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Effect of river plume on Ekman drift velocity in the sea surface layer (dimensional analysis and numerical simulation)

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An idealized 1D river plume in the sea can be presented as the upper layer of zero salinity and thickness h, lying above a saline water column, so that the density jump between the two layers is $\Delta\rho$. Since the Ekman transport (i.e. vertically integrated drift velocity) is directed right-hand relatively to the wind direction and its value u_*^2/f (where u_*^2 is the squared friction velocity, defined as the wind stress divided by the water density ρ_0, and f is the Coriolis parameter) does not depend on the presence of river plume, while the density stratification works to confine the Ekman transport mainly within the river plume layer, one may expect that the river plume causes an increase of both the scalar value of the sea surface drift velocity and the clockwise turn angle of the velocity vector. To develop more detailed, quantitative description of the effect of river plume on the sea surface Ekman drift velocity, dimensional analysis along with numerical simulation has been applied.

In a case of no river plume, the sea surface Ekman drift velocity components,(u_0, v_0)(or the velocity scalar and angle (U_0, φ_0)), depend on, apart from u_* and f, two parameters of the length dimension — the roughness parameter z_0 and some averaging landscale z_a specifying the features of the drift velocity measurements/simulations. The dimensional analysis implies functional forms as follows

$$U_0 = u_* F_0(L_E/z_0,\ z_a/z_0), \quad \varphi_0 = \Phi_0(L_E/z_0,\ z_a/z_0) \tag{1}$$

where $L_E = 0.4u_*/f$ is the Ekman length and F_0 and Φ_0 are some functions of two non-dimensional variables.

Implying that the dependencies (1) are known and focusing on the net effect of river plume on the Ekman drift in the sea, we can suggest for the sea surface velocity scalar and angle (U, φ) following functional forms

$$U = U_0 \cdot F\,(\mathrm{E}) \cdot (\mathrm{Fr}^2/\mathrm{E})^{\alpha}, \quad \varphi = \varphi_0 \cdot \Phi\,(\mathrm{E}) \cdot (\mathrm{Fr}^2/\mathrm{E})^{\beta} \tag{2}$$

where $\mathrm{E} = L_E/h$ and $\mathrm{Fr} = u_*/(g_* h)^{1/2}$ are the non-dimensional Ekman and Froude numbers, accordingly, $g_* = g \cdot \Delta\rho/\rho_0$ is the reduced gravity, $F(x)$ and$\Phi(x)$ are some functions of a variable x, α and β are the exponents of power functions (to be determined). The sense of choosing of $(\mathrm{Fr}^2/\mathrm{E})$ for the second non-dimensional parameter is to make it free of any h–dependence, and thereby to confine the h–dependence within the first non-dimensional parameter E. It is evident from simple physical reasons that $U \to U_0$, $\varphi \to \varphi_0$ at $h \to 0, \infty$, which corresponds to asymptotics of $F\,(\mathrm{E})\,,\ \Phi(\mathrm{E}) \to 1$ at $\mathrm{E} \to 0,\infty$ and implies maxima of $F\,(\mathrm{E})$ and $\Phi(\mathrm{E})$ at some intermediate values of E where $F,\ \Phi > 1$.

To estimate non-dimensional dependencies (2), numerical simulations of the Ekman drift at different value of the wind stress in the presence of a river plume of different thickness and density jump were performed by means of a 1D version of the Princeton Ocean Model (POM) with a 2.5 moment turbulence closure sub-model embedded (Mellor & Yamada 1982). The prognostic runs of the 1D POM at constant value of the friction velocity were used to obtain time series of current velocity in the surface layer with inertial oscillations filtered out, and to calculate the maximum value of the velocity scalar achieved in the course of river plume erosion and thickening caused by turbulent mixing. The numerical simulations showed that the maximum value of $F\,(\mathrm{E})$and $\Phi(\mathrm{E})$ in (2) is achieved at E=15–18 and E=8–10 accordingly, and the exponent for the power function of $(\mathrm{Fr}^2/\mathrm{E})^{\alpha}$is estimated at $\alpha = -1/4$.