form a uniform, optically thick layer quickly, which is in contradiction with the observed surface heterogeneity.

If the atmospheric pressure at the surface gets low enough, haze production may be altered, suppressed or stopped completely. In Pluto’s current atmosphere, haze aggregation occurs at pressures higher than 0.5 μbar, therefore if the surface pressure drops below this level, monomer haze particles may be deposited instead of aggregates, potentially changing the appearance on the surface [3]. Additionally, if the surface pressure drops to less than 10^{-3} μbar to 10^{-4} μbar, the atmosphere would be transparent to ultraviolet radiation [5], which would shut off the photolysis of N₂ and CH₄, suppressing haze production at its source and allowing direct photolysis of surface ices [6]. For surface pressures less than ~0.06 μbar Pluto cannot support a global atmosphere [7], and instead the atmosphere becomes local, or “patchy”, which would restrict the region in which haze particles are deposited.

Climate Model: As described in [7, 8], the 3-Dimensional Volatile Transport (VT3D) model imposes local energy balance (insolation, thermal emission, conduction, and latent heat of sublimation) and global mass balance for volatile-covered bodies with efficient transport of volatiles. Here, we (i) assume one of the two static N₂ distributions described below, (ii) calculate the solar insolation onto the N₂-covered surfaces (iii) run VT3D for twenty orbits, producing a temperature versus time curve, and finally (iv) use the compilation of [9] to convert these surface volatile temperatures into surface pressures.

As used here, VT3D has three free parameters: Bond albedo A, thermal inertia Γ, and emissivity ε of the volatiles. For each pair of A and Γ, there exists a unique ε such that the model-predicted pressure in 2015 matches the 11 μbar surface pressure observed at the New Horizons flyby. We constrain our grid search of the (A, Γ, ε) parameter space by two criteria: (i) that the emissivity is less than one and greater than some minimum physical value, and (ii) that the modeled increase in pressure change between 1988 and 2015 matches the pressure increase measured from occultations. Comparing the pressures at 1205 km radius (~15 km altitude), the 2015 New Horizons radio occultation pressures [10] are 1.82 to 3.14 times higher (3-σ range) than the pressures from the 1988 ground-based occultation [11]. If the modeled pressure ratio is not within this range, then the (A, Γ, ε) triplet will be eliminated. This gives a restricted range of allowable parameter space.

Nitrogen Distributions: Fig. 1 shows the N₂ spatial distributions used here. The red outline encloses Sputnik Planitia (SP), as defined in [12]. For our first distribution, we assume everything enclosed by this outline is filled with N₂ ice of uniform albedo, thermal inertia, and emissivity, and that no N₂ ice is present elsewhere on the surface. This is not a realistic situation, but serves as a lower limit. For our second (more realistic) distribution, we use the N₂ map created by [13]. This map combines spectral data from observations and Hapke modeling on the encounter hemisphere of Pluto [14, 15]. [13] extends the observed/modelled fractional coverage of N₂ ice to the non-encounter hemisphere, by assuming the fractional coverage is constant within a zonal band (across all longitudes at a given latitude).

Fig. 1: N₂ distributions, as described in [13]. White regions are assumed to be covered with N₂ ice, black are bare. The red outline shows the border of Sputnik Planitia (SP), as defined in [12].

Climate Modeling Results:

SP-only distribution. The restricted parameter space, and five example pressure versus time curves using the SP-only distribution are shown in the top panels of Fig. 2. Pressures in three of the five cases (black, red, and orange) stay above all of the critical haze production pressures, so atmospheric collapse is not a viable means of disrupting haze for these sets of (A, Γ, ε) values. In
the other two cases, pressures dip below the haze aggregation limit near northern winter solstice, so the haze particles being deposited at this time could have a different visual appearance than those deposited at other times of year, leading to surface heterogeneity.

**Full northern N₂ distribution.** The bottom panels of Fig. 2 show the analogous restricted parameter space and pressure vs. time curves for the full northern N₂ distribution from [13]. The allowable (A, Γ, ε) triplets are shifted towards higher thermal inertia, and the minimum pressures are higher than the SP-only case; the surface pressure never drops below any of the haze-production pressures for this N₂ distribution.

**Conclusions:** Based on these N₂ distributions, haze production is not likely to be significantly disrupted by reductions in atmospheric pressure. With a SP-only distribution, there is a short amount of time when monomers might be deposited instead of aggregates, but this is not the case for the more realistic full N₂ distribution. The addition of unseen N₂ in the southern hemisphere might be sufficient to cool the atmosphere and affect haze production, which we will explore in the future.

Additionally, the haze particle sedimentation may occur at a faster rate during the low-pressure period near northern winter solstice, although more work is needed before conclusions can be drawn about how this would affect the surface heterogeneity.


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**Fig. 2:** Climate model results for the SP-only N₂ distribution (A and B) and the full northern N₂ distribution (C and D). B and D show the restricted parameters space; the red lines show contours of minimum pressure, in μbar, and the gray shading indicates the minimum surface pressure experienced for that (A, Γ, ε) triplet. Five example cases are shown in A and C; the colors correspond to the circled letters in B and D. Note that the jump present in all of the pressure curves around 5 μbar is due to the α-β phase transition of N₂.