How Radiative Haze Reshapes Pluto's Atmospheric Dynamics

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As one of the ten atmospheres in the Solar System, Pluto offers a remarkable natural laboratory to test our understanding of atmospheric dynamics and physics, and to investigate the diversity of possible climate regimes.

We present a new version of the 3D Pluto Planetary Climate Model (PCM) in which haze microphysics is fully coupled to radiative transfer, allowing for the first time for a self-consistent representation of the radiative impact of photochemical and icy aerosols in Pluto's atmosphere [Bertrand et al., 2020, Falco et al., 2024, de Batz de Trenquelléon et al., 2025]. The inclusion of radiatively active haze reduces the atmospheric radiative time constant by approximately an order of magnitude compared to the gas-only configuration [de Batz de Trenquelléon et al., this issue]. This modification leads to profound changes in the simulated climate and circulation.

In the absence of haze, the general circulation in the lower atmosphere is dominated by a retro-rotation. The long radiative timescale results in weak meridional temperature gradients and meridional winds. This is an angular-momentum-dominated general circulation regime, in which heating gradients imposed by insolation are efficiently erased by dynamical mixing before building significant energy for baroclinic wave formation [Forget et al., 2017, Bertrand et al., 2020].

In contrast, simulations with radiatively active haze exhibit a markedly different dynamical behavior. The shorter radiative timescale enhances radiative heating gradients and allow weak meridional temperature gradients. This leads to an enhanced baroclinic activity, associated with significantly stronger meridional shear associated with mid-latitude prograde jets.

Our results illustrate that radiative feedbacks from the haze can shift Pluto's atmosphere between fundamentally different dynamical regimes, from a quiescent, angular-momentum-controlled state to a more active, baroclinic circulation. They also place Pluto in a broader comparative context. In particular, a strong analogy can be drawn with Mars, where variations in dust loading similarly modulate the radiative timescale and control the intensity and vertical structure of baroclinic activity. Our results also provide some explanations for several observations of Pluto, in particular the atmospheric meridional heating gradient observed with ALMA [Lellouch et al., 2022] as well as the year-to-year variability in haze opacity derived from stellar occultations [see review in Meza et al., 2018].

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