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Crustal Contributions to Moment of Inertia as Key Constraints for Earth-Like Mantle Convection Models: "Munk & MacDonald (1960)" Revisited

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In their seminal work, **Munk and MacDonald (1960)** showed that considering only the crustal contribution to the Earth's moment of inertia (MOI) would predict a rotation axis passing through a location near Hawaii – clearly inconsistent with the present-day geographic pole. This finding implied there must be additional mass anomalies, which the authors speculated to be in the convecting mantle, that realign the rotation axis with the observed North Pole.
Modern geodynamic studies confirm that **isostatic compensation** of crustal thickness and density variations explains much of Earth's observed topography, yet the crust's gravitational contribution is often overlooked because it is relatively small compared to that generated by density anomalies in the mantle. As a result, **residual topography** (the difference between observed and isostatic topography) remains a prominent global constraint on the amplitude and spatial distribution of mantle density anomalies, while **residual geoid** (the difference between observed and crustal isostatic geoid) is utilized far less frequently. Crucially, this omission disregards the crust's influence on Earth's moment of inertia (MOI) and, by extension, its impact on the location of the rotational axis. Overlooking crustal mass heterogeneities can therefore lead to unrealistic (non-Earth-like) inferences of mantle density anomalies that do not correctly predict the location of the **present-day rotational axis**.
By analyzing **satellite-derived non-hydrostatic geoid data** and comparing modeled and observed moments of inertia, we find that preserving the present-day location of the rotational axis requires systematically accounting for crustal contributions. We implement a **second order-accurate isostasy** model – which integrates crustal buoyancy variations in a deformable crust – to more accurately capture the interplay between surface topography, the geoid, and the convective mantle. **Neglecting this refinement** not only fails to preserve the present-day rotational axis position but also compromises **True Polar Wander (TPW)** predicted by time-dependent mantle convection simulations.
Our findings suggest that integrating a second-order accurate isostasy framework into global mantle convection models is essential for producing consistent TPW trajectories, ensuring alignment between the modeled rotational axes and Earth's observed pole positions.