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The Knudsen and Total Exchange Flow relations for mixing in estuaries

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The well-known Knudsen theorem and the Total Exchange Flow (TEF) analysis framework are derived from the conservation laws of mass and salt by means of the Gauss theorem applied to the volume of a confined estuarine or marginal sea basin. These theories provide quantifications of exchange flow across an open boundary to the adjacent ocean in terms of bulk values (Knudsen theory: inflow and outflow volume and salt transport) or with resolution in salinity space (TEF: profiles of volume and salt transport in salinity coordinates). In the present study, these theories are extended towards mixing of salinity, defined as the decay of salinity variance due to turbulent mixing. These new Knudsen and TEF relations for mixing are derived by applying Gauss' theorem to the salinity variance equation (or, alternatively, to the salinity-squared equation). As a result, long-term averaged mixing in estuaries and marginal seas can be estimated by simply considering inflowing and outflowing salinities at the open boundary as well as net freshwater run-off. As a rule-of-thumb, long-term averaged estuarine mixing can be estimated as the product of inflowing and outflowing salinity with the freshwater run-off. Idealised estuarine model simulations will be used as illustration. Finally, the new theory will be demonstrated for a realistic simulation of a non-tidal estuary in the Baltic Sea.