

Final Responses

Thank you very much for your effort and time to review/comment on my manuscript.

My manuscript addresses a largely unexplored area, as highlighted by Staniforth and White (2025) in “*Almost everything you always wanted to know about representing gravity in global models but were afraid to ask.*” In particular, I demonstrate the coordinate invariance of combined gravity and pressure-gradient forces and show how a bumpy-geoid gradient naturally emerges in the horizontal momentum equation when expressed in geopotential coordinates.

I believe my rebuttal clearly demonstrates that the manuscript merits a decision of “major revision” rather than “rejection.”

Below is an outline of the revised manuscript, including a proposed title change. In the revision, I will aim to present the arguments with minimal reliance on formal mathematics, emphasizing physical interpretation and clarity.

Proposed Title:

Coordinate Invariance of Gravity–Pressure Gradient Forces and the Limitations of Spherical/Spheroidal Geopotential Approximations

Abstract: Gravity-pressure gradient forces, $-(\nabla p)/\rho + \nabla\Phi$, are the only body forces for frictionless flow in oceans and depend on three scalar fields: density ρ , pressure p , and geopotential Φ . The gradient operator ∇ varies with coordinates, but the gravity-pressure gradient forces, $-(\nabla p)/\rho + \nabla\Phi$, do not. Such a coordinate invariance causes the emergence of the bumpy-geoid (N) gradient ($g_0\nabla_h N$) in the horizontal momentum equation expressed in all coordinates used in ocean models. Use of publicly available ocean and geoidal (N) datasets lead to the rejection of popularly used spherical/spheroidal geopotential approximation.

1. Introduction
2. True Horizontal and Horizontal Defined in Ocean Models
3. Gravity-Pressure Gradient Forces in Various Coordinates
 - 3.1. Local Cartesian Coordinates
 - 3.2. Geopotential Coordinates
 - 3.3. Pressure Coordinates
 - 3.4. Terrain-Following Coordinates
 - 3.5. Isopycnal Coordinates
 - 3.6. Hybrid Coordinates
4. Publicly Available Datasets
5. Invalid Spherical/Spheroidal Geopotential Approximation
 - 5.1. Geostrophic Flow and Thermal Wind Relation
 - 5.2. 1½ Layered Model with Rigid Lid
 - 5.3. Sverdrup-Stommel-Munk Wind-Driven Circulation Models
 - 5.4. Global Sverdrup and Stommel Volume Transport
6. Conclusions