

Large-Scale Validation on SIMOC

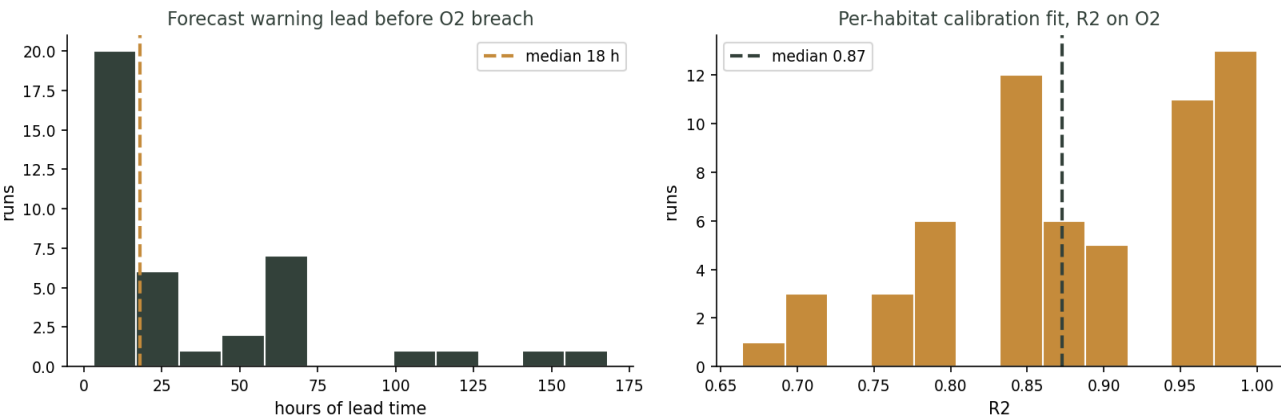
A 60-run ensemble across seven closed-habitat configurations, run against SIMOC-ABM, the agent-based closed-ecosystem model developed with Biosphere 2.

What we ran

We installed SIMOC-ABM and ran seven distinct closed-habitat configurations: two Mars crew habitats, a single-crop radish habitat, a four-crew Mars greenhouse, and three Biosphere-2 mission presets. For each habitat we swept the onset time of a life-support fault from hour 72 to hour 216, and in the greenhouse configuration we graded the fault severity by disabling one to six grow lamps. That produced 60 independent scenarios. In every scenario Terra sees only two sensors, cabin CO2 and O2. It calibrates its life-support model to that specific habitat using its Bayesian calibration pipeline, estimates the hidden air-balance state online, and forecasts the probability of crossing a crew-safety O2 limit.

Headline results

Measure	Result
Scenarios run (7 habitats x onsets x severities)	60
Scenarios that breached the O2 safety limit	41
Breaches forecast before they occurred	40 of 41 (98%)
Median warning lead on detected breaches	18 h (IQR 5 to 61 h, up to 168 h)
False-alarm rate on non-breaching scenarios	2 of 19 (11%)
Per-habitat calibration fit, R2 on O2	median 0.87 (0.83 to 0.97, min 0.66)



Left: distribution of forecast warning lead across all breaching scenarios. Right: distribution of per-habitat calibration fit (R2 on O2). Both computed over the full 60-run ensemble.

Two regimes, reported honestly

The results split cleanly by fault physics. In crew-only habitats a scrubber loss degrades the air balance slowly, and Terra forecasts the breach a median of 65 hours ahead. In the greenhouse, a lighting failure crashes the bioregenerative loop fast, so the runway is shorter: Terra still forecast every one of the 30

greenhouse breaches, but with a median lead of about 7 hours. The system detects both, and the lead time honestly reflects how much warning the physics allows.

Where it missed, and why that is the point

Two of the nineteen non-breaching scenarios drew a false alarm, both in a single Biosphere-2 mission preset whose oxygen was actually rising through a model transient. One breach was caught with essentially zero lead. Calibration R2 dips to 0.66 on the smallest single-crop habitat, where two gases carry little information. These are exactly the cases a field-calibration phase against real facility telemetry is designed to tighten, and we would rather show them than hide them. No customer hardware was involved: this is simulation-to-simulation validation against an independent, peer-built model, not flight data.

What it signals

Across sixty fault conditions in seven habitats it had never seen, the engine recovered a life-support variable it never measures, calibrated itself from two gases, and converted that into actionable warning time with a low false-alarm rate. That is the same estimation-and-forecasting core Terra deploys for land-based aquaculture and controlled-environment agriculture, validated here on the hardest closed loop we could find. The full per-run table is included as `SIMOC_validation_results.csv`.