A non-dimensional parameter to represent transverse residual flow structures in estuaries

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SWITCH
FORTNIGHTLY SWITCHING OF RESIDUAL FLOW DRIVERS IN ESTUARIES

Introduction

The axial transverse structure of residual flows in estuaries is constituted by inflows and outflows that are laterally sheared, vertically sheared, or a combination of both (Fig. 1). This structure depends on the competition between baroclinic, barotropic and frictional forcings infuenced by the cross-section geometry. Under some poorly addressed circumstances, the residual flow drivers may vary both temporally (e.g., between spring and neap tides) and spatially (i.e., along the channel).

The present study proposes a non-dimensional parameter (γ) that represents the various transverse residual flow structures predicted by theoretical studies. The parameter allows specifying the variability of the lateral flow structures obtained from numerical experiments. It is exemplified that γ is a useful tool to explore the dynamics of residual flows that are forced by both significant barotropic and baroclinic forcings.

Methods

1) A non-dimensional parameter (γ) is proposed to characterize the symmetrical transverse residual flow structures predicted by analytical solutions:

$$\gamma = \frac{u_{sh}}{|u_{sh}|} \times \frac{1}{5.44} \times (e^U + e^L)$$

u_{sh}: residual flow at the shoal (>0 landward)

U and L: normalized depth (from surface) of the upper and lower boundaries of the inflow at the thalweg (see Fig. 1a,b,c).

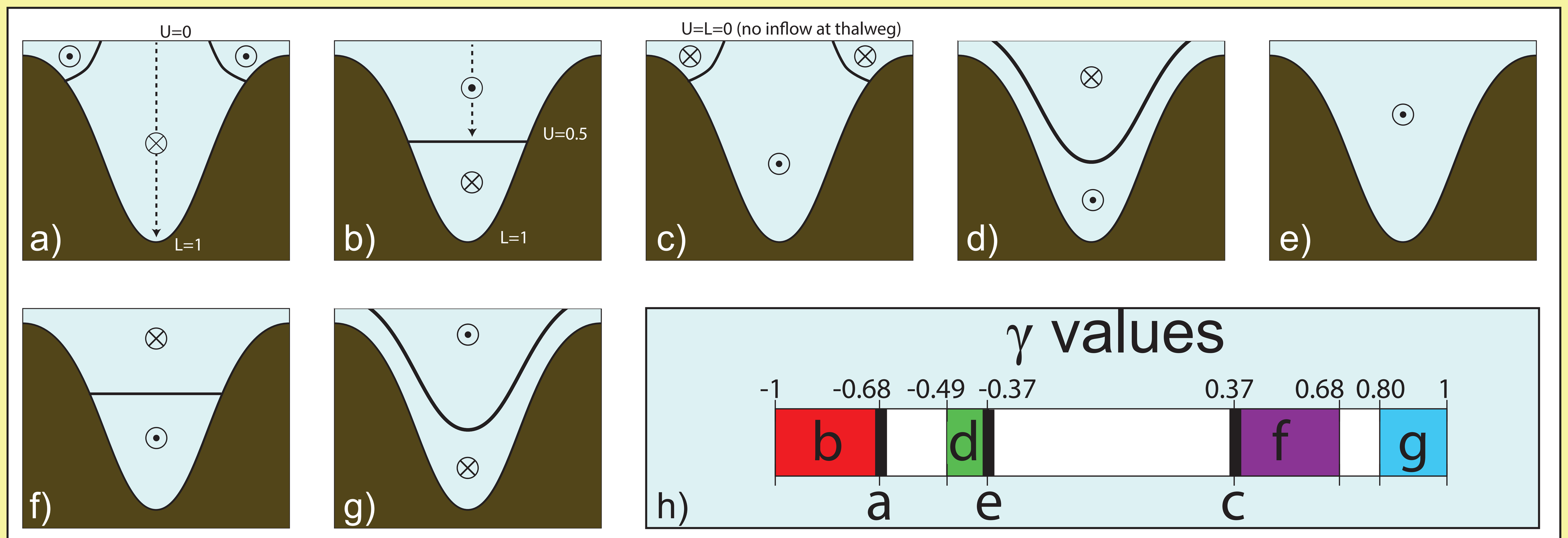
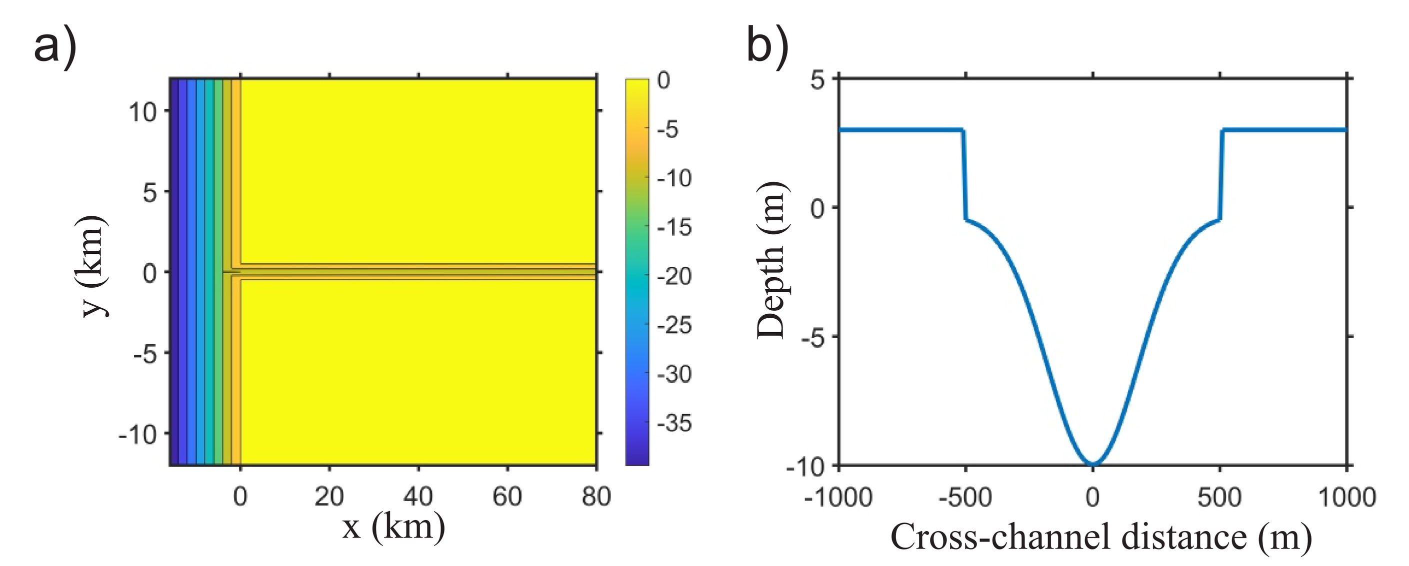


Figure 1. Transverse structures of theoretical along channel residual flows for either barotropic (a,c,d,e,g) or baroclinic (a,b,f) residual flows (with cross: inflow; points: outflow). The γ values (h) correspond to each of those cross-channel structures, being either a fixed value (a, c,e) or a range of values (color areas b,d,g,f, with no structure for the values corresponding to the white areas).

2) The applicability of γ is exemplified with 3D numerical experiments (using Delft3D) on an idealized estuary featuring a symmetric Gaussian cross-section (Figure 2):



Model set up:

- Semi-closed channel (80 km x 1 km)
- Along-channel bed slope: 0.00001
- Thalweg depth at the mouth: 10 m
- Grid size: Δx=333 m, Δy= 67 m
- Grid cells in the channel: 240 along, 15 across amd 20 vertical
- Freshwater discharge: 50 m^3/s
- Tide: M2 (1 m) + S2 (0.8 m)
- No Coriolis effect

Figure 2. a) Model domain bathymetry; b) Cross-section bathymetry

3) The baroclinic and barotropic drivers of the simulated residual flow (u) are computed from the tidally-average momentum balance, neglecting the Coriolis force:

$$g\partial_x\eta + \frac{g}{\rho_0}\int_{-H}^{z}\partial_x\rho dz + u\partial_x u + v\partial_y u = \partial_z(A_v\partial_z u)$$

surface slope + horizontal density gradient + tidal stresses = friction

Results

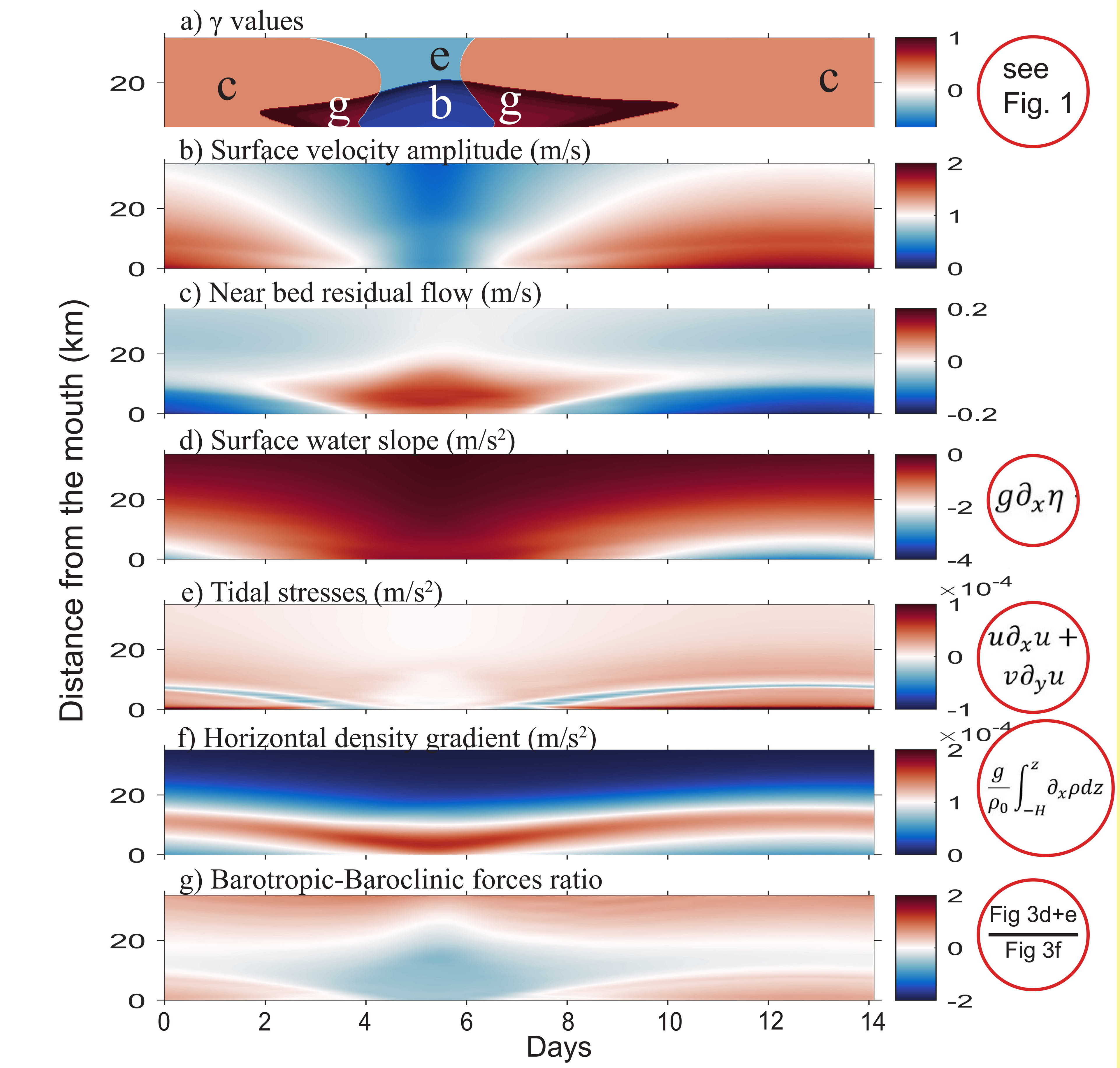


Figure 3. Fortnightly variability along the lower estuary half of a) Gamma, b) the surface tidal velocity amplitude, c) near-bed residual flow, d) surface slope, e) tidal stresses, f) horizontal density gradient, and g) barotropic/baroclinic forces ratio (>0 : barotropic dominates; <0: baroclinic dominates). b-g are represented at the thalweg location.

- γ identifies variations in the residual cross-channel structure, both along the lower estuary half (from the mouth to 35 km upstream) and through the spring-neap cycle (Fig. 3a).

- These variations suggest a switching between barotropic (γ = c,g,e) and baroclinic (γ = b) drivers of residuals flows, both spatially and temporally.

- At the thalweg, these variations correspond to fluctuations of:
  - The amplitude of the tidal flow, being stronger at spring tide (Fig. 3b)
  - Near bed residuals, with inflow at neaps and outflow at spring (Fig. 3c)
  - The surface slope, being stronger at spring and almost flat at neap (Fig. 3d)
  - Tidal stresses, stronger at spring (Fig. 3e)
  - The horizontal salinity gradient, stronger at neap (Fig. 3f)

- The ratio of barotropic/baroclinic forces indicates that γ corresponds to a change of the dominant forcing, as predicted by conceptual models (Fig. 3g). The “g” structure develops at the transition between tidally- and density-driven residual flows (see “g” in Fig. 3a).

Conclusions

- Numerical simulations with barotropic and baroclinic forcings indicate that the structure of axial residual flows at estuaries may vary both spatially and temporally depending on their dominant drivers.

- The proposed parameter γ successfully represents such variability.

- γ constitutes a practical tool to quickly identify (as a first approach) distinct residual flow dynamics at systems where both forcings can be dominant.

Acknowledgments

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