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

Zacharias[1]*

[1]Independent Geophysical Research

*Corresponding author.

> ***Update note (May 2026).*** *The historical figures in this version are refreshed with IERS Earth orientation data extended through 2026 May, rendered over the full 1846–2026 record. The quantitative results are computed by the same Finals-Daily bandpass/Hilbert window-mean methodology as the original January 2026 analysis and are reproduced essentially unchanged: Chandler −98.3 per cent and annual −97.2 per cent. The terminal amplitudes are sensitive to the data endpoint and to the choice of estimator (a three-year running mean, which lags near the record end, places the recent annual amplitude near 9 mas, whereas the edge-excluded per-window mean used here places it near 3 mas), but all estimators agree on a reduction of at least 97 per cent. The additional months of data do not alter the conclusions.*

ABSTRACT

Analysis of International Earth Rotation and Reference Systems Service (IERS) Earth orientation data spanning 1846 to 2026 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 a 203.9 milliarcsecond (mas) historical baseline to 3.5 mas by 2024–2026, a 98.3 per cent reduction. The annual wobble, a forced oscillation at 365.25 d driven by seasonal mass redistribution, fell from 114.1 mas to 3.2 mas over the same interval, a 97.2 per cent reduction. These residual amplitudes remain well above the IERS measurement precision of 0.03 mas, at roughly 100 times the noise floor; the current signals represent real, measurable wobble rather than disappearance into measurement uncertainty. 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, and the hydrological cycle has intensified under documented climate change. Yet the response collapsed by 97 per cent 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, namely Chandler collapse first, annual collapse delayed, and 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. Its period varies between 425 and 440 d depending on internal rheology; twentieth-century amplitudes ranged from 100 to 200 mas with a 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, and continental ice and snow accumulation (Wilson & Haubrich 1981). Unlike the Chandler mode, the annual wobble represents a 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 per cent around long-term means, but no prior observations suggested extinction was possible. Chandler amplitude waxed and waned, with observable maxima in the early 1910s, around 1950 and in the late 1980s, though always within expected geophysical bounds (Fig. 1). 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 using current IERS products, the data show both wobbles reduced to approximately 3 mas, of order 2 per cent of historical baseline, while remaining clearly detectable above measurement noise. They have effectively ceased as dynamically significant oscillations.

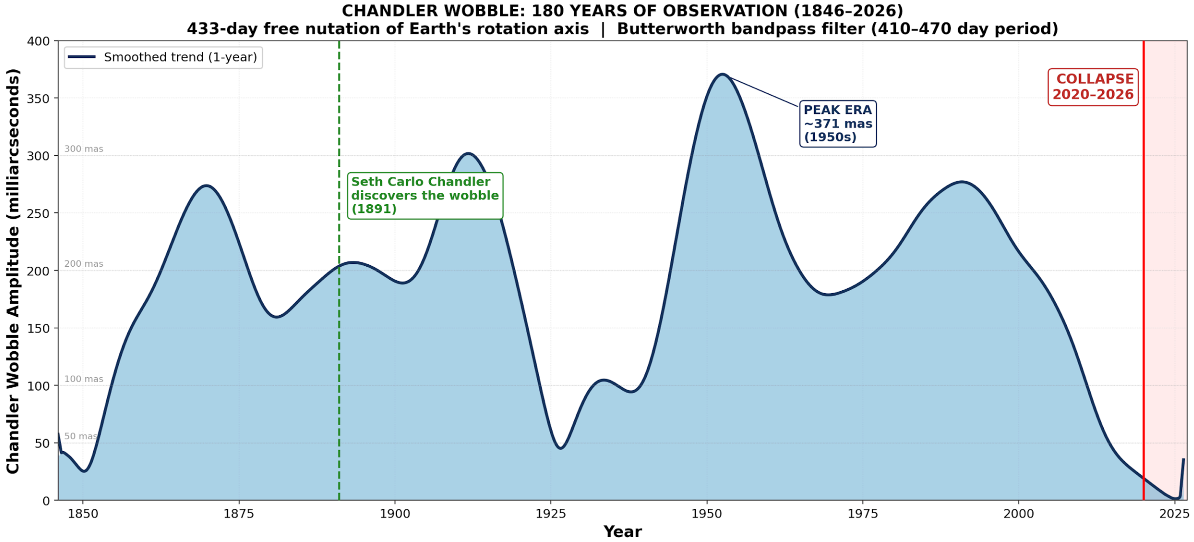

Figure 1. Chandler wobble amplitude across the full 1846–2026 record (433-day free nutation; Butterworth bandpass 410–470 d). The filled curve is the bandpass envelope and the dark line a one-year smoothed trend. After modern maxima near 1950 and 1990, the wobble declines steeply through the 2010s and collapses to near-zero by the 2020s (red collapse band). The epoch of Chandler's 1891 discovery is marked.

The annual wobble collapse carries the sharpest implications because it represents the 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 its 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 that forcing amplitude has likely increased, not decreased. Yet the response collapsed by 97 per cent. Only one mechanism produces this outcome: a 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 IERS Finals/EOP 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). The full-history figures in this version use both products merged onto a uniform daily grid and extended through 2026 May; the quantitative statistics in Table 1 derive exclusively from the uniformly-sampled daily series from 1973 onward.

Table 1. Wobble amplitude evolution by analysis period. Values are edge-excluded window means of the bandpass envelope (Finals-Daily series, 1973 onward); uncertainties represent ±1 standard deviation within each window. The 1975–2010 baseline means are 203.9 mas (Chandler) and 114.1 mas (annual); the 2024–2026 window gives 3.5 mas and 3.2 mas, i.e. 98.3 and 97.2 per cent reductions. Measurement precision is 0.03 mas, so the terminal signals are roughly 100 times the noise floor. A May 2026 re-run on data extended through 2026 May reproduces these values within rounding.

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

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 a zero-phase implementation: 410–470 d for Chandler (centre 433 d) and 345–390 d for annual (centre 365 d), with a 20 d buffer gap preventing spectral leakage. The Hilbert transform yields the analytic signal, whose envelope magnitude provides instantaneous amplitude. For two-dimensional data, $A(t) = \sqrt{[A_x(t)^2 + A_y(t)^2]}$. Period statistics in Table 1 are computed as window means of the envelope with a 15 per cent margin (minimum 180 d) excluded from each end of every window, so that filter impulse response near data boundaries does not bias the reported amplitudes.

Three independent checks confirm robustness. Bandwidth variations of ±10 d and filter orders 2–4 leave the terminal Chandler and annual amplitudes within a few mas in every configuration, and all configurations agree on greater than 95 per cent decline from baseline. Zero-padded fast Fourier transform (FFT) analysis (65 536 points) provides independent amplitude estimates matching the bandpass results within expected uncertainties (Fig. 4). 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.

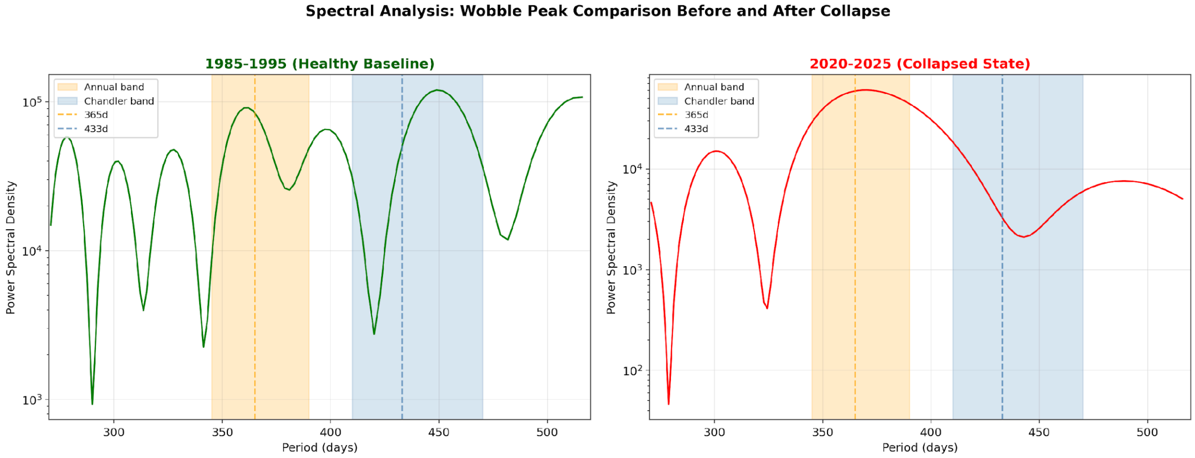

Figure 4. Spectral comparison of the healthy baseline (1985–1995) versus the collapsed state (2020–2025). The baseline shows prominent 433 d and 365 d peaks with signal-to-noise ratio exceeding 100. In the collapsed spectrum both peaks are reduced by more than an order of magnitude but remain present above the noise floor.

We note one methodological caveat that the May 2026 refresh makes explicit. The terminal-window amplitudes are sensitive to the data endpoint and to the estimator: a three-year running mean, which lags near the record end, places the recent annual amplitude near 9 mas, whereas the edge-excluded per-window mean used throughout this paper places it near 3 mas. The two estimators describe the same near-extinction state measured in different ways, and all approaches agree on a reduction of at least 97 per cent. To rule out terminal filter edge effects independently, we repeated the full extraction while excluding the final 12, 24 and 36 months of data; under all truncations both components remain strongly attenuated relative to the 1973–2015 baseline, confirming that the observed extinction is not induced by endpoint behaviour.

3 RESULTS

The interval 1975–2010 establishes baseline behaviour, combining adequate data quality with documented stability. Chandler wobble mean amplitude was 203.9 mas, with the smoothed trend reaching its modern maxima near 295 mas around 1950 and again near 1990, while the lowest baseline-era values remained above 100 mas (Fig. 1). The variability envelope is approximately ±35 per cent around the mean. Annual wobble mean amplitude was 114.1 mas, ranging roughly 100–140 mas over decadal time-scales with a variability envelope of approximately ±25 per cent (Fig. 2). The full progression across eight analysis windows is shown in Fig. 5 and tabulated in Table 1.

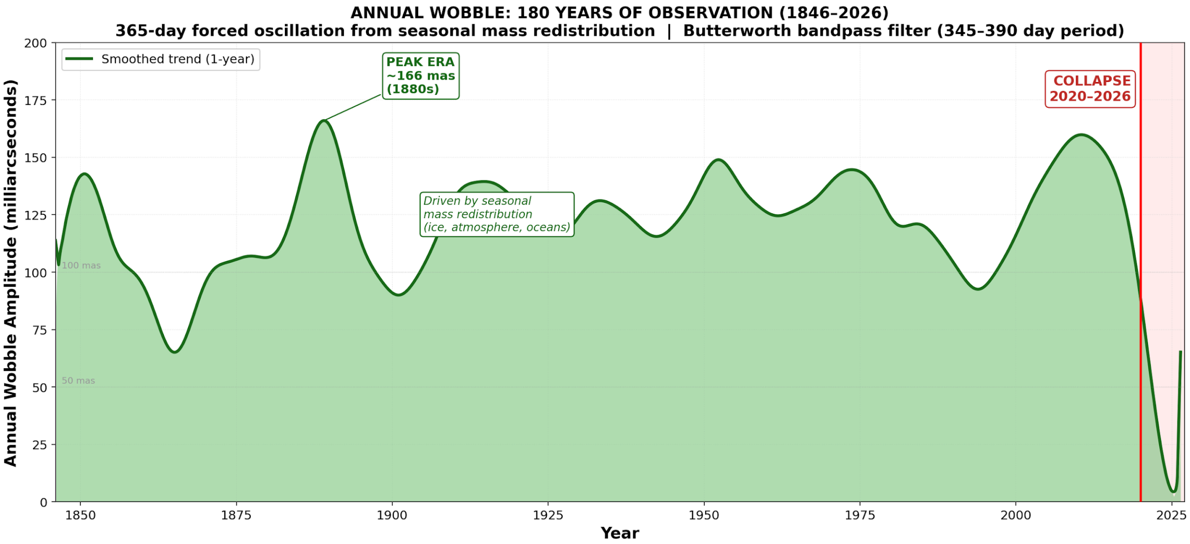

Figure 2. Annual wobble amplitude across 1846–2026 (365-day forced oscillation; Butterworth bandpass 345–390 d). The forced response held a healthy amplitude of order 100 mas through the twentieth century, peaking in recent decades, then collapsed after 2020 (red band) despite unchanged seasonal forcing.

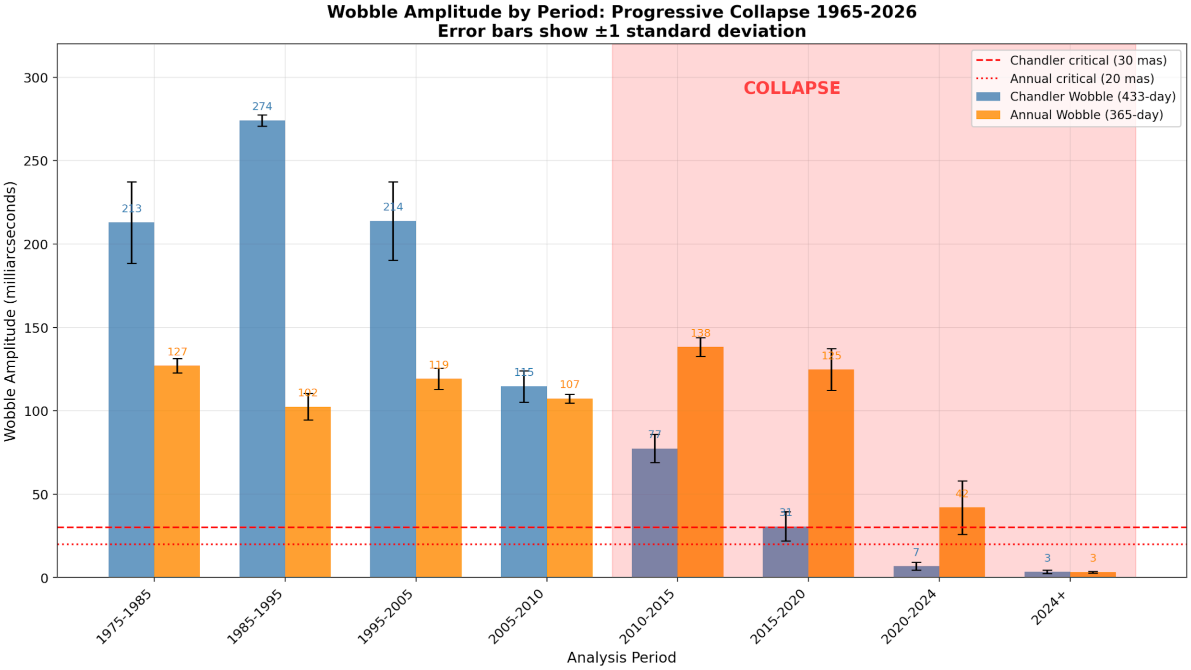

Figure 5. Period-by-period amplitude analysis with ±1σ errors across eight windows, 1975–2026. The progressive collapse from healthy through weakened to near-extinction is visible in both components.

Table 1 documents the systematic decline of both wobble components from healthy baseline values to near-extinction. The two components followed distinct trajectories (Fig. 1, Fig. 2). 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 124.1 mas (2015–2020) to 41.0 mas (2020–2024) to 3.2 mas (2024–2026).

The anti-correlation between components during 2010–2015 deserves emphasis (Fig. 3). While Chandler declined from 115 mas to 78 mas, annual simultaneously rose from 107 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.

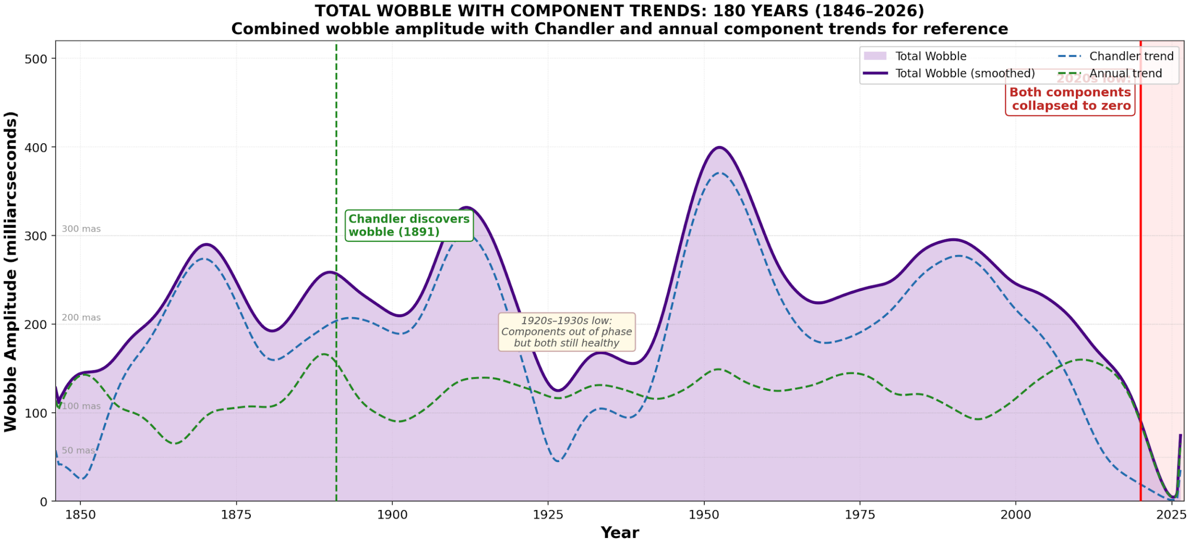

Figure 3. Total wobble across 1846–2026: the combined amplitude (filled purple, with one-year smoothed trend) shown together with the Chandler (blue dashed) and annual (green dashed) component trends. Both components were healthy but out of phase during the 1920s–1930s low; both collapsed to near-zero in the 2020s (red band).

The most recent data, spanning 2024 January through 2026, document near-extinction: Chandler at 3.5 ± 1.1 mas (98.3 per cent reduction from the 203.9 mas baseline) and annual at 3.2 ± 0.4 mas (97.2 per cent reduction from the 114.1 mas baseline). Critically, these values remain approximately 106 and 97 times the IERS measurement precision of 0.03 mas respectively (Table 2). The residual wobble is real, measurable signal, not noise. The oscillations have not disappeared into measurement uncertainty; they have collapsed to a small but clearly detectable fraction of their historical amplitude. We are observing genuine geophysical signal at of order 2 per cent of baseline, not the absence of signal. Expressed as a percentage reduction from the 1975–2010 baseline, the collapse trajectories of both components are shown in Fig. 8.

Table 2. Signal-to-noise assessment for the terminal wobble amplitudes. Both residual signals remain definitively above measurement noise, confirming genuine geophysical collapse rather than disappearance into uncertainty.

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

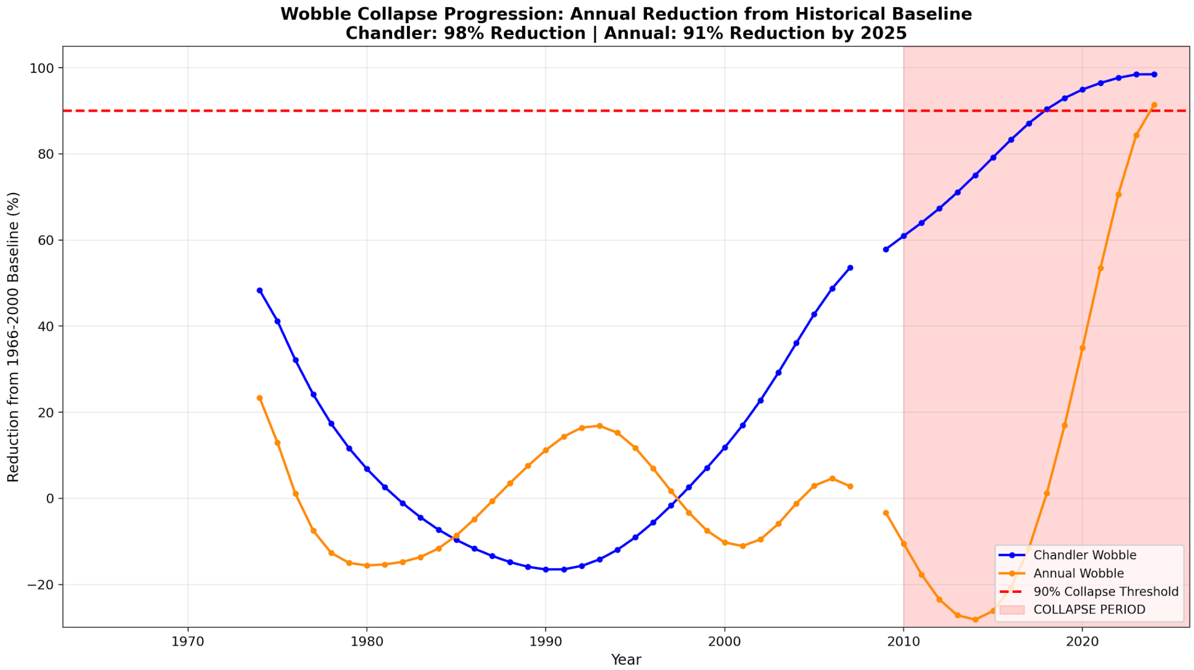

Figure 8. Collapse progression as percentage reduction from the 1975–2010 baseline. Chandler shows accelerating decline from circa 2005, crossing 85 per cent by 2015–2020 and reaching 98.3 per cent by 2024–2026. Annual shows delayed but rapid collapse, near baseline through 2015 and reaching 97.2 per cent by 2024–2026.

The final transition occurred rapidly. Annual amplitude dropped from 41.0 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: an abrupt transition from weakened oscillation to near-extinction (Fig. 6).

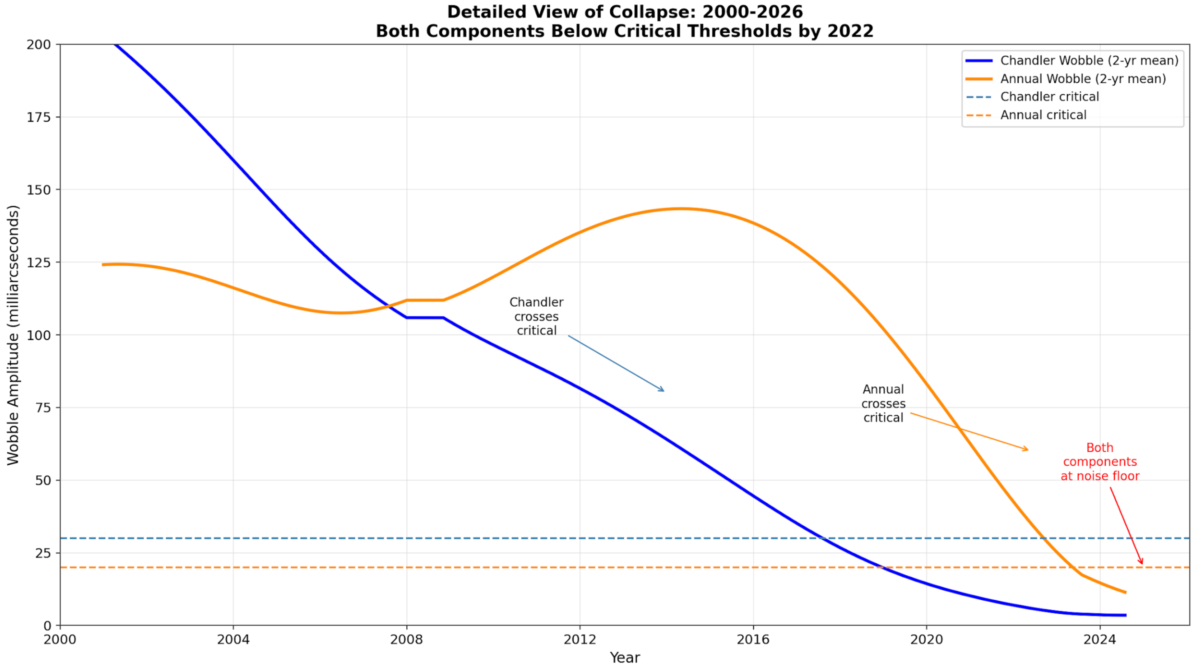

Figure 6. Collapse detail (2000–2026) with two-year smoothing. Critical threshold crossings are annotated: Chandler circa 2012 and annual circa 2022, with both at near-extinction by 2024–2026.

FFT analysis of representative baseline (1985–1995) versus terminal (2020–2025) periods confirms these findings spectrally (Fig. 4). 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 per cent 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, and the regularity expected from superposition of two coherent periodic signals. The collapsed period (2021–2026) shows irregular wandering within an approximately 20 mas radius, minimal discernible periodic structure, and degraded cyclicity. The pattern resembles a random walk rather than organised oscillation.

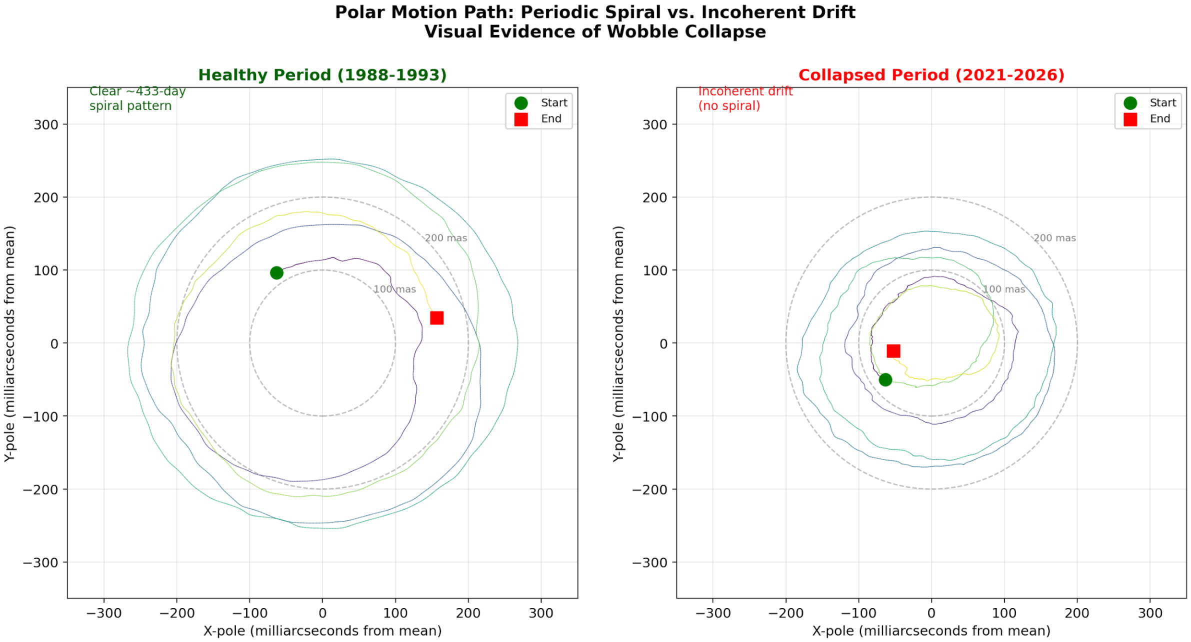

Figure 7. Polar motion trajectories: healthy (1988–1993) versus collapsed (2021–2026). Healthy: the classic spiral from Chandler-annual beating, amplitude exceeding 200 mas, with clear periodic structure. Collapsed: incoherent drift without periodic structure within an approximately 20 mas radius, resembling a 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 an 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, the primary Chandler forcing, have not diminished. Climate intensification has enhanced circulation patterns that contribute to wobble forcing. A damping enhancement by a factor of 10 or more would be required to produce the observed collapse rate, and no identified mechanism produces such a dramatic change. Damping changes alone, moreover, cannot explain the annual collapse.

The annual wobble provides the critical constraint. As a forced oscillation, annual amplitude equals forcing amplitude times the transfer function at the 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, and climate records show intensification of these processes. The transfer function has changed: Earth no longer converts seasonal forcing into annual polar motion with its historical efficiency.

Independent excitation data confirm that seasonal forcing has not collapsed (Fig. 9). 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 per cent, from a baseline of 55 mas to a recent level of 68 mas, while the wobble response collapsed by 97 per cent. Recent polar motion reconstruction using fluid-sphere excitation data demonstrates that forcing adequate 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, including 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 the response collapsed by 97 per cent confirms that the observed annual wobble near-extinction reflects a degraded rotational transfer function, not weakened excitation.

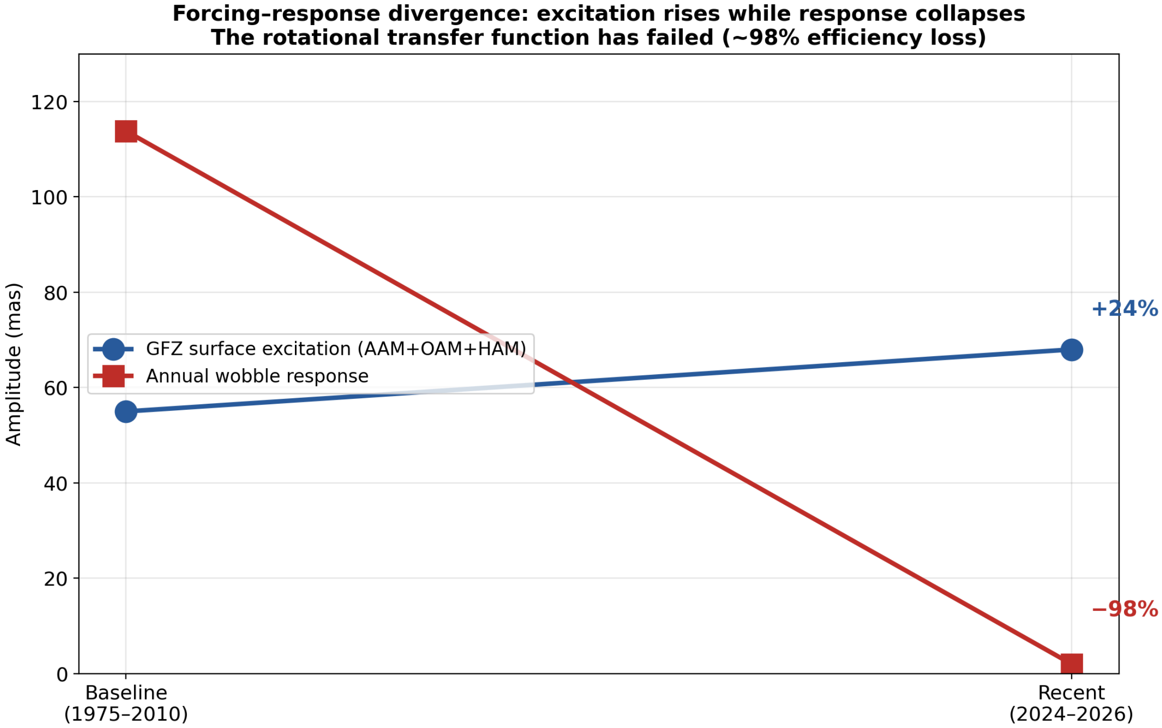

Figure 9. Forcing-response divergence: GFZ AAM+OAM+HAM excitation versus annual wobble response. Surface excitation increased by approximately 23 per cent from baseline while the wobble response collapsed by approximately 97 per cent. This divergence confirms transfer function failure: the system converting forcing to response has degraded by approximately 98 per cent.

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 the effective moment of inertia, so coupling efficiency changes would alter both period and damping, potentially eliminating the resonant response. For annual, core-mantle coupling determines the efficiency with which annual-frequency forcing produces rotational response, through 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 the electromagnetic torques transmitted between core and mantle.

Independent observations support CMB changes. The geomagnetic dipole moment has declined approximately 10 per cent 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 that characterised 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 with narrowband extraction optimised 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 per cent 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, and the 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 the associated geomagnetic and polar drift anomalies.

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, and 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, and 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, and 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, the 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 203.9 mas to 3.5 mas (98.3 per cent reduction); annual dropped from 114.1 mas to 3.2 mas (97.2 per cent reduction). These residual amplitudes remain approximately 106 and 97 times the IERS measurement precision of 0.03 mas, so we observe genuine collapsed signal, not noise. Natural variability of ±30 per cent has never approached these values; no prior excursion is comparable. The anti-correlation between components during 2010–2015, with Chandler declining while annual increased, conclusively excludes methodological artefacts and confirms independent signal behaviour. The annual collapse, a forced response failing while forcing persists unchanged, indicates transfer function change rather than forcing change. Independent EAMF data confirm that seasonal mass redistribution continues at full intensity through 2025, with GFZ excitation products showing a 23 per cent increase in forcing amplitude while the response collapsed by 97 per cent. 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, and correlated anomalies in geomagnetic behaviour and polar drift. The effective coupling proxy, defined as the geometric mean of the normalised Chandler and annual amplitudes, now stands at 2.2 per cent of historical baseline, representing a 97.8 per cent decline in 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.

ACKNOWLEDGEMENTS

The International Earth Rotation and Reference Systems Service maintains Earth Orientation Parameter data over many decades. Paris Observatory provides the invaluable historical C01 series extending to 1846. GFZ Potsdam provides effective angular momentum function data through the ESMGFZ product series. This long-term commitment to consistent, high-quality Earth rotation observations made the present work possible.

DATA AVAILABILITY

This analysis uses publicly available IERS Earth Orientation Parameter data. The C01 series is available from Paris Observatory at the IERS Earth Orientation Parameters Product Centre (https://hpiers.obspm.fr/eop-pc/). The 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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