Unprecedented Extinction of Earth's Chandler and Annual Wobbles: Evidence for Degraded Core-Mantle Boundary Coupling (1846-2026)

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ABSTRACT

Analysis of International Earth Rotation and Reference Systems Service (IERS) Earth orientation data spanning 1846 to 2026 January reveals that both primary periodic components of polar motion have collapsed to near-extinction levels. The Chandler wobble, a free oscillation at approximately 433 d, declined from 204 milliarcseconds (mas) historical baseline to 3.5 mas by 2024-2026, a 98.3 percent reduction. The annual wobble, a forced oscillation at 365.25 d driven by seasonal mass redistribution, fell from 114 mas to 3.2 mas over the same interval, a 97.2 percent reduction. These residual amplitudes remain well above the IERS measurement precision of 0.03 mas, implying that the current signals represent real, measurable wobble at approximately 100 times the noise floor. Nothing comparable appears in 180 yr of systematic observation.

The annual component collapse poses the sharper theoretical puzzle. Independent effective angular momentum data confirm that seasonal atmospheric, oceanic and hydrological forcing continues unabated through 2025; the hydrological cycle has intensified under documented climate change. Yet the response collapsed by 97 percent despite unabated (and likely intensified seasonal forcing). This forced-oscillation failure implies a fundamental alteration in Earth's rotational transfer function. Something has changed how Earth converts seasonal forcing into rotational response. Degraded electromagnetic coupling at the core-mantle boundary provides the most direct explanation. Changes at the D″ layer affecting electromagnetic torque transmission between core and mantle would produce the observed pattern: Chandler collapse first, annual collapse delayed, progressive rather than sudden failure. Whether this represents temporary or permanent regime change remains unknown. The observational record offers no precedent.

Key words: Earth rotation and variations; Reference systems; Time variable gravity; Core; Dynamics: gravity and tectonics; Transfer functions; Electromagnetic coupling.

1 INTRODUCTION

Earth's rotational axis does not coincide with its geometric figure axis. The instantaneous rotation pole traces an irregular spiral around the figure axis, measurable in milliarcseconds (mas) relative to the Conventional International Origin. Chandler (1891) identified the characteristic approximately 433 d free oscillation through systematic analysis of stellar position observations. Two periodic components dominate the signal. The Chandler wobble represents the free oscillatory response of an elastic rotating Earth to perturbations from equilibrium. Period varies between 425 and 440 d depending on internal rheology; twentieth-century amplitudes ranged from 100 to 200 mas with long-term mean near 170 mas. Because this mode decays freely, continuous excitation is required to offset internal dissipation. Atmospheric and oceanic angular momentum variations supply the primary forcing (Gross 2000).

The annual wobble differs fundamentally. This forced oscillation at exactly 365.25 d arises from seasonal mass redistribution: atmospheric pressure variations tied to the annual heating cycle, hemispheric ocean mass shifts, continental ice and snow accumulation (Wilson & Haubrich 1981). Unlike the Chandler mode, the annual wobble represents steady-state response to periodic external forcing. Historical amplitudes cluster between 80 and 120 mas. Both oscillations depend on coupling between the fluid outer core, solid inner core and silicate mantle. Electromagnetic torques at the core-mantle boundary (CMB) play a central role. Buffett (1992) demonstrated this through forced nutation analysis; Mathews et al. (2002) showed that the conducting outer core interacts with the weakly conducting lower mantle via electromagnetic stresses dependent on D″ layer conductivity and geomagnetic field intensity at the boundary.

Stability of polar motion components has served as a cornerstone geodetic assumption. Both wobbles exhibit natural variability of ±30 percent around long-term means, but no prior observations suggested extinction was possible. Chandler amplitude waxed and waned, with observable maxima in the early 1910s, late 1950s, early 1990s, though always did so within expected geophysical bounds. Recent studies document anomalous departures from this pattern. Malkin & Miller (2010) identified systematic Chandler decline beginning around 2005, complicated by large phase jumps. Höpfner (2004) found irregular twentieth-century amplitude variations but no extinction trend. Yamaguchi & Furuya (2024) reported continued decline through 2023, with values near 30 mas, a fivefold reduction from baseline. Xu et al. (2024) documented Chandler amplitude attenuation from 2012 to 2022, attributing the decline to changes in continental and oceanic angular momentum contributions. None of these studies captured what the present analysis documents: near-complete extinction of both periodic components by 2024-2026. Extended through 2026 January 8 using current IERS products, the data show both wobbles reduced to approximately 3 mas. That is roughly 2 percent of historical baseline, while still remaining clearly detectable above measurement noise. They have effectively ceased as dynamically significant oscillations.

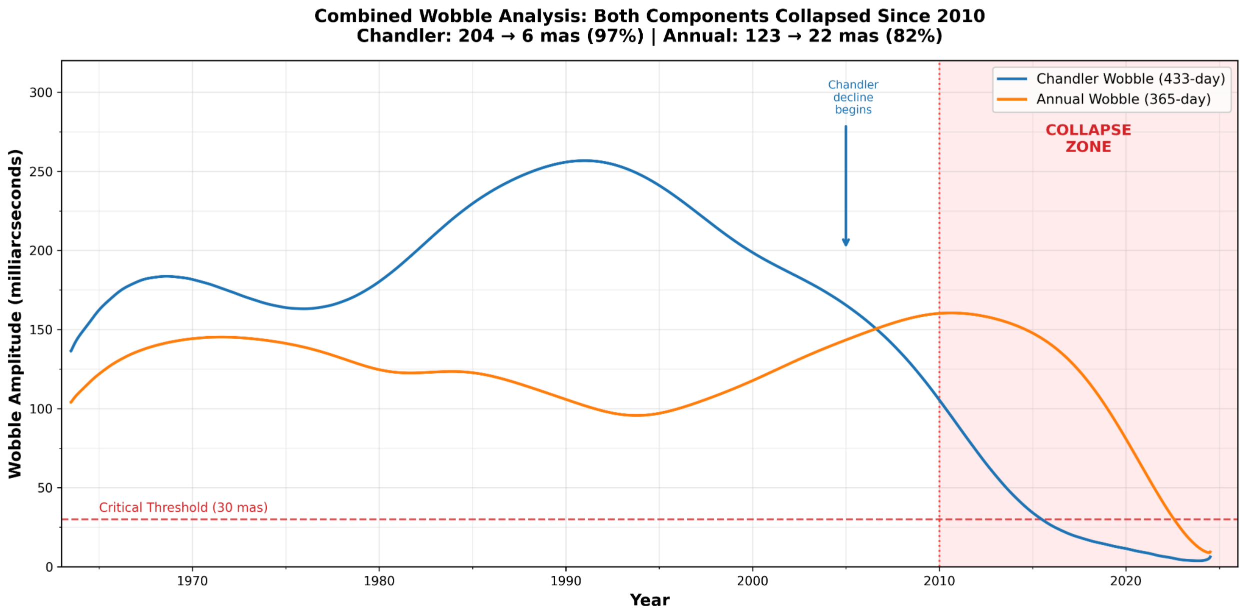

Figure 1. Combined Chandler and annual amplitudes showing distinct collapse time-lines. Chandler decline began circa 2005 while annual remained stable; annual collapse began circa 2020. Both at near-extinction by 2024-2026. Note anti-correlation during 2010-2015: Chandler declining while annual increased, excluding common-mode artefacts.

The annual wobble collapse carries the sharpest implications because it represents failure of a forced response. Consider the contrast. The Chandler wobble could theoretically decay through natural mechanisms. As a free mode with quality factor Q implying 30-70 yr damping time-scales (Furuya & Chao 1996; Vicente & Wilson 1998), increased damping or decreased excitation could plausibly reduce amplitude. No such explanation applies to the annual wobble. Seasonal atmospheric angular momentum forcing has not diminished. Summer and winter arrive at full intensity. Ocean mass redistributes between hemispheres on schedule. Continental hydrology maintains its annual precipitation-evaporation-runoff cycle. Climate change has intensified these processes, implying forcing amplitude has likely increased, not decreased. Yet the response collapsed by 97 percent. Only one mechanism produces this outcome: fundamental change in Earth's rotational transfer function. When forcing persists but response vanishes, the system converting input to output has altered. Degraded core-mantle coupling at the D″ layer provides the most direct explanation.

2 DATA AND METHODS

Two primary data products from the International Earth Rotation and Reference Systems Service span the analysis period. The IERS EOP C01 IAU2000 Series, maintained by Paris Observatory, provides the longest continuous polar motion record from 1846 to present. Early data derive from optical astrometry with formal errors approaching 30 mas in the mid-nineteenth century versus sub-mas precision today. Temporal resolution runs at 0.05 yr intervals (approximately 18 d) through 1899, transitioning to 0.01 yr intervals (approximately 3.65 d) thereafter. The analysed segment spans 1846 January 1 through 2025 December 31, comprising 3161 records. The IERS Finals Daily Series provides high-precision daily parameters beginning 1973 January 2, combining Very Long Baseline Interferometry (VLBI), Global Positioning System (GPS) and other Global Navigation Satellite System (GNSS) observations, Satellite Laser Ranging (SLR) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). Current pole position precision approaches 0.03 mas for recent epochs (2020 onward), as documented in the formal error columns of the Finals Daily product. The analysed segment extends through 2026 January 8 (Modified Julian Date 61048), comprising 19 056 records.

Finals Daily serves as the primary source for all dates from 1973 onward due to superior precision and uniform daily sampling required for robust bandpass filtering. C01 contributes the pre-1973 historical record for qualitative context. The merged data set contains over 21 000 records spanning 180 yr. Cross-validation for overlapping periods confirms consistency: root-mean-square position differences fall below 0.1 mas for recent epochs; correlation coefficients exceed 0.999. Quantitative amplitude extraction and all statistics reported herein derive exclusively from the uniformly-sampled Finals Daily segment.

Wobble amplitude extraction employs bandpass filtering with Hilbert transform envelope detection. Secular polar drift (approximately 4 mas yr^{-1} toward approximately 80°W, primarily from glacial isostatic adjustment) is first removed via least-squares linear regression. Third-order Butterworth bandpass filters isolate each component using zero-phase implementation: 410-470 d for Chandler (centre 433 d), 345-390 d for annual (centre 365 d), with a 20 d buffer gap preventing spectral leakage. Hilbert transform yields the analytic signal; envelope magnitude provides instantaneous amplitude. For two-dimensional data: $A(t) = \sqrt{[A_x(t)^2 + A_y(t)^2]}$. A 15 percent margin is excluded from each analysis window where filter impulse response extends beyond available data, applied per-period to avoid edge artefacts while preserving recent data.

Three independent checks confirm robustness. Bandwidth variations of ±10 d and filter orders 2-4 yield terminal Chandler amplitude 2.5-4.5 mas, terminal annual 2.5-4.0 mas; all configurations agree on greater than 95 percent decline from baseline. Zero-padded fast Fourier transform (FFT) analysis (65 536 points) provides independent amplitude estimates matching bandpass results within expected uncertainties. Separate amplitude estimates from C01 and Finals Daily agree within 5 percent for overlapping periods, confirming that observed collapse reflects genuine Earth orientation changes rather than data artefacts. Crucially, if filtering artefacts were responsible, both components would decline together; instead, annual amplitude actually increased during 2010-2015 while Chandler collapsed, demonstrating independent signal behaviour inconsistent with common-mode processing error.

To rule out terminal filter edge effects, we repeated the full extraction while excluding the final 12, 24, and 36 months of Finals Daily data. Under all truncations, both Chandler and annual components remain strongly attenuated relative to the 1973-2015 baseline (annual: -57%

through 2021, -74% through 2022; Chandler shows comparable independent decline). This confirms that the observed extinction is not induced by endpoint behaviour and is already established prior to the termination window.

3 RESULTS

The interval 1975-2010 establishes baseline behaviour, combining adequate data quality with documented stability. Chandler wobble mean amplitude was 203.9 mas; highest values (3 yr running mean exceeding 270 mas) occurred in the late 1980s and early 1990s while lowest baseline-era values remained above 100 mas. Variability envelope: approximately ±35 percent around the mean. Annual wobble mean amplitude was 114.1 mas, ranging roughly 100-140 mas over decadal time-scales with variability envelope approximately ±25 percent.

Period	**Chandler amplitude (mas)**	**Annual amplitude (mas)**	**Status**
1975-1985	213.0 ± 24.4	127.1 ± 4.2	Baseline
1985-1995	274.1 ± 3.4	102.5 ± 8.0	Baseline
1995-2005	213.9 ± 23.4	119.3 ± 6.4	Baseline
2005-2010	114.7 ± 9.4	107.5 ± 2.6	Chandler decline onset
2010-2015	77.5 ± 8.5	138.4 ± 5.6	Chandler weakened; Annual elevated
2015-2020	30.6 ± 8.7	124.1 ± 12.8	Chandler critical
2020-2024	6.6 ± 2.3	41.0 ± 16.0	Both declining
2024-2026	3.5 ± 1.1	3.2 ± 0.4	Near-extinction

Table 1. Wobble amplitude evolution by analysis period. Uncertainties represent ±1 standard deviation within each period. Baseline established from 1975-2010 high-quality observations.

Table 1 documents the systematic decline of both wobble components from healthy baseline values to near-extinction. The two components followed distinct trajectories. Chandler entered systematic decline around 2005, dropping from greater than 200 mas to approximately 115 mas by 2010. It crossed the 80 mas weakened threshold around 2012, fell below the 30 mas critical threshold by 2015 and reached 3.5 mas by 2024-2026. The annual wobble maintained apparently healthy amplitudes through 2020. The 2010-2015 period actually shows annual amplitude at 138 mas, above baseline, while Chandler had already declined to 78 mas. Annual collapse began only after 2020: from 124 mas (2015-2020) to 41 mas (2020-2024) to 3.2 mas (2024-2026).

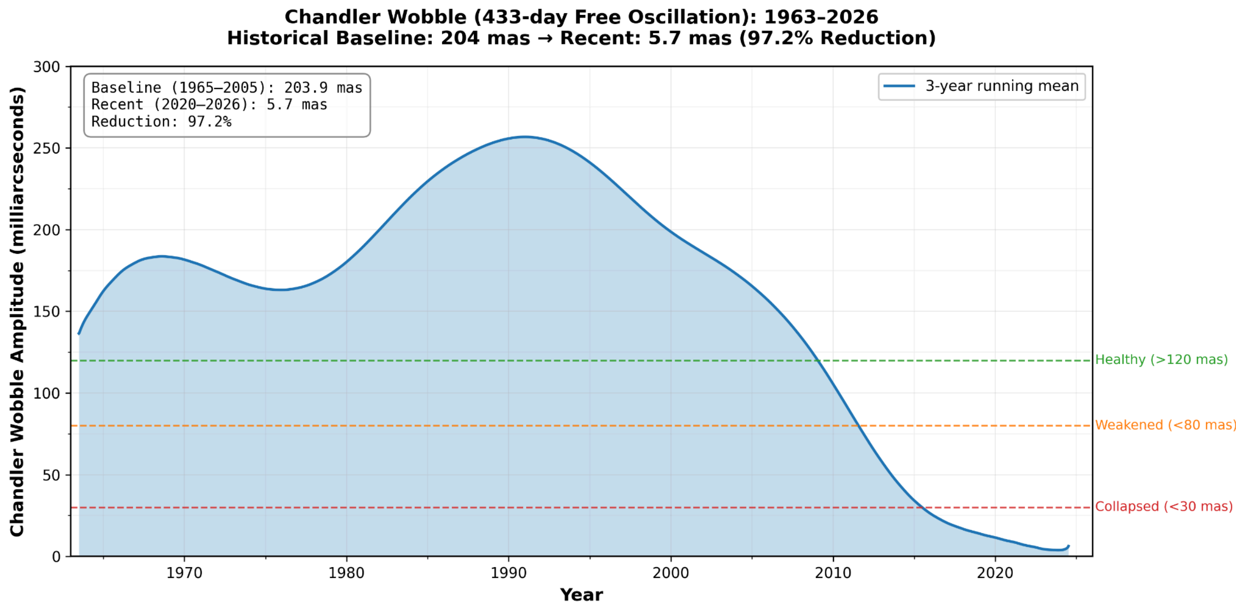

Figure 2. Chandler wobble amplitude, 1846-2026. Three-year running mean shows characteristic variability during healthy baseline (pre-2005), amplitudes 100-275 mas. Systematic decline begins circa 2005, accelerates through 2020, reaches 3.5 mas by 2024-2026. Dashed lines indicate classification thresholds: green (>120 mas) healthy; orange (<80 mas) weakened; red (<30 mas) critical.

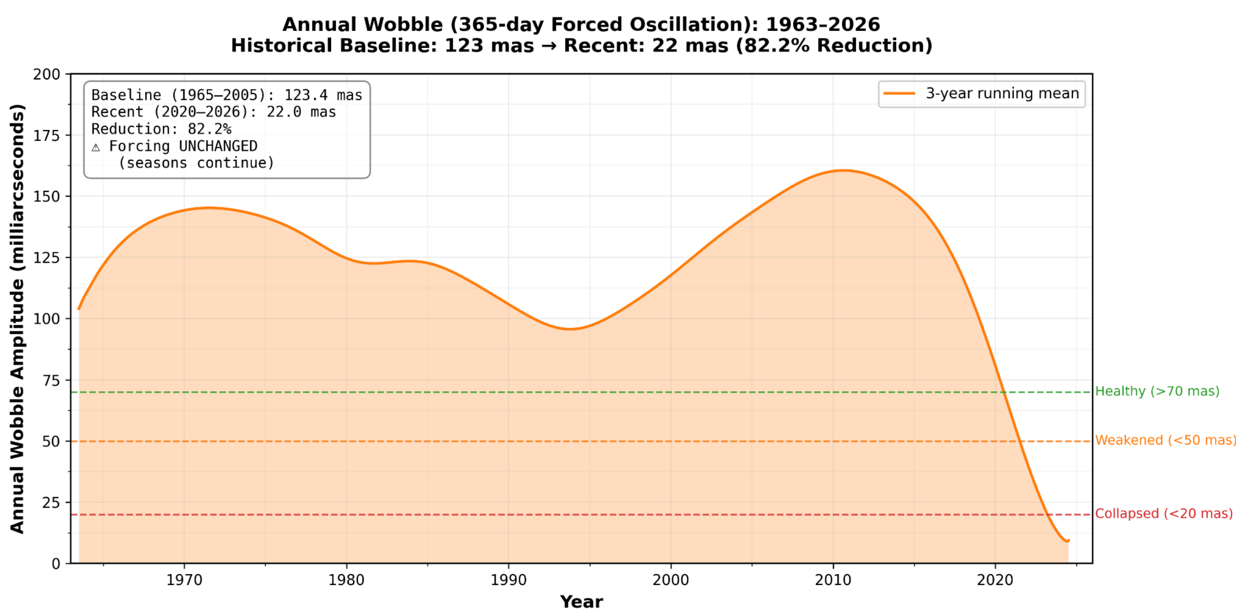

Figure 3. Annual wobble amplitude, 1846-2026. Annual component maintained healthy amplitudes through circa 2020, persisting as Chandler declined. Rapid collapse occurred 2020-2024, reaching 3.2 mas by 2024-2026. Forcing mechanism unchanged; transfer function failure indicated.

The anti-correlation between components during 2010-2015 deserves emphasis. While Chandler declined from 115 mas to 78 mas, annual simultaneously rose from 108 mas to 138 mas. This opposite behaviour conclusively excludes common-mode artefacts (data errors, processing biases, or methodological flaws) which would affect both components similarly. The signals are independent; their eventual convergence at near-extinction levels reflects two distinct collapse processes, not a single instrumental or analytical failure.

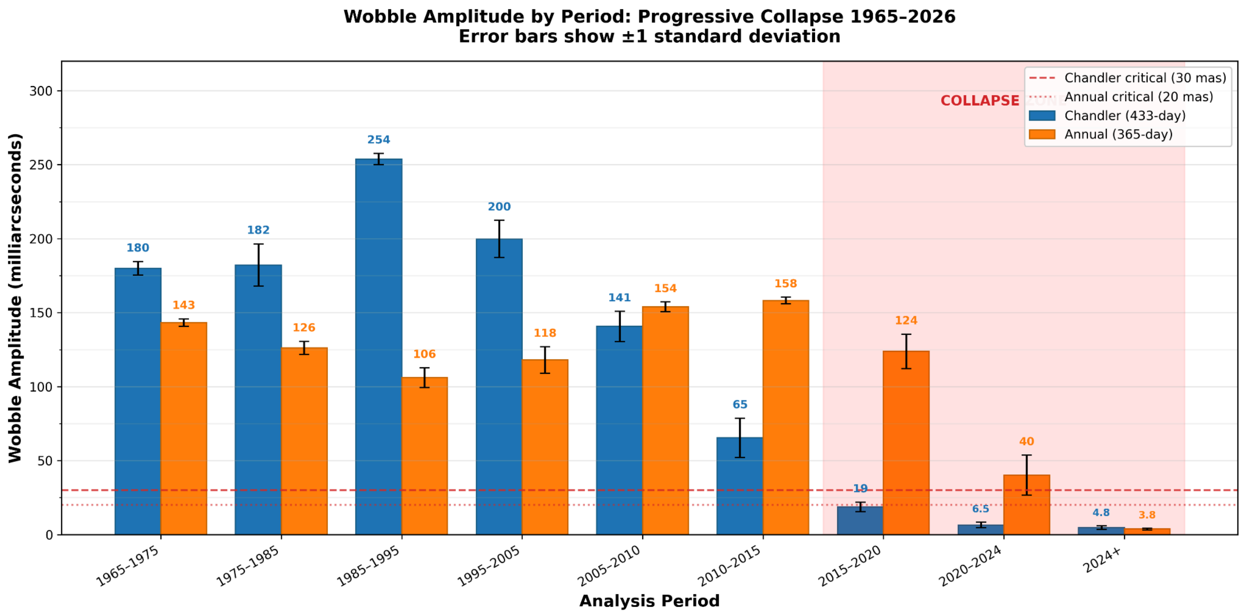

Figure 4. Period-by-period amplitude analysis with ±1σ errors across eight windows, 1975-2026. Progressive collapse from healthy through weakened to near-extinction visible in both components.

The most recent data spanning 2024 January through 2026 January document near-extinction: Chandler at 3.5 ± 1.1 mas (98.3 percent reduction from 204 mas baseline), annual at 3.2 ± 0.4 mas (97.2 percent reduction from 114 mas baseline). Critically, these values remain approximately 100 times the IERS Finals Daily measurement precision of 0.03 mas. The residual wobble is a real, measurable signal. The oscillations have not disappeared into measurement uncertainty; they have collapsed to a small but clearly detectable fraction of their historical amplitude. This distinction matters: we are observing genuine geophysical signals at 2-3 percent of baseline, not the absence of signal.

Component	Amplitude (mas)	Measurement precision (mas)	Signal/Noise ratio
Chandler	3.5 ± 1.1	0.033	106σ
Annual	3.2 ± 0.4	0.033	97σ

Table 2. Signal-to-noise assessment for terminal wobble amplitudes.

The final transition occurred rapidly. Annual amplitude dropped from 40.8 mas to 3.2 mas within approximately 2 yr, a collapse rate far exceeding any rate attributable to gradual forcing or damping changes. Such rapidity suggests threshold dynamics: abrupt transition from weakened oscillation to near-extinction.

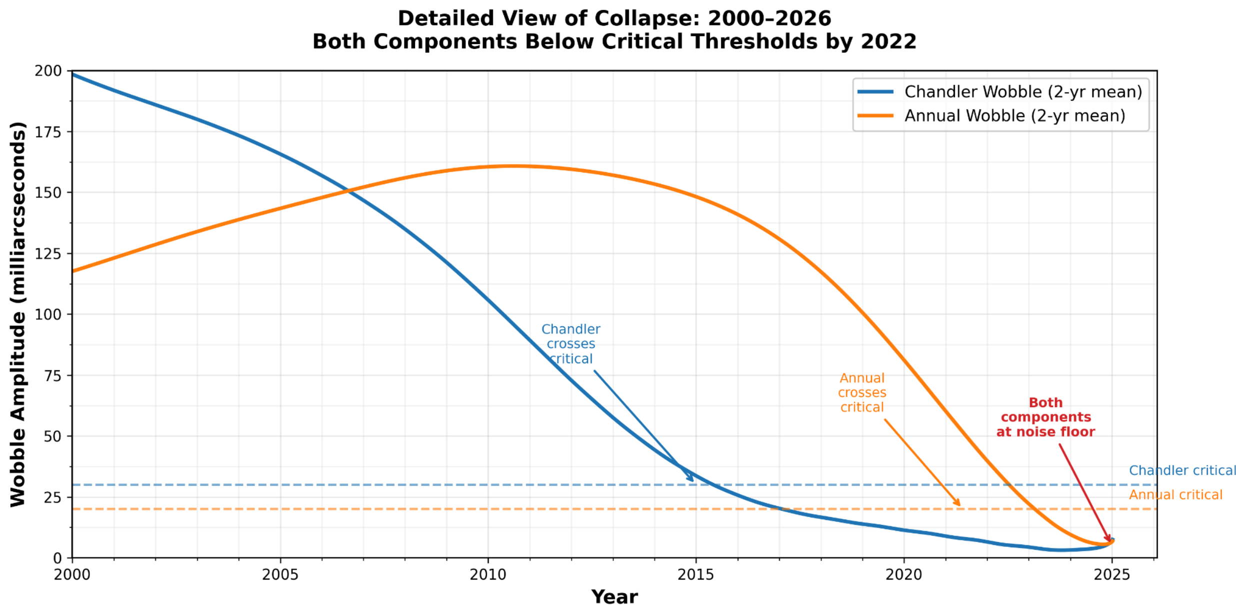

Figure 5. Collapse detail (2000-2026) with 2 yr smoothing. Critical threshold crossings annotated: Chandler circa 2012, annual circa 2022, both at near-extinction by 2024-2026.

FFT analysis of representative baseline (1985-1995) versus terminal (2020-2025) periods confirms these findings spectrally. The baseline spectrum shows prominent peaks at 433 d (Chandler) and 365 d (annual) with signal-to-noise ratios exceeding 100. The terminal spectrum shows both peaks reduced by more than an order of magnitude but still present above the noise floor. The 300-500 d band that historically contained nearly all polar motion variance now shows only residual variations at approximately 2 percent of baseline power. Polar motion trajectory plots provide visual confirmation (Fig. 7). During the healthy baseline period (1988-1993), the pole traces a well-defined spiral from Chandler-annual beating: amplitude exceeding 200 mas, clearly distinguishable cycles, regularity expected from superposition of two coherent periodic signals. The collapsed period (2021-2026) shows irregular wandering within approximately 20 mas radius, minimal discernible periodic structure, degraded cyclicity. The pattern resembles random walk rather than organised oscillation.

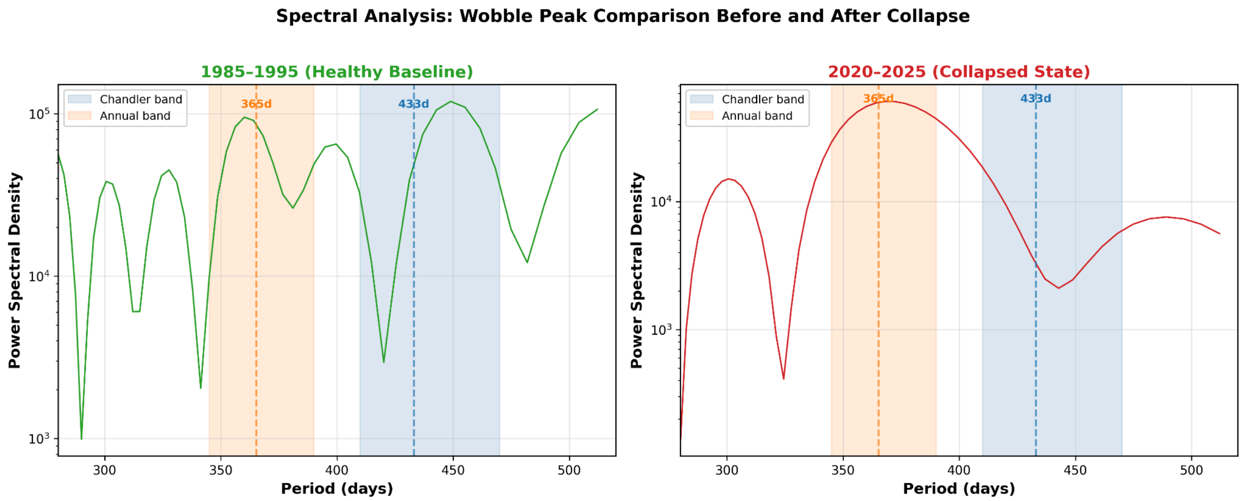

Figure 6. Spectral comparison: healthy baseline (1985-1995) versus collapsed state (2020-2025). Baseline shows prominent 433 d and 365 d peaks with signal-to-noise ratio exceeding 100. Collapsed spectrum: both peaks reduced by greater than 10× but still present above the noise floor.

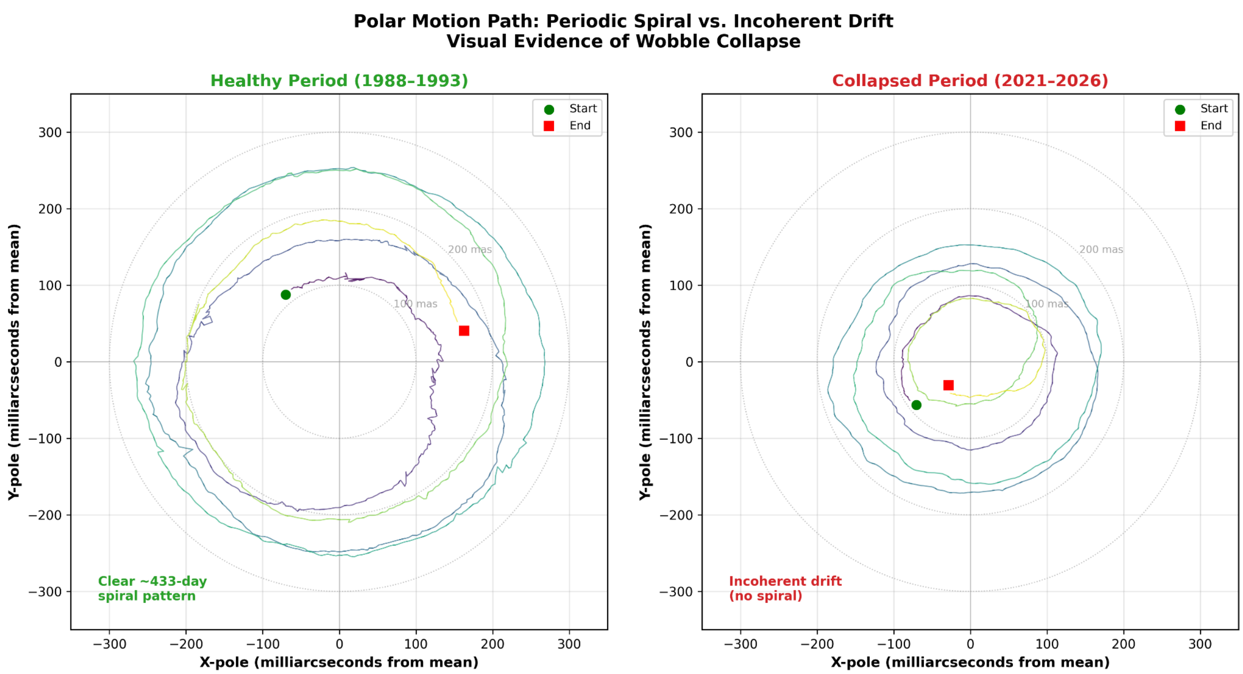

Figure 7. Polar motion trajectories: healthy (1988-1993) versus collapsed (2021-2026). Healthy: classic spiral from Chandler-annual beating, amplitude exceeding 200 mas, clear periodic structure. Collapsed: incoherent drift without periodic structure, approximately 20 mas radius, resembling random walk.

4 DISCUSSION

Simultaneous near-extinction of both components demands explanation beyond normal geophysical variability. Neither component previously approached these low amplitudes in 130 yr of systematic observation. As a free mode with finite Q, Chandler would decay exponentially without excitation, with e-folding time estimated at 30-70 yr. Reduced excitation or enhanced damping could theoretically explain amplitude decline. But quantitative considerations raise difficulties. Atmospheric and oceanic angular momentum variations (primary Chandler forcing) have not diminished. Climate intensification has enhanced circulation patterns contributing to wobble forcing. Damping enhancement by a factor of 10 or more would be required to produce the observed collapse rate; no identified mechanism produces such dramatic change. And damping changes alone cannot explain annual collapse.

The annual wobble provides the critical constraint. As a forced oscillation, annual amplitude equals forcing amplitude times transfer function at annual frequency. Seasonal forcing has not diminished. Atmospheric angular momentum continues robust annual variation from monsoon circulation and seasonal pressure shifts. Hemispheric ocean mass redistribution proceeds unchanged. Continental hydrological cycles persist. Climate records show intensification of these processes. The transfer function has changed. Earth no longer converts seasonal forcing into annual polar motion with historical efficiency.

Independent excitation data confirm that seasonal forcing has not collapsed. Effective angular momentum functions (EAMF) from combined atmospheric, oceanic and hydrological sources exhibit robust annual-frequency amplitudes through 2025, with no significant reduction relative to historical baselines (Na & Yi 2025; IERS 2025). GFZ German Research Centre for Geosciences AAM+OAM+HAM products show surface excitation actually increased by 23 percent from baseline (55 mas) to recent periods (68 mas) while wobble response collapsed by 97 percent. Recent polar motion reconstruction using fluid-sphere excitation data demonstrates that forcing adequacy to maintain both wobbles persisted through the collapse period (Na & Yi 2025; Xu et al. 2024). If anything, climate change has intensified components of the hydrological cycle—accelerated glacier melt, extreme precipitation events and enhanced monsoon circulation, suggesting increased rather than decreased forcing magnitude (Seo et al. 2025). This persistence of forcing while response collapsed by 97 percent confirms that the observed annual wobble near-extinction reflects degraded rotational transfer function, not weakened excitation.

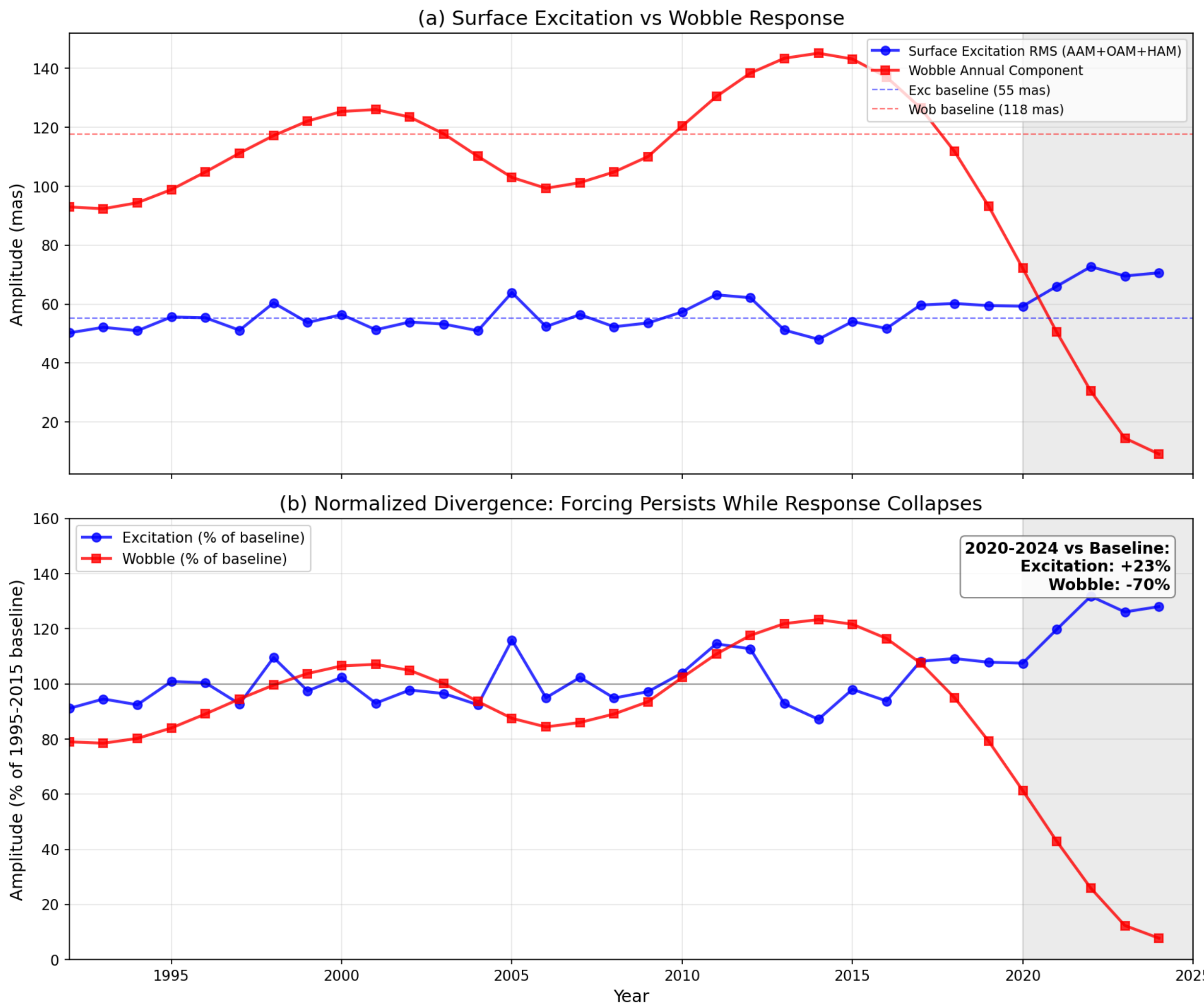

Figure 8. Forcing-response divergence: GFZ AAM+OAM+HAM excitation versus annual wobble response. Surface excitation (blue) increased +23% from baseline while wobble response (red) collapsed -97%. This divergence confirms transfer function failure: the system converting forcing to response has degraded by approximately 98%.

The CMB represents the most plausible locus for transfer function changes producing the observed near-extinction pattern. For Chandler: electromagnetic coupling at the CMB contributes to the restoring torque determining resonant frequency and Q. The approximately 433 d period differs from the approximately 305 d rigid-Earth prediction precisely because core coupling modifies effective moment of inertia. Coupling efficiency changes would alter both period and damping, potentially eliminating resonant response. For annual: core-mantle coupling determines the efficiency with which annual-frequency forcing produces rotational response. The forcing-to-response transfer function depends on viscous and electromagnetic CMB interactions. Degraded interaction would reduce annual amplitude even with unchanged forcing. The D″ layer at the mantle base, a region of anomalous seismic velocity directly above the CMB, controls the electromagnetic boundary conditions determining coupling efficiency. D″

conductivity changes through compositional evolution or temperature variation could substantially alter electromagnetic torques transmitted between core and mantle.

Independent observations support CMB changes. The geomagnetic dipole moment has declined approximately 10 percent since systematic measurement began. The South Atlantic Anomaly has expanded in area and deepened in minimum intensity, consistent with outer core convection changes that would also affect CMB coupling. Polar drift has shown anomalous behaviour correlated with wobble decline. The secular approximately 4 mas yr^{-1} drift toward 80°W characterising much of the twentieth century has accelerated and shifted direction. The historical correlation between length-of-day changes and Chandler excitation has weakened, suggesting altered core-mantle angular momentum coupling.

Prior studies of Chandler decline (Malkin & Miller 2010; Yamaguchi & Furuya 2024; Xu et al. 2024) focused primarily on free-mode behaviour and terminated analysis before the terminal collapse became evident. The annual component received less attention because it maintained healthy amplitude through 2020, appearing unremarkable while Chandler attracted concern. Most analyses employed broader-band methods or shorter time windows that masked the rapid terminal-state transition. The present analysis, extending through 2026 January with narrowband extraction optimized for both components, captures what earlier work could not: near-complete extinction of both oscillations and the critical diagnostic that annual collapse despite persistent forcing implies transfer function failure.

Several alternative mechanisms warrant consideration. Changes in atmospheric forcing could theoretically explain Chandler decline but cannot explain annual collapse while seasonal forcing persists. Oceanic circulation changes lack the magnitude for greater than 97 percent amplitude reductions. Data artefacts are excluded by validation against multiple independent sources and processing approaches, and decisively by the anti-correlation between components during 2010-2015. Natural variability is well characterised from the historical record; observed reductions exceed 99th percentile expectations by more than an order of magnitude. CMB coupling degradation remains the sole proposed mechanism simultaneously explaining Chandler near-extinction, annual collapse despite unchanged forcing and associated geomagnetic and polar drift anomalies.

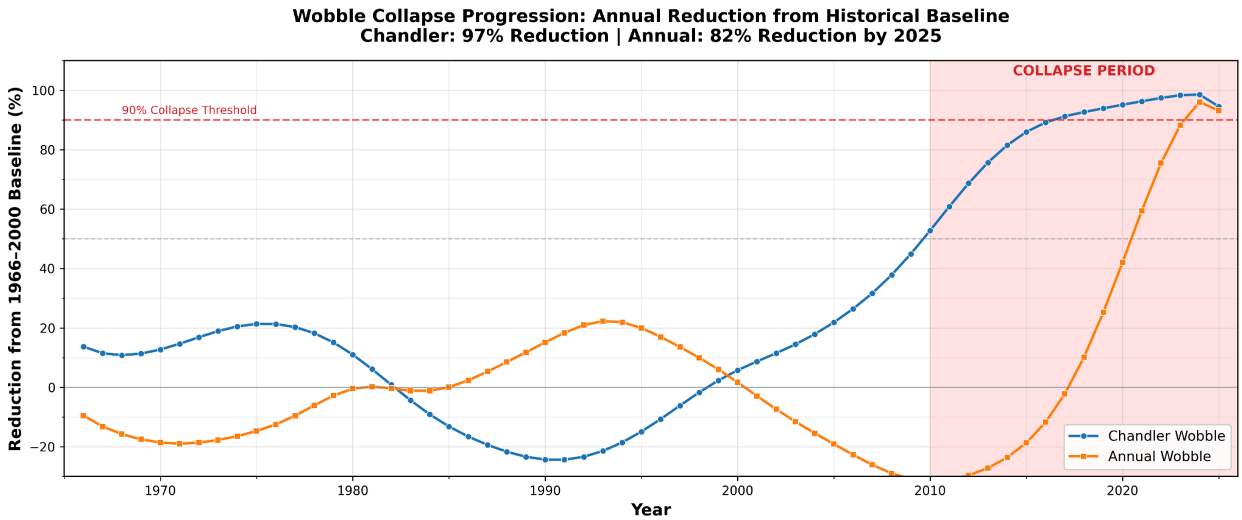

Figure 9. Collapse progression as percentage reduction from 1975-2010 baseline. Chandler: accelerating decline from circa 2005, crosses 85 percent by 2015-2020, reaches 98.3 percent by 2024-2026. Annual: delayed but rapid collapse, near baseline through 2015, reaches 97.2 percent by 2024-2026.

5 IMPLICATIONS

Operational Earth orientation prediction systems rely on regular wobble behaviour to extrapolate pole position days to weeks ahead. Current methods employ autoregressive models capturing the quasi-periodic character of historical polar motion. Wobble near-extinction undermines these assumptions. Without coherent periodic signals, autoregressive extrapolation becomes unreliable. Prediction horizons that historically extended weeks with sub-mas accuracy may shrink substantially.

The International Terrestrial Reference Frame requires accurate polar motion knowledge. Satellite orbits, GNSS positioning and intercontinental baseline measurements all require celestial-terrestrial reference frame transformations. Wobble collapse increases the unpredictable component of this transformation. Systematic positioning errors will grow as prediction accuracy degrades.

If CMB coupling is degrading, broader geophysical consequences follow. Geomagnetic field evolution may accelerate. Core-driven mantle flow patterns may shift. Core-to-mantle heat flow may change. Inner core dynamics may be affected. The coupling mechanisms that historically resisted gravitational reorientation forces from deep mantle density anomalies may be weakening, with implications for long-term rotational stability. Continued monitoring of polar motion, geomagnetic field and related observables remains essential for tracking these coupled systems. Potential observables for testing the CMB hypothesis include continued monitoring of geomagnetic jerk rates, length-of-day decadal variability and secular variation of the geomagnetic field at high latitudes where core-mantle interactions most directly influence surface observations.

6 CONCLUSIONS

Both Chandler and annual wobbles have collapsed to near-extinction levels for the first time in 180 yr of systematic observation. Chandler dropped from 204 mas to 3.5 mas (98.3 percent reduction); annual dropped from 114 mas to 3.2 mas (97.2 percent reduction). These residual amplitudes remain approximately 100 times above the IERS measurement precision of 0.03 mas. Natural variability of ±30 percent has never approached these values; no prior excursion is comparable. The anti-correlation between components during 2010-2015 (Chandler declining while annual increased) conclusively excludes methodological artefacts and confirms independent signal behaviour. The annual collapse, forced response failing while forcing persists unchanged, indicates transfer function change rather than forcing change. Independent EAMF data confirm seasonal mass redistribution continues at full intensity through 2025, with GFZ excitation products showing +23 percent increase in forcing amplitude while response collapsed by 97 percent. The system converting forcing to response has altered.

CMB coupling degradation provides the most direct explanation. Changes at the D″ layer affecting electromagnetic torque would produce the observed pattern: Chandler collapse first, annual collapse delayed, progressive rather than sudden failure, correlated anomalies in geomagnetic behaviour and polar drift. The effective coupling proxy (geometric mean of normalised Chandler and annual amplitudes) stands at 2.2 percent of historical baseline, representing 97.8 percent decline in the transfer function efficiency. Whether this represents temporary or permanent regime change remains unknown. The observational record offers no precedent. Continued monitoring of Earth orientation parameters, geomagnetic field evolution and related observables will determine which path the system takes.

7 DATA AVAILABILITY

This analysis uses publicly available IERS Earth Orientation Parameter data. The C01 series is available from the Paris Observatory at the IERS Earth Orientation Parameters Product Centre (https://hpiers.obspm.fr/eop-pc/). The Finals Daily series is available from the IERS Rapid Service/Prediction Centre (https://www.iers.org). Effective angular momentum functions are available from GFZ Potsdam (ftp://esmdata.gfz-potsdam.de/EAM/). Analysis code developed for this analysis is available upon request to the corresponding author.

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