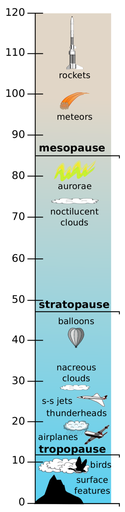
Cloud Habitability from Earth to Venus: Science & Technology Considerations

D. M. Gentry[1], L. Iraci[1], A. Cassell[1], A. Mattioda[1], A. Brecht[1], K. Simon[2], P. Sobron[2], A. Davila[1]

[1]NASA Ames Research Center [2]Impossible Sensing

Earth's Aerobiosphere



Viable microorganisms are found at altitudes up to 40 km:

- 1×10^4–1×10^8 $\frac{\text{cell}}{\text{kg}}$ found viable as dry (inactive) particles near ground (1×10^1–1×10^6 $\frac{\text{cell}}{\text{kg}}$ near ocean)
- $\sim 25\,\%$ of other particulates are bioaerosols (incl. dead cells, debris, etc.)
- 1×10^3–1×10^5 $\frac{\text{cell}}{\text{mL}}$ in ground-level cloud water, some metabolically active
- 1×10^3 $\frac{\text{cell}}{\text{kg}}$ above 10 km, believed to be inactive
- biodiversity may approach that of soil, though biomass is far less

Airborne microbes are factors in local and global biogeochemistry:

- surface and cloud albedo
- ice and cloud nucleation
- fog and rain water chemistry
- local and long-distance species transport

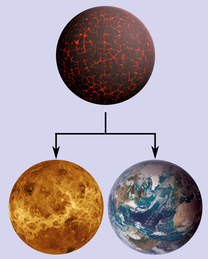
Although airborne reproduction has not yet been observed *in situ*, this may be due to the relatively short lifetime of Earth clouds.

Venus Habitability Science Targets

Table 1. Venus aerosol constituents of interest. In addition to mass spectrometry, many could be detected optically; only the strongest bands are listed.

Elements	LIBS peak (nm)	science goal
C	247; 910; 940	composition
N	447; 821; 868; 904; 939	composition
P	213; 253	composition
Cl	808; 837; 858; 912; 959	composition
Fe	239; 260; 275	composition
Molecules	**Raman peak (cm^{-1})**	
H_2SO_4	400, 560, 915, 1145, 1360	composition
SO_4^{2-}	451, 613, 974, 1067	acid activity
HSO_4^-	890, 1040, 1200	acid activity
SO_2/SO/S_2O	1140-1150	composition
PO_4^{3-} (aq)	415, 554, 936, 1013	acid activity
HPO_4^{2-} (aq)	855, 990, 1083	acid activity
CS_2	656	composition
OCS	517, 870, 1986	composition
S_8 (natural)	153, 220, 473	composition
Moieties	**Raman peak (cm^{-1})**	
C=C	1520-16004, 1575-1635	organics
C=O	1670-1700	organics
C≡N	2220	organics
R-C=O	1725-1740	organics

Motivation



Venus and Earth are believed to have had similar conditions during the period in which Earth life arose (surface water, geological activity).
Could an Earth-like biochemistry have arisen on Venus? Could such life have persisted in the remaining water, i.e., in the sulfuric acid cloud/haze layers?

Venus and Earth represent two possible evolutionary paths for rocky worlds with water.

- Under what conditions should cloudy worlds be considered potential habitats?
- What are the short- and long-term requirements for a planetary aerobiosphere?

Analogue Environments

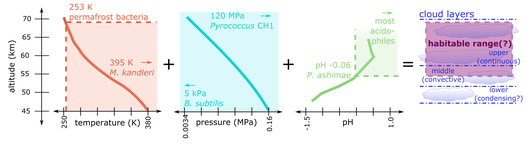
Earth has no perfect analogue for the Venus clouds, but it has a variety of partial analogues that together cover much of Venus's chemical and physical aerosol properties.

Table 2. Venus operational and scientific analogue enviroments available for exploration or validation.

Properties	Venus Haze & Upper Clouds	Sea Spray	Marine Fog	Stratospheric Sulfate Aerosols
location	55-90 km	coastal (≤ 20 m), ≤ 7 m AGL	$\sim$ 20–50 m AGL	$\sim$ 13–18 km AGL
phase	liquid (?)	liquid, solid	liquid	liquid w/ inclusions
diameter (µm)	0.2 (Mode 1) 0.4–1.0 (Mode 2)	0.04–0.06 (sub-µm) 1–10 (coarse)	5–10	$\sim$ 0.1–1.0
number density (cm^{-3})	Haze: $\sim$ 50–500 (Mode 1) $\sim$ 0.1–1 (Mode 2) Upper Cloud: $\sim 2 \times 10^3$ (Mode 1) $\sim$ 50 (Mode 2)	500–1500 (sub-µm) 0.1–1 (coarse)	80–250	1–100
composition, bulk (wt %)	75–83 H_2SO_4, 15–25 H_2O (?)	H_2O	H_2O	60–80 H_2SO_4 40–20 H_2O
composition, trace	$FeCl_3$, H_3PO_4, NH_3, S_2O, S_x, (. . . ?)	Cl^-, Na^+, Mg^{+2}, Ca^{+2}, $HSO4^-$, organics, other salts, . . .	HPO_4^{-2}, HSO_4^-, $H_2PO_4^-$, NH_4^+, NO_x^-, organics, other salts, . . .	meteoric iron, organics, (. . . ?)

Short-Term Habitability Limits

For $\sim 80\,\%$ H_2SO_4 aerosols, conditions are within the limits of life for temperature, pressure, radiation, redox and/or photonic energy sources, bioavailable chemistry (CHNOPS), size, and residence time.



However, water activity is far too low for active metabolism (Table 4). A long-term stable aerobiosphere must have a mean generation time shorter than the mean residence time (Figure 1).

Long-Term Habitability Limits

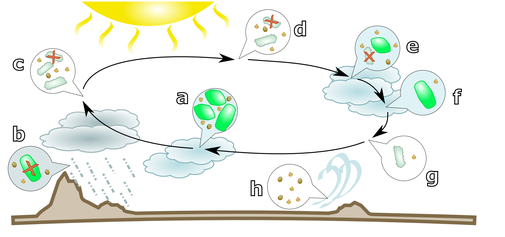


Figure 1. Notional Earth-like aerobiosphere. [a] Microbes accumulate enough nutrients in a warm, wet cloud to divide. Some [b] "rain out"; others [c] dry out and [d] accumulate damage. [e] A few encounter wet conditions, rehydrate, repair, and [f] consume. [g] Hydration cycles repeat until [h] conditions allow division again.

Technical Considerations

Uniquely in atmospheric exploration, the sampling platform defines the rate, density, distribution, and total number of sampled aerosol particles, in turn constraining the sensitivity and sample analysis cadence needed.

Table 3. Mission concepts spanning sampling regimes.

Aerosol Sampling Concept	Typical Sampling Velocity ($\frac{\text{m}}{\text{s}}$)	Typical Sampling Duration (h)	Mission Concept Example(s)
descent sonde	≥ 35	≤ 1	DAVINCI
glider/drone	3–5	≥ 24	VAMP, Black Swift UAS
variable-altitude balloon	0.1–1.5	≥ 240	VALENTInE, VFM
stationary balloon	≤ 0.1	≥ 240	Venera-D, VCM

Earth bioaerosols – like most life in extreme conditions – is often inactive and clustered in 'hot spots'. For example, viable microbes in cloud water may have concentrations of 1×10^{-2}–1×10^{-9} per particle.

Key Questions & Measurements

Key *in situ* measurements:

- Detailed aerosol composition, esp. compounds that affect water and acid activity (Table 4)
- If composition is differentiated by particle size
- Mixing and lofting dynamics, esp. related to water

Table 4. Typical water activities of Earth habitats and barren environments. Venus's aerosols are far below the known microbial growth limit.

Phenomenon	a_w
Microbial growth media	0.996
NaCl solubility	0.74
Microbial growth	≤ 0.6
Atacama desert soils	0.01–0.52
75 % H_2SO_4 solution	0.02

Key supporting questions:

- If microbial reproduction occurs while airborne
- If microbial activity is limited to clouds
- Life cycles, growth rates, and limiting combinations of stressors for airborne microbes

Acknowledgements

D. Smith, S. Waters, A. Cassell, and E. Venkatapathy (NASA ARC); K-L. Jessup and E. Barth (SwRI); K. McGouldrick (CU).