

Analog Environments for Venus Aerosol Instrument and Mission Concept Testing

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The most common hypothesis discussed for life on Venus is a habitat in the dense, persistent clouds, which are primarily sulfuric acid with a secondary water component. Although Earth lacks a complete Venus analog environment, several partial analogs exist which can inform our understanding of the requirements for cloud habitability as well as serving as potential testbeds for future Venus instruments or missions.

Earth's tropospheric clouds have larger particles, more water, and shorter lifetimes than Venus's; however, they have a partial overlap in pressure and temperature, and are our only example of an airborne habitat. They can inform how particle residence time and microbial generation time constrain habitable atmospheric regions. On the biological side, this includes available nutrients and energy, environmental stressors such as radiation, osmotic potential and acidity, and time spent in protective but inactive forms (endospores, cysts, akinetes); on the physical side, gravity, air density and viscosity, thermal lofting, gravity waves, scavenging due to precipitation, and other airflow dynamics, as well as effective particle radius and electrical charge. They can also enable sampling strategy tests for airborne life detection, ranging from 10^2 to 10^8 viable cells/mL (10^{-3} to 10^{-9} cells/particle).

Conversely, Earth's stratospheric sulfate layer lacks an active microbial presence, and is at a colder and less dense altitude but has partially analogous values in terms of H_2SO_4 and water concentration, particle size, and number density. These aerosols are accessible to aircraft and high-altitude balloons. Even more accessible potential analogs include sea spray, which overlaps with the smaller (haze) particle sizes and densities at Venus and contains trace organic constituents; marine fog, which at higher densities can match Venus's larger (Mode 2) particle properties and contains a range of trace compounds including ammonia, phosphates, sulfates, and nitrates; and spray from acidic hydrothermal systems, which can cover a wide variety of sizes, densities, and chemical compositions. These analogs could improve the development of Venus cloud sampling instruments or sondes, including field tests of material compatibility, particle capture efficiency, and analysis sensitivity.