

Complexity, variability, and the behavioral layer of gerophysics: a commentary on Unfried et al. (2026)**Jean-Jacques Temprado¹, Rita Sleimen-Malkoun¹**¹Aix Marseille Université, CNRS, ISM, Marseille 13288, France**Correspondence to:** Jean-Jacques Temprado; email: jean-jacques.temprado@univ-amu.fr**Keywords:** aging, dynamical systems, complexity, behavior**Received:** July 13, 2026**Accepted:** August 21, 2026**Published:** September 12, 2026

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ABSTRACT

The report of the Global Conference on Gerophysics [Unfried et al., 2026] aimed to “bridge changes across biological scales: from subcellular to organism level”, with dynamical systems, entropy, network theory, and stochastic processes as its theoretical pillars. In this commentary, we contend that this ambition can be extended to account for the organism-environment interactions as expressed through behavioral dynamics, thereby adding a continuous layer to the field. Integrating such ideas within Gerophysics would allow interventions to be designed and tested simultaneously at the molecular, network and behavioral levels. Gerophysics would thus benefit from integrating researchers working at the organism-environment scale.

The report of the Global Conference on Gerophysics [1] aims to “bridge changes across biological scales: from subcellular to organism level”, with dynamical systems, entropy, network theory, and stochastic processes as its theoretical pillars. This ambition can be extended to account for the organism-environment interactions as expressed through behavioral dynamics, thereby adding a continuous layer to the field. Gerophysics already spans scales from the molecular to organism-level (frailty, resilience, physiological decline, and population-level health trajectories); yet, capturing how the aging organism copes in real time with everyday demands requires specific measures, formalized within the same framework.

Well before the term “Gerophysics” was introduced, Lipsitz and Goldberger [2] proposed that aging is accompanied by a measurable reduction in the dimensionality and adaptive richness of physiological and behavioral output. They argued that healthy physiological systems generate fractal-like fluctuations across multiple time scales and that aging degrades this complexity, yielding outputs that are either more random or more deterministic, reflecting a loss of adaptive functional solutions. This age-related *loss of complexity* may offer a testable behavioral correlate of the reductions in stability, resilience and robustness

addressed by Fedichev and Gruber and by Rutenberg and Pridham within the Gerophysics framework. Whether this loss of complexity is formally equivalent to a reduction in attractor dimensionality in these models remains an open hypothesis rather than an established correspondence.

Entropy-based and fractal indices of time-series complexity have been applied across sub-levels of the integrated brain-mind-body system, including the way in which aging reshapes cognitive-motor interactions [3]. Findings ranging from brain [4] to muscular [5] signal complexity, and from movement variability [6] to the prediction of future falls [7], collectively constitute a coherent organism-level framework rather than isolated observations. A further argument for its irreducibility comes from Kerepesi’s preliminary and as-yet unpublished findings suggesting that network entropy decreases with age in adults, in contrast to molecular entropy, which increases. If confirmed, this divergence would suggest that entropy and complexity are level-specific constructs and that a decrease in network entropy need not be a simple mirror image of molecular entropy. On this view, the loss of behavioral complexity would be neither equivalent to nor inferable from molecular disorder or network entropy.

Measuring complexity at the behavioral level may yield clinically relevant markers of declining adaptability near the transition to frailty. Pridham's stochastic dynamical model reveals a critical tipping point at which repair capacity can no longer offset damage accumulation, but it operates on binary or categorical snapshots of health variables. Conversely, time-series complexity analysis of behavioral outputs offers a higher-resolution, continuous-time window onto the same transition, at the level of functional outcomes that matter most to clinicians.

From this perspective, the capacity to maintain adaptive behavior under real-world perturbations is a distinct counterpart to the thermodynamic resilience at the heart of Fedichev and Gruber's theory. We propose the notion of *complexity reserve* to denote the residual buffer of dynamical flexibility available before the system crosses into irreversible functional decline. This construct could be operationalized either by assessing the extent to which the multiscale structure of behavioral output is preserved when the system is challenged by standardized perturbations of graded intensity or by quantifying the age-related reduction in the margin separating the current operating regime from a task-specific dynamical transition, such that a minor stressor may suffice to compromise stability. Framed in this way, complexity reserve integrates both retrospective and prospective dimensions. Retrospectively, it is hypothesized to reflect the cumulative effects of prior exposure to rich and stimulating environments, extending the logic of cognitive and physical reserve to the dynamical organization of behavior. Prospectively, we hypothesize that complexity reserve may predict an individual's responsiveness to future interventions, potentially providing a framework for understanding heterogeneity in responses to exercise and environmental enrichment that is not fully captured by molecular biomarkers. These propositions define a testable research program whose empirical validity remains to be established.

Finally, the concept of complexity matching [8] motivates a theory-driven research hypothesis: that exposure to fractal-structured stimuli might help restore the expressed age-related loss of neuro-behavioral complexity. We stress, however, that complexity matching does not by itself establish clinical restoration of healthy organismic complexity and should be regarded as a hypothesis to be tested rather than a demonstrated effect.

Integrating such ideas within Gerophysics would allow interventions to be designed and tested simultaneously at the molecular, network and behavioral levels. Gerophysics would thus benefit from integrating researchers working at the organism-environment scale. As a step in this direction, we propose extending the panel's closing formula to explicitly acknowledge the organismal level as a level of (gero)physical organization: "*physics predicts, biology validates, computation unifies, and behavior translates.*"

CONFLICTS OF INTEREST

The authors declare no conflicts of interest related to this study.

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