# PelagicGlobe: 3D Ocean Currents Globe, Conformal Spilhaus World Ocean Projection, and NOAA ENSO Workstation in Rust

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**Canonical DOI:** 10.5281/zenodo.24442089 • **Apps Hub:** https://crvscience.com/apps • **Repository:** https://github.com/bpwhite/crvscience-pelagic-globe

**Abstract —** PelagicGlobe (v1.1.0) is an open-source, cross-platform ocean circulation and El Niño–Southern Oscillation (ENSO) workstation implemented in memory-safe Rust across core library modules under GPL-3.0-or-later licensing. Unlike conventional atmospheric map projections that bisect the Pacific or Arctic basins along land-centered meridians, PelagicGlobe unifies an interactive 3D orthographic ocean globe, an equirectangular 2D world ocean map, and a conformal Spilhaus World Ocean square projection (ESRI:54099) centered over Kerguelen (66.95°E, 49.56°S) with continental perimeter seams converging along the Bering Strait and Americas. The application embeds 921 seasonal Oceanic Niño Index (ONI) records spanning 1950–2026 (NOAA CPC ERSSTv6) paired with flavor-resolved spatial SST anomalies (Canonical Eastern Pacific, Central Pacific Modoki, NE Pacific Warm Blob, and La Niña Cold Tongue), a real-time 20°C equatorial thermocline cross-section (120°E to 80°W), 4,200 advected Lagrangian surface drifters across 14 boundary and equatorial currents, SQLite bookmark persistence, and background-threaded NOAA CoastWatch ERDDAP OISST v2.1 / NESDIS geostrophic raster ingestion. Across 12 compiled unit and CLI checks (12/12 passing), Spilhaus round-trip coordinates match analytic targets to 1e-4°, headless SVG export generates 797 current vectors and 65 continent polylines, Eastern Pacific 20°C thermocline depths shift from 16.0 m in the 1973 NDJ La Niña (-2.0°C) to 156.8 m in 1997 NDJ (+2.4°C), and live ERDDAP ingestion resolves 10,741 valid ocean grid cells for 2015-12-15 (stride 8).

## 1. Introduction

Standard Atlantic- or Pacific-centered global maps cut oceanic basins across artificial antimeridian edges, disguising the single connected World Ocean framed by Antarctica, the Southern Ocean, and the Indian, Pacific, and Atlantic gateways[1,2]. When studying El Niño–Southern Oscillation (ENSO) teleconnections or boundary-current transport across multi-decadal records, splitting the basin complicates spatial comparison between western warm-pool convection, central-Pacific Modoki events, eastern-Pacific Kelvin wave flattening, and northeast-Pacific marine heatwaves[3,5,6].

**PelagicGlobe** (v1.1.0) integrates conformal Spilhaus cartography (`ESRI:54099`), NOAA Climate Prediction Center ERSSTv6 Oceanic Niño Index (ONI) time series (1950–2026)[3], and live background NOAA CoastWatch ERDDAP OISST v2.1 ingestion[4] inside a native standalone Rust desktop workstation (`#![forbid(unsafe_code)]` across core modules) integrated into the CRV Science Open-Source Apps ecosystem[7–28].

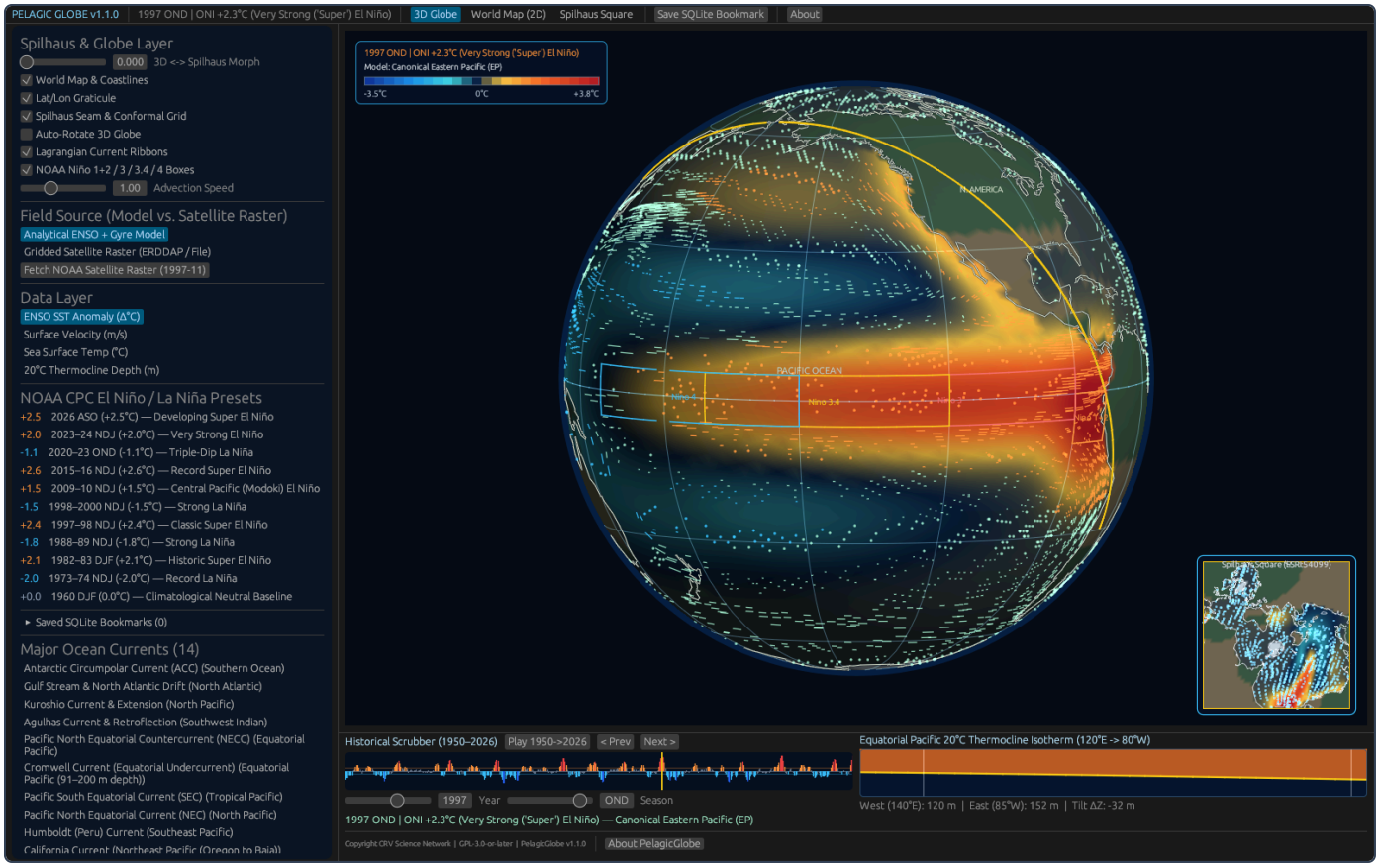
## 2. Cartographic Engine & Multi-Flavor ENSO Model

PelagicGlobe compiles eleven modular Rust files separating spherical Spilhaus/Adams conformal math, continental polygon boundary clipping, historical ONI look-ups, Lagrangian current advection, background ERDDAP networking, SQLite bookmark persistence, and offscreen/interactive GPU rendering (Table 1). Users inspect four synchronized scientific variables: ENSO SST Anomaly (Δ°C), Surface Velocity (m/s), Sea Surface Temperature (°C), and 20°C Thermocline Depth (m). Historical scrubbing across all 921 seasonal indices from 1950 DJF through 2026 ASO dynamically distinguishes canonical Eastern Pacific surges (1982–83, 1997–98) from the 2015–16 Mixed Super + NE Pacific Warm Blob[6], the 2009–10 Central Pacific Modoki[5], and cold-tongue La Niña regimes.

Table 1. Core Rust Architecture Inside `crvscience-pelagic-globe` v1.1.0

| Source File | Subsystem Role |
|---|---|
| `src/spilhaus.rs` | Conformal Spilhaus World Ocean (`ESRI:54099`) forward/inverse transforms anchored at Kerguelen (66.95°E, 49.56°S) and Bering Strait seam sampler. |
| `src/enso.rs` | Embedded 1950–2026 NOAA CPC ERSSTv6 ONI table (921 seasons), flavor classifier, 4 Niño boxes, climatological SST, and 20°C thermocline depth. |
| `src/currents.rs` | 14 major surface gyre, boundary, equatorial countercurrent, and circumpolar circulation velocity kernels modulated by ONI phase. |
| `src/coastlines.rs` | Embedded global continental coastlines and fast land/ocean bitmask classification (`WorldLandMask`) for vector advection. |
| `src/raster.rs` | Non-blocking NOAA CoastWatch ERDDAP OISST v2.1 (Sep 1981+) & NESDIS currents (2017+) HTTP client + local CSV/JSON/image import. |
| `src/storage.rs` & `src/app.rs` | SQLite WAL bookmark persistence, ERDDAP tile cache, 3D/2D/Spilhaus viewport GUI, 1950–2026 sparkline scrubber, and offscreen 1600 × 1000 PNG capture. |

**Figure 1. Offscreen Headless Capture (1600 × 1000 RGBA): 3D Globe — 1997–98 Super El Niño (OND 1997)**




3D Globe view of the 1997 OND Super El Niño (+2.3°C ONI / Canonical Eastern Pacific model) showing Niño 1+2 through 4 boxes, Lagrangian surface drifters, docked conformal Spilhaus inset, 1950–2026 ONI sparkline, and 20°C equatorial thermocline cross-section (120 m West vs. 152 m East).

## 3. Conformal Projection, Historical Episode & ERDDAP Benchmarks

Deterministic CLI execution ( `21_Pelagic-Globe.exe` ) confirms exact numerical invertibility across six global ocean checkpoints (Table 2) and distinct zonal thermocline tilt signatures across landmark historical episodes (Table 3; Figure 2). During strong La Niña forcing ( `1973 NDJ` , ONI −2.0°C), intensified trade winds pile warm water westward and shoal the Eastern Pacific 20°C isotherm to **16.0 m**, whereas Eastern Pacific Super El Niño relaxation flattens the thermocline down to **153.1–156.8 m** (1997 NDJ and 2015 NDJ). By contrast, Central Pacific Modoki forcing ( `2009 NDJ` , +1.5°C) concentrates warming near the Date Line and holds Eastern Pacific depth intermediate at **85.4 m**. Standalone SVG export emits **797 current velocity vectors** and **65 continental polylines**, while live ERDDAP ingestion for `2015-12-15` retrieves **10,741 valid ocean cells** across a 180 × 90 grid (stride 8).

Table 2. Conformal Spilhaus Forward/Inverse Coordinate Verification ( `--project-coord` )

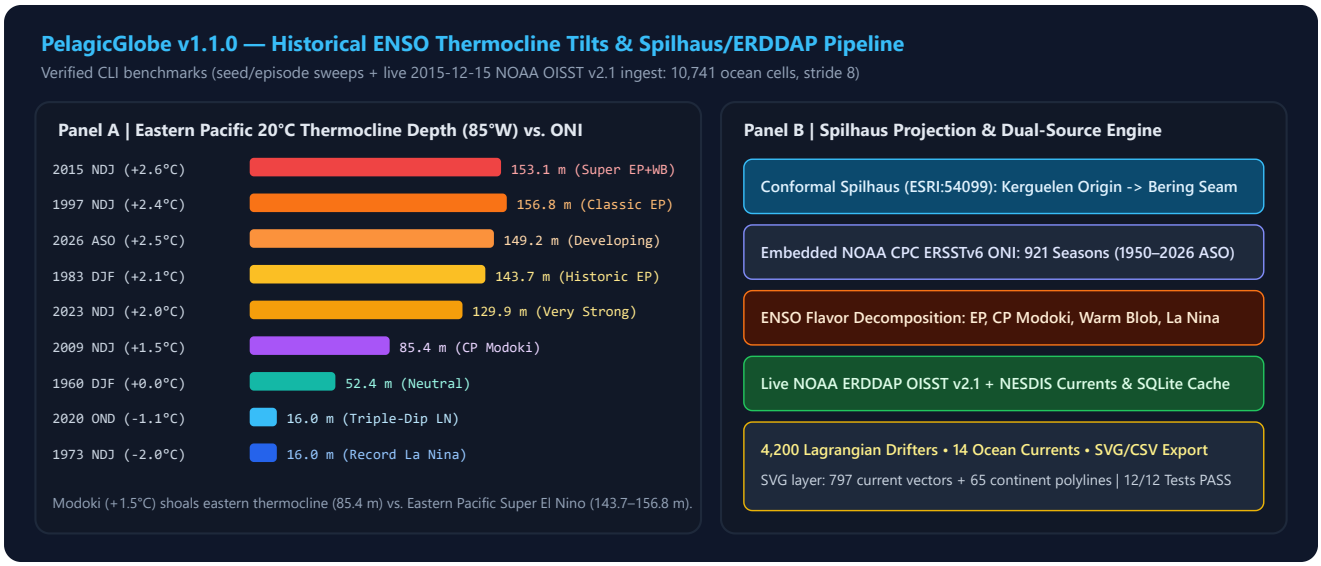
| Oceanographic Station | Input (Lon, Lat) | Spilhaus Normalized (u, v) | Inverse Round-Trip |
|---|---|---|---|
| San Francisco (California Current) | -122.4194°, 37.7749° | (+0.702469, -0.777589) | -122.4194°, 37.7749° |
| Equatorial Nino 3.4 | -145.0000°, 0.0000° | (+0.419870, -0.504781) | -145.0000°, 0.0000° |
| Gulf Stream (Cape Hatteras) | -74.0000°, 35.5000° | (-0.805026, +0.459217) | -74.0000°, 35.5000° |
| Kuroshio Extension | 145.0000°, 34.0000° | (+0.777290, -0.049588) | 145.0000°, 34.0000° |
| Southern Ocean Drake Passage | -62.0000°, -58.0000° | (-0.179412, -0.330967) | -62.0000°, -58.0000° |
| Kerguelen Spilhaus Origin | 66.9498°, -49.5637° | (+0.000000, +0.000000) | 66.9498°, -49.5637° |

Table 3. Historical ENSO Episode Benchmarks Across 11 Landmark NOAA CPC Presets ( `--self-test` )

| Preset Slug | Season | ONI | Classified Phase | East Pacific 20°C Isotherm |
|---|---|---|---|---|
| `super-2026` | 2026 ASO | +2.5 °C | Very Strong ('Super') El Niño | 149.2 m |
| `strong-2023` | 2023 NDJ | +2.0 °C | Very Strong ('Super') El Niño | 129.9 m |
| `lanina-2020` | 2020 OND | -1.1 °C | Moderate La Niña | 16.0 m |
| `super-2015` | 2015 NDJ | +2.6 °C | Very Strong ('Super') El Niño | 153.1 m |
| `modoki-2009` | 2009 NDJ | +1.5 °C | Strong El Niño | 85.4 m |

| | | | | |
|---|---|---|---|---|
| `lanina-1999` | 1999 NDJ | -1.5 °C | Strong La Niña | 16.0 m |
| `super-1997` | 1997 NDJ | +2.4 °C | Very Strong ('Super') El Niño | 156.8 m |
| `lanina-1988` | 1988 NDJ | -1.8 °C | Strong La Niña | 16.0 m |
| `super-1982` | 1983 DJF | +2.1 °C | Very Strong ('Super') El Niño | 143.7 m |
| `lanina-1973` | 1973 NDJ | -2.0 °C | Strong La Niña | 16.0 m |
| `neutral-1990` | 1960 DJF | +0.0 °C | ENSO Neutral | 52.4 m |

**Figure 2. Historical ENSO 20°C Thermocline Depth Tilt & Dual-Source Engine Architecture**

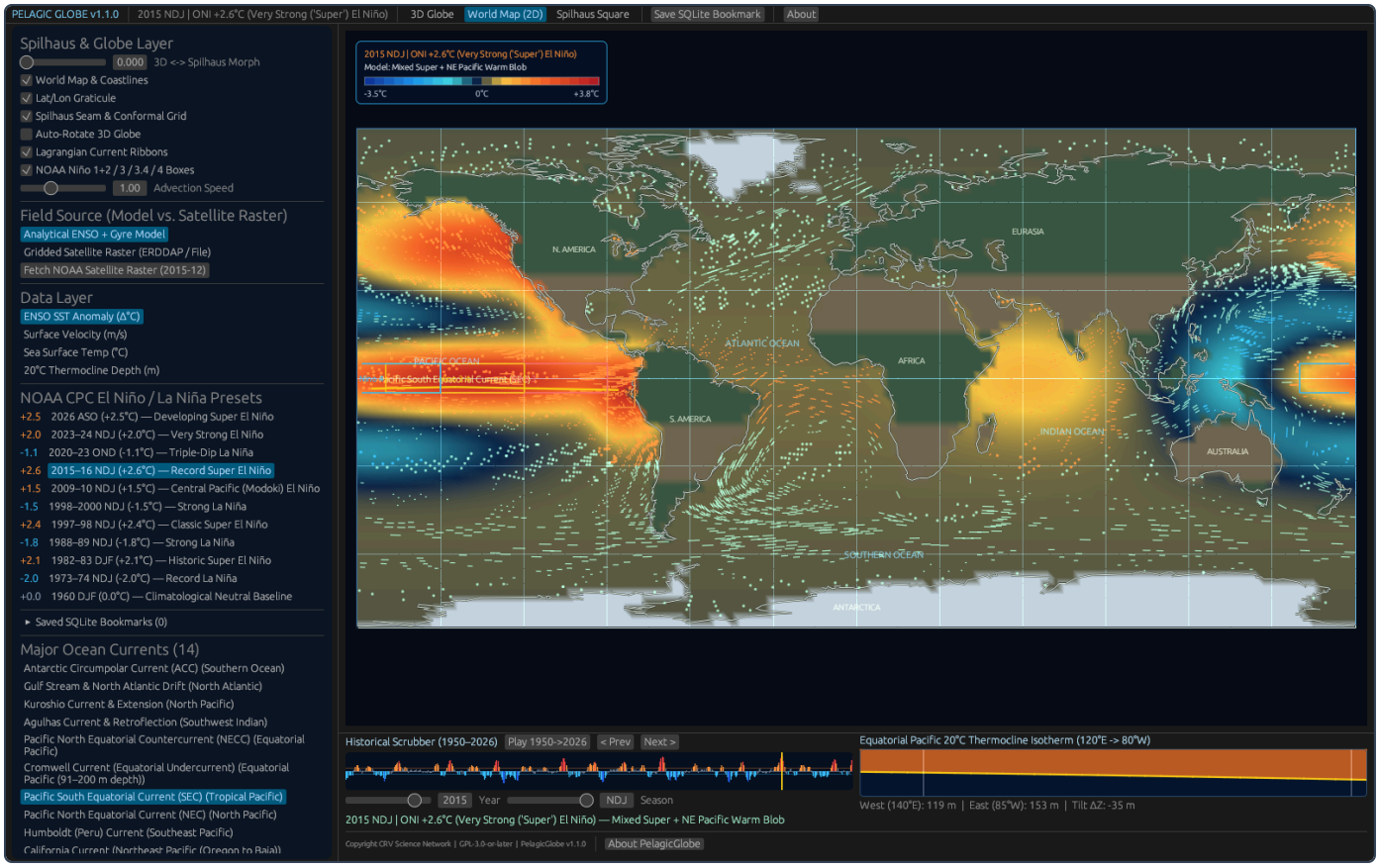



Left: Eastern Pacific (85°W) 20°C isotherm depth response across historical El Niño, Modoki, Neutral, and La Niña seasons. Right: Conformal Spilhaus transform coupled to 921-season ERSSTv6 lookup and background ERDDAP OISST v2.1 raster caching.

## 4. Multi-Projection Visualization Modes

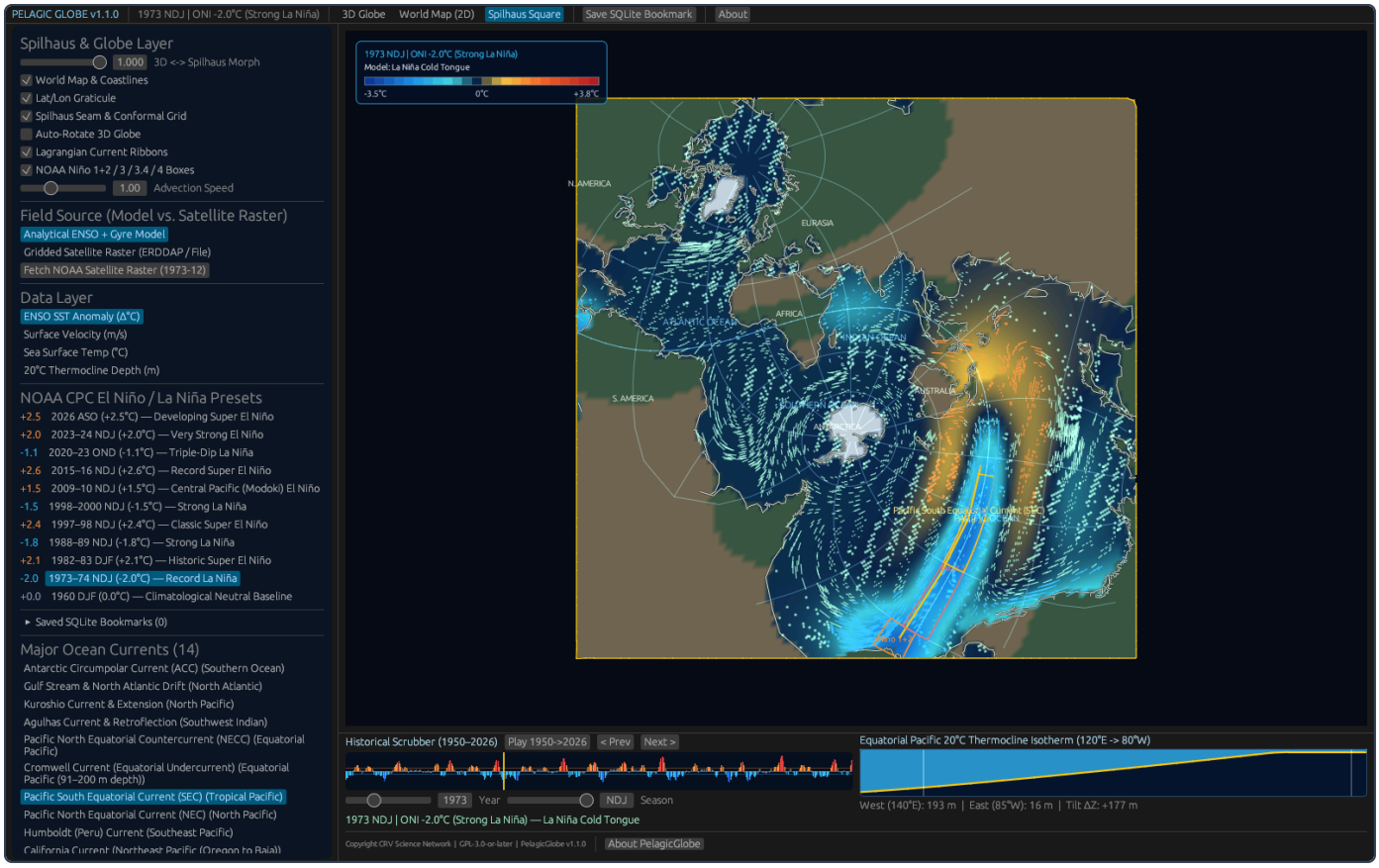
Switching instantaneously between equirectangular 2D global projection and the continuous Spilhaus square isolates regional vs. planetary basin structure (Figures 3–4). In 2015 NDJ (+2.6°C, Figure 3), the equatorial Eastern Pacific warm tongue coincides with both the Northeast Pacific Warm Blob off North America and Indian Ocean Dipole warming; in 1973 NDJ (−2.0°C, Figure 4), the conformal Spilhaus square preserves seamless equatorial-to-Antarctic current connectivity along a continuous World Ocean canvas.

**Figure 3. Headless 2D World Map Capture: 2015–16 Record Super El Niño + NE Pacific Warm Blob**




2D equirectangular view of 2015 NDJ (+2.6°C ONI) capturing intense equatorial Pacific warming paired with the North Pacific Warm Blob anomaly and vector drift streamlines across major gyres.

**Figure 4. Headless Spilhaus World Ocean Square (ESRI:54099): 1973–74 Record La Niña Cold Tongue**




Uninterrupted Spilhaus World Ocean view of 1973 NDJ (−2.0°C ONI) displaying intensified eastern equatorial cold tongue upwelling (16 m thermocline depth in East Pacific vs. 193 m in West Pacific) bounded by the continental coastline seam.

## 5. Software Availability & Network Integration

**PelagicGlobe** (v1.1.0) is released with complete source code, CLI harness, 12 automated tests, and validation artifacts under GPL-3.0-or-later via the isolated CRV Science Open-Source Apps hub at https://crvscience.com/apps[7–28]. Across the network, PelagicGlobe complements TerraTwin for long-term radiative-forcing warming projections, TrophicHearth for marine/intertidal ecosystem energetics, and AeroFlyway for coastal wind and atmospheric telemetry.

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