

Abstract

Estuaries are diverse systems characterized by a bidirectional exchange flow, with a near-bottom landward inflow of saline seawater, which is mixed with riverine freshwater and transformed into a near-surface outflow. Aside from the density gradient between the river and the ocean, tidally induced effects, as well as lateral processes, wind is a key mechanism in estuaries. The latter is, contrary to the other drivers listed, often highly variable in magnitude and directionality, raising the question of the sensitivity of the estuarine circulation to wind forcing. The present study shows results describing the influence of wind on the estuarine exchange flow. A newly derived analytical formulation of wind-driven along-estuary velocity profiles motivates a critical basic Wedderburn number (balance of non-dimensional wind stress and density gradient) as a measure for the sensitivity of an estuary to wind. Results show that in the idealized stationary solution up-estuary wind stress is able to invert the classical exchange flow direction when the basic Wedderburn number has reached 15%. Numerical simulations suggest that in the presence of tides, and their feedback of varying vertical mixing and stratification on the estuarine circulation, this value increases stepwise to up to approximately 45%, meaning that three times more wind is necessary to invert the circulation. The basic Wedderburn number increases even further to up to values of 130% if lateral effects are additionally taken into account. Realistic simulations of a tidally energetic estuary in the Wadden Sea (60%) and a weakly tidal estuary in the Baltic Sea (33%) confirm the applicability and robustness of the newly developed theory towards transient conditions.