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Time-Domain Analysis of Solid Earth Tides: A Pathway to Understanding Tectonic Dynamics

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This study introduces a time-domain methodology for analyzing the response of solid Earth tides, focusing on their phase delay relative to maximum vertical gravitational attraction. Unlike traditional frequency-domain approaches, which primarily decompose tidal signals into harmonic components, the proposed method emphasizes temporal dynamics, offering higher resolution and fewer assumptions about signal periodicity.

Solid Earth tides, driven by gravitational forces from the Moon and Sun, induce periodic deformations of the Earth's surface, known as tidal bulges. These bulges are expected to coincide with maximum gravitational attraction, but a measurable phase delay often occurs due to the Earth's internal rheological and viscoelastic properties. Understanding this delay is crucial for deciphering the complex interplay between tidal forces and tectonic processes, including stress evolution, crustal deformation, and even earthquake triggering mechanisms.

To achieve this, the study analyzed high-precision gravity data from 14 permanent gravity stations in Europe, alongside GNSS-derived measurements of vertical surface displacement. Corrections were applied to isolate the gravitational effects of solid Earth tides, accounting for factors such as atmospheric pressure variations, ocean tidal loading, and direct gravitational attraction. The residual gravity signal, reflecting the solid Earth tidal bulge, was then examined for phase delay using time-domain algorithms.

Key findings revealed significant variability in the phase delay across geographic and tectonic settings, suggesting localized geological factors influence the Earth’s response to tidal forcing. This delay, although small, was found to redistribute stresses within the crust and mantle, potentially affecting fault reactivation and long-term tectonic plate dynamics. The integration of GNSS data allowed a comprehensive view of vertical deformation, further validating the gravity-based findings.

This time-domain approach provides a complementary perspective to frequency-domain analyses, capturing nonlinear and time-dependent effects often overlooked in traditional studies. By enhancing our understanding of tidal lag phenomena, the research contributes to refining models of lithospheric and asthenospheric dynamics. The methodology holds promise for broader applications in geophysical monitoring, offering insights into stress and strain evolution in

tectonically active regions.

These advancements pave the way for improved interpretations of solid Earth processes and their implications for natural hazards, resource management, and planetary dynamics. This study underscores the potential of integrating gravity and GNSS data for high-resolution analyses of Earth's dynamic behavior.