Geophysical Research Abstracts,
Vol. 11, EGU2009-2130, 2009
EGU General Assembly 2009
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Combined effects of wind, tide and horizontal density gradients on stratification in estuaries and coastal seas

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The aim of this one-dimensional water column study is to combine modified versions of three characteristic parameters for periodic tidal flow under the influence of a longitudinal buoyancy gradient, the horizontal Richardson number, the inverse Strouhal number and the Ekman number, into a parameter space study, including constant wind forcing from various directions. It is shown how the underlying dynamical equations can be cast into non-dimensional form, depending mainly on these three non-dimensional parameters plus the relative wind speed and the wind direction. Idealised model simulations are carried out for the whole realistic range of horizontal Richardson and inverse Strouhal numbers for various latitudes, showing the amplitude of the tidally induced stratification for a wide range of scenarios. It is found that classical threshold values for the horizontal Richardson number indicating the switch from periodic stratification to permanent stratification are valid only for special cases, and that this switch also strongly depends on the inverse Strouhal number, the Ekman number and the wind vector. Transverse residual flow is close to thermal wind balance for a variety of parameters, and non-dimensionalised longitudinal residual flow shows the classical estuarine exchange flow pattern with little variation of the near-bed onshore component. Wind straining is confirmed as an important estuarine and coastal process, enhancing estuarine circulation for offshore (down-estuary) winds and vice versa. Agreement with field data from Liverpool Bay is good, including the explanation of a flood tide local maximum of dissipation rate in the upper half of the water column. An equation for the second time derivative of the potential energy anomaly is derived for quantifying the dynamical processes leading to stratification due to straining of the horizontal density gradient.