Geophysical Research Abstracts
Vol. 21, EGU2019-15955, 2019
EGU General Assembly 2019

Sensitivity of hydrodynamic tidal models to spatial resolution: effects of staircase coastlines

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Purely hydrodynamic (forward) models of global tides typically show a strong sensitivity as the spatial resolution increases from circa $1/4$ to $1/12$ degree, as is evident, for example, from the benchmark solutions of Egbert et al. (J. Geophys. Res., 2004; figure 2). Many such models are discretised in space using finite-difference schemes on rectangular grid cells, with the coastlines taken to lie along cell edges, leading to so-called staircase coastlines. However, it can be shown that even when the finite-differences in the ocean interior are second-order accurate in grid spacing, in general the staircase coastlines lead to first-order errors in the resulting numerical solutions, and thus slow convergence. The effects are particularly damaging for tides, which often involve a near-resonant response to astronomical forcing. Thus first-order numerical errors in the frequency of global normal modes (or in the underlying shallow-water waves) can lead to non-trivial changes in the tidal response.

These effects are first demonstrated in idealised configurations (channels and circular basins of constant depth), using a standard Arakawa C-grid discretisation and barotropic dynamics. Here the response is dominated by near resonances of Kelvin waves. However, the Kelvin wave speeds (and thus the resonant frequencies) are degraded by staircase coastlines, and this can be quantified. For example, for a straight channel, over 200 grid points per wavelength are required to obtain the wavespeed accurate to within 1% on a perfect staircase coastline; in contrast, only 13 grid points per wavelength are required when the coast and grid are aligned (and second-order accuracy is indeed obtained).

The effects of staircase coastlines are then investigated in a C-grid global barotropic tidal model, with parameterised internal tide drag and a full treatment of self-attraction and loading using spherical harmonic transforms. Here the staircase effect is harder to isolate, as increasing spatial resolution also changes coastal geometries and the extent of shallow dissipation sites. However, we highlight the dangers of tuning drag coefficients to match observed tides, since the tuning may mask an underlying deficiency in the numerical scheme. Whilst this may sometimes be defensible, it is dangerous when the same model is then used in a different tidal regime (e.g., for paleotides).