Corrections to the nonlinear momentum advection terms in Mecca 2.0

D.A. Brooks
Department of Oceanography
Texas A&M University

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The numerical circulation model known as Mecca (Model for Estuarine and Coastal Circulation Assessment; Hess, 1986, 2000) uses a first-order upwind scheme to difference the momentum advection terms, which are included when switch IBETAA=1. These terms have caused trouble with Mecca since the first version. The latest version (2.0 et seq, Hess, 2000) is improved over earlier versions and has some corrections that are advertised to fix previous shortcomings, but current experience still shows stability problems with the internal mode. From many experiments, it is apparent that the trouble is coming from the internal momentum advection terms in subroutine UPVP through the HCP/HCM terms. The following summary is condensed from my notes log for the benefit of others who may be having difficulty with the nonlinear aspects of this model.

The symptoms.

In the unmodified code with tidal forcing only and full 3-D non-linear calculations each internal time step, the surface velocity quickly develops parallel convergence streaks (“cornrows”) in the direction of the flow. Eventually the sea level gradients in the cross-streak direction and the associated along-streak velocities become unrealistically large. The rows are separated typically by 4-6 grid cells, so it doesn’t seem to be a ‘2 delta-x’ problem, and halving the time step doesn’t improve the situation. Bottom topography seems to have some influence. The effect can be reduced or delayed by increasing the lateral viscosity to large values, but the excessive ‘glue’ is also unrealistic. The streaking seems worse near the open boundaries and in some cases seems to emanate from them; however, changing the open bc’s to radiation in any of the available forms does not fix the problem. It’s possible to start a NL run from a fully spun-up linear case (e.g. a 3-day .dat file), and it will run fine for a day or so, but the cornrows appear by the second tidal cycle and eventually will crash the run.

The problem.

Subroutine UPVP calculates the internal mode velocities by subtracting the vertically integrated equations (external mode) from the full equation set. Numerous factors based on combinations of the principal constants (e.g. internal time step dt and horizontal grid spacing dl) are used in the finite-difference form of the equations. For example, in the discretizing of the terms in NB, which includes the depth-dependent parts of (u2)x and (uv)y terms in the x-direction, the HBXM, HBX, and HBXP terms (u2)x should be weighted by dt/4*dl = B8, whereas the HCP, HCM terms (uv)y should have weight dt/16*dl = B7, and similarly in the y-direction. The factor of four difference comes from
the way the upstream differencing is applied, and because the HBX terms involve averaging only two depths versus four in the HCP/HCM terms.

After more scrutiny, it was discovered that the B7 and B8 weights described above were reversed in the UPVP code that I received. This error under-weights \((u2)x\) by a factor of four and over-weights \((uv)y\) by four in the x-direction, and similarly in the y-direction, for a relative overweight of the cross-derivative terms by sixteen – no wonder the results seemed so sensitive to the cross-derivatives. See the original Mecca documentation (Hess, 1986) pp I-56 to I-57 for weighting details.

**The fix.**

In subroutine UPVP of the model code, the affected lines follow shortly after the comment line “C NON-LINEAR TERMS” in both the x- and y-directions. In my current version of the code, these lines are numbered 2762-6 for x and 2904-8 for y. Ascertain that the three HB terms are weighted with \(F1=B8\ldots\) and the two HC terms are weighted with \(B7\ldots\) in each direction, and not vice-versa. With these corrections, the cornrowing noted above is absent, and stable nonlinear performance results with a wide range of forcing environments.

**References.**
