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Connecting the Interiors and Atmospheres of Volatile-Rich Sub-Neptunes through Cloud Chemistry

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Sub-Neptune atmospheric observations show that cloud formation is likely, directly altering a planet's atmospheric composition through dissolution and condensation of gaseous species **[1-3]**. They also act as a source of opacity and reflectivity, influencing the climate and habitability beneath them. Understanding cloud chemistry is a crucial step towards connecting the upper atmospheric composition as observed by the James Webb Space Telescope (JWST) to that of the unobservable lower atmosphere. This will allow us to infer the true surface or interior conditions, while elemental ratios (C/O, C/N) provide hints on the planet's formation history.

One dissolving species of interest is ammonia (NH_3), which has been consistently non-detected in temperate exoplanet atmospheres. NH_3 is proposed to be a key atmospheric observable that can distinguish between interior/surface conditions **[4]**. It is predicted to be prevalent in sub-Neptune atmospheres **[5-9]**, yet the lack of detections has created a "Missing Ammonia" mystery. With the likely existence of water clouds, it is timely to investigate their role in NH_3 depletion.

We developed an exoplanet cloud dissolution model that integrates aqueous chemistry from PHREEQC to track the evolution of a multiple-phase system and calculate dissolution and condensation at each pressure. Our model accounts for shifts in acid-base equilibrium that may alter the gas-phase solubilities. Using sub-Neptune K2-18 b as a test case, we determine how much NH_3 dissolves in water clouds for a range of pressure-temperature profiles, accounting for CO_2 co-dissolution and non-ideality. We find that dissolution in a cloud layer is insufficient for depleting NH_3 below the detection limit of JWST. This work advances our understanding of how clouds can influence atmospheric observables on volatile-rich sub-Neptunes.

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