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Toward a Unified Theory for 20th Century Secular Polar Motion

Erik Ivins (1), Surendra Adhikari (1), Lambert Caron (1), Bernhard Steinberger (2,3), John Reager (1), Kristian Kjeldsen (4), Ben Marzeion (5), and Eric Larour (1)

(1) JPL/Caltech, Pasadena, CA, United States (erik.r.ivins@jpl.nasa.gov), (2) GFZ German Research Centre for Geosciences, Potsdam, Germany (bstein@gfz-potsdam.de), (3) Centre for Earth Evolution and Dynamics, University of Oslo, Oslo, Norway, (4) Department of Geodesy, Technical University of Denmark, Kongens Lyngby, Denmark (kkjeldsen@snm.ku.dk), (5) Institute of Geography, University of Bremen, Bremen, Germany (ben.marzeion@uni-bremen.de)

Astrometric and geodetic measurements show that the mean position of Earth's spin axis drifted through the solid crust toward Labrador, Canada at an average speed of 10.5 $\pm$ 0.9 cm/year during the 20th century [Gross, 2007]. Understanding the origins of this secular polar motion (SPM) has significance for modeling the global climate, as it provides a link to ice mass balance and sea-level rise [Mitrovica et al., 2015; Nakada et al., 2015]. A perplexing issue, however, is that while glacial isostatic adjustment (GIA) models satisfactorily explain the direction of SPM, the associated prediction of the amplitude is insufficient [Mitrovica and Wahr, 2011; Cambiotti et al., 2011]. Using a recently published Bayesian global GIA analysis constrained by both relative sea-level and vertical land motion data [Caron et al., 2018], we show that this process only accounts for 33$\pm$18% of the observed SPM amplitude. This motivates a more broadly scoped reassessment of SPM drivers. To address this, we assemble a complete reconstruction of Earth's surface mass transport derived from recent advancements in modeling the global 20th century seismogenic, cryospheric, hydrologic, and oceanic mass exchange. Yet the summed signals fall short of reconciling the observed SPM, even when considering the error statistics of each driver. An additional factor then might explain the residual, one that heretofore has been more challenging to model: changes in Earth's inertia tensor caused by mantle convection. Sophisticated models have recently been advanced in tectonic plate reconstructions, in conjunction with geoid and seismic tomographic models [e.g., Domeier et al., 2016; Steinberger et al., 2017]. We use these models to compute new estimates of SPM. While the convection-driven SPM has considerable uncertainty, the average direction of 82 recent models, not tuned to study polar motion, aligns with the residual SPM (within 2.7 $\pm$ 17.8 °) and are robust in amplitude, thus eliminating the gap between observed and predicted SPM. We conclude that a key mechanism supplying ongoing changes in the inertia tensor, and thus driving 20th century SPM, is long-term time variation in mantle convection. We also explore implications for modelling the pole tide for the time-varying GRACE gravity field.