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Differences between tangential geostrophy and columnar flow

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Core flows inverted from time-dependent geomagnetic field models image the geodynamo at the top of its generation region, the Earth's outer core. Physical assumptions incorporated in these inversions may affect the resulting flows. Based on rapid rotation dominance, two assumptions similar in form yet different in essence were proposed: Tangential geostrophy (TG, LeMouël, 1984) and columnar flow (CF, Amit and Olson, 2004).

We show that CF is theoretically consistent with the quasi-geostrophy (QG) theory for an incompressible fluid with spherical solid boundaries, whereas TG is not. The areas of ambiguous patches at the core surface where invisible TG or CF flows reside are roughly comparable. The spatial distribution of ambiguous patches for both TG and CF is quite asymmetric about the equator, so assuming equatorial symmetry may hypothetically reduce the non-uniqueness significantly. TG flows exhibit a strong Atlantic/Pacific hemispheric dichotomy and a well-defined eccentric gyre, whereas in CF flows the dichotomy between these two hemispheres is weaker and the gyre is less clear, suggesting that the eccentric gyre might not conserve mass. Both TG and CF upwelling/downwelling patterns are strongly localized in the equatorial region. In addition, in both cases upwelling/downwelling is correlated with equatorward/poleward flow respectively, as expected for QG convection. CF upwelling is more intense than TG upwelling but the magnitude ratio is smaller than the factor 2 distinguishing the analytical expressions of the two assumptions due to the dominance of magnetic field advection by toroidal core flow in the geomagnetic secular variation.