CROSS-EQUATORIAL GEOSTROPHIC APPROXIMATIONS

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ABSTRACT

A new formula for steady geostrophic zonal equatorial currents is derived from a nonlinear shallow water equation formulation. It is shown that upper layer zonal geostrophic currents may be obtained from a root of a single cubic equation involving sea surface slopes and curvatures. The estimate is continuous across the Equator, and connects smoothly the f-plane off equator and the beta plane equatorial geostrophic formula based on meridional curvature. This approximation is tested by use of CTD-derived data over the ship track and satellite-derived surface topography to estimate synoptic currents, which are shown to compare well with ETAMBOT cruise ship-mounted ADCP current data spanning the Equatorial western Atlantic at the top of the thermocline. Validation tests are also made for cross-equatorial cruise data in the Pacific Ocean at 110W, with very good results. The regularization of the equatorial singularity for meridional component is then presented. This theoretically-based methodology is much simpler and more general than recently published ad-hoc fits between off-Equator and Taylor-expanded second meridional derivative formulas (e.g., Lagerloef et al., 1999). The method is interesting for the study of the short meridional scale geostrophic flow convergence into the Equatorial Undercurrent by use of altimeter-derived sea surface topography. Circulation patterns presented by Bourlès et al. (1999) and Arnault et al. (1999) off the Equator, the latter calculated by use of Topex/Poseidon Sea Surface Height Anomaly data, are consistent with the more complete pictures obtained in the present work. The method is then applied to estimate the Ekman contribution to these currents, which constitute the larger part of the ageostrophic currents. This is done by use of ERS scatterometer wind data.

An Alternative Way to Estimate Current Velocity from SSH Slopes and Curvatures

Use of the geostrophic formula to calculate currents derived from adjustment to mean SSHA, in the time scale of a few days, from altimeter measurements, have given good results off the Equator. Two major limitations appear when cyclostrophic terms are important due to eddies, and near the Equator. The latter problem is usually solved by fitting a zonal current estimate over the Equator based on the meridional Taylor expansion of the SSH field, and a fit with the off–Equator geostrophy (see, i.e., Lagerloef et al., 1999).

However, the recent analysis of Pedlosky (1996) on the non-dissipative inertial theory of the EUC is shown to be useful to connect naturally these two approximations. The basic ingredient is the conservation of both Potential Vorticity and Bernoulli Function over a streamline. We start here with the time-independent Shallow Water Equations for a single baroclinic mode.

$$(f + \zeta)\,\mathbf{z} \times \mathbf{v} = -\nabla B \qquad (1.a)$$

$$\nabla \cdot (\eta\, \mathbf{v}) = 0 \qquad (1.b)$$

Where $B = g\eta + (1/2)(u^2 + v^2)$, $\zeta = \mathbf{z} \cdot \nabla \times \mathbf{v}$ and $\mathbf{v} = u\,\mathbf{x} + v\,\mathbf{y}$.

$\mathrm{v} = \mathrm{u\,x} + \mathrm{v\,y}$ is the horizontal velocity with components u and v in the eastward and northward direction respectively, g is reduced gravity and the instantaneous pycnocline depth, not to be confused with the altimeter-measured Sea Surface Height Anomaly (SSHA).

Taking the divergence of (1.a),

$$\beta u + \mathbf{z} \times \mathbf{v} \cdot \nabla \zeta - (f + \zeta)\,\zeta = -\nabla^2 B \qquad (2)$$

We may expand this and collect terms to get

$$(f+\zeta)\zeta = \beta u + g\nabla^2\eta + (\nabla u)^2 + (\nabla v)^2 + u(u_{xx} + v_{xy}) + v(v_{yy} + u_{xy}) \qquad (3)$$

If we substitute ζ from the meridional component of (1.a), and insert it in (3), we get

$$[(1/u)g\eta_y + f][(1/u)g\eta_y] - \beta u - g\nabla^2\eta - \varepsilon = 0 \qquad (4)$$

where, neglecting the two last terms of (3), we may write $\varepsilon = (\nabla u)^2 + (\nabla v)^2$

This quantity is always positive. Equation (4) can be written as a cubic equation in u,

$$u^3 + (u_e + \varepsilon)u^2 - afu - \beta a^2 = 0 \qquad (5.a)$$

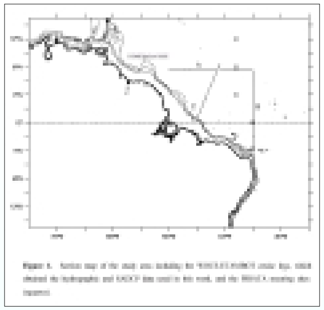
With

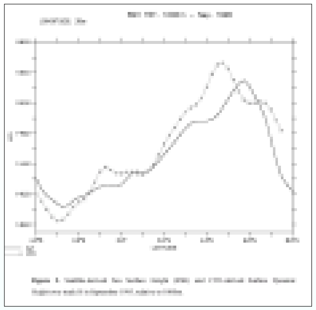
$$u_e = (g/\beta)\nabla^2\eta; \quad a = (g/\beta)\eta_y \qquad (5.b)$$

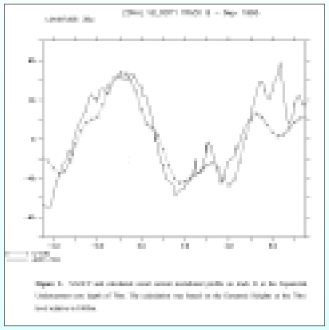
The x and y subscripts denote derivatives. We can easily see that if the last two terms are negligible, we get the now traditional equatorial geostrophic estimate $u = -u_e$ if we only consider meridional second derivatives and $\varepsilon = 0$. This can be viewed as a strong current case. The linear approximation to (5.a) leads to the geostrophic formula for u, which is a small current approximation.

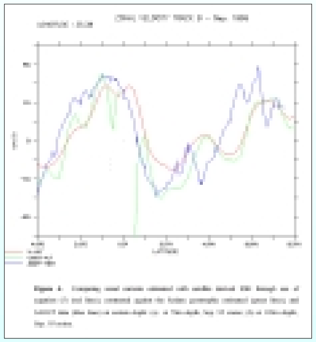
This estimate is useful to determine the equatorial convergence or divergence of the meridional flow into the Equator when there is a zonal pressure gradient and meridional curvature. However, since v is small near the Equator due to its derivative in the zonal direction, we can in this case test the applicability a simple regularization of the type to compute v from the geostrophic formula, avoiding the calculation of higher (meridional) derivatives.

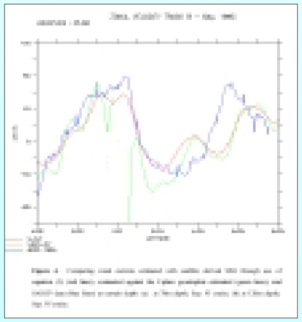
Equation (5) may be solved numerically for the SSH maps to give smooth u-component grids spanning the Equator. The "offset" in (5) will be used as as a constant, to get the best fit between solutions of (5) and the off-equator geostrophic u.

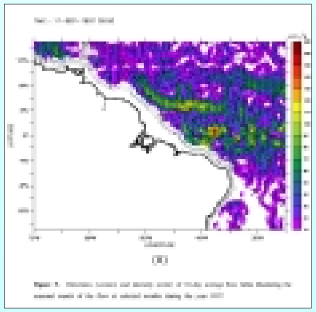












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