National Aeronautics and Space Administration

FY25 Strategic University Research Partnership (SURP)

# Conditioning the atmospheric environments of ice giants

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Objectives: 1. Develop an environmental model of Ice-Giant atmospheres for a mean atmospheric state and its variability using a fully non-linear dynamics integrated with realistic radiative transfer and cloud microphysics. 2. Create an empirical climatological databased. Combine the model results and observations using a Bayesian statistical framework.

Background: The Ice Giants Uranus and Neptune, exhibit unique properties. Uranus emits little observable internal heat and its axial tilt is close to 90°. Neptune continually creates planetary-scale storms. They are not only key to understanding solar-system formation and evolution, but also our closest analogs to most detected exoplanets. This collaboration will strengthen the interaction between the University of Michigan and JPL, combining model simulations and their constraining observations.

Approach and Results 1: Environmental model simulation. 3-D cloud-resolving models for Uranus and Neptune have been constructed including $H_2O$, $NH_3$, and $H_2S$ as the cloud-forming vapors, following earlier work (Li & Chen 2019). Condensation of these vapors from various clouds are being matched to the cloud properties derived from near-infrared images of Uranus and Neptune. The expected microwave signal has been calculated based on the simulated vertical profiles of these vapors since they are the major absorbing species in the microwave (Moses et al. 2020), and we will model the NIR reflectance next. A radiative-transfer library has been built using the updated opacity from the JPL PI (Orton et al. 2025). A global model of atmospheric circulation has been constructed with moist convection, cloud formation and realistic radiative transfer. We have run the global simulations of Uranus and Neptune to study the seasonal effects and the impact of large-scale circulation as observed by Voyager. We get patchy methane cloud formation in the model, with a more laterally homogeneous $H_2S$ cloud deck.

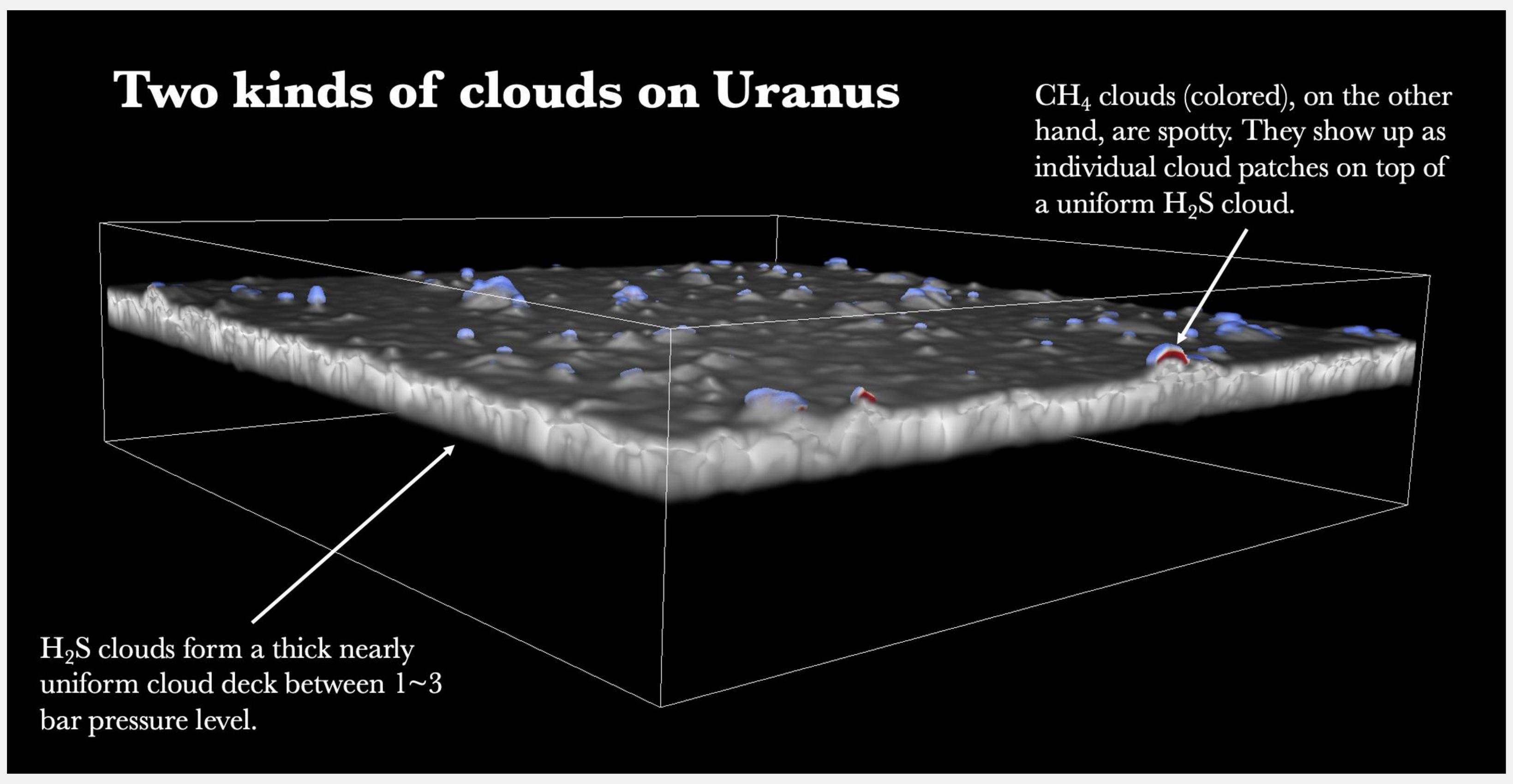


**Figure 1.** 3D cloud-resolving simulations of ice giants. We find that there are two types of clouds. The $H_2S$ clouds are almost uniformly distributed between 1 and 3 bars of pressure, while the $CH_4$ clouds are spotty, randomly distributed on top of a thick $H_2S$ cloud deck.

Significance/Benefits to JPL and NASA: This work is critically relevant to the Solar System Exploration Program. With the planning for dedicated missions to explore these planets underway, our work will fill a knowledge gap that will inform the spacecraft instrument development and payload (Fletcher et al. 2020).

Approach and Results 2: Empirical climatological data base. An update of the collision-induced absorption models for $H_2$-$H_2$ and $H_2$-He interactions used to model the thermal emission and reflected sunlight at mid- and near-infrared wavelengths, was created and adopted into our radiative-transfer code (Orton et al. 2025). Cloud tracking from near-infrared imaging of Uranus and Neptune with Adaptive Optics stabilization continued at the Palomar 200-in telescope (Fig. 2). On Neptune we observe intense variability in the distribution of clouds. On Uranus, we observe high-altitude haze formation and strong lateral gradients in reflectance. We started to assess temporal variability in cloud formation. We will run retrievals to find cloud particle abundance/size, altitude, and composition. A coupled radiative transfer/photochemical climate model is now complete, with which we will cross check our retrieval results to infer haze composition.

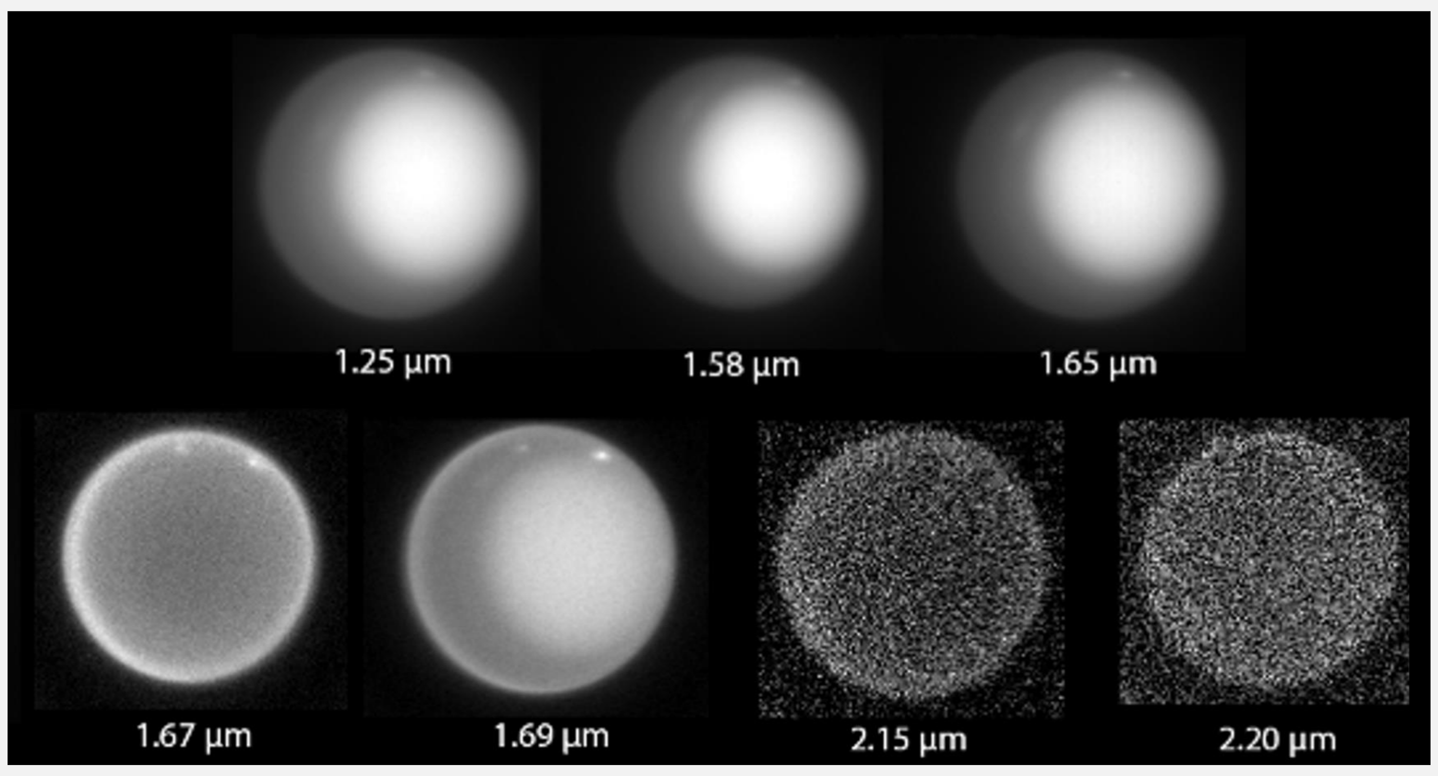


Figure 2: Peak-reflectivity scaled Uranus images from 2024 October. Small storm features may be short-lived $CH_4$ convective events. The 1.67- and 1.69-µm limb-brightened images indicate a high-altitude haze. The low SNR at 2.15- and 2.20-µm is the result of their low reflectivity.

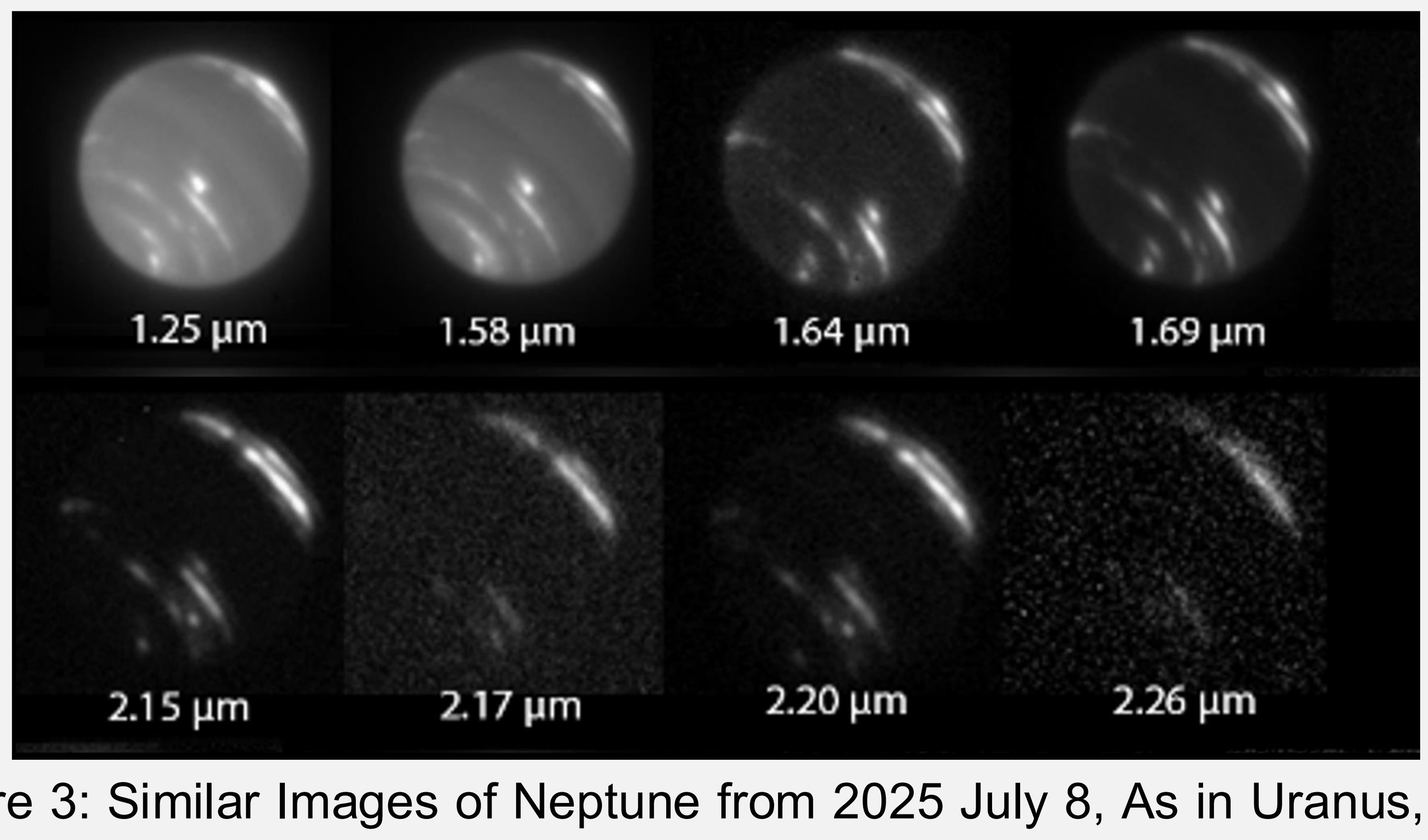


Figure 3: Similar Images of Neptune from 2025 July 8, As in Uranus, bright features are short-lived methane-cloud convective events. Shown here is a more dynamically active hemisphere of Neptune.

## References

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