LIFE ON A SUSTAINABLE PLANET
Smithsonian

The Smithsonian Living Earth Digital Twin

An Ecological Feedback Layer for Planetary Models

AN OUSSR INNOVATION CONCEPT PROPOSAL FROM
Smithsonian Astrophysical Observatory (SAO, Proposal Lead), Smithsonian Environmental Research Center (SERC), & Smithsonian Tropical Research Institute (STRI)

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1. The Sustainability Challenge addressed by this Proposal

Earth "Digital Twins" are high-fidelity computational replicas of our home planet, designed to simulate, predict, and stress-test the Earth's climate in silicon. These are amongst the most ambitious frontiers at the interface of environmental science and our ongoing revolution in AI, and represent a massive investment by governments and technology leaders worldwide. NVIDIA's Earth-2 platform, powered by its "Climate in a Bottle" (cBottle) generative AI foundation model, now simulates global atmospheric states at kilometer-scale resolution thousands of times faster than traditional numerical models. Meanwhile, large governmental efforts like NASA's Earth System Digital Twins (ESDT) and the European Commission's Destination Earth (DestinE) initiative, are pursuing digital twins for weather extremes and climate adaptation across the globe.

Together, these efforts represent an unprecedented capacity to model atmospheric physics and fluid dynamics. Yet they share a critical blind spot: they are *biologically inert*. The world's most important natural carbon sinks, tropical forests and coastal wetlands (which together sequester ~5 Gt CO_2/yr) are treated by these simulations as **static boundary conditions** rather than as living, reacting systems with nonlinear feedback loops. This means that the tipping-point behaviors on which global net-zero targets most critically depend cannot be captured until they are already underway. Threats to carbon stocks include abrupt forest mortality, accelerating wetland methane, and collapse of various blue carbon ecosystems, all of which are essentially ignored by existing models. The Smithsonian Institution, operating both orbital atmospheric instruments (SAO's TEMPO) and the world's deepest ecological field networks (SERC and STRI) under one institutional umbrella, is uniquely positioned to close this gap and meaningfully contribute to these multibillion dollar commercial and governmental efforts.

2. Our Idea

We propose to develop the ***initial*** **scientific architecture** for a Smithsonian **Living Earth Digital Twin** (hereafter LEDT)—the first high-fidelity ecological feedback layer designed to integrate with **existing** planetary digital twin infrastructure from (e.g) NVIDIA, NASA, and DestinE. Rather than duplicating climate models, we occupy a complementary lane of synergy empowered by the Smithsonian's unique cross-Unit strengths and world-unique assets: linking *what the atmosphere delivers* (solar variability, pollutant loads, GHG concentrations from SAO's TEMPO and MethaneSAT) to *how ecosystems respond* (carbon flux shifts, species turnover, tipping-point signatures from STRI's 70+ tropical forest plots and SERC's Global Change Research Wetland, host of the world's longest-running elevated CO2 experiment, as well as its Coastal Carbon Network with >15,000 observations).

The animating question behind this proposed cross-Unit pursuit is *how does variability in solar radiation, including extreme events, propagate through the atmosphere and climate system to influence carbon cycling and ecosystem stability across latitudes?* TEMPO's hourly measurements of NO2, O3, HCHO, aerosols, and solar-induced chlorophyll fluorescence (SIF) across North America reveal the atmospheric chemistry modulating UV exposure, ozone vegetation damage, and nitrogen deposition. Fusing these orbital data from SAO with decades of *in situ* time series from SERC's Chesapeake and global blue carbon sites and STRI's ForestGEO network enables AI models trained on real ecosystem responses to the specific forcings TEMPO observes.

For this Innovation call, we propose a $150K seed investment to incubate a long term, fully cross-Unit collaboration in pursuit of this LEDT architecture. The proposed funding will enable a **one-week Innovation Design Lab** convening 30–40 researchers from all three units. The Lab will: (1) define the data architecture linking TEMPO atmospheric products to ForestGEO, GCReW and Coastal Carbon Network ecological time series; (2) prototype a "Methane-to-Mangrove" pipeline tracing pollutant plumes from satellite detection through atmospheric transport to predicted ecosystem impact; (3) identify which astrophysical signal-processing techniques (e.g., from SAO's AstroAI & EarthAI centers) can detect

ecological tipping-point signatures in remote sensing data; and (4) produce a **scoped external proposal for the Bezos Earth Fund AI Grand Challenge** or equivalent program. Additionally, the funding will enable a post-Design lab cross-Unit “Hackathon” with ODI, SERC, STRI, and SAO to integrate data streams and build a pilot data "bathtub" or developer space where realtime environmental data can be integrated with AI tools.

3. Deliverables & Impact

By the end of period of performance in 2027 we aim to have (a) completed Innovation Design Lab and published white paper defining the architecture of Smithsonian’s Earth Digital Twin layer, as well as how it might interface with the existing frontier Digital Twin models (e.g. via an extension to CorDiff for NVIDIA’s Earth 2 model, etc.); (b) working prototype of the SI pipeline on at least one TEMPO–SERC and one TEMPO–STRI test case; (c) submission of ≥1 major external proposal to the Bezos Earth Fund or comparable private or federal program; (d) cross-unit MOU for sustained Earth Digital Twin collaboration.

4. The Smithsonian Advantage

No other institution simultaneously operates an orbital atmospheric chemistry platform (TEMPO), the world’s largest permanent tropical forest plot network (STRI), and its most intensively studied tidal wetland and related global coastal carbon database (SERC). SAO delivers hourly atmospheric data via TEMPO, SERC’s Global Change Research Wetland has 40 years of experimental blue carbon data, STRI’s ForestGEO is the richest longitudinal record of tropical forest dynamics on Earth. This is a unique “atmosphere-to-ecosystem” pipeline, under one institutional umbrella that advances our *Life on a Sustainable Planet* goals.

5. Pathway to impact: the 3-5 year vision

Year 1 (2026–27): Innovation Design Lab; cross-unit data framework; white paper and prototype; first external proposal. **Years 2–3 (2027–28):** With external funding, stand up the prototype Smithsonian Digital Twin research platform. Integrate TEMPO L2 products and legacy MethaneSAT flux maps with SERC eddy-covariance and STRI census data. Deploy adapted AstroAI tipping-point detection algorithms on TEMPO-observed landscapes adjacent to field sites. **Years 3–5 (2028–31):** Position the Smithsonian Digital Twin model as the *Biological Extension* for NVIDIA Earth-2, NASA’s ESDT and/or DestinE, providing proprietary ecological ground-truth and AI models to make planetary digital twins “living.” Deliver the first real-time, verifiable Carbon Audit linking satellite-observed atmospheric forcing to measured ecosystem carbon response. This positions the Smithsonian as the global standard for ecological digital twin validation, with direct relevance to carbon markets, Nature-Based Solutions, and IPCC frameworks.

6. Partnerships & Collaboration

This is a truly cross-unit collaboration built on a synergy of expertise between SAO, SERC, and STRI and their combined *world-unique* assets (TEMPO, EarthAI, ForestGEO, GCReW, & the Coastal Carbon Network). We will additionally engage NMNH (taxonomic AI, biodiversity informatics) and the Smithsonian Data Science Lab (ML infrastructure). Externally, we’ll pursue partnerships with (e.g.) **NVIDIA Earth-2** and the **Bezos Earth Fund** as the primary follow-on funder, as their AI Grand Challenge is closely aligned with our goals. The Lab will include 3–5 invited external participants (from e.g. NVIDIA) to pressure-test feasibility and build pre-proposal relationships.